GOUGEON

Technical
Information

Rudder Blades and Centerboards

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How to Build Rudder Blades & Centerboards – *J.R.Watson*

For the builder/sailor whose boat floats forlornly in need of rudder blade or centerboard here is a design that will do just fine. In fact, the best designers and builders will be hard-pressed to do better.

How to Loft Airfoil Sections – *J.R. Watson*

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Durable Edges for Centerboards & Flip-up Rudders – *Jim Derck*

Techniques that create an epoxy barrier, limiting water penetration into the blade and for a fiberglass covering that has proved to provide a long lasting trailing edge.

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How to build rudder blades and centerboards

By J.R. Watson

When the centerboard of my Searunner trimaran broke in the middle of a windy race around the Black Hole, the question I kept asking was "why now, after working fine all of this time, and when we were leading the race?"

"Guess it just wore out" was my excuse to myself. This centerboard was built of laminated layers of plywood, resulting in a thickness of 2". It was then covered with two layers of 6-oz woven fiberglass fabric. It was a deep and wide board with a lot of area, and like any rudder or centerboard on a boat that is sailed hard, it was exposed to a fair amount of stress.

The answer to "why now—while leading the race?" could have been fate. But there is a more scientific answer. Extensive laboratory testing at Gougeon Brothers, Inc. defines why the centerboard failed. Understanding why can help us design and construct components that will perform more efficiently and last much longer.

The plywood centerboard did, in fact, wear out—or more accurately—it failed from rolling shear fatigue. Fatigue cracks in a material result from repeated (cyclic) stress. Fatigue is a reality of all structures and materials, and eventually culminates in structural failure. Repeated loading and unloading or even worse, loading one way and then the other (reverse axial), rapidly reduces a material's physical integrity and accelerates degradation. The higher the load is as a percentage of the material's ultimate strength, the more rapid is the deterioration.

Materials

Some materials have a greater fatigue life than others. Ounce per ounce, wood is capable of operating at a much higher percentage of its ultimate stress level than most other materials. That is why such wonderfully efficient structures can be built with wood. However, plywood is not a good choice for cantilevered structures such as rudder blades and centerboards. This is because plywood is susceptible to *rolling shear*, shearing forces that roll the structural fibers across the grain. Plywood's unidirectional wood fibers are laid in alternating layers, approximately half of them are oriented 90 degrees to the axi of the loads. Like a bundle of soda straws which resist bending moments quite wel one way, they simply lack cross-grain strength laterally and can roll against one another and fail under relatively low stress, especially in a cyclic environment. Therefore, when anticipated loads are primarily unidirectional, it is ideal to use a material with good unidirectional strength. Since only half of plywood's wood fiber is used to advantage, a plywood rudder blade or centerboard going from tack to tack (reverse axial loads) will fatigue much more rapidly than one built as described in this article.

If you were to look at the end of the board, say a fish's view of a centerboard or rudder blade, you'd view its cross section. A section that has a faired airfoil shape is preferred over one that is flat with parallel sides. This is because the airfoil shape produces lift when moving through the water, thereby counteracting the sideward forces exerted by the sail rig. A flat section produces less lift and at a great expense of drag, slowing the boat and making it more difficult to steer.

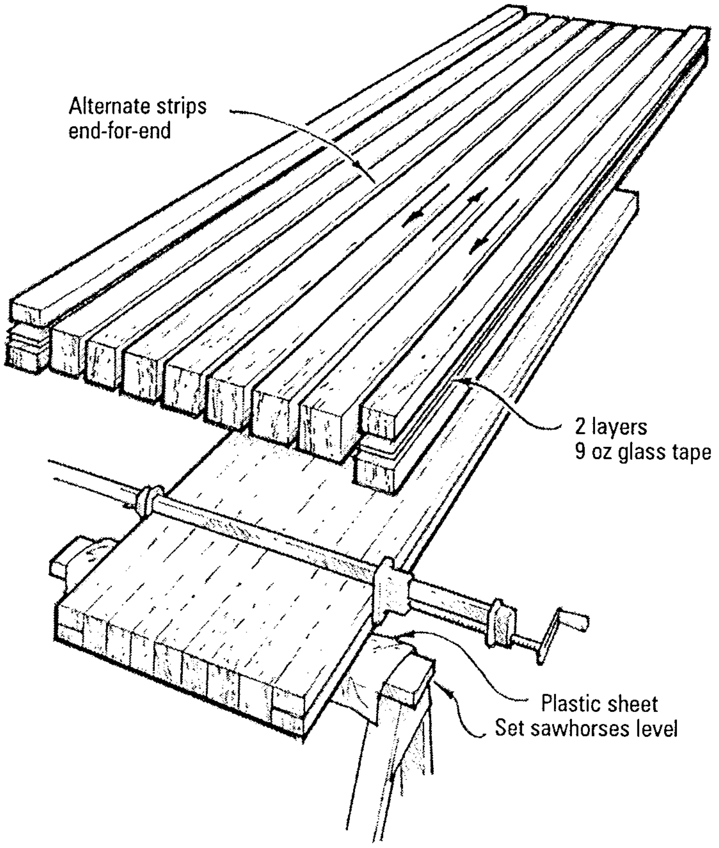
Selection of a proper camber and section can be a subject of great theoretical debate. One can become intimidated with technical terms such as Thickness distribution, Reynolds number, Boundary layer, and so on. These terms do relate to the subject, however, for the builder/sailor whose boat floats forlornly in need of rudder blade the following will do just fine. In fact, the best designers and builders will be hard-pressed to do better.

An excellent choice for most craft, is a realistically accurate and fair NACA (National Advisory Committee for Aeronautics) 0012 airfoil, where maximum board thickness is 12% of the fore/aft length (chord length). Maximum thickness is located about 30% of the chord length measured from the leading edge (see sketch). The dimensions used to establish a specific shape (called offsets) are given in the appendix of *The Theory of Wing Sections**. See the following article, *How to loft Airfoil Sections.* From offsets make a good drawing of half the section on transfer paper.

Western red cedar and redwood are good choices of wood to use for rudder blades and centerboards for boats up to 25 feet. Both of these woods bond very well, are generally clear and straight grained, have good dimensional stability, are easily worked and affordable. Cedar is just a little heavier than the foams used for rudders, is much stiffer and has far greater shear strength values. On larger craft, a higher-density material like African mahogany is a better choice. Oak is not a good choice.

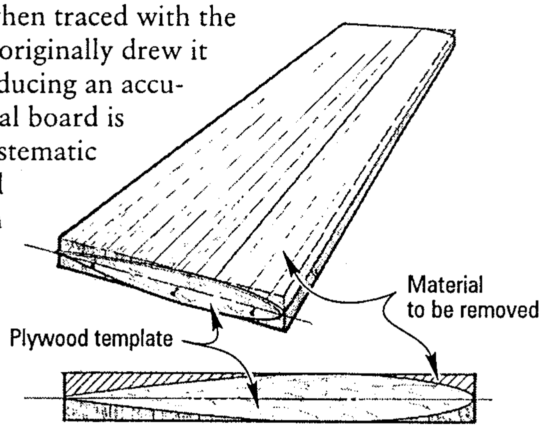
Construction

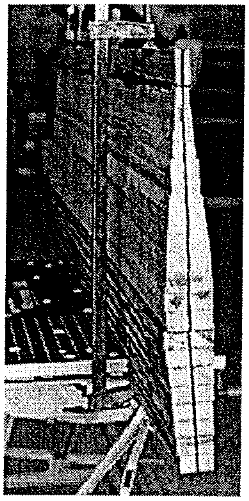
Buy flat-grained 2"×6"s or 2"×8"s, and then rip them to the designed board thickness. Turn every other ripping end-for-end to neutralize the effects of any grain that does not run exactly parallel to the blank, and to reduce tendencies to warp or twist (see sketch). Rotating the rippings 90 degrees to expose vertical grain will permit easier shaping with a plane. The last trick is to rip the end pieces of the nose and tail in half. Bonding with a couple of layers of glass tape between keeps the fine edge of the tail from splitting too easily and offers a precise centerline.



Bond the ripping with a slurry of epoxy and 404 High-Density filler. Plastic strips prevent inadvertent bonding to leveled sawhorses (see sketch). With both sawhorses leveled, you're positive no twist exists in the laminated blank. Bar clamps should be snugged until excess glue squeezes from the joints. Over tightening only stresses joints and tends to squeeze all the adhesive from them. When the laminate is cured, a light planing to clean the surfaces is all that is needed before shaping begins.

First, tack the ⅛"-thick plywood template that describes the cross section shape to the blank's ends. This is sawn from the impression made when traced with the transfer paper you originally drew it on. The key to producing an accurate and symmetrical board is maintaining of a systematic removal of material from one side, then from the other. To do this, mark the shape to be removed, stick to straight-line shapes (see





An alternative clamping method to align the strips during the gluing operation.

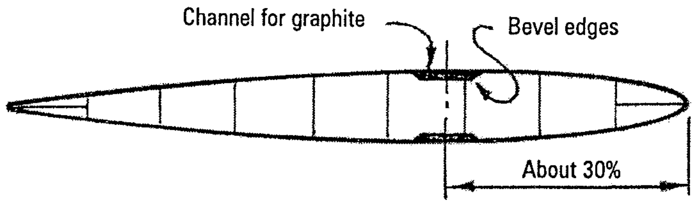
Saw a ½" slot in the ends of each strip at the centerline into which a strip of ⅛" plywood will fit snugly.

sketch). Use a smoothing plane to remove the wood. After planing to the guide lines on one side, flip the blank over and plane the same shape on the other side. The procedure is similar to producing a round shape from a square by first forming an octagon, and then flattening the resulting eight corners to produce a 16-sided shape and refining that until very minute flat surfaces exist. Fifty-grit sandpaper bonded with 3M brand feathering disc adhesive to a ½" thick by 11"×4.5" wide plywood sanding block is a good tool to use for fairing this out.

Reinforcing the blade

Now you should decide if the board needs reinforcement. Your board requires reinforcement if the chord thickness is at or below 4% of the unsupported span. The unsupported span of a daggerboard or centerboard is that measurement from where it exits the hull, to its tip when fully lowered. The unsupported span of the rudder blade is that distance from the rudder case to the tip. If it is a non-retracting blade, measure from the waterline to the tip. So, if the board extends 48" below the bottom of the hull and is 2" thick, .04", it should be reinforced for strength and stiffness.

If the board needs reinforcement, graphite fibers are a good choice as the strain-to-failure values of wood and graphite fiber are quite similar, hence they enhance each others performance. The high-modulus qualities of the graphite fibers provide stiffness. The addition of graphite will efficiently increase stiffness and ultimate strength. Don't be intimidated by the high-tech qualities of graphite fibers, they are easy to work with.



The amount of reinforcement needed is usually figured at 10% chord thickness. Using the same board for our example, the board is 2" thick, then 10% equals .20" total reinforcement, .10" per side. Graphite fiber tows are .01" thick, so 10 tows per side should give the necessary reinforcement to do the job.

The graphite fibers will be laid into a channel that is routed into the shaped board (see sketch). The specific depth of the channel is determined by the above rule. Make the channel a little deeper than what's required (1/16") so you won't be sanding the graphite fibers.

The profile of the channel is similar on all boards. The centerline of the channel is usually located at the point of maximum chord thickness (about 30% from the leading edge). The widest point of the channel is where the board exits the hull when completely lowered. The channel width at this point should be about 16% of chord length. Toward the ends of the board, the width of the channel narrows by about one third that of the widest dimension. Keeping this in mind, more graphite can be laid in that area, a little above and more below that point that exits the hull. Maintain a consistent channel depth throughout.

Take a 1" square stick to serve as a router guide. It's best to bevel the edge of the channel to reduce stress concentration. A rabbet plane serves best for this task. A layer of 6 oz fiberglass cloth is laid in the channel first (this serves as an interface between the wood and graphite fiber), followed by the schedule of graphite. You can complete the entire bonding operation for a side in one session. Try to do the other side the next day. Finally, fair the reinforcement area with WEST SYSTEM brand epoxy and a low-density filler.

A layer of 6-oz woven-glass fabric should then be bonded to the faired board to improve the cross-grain strength and abrasion resistance. The radius of the leading edge should be about a 1% radius of the chord length, and may not permit the fiberglass fabric to lie flat around the radius. In that event, cut a strip of woven glass fabric on the bias (which will lie around a tighter radius) and bond it around the leading edge.

It is better to leave the trailing edge slightly squared rather than razor sharp. This will cause less drag and the centerboard will be less vulnerable to damage. Flatten the trailing edge to 1/16" or 1/8" on small boards, and closer to 1/4" on larger boards.

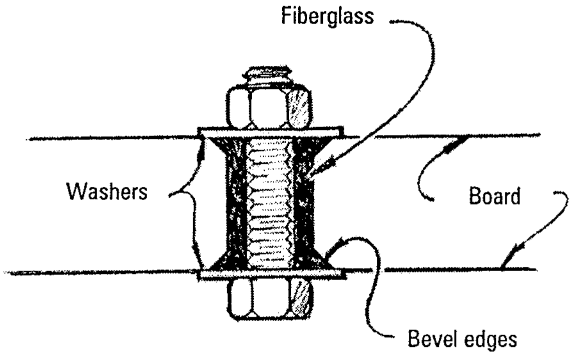
Axle installation

Any board, no matter how stiff, will deflect. To prevent the axle hole that the centerboard pivots on from binding when deflection occurs, make the hole somewhat larger than the pin diameter. The perimeter of the axle hole should be thoroughly protected with fiberglass, as exposed end grain can absorb moisture.

Abrasion of the axle against the axle hole dictates that you should bond fiberglass into hole's perimeter. To do that, wrap fiberglass tape around a waxed (use auto paste wax) metal rod that is about 10 to 15% larger in diameter than the actual axle pin. The hole should be heavily chamfered on each side, so when the wet layup is placed in the hole and the nuts tightened, the fiberglass is pressed by the large washers into the chamfers on both sides of the board (see sketch). The same procedure may be used on retractable rudder blades; but the tolerance between axle hole diameter and the diameter of the axle pin should be closer.

You can bond control lines for centerboards and rudders-in-place by wetting a slightly oversized hole (about 1½" to 2" deep) with epoxy/404 High-Density filler mixture. It helps to mark the hole's depth on the rope with vinyl electricians tape to serve as a guide. Then, after soaking that end of the rope to be bonded in epoxy for a minute or so, shove it in the full depth of the hole.

Centerboards and rudder blades are often overlooked components that are of vital importance to a boat's performance. Built correctly, they will reliably operate with the efficiency of a fish's fin, and you should note a measurable improvement in the quality of pointing and steering of your windship.



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2. Johnston, Ken, *Some Thoughts on Rudder Sections*, Multihulls Magazine (Jan/Feb 1980)

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*5. Abbott and Doenhoff, *Theory of Wing Sections*, Dover Publications, Inc. New York (1959). ■

How to loft airfoil sections

by J.R. Watson

Airfoils are cambered sections that are designed to produce lift (with minimum drag) as they operate in a fluid (air or water). Certain sections produce the most lift with the least amount of drag for a given condition.

When a designer chooses a foil section for a particular design, that section is often not produced to a close tolerance. I sailed on a boat that was noted for its erratic steering: the problem boiled down to an asymmetrical rudder. Optimization of the airfoil section translates into measurable performance and handling benefits.

Whether you are going to build an airfoil from scratch or fair an existing foil with a template, you have to establish the section profile accurately.

Airfoil sections of all NACA (National Advisory Committee for Aeronautics) families are obtained from dimensions off the centerline from specific station points. Station points begin at zero at the nose. The stations are spaced more closely in the forward third of the foil section's chord length. This area carries more shape, thus requiring more reference points to define it.

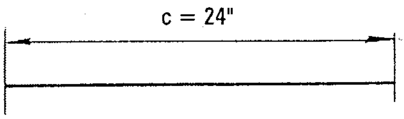
Chord line is defined as the straight line connecting the leading and trailing edges (or centerline). *Station locations* are expressed as a percentage, measured from the forward #0 station, of the chord line. *Chord thickness* is described as a percentage of chord line, measured in half breadths at a particular station.

x (per cent c)	y (per cent c)	$(v/V)^2$	v/V	$\Delta v_a/V$
0	0	0	0	1.988
0.5	.....	0.640	0.800	1.475
1.25	1.894	1.010	1.005	1.199
2.5	2.615	1.241	1.114	0.934
5.0	3.555	1.378	1.174	0.685
7.5	4.200	1.402	1.184	0.558
10	4.683	1.411	1.188	0.479
15	5.345	1.411	1.188	0.381
20	5.737	1.399	1.183	0.319
25	5.941	1.378	1.174	0.273
30	6.002	1.350	1.162	0.239
40	5.803	1.288	1.135	0.187
50	5.294	1.228	1.108	0.149
60	4.563	1.166	1.080	0.118
70	3.664	1.109	1.053	0.092
80	2.623	1.044	1.022	0.068
90	1.448	0.956	0.978	0.044
95	0.807	0.906	0.952	0.029
100	0.126	0	0	0
L.E. radius: 1.58 per cent c				

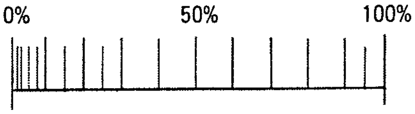
NACA 0012 Basic thickness form

Lofting a NACA 0012 foil section

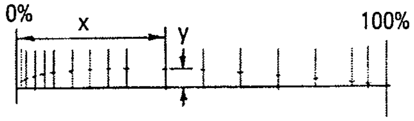
1. Establish overall chord line length (*c*); our example is 24".



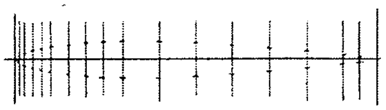
2. Refer to NACA 0012 Basic Thickness Form. Calculate and mark the station locations (*x*) which are a percentage of the overall chord line length, measured from 0%.



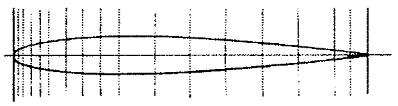
3. Calculate and mark the *y* dimensions (thickness from the chord line) at each station.



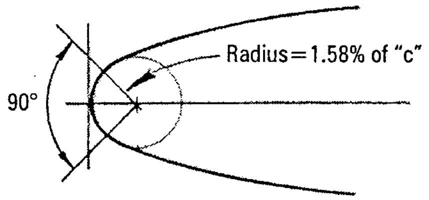
4. Duplicate the *y* dimension points on the other half of the foil.



5. Connect the plotted points with a batten or ship's curve.



6. Lay out the leading edge radius. The actual radius is a 90 degree segment of a circle drawn tangent to #0, bisected by the chord line. Its radius is 1.58% of the chord line length (*c*). ■

