

Singlehanded Sailing Society

Self Steering and Emergency Rudders
Seminar

November 14, 2001

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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 .

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.

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.

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, regulator/controller 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 usually an undamped 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 damped 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.

Autopilot considerations

The compass is the heart of your basic electric autopilot, and as such look carefully at the compass design before you purchase a pilot. Note that you can also interface an autopilot to boat instrumentation (wind, heading and speed) and performance polar curves via an outboard computer (e.g., a laptop sitting in the nav station) and control the autopilot to drive the boat to it's polars.

Basic compass data

A compass card does not, in fact, turn at all - it stays pointed north. The boat turns beneath the compass with the effect (when you're standing in the cockpit looking at your compass) as if the compass has turned. When I say the compass turns, this means the card is turning relative to boat heading.

A compass is effected by tilt above or below horizontal, acceleration in any horizontal direction (but not vertical), and it's own mass and momentum. The mechanical compass still operates on the same basic method as the earliest ones, with "modernizations" aimed at improving bearings, damping the card with oil or alcohol, keeping the compass level via gimbals, and adjusting a compass to indicate magnetic north via adjustable magnets or ferrous masses (the large iron spheres you see next to ship compass binnacles).

To see the effects of tilt, take a simple Autohelm flat fluxgate compass and lay it flat on a table and read the direction it is pointing. Now tilt the compass by lifting one end of the case a couple inches above the table and take another reading. They won't be the same.

The first significant change to a compass was the gyroscope inertial guidance systems used on

submarines. Here was a machine that would point consistently in one direction all the time and would remain level at all times (through conservation of momentum - a spinning wheel wants to remain spinning in it's original plane and resists angular changes).

Another huge change in compass technology was the fluxgate compass.

And lately, advancements in microgravity experiments yielded the solid state accelerometer and then the solid state rate-gyro. Consider these to be motion indicators in a computer chip.

The are four basic types of compasses used in autopilots:

oil filled mechanical compass

rarely used now, as manufacturers have switched to fluxgate compasses. Information from the compass was passed to the pilot via string wrapped around the compass card - when the compass card turned, the string was pulled and the pilot could "see" the movement of the string.

flux gate compass

fluxgate compass is a set of wire coils wrapped around a pair of ferrite bars. Applying a signal to one wire will result in a voltage in the other wire. The signal undergoes a phase shift due to the earth's magnetic field; the phase shift is indicative of the coil angle relative to magnetic north.

oil-dampened fluxgate compass

A fluxgate compass in an oil bath, the oil is intended to dampen the core's swinging and provide a more stable reading.

powered north-pointing gyroscopes

A powered, spinning gyroscope. As an alternative, KVH Azimuth Digital Gyro - about \$3,000. Very inexpensive for a true gyro compass, very interesting - appears to be using a trio solid state rate gyros to determine tilt angles and mathematically back out errors induced by the tilt(s).

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.

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 associated 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 accelerates 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.

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')

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 or 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 its 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.

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. Jettison the primary rudder.
5. Self steering for the emergency 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 ratio 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 is 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.

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 rudder stock which you can push back down in place of the stock.

Self Steering. If the emergency rudder can be hooked up to a self steering mechanism 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.

NACA 0015 shape

For a racing blade a good shape is a NACA 0012 or 0015 series. 0015 is thicker than 0012 (good structurally) and more forgiving (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).

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.

Construction

The construction approach outlined here is for a do-it-yourself composite blade of fiberglass over

foam. 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.

Select the foam

After designing the blade, purchase foam thick enough such that two layers of foam will be slightly thicker than the complete rudder blade (e.g., for a 3.75" thick rudder, get 2" thick foam). The purpose of having two and only two sections is a) you can access the center of the blade for insertion of material, and b) there will only be one seam line in the foam, and that seam line will be on centerline. If you laminate a blade from more than two layers of foam you will have a seam line at you will have to sand; you will discover that hardened spooge is much harder than foam and therefore it will not fair evenly during the sanding process (the hard spots will be proud, the softer foam will be cut away too much), resulting in extra unnecessary fairing at the end.

