Build Your Own Trim Tab Self-Steering System

By Eric Baicy

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TRIM TAB SELF STEERING

This document is intended to illustrate the details of our trim tab design. It won't work for every boat and it is still in the process of evolving on ours. If you are considering building your own design, make sure you have plenty of spare time to play around with it.

We built our first pass design a couple of months before setting off on a two month shake-down cruise. As time slipped away and we quickly neared our departure date, we were unable to even test it until one week into our cruise. The first pass of the wind vane design was a resounding failure and after finishing our cruise, we spent four weeks dedicated to finding something that would work before heading offshore again.

Fortunately the trim tab itself was designed properly, and the work was all above the waterline, but having the time to test it fully and make changes takes more time than you would expect.

Getting Started and Getting Help

Sarana's self-steering system is a trim tab based design inspired by John Letcher's drawings and design work (*Self-Steering for Sailing Craft*, Publisher: International Marine/Ragged Mountain Press 1974, ASIN 0877420424, http://www.amazon.com/exec/obidos/tg/detail/-/0877420424/qid=1093396695/sr=1-1/ref=sr_1_1/102-9570029-3344115?v=glance&s=books). It was also built with inspiration from Lin & Larry Pardey (and their builder at www.freehandsteering.com) and several other people on the wind vane online forum (http://www.cruisenews.net/cgi-bin/windvane/windvane.pl?#16). Bill Belcher also has an excellent book. If his book is used in combination with John Letcher's book, you will have an outstanding chance of success.

Why a Trim Tab?

It's simple, light, cost effective (metal is the biggest expense), and you don't need any special tools, just some help from a welder. You can repair it fairly simply just about anywhere, and it makes a *great* way to steer the boat with an autopilot or with an emergency tiller.

If you have an aft hung rudder, you're a prime candidate for this type of steering system. It can be done on spade rudders, or other types of rudders, but it is more complicated. Also if you lack a boomkin or have a narrow stern, the standard servo-pendulum type steering systems will require you to add quite a bit of stainless tubing to support it. In contrast to off-the-shelf servo-pendulum designs, a trim tab doesn't need much hardware for attachment and will probably save you some weight.

Letcher suggests you perform a simple test for yaw resistance on your boat at different wind angles prior to choosing the type of self steering system that will work for you. If you're able to balance the helm under all different types of conditions and sailing angles, and you know your boat well, then you can probably skip the yaw resistance test.

Downside of a Trim Tab

There are only a few negative aspects to using a trim tab. First, the trim tab does add extra surface permanently in the water which will increase drag slightly. Second, the tab turns in the opposite direction of the rudder which reduces the rudder's efficiency so it must be designed carefully to avoid impacting the main rudder. And, it is another thing that could get fouled or damaged and ruin your day.

The Design

We broke the project into three separate portions: Trim Tab, Controls, and the Wind Vane. The Tab had to be done with the most care, as we didn't have time to build more than one, or haul out more than once if modifications had to be made. The Controls and the Wind Vane were designed separately and not discussed in this article.

Trim Tab Design Procedure

The procedure for designing your trim tab requires the following steps which will be explained in the text below:

1. Testing for Yaw Resistance.
2. Determining the self-volume of your main rudder.
3. Determining your required self-volume of your trim tab.
4. Determining the chord length, and span (or aspect ratio).
5. Computing the physical design profile for your trim tab using the NACA0010 table.
6. Building it.

Testing for Yaw Resistance

The idea behind this test is to see how well your boat holds its course without much force on the tiller or wheel while the boat is in motion. Additional forces due to the balance of the sails, like weather or lee helm, contribute additional problems for steering gears because they must correct for this force as well. Typically the sails can be balanced in such a way as to help reduce any tendency for the boat to yaw because the steering gear only needs to overcome the dynamic force due to yawing. Some of the early self steering gears worked only because the sailor was forced to carefully balance the sails under all conditions.

If you are not sure how your boat yaws under sail, you can perform Letcher's test for yaw resistance as summarized in the following text.

You'll need a stiff wire (like a coat hanger), a board which you can mark compass headings on and clamp under the tiller, a friend to read the compass for you.

Take your boat out and find a nice reaching course in *moderate* wind. Clamp the board under the tiller and tape a piece of paper to it. Once you are on course, calibrate your board.

To calibrate your markings, start by marking the point that holds your boat on course as 0. Next move the tiller until your course changes by 5 degrees. Mark this as your 2.5 degree increment. Now use this spacing to create the other markings on the board, until it looks like Figure 1. If you have trouble visually lining up the tiller with the heading, use a piece of stiff wire and wrap it around the tiller so that one end of it points down the board.

The resulting board will provide you roughly with a board which closely resembles a commercial controlling system which often have a gain of up to 2.

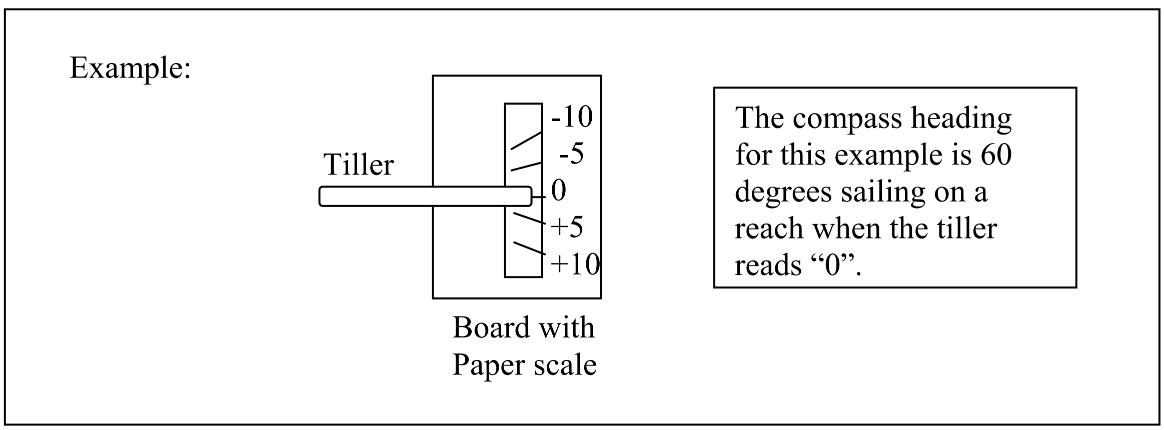

Figure 1: Letcher's Yaw Resistance Setup

Once you are setup, steer the boat 10 degrees off course. After you are settled on the new heading (don't adjust the sails!), have the person on the helm steer back to the original course following the markings while the person on the compass calls out the headings.

The person on the helm may only look at the board while slowly returning to the original heading of "0" on the board, while the compass person calls out the heading. The person reading the compass should make note of the boat's heading at a regular time interval. The time interval should be long enough to average out changes from the wave motion, but not so long that major heading changes are not recorded.

Through this process you are simulating a simple wind vane system. You are applying a force proportional to the error to correct the course. Using the example above, if the compass person calls out 65 degrees, the helms person should steer +5 degrees on the marking (which is really a 5 degree correction in the opposite direction).

If the boat oscillates too wildly for the helm to keep up with the compass, then you have to change the scale on the piece of paper. Try using a spacing of ½ less than the spacing you used previously on the piece of paper. This will slow down the corrections to allow for the natural delay between compass readings and the steering. If the smaller spacing makes the steering too sluggish, then your scale is too small. This could mean that your boat is negatively damped or neutrally damped, see Figure 2.

In general, you should note one of four patterns when you steer your boat back onto course as illustrated on the following graph.

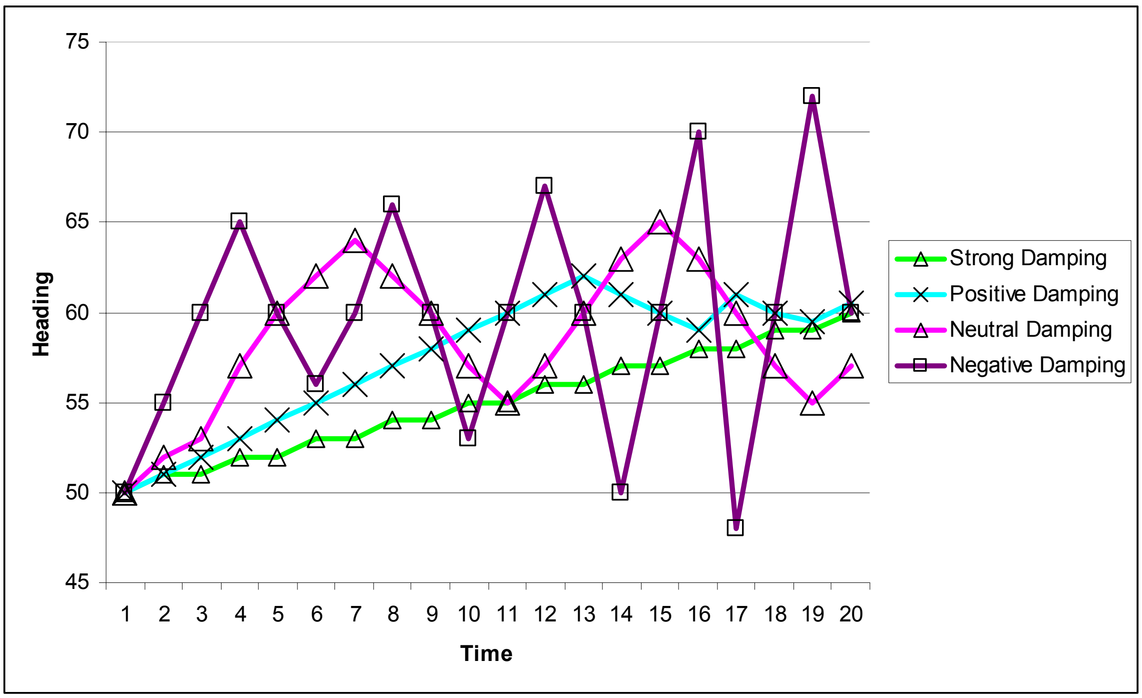

Figure 2: Four Possible Yaw Resistance Test Results

Strong damping means that the boat will progressively head to the right direction and stay on course. This type of boat will tolerate just about any type of self-steering gear.

Positive damping shows that the boat is very quick to respond and overshoots, but it eventually settles down onto its course. The self-steering design will require a bit of damping in the linkage to keep the boat from over-steering in downwind conditions, but you should be able to design a system to stabilize the boat. You might need to consider over-sizing the trim tab some, ensuring you still have enough torque from the dampened wind vane to steer the boat properly.

Neutral damping means the boat wanders around its proper course, but never settles down. In this case, you'll need to use a more powerful servo-pendulum type of design. An auxiliary rudder could be designed, like a stand alone trim tab, to steer the boat with the main tiller lashed to reduce yawing. However, careful consideration must be taken when designing the linkage and the vane to stabilize the boat.

Negative damping means the boat steers at ever increasing amounts of error. Only a large servo-pendulum design with a large dual-axis wind vane and a dampened control linkage design will probably stabilize this boat.

Determining the Self-Volume of Your Main Rudder

In order to discuss the tab in terms of force, Letcher introduces a term called self-volume. Put simply, it is the surface area of a rudder times the length of the rudder arm. The rudder arm is the distance between the center of pressure and the axis of the rudder. We'll discuss the center of pressure later, but first here's an example for a simple rudder:

A rectangular[1] rudder that is 3 feet long, and 2 feet wide, has the surface area of 6 square feet. If it is mounted on the transom of a boat so that the center of pressure is .5 feet from the gudgeon pins, its self-volume is 6 square feet * 0.5 feet = 3 cubic feet. The units are often dropped, as this is just a numeric tool for comparing the trim tab to the main rudder.

This term, the self-volume[2], is handy because it lets us quickly estimate how much rotational force must be applied to turn the rudder, which in turn will rotate the boat. It also makes it easy to compare the boat's main rudder to the new trim tab being added.

The basic assumption behind this analysis is the current rudder can steer the boat well, so its volume is correct for the boat. Therefore, if we understand the force required to turn the main rudder (the self-volume) then we can start to design the controlling trim tab. With this as a starting point, the trim tab will be designed to simply steer the main rudder with a force proportional to the main rudders self-volume.

<u>Example of computing an odd shaped rudder's surface area:</u>

We will use our Mariah 31 for this example, which has an odd shaped rudder. We had to estimate the area while it was in the water. Once we actually hauled the boat to install the trim tab, we were able to make more accurate measurements of the rudder, just for the record.

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[1] For general geometric formulas for surface area see the Appendix.

[2] For those interested in what this term really is, it is a force called a moment. A moment is a rotational force, or torque, about an axis of rotation. It is calculated by M = F * D, or the Moment is the Force times Distance. In our case, the force is the water acting on the surface area of the rudder times the distance between the average center of that force (center of pressure) and the axis of rotation or the gudgeons on the rudder. If we make some assumptions that the water forces are similar between the main rudder and the trim tab, the force can be ignored, and substituted by the surface areