Yumi Making Re-examined

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The photograph of figure 1 documents the outcome of a yumi building process we describe here. Most of the materials and design are in apparent proximity to long standing yumishi traditions. The core features multiple

Figure 1: First panel - Overall shape with "broken mirror symmetry" curve proportions. Second panel - Upper strike plate. Third panel - Side view in vicinity of grip. The thin black lines are the carbon laminations. Fourth panel - Bottom strike plate and signature.

strips of alternating hardwood and bamboo very much in the traditional mode. The geometry of tapering, both in thickness and in width closely follow the work of yumishi Don Symanski. The placement of the grip, and of the nodes on the back and belly bamboo laminations follow the traditions described in the article "Geometry, Aesthetics and the Yumi." The braced shape embodies "broken mirror symmetry" proportions of its five curves. In the same article, we present the aesthetics behind these curve proportions and document the proximity of the resulting shape to existing yumi.

In its material construction, the main departure from traditional take-yumi are two unidirectional carbon laminations, 10 $mill = .010$" thick which are between the core and the bamboo skins. This by itself is significant, as we'll later explain. Nevertheless, the main departures from tradition are not in the "what?" but rather in the "how?" For completeness we describe the whole process, both in its debt to and departure from tradition.

I. The bamboo grove

Figure 2: Entrance into the Duke Forest bamboo grove. I thought about searching for a "pretty" picture, with elegantly arcing bamboo culms rising from a nice carpet of leaves and duff. *This* is how most of the grove really is. Nevertheless it has consistently provided nice hard, resilient yumi laminations.

The photograph of figure 2 is taken in the (many acres) Duke Forest bamboo grove. The diameters of culms just above ground level range from 4 *cm* to over 12 *cm*. The first job is to cut 300 *cm* lengths from the lower part of culms free of branches and leaves. The 300 *cm* length is significantly longer than the longest yumi, such as Rokusun at 239 *cm*. The extra length allows more freedom in selecting back and belly pairs of strips with nodes correctly positioned in relation to each other. Older culms from previous seasons are preferred over new growth. In figure 3, the culm to the right is young growth.

Figure 3: The culm to the right is young growth. The culm to the left, old growth.

Nice, unblemished dark green. Attractive looking. Nevertheless, leave it be. The culm on the left is typical old growth. Faded, grey-green. Likely to be blemished. Occasional bore holes of insects, especially near nodes. Not so pretty, but *very much preferred*. Even in the grove you can feel that the old growth is harder and denser. The old growth has greater dimensional integrity as it undergoes the initial air drying. We'll come back to this point.

The most exacting requirements of initial culm selection are related to nodal spacings. The arrangement of back and belly nodes on a yumi are described in the article "Geometry, Aesthetics and the Yumi." Let's say I'm seeking bamboo for a Nissun yumi. I have a "Nisssun stick" with marks corresponding to nominal nodal positions. In particular, one mark is for the belly node at the top of the grip. Go out into the grove with this stick.

You will likely observe that nodal spacings of large diameter culms (12 *cm*, say) are way too large for Nissun. You need to be in the part of the grove where diameters are more like 5 *cm*. Similarly, I have Namisun, Yonsun and Rokusun sticks. In the selection, you must compromise and balance variations from the ideal. Still, this is better than "flying blind." The more exacting and demanding you are, the longer the time you spend in the grove. Figure 4 depicts a culm side by side with the Nissun stick.

Figure 4: The nodes of this culm line up closely with the white marks of the "Nissun stick." This culm is a better than average find.

II. Splitting, drying and heating

The yumishi Don Symanski splits green culms into four section immediately after they are harvested. The splitter consists of two wedges that cross at right angles. Culms typically have some bend, so one needs to orient the splitter so as to obtain two sections which can be laid out flat and straight. The other two which cannot are cut into narrower strips for the yumi core. My process begins by securing the ends of the culm with blocks and clamps so its center axis (approximately) traces an "arch" in a vertical plane. A 1 1/2" wide strip of marking tape straddles the "ridge" of this arch. This marks one of strips for a yumi lamination. Two lengthwise cuts following the edges of the masking tape are executed with a Japanese pull saw. The Japanese pull saw is an especially nice tool. The cuts accurately trace the intended lines with pull strokes of minimal force. After the cuts are done, the strip marked by masking tape remains lightly secured to the culm by internal walls which span cross sections of the culm at nodes. Leave it in place. Now flip the "arch" upside down, so what was formerly its "underside" is exposed. The ends of the culm are elevated and its center touches down onto the work table. A second strip of masking tape straddling the ridge of this underside marks the second strip for a yumi lamination. Two more Japanese pull saw cuts follow the edges of the masking tape as before. After the second pair of cuts is done, the culm is easily deconstructed into the two yumi lamination strips, and two "curvy" leftovers. These leftovers are easily band sawed into narrower strips about 1 *cm* wide for the yumi core.

Sometimes the original culm is so straight that a shorter, easier process is possible: Band saw the culm into two half cylinders, and then band saw each of these into three strips. If you are lucky, one culm delivers six back or belly strips.

One can wait for the strips to air dry before further processing. Instead, I immediately pass green strips through a spindle sander jig with coarse 36 grit to produce a uniform width somewhat greater than the width of a yumi limb. Next, the inside surface of the strip is sanded flat to obtain a first rough approximation to a yumi back or belly lamination. Figure 5 depicts a pair of Nissun laminations just after this initial processing.

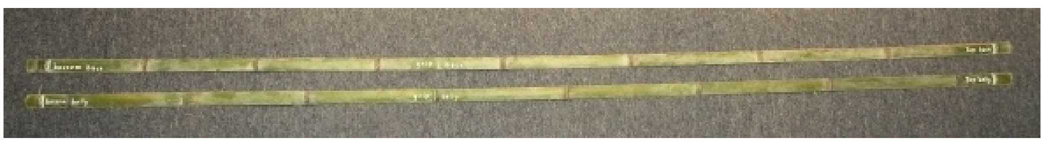

Figure 5: Bamboo laminations after preliminary shaping while still green. We see the positions of nodes relative to each other. The labeling with white out pen may seem excessive, as if you were elaborating instructions for an idiot. Exactly.

The immediate processing of green culms into rough yumi laminations has these advantages: (i) As an intact culm dries, circumferential stresses which induce lengthwise splitting arise. Due to their much smaller cross section dimensions, the initial rough yumi laminations have much smaller internal stresses. They dry without splitting. (ii) Due to all the cutting and sanding, the pithy, moisture-laden layers beneath the hard outer surface of the culm are much more exposed. Air drying is *much* faster. Moisture content reaches a dry equilibrium in a few weeks. The progression of drying is visible on the hard outer surface. Its shade of green lightens, starting from the edges and progressing towards the center. We see this in figure 6.

The cross sections of laminations cut from old growth are stable during the rapid drying. Laminations cut from young growth, not so much. As the soft and moist inner layer contracts relative to the hard outer layer during drying, the cross section buckles as depicted in figure 7.

The air dried rough laminations undergo a final heat treatment before refined sanding. Figure 8 shows the "oven." Two sections of 6" diameter sheet

Figure 6: As the air drying proceeds, the dark green patches shrink and disappear. This picture is taken after only three days of air drying.

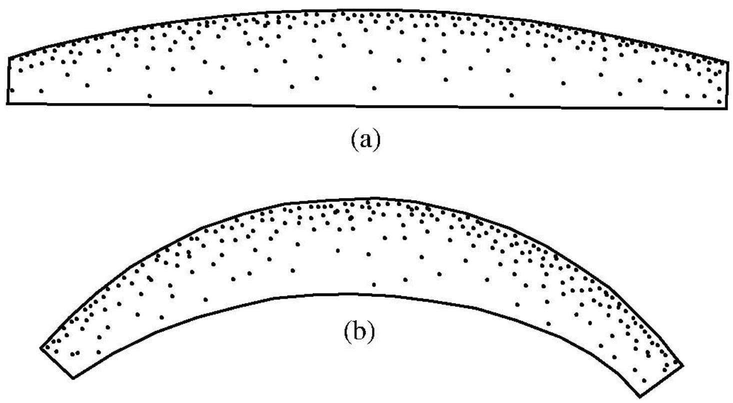

Figure 7: How the cross section of a young growth lamination buckles as it dries. (a) Initial cross section. (b) Cross section after drying.

metal stove pipe are joined to achieve a total length of 9′. Inner 3" diameter pipes are fastened inside the walls of the outer pipes. When the two outer pipes are joined, there is a gap between the two inner pipes. Heat guns placed at both ends drive streams of heated air towards this gap and they come out through the inner pipes. This design is adaptation of an oven developed for tempering bamboo fly fishing rods. A 250^o to 300^o temperature is established and maintained for a half hour. This is a bit below the requirements for real tempering. Nevertheless it drives out waxes and oils through the hard outer layers of the strips. The heat treatment alters the cross section of a strip as depicted in figure 9. This looks a bit like the reverse of the buckling that happens to young growth laminations. If it isn't the expansion of the soft material near the inner surface, maybe it is the contraction of the outer layers as the waxes and oils are expelled. In any case the inner surface of the lamination becomes convex. The outer surface remains convex, but less so. There are mechanical insights related to the convexity of the outer surface. We'll come to that.

Figure 8: The oven for heat treating laminations

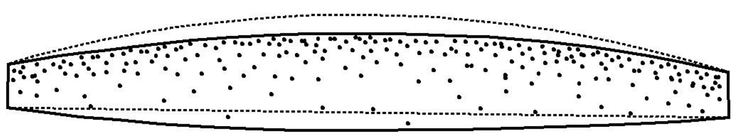

Figure 9: The dashed line indicates the cross section of a rough lamination before heating. The inside surface bulges out into convexity. The outside surface remains convex, but less so.

III. Fine shaping and pairing of bamboo laminations

The bamboo laminations emerge from the heat treatment with a ”varnish” of oils and waxes on the outer surface. This is cleaned with fine steel wool soaked in acetone. Due to the relatively brief time of air drying and heat treatment, the outer surface retains an olive green color. If the laminations are not intentionally bleached in the sun, the traditional beige color slowly appears after a year or two. Sometimes, I've sanded away the very superficial green layer upon request.

Fine sanding begins by refining the uniform width of the laminations. A uniform width of the bamboo laminations and core facilitates the layup with glue in the lamination form. Next, the outer convex surfaces of the laminations are covered with blue masking tape which remains in place until the laminated yumi is cured. The dark blue of the masking tape provides a visual contrast with the light beige color of the bamboo beneath its outer surface. The inside surface of a lamination which became convex during heat treatment is sanded flat. Due to the irregular geometry of the convex outer surface with its nodal bumps, there is no fence for this pass through the spindle sander. It is done by hand, eye and feel.

After a first pass, the maximum thickness of the cross section is measured with a digital caliper at a sequence of positions along the length, half way in between adjacent nodes. The measurements are written down on the blue masking tape with a white out pen at the locations where they are taken. Corrective sanding follows, until all measured thicknesses wiothin 10% of a uniform value. For Symanski yumi I've examined, .150" is a typical thickness. A belly lamination pried off an old Japanese take-yumi is .200" thick. My laminations tend to be thinner, between .100" and .125" thick. The dense, hard outer layer of the bamboo which provides most of the strength is about $2mm \approx$ .080" thick. Material near the inner surface of a culm is much spongier and weaker than this hard outer layer.

After the corrective passes through the spindle sander are done, there is a final refinement: 50 grit sanding belts are glued to a thick, heavy aluminum slab with a top surface whose dimensions are 30" by 10". When the inside surface of a lamination is passed over this sanding block, departures from flatness under nodes are very reliably removed. I've seen yumi whose glue lines under nodes are irregular because this detail is not attended to. Not in Symanski yumi. But I'm not saying who.

Finally, there is the mating of back and belly pairs. Recall that we obtain at least two laminations from one culm which can be laid out flat and straight. Any node of a belly lamination should be nearly half way between adjacent back nodes. Hence one lamination is displaced by half of a nodal spacing relative to the other. The laminations are oriented so that as we ascend the yumi from bottom to top, we ascend the culm in the direction it grew. The nodal spacing increases significantly as we ascend a bamboo culm, so the staggering of belly and back nodes relative to each other is approximate.

Trial and error balancing acts due to natural departures from ideal geometry are inevitable. In particular, certain nodal positions solicit extra attention. The upper strike plate on Symanski yumi are close to 18 *cm* long. I have no reason to change that. There is about 5 *cm* of rattan wrapping that proceeds downward from the base of the upper strike plate. You want the top back node to be well clear of this wrapping. On Symanski yumi, the gap between the bottom of this wrapping and the top back node is on the order of 10 *cm*. You want to avoid too small of a gap, like 2 *cm* or 3 *cm*. The first back node above the grip is also a potential problem. Typically, this node is 15 *cm* above the top of the grip, and there is sufficient room for the rattan work above the grip. Again, you want to avoid the top of the rattan work crowding this node as well. Once the back and belly pairs of laminations are mated, the lengths can be trimmed. I usually leave a few centimeters beyond the nominal tips of the yumi.

A significant innovation of design

Figure 10

Figure 10 is a side view of a Symanski yumi near its upper tip. The specific point of attention is the *continuation* of the belly bamboo lamination underneath the upper strike plate. An older tradition truncates the belly lamination where it meets the bottom of the upper strike plate, so the strike plate attaches directly to the core. The vertical joint where the belly lamination and strike plate meet is an obvious weakness. Its proximity to the upper tip where the shock and vibration loosed by Hanare are greatest is not good. I've rebuilt yumi whose belly bamboo delaminates, starting from the vertical joint. The rebuild features a new, full length belly lamination that extends underneath both strike plates according to the Symanski design.

This sort of construction raises a question: How do you do it? Joining one flat surface to another is convenient. Maybe this is a motivation for the traditional construction. The hard outer surface of bamboo is not only convex, but oily and waxy as well, so even high grade epoxy bonds to it

Figure 11

poorly. Presumably one can simply sand away the superficial unbondable layer. A convex surface remains and the bottom of the strike plate can be sanded concave to match. Figure 11 shows the simpler solution I use. A segment of the outer bamboo surface is sanded flat by a pass through a spindle sander jig. The depth of sanding feathers to zero within two centimeters or so of the lower end. The bottom of the strike plate which joins to the belly bamboo is mainly flat except for a small (easy) adjustment near its lower end.

IV. The yumi cross section

De Prospero sensei's book, "Kyudo, the Essence and Practice of Japanese Archery," has a series of illustrations showing the evolution of the yumi cross section design over the centuries. Figure 12a is based on the last figure in that series. This cross section emerges in the eighteenth century and informs the work of yumishi today. The side and middle strips of the core are hardwood. There are four bamboo strips, two on either side of the middle hardwood strip. Figure 12b is a schematic cross section typical of my work. Some details: The hardwood strips are Hickory, whose strength and elasticity metrics are conspicuously greater than most domestic hardwoods. The growth rings are aligned close to vertical. The bamboo strips are thinner than traditional, so they consist mainly of the strong, dense fibers from the outer 2 *mm* layer of a culm. A thin Hickory lamination is included in addition to the traditional core. Its thickness is easily modified so that the overall limb thickness meets a design value, which in turn is related to the yumi strength. As mentioned before, the biggest departure from tradition is the inclusion of 10 *mill* = .010" or 14 *mill* = .014" unidirectional carbon laminations between back and belly laminations and the core. In figure 12b, these are indicated by the thick black lines. Another departure from tradition is the overall shape of cross section. A traditional cross section is trapezoidal, with the back lamination wider than the belly. My cross sections

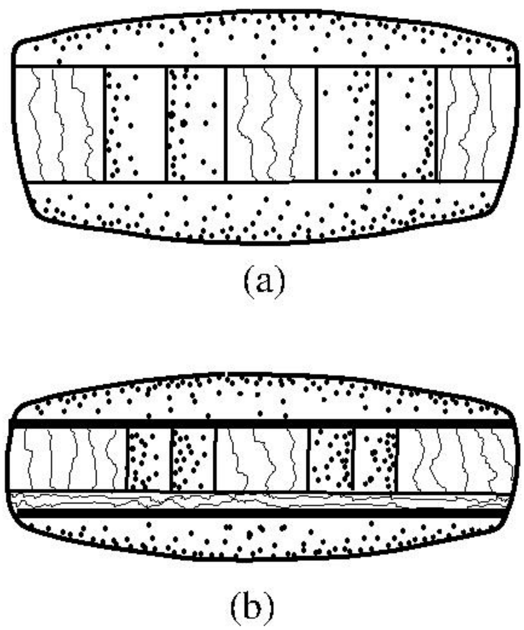

Figure 12

are closer to rectangular. They are also thinner, relative to the cross section of a Take-yumi of similar strength. We present physics based motivations for the modified cross section later.

Here, we describe the fabrication of the core. Yumi length strips of hickory are obtained by re sawing a plank with a 14" bandsaw. The cross section dimensions close to 8 *mm* by 8 *mm* are sufficient for my relatively thin cores. Figure 13 is a schematic of the spindle sander jig to refine the rectangular cross sections of hickory or bamboo strips. The first passes are with a very coarse 36 grit sanding belt. Final passes use an 80 grit sanding belt. The first rough sanding of the bamboo strips happens while they are still green. First, nodal ridges on the hard outer surface are sanded flat. The cross section dimensions of the bamboo strips are close to 8 *mm* by 3 *mm*. The first rough approximation to the 3 *mm* thickness is achieved by a pass through the spindle sander jig with the hard outer surface against the fence. This pass eats away the soft, spongy layer, leaving only the hard elastic outer layer. Like the back and belly laminations, the bamboo strips undergo air drying followed by a half hour in the long oven at 250^o to 300^o. In the fine sanding which follows, the hard outer surface is flattened. We take away just

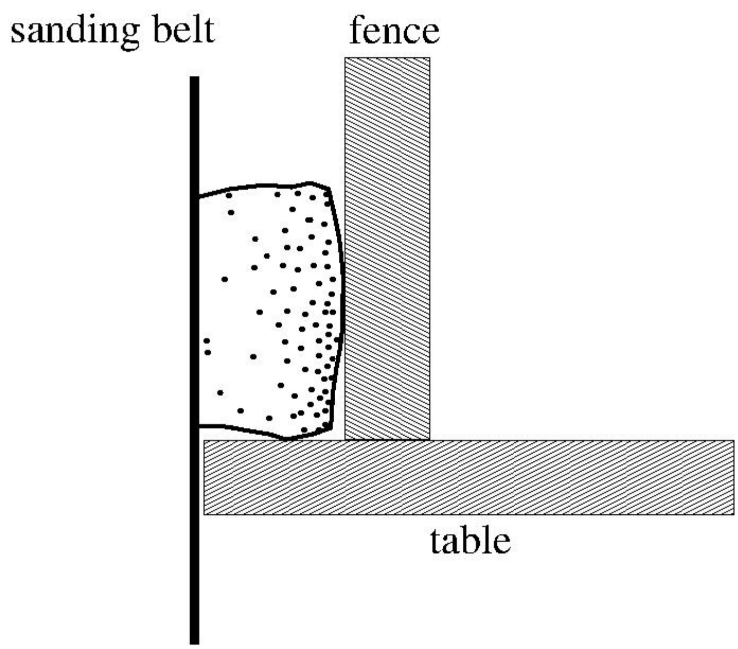

Figure 13: Schematic of the spindle sander jig to produce rectangular cross sections. Here, the piece undergoing sanding is a bamboo strip with its hard outer surface against the fence. The roughly 3 *mm* thickness is obtained by sanding away the soft spongy layer underneath the hard, elastic outer surface.

enough material to remove the oily, waxy "enamel" which does not glue well.

The lamination process begins by wetting all surfaces to be joined by glue. The glue is EA 40 Smooth-on, a main choice of bowyers. The proportion of resin to hardener by weight is two to one. The strips are lightly secured in the correct configuration by wrappings of blue masking tape at roughly 30 centimeter intervals. The core is laid on top of an 8′ long, 1″ wide aluminum strip topped with polyethylene. The aluminum strip is a "guide" to enforce straightness. The photograph in figure 14 shows the clamping arrangement. The half cylinders come from 1" dowels cut lengthwise in half. Polyethylene is glued to their flat surfaces which contact the core. The half cylinders press the core from above and below when band clamps which wrap around them are tightened. The width of the core should exceed the 1″ width of half cylinders and the aluminum strip so the band clamps press the core from the sides as well.

