SINGLEHANDED SAILING SOCIETY
NOTES ON SELF-STEERING
(Robby Robinson 10-8-97)

A singlehander must have a reliable self-steering system that works in all conditions. The system should be rugged, simple and user friendly. The singlehanded racer needs all the above plus a system that will drive the boat at the maximum possible speed in the correct direction.

Self-steering performance is somewhat specific to the boat. A boat that is hard to steer for you is hard to steer for a selfsteering system. It is therefore important to "balance" the sailplan when sailing to the extent possible even if a small speed loss is the result. Going very fast in the wrong direction (e.g. broaching or zig-zagging) is not fast.

Many boats that race the SSS TRANSPAC are not dedicated race boats, but sail the return trip and whose owners cruise or plan to cruise. Therefore the selected system is often purchased for more then just a "one time" use.

My choice in 1979 was a MONITOR vane gear with a tiller autopilot for use in light airs when motoring or sailing in very light wind. I've never regretted this choice. Interestingly I've used the MONITOR on two boats in two TRANSPACs plus extensive cruising during those years with little maintenance. On the other hand I've purchased a total of three (Autohelm) autopilots in the same period of time. Including the repair costs, the autopilot costs have far exceeded the cost of a new windvane gear.

The TRANSPAC sailor who has entered the race who intends to come in first, and who has the experience and skill to do so, plus a boat capable of accomplishing this will generally use a "state of the art" underdeck auto-pilot. An example is STAN HONEY who broke the record in "94" with his Cal-40 using an ALPHA autopilot which steered the boat all the time using software he developed and powered by his laptop computer. He did not have windvane back up. On the other hand, BOB CRAMER-BROWN sailing a 60" ketch ETOSHA, a boat with "first to finish" potential in "88" was stopped due to autopilot failure and did not, I'm sure, have much fun handsteering half way to Kauai.

I've worked off and on (between cruises) since 1989 for SCANMAR INTERNATIONAL the manufactures of the MONITOR, AUTO-HELM and SAYE'S RIG windvane gear as well as importers of the French NAVIK. I have attached some general information regarding the MONITOR vane gear from SCANMAR.

I wish you all good sailing, fair winds, and most importantly HAVE FUN DOING THIS!!

Robby Robinson has raced and completed the single handed TRANSPAC twice. The first time in 1882 in a Hawkfarm, a 28 foot Tom Wiley one-design, and the second time in 1988 in Rolling Stone, a 35 foot IOR One-Tonner. He is a former Secretary, Newsletter Editor, TRANSPAC race committee member, and Commodore of the Single-handed Sailing Society. A cruiser at heart, he and his wife Dolores have Cruised from SF to BC & Alaska in 92 & 93 and from SF through the Panama Canal to Newfoundland since 94.

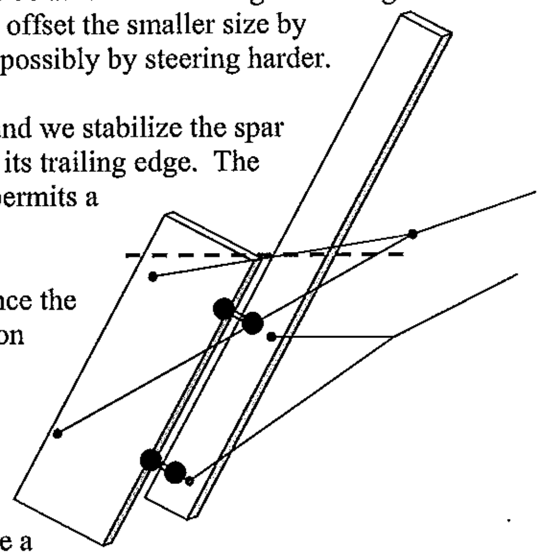
A Simple Backup Rudder for Ocean Voyagers

Michael Moradzadeh (Michael@yachtPC.com)
Cayenne, Passport 40, WMPC 2000 & 2002

In the 2002 WMPC, five boats had serious rudder problems, and one boat was abandoned. Here is a simple design for a backup rudder that is light, small, and cheap.

Rudder Design

A common rule of thumb is that the backup rudder should be at least half as big as the original rudder. This should be big enough to steer the boat. You offset the smaller size by deploying the backup rudder abaft the normal rudder and possibly by steering harder.



Our design is set out here. The rudder attaches to a spar, and we stabilize the spar with guys. We limit stress on the rudder by steering it by its trailing edge. The rudder is therefore supported around its perimeter. This permits a lighter, slimmer, and less expensive design overall.

The major role of the spar is to hold the rudder down. Since the guys take up the side-to-side stress, the only critical load on the spar is upward compression. A 2x4 or spinnaker pole will easily handle the job.

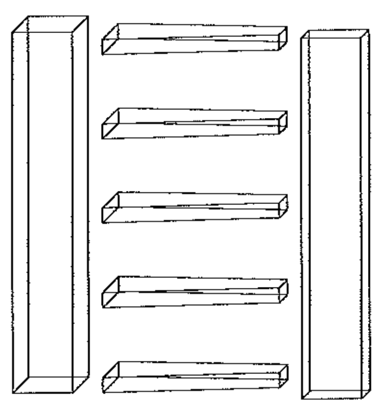
Specifics

Cayenne is a Passport 40, a "performance cruiser" displacing 12 tons. Looking at the existing rudder, I chose a rudder area of four square feet. This is a bit more than half the existing rudder. I also know this to be adequately sized having tried out a prior model.

Smaller boats can scale the rudder down, preferably by shortening it, keeping the same width. Larger boats could scale up in either direction. If you are over 50 feet, you'll probably want to scale everything up!

Construction

The leading edge is a 2x4. The trailing edge is a 1x4. The sides are made from ¼ inch plywood. The top, bottom, and 3 internal ribs are wedges cut from either ¾ inch ply or a hardwood. The whole thing may be sheathed in a layer of light fiberglass to improve strength.



All lumber should be kiln-dried. The plywood should either be marine ply or certified sanded ABX exterior plywood. The "certified" ply at Home Depot is remarkable! No voids.

1. Cut the plywood, the 2x4 and the 1x4 to length (4 feet). The plywood should be 16" wide, though wider would work also.

2. Cut out the wedges for the ends and ribs. These will be as wide as the 2x4 at one end and as wide as the 1x4 at the other. The easiest way to cut these, I found, is to cut a 9" plank out of your heavy wood. Then set your table saw's sliding miter gauge at about 2° and cut in alternating directions using your rip fence as a stop. Cut several extras.

3. Once the wedges are cut, lay them out with the long pieces on one of the plywood sheets. Unless you are Norm Abrams, your wedges will be uneven. Sort them from widest to narrowest, clamp them together, place between the 2x4 and the 1x4, and belt sand with fervor. Your goal is to make the whole arrangement fair, so that the wedges mate nicely with the stringers, and each is fairly similar to its neighbor.

4. Build the internal frame of the rudder. Test-fit first. Lay the 2x4 down with its narrow edge facing up. Position the wedges one at each end and the other three evenly between them. Use masking tape on one side to "hinge" them in place. Goop some epoxy thickened with colloidal silica to the "mayonnaise" stage into each joint. Stand the ribs up and tape the other sides down. Now goop some more thickened epoxy onto the tips of the ribs and stand the 1x4 on them, taping in place.

5. Once the epoxy has set, get out the old belt sander and fair the stringers and the wedges so that the whole frame will accept the plywood skins without significant gaps. If you want to be fancy, you can work in a bit of a curve, which will make the whole thing stronger and a bit more aerodynamic. Be sure to wear a face mask. The epoxy dust is bad for you.

6. Use tack-and-glue technique to attach the first skin to the frame: Lay the frame over the skin and mark the positions of the ribs. Do the same with the other skin. The prudent worker will mark each skin as left or right, and its top and forward directions. Now put the skin on the frame and drill pilot holes every 8 inches or so for the screws that will hold your assembly together while the epoxy sets. Mix a batch of epoxy, thickened to the syrup or mayonnaise consistency. You'll need about 10 squirts per side. Apply the epoxy to the frame, lay the proper skin over it, and screw it down. I like to use stainless deck screws for this. Stainless is good in case you want to (or need to) leave some screws in the assembly.

7. Flip the thing over. Now you have some options. You may epoxy the inner surface of the skin so as to exclude water, and/or you may fill the spaces between the ribs with foam to reduce the risk of waterlogging. For foam, I used "Great Stuff" triple-expanding foam. The 20 oz can was enough to do two rudders, and this material is compatible with WEST epoxy. If you overfill, the stuff will overflow the frame à la Lucy and Ethel, and you'll have to wait till it hardens to trim it down. Attach the other skin.

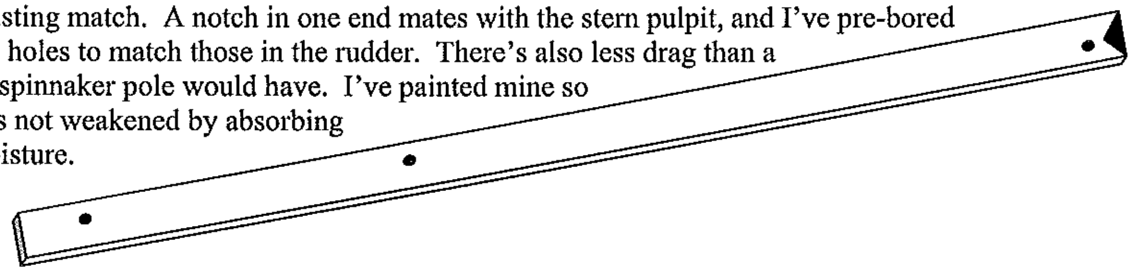
8. Once the epoxy sets, remove the screws. Make the rudder more aerodynamic: at the trailing edge, set your table saw to 45° and chamfer the edge. At the leading edge, first make a 15° cut on each side and then a 45° cut, to give a rounded profile. Try this on some scrap first. Run the ends through the saw as needed to even the plywood with the wedges, and then chamfer them at 30°, or just round over using a router. Get out the belt sander and smooth everything out.

9. Glass the rudder. Cut your glass to size. Then fill any gaps or holes with thickened epoxy. Immediately lay the glass in place and start wetting it out and smoothing. You can do this one side at a time (wish I had) or you can hang the rudder from a couple of screws and do both sides at once (sloppy work). When the epoxy has set, trim the edges and glass some tape around the edges. Admire your work.

10. Bore four holes. Two half or 5/8 inch holes spaced in one rib from each end and centered in the 1x4 and 2x4. Use a router or a file to smooth the edges of the holes. You can add a fifth hole for a retaining lanyard if you want.

The rudder is complete. You only need to pre-fit it to your boat. This involves making or identifying the spar you will use, pre-setting the lines, and **testing it.**

I prefer to carry an 8-foot 2x4 with one edge shaped like the rudder as the spar. It's fairly light and may come in handy for other emergency tasks such as splicing a boom or an impromptu jousting match. A notch in one end mates with the stern pulpit, and I've pre-bored the holes to match those in the rudder. There's also less drag than a 4" spinnaker pole would have. I've painted mine so it is not weakened by absorbing moisture.



Reeve lines through the upper and lower leading edge of the rudder, center them, and tie square knots tight against the edge. This is the pivot point for the rudder. Attach these lines to the spar so that the rudder can pivot freely. Remember to attach things so the rudder does not ride up!

Now attach four lines: two from the quarters of the boat through the holes in the trailing edge of the rudder, and two to the spar. See the diagram in figure 1. Don't tie the lines off as bridles till you have the geometry right. You'll want the rudder control lines to be as far outboard as possible and the spar guys to be both outboard and more forward.

Haul in the spar guys so that the spar comes down to at least 45° or deeper. Cleat them off. Get underway. The steering lines should be led to spare winches, though you can usually steer by pulling on the centers of the lines. Try to steer the boat, both with the rudder fixed amidships and swinging freely. If it is all working right, tie the steering lines into a bridle; this will be easier to manage. Whether to tie the spar guys into a bridle is a matter of choice.

Congratulations! You have a backup rudder. That's one task down and several dozen to go!

Appendix: Math

How much force will be applied to the rudder? This question is key, as a too-light rudder will break. However, a set of overly conservative assumptions will leave you carrying a blade that could steer the *Queen Mary!*

On ours, I calculated a load of about 700 pounds tops. This assumes all values are maxed out (sharp turn at extreme speed). We would still add some backup strength beyond this.

Our rudder, being supported at its edges will need to support around 700 pounds over a portion of its 4 foot length. Since we support the rudder at four points at its edges, we generate a maximum of only a few hundred pounds of force over any portion of the rudder.

Weighing a couple hundred pounds myself, I was in a great position to bench test the rudder by standing on it. It suffered no appreciable deflection when my entire stocky bulk was applied to its entire span.

How Much Force?

The basic formula is

$F = A * C * \frac{1}{2} * \rho * V^2$

Where

F = Force in pounds

A = wet area in the direction of water flow

C = coefficient of lift or drag

ρ = water density (slugs per cubic foot $\approx$ 2)

V = velocity of water flow

Application of formula

A = 2.8: although the side area is 4 square feet, the rudder presents its narrow edge to the water except when turning. Even with an extreme rudder angle of 45°, the area "seen" by the water is only 2.8 square feet.

C = 1.2: The coefficient of drag for a nicely faired ellipse is about .3; for a rectangle it's 2. We'll fair it and call it a very conservative 1.2.

V = 14: how fast will water flow past your rudder? This value is squared, so it's important. Our top speed (going down a wave in a 40 knot squall) is 13.9 knots. Hint: sail more slowly!

So, if $F = A * C * \frac{1}{2} * \rho * V^2$ then

$F = 2.8 * 1.2 * \frac{1}{2} * 2 * 14^2 =$ **688 lbs.**

ORCON CORPORATION

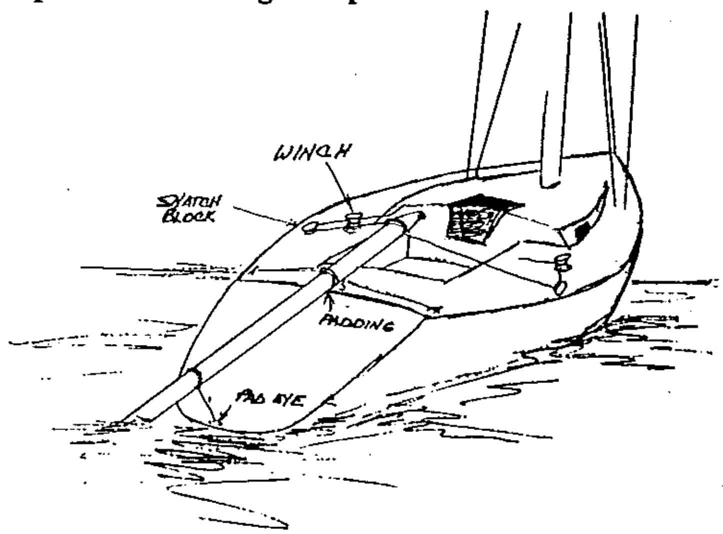
Emergency Steering Methods & Rudder Construction

By Dan Newland & Orcon Corporation

1570 Atlantic Street
Union City, CA 94587-3299
415-489-8100
Telex: 17-6059
Fax: 415-471-3410

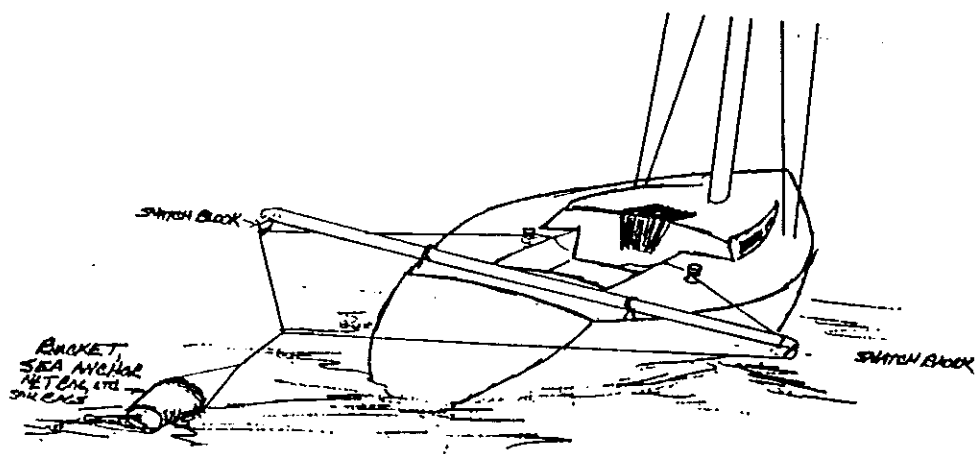
ALTERNATE STEERING METHODS

I. Use spinnaker pole as a steering sweep.



NOTE: Pawls in the winches can be removed to allow winches to grind both ways. The end of the pole in the water can have a canvas bucket or other item to increase effectiveness.
Main will probably require being reefed or furled and two small jibs being wing out in order to minimize load downwind.

II. Use lashed down spinnaker pole across boat to drag side to side a sea anchor or hanging net with laundry, etc.



Boat will probably require jibs wing and wing for balance downwind.

REMEMBER: A boat going upwind in winds over 10 knots is the conditions which most easily allow you to balance a boat without you having to steer.

Rudder Construction

Emergency rudder construction is not extremely difficult. This article will describe some basic guidelines as to the design and construction of an emergency steering rudder. Some people have said that once your primary rudder is broken, you are out of the race. If I were to think that, I would not spend much time on an EFFECTIVE emergency rudder. Although it can be an annoyance for storage, a well designed emergency rudder can allow you to remain competitive and more importantly, allow you to make it to port without assistance and utter exhaustion.

Let's break this up into several main topics. First the design: The first question is how big and what should the shape be? For this article, lets assume the emergency rudder is to be transom hung. The easiest answer is to make the area BELOW THE WATERLINE the same size as what you have now. This will in almost all cases be much more than adequate. If you want to save weight, space, time, and materials, and you only require a rudder to get you to port, cut this area by up to 1/2 original area. If you have a boat with long overhangs high out of the water, such as a Catalina 38, keep the area on the large side because the rudder tends to come out of the water more easily and it is less effective. If you don't know the size of your existing rudder, use this formula to give you an idea of the full size area, (for the purpose of this article, I will only use the projected area when speaking of area, which is the area of the profile). Take the area of your mainsail and 100% jib and multiply that by .0135 to obtain the total underwater projected area. For these calculations, a sailplan is helpful, but not essential. A class rules sheet or sales brouchure can give you what you need.

Now that the area is determined, the profile has to be determined. I will only be speaking of straight sided rudders here, in order to simplify calculation. The first thing is that unlike keels, rudders operate more efficiently if they are of only moderate aspect ratio. Try to get the length to be about 2.5 times longer than the width. Once you get this basic shape as a rectangle, you can play with tapering the end if you want. Aside from some slight efficiency benefits, it is better to have a thick top structurally. If you want, you can design the bottom of the rudder parallel to the waterline, otherwise it is best to have a rounded tip. Do a scale drawing of the transom and see if everything looks OK. You now should sketch in the tiller and how you intend to miss things like the backstay, windvane, etc.

Since this is a trapezoidal type of rudder, there are only two foils that have to be drawn. These are the ones at the tip and the one at the waterline or slightly above. Since the proportions are all similar, the vertical dimensions will all be straight lines. At this stage, to be very honest, if you are fairly good at sketching, you can draw a section that will do an excellent job of steering, just draw a foil that is about 12% as thick as it is long. Minor differences in shape will make very little difference at this point, with only this one hint. A rudder works at high angles of attack and due to the nature of fluids, a larger radius at the front of the rudder will postpone stall longer than a keel type of shape. For this reason don't go too pointy on the leading edge. For those of you that want to be scientific, a table of offsets is provided. It is all based upon the length of the chord, (the width of the foil), and will require some conversion to inches. The math is easy, just remember that 1.5% is .015 (for instance), for your calculations.

Although there are many other shapes and thicknesses for a rudder, the NACA 0012 is a very good all around shape and is thick enough to give good strength.

You now have the basic shape of the foils, the size and thickness of the rudder, so you're ready to start ordering materials. Clark foam is very good material to make a rudder from. It is extremely easy to work with, is not affected by polyester resin and is relatively inexpensive. Naturally it has very little inherent strength and will require fiberglassing. Wood such as white pine or cedar are good, relatively easy to work with woods but should be laminated from pieces to keep it from warping. Therefore there is no savings in time with wood over foam and glass, nor is there much of a dollar savings. It becomes a matter of preference, I have built rudders, dagger and centerboards in both and prefer working in wood because it is pleasing to work with. For pure strength and weight considerations, I prefer foam and glass.

The following is a list of materials for the construction of a foam and glass rudder:

Clark foam 4 or 6 lb. cu. foot density. Thickness to be at least 1/2 the thickness of the rudder. Foam size is limited to 2'x8' "blanks."

