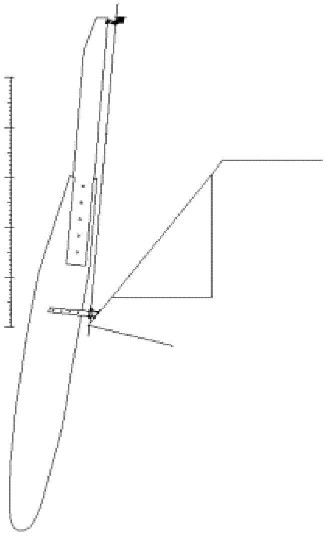
# *PACIFIC CUP 2004*

## *Preparation Seminar No. 1*
## *Emergency Rudder Design and Construction*

*Berkeley Yacht Club���������������������������������������������*
*June 1 2003*

**DESIGN REQUIREMENTS:**

� Cheap and easy to build
� Light weight



**SOLUTION #1:**

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.)

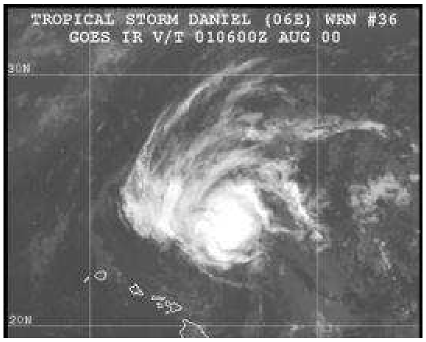
**3) CALCULATE FORCE ON THE BLADE:**

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.]

**SOLUTION #2: The soft rudder**

This is a rudder that will not allow the boat to keep racing, but is very cheap and easy to build, and also light weight and easy to stow. It has been tested on a Merit 25 and on a Santa Cruz 52, and allowed good control, including tacks and jibes in moderate wind, with the main rudder either locked or free.

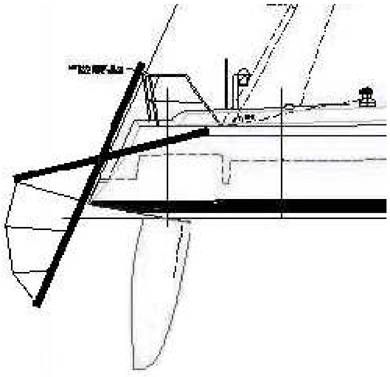
The concept is to use an underwater sail supported by spars. This system has the advantage of adding a lot of rudder area, which could be critical for regaining directional stability after the rudder is lost. It is very easy to deploy and can be repaired many times with materials on board.

For small boats, the "rudder sail" can be the top part of a windsurfer sail, and the spars can be a windsurfer mast cut in half.

The bottom "gudgeon" is a pair of pad eyes low on the transom. Gudgeon lines are lashed to the spar just above the rudder sail and lead through these eyes and then up to cleats on deck to hold the spar close against the transom.

The top gudgeon is at the lifeline level. In this case, a short spar is clamped between the two corner pulpits with an eye on centerline for the top lashing to the rudder stock/mast.

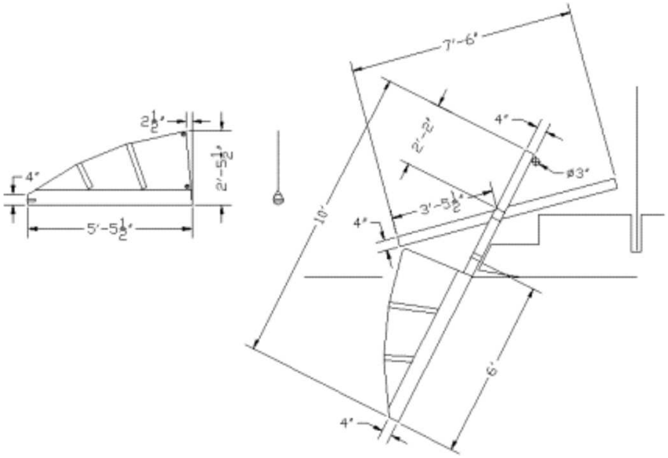
Note that it is necessary to control twist. This is done with a "vang" between the top end of the stock/mast and the aft end of the tiller/boom. To keep the gooseneck lashing from slipping aft under thrust from the vang and sail, an inhaul is rigged from the gooseneck lashing to the forward end of the tiller/boom.



For the Santa Cruz 52 installation, the sail was professionally built to order. Spars are from scraps of broken carbon spinnaker poles from boats of similar size.
As rule of thumb, a big boat's own spinnaker pole is probably only about half as strong as necessary for this design. However, loads can be moderated by carefully limiting the length of the tiller so that a human driver will not be able to push hard enough to overload the spars. Because there is a very approximate axis of symmetry about the diagonal of the sail, bending loads on the mast/stock are about the same as bending loads on the boom/tiller. This makes it relatively easy to limit bending on the mast by controlling maximum moment applied to the tiller.

Spars prepared in advance for this type of emergency steering should be wrapped with additional fiber and resin to increase strength in way of areas of high bending load.

Another possible problem is flutter caused by periodic vortex shedding around the circular spars. This was has not been observed to any significant extent in trials to date, but a possible fix would be a larger luff pocket in the sail with a foam insert to fair in the trailing edge of the spar.



"Underwater luffing" has not been observed, but it seems desirable to keep the rudder sail very flat and to use battens to suppress any tendency to flutter.