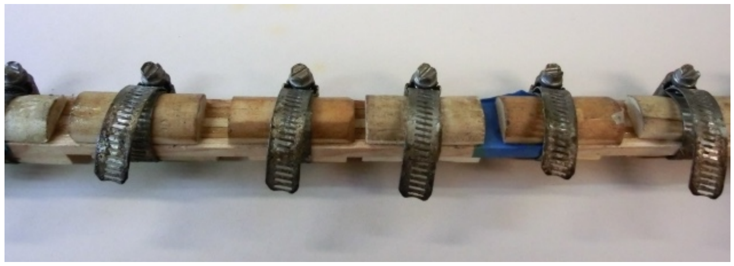

Figure 14: Clamping the core. The aluminum strip underneath the core is not visible. You can see one of the masking tape wrappings that loosely secure the whole assembly before the clamps are secured.

Later, when we laminate the Urazori shape of the yumi, the band clamp system really comes into its own. The surfaces of half cylinders which contact the back and belly laminations are cambered to match their convexity. The band clamp system easily accommodates the curves of the Urazori shape.

After the clamps are secured, the clamped core is inserted into the long oven depicted in figure 8. The two heat guns with their lowest fan and heat settings easily maintain a curing temperature of $130^o F$ for six hours. Finally, the cured cores are passed through the spindle sander jig to create a uniform thickness with clean, flat surfaces.

Thickness tapering

The thickness of a yumi tapers as we proceed from the grip towards either tip. The tapering of existing yumi is a reference point for our own work. The Symanski Yonsun examined in the article "Geometry, Aesthetics and the Yumi" provides a typical example. The horizontal axis of the graph in figure 15 is the arc length along the yumi in centimeters as we proceed from the upper nock to the lower. The measurement points are midpoints of intervals with no nodes. Thickness measurements in millimeters are taken with digital calipers. The diamonds correspond to the total thickness, which includes the back and belly bamboo layers. The squares correspond to the core thickness.

The graph in figure 15 is quite consistent with traditional tapering rules as Don once explained to me many years ago. At the grip, the core thickness is about one half of the total thickness. The vertical intervals between the diamonds and squares are roughly uniform, indicating that most of the tapering is in the core and not the bamboo back and belly laminations. The

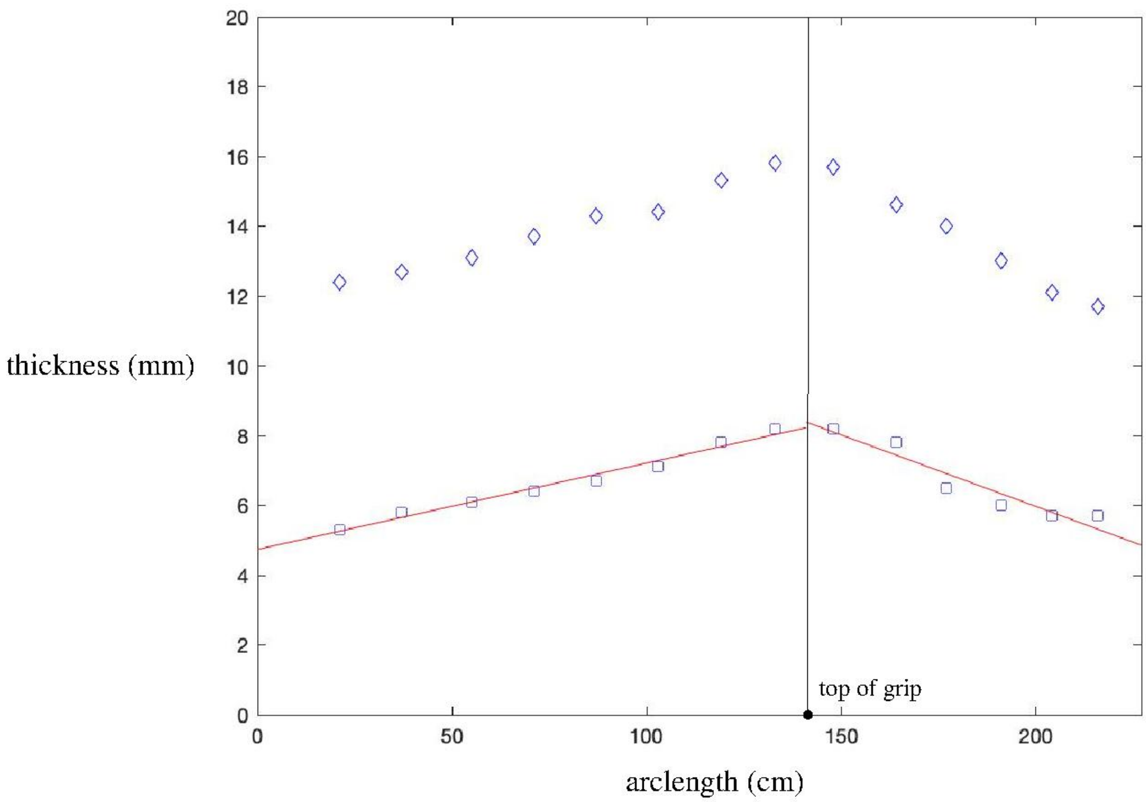

Figure 15

core thicknesses close to the top and bottom ends of the yumi are roughly equal. This means that the rate of taper above the grip is less than the rate below. In figure 15, least squares lines fitted to the core thickness data indicate rates of taper, .00247 mm/mm above the grip, and .00410 mm/mm below.

How do we choose rates of taper? In practice, yumi thicknesses at top and bottom ends are consistently close. So is the proportion between thicknesses near the grip and thicknesses near the ends. For each of four Symanski Yonsun, I measure their thicknesses 10 cm above the grip and 3cm from the bases of top and bottom strike plates. These measurements are recorded in the first three columns of table 1. The averages of the top and bottom thicknesses are computed as fractions of the grip thickness. These numbers

Table 1: Thickness proportions

grip	top	bottom	proportion
15.8 *mm*	12.4 *mm*	11.9 *mm*	.769
14.2 *mm*	11.4 *mm*	11.3 *mm*	.799
16.3 *mm*	12.3 *mm*	12.0 *mm*	.745
16.5 *mm*	12.2 *mm*	12.2 *mm*	.739

appear in the fourth column labeled "proportions." We see that the top and bottom thicknesses are indeed close. As a rule of thumb, we might say that the end thicknesses are close to 75% of the grip thicknesses. Cores can be tapered so as to achieve this overall proportion between end and grip thicknesses.

How is core tapering actually carried out in the shop? Since my cores tend to be thin relative to typical take-yumi, large and powerful machines such as thickness planers re risky. The thin tapers used in western bow limbs are shaped by belt sander jigs. The slow but highly controlled sanding process allows you to achieve thicknesses less than half a millimeter. In my shop, I have "reference tapers." These are strips 4 *cm* wide and 1.5 *m* long, with thickness tapering rates of .002 *mm/mm* or .003 *mm/mm*. These can be tacked onto cores with rubber cement. The cores backed with tapers are run through the spindle sander jig, with the taper against the fence. Tapering above the grip uses the .002 *mm/mm* taper, and the tapering below uses .003 *mm/mm*. The lengths of core actually tapered are adjusted so the end thicknesses of yumi are close to 75% of grip thicknesses. For very light yumi with extremely thin cores (3 *mm*, say), the tapering may not reach all the way from the ends to the grip. In my experience, these variations from nominal standards don't degrade the feel of the yumi when it is shot. The main tapering pitfall is not enough thickness at the upper tip which makes the top curve of the yumi twisty and unstable. In my experience, this does not happen if the nominal end to grip thickness proportion of 75% is upheld.

V. Spline table lamination of the Urazori shape

Yumi with carbon strips between back and belly bamboo laminations and the core are very stable. After the lamination cures, it is very difficult to adjust the shape by heat-aided bending. The correct Urazori shape must be achieved during the initial layup and curing. We need a process with more precision and control than the traditional ropes and splints process mentioned in the article "Geometry, Aesthetics, and the Yumi."

Years ago as an undergraduate physics major, I ended up in the basement lab of a famous experimentalist. On a large piece of graph paper atop a drafting table, he marked a sequence of discrete points representing data from measurements. These points presumably sample a curve in the plane. The approximate reproduction of the whole curve from a sampling of points along it is called *interpolation*. This visit to the lab happened in the early '70's, well before digital computers took over all such tasks. How was it done?

Heavy brass cylinders are laid on the graph paper, each one "kissing" a data point. A thin fiberglass strip is threaded through the maze of cylinders. After some trial and error adjustment, the strip passes through each data point, so defining a curve that *interpolates* the data. The elastic strip which accomplishes the interpolation is called a *spline*. The term is likely borrowed from woodworkers. From woodworking, the term "spline" makes its way to modern computer assisted mathematics. For instance, in the article "Geometry, Aesthetics and the Yumi," we introduce formulas called *trigonometric splines* to quantify yumi curves between inflection points. For the task of laminating the Urazori shape of the yumi, it is the old fashioned woodworker meaning of "spline" which is relevant. In fact, *the uncured yumi is the spline.*

Figure 16 is a photograph of the *spline table* set up for laminating Nissun yumi. Two inch diameter pine cylinders are secured to an $8' \, 1'' \times 12''$ pine board by $1/2''$ hex bolts. These are analogous to the brass cylinders placed on the physicist's graph paper. An un tapered core is treaded through the array of cylinders, analogous to the fiberglass spline that the physicist uses to trace the curve interpolating his data points. The cylinder placements are arranged so the edge of the spline analogous to the back of the yumi follows a prescribed Urazori shape curve. The black dots indicate where the tips of

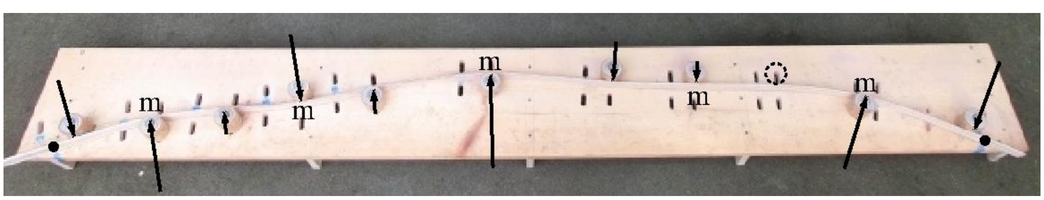

Figure 16: The spline table

the yumi would be. The devil is in the details. Let us begin.

The article, "Urazori Shape from the Braced Shape" explains how the Urazori shape is computed. The output of that calculation is the graph of the Urazori shape curve in figure 17. Like the braced shape, the Urazori shape has five curves, but their lengths and depths are different. The hollow dots mark the endpoints of curves: The upper and lower tips and the four inflection points between them. We've labeled the cartesian coordinates (x, y) of the curve endpoints with x and y in centimeters. The midpoints of curves are marked by black dots. The depth of a curve is the perpendicular displacement of its midpoint from the chord connecting its endpoints. We've indicated the curve depths in centimeters. This whole geometric construction is scaled up and transcribed onto the spline table. It informs the placement of the cylinders.

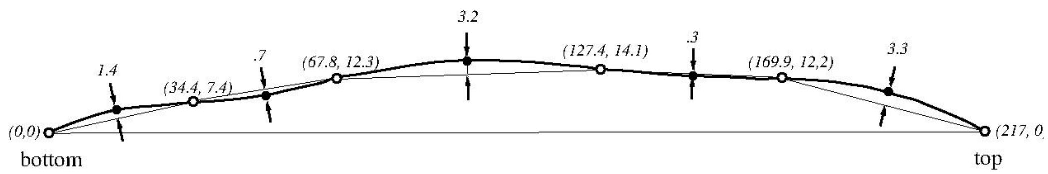

Figure 17: Geometric construction of the Urazori shape

Figure 18 depicts a spline interpolating an array of three cylinders. The spline contacts cylinders at two "endpoints" a and b, and at a "midpoint" c. The arrows represent forces that the cylinders impose upon the spline. The force imposed on the spline at c is opposite and equal to the sum of the forces imposed at endpoints a, b. Elastic mechanics dictates that the spline has zero curvature at the contact points a and b with endpoint splines. The arc abc is a single curve whose endpoints are inflection points.

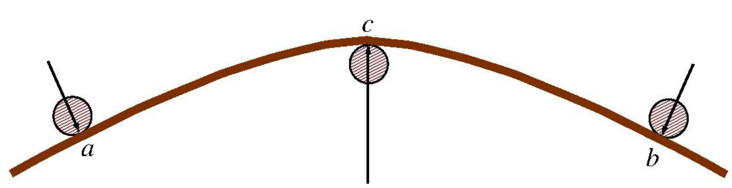

Figure 18

For the Urazori shape with its five curves joined end to end, one might expect six cylinders kissing endpoints of curves and five kissing midpoints.

Eleven in all. In the spline table photograph of figure 16, five cylinders kissing midpoints are labeled "m." The remaining cylinders kiss endpoints. There are only five. The dashed circle marks the "ghost" of the missing cylinder. For a sequence of curves joined end to end, the physics of force induced bending is more complicated than the simple situation of figure 17 and some trial and error fiddling happens. The cylinders are arranged so that the spline interpolates all six endpoints and five midpoints. In practice, the four endpoints in between the top and bottom are not exactly inflection points, but overall the interpolated shape is not too far off. The arrows in figure 16 qualitatively indicate the forces imposed by the cylinders upon the spline, like the arrows in figure 18. The endpoint without a cylinder marks the bottom of the top curve. The spline nicely interpolates this endpoint without a constraining cylinder.

The spline table enforces a strong control of the Urazori shape. There is another benefit as well. The traditional ropes and splints layup is not mechanically constrained to a plane curve. In a spline table layup with the yumi laminations flush against the flat tabletop, the resulting yumi follows a nice in-plane curve. Any "snaky or twisty" tendencies of the bamboo back and belly are powerfully suppressed.

Each yumi size requires its specific arrangement of cylinders. The spline table in figure 16 has additional slots for placing cylinders in a Yonsun configuration. A second spline table accommodates Namisun and Rokusun.

No drama layup

The actual layup of the yumi begins by wetting all surfaces of laminations which join in glue lines with the EA 40 Smooth-on epoxy. As mentioned before, the proportion of resin to hardener is two to one by weight. There are simple common sense details. For instance, let's say we have wetted the joining surface of the belly bamboo. We lay it wetted face up on the work table and place one of the carbon strips on it. We wet the exposed surface of the carbon strip, peel it off the belly bamboo and lay it back on with the wetted face joining the wetted bamboo surface. The partially wetted carbon surface is now fully wetted. Now lay the core on top of the carbon strip and wet the exposed surface. Again peel it off and lay it back on wetted side down. As with the carbon strip before it, the partially wetted core surface is fully wetted. It is clear how this process continues with subsequent laminations. The strike plates are joined to the assembly. The joining surfaces of the strike plates are not flat, but curves so the top and bottom yumi curves continue over the lengths of the essentially rigid strike plates. The completed stack of laminations is not stable due to "lubrication" by uncured glue. The stack loosely secured in good order by masking tape wrappings or small zip ties.

Now comes the installation of the band clamps and half cylinders in a configuration similar to figure 14. The surfaces of the half cylinders are concave so they fit snugly on the convex bamboo surfaces. There is some common sense logistics. The band clamps are already closed, and we "string" them along the proto-yumi like beads on a necklace. We concentrate them in appropriate bunches so they don't get in the way when we thread the proto-yumi through the cylinders of the spline table. Now, one by one, we insert the half cylinders and lightly tighten the band clamp screws. In addition to the cylinders with the nominal 2" length, we have short extras, 1" or 1/2" long, to deal with irregularities like bamboo nodes, or proximity to a spline table cylinder. We also need to adapt the band clamp process to the sections with the strike plates. Rather than engaging in long explanations, we let photographs of assemblies near the upper and lower strike plates do the talking. These appear in figure 19, along with a photograph of the layup along its entire length. The layup does not literally lie on the spline table