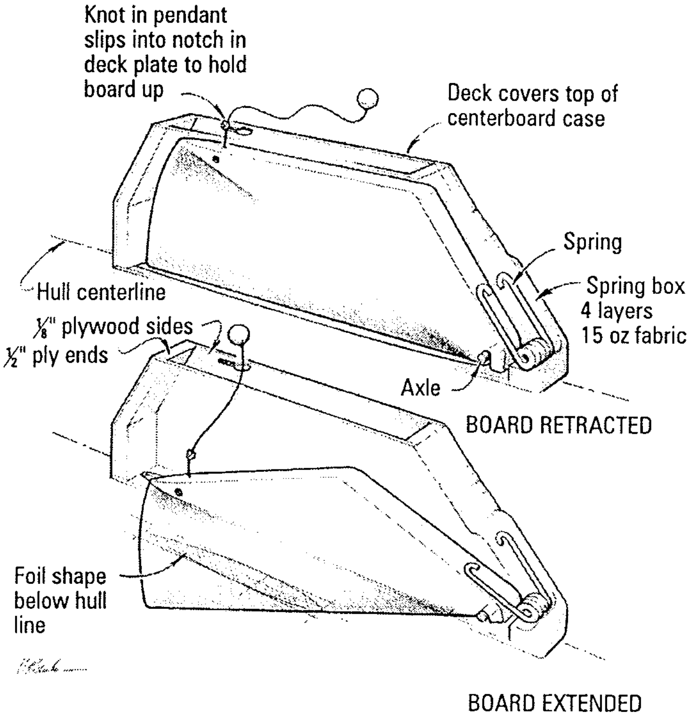


Building a spring-loaded centerboard

By J.R. Watson

All boats need lateral resistance in order to move efficiently through water. Boats with U-shaped hulls require centerboards or daggerboards to provide lateral resistance, but boards are a hassle when sailing in shallow water and are easily damaged by groundings. Hobie Cats and similar catamarans have V-shaped hulls to provide lateral resistance. And, although V-shaped hulls eliminate the need for the vulnerable boards, they have greater wetted area and more drag, causing the boat to move more slowly in water. V-shaped hulls also dig into the ground, making launching more difficult. A board's aspect ratio is more efficient than that of a V-shaped hull's, permitting a boat with boards to point higher when sailing to windward.

I wanted to build a boat to have the speed and handling advantages of U-shaped hulls with boards, but I didn't want the problems and hassles associated with daggerboards or centerboards. So I designed special centerboards to minimize board-related hassles. They are fitted with a heavy spring, set in a pocket in the centerboard case. The spring pushes the centerboard down. Since there isn't a lanyard holding it down, the centerboard comes up automatically when it hits the bottom, and goes back down when the water gets deeper. The only adjustment is a line to hold it in the up position as desired for shoal water operation.



Centerboard case construction

Building the case was fairly straightforward, but the spring housing posed some interesting challenges. When the centerboard is retracted (nearly all the time except when sailing), the load on the spring is about 30 pounds. The housing had to be just wide enough to house the spring or the spring would flop over on its side. The housing had to be shallow enough to allow the spring's force to fully extend the centerboard, yet deep enough to house the compressed spring and the centerboard.

The configuration would be tough to fabricate of wood, so I formed the housing out of fiberglass and attached it onto the forward end of the centerboard case. I bonded some blue home-insulation foam to the forward end of the case and shaped it with 50 grit sandpaper. I figured 3/16" thick biaxial fiberglass would be strong enough to accept the spring loading. The glass also had to—while extending onto the case sides for attachment—fasten the stainless steel axle in place. To get a 3/16"-thickness of biaxial fabric it takes 4 layers of 15 oz E-glass fabric. I wet each precut layer of glass and placed it over the foam and onto the plywood of the centerboard case. I covered the wet lay-up with release fabric and heavy polyethylene, then smoothed the laminate. After it was cured, I removed the plastic and release fabric and trimmed the edges. The soft foam was easily dug out of the spring cavity. Where it was difficult to get at, I sloshed a little solvent to dissolve the foam.

With the hulls upside down, I created the centerboard slots by first cutting undersized slots in the hull bottoms. Then I stuck the narrow end of the boards up into the slots. After lining the board centerlines with the hull centerlines, I scribed an oversized line around the boards and trimmed the slots to the lines. I repeated the process several times until the slots were just slightly larger than the foil section of the fully extended boards. ■

Durable edges for centerboards & flip up rudders

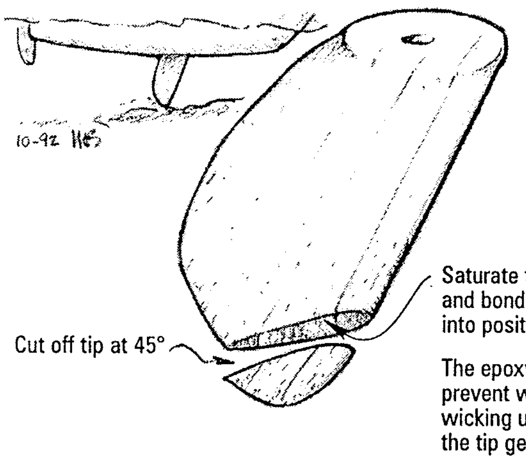
by Jim Derck

When centerboards and flip up rudders drag across the bottom, the first fiberglass to abrade away is usually the leading edge at the bottom. This exposes the end grain of the wood, allowing water to be absorbed the length of the centerboard or rudder. The wood then expands, cracking the fiberglass along the leading edge and causing more problems. When it is time to repair the tip, it usually takes a long time to dry the wood for an effective repair.

Water resistant tips

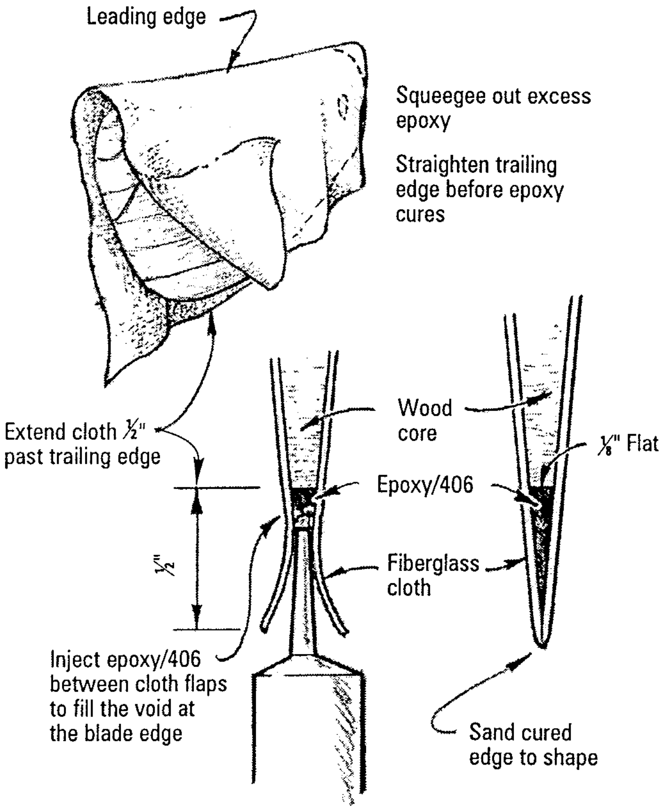
This technique creates an epoxy barrier that limits how far water can wick up into the blade. To isolate the end grain of the tip, cut diagonally from the leading edge to the bottom, apply several coats of epoxy to both pieces and bond the tip back on.

In the future, if the fiberglass cloth abrades away and the wood gets wet, it is quick to dry out the short length of end grain prior to making the repair.



Durable trailing edges

Here is a technique for fiberglass covering that has proved over the years to provide a long lasting trailing edge. When rebuilding an existing blade or before applying fiberglass cloth to a new blade, plane a flat on the trailing edge about ⅛"-wide (wider for large rudders and centerboards). When applying the fiberglass cloth, position the rudder or centerboard horizontally so the leading edge is up. Drape the fiberglass over the foil and trim so that it extends ½" past the trailing edge. If you make a full-scale drawing of the trailing edge of your board or rudder, you will get a better idea of exactly how much fiberglass cloth to leave.



After the fabric is wet out, use an 807 syringe to apply epoxy thickened to a non-sag mix with 406 Colloidal Silica to fill the gap between the two layers of fiberglass cloth.

Squeegee out excess epoxy and align the trailing edge so that it is straight. If necessary, clamp a plastic covered straight edge in place to make the fabric conform to the shape of the trailing edge. After the epoxy cures, do the final shaping with a sander or sandpaper and a block of wood. Use caution, the edge can be very sharp! ■