Custom Composite Foil Fabrication

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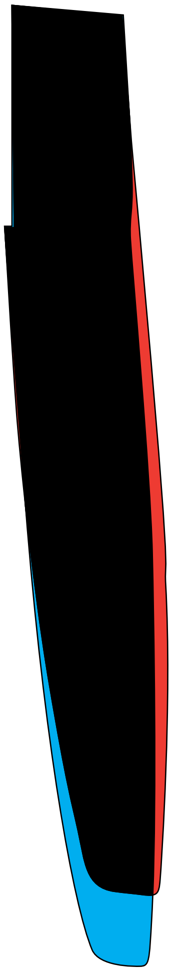
As way of introduction, I've been sailing Fireballs since 1995, and like 505 sailors, Fireball sailors like to tinker with their boats. I'd been building my own hand-shaped foils (with one set helping me to a 4th at the North Americans), all the while watching the price of a certain CNC milling machine climb higher as target markets moved from home hobbyist to the small business. I often thought about the great foils I could build with a milling machine rather than hand-shaping the core myself.

The wide sweeping layoffs in the Telecom industry gave me a chance to see if I could successfully run a small business building foils. I felt there was a niche available for the custom builder, and with local software jobs being nonexistent, I thought it was worth the gamble. In the fall of 2002 I started equipping a home workshop with the aforementioned CNC milling machine (three axis, 4'x8' table, with a 2.5hp router doing the cutting), a second hand Pentium II PC as an overpowered DOS box to run the CNC controller, and all the other necessary tools. I have a laminating station that's separated from the rest of the airspace by vapor barrier and is vented to the outside. I fitted my sanding station with a downdraft table to help reduce dust. And recently I built a paint shed in the yard so that I can work with the more volatile paints (i.e. linear polyurethanes). I use only epoxy resins (West System™ for bonding and flow coating, and ProSet™ for laminating) and I'm careful to keep them out of the general airspace of the house. Now that this is a business and not a hobby, I also wear an organic vapor respirator whenever I'm working with epoxy, and make sure its fully cured before sanding. Developing a case of epoxy sensitivity would not be a good thing! I've found that the most difficult skill to develop is that of applying a world-class final finish. Fortunately,



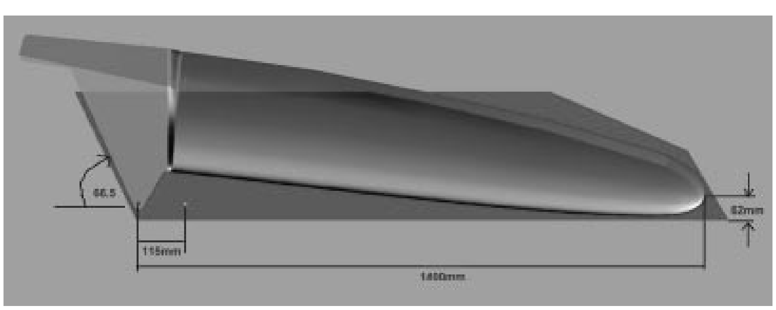
my customers have all been very understanding of minor finish issues, and I'm careful to price my products at a level commensurate with my own learning curve.

My operation relies on good software. I'm using RhinoCad® as a 3D computer aided design package, and VisualMill® as the milling software that takes the Rhino files and generates cutting instructions from them. Making a specialty custom part really does make sense with this setup. Customers requiring a different lamination schedule or foil section (other than the standard NACA 4 digit section) are easily serviced. It takes just one to two hours to generate a new 3D surface over an existing planform (i.e. profile) and then generate the milling instructions. After this initial design work, the project proceeds as normal—mill the core, sand out the machining marks, complete the layup, vacuum-bag, fair, post cure, paint, and ship. It is also relatively easy to come up with an entirely new design if that's what the customer desires. The CAD software easily calculates wetted area for comparison to existing foils, and can superimpose one foil over another to demonstrate the evolution in design.

I'll walk you through a couple of early projects that were ordered by 505 customers kind enough to take a chance on this fledgling business.