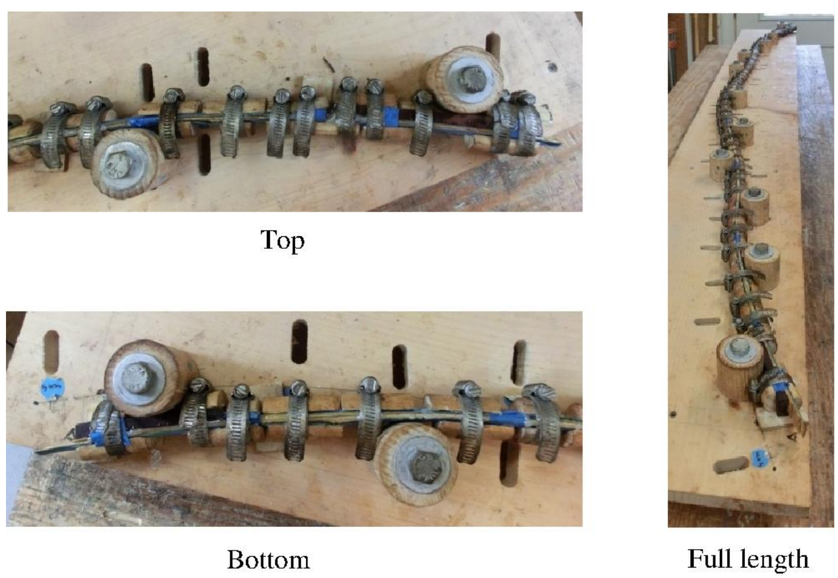

Figure 19: Band clamping of yumi laminations.

surface, since we don't want to glue the yumi to the spline table. 1/8" spacers separate the layup from the table at roughly 1′ intervals. The Urazori shape is very close to a plane curve. The final step of the layup is to tighten all the band clamp screws, sufficient to close all glue lines. For epoxy, the tightness need not be excessive. The layup is detailed and fiddly. How long does it

Figure 20: The spline table becomes the floor of the curing oven.

take? From mixing the epoxy to the final tightening of clamps, two hours. Well within the the working time of the EA - 40 Smooth on epoxy.

Figure 20 shows how the spline table is the floor of a "curing oven." The two heat guns at either end are set to a 280^oF temperature, which is low for them, and at the lowest fan setting. In the photograph to the right, the lid of the oven has been installed, along with three digital meat thermometers. The heat transfer is by air convection, and a steady oven temperature of 130^oF is soon achieved and maintained over a cure time of six hours.

We have elaborated many "mundane details." This whole process evolved so as to do away with drama. Early attempts at yumi lamination before all the details gelled were "Friday night ER in Oakland, CA."

VI. Finish work

We pass the cured yumi lamination though the spindle sander jig in figure 13 to clean glue dribble from the sides and impose a uniform width along its entire length. We cut and shape the notches at the tips which hold the tsuru loops. We can brace the proto-yumi for a first look at its shape.

Traditional yumi taper in width as we proceed from the grip towards the upper or lower strike plates. The taper is modest: On Symanski yumi the width at the ends is 90% of the width at the grip. Paper strips serve as templates to precisely control the tapering. For instance, we cut a paper strip which spans the whole upper limb from the grip to strike plate. This strip has a uniform taper, so the width at the tip end is 10% less than the width at the grip end. We spray one side of the strip with aerosol adhesive and then tape it to the length of back bamboo from the top of the grip to the base of the upper strike plate. We are careful to "center" it. With the paper strip template secured, we perform the tapering by spindle sander.

The nominal 10% tapering may be modified by contingencies. For instance if the the braced shape indicates too much stiffness in the upper limb, we may taper it a bit more than the nomina 10%. Tricks like this produce *very modest* shape changes, so the initial un-tapered shape should not be too far off.

Next we produce the traditional rounding of the yumi's sides. Since the yumi lamination includes carbon which is extremely destructive to steel rasps, we use improvised rasps consisting of 50 grit belt sander strips glued to 18″ by 2″ wooden slats. The rounding of the sides with the belt sander rasps is somewhat tedious. Nevertheless some attention to detail is recommended. Sections of yumi near bamboo nodes are more resistant to abrasion. Careless rasp work can result in yumi with scalloped sides. I've seen it (not in Symanaski yumi).

Finally, there is the truly tedious business of finish sanding as one eliminates all of the scratches due to the 50 grit sanding belt rasps. In particular, the first coat of lacquer or polyurethane over sanded surfaces tends to reveal hidden scratches and you go back to sanding.

Grip underlayment

Grip underlayment, nigiri, and rattan work are in the realm of routine maintenance, so we don't dwell on them, save for one innovation: A traditional grip underlayment may be consist of paper layers stuck together with wheat paste or glue, or rubber strips with a rounded upper surface. Alternatively, one can saturate layers of leather in water based wood glue and stack them to produce a thickness on the order of a quarter inch. The stack is taped to a PVC pipe with a 3″ radius and allowed to cure. The cured stack fits nicely onto the convex surface of the belly bamboo. The cured stack is trimmed to proper length and width. Finally, it is sculpted with sanding drums of a Dremel tool to produce customized shapes upon request. The finished underlayment is secured to the yumi with contact cement.