Insert support sticks in the foam

Lay the two layers of foam on your table and draw the rudder profile on the top piece of foam. Select two hardwood sticks which are longer than the entire blade by 2 feet. Separate the foam halves and cut a groove to accept the stick in one piece of foam using a router or table saw. The sticks should be as widely separated in the foam as possible, with the caveat that you must not cut all the way through the foam when making the groove. 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 foam together

Laminate the two layers of foam together using a resin/microballoon mash (aka spooge). You want the foam to be flat, so the table should be flat. Place a polyethylene tarp over the table and place the bottom foam blank on the tarp. Paint the grooves with spooge and lay the sticks in. Spooge should flow out of the grooves, leaving no air pockets. Use the foam roller to apply a coat of spooge to each foam blank. Lay the blanks on top of each other. Place weights or use clamps to press the foam together while the spooge is drying. Spooge should squish out of the seams, indicating there are no air bubbles in the laminate. Wait 12 hours before removing the weights.

Remove the upper box section

Saw off the foam above the portion of the blade that will be shaped, and save this piece - it will become the top of your rudder. Mark the end you cut, and the orientation towards the nose of the rudder so you can later determine how it fits back on.

Create the section templates

Create two section templates, one for the top and one for the bottom. As this rudder is the same

section throughout, the templates will be identical. Take the NACA foil numbers and plot onto a piece of paper at full scale. Use spray glue to attach 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 ends of the foam blank with screws or glue. The templates should be exactly parallel to each other and perpendicular to the foam blank..

Shape the blade

Create a long board sander with a length of straight hardwood (3/4" x 2" works well) that is two feet longer than blade. Wrap the narrow edge of the board with 60 grit sand paper held in place with staples. Lay the longboard across your foam blank so the longboard lines up at the same percentage mark on the top and bottom templates, such as from the 20% chord point at the top template and the same 20% chord point at the bottom. Sand evenly in the vertical direction of the blade (top to bottom) to cut into the foam until the long board just touches the templates at each end of the board. This will cut a groove through the foam that has exactly the correct depth for the section at the particular chord point your are working at. Continue to do all points on both sides of the blank. Be careful, foam cuts very quickly. When you are done you should have grooves cut in the board, with raised areas in between. Use a surform tool to remove some of the extra material, then go back around the templates with the long board, working at areas in between the chord points you did the first time.

Continue this until the entire surface of the blade conforms to the template section.

Hand sand the board at the front and trailing edges using 100 grit sandpaper. The front is more important - you want a parabolic nose. If it looks about right, then it probably is.

Reattach the top section

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.

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 which allows the blade to 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.

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 | Divynylcel is best (closed cell). Size the thickness of the blade such that two layers of divynylcel 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 template | 3/4" x 3/4" oak make good support sticks. 3/4" x 2" makes a good sander |
| respirator | masonite or 1/4" plywood |
| hard roller | get a good one, fiberglass dust is nasty stuff. |
| foam roller | 3" wide is fine |
| roller tray | disposable 3" rollers of fine foam |
| gloves | use a tray with disposable plastic inserts |
| mixing pots | buy a boxful of surgical gloves |
| acetone | plastic or paper pots are ok, but NO waxy pots |
| brushes | get a gallon. good for cleaning tools, not good for cleaning hands. |
| fairing | cheap 1" bristle brushes, you go through them quickly |
| resin | West System, get one large container of medium density |
| wax paper | MVE resin, get two or three gallons with plenty of MEKP catalyst |
| tape | get some from the grocery store or the kitchen |
| plastic tarps | 2" wide blue masking tape |
| marking pens | polyethylene tarps keep the garage floor clean |
| scissors | Sharpie Fine Point, black |
| sandpaper | inexpensive kitchen scissors are ok, the fiberglass will ruin them |
| | 60 grit sheet paper for the long board, 100 grit for hand sanding, 180 for final sanding |

Suppliers

Svendsen's Boat Works
Tap Plastics
Monterey Bay Fiberglass