AME 4000 resin, (and MEKP catalyst) OR:	One gallon
Epoxy laminating resin, i.e., WEST. System 3, etc.	One gallon
Acetone	1 quart
Rubber gloves	
Orcon "S-500" fiberglass, or G-450 Carbon Fiber 1' width-3 layers both sides	
18 oz. fiberglass roving 36"-48" wide	One yard
Microballoons	1 pound
3/4" x 3/4" STRAIGHT sticks 1' longer than rudder	2 required
36 grit sandpaper	4 sheets
120 grit sandpaper	6 sheets
Sanding primer paint (optional) epoxy, Featherfill Polyester, etc.	1 quart
Color paint (optional)	1 quart
33" long 1" x 4" <u>STRAIGHT</u> sanding board	1
4 1/2" x 9" approx. sanding block	1
"Bondo" fast drying putty (optional)	1 quart
Plastic putty squeegees	3
3" paint roller	1
Throwaway brushes	
Large "C" or bar clamps	2
Large "Surform" tool	1
Hand saw	1
Sand bags, cinder blocks, or other weights	6-10
Pintles and gudgeons	2 pair
4' x 1.5" aluminum tube for tiller	1
Felt tip pen	
Straight edge the length of the foil shape	

Clark foam , AME, or Epoxy resins, "S-500" G-450, roving, and microballons can be order from MONTEREY BAY FIBERGLASS in Santa Cruz, phone: (408) 476-7464. The rest can be obtained at most lumber, or hardware stores. If you plan to build a wood rudder, a covering of 10 oz. glass and AME or Epoxy is a good idea and is also available at M.B. Fiberglass. The pintles and gudgeons are specialty items that probably will have to be ordered from a chandlery. Some large size boats may require specially designed and fitted pintles and gudgeons. Contact local chandleries for local stainless steel fabraicators.

CONSTRUCTION

You will need a flat surface, a work bench is best, but plywood sheets will work if you have two saw horses. If your rudder is less that the blank size, begin by putting two 3/8" deep by 3/4" wide channels in the foam for the full length for both halves. They should be separated as much as possible, but they should leave at least 1/16" of material on the outside of the final foil section. This can be done with a pocket knife and chisel or better yet a table saw. (A note about table saws! Table saws can grab the foam and jerk it out of your hand--<u>USE A PUSH STICK</u>!!) Next, cut out the section you have sketched in either wood or a slice of extra foam. This wood or foam slice should be between 1/4" and 1" thick. Cut out 3/4" x 3/4" square holes in the sections match the width of the channels.

Cut apart the blank at the top section. Assemble the 3/4" sticks through the section templates and insert in the channels in the blanks. If the fit is adequate, place on your flat work area and glue together with your resin. If there is some gaps, these may be filled with a thickened mixture of resin and microballoons. Be sure to check that the sticks and blank are not twisted. A few bricks or sand bags would enhance bonding at this point.

When cured, cut away the excess foam in large blocks with a hand saw. The extra length on the alignment sticks can now be used to clamp to a table which really facilitates accurate and quick shaping. Begin shaping with the "Surform" tool. Work lengthwise and check your work often with a straight edge. Leave the area above the pintles basically square with only enough rounding of the corners to facilitate lamination. Remember, you want straight lines between similar portions of the sections; i. e., a straight line between the 30% ordinate of the top section to the 30% ordinate on the bottom section. This goes extremely quickly, so begin sanding with the longboard BEFORE you get to the final shape. As the last item before lamination, cut out two wood blocks to go underneath the pintles to take the high crushing loads of the bolts. Glue them in as before with resin and Microballoons to fill any gaps.

Begin lamination by putting a heavy layer of catalyzed resin on the shaped blank, then apply the first layer of "S-500" ORG-450 at 15 degrees from vertical. Cover the foam completely and wrap the material around the leading edge. Use a paint roller or brush, a plastic squeegee to work resin. When complete, do the next layer vertically, and finally the last unidirectional layer of "S" 500 at 15 degrees from vertical but opposite the first layer. If the tiller is not to swivel it may be glassed in. Simply wrap one layer of wax paper around the tiller and tape the wax paper and tiller in place. This only has to hold the tiller in place long enough to laminate two layers of 18 oz. roving over the tiller and whole rudder head. One additional layer 9" wide should go over the top of the tiller. When cured, pull the tiller out and begin rough sanding with 36 grit paper. Be sure to wear a respirator and long sleeves due to the excellent itch properties of fiberglass. The objective is to remove as little material as possible and get a good smooth shape. Grind off any glass pikes, then sand with the long board to remove any gross high areas. You should very shortly have a good idea of where your rudder has low areas to fill and it will of course have the fiber pattern to fill. With a straight edge plot the lows and mark with a felt tip pen. This first layer should be resin and microballoons. Once cured, the small sanding block and 36 grit can be used. This fill/sand cycle can be repeated as required. If you used the Epoxy, you should continued using Epoxy and microballoons. If you are using the AME polyester resin there will be a substantial resin build up problem on the paper. This can be partially offset because you can use "Bondo" for the last thin putty layers, which will speed up your process.

Once the surface fairness is to the standard you want, it can either be left alone or it can be painted. Most sanding primers will fill 120 grit sanding scratches so leave the last layer of sanding with a 120 grit finish. I generally prefer an epoxy primer but others can work just as well. Spray or brush as you prefer. Sand to a 220 wet sandpaper grit if desired, or if you wish to paint in a hard gloss, sand to a 180 grit finish and paint as desired.

The final details such as pintle installation and drilling a retainer pin hole in the glass sleeve and tiller may now be done. On the pintles, the bottom pin should be longer than the top and rig a safety wire for rudder so that you don't loose it..

Total time on a project like this for a boat around 30 feet would be approximately 24 hours less installation of gudgeons onto the transom. Although it may seem like a lot of work, it really can be **fun**. Of course if you should need it, it will be an asset almost beyond measure. Good luck on your project!!!

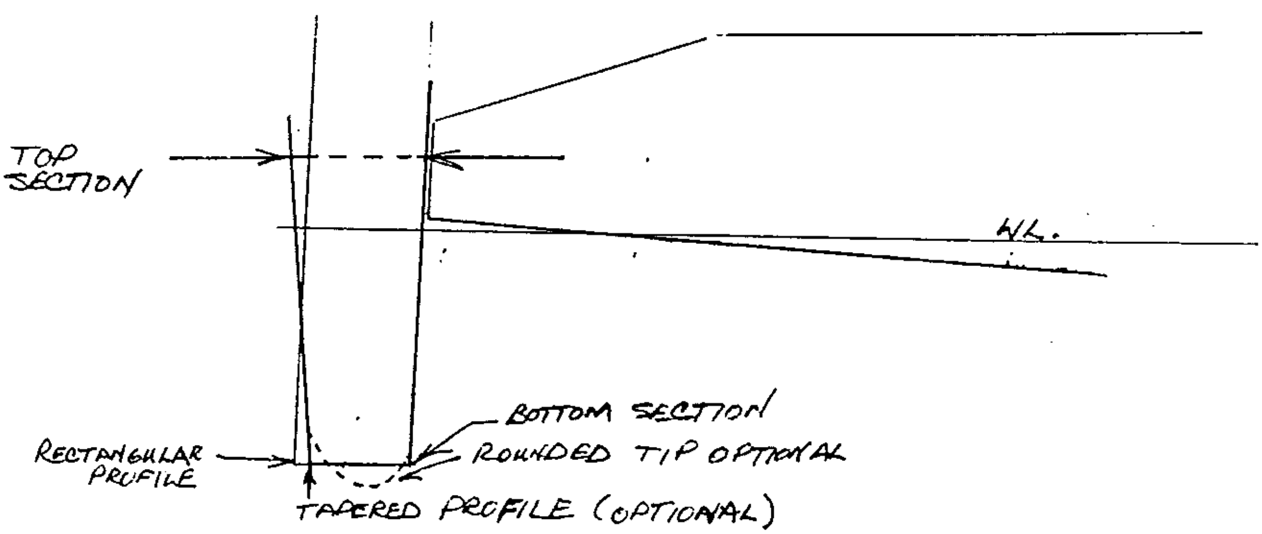
STEP 1 - AREA OF MAIN + JIB x .0135
OR ·
I x J x .5 + P x E x .5 = SAIL AREA WITH 100% JIB - x .0135

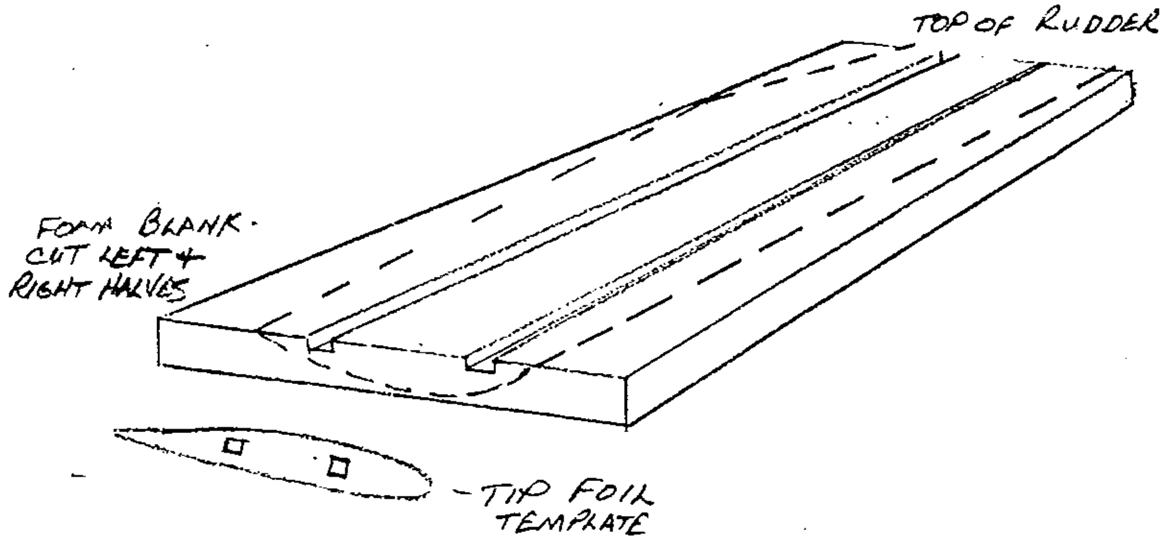
FOR INSTANCE, USEING THE 368 PLANS I = 36.4 J = 12, P = 36 E = 12.38

