Shark Rudder Rebuild

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March 28, 2004

Introduction

My winter boat project this year was to give my old rudder a performance facelift. I ended up spending enough time on the project that I though it worthwhile documenting what I did and what I learned in the process. I absolutely encourage people to offer any feedback they like. I'm always eager to learn more, and any insights or corrections are welcome.

Basic Objectives

To the left is a picture of my rudder as it was when I got the boat. As you can see, it is a rectangular profile with a forward undercut intended to provide a more balanced helm. Interestingly, the designers also aligned the leading edge vertically and not in line with the transom (the pivot axis) somewhat lessening the balancing effect of the undercut (but still keeping the CL forward).

Note, that the point of maximum thickness from the leading edge is 4"-5". On a chord length of 11 ¾", this places the maximum draft at about 34-44% aft of the leading edge. I'll talk about this in more detail later, but this indicated to me that this wasn't a NACA 4-digit foil and this ended up complicating the process of making the foil shape confirm to the NACA 4-digit series foil shape.

As you can also see from the picture, the rudder is constructed from mahogany. It is glued up from ~3" pieces that are doweled together (more on that later). It appears that the complete rudder is coated with epoxy or polyester resin (smells like fiberglass when sanded), but there is no sheathing.

The leading edge of the rudder above the forward undercut is perfectly flat. Now as most of you know, and as can be seen by hanging over the back of your boat while traveling at speed, water is sucked up above the static waterline (which is slightly below the transition between black bottom paint and wood on my rudder pictured above) for a number of reasons[1]. The result is that the undercut and a portion of the flat forward facing rudderstock plows through the water like a brick wall. This disturbs the lift, increases cavitation, and generally slows things down.

The trailing edge of the rudder stock (once again at the waterline), quickly becomes square, and (by hanging over the back of the boat, again …) I have observed that the waterline, while sailing at speed, at the trailing edge of the rudder, can be 2-4" above the marked water line. Yet more cavitation, drag, and bad things!

Some of the things you can't see from the picture is that the trailing edge has two visible spots where, as I found out later, the doweling was exposed. It turns out that the trailing edge appears to have dowels that extended right through the last strip of mahogany. When the rudder was subsequently shaped and the trailing edge taper applied, the dowels became exposed for the last 1 ½". Because the grain of the dowels was perpendicular to the grain of the rudder, and the dowel end grain was exposed, these dowels expanded and contracted and were always showing through the paint/epoxy. Even worse, these dowels effectively divided the trailing edge strip of mahogany into three disconnected sections. Thus, it was not a big surprise that the last glue line appeared to be cracking at various places on this last strip of the rudder glue up.

The rest of the rudder appeared quite sound. It wasn't evident until I started cutting for the new shape, but the leading edge also had exposed dowels, but being thicker, this appeared not to have compromised strength or caused any problems.

So What is the Fastest Shape?

We'll, let's be honest, a perfectly efficient rudder (min drag, max lift) plays a relatively small part in the overall performance of a boat, and one bad maneuver will easily lose more than a perfect rudder would gain. But, unlike the golfer who expects a new set of clubs to "fix" his or her game, I merely would like to reduce the number of variables working against me. So, while I work to improve my on water performance, and watch the snow build up outside, I might as well make improvements where I can.

With that in mind, my basic goal is to "try" to turn my existing rudder into something that performs better and handles better too. Here is my plan:

- Adopt an elliptical planform (generally agreed to be more efficient, less drag, etc).
- Ensure an efficient foil shape using the NACA 00 series foils (once again, for rudders on boats of this size and performance, this foil shape is generally considered a good compromise for low drag, high lift, and resistance to stalling)

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[1] Discussion of this can be found in many texts on hydrodynamic, but interestingly, I read recently that one of the past Australian America's Cup boats attempted to take significant advantage of the difference between measured waterline (standing still, 3" above the waterline) and the actual waterline while underway.

- Improve the foil cross section at the water air boundary area (my rudder is basically square at the waterline once underway … bad)

I'll discuss some of my rational behind these stated goals below.

Strength of Old and New Shape

There's no point cutting up my current rudder for a new shape if it's not going to be strong enough (I'll eat these words a little later). I decided to check both my existing and planned shape against Richard Hinterholler's article on rudder strength.