Van Munster Centerboard

A request came in to build a high aspect centerboard for a Van Munster 505. The difficulty was that the Van Munster's centerboard case is shorter than both the Waterat and Rondar. I had on hand a tracing of a centerboard that was said to fit a Rondar. This was used as the basis for the planform design. From there, we had to decide on the foil section, core material, and lamination schedule. The customer emailed me a dimensioned 2D CAD drawing of their centerboard case. Inputting this file into my design software, I was able to increase the length of the board while retaining the desired wetted area by modifying the tip (a bit more round) and the angle on the head (to match the front of the case). After a new pivot point was selected (forward of the original point), my CAD program was able to rotate the board around this point to visually confirm that the board would not have any interference problems with the case. By trading CAD drawings back and forth by email we were able to quickly settle on a specification, and the centerboard was milled soon thereafter.



Very High Aspect Rudder

Ali Meller and Jesse Falsone contacted me to build a rudder of very high aspect ratio. The specifications were to keep the wetted area and sweepback angle similar to the 2002 Waterat high aspect ratio rudder, but to increase the wetted length to 37 inches. After a couple of iterations of sending them rendered CAD drawings and getting their feedback, the design was quickly finalized. Such a thin blade was going to require a substantial carbon fiber layup in order to survive heavy loading, like during a full stall condition. With help from a spreadsheet formula provided by Barney Harris (a variation on cantilever beam theory that uses a foil cross section rather than a rectangle) a suitable layup was determined. With the waterline area being under such a high load on this rudder, I wanted to keep the lamination fibers as straight as possible to maximize strength. Rather than flaring the core out at the head (where the fittings attach) the core maintains its foil shape right up to the tiller tube. This removes any hard spots in the carbon layup caused by the laminate bending around the rudder head flare. After applying the carbon, cheeks of red cedar were laminated over the carbon skin to form the rectangular head section, and then the whole assembly was vacuum bagged.

My typical approach is to determine the outside dimensions of a foil, then subtract the skin thickness, and design the core around the resulting numbers. I

had concerns that with the skin being such a significant percentage of the overall thickness of the foil we would be pushing the boundaries of accuracy of this approach. Fortunately the blade has proven to be a success (see sidebar by Ali).

Future Research and Development

The production side of the business has been keeping me from doing as much R&D as I'd like, but I feel there is a lot to be learned in terms of foil size, stiffness, flex, and twist. As Bransford Eck pointed out in his landmark article on foil design (*Tank Talk*, March 1976), the amount of lift generated by your foils is directly proportional to the amount of righting moment the helm and crew are able to generate. A typical 160 pound helmsman and 200 pound crew will generate about 1850 pound-feet of righting moment, whereas a light team weighing in at 160 and 140 respectively may only generate 1400 pound-feet—25% less. In equilibrium, the righting moment balances both the heeling moment of the sails and the side force of the foils. Divide the available righting moment by the distance between the center of pressure of your sails and the center of lateral resistance of your foils (in the 505 that's about 12.5 feet), and the result is the maximum side lift that your foils need to generate. For the heavier team, this comes to about 148 pounds, while the lighter team only generates 112 pounds. Tailoring the size and stiffness of the centerboard to match the crew size may give performance advantages, especially in windy, puffy conditions.

I've built a jig that applies pressure uniformly to the backside of a foil, and can very accurately measure deflection along its length (using my CNC milling machine as a test probe). This will allow me to build a database of real world data as I build more boards and experiment with flex tips and tapered layups.

It's a Rudder

The Team CSC budget included a few dollars for R&D, and Jesse and I decided that rudders was something we could afford to experiment with. The America's Cup boats use very high aspect ratio rudders, and there are indications that rudders as deep as centerboards may be good. Our budget was enough to have Phils Foils build us a rudder, so after coming up with a design (planform, area, rake of blade, section and how much carbon it needed) in a four-way e-mail discussion between Phil, Jesse, Barney and Ali, Phil built us a foil. Our specs for the tiller angle were not clear enough, so we had to do a little work to get the rudder to fit the boat with the tiller at the correct height, but once that was done, we had a cool rudder. It is noticeably deeper and lighter than the Waterat rudder I have. Jesse put it across two chairs and sat on it (though he did not bounce on it). We used the rudder at the first Larchmont event and the East Coast Championship, winning both. We also used the rudder at the pre-worlds and World Championship. We seem to be quick with the rudder. I have stalled it on a few gybes, and once or twice while reaching, but I think this can be dealt with by altering our technique slightly. The rudder has withstood several heavy air races without any sign of trouble.