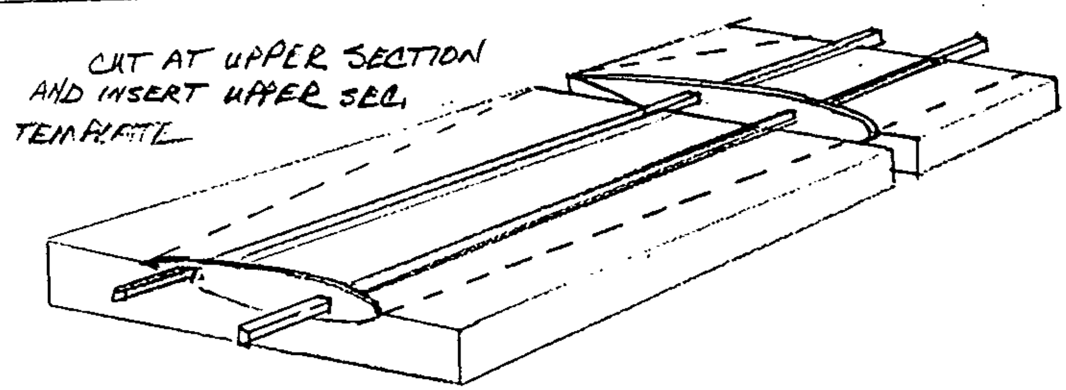
36.4 x 12 x .5 = 218.4 SQUARE FEET + 36 x 12.38 x .5 = 222.84.
SAIL AREA TOTAL = 441.24   441 x .0135 = 5.95 SQ FEET RUDDER AREA

STEP 2 - DETERMINE SHAPE GIVEN 5.95 SQ FT AS THE AREA.
WE DETERMINE THAT A RUDDER 3.9' DEEP AND 1.55' WIDE WILL GIVE US THE RIGHT ASPECT RATIO AND AN AREA SLIGHTLY LARGER THAN CALCULATED - AREA = 6.05 SQ FT.

STEP 3 - SKETCH THE TRANSOM AND RUDDER AS CALCULATED;

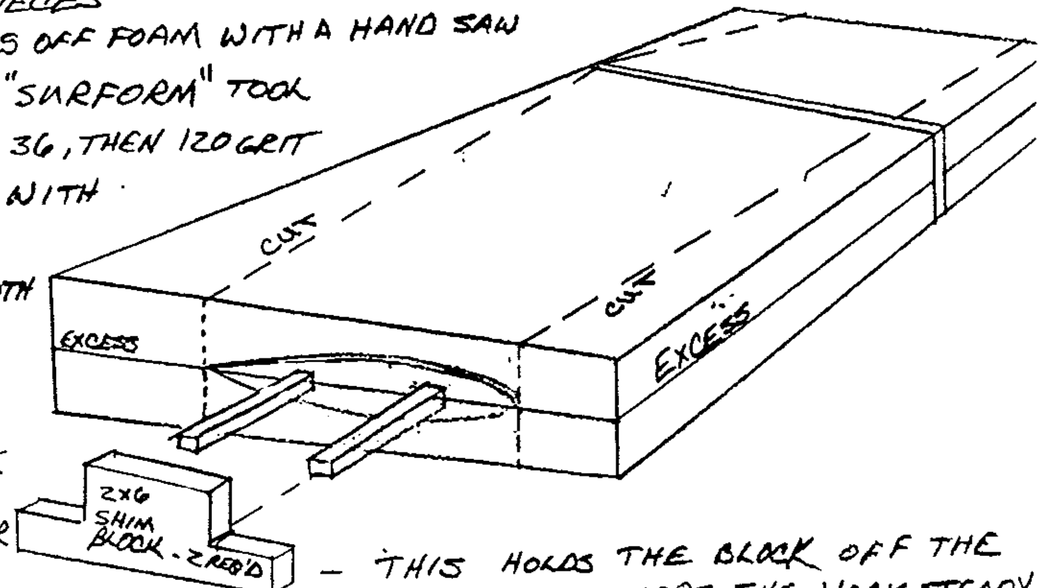






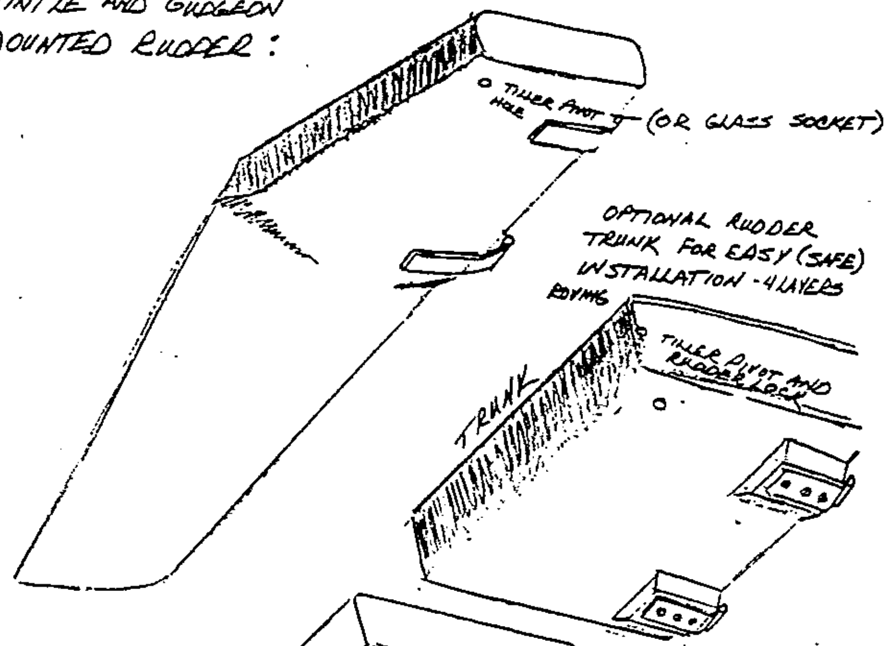
GLUE TOGETHER PIECES
CUT OFF LARGE PIECES OFF FOAM WITH A HAND SAW
ROUGH SHAPE WITH A "SURFORM" TOOL
FINAL SHAPE WITH 36, THEN 120 GRIT
GLASS, THEN SMOOTH WITH
MICROBALLOONS/RESIN
MIXTURE. - SAND. SMOOTH

NOTE: BONDO OR OTHER
AUTO-BODY FILLER CAN BE
USED BUT ONLY WITH ANE
OR OTHER POLY OR VINYLESTER
RESINS.



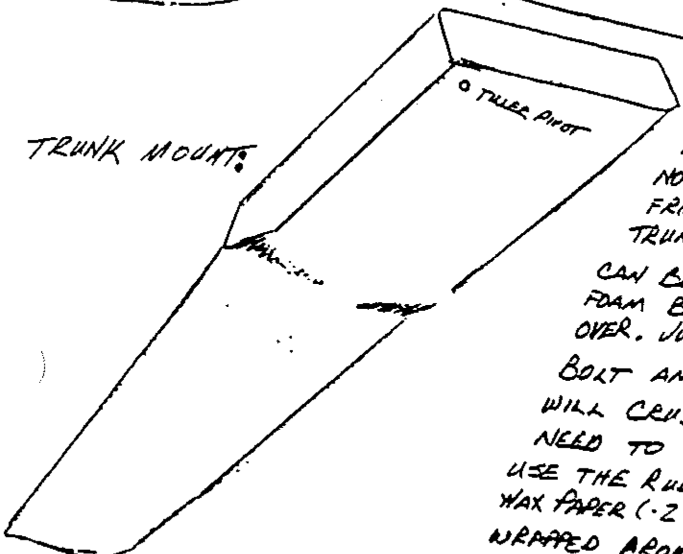
- THIS HOLDS THE BLOCK OFF THE
TABLE AND KEEPS THE WORK STEADY

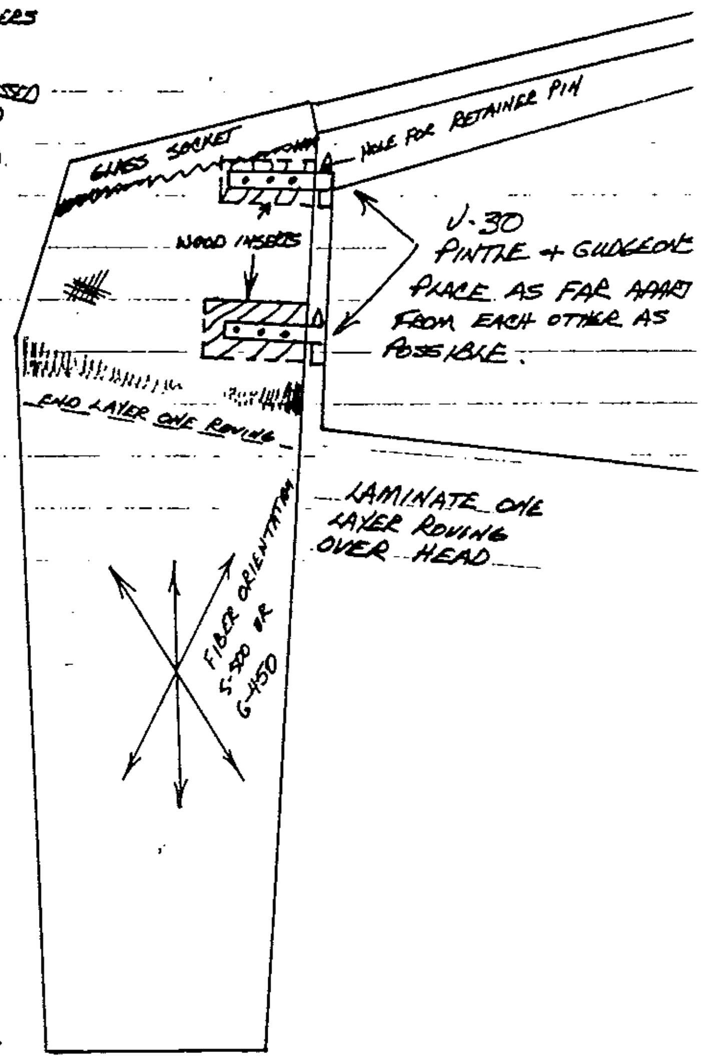
PINTLE AND GUDGEON MOUNTED RUDDER:



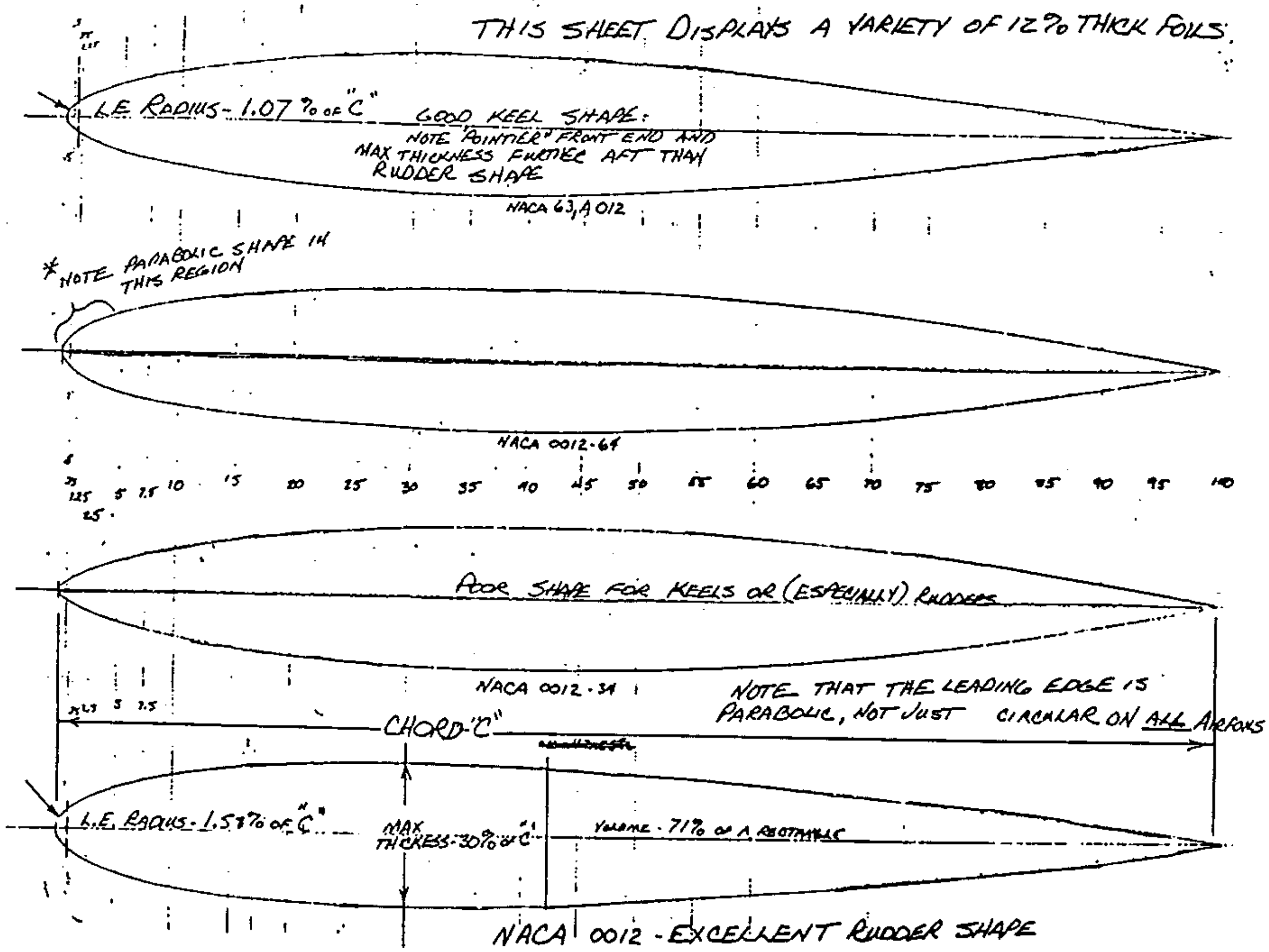
NOTE THAT NUTS FOR GUDGEONS MUST NOT PREVENT RUDDER FROM SLIDING IN TRUNK. THESE SPACERS CAN BE CUT FROM FOAM BLOCKS AND GLASSED OVER. JUST DRILL AND BOLT AND THE FOAM WILL CRUSH WITH NO NEED TO REMOVE IT. USE THE RUDDER WITH WAX PAPER (-2 OR 3 LAYERS) WRAPPED AROUND IT FOR A PLUG.

TRUNK MOUNT:





NOTE: RUDDER CAN BE OFFSET TO AVOID BACKSTAY, VANE, ETC. FAVOR THE PORT SIDE FOR THE HAWAII RACE.



AREA = 71% OF A RECTANGLE

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

Emergency Rudders

Important Points

Vertical blade is better than a swept back "oar"

- shorter rudder length overall (easier to store)
- less torque at lower bearing
- provides better steering control

Decide where you'll stow the blade before building it

- make sure the rudder will fit on the boat. If you can't stow a 10' long rudder then don't build one - come up with a design that's shorter.

Allow for self-steering of the emergency rudder

- self-steering of the blade is really nice, it means you can get on with sailing the boat rather than just steering until you get exhausted

Build early and test

- building the rudder takes time, don't wait until the last minute
- don't just try out the rudder in flat water - take it out to the ocean for a test spin

Know how to jettison your primary rudder

- The primary blade is a big problem if it's only bent or jammed and not sheared away. You may need a long stick or push rod to shove the whole blade out of the boat. Carry the tools needed to disconnect whatever is attached to the stock (quadrant, top casting, autopilot brackets, etc.). You may need an extra-big plug or bung to fill the hole left by the rudder stock when it's gone.
- Have the rudder and stock dimensions in hand before you leave, because you'll need them if you do in fact jettison the rudder.

Design Considerations

The rudder should ideally have the same underwater surface area as the primary rudder. If that's impossible, go no smaller than 1/2 the area.

If the rudder has a tiller, the backstay and stern pulpit can get in the way of swinging the tiller, especially if you want to steer from inside the cockpit. With a short tiller attached to the rudder you can lead lines from it to winches in the cockpit (you can remove pawls to make the winches spin in both ways). You might lead lines via blocks to the normal tiller or wheel and steer that way.

Installing the blade can be difficult. If you've installed an El Toro rudder when the boat's in the water you know how difficult it is to control the blade once it's immersed. Now imagine wrestling with a much bigger blade in a wind-swept ocean swell - your fingers can get crushed between the blade and the hull.

The safest rudder to install is a two-part system. The first part is a trunk or box (like a centerboard trunk) that mounts above the water and has the hinging mechanism, the second part is the rudder blade with the tiller, which inserts into the box and can be slammed home quickly. A foam core rudder has a lot of buoyancy - think of a way to lock it down in place.

Another safe design is a section of T-track bolted vertically to the transom and a series of custom-welded track sliders mounted on the rudder. The idea is you can get the first two sliders on the track before the blade hits the water, keeping the rudder lined up while you get the rest of the sliders onto the track. You need a fairly vertical transom for this to work well, or else the rudder blade becomes quite long before you get enough blade area in the water to be useful.

Calculate the Loads

You don't want to be Roy Disney when *Pyewacket*'s main rudder sheared off in the middle of the Atlantic. They popped on the emergency rudder, got back up to speed and BANG! - the mounting structure collapsed after a few hours of high speed surfing.

Loads generated by a spade rudder are high - a simple approximation is you should be able to suspend the entire boat from the rudder stock. Calculate the blade loads to aid in designing the support structure.

The highest blade loads occur when surfing at max speed on the verge of a broach with the rudder cranked over trying to control the boat. Load calculations use the square of the boat speed and therefore design speed greatly effects calculated loads. The coefficient of lift (Cl) is also variable depending on the safety margin you want (Cl indicates that a shaped blade produces more lift than a flat board dragged sideways through the water). The top speed I've done on the Newport 33 is 16 knots surfing down a wave - so I used 16 knots as the design speed.

Blade Loading

Force (lbs) = A $\times$ Cl $\times$ 0.5 $\times$ H_20 Mass Density $\times$ $(\text{Velocity})^2$

A — area of blade, in square feet

Cl — coefficient of lift, anywhere from 2 to 3, 3 is more conservative
(note: Jim Antrim suggests 1.2 as max Cl)

Velocity — feet per second (1 knot = 1.6889 fps)

H_20 Mass Density — 1.98 (density/gravity = 64pcf / 32.17)

Example: 6' blade area, 18" wide by 4' deep, design speed 16 knots

Force = $6 \times 3 \times 0.5 \times 1.98 \times (27.04)^2 = 13{,}012$ pounds

Bending Moment at lower bearing

The blade force is centered midway between the lower bearing and the bottom of the rudder, assuming a rectangular blade profile:

BM (foot pounds) = $0.5 \times L \times F$

L — length of blade between bearing and tip

F — blade load

Example for 4' blade and 13,012 pound design max load

BM = $0.5 \times 4 \times 13{,}012 = 26{,}024$ foot pounds

Top and Bottom bearing loads

Upper bearing load = Bending Moment / distance between bearings (feet)

Example 14" between bearing points (14" = 1.17 feet)

Load = 26,024 / 1.17 = 22,242 pounds

Bottom bearing load = Blade load + Upper bearing load

Example Bottom load = 26,024 + 22,242 = 48,266 pounds

A civil engineer friend worked up the cross sectional areas of the 6061-T6 aluminum used to build the structural supports. A typical question would be, "How wide does a 20" long 3/4" thick aluminum bar need to be to handle 8 tons in compression?" (Answer: 2")

The net result is an appreciation of how loaded the system can get and if you build to the calcs and their inherent safety factors it's unlikely the support structure will fail. In my case, the max speed I saw with the emergency rudder was 8 knots, producing 15% of design loads - well within the rudder's limitations.

Attachment mechanism

You're probably going to attach the rudder to the hull at points that were never intended to carry the loads a rudder generates (see above!). Consider adding additional fiberglass inside the boat to strengthen the hull or transom where the mounts will be. If the hull is balsa or foam-cored, re-core the mounting areas with plywood or solid glass. Don't underestimate the loads, and use BIG backing plates!

It is extremely unlikely the stanchions or stern pulpit can carry the loads generated by the rudder without bending (a lot) - don't count on them for structural support.

I built mounts from 3/4" thick 6061-T6 aluminum stock shaped with a bandsaw and drilled to accept the rudder support armature. The mounts are attached to the hull with 3/8" stainless steel bolts set into 1/4" aluminum backing plates. The backing plates are set into the hull with a resin/filler mash to create uniform support across the area of the backing plate. The plates are made as big as would fit and I chose areas in the hull near corners (extra rigidity from the layup geometry) and away from wide flat surfaces.

Blade Shape

Basically the blade shape is easy to fake, give the blade a parabolic leading edge and a fairly flat taper aft. The tricky part is giving the front third a good foil shape. Use a NACA 0012 foil as a guideline and talk with Dan Newland or Jim Antrim about rudder shapes. Remember this is an emergency rudder so perfect shape is not essential, but a properly shaped blade will work better than a flat board.

Construction

An emergency rudder can be built in all sorts of materials. Carved from solid lumber, built up with plywood laminates (a replacement blade for a BOC boat was built of a plywood laminate and wrapped in fiberglass - worked for 6,000 miles of racing), fiberglass. I built in glass over foam because I like the material, the result is relatively light and it's easy to work with.

Total cost of the rudder was around $500, including the metal mounting structure where the blade attaches to the hull. The major costs were the metal, machine shop time (lathing), foam, resin and fiberglass.

.Materials

Boat cloth. Woven E-glass. OK, not great, bends more easily than Nytex.

Nytex DBM double biaxial E-glass with/mat, sewn together as a unidirectional cloth with no weave - very good stuff, nice to work with.

Orcon S-glass unidirectional single layer held together with glue. Very strong, lightweight, lays up very thin, easy to bend. Expensive, produces a high strength laminate. Difficult to work with.

Foam - use closed cell PVC Divinycel or Klegecel. Divinycel is slighter better.

Resin - use vinyl ester or epoxy. Vinyl ester is about 1/3 the cost of epoxy and a better resin than regular polyester.

I used 5 layers of S-glass oriented at 45 degree angles to create a layup to handle loads from different directions and 2 layers of Nytex 17 oz fabric wrapped around the blade, all held together with vinyl ester resin. The rudder box was built from Nytex and some woven roving I had left over from another project.

Shape the foam

Create a template in masonite or thin plywood. To keep things simple don't taper the blade from top to bottom (e.g., a trapezoid), and don't make the blade thinner towards the tip. Keep it a simple rectangle - it's easy to build and you can use the same template at all points on the blade.

You'll need to glue two sheets of foam together to get a thick enough foam block to shape the rudder from. While gluing the sheets together insert two hardwood sticks the length of rudder (from top to bottom) in the foam, and let the ends poke about 6" or so. The sticks provide some rigidity, but more importantly allow you to support the foam while working on it. I used 3/4" x 3/4" oak 7' long set into channels cut into the foam with a circular saw (a router would have been a much nicer way to cut the channels).

A Surform tool (like a big cheese grater) is a great way to shape the foam - it's fast and accurate. They're at the local hardware store.

Use low-density filler and resin to fill the accidental divots or gouges in the foam, then sand.

Cut and fit the fiberglass

After shaping the core, suspend it horizontally using the hardwood sticks as supports, with the leading edge face up. Best way is to hang the blade from lines tied to the garage ceiling so you can walk around it to work on both sides.

Cut and fit the cloth to the foam blank, draping the cloth over the core in exactly the same way you will apply the cloth when the resin goes on. If the cloth moves around too much you can staple it to the foam . Mark the cloth (Sharpie permanent markers work well) so when disassembled you can easily reproduce the layup - the goal is to be ready when the resin goes on.

Bear in mind the glass will conform rather exactly to the shape you've created in the foam - don't count on "covering up" dips or valleys in the foam with the glass. You're more likely to create air pockets in the laminate, which greatly weakens the laminate structure. Fill and fair any hollows before you apply the layup.

Do the layup

Apply all resin or epoxy in one process if possible - this produces a chemical bond, which is stronger than a mechanical (glue) bond. Have all the cloth cut and fitted before you start mixing up the resin. Depending on the resin you may have up to 60 minutes of pot life to do the entire layup, so you have to be organized before you start.

With polyester or vinyl ester resin meter the resin and catalyst ratios (about 1-1.8 % by weight catalyst to resin). I use a 10ml graduated cylinder and a 2 pound postal scale. With epoxy be even more careful about getting the ratios correct. West System makes pre-measured push-pumps that screw into the cans that do the measuring for you.

To get the glass to adhere to the foam, make a pot of resin & filler (West System 404 High Density microballoons) and paint this onto the foam in a fairly thick, even layer. Immediately add the first layer of glass, then complete the layup using straight resin without filler.

Suppliers

Svenson's Boatworks

Monterey Bay Fiberglass - has everything, a long drive

West Marine

TAP Plastics

Alco Metals - good source of scrap aluminum

Materials

Fiberglass cloth

Resin / epoxy

Foam (8' x 2' x 2" thick - two pieces)

hardwood sticks (two)

microballoons / filler

paper buckets / mixing pots

latex gloves

stir sticks

2" paint brushes (cheap chip brushes work great)

paper towels

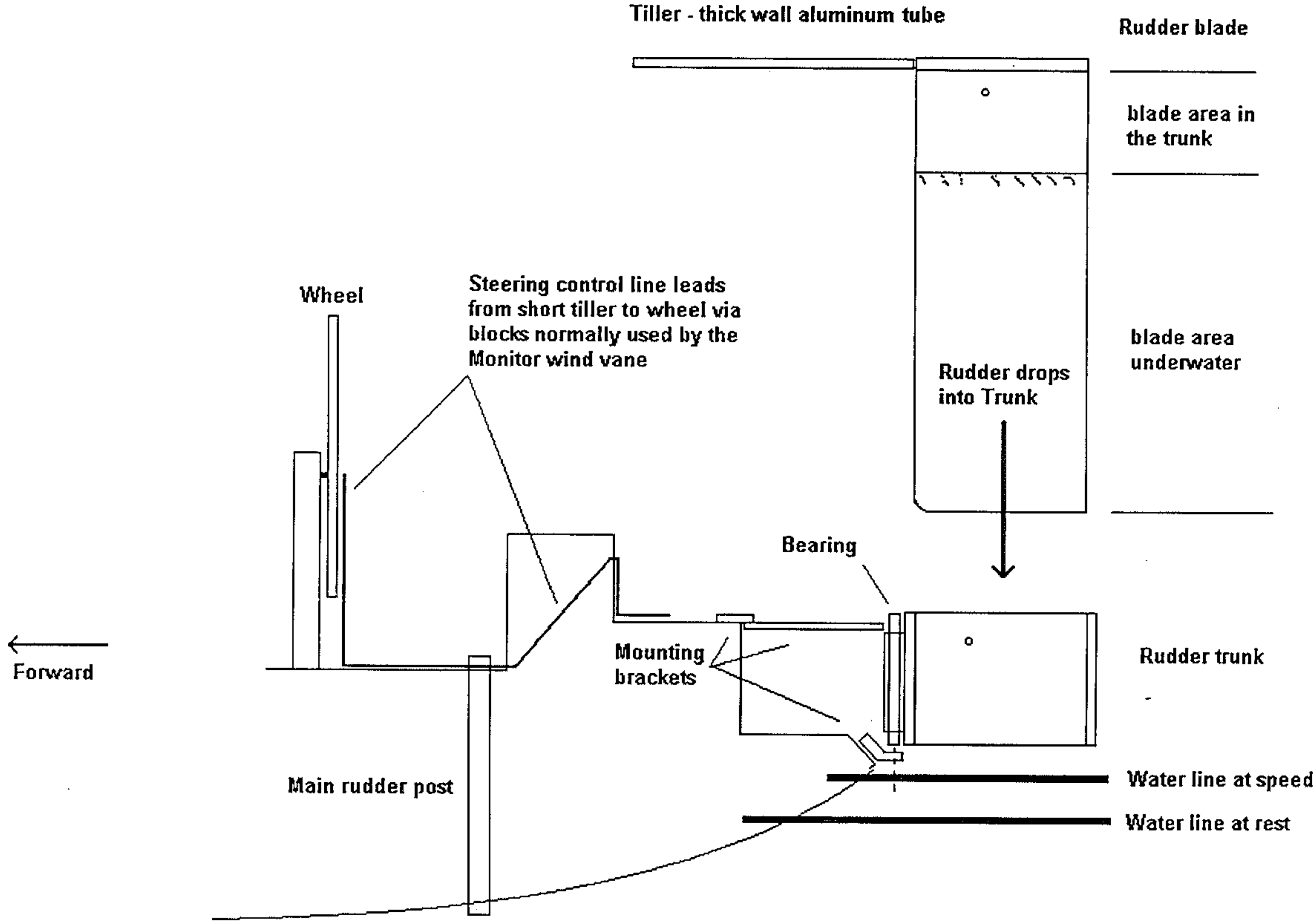
acetone

respirator / dust mask (for sanding)

metal roller (to move air bubbles out of the laminate)

EMERGENCY RUDDER FOR TIGER BEETLE

Section through the hull at transom
(the transom has two built-in steps)



Emergency Rudder Design and Construction

Paul Kamen

DESIGN REQUIREMENTS:

Cheap and easy to build
Light weight

SOLUTION:

Build blade like surfboard. Thick blade for strength and light weight. Moderately rough surface okay.

Keep gudgeons well separated to keep upper gudgeon lightly loaded.

For swim step transom, use stern pulpit to support top gudgeon.

MATERIALS AND SUPPLIERS:

Foam blank - "Lastafoam" medium density urethane foam boards available from Svendsen's in 1.5" x 4' x 8' sizes or cut fractions at $8.59 per square ft.

Epoxy: TAP Plastics 314 marine epoxy resin ($50.25/gallon) and 143 slow hardener ($33.35/half gallon). Or West System epoxy (West Marine or Svendsen's).

Glass: "Knytex" from Tap Plastics, or similar. This is a mat-cloth combination totaling 25.3 oz. per sq. yard. $12 per 36" of 50" wide material. Selvege tape lapped around leading and trailing edges. (Tech. contact at TAP: Russ Miller, manager at San Leandro, 510-357-3755.)

Rules for fiberglass/resin/foam work:

1) Always make a test patch
2) Cut glass carefully to size before mixing resin
3) Use a very good particle mask

DEPLOYMENT:

Allow full rotational degrees of freedom at lower gudgeon during deployment. Only one bolt in rudder and one bolt in transom, fitted loosely. Additional bolts added after top gudgeon is in place to establish alignment.

DESIGN METHODOLOGY:

1) ESTIMATE DESIGN SPEED

This determines the maximum force on the rudder blade. Suggest 10 knots for 45 ft. boat, 6 knots for 30 ft. boat.

2) DETERMINE LENGTH OF THE BLADE

Try to go to at least half the depth of the original rudder, and up to the middle or upper stern rail. (Measure depth from the transom bottom, not from the static waterline.)

3) CALCULATE FORCE ON THE BLADE:

Use the formula:

F = A * Cl * 1/2 * RHO * V^2

F = force (lb)
A = area below transom (ft^2)
Cl = Coeff. of lift (use 3.0 to allow for pumping transients)
RHO = density of water (1.9905 slugs/ft^3)
V = design speed (ft/sec)
(1 knot = 1.6878 ft/sec)

F = 8.5 * A * V^2

F = force (lb)
A = area below transom (ft^2)
V = design speed (knots)

[example: 1 ft. x 4 ft. blade, 7 knots: F = 1,666 lb.]

4) DETERMINE BENDING MOMENT AT THE LOWER GUDGEON:

Assume the force is centered between the lower gudgeon and the blade tip. if this distance is L, then:
M = 1/2 * L * F

M = bending moment (ft-lb)
L = distance from lower gudgeon to tip (ft)
F = maximum blade force at design speed

[example: L = 4 ft, so M = 3,332 ft-lb)]

5) DETERMINE THE REQUIRED SECTION MODULUS:

Use 10,000 psi as design stress in low-tech laminate.

Required "section modulus" = M*12/10,000
(the 12 is to change moment from ft-lb to in.-lb)

[example: SM required = 4.0 in^3

6) DETERMINE THE REQUIRED THICKNESS OF FIBERGLASS LAMINATE:

SM = W * (T^3 - t^3) / (6 * T)
(section inertia divided by half of max thickness)

SM = section modulus (in.^3)
W = width of blade (in.)
T = overall thickness of blade (in.)
t = thickness of core material (in.)

[example: blade is 12" wide (but use 10" to account for shaping), core is 1.5" thick: By trial and error, use T = 2.02". SM = 4.02 in^3. So required thickness of fiberglass = 1/2 (2.02 - 1.50) = 0.26 in.]

7) CALCULATE LOAD ON UPPER GUDGEON:

Upper gudgeon force: FU = M/D

FU = force on upper gudgeon (lb)
M = Bending moment at lower gudgeon (ft-lb)
D = distance between gudgeons (ft)

[example: For D = 6.0, FU = 3,332/6 = 555 lb]

8) CALCULATE LOAD ON LOWER GUDGEON:

Lower gudgeon force: FL = FU + F

F = force on blade (lb)
FU = force on upper gudgeon (lb)

[example: FL = 555 + 1666 = 2221 lb.]

9) SIZE PINTLES:

For pins in double shear (as in turnbuckle clevis pins) use safety factor of 5 and look in rigging catalog for appropriate turnbuckle size. Or use allowable shear stress of 6,000 psi for same result.

A = 1/2 * FP/sigma (for double shear)

sigma = allowable shear stress (use 6,000 psi for 316 stainless)
FP = force on pintle (upper or lower, lb)
A = required area of pintle pin (in.^2)

Solve for required pin diameter = sqrt(4 * A / PI)

[example: A = 1/2 * 2,221/6,000 = 0.1851 in.^2; pin diameter = 0.486 in., use 1/2 in. diameter pin for bottom pintle. For top, 1/4 in. diameter is sufficient, but use 3/8 in. for easier alignment.]

Singlehanded Sailing Society

Self Steering and Emergency Rudders Seminar

November 10, 1999

Rob Macfarlane

An electric pilot will point the bow straight at Hanalei and then it's up to you to trim the sails as the wind shifts; you are sailing shortest distance at the expense of electricity and attention to the sails. In the opening windy two or three days of the race you had better be sure your diesel fuel is in good shape, the Racor filters are clean and you have a lot of spares. If you lose the motor due to clogged filters you will lose your autopilot too.

Ideally the autopilot should have adjustable compass gain and deadband. Deadband describes how far the boat will turn before the compass senses the turn, and gain refers to how rapidly the autopilot turns the rudder to get the boat back on course. Upwind set deadband high and the gain high - you want small corrections quickly. Downwind the deadband is low and the gain is low - you want large corrections executed slowly.

Alternatively, a wind vane will maintain excellent sail trim (provided you set the sails up that way to begin with) but you will alter course as the wind shifts. Wind vane will not sail shortest course but will keep the sails trimmed for you.

Spinnakering under autopilot

Some people are amazed that singlehanders are dumb enough to go to sleep with a spinnaker up and drawing. The truth is it's not that hard, you just don't sleep for very long periods.

Autopilot will correct quickly (if it has a fast ram) and keep the boat on course while surfing down waves. It will not notice if the wind shifts unless you've connected it to wind instrumentation and the instruments are working. It just keeps you headed the same direction all the time. You need to pay attention to what the wind is up to and look out for squalls and their wind shifts. One thing that gets mentioned by the Vendee and BOC folks is that autopilots have no fear - they will happily launch the boat down the face of a 40 foot wave. Fortunately, that's usually not a problem for the TransPac.

Wind vanes are problematic for boats that surf easily. A vane is working with apparent wind angle (AWA) and knows nothing about true wind angle or swell height or any of that stuff.. When you start down the wave on a surf the AWA moves forward as the boat accekerates and the wind vane will see this as a wind shift forward and reacts by turning downwind to restore the AWA. As you go faster, it turns downwind more. This can lead to catastrophe in the form of a round down - I did that in a matter of seconds when the boat went from 7 knots to 11 knots on a 3' wave in 20 knots of breeze of Los Angeles. Wind vane spun the boat into a perfectly executed highly professional round down followed by an amazing round up, then we rounded down again and that was the end of that spinnaker.

Hint - you can use bungee cord tied to the counterbalance weight of a wind vane to dampen the vanes sensitivity to wind shifts, and make the vane return to center course rapidly. Play around with it, you'll find out the nuances quickly. This is a great trick for running DDW with poled out headsails - something you might not want to do with an autopilot that is NOT connected to wind instrumentation.

First Decision - autopilot, windvane or both

Two types of self steering devices:

autopilot - compass driven electrical unit

wind vane - wind and boat speed driven mechanical device

Cost considerations play a big part in self-steering purchase, and there is no "cheap" approach. An electric autopilot will require investing in a hi-output alternator and substantial battery bank. A wind vane requires none of that but is not cheap nor will it do as well on a downwind TransPac race.

Above deck electric autopilots are the least expensive way to go, but anything mounted in the cockpit is a candidate for water and mechanical damage. Therefore you need multiple autopilots to make sure one is still running 2,200 miles later (plus another 2,500 miles if you sail the boat home). Not generally repairable, carry a lot of spares. Compass is usally an undampened fluxgate.

Below deck autopilots add cost, installation complexity and power requirements. However, they are installed down inside the transom, so are less likely to get wet and short out or get snagged by an errant spinnaker sheet and flipped overboard. Not generally repairable, carry at least one complete spare. Compass is a dampened fluxgate, some with addition of solid state rate gyros. A north-pointing gyro compass is not the same as a rate gyro.

A windvane is as expensive as a below deck autopilot and weighs more. The wind vane is well suited to trans-ocean sailing and works especially well upwind. Big advantages over an electric pilot are no electricity is needed to make them work, they are silent, and will keep the boat in good sail trim upwind or reaching. Possibly repairable, but unlikely to break in the first place. Carry spare parts kit, air blades, break away tubes, and don't forget to tie a really strong line to the water paddle.

Things to learn with self-steering

Sail trim is critical to efficiency and reducing power consumption. You probably sail with too much sail up, therefore too much heel angle, therefore too much autopilot work. Reducing sail area will usually make the boat flatter, the autopilot happier and the boat faster.

The autopilot will steer better than you can, especially if you're down below making dinner.

Special Considerations

The TransPac is essentially a heavy air reach followed by light spell followed by the thousand mile downhill ride. You know exactly where you're going when you exit the Gate, and you want to minimize distance sailed to get there.

Emergency Rudders

There are basically two types of emergency rudders:

"Get home" rudder that will allow you to control the boat well enough to make port.

"Racing" rudder that will allow you to continue sailing the boat hard.

Getting an emergency rudder

The only off-the-shelf emergency rudder I'm aware of is ScanMar's attachment for their Monitor wind vane. I consider this a "get home" rudder. It's small, easy to stow and set up. If you already have a Monitor vane on the back of your boat then you should consider their design a viable system.

The other way to get on is build it yourself (or have someone build it for you). Building it yourself is fairly simple if you have experience in fiberglass composite construction. Hiring it out is the same thing, just more expensive. Arne Jonsson Boat Builders in Alameda have the expertise to build one for you.

Testing

Very important - don't purchase or, if you're so inclined, design and fabricate an emergency rudder without then trying it out. Trying it out does NOT mean hanging it on the transom while you're standing on the dock, and it does NOT mean motoring up and down the estuary while steering with it.

At the very least, get out in the bay and try sailing around with it.

A far more accurate test of the system is to sail out to the lightship, drop all sail and install the rudder while bouncing around in the swell and wind, then head out and loop the Farallone islands. By the time you get back to the lightship you'll know a) how to install the thing, b) how to trim the sails to use it, and c) whether nor not it REALLY works.

What you do NOT want to be is Pyewacket - blow off your rudder in the middle of the Atlantic, set up the emergency rudder and then an hour and a half later have the emergency rudder blow off it's bearings and disappear behind the boat. If you're Roy Disney you make for the nearest island and call in your private jet to drop off the delivery crew and a new rudder while you and your mates jet off home. That's a little outside our league and the reality is you're looking at a long, long time to analyze your emergency rudder in excruciating detail as it gets you to your destination.

Nor do you want to do a Robin Davie - get to the middle of the South Atlantic, shed your rudder then discover that you've left some fairly important parts to your Monitor E-mon system at home.

Recommendations

Oversize below deck autopilot connected directly to the rudder stock independently of the quadrant.

Hi-output alternator with a large battery bank.

Lots of spare fuel filters.

A solid windvane:

Navik for smaller boats (less than 30')

Monitor for larger boats (more than 30') rudder stock which you can push back down in place of the stock.

For a racing blade a good shape is a NACA 0012 or 0015 series. 0015 is thicker than 0012 (good structurally) and more foregiving (more difficult to stall). The shape numbers are provided below. For a get home blade any flat board will do provided it's strong enough. To keep construction simple the design will have no taper - just straight parallel front and trailing edges with a chopped off bottom (exotic elliptical rudders need not apply).

NACA 0015 shape

Chord length is length of section from front to back.

X is a percentage of chord length from the front.

Y is a percentage of chord length, measured perpendicular from chord.

X	0	1.25	2.5	5	7.5	10	15	20	25
Y	0	2.367	3.268	4.443	5.25	5.853	6.682	7.172	7.427

X	30	40	50	60	70	80	90	95	100
Y	7.502	7.254	6.617	5.704	4.58	3.279	1.81	1.008	.158

Engineering. The loads generated by a rudder are very high, and typically the first failure of any emergency rudder is the attachment point to the hull when the lower gudgeon or pintle breaks off. The blade itself rarely fails. Refer to Paul Kamen's article to calculate the blade loadings for your boat. Note that loadings are dependent on the speed of the boat **squared**, so the design speed (a number you think appropriate for your boat) is critical. I think Paul's numbers are too low - I hit 8 knots with my emergency rudder in my 33' boat, and am using 16 knots as design speed for the 45 footer, not Paul's suggested 10. Beetle hits 10 knots too easily.