My current rudder shape is rectangular, so it easy to calculate the surface area. My planned shape is elliptical and thus not quite as easy, but not too hard. I had a full scale drawing of the new shape, so I was able to divide it into rectangular sections (for which I could easily calculate the area), until the remaining non-rectangular sections were easily estimated. I eventually used data from my measurement data in an Excel spreadsheet to approximate the area.

Anyway, the strength results are interesting. According to the two charts in Richard's paper on rudder strength, I get the following results:

	Original Rudder	**New Rudder**
Actual Area	423 sq in. (2729 cm^2)	366 sq in.(2359 cm^2)
Thickness (at Water Line)	38.1 mm	38.1 mm
Thickness (at Pintel)	44.4 mm	44.4 mm
Chord Length (WL)	228.6 mm	220 mm
Chord Length (P)	200 mm	200 mm
Maximum Area (WL)	1900 cm^2	1855 cm^2
Maximum Area (P)	2400 cm^2	2400 cm^2

So, it appears that using the two methods computation of (at the waterline and at the lower pintel) the dimension at the pintel allows for a maximum area of 2400 cm^2. The old rudder area is a little over that, but the new rudder area is under, so good on that point. The second computation, for the water line dimensions only allows for a maximum area of about 1900 cm$^{2.}$ This is less than the actual area before and after. Bummer. I'm 11% over area for this calculation, but that's better than 32% over with the original rudder!

So what should I do? I can risk it, or I could epoxy a layer of cloth over the blade, and up to the pintel point. Given some of the trailing edge work/repairs I have ended up doing (see below), I ended up adding a layer of cloth.

Planform, Foil Shape and Rules

There are lots of things consider when designing a rudder. Fortunately there are many people smarter than I who have put much effort into this problem and I have simply spent some time reading as much reference material as I can get my hands on. The following is my best attempt at interpreting the information I've been able to find.

Foils are now generally lumped into two basic categories. These are 1) Turbulent flow foils (NACA 4-digit series, etc) and 2) Laminar flow (NACA 6-digit, etc) foils. There are many (And I mean a whole lot!) of different foil designs, but most do fall into one of these two categories. It turns out that laminar flow foils can achieve about half the drag as turbulent flow foils under certain conditions.

Why shouldn't everyone simply use these laminar flow foils? It turns out that this significant lowering of drag can only be achieved at low angles of incidence of < 3 degrees, proving again that you can't have your cake and eat it too. Laminar flow foils can have higher drag than turbulent flow foils at higher angles of incidence and are much more intolerant of imperfections. Given that a Shark easily has 3-4% leeway going upwind, such foils are not going to be able to provide much, if any, benefit.

The choice of foil section to use depends on type of boat you have. High performance skiffs that can be sailed flat, and at high speeds and lower leeway might be able to justify laminar flow foils for their rudder or centerboard, but for a small keel boat (like a Shark), the turbulent flow foils are likely the best compromise for the rudder, while the laminar flow foils "might" be better for keels because the keel will not be subject to the dramatic incidence angles that a rudder would. Though, one must consider that on a Shark, the normal upwind leeway may be outside parameters that a laminar flow foil can operate efficiently in. Anyway, given the rules, there's not much that can be done to a Shark keel except keep it smooth and faired, and maybe tidy up the leading and tailing edges.

NACA Foil Sections

The following is the formula for a NACA 4-digit foil in MS Excel format (simplified to remove the factors relating to camber, which aren't needed for most normal rudders!):

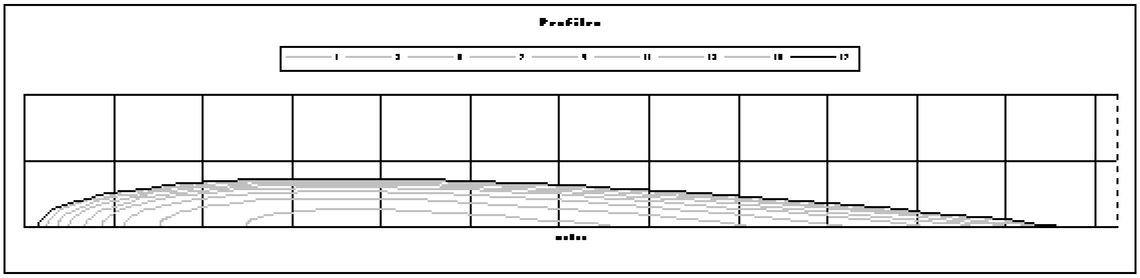
> Y =+(*XX*/0.2)*(0.2969*SQRT(*X*)-0.126**X*-0.3516*POWER(*X*,2)+0.2843*POWER(*X*,3)-0.1015*POWER(*X*,4))

Where *XX* is the thickness percentage, and *X* is the chord position from the leading edge. For, my rudder, I've used 13% (0.13) for the *XX* value. Punch this into Excel with X values from 0 to 1.0, and the results will be a non-scaled NACA-00XX foil.

At this point you simply need to either print or plot this data to match the actual chord length you need. I explored many way to try to print these foil section to scale (1:1 inch), but couldn't anything flexible enough. In the end I simply using Excel's graphing capabilities, and adjusted the graph scaling until the output was exactly to the correct scale.

I did this by scaling the data to the exact chord lengths that I needed (see attached spread sheet), and setting up my Excel graphs to have grid lines every inch. It took about 4-5 trial prints before my trusty Starrett combination square told me I had the scale correct (Starrett squares have very accurate graduations). The accuracy I managed far exceeds the tolerances I will be able to produce with my belt, orbital and hand sanding.

Below is a sample of one of the graphs I ended up using to create my templates:



The graph above shows the foil sections from a distance of about 17" from the rudder tip to 1" from the tip in 2" increments. All of the sections in the graph are 13% 4-digit foils.

There are a number of additional factors to consider if you lay out your own templates. I have decided to put a layer of fiberglass and epoxy on the foil to ensure that my repairs are strong enough, add additional strength, and provide some additional resistance to abrasions (motor props, etc). Because of this, you might need to account for this additional thickness when doing your computations. For me, my chord length was determined by the amount of wood I was left with after I cut my planform onto the old rudder. I designed the trailing edge of the "wood" to come to a sharp trailing edge. This is generally not considered durable enough, and a slightly squared trailing edge will help prevent alternating vortices, but once I add the fiberglass/epoxy sheathing, the extra thickness will allow me to square off the trailing edge.

If you happened to work the other way around, where you have a final desired chord length and are planning on putting a coating on your blade, then your templates will need to be undersized based on your skin thickness.

The contribution of a skin (fiberglass for example) to a chord length is represented by the following Excel formula:

T+(T/ABS(COS(90-A)))

Where T is you skin thickness, and A is your trailing edge angle (for a 13% 4-digit foil this is about ~8.07 degrees).

Don’t forget that having a sharp trailing edge (which the NACA formula noted above will produce) is not likely to last very long, and a sharply square trailing edge may help the flow detach more easily. Depending on various factors, this might also induce vibrations due to alternating vorticies.

Chord Thickness

It appears common that something near 12% is used for rudders on boats of this speed. The chord thickness (and profile for that matter) really should be chosen to suite the type of boat you have. Faster than wind skiffs, for example, might be better suited with other higher performance foil sections that are suitable for their average speeds. At their higher speeds (faster than wind), thinner foils are a must.

As it was quite easy to do with Excel, I increased the chord thickness near the water line so that the thickness was eventually equally to the thickness of the main rudder stock. I figured that this would improve strength at the cost of a little extra drag due to a thick profile.

Trailing Edge

It is generally thought that a squared off trailing edge is of benefit for a few reasons. It’s obvious that a sharp trailing edge is bound to be weaker and susceptible to damage. But what is the exact nature of any technical advantage.

Marchaj [2, pp224-226] discusses a specific example where foils with and without cut–off trailing edges are compared (5% of the chord length removed from the trailing edge). The result is that this difference effectively improves lift by ~10%. This benefit applies at all angles of incidence, and appears to extend the useful angles of incidence (before stall occurs) by a small amount too.

It is important that the trailing edge “squaring” be as sharp as possible in order to break the laminar flow, and create as much suction in the area behind the trailing edge.

Garrett [3, p200], somewhat on the other hand, shows that drag increases linearly as more of the trailing edge is removed. On an average smooth Shark rudder, the removal of ½” of the trailing edge would increase the section drag by about 10%.

So what can one make of this? Well, the reality is that a knife-edge is impractical. And removing more that 10% of the trailing edge will introduce too much drag. Garrett’s view appears that he favors lowering drag over increasing lift, and thus indicates that you should make the thickness of the trailing edge as small as practical.

Elliptical Shape

The quick summary first; Elliptical planforms eliminate (or at least reduce) the induced drag that can occur at the tip of a rectangular rudder. This is especially true for square ended rudders (like mine). For square tipped rudders the pressure differential between the two sides of the blade near the tip can “leak” under the bottom of the rudder from the leeward side to the windward side (assuming some weather helm) and robs the rudder of lift. This induced drag applied to sails, and thus the artificially wide booms on some of the AC boats (also a good reason to ensure that your genoa sweeps the deck).

The down side of an elliptical shape is that when they stall, they suffer a complete stall (for the full length of the blade). A rectangular shape (like I started with) tends to stall in a progressive manner (from the tip up towards the waterline).

I suppose that you could argue about which of the two negative effects is worse, but my figuring is that full stall situations occur under more extreme conditions, and even less often on round the buoys windward leeward type racing (maximum weather helm occurs more often on reaches).

Note that others prefer various non-elliptical, tapered planforms for exactly the reason discussed above. That is, the helmsman will feel the stall coming on, and can take the appropriate actions. With an elliptical planform, one might be faced with an unexpected round-up when the rudder goes into a full stall less predictably.

It worth noting that the loss of force experienced during a stall varies significantly with boat speed. For a Shark sailing at upwind speeds, one might expect a full stall to lose about 10% of you steering capability. For a screaming reach, the loss might be 15%, possibly enough to result in a wipe out if you’ve got the kite up and are sailing in big waves. In either case, a quick wiggle of the tiller may re-attach the flow (I’ve done that in my Laser while at full speed and ended up ejecting myself from the boat!).

Finishing

How the final finish of a foil affects performance is an often-debated subject. There is no argument that any foil must be fair to perform well. There can be no bumps or hollows (bumps are worse than hollows). The final fairing process needs special care. Use of long sanding blocks, use of paint or pencil marks combined with sanding and other techniques can help ensure a fair rudder (or hull, or keel, etc).

Once you have the rudder fair, one needs to consider the final finish. I think the evidence-based literature clearly indicates that having a polished foil can produce a significant reduction in drag (at least under ideal situations). You might be surprised to learn that the difference between 1200 grit wet sanding and the same but with a polish is measurable [1, p. 235]. A Laser rudder, operating at Shark speeds, could expect to have greater than 10% reduction in drag, and at top speeds (~11 knots), would see ~25% reduction.

Clearly, the orange peel result of a rolled on final finish is not going to cut it. Bottom paint would need to be very well burnished to achieve this level of finish. Weeds, a bag, or the smallest layer of bottom growth will add to you rudder drag significantly.

The same holds for keels too. For a small amount of perspective here, I realize that the differences I'm talking about are somewhat insignificant compared to drag created by the current state of my keel. It looks smooth from a distance of 20 feet, but if you get close, you will see that it's not.

Getting the Job Done

I cheated a little for deciding on the details of me elliptical shape. In the fall, on haul out day (for Sharks, a month or so after official haul out), I found a fellow Sharkie with a fast looking rudder, and traced it onto to mine. To my surprise, it almost completely fell within the boundaries of my existing rudder.

It turns out that what really matters when making an elliptical shape (for rudders at least), is that the absolute chord lengths should vary elliptically from waterline to tip, and not that is look like a traditional ellipse. In fact a perfectly straight leading or trailing edge would be quite acceptable as long as the chord lengths change elliptically.

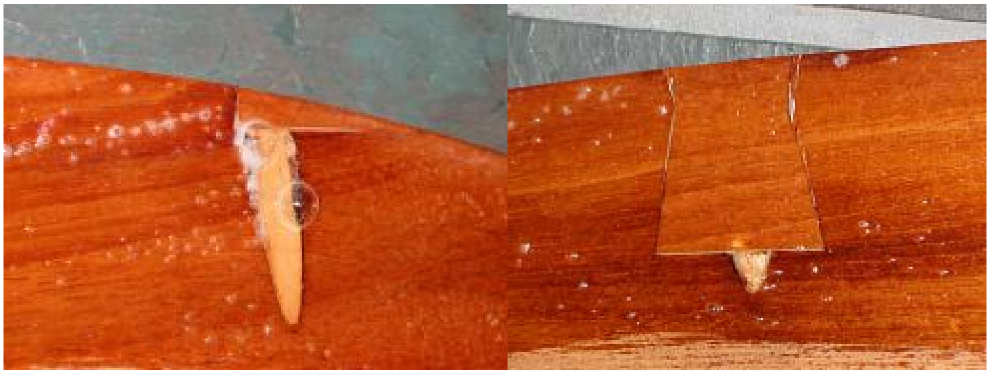
It turns out that a rudder with a straight leading AND trailing edge, but with the appropriate taper will produce results that can almost approximate a true elliptical shape. Easier to construct too!

Typically, regardless of your final shape, people try to keep the position of maximum thickness in a straight line for easier construction. When producing an elliptical planform, this technique results in the familiar Spitfire shape.

So, with my "traced" outline, I took to my rudder with a hand held jig saw. Within 5 minutes I had passed the point of no return. Once the saw dust had settled, I was able to see all of my problem dowels cleanly exposed on both the leading and trailing edges.

Before I went any further I needed to fix these dowels. I decided to use some of the wood I had just removed to completely replace the exposed dowels with butterfly/bowtie splices (pictured below). The splices would be the same wood, with the same grain direction, and due to the butterfly cut, were inherently strong and captive. Add some epoxy, and some sanding, and I felt confident that I was back in business.

Before Shaping

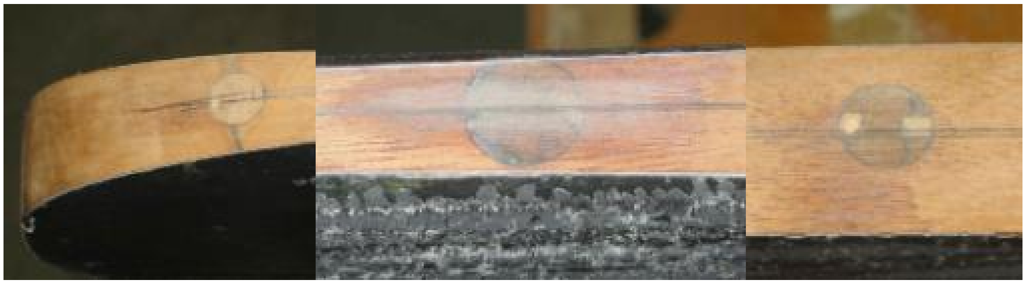


After Shaping

Pictured above are close-ups of the repairs for the exposed dowels both before and after I did the shaping. The shaping process, as a result of removing more material from the rudder, let the dowels re-exposed themselves. I wasn’t too worried about that because the repair splices were both butterflied into the trailing edge and I was going to cover the blade with a layer of cloth anyway (Note the bubbles in the epoxy; see comments below!).

Finding the Center Line for Reference

It’s critical to have a solid reference point for aligning the templates when doing the shaping. Rather than using any type of jig, I decided to mark a center line all the way around the rudder for use as a template guide. The edges of the rudder had a flat surface left after the initial shape cutting and sanding, so marking a center line would not be a problem (hah!).



Close-up of leading edge

The pictures above show the dowels in the leading edge, as well as some of my initial attempts at getting a reference line drawn. Notice how broad the flat surface of the leading edge is. This gives you an idea of how much sanding I have in store.

I initially used a flat section of my garage floor that I tested flat with a long straight edge and a small block of wood cut to the correct size (Half the thickness of the rudder head less half the thickness of the pencil I used). I simply had my son stand on the rudder stock while I used the pencil on a block to trace a center line all the way around the blade I then flipped the rudder over and did it again to be sure I had it right.

Well, I found out that my floor wasn’t as flat as I expected. It doesn’t take much of an anomaly in the floor to make a mess of this, so I moved to my kitchen counter. This produced much better results, though I did flip the rudder over and repeated the process for both sides just to be sure.

A pencil line was not going to stand up to the sanding and shaping work to come, so I took my very fine Japanese dovetail saw, and cut a hairline kerf on this center line so I would have a permanent reference line all the way around the rudder

This whole process of finding a center line turned out to be a very interesting exercise. My original rudder was significantly out of wack in a few different ways. There was a big wow in the trailing edge, so bad in fact that my center line could not be scribed at points (it was in free air!) The rudder turned out not to be completely straight from top to bottom either.

Templates, and Sanders

As described above, I used MS Excel to create my templates. I printed onto the stiffest stock that would go through my laser printer. Once printed, a bit of care with an Exacto knife left me with a stack of templates. (Note: now that the job is done, I’ve found out that sign makers have machines that could have produce near perfect templates from the data/graphs I produced, ah well, live and learn). Time to take sander to wood and get dirty.

At this point I put the 80 grit on the belt sander, got my dust mask on, and started sanding. Checking with the templates continuously, I was able to get to a rough shape quite quickly.

One Side at a time!

After completing the shaping of one side, and after leaving the rudder for a few days, I found myself with a problem. The unfinished side of the rudder was still covered with bottom paint, other paint and epoxy, or polyester. The result was that the newly exposed wood of the side I had just completed must have been giving off moisture (drying out a little, it’s the middle of winter at this point in Kingston, and –25 outside, so the humidity is quite low). The result is that my near perfect shaping was cupping significantly. This was likely due to the trailing edge, which being quite thin now, was more flexible. Where my templates had showed less that 1/64” of a gap previously, now I was seeing 3/16”!

Not to panic, I had a plan. I was intending to apply a light coat of epoxy to the newly finished trailing edge before working on the other side anyway. This would stabilize the dowels and repairs I had done (the belt sander can be a little harsh), but now I also hoped that this epoxy would soak into the wood, and thus expand the wood a little to restore the intended shape (remove the cupping of the trailing edge).

In hindsight, I should have worked on both sides equally. First I should have removed the old finish from both sides, and they work progressively from both sides. This would have allowed the wood to acclimatize more evenly, and even if a warping or cupping had occurred, it might have showed up before the final shaping, and allow me to compensate for it.

It wasn’t until I shaped the other side, that the first side returned to normal. I actually ran into the same problem on the second side. The trailing edge was swinging back and forth as I removed wood and it dried out.

The thing to be learned here would be that no matter what state your wood is in (dry, wet, whatever), do your shaping equally and progressively on both sides and you wont have the problems that I had. I was fighting with myself by doing one side at a time, and ended up adding some extra filling/fairing simply to make up for the fact that I did some final shaping when the wood had not yet stabilized.

Using Epoxy!

Or Polyester resin for that matter! I’ve been working on this project during the winter in my garage shop. It’s heated, but not enough to trust epoxy to cure in my lifetime.

As you may notice in some of the pictures above, my first coat off epoxy has significant bubbles in it. Not at big deal at this point, but worth thinking about for next time. I brought my rudder into my kitchen to cure (radiant heat floor!). This resulted in a temperature change from ~12C to 25C (or more at floor level). Quite predictably, the air trapped in the wood expanded and caused bubbles in the finish. At this early stage, I’ll be sanding and applying more coats, so it was not a problem.

I should have let the rudder get up to temperature (or a little warmer) before applying the epoxy. This would have resulted in the air in the wood either staying stable or shrinking, and wouldn’t have resulted in bubbles, and would have ensured that the epoxy would have kicked off appropriately or even more quickly.

Not only would pre-heated wood have prevented some bubbling, but also it would have reduced the viscosity of the epoxy and promoted better absorption into the fibers. As it was, I preheated the epoxy to promote absorption, but given the thermal mass of the rudder, I would have been better to heat the wood first before applying the epoxy. Having both warm would have been the best of all worlds; ease of application, better absorption, and faster cure time.

Shortcomings in the Original Rudder Thickness

It turns out that the point of maximum thickness of my old rudder was about ~50% along the chord. In order to move the point of maximum thickness to 30%, my existing rudder would have required a fair amount of filler near the leading edge to make up for the change in the position of maximum thickness.

This problem was significantly moderated by the fact that I was changing the planform so dramatically. In the lower half of the rudder, the tapering effect of the elliptical shape meant that the old rudder had sufficient wood in all the necessary places. The same went for the upper sections of the rudder. The problem was at the half way point, where the old shape and new shape had the same chord thickness. It was inevitable that I would need some filler to compensate.

The following picture shows the “missing” wood that I had to account for using filler.

Adding Filler

It turned out that the thickness of the filler (seen picture above), was barely 1/16” at it’s thickest.

Filling and Fairing

I found that the difference in hardness between West Epoxy with 410 Microlight filler was significant enough (filler being harder than the mahogany) that I decided to apply a protective coat of epoxy over the whole blade before doing the final fairing and sanding. This made it completely evident when I was sanding too much material away.

It did take a few rounds of filling, sanding, checking with the templates and repeating until I had finalized the shape. As I noted above, the difference in hardness between mahogany and epoxy is significant. I would recommend that an initial coat of epoxy be applied over the whole blade before working with the filler. Note in the picture above, that I did apply a coat of neat epoxy in the area to be filled before applying the filler. This epoxy is intended to soak into the wood, and thus allow the filler to bond better.

Application of Cloth Sheathing

My plan is to drape a single piece of 6 oz cloth over the leading edge. I will need to cut it to shape before hand to account for the curve of the tip, but hope to simply work the cloth over the rest of the curves. For the trailing edge, I will simply let it drape straight down, and trim it off once it has gelled.

I will extend it up past the lower pintels by about 6 inches in order to provide strength where is it needed.

I will be using the 207 hardener which is suppose to improve flow and reduce viscosity when laying up cloth (among other properties 207 has). I intend on applying the cloth and the next few weave filling layers of epoxy such that they all chemically bond with each other. The 207 helps with this by extending the cure time to about 12 hours. If I miss this window, then I'll need to sand to ensure a good bond between layers.

Finishing

I followed the standard instructions and applied enough layers of epoxy to completely fill the weave in the cloth. I used white pigment in the layers subsequent to the initial cloth layer of epoxy. This allowed me to detect if I was sanding to close to the initial cloth layer. In the process of filling the weave, I sanded between coats to help fair the minor bumps and wiggles in the cloth application.

Once I had the necessary layers of epoxy, I sanded to ensure that everything was completely fair. After that I applied a bunch of coats of InterProtext 2000, and then a bunch of coats of the VC Bottom Epoxy (all according to instructions). This was certainly a bit of overkill, but the result is an excellent, tough and waterproof finish. The VC Bottom Epoxy, when combined with wet sanding, can produce a great finish.

I used a foam roller for application of all coatings. This works very well at getting an even thickness of material, but does result in significant orange peel texture. This then necessitates more sanding than if the finishes were sprayed on (that's what is recommended for the VC Bottom Epoxy).

I bought wet paper in various grades up to about 1500. The result is a mirror finish. With this tough final finish I was also able to make the squared off trailing edge very sharp.

Given the number of coats of finish (all highly waterproof), I could easily put a burnished coat of VC17 on and leave the rudder in during the season. The advantage to this would be convenience and reducing the chance of putting a ding in the finish while putting it on and off the boat throughout the season.

All Done!

Once the sanding was complete, I put the hardware back on and I was done. The picture above shows the rudder back on the boat. You can see from the shadows in the picture that the blade is profiled above the static water line, and especially at the trailing edge. This should ensure that an efficient shape if always in the water.

The project did consume a significant number of hours, but that was mostly due to the many coats of epoxy, epoxy paint, and more epoxy paint. Now, if I can avoid running over any anchor chains, or running it aground, I expect it will last for a very long time.

Now I need a rudder bag to protect all the hours invested!

Additional Information

The following spreadsheet is what I used to do the computations, and to generate the graphs for the templates. I can't promise that it will make any sense to anyone but me, but maybe there is some handy information there.

"Shark Rudder
Rebuild.xls"

References

1. *High Performance Sailing* Frank Bethwaite, International Marine 1993
2. *Aero-Hydrodynamics of Sailing* C. A. Marchaj Adlard Coles Nautical, Thrid edition 2000
3. *The Symmetry of Sailing* Ross Garrett, Sheridan House Inc. 1996