The other contentious number for shaped blades is the Coefficient of Lift. A blade on the verge of stalling (such as when you're surfing down a wave and about to broach) will generate more load than the same blade simply dragged sideways through the water down that same wave. The increase in side load is accounted for by the Coefficient of Lift. NACA shapes will typically generate 1.8 times the load, so using 2 in your calcs creates a small safety factor. Using 3 creates a nice large safety factor. Use 3.

While you can then proceed to amaze your friends with how resourceful you are at fabricating parts out of thin air to get it to work, you will also be disgusted with yourself for doing something so silly.

Design Considerations

1. Blade size (underwater surface area)

2. Attachment method to the hull - how will you install the rudder out in the ocean?

3. Stowage - where are you going to keep the blade when you're (hopefully) not using it?

4. Self steering for the emergency rudder.

5. Jettison the primary rudder.

Size and rotational axis. The rudder should pivot on a vertical axis, located at the back of the hull on center line. The underwater surface area in profile should be the same as the existing rudder on your boat, with a minimum surface area of 1/2 existing rudder area. Aspect ration should be roughly 3:1 (height : width). Leading edge is parabolic, trailing edge is thin and flat, not a knife edge.

Installation. If you've installed an el toro rudder with the boat in the water you know how difficult it to control the blade while lining up the pintles & gudgeons. Doing the same thing in the open ocean is not just difficult, it is dangerous - so pintles and gudgeons are not a good solution. Simplest installation mechanism is via a cassette box mounted on a vertical hinge axis at the transom. The rudder blade drops down into the cassette box (much like a dinghy centerboard drops down into the centerboard trunk). The tiller is attached to the cassette or the top of the rudder blade, your choice. Hinge can be a length of 1" diameter aluminum dowel.

Stowage. You have to keep the rudder somewhere on the boat, normally down below stuffed away in the forepeak or the transom. Some people have suspended them up against the overhead in the main cabin (good if you're short). Don't build a 9 foot long blade when you have only a 6 foot space to show it.

Self Steering. If the emergency rudder can be hooked up to a self steering mechansim you'll be much happier than if you have to stand in the back of boat and hand steer the entire way to wherever you're going. While not a big deal on a full crew boat, it can be very valuable for a singlehander.

Jettison primary rudder. The primary rudder may not in fact break away completely. The drag and turning force the broken or bent blade causes can significantly hamper the ability of the emergency rudder to steer the boat. Have a way to a) get rid of the primary rudder and b) plug the hole the now gone rudder stock has left in the hull. A sledge hammer and a long wood dowel is all you need to push a rudder blade down out of the boat. A large wooden bung may be sufficient to pound into the hole, or you can carry 18" of wooden dowel the same diameter as

Suspend the foam blade over a work table that you can walk completely around (this is where the sticks inserted into the blade come in handy - hang the blade from these). The nose should be up, the trailing edge hanging down.

Drape fiberglass over the foam, aligning the fiber orientation to be 45 degrees off axis (see drawing). Cut the glass to fit, leaving at least two inches of fabric hanging below the trailing edge of the rudder. Continue until you have reached the glass thickness you calculated. Number the fiberglass sheets and mark centerline of each sheet along the centerline of the nose.

Laminating. Do the entire lamination in one process from start to finish (allow at least two hours, so start early in the evening). Mix a pot of spooge and roll it onto the foam blade. Mix a pot of resin and lay out the DBM on the table. Wet out the DBM on both sides and drape it over the blank.

HINT: wet out one side of the DBM with a foam roller, turn the cloth over and wet out the other side, then roll the cloth up. Lay the rolled up cloth on top of the blade with the marked centerline on the center of the nose, then unroll the cloth along the top of the blade. This keeps cloth distortion to a minimum.

Continue until all the cloth is applied. Work quickly - the resin will typically begin to set in 30 minutes or so, depending on how much you catalyzed it. It is a good idea to mix small pots of resin as you move through the job rather than one large pot for the whole layup.

Use the hard roller to press/roll the cloth down so it evenly contacts the foam blank. The roller squeezes out air bubbles, excess resin, and makes the cloth lie flat and even. Allow the resin to dry overnight (24 hours is better).

Final shaping. Sand off any rough bumps, drips, etc. from the laminate. Shape the trailing edge with a sander. Fair in shallow spots with low-density spooge. Paint the blade if you want.

Construct the Cassette, pivot point, tiller stock.

When the blade is complete, you need to create the cassette, which incorporates the forward bearing.

Wrap the box-shaped top of the rudder in two layers of wax paper - this is the mold release and leaves a thin gap for the blade will slide into the cassette. Using the same procedures as for the blade, cut and mark the cloth to wrap around the box, then laminate the cloth around the box.

For the hinge point, add a piece of hardwood to the leading edge of the box so the bearing point will be 1-2 inches forward of the rudder. Take the metal bearing/support, wrap it in two layers of wax paper, and laminate it to the front of the cassette.

Wait a day, then remove the rudder and hinge from cassette.

Construction

The construction approach outlined here is for a do-it-yourself composite blade of fiberglass over foam, and is based on Dan Newland's method. Metal structures are usually custom built, and should be stainless steel or 6061-T6 aluminum. The cassette box is solid fiberglass layup. Aluminum is lighter and easier to shape with typical wood working tools than stainless steel. If you haven't worked with foam/glass construction before, make a test piece first (e.g., shape a bit of foam, laminate a full layup schedule onto it) to see how the materials work.

After designing the blade, purchase foam thick enough such that two layers of foam are slightly thicker than the complete rudder blade (e.g., for a 3.75" thick rudder, get 2" thick foam).

To create the blade, start with two layers of foam and draw the profile on the top layer. You want to insert two hardwood sticks through the blade so they extend out from each end. Do this by cutting a groove in the foam using a router or table saw. The sticks provide a means of hanging the blade when you apply the fiberglass laminate (the sticks do nothing structural, they are just a convenience.)

Laminate the two layers of foam together using a resin/microballoon mash (aka spooge). You want the foam to be flat, so the table shoudl be flat. Place weights or use clamps to press the foam sheets together while the spooge is drying. Wait 12 hours before removing the weights.

Mark the blade outline (profile) on the foam. Saw off the foam above the shaped portion of the blade and save this piece - it will become the top of your rudder.

Create two section templates (top and bottom). Take the NACA foil numbers and plot onto a piece of paper at full scale. Glue the paper to a flat board of masonite or plywood and cut out the shape with a bandsaw or saber saw. Fair the profile by sanding. Mark the templates at equal chord points (e.g., 10%, 20%, 30%...)

Attach the templates to the top and bottom of your blade with screws or glue. They should be exactly parallel to each other and perpendicular to the foam blank..

Shape the foam blank. Make a long board sander with an 8 foot length of straight hard wood (3/4" x 2" works well) by wrapping the board with 60 grit sand paper. Lay the longboard across your foam blank so the longboard lines up at the same percentage mark on the top and bottom templates. Sand evenly in the vertical direction of the blade (top to bottom) to cut into the foam until the long board touches the templates at the top and bottom. Continue to do all points on both sides of the blank. Be careful, foam cuts very quickly.

Hand sand the board at the front and trailing edges. The front is more important - you want a parabolic nose. If it looks about right, then it probably is.

Round the edges of the rectangular chunk of foam you saved from the top of your blank. Glue this piece back onto your now-shaped foam rudder with spooge. Apply fairing at the joint to smooth the transition from the shaped blade to the squared upper box.

Suppliers

Svendsen's Boat Works
Tap Plastics
Monterey Bay Fiberglass

Finishing

You may need to wrap a piece of cloth around the trailing edge of the rudder if the rudder skins did not get laminated together.

The blade will float, so you'll need to incorporate a pin running horizontally through the cassette and blade to keep the blade from rising when immersed in water. Harken FastPins work well.

Naval Architects

Jim Antrim

Carl Schumacher

Materials

foam	Divinycel is best (closed cell). Size the thickness of the blade such that two layers of divinycel are slightly thicker than the finished blade.
resin	Modified Vinyl Ester (MVE) works very well. Stronger than polyester resins, much cheaper than epoxy.
fiberglass	Knytex 1708 DBM (double/biaxial with matt) is very good. The cloth is two layers of glass strands oriented at 90 degrees to each other, with a fine layer of matt sewn on one side. There is no weave to the cloth, so no wasted crimp space. Cuts nicely and doesn't fall apart. Four layers of 1708 will yield 3/16" - 1/4" of final layup thickness.
hardwood	3/4" x 3/4" oak trim make good support sticks. 3/4" x 2" makes a good sander
template	masonite or 1/4" plywood
respirator	get a good one, fiberglass dust is nasty stuff.
hard roller	3" wide is fine
foam roller	disposable 3" rollers of fine foam
roller tray	use a tray with disposable plastic inserts
gloves	buy a boxful of surgical gloves
mixing pots	plastic paper pots are ok
acetone	get a gallon. good for cleaning tools, not good for cleaning hands.
brushes	cheap bristle brushes, you go through them quickly
fairing	West System, get one large container of medium density
resin	MVE resin, get two or three gallons with plenty of MEKP catalyst
wax paper	get some from the grocery store or the kitchen
tape	2" wide blue masking tape
plastic tarps	polyethylene tarps keep the garage floor clean
marking pens	Sharpie Fine Point, black
scissors	inexpensive kitchen scissors are ok, the fiberglass will ruin them
sandpaper	60 grit sheet paper for the long board, 100 grit for hand sanding, 180 for final sanding

Self Steering

Goal of self steering

To control the boats direction so you don't have to do that job. Therefore you have time to sleep, navigate, repair sails and gear. Might even have time to enjoy the trip.

at a minimum - keep the boat sailing straight ahead for a short period of time so you can leave the helm and do something other than steer. Such as, say, toast a pop tart for dinner.

at a maximum - sail the boat efficiently over the entire course, from San Francisco to Hanalei, without ever touching the helm .

Knock-on effects

Self steering is a system, not just a bolt on box. Using a self-steering gear will have follow-on effects in electrical consumption and battery charging, sail trim and sleeping.

Get the self-steering device on the boat as early as possible and use it. This is doubly true for windvanes - they are not as easy to understand as an autopilot. Do NOT decide to learn how your windvane works on your trip to Kauai.

Requirements to achieve this

Correct autopilot for boat size and handling characteristics.

Ability to keep autopilot or windvane functioning (spares, replacements).

Most importantly - you have to trust your self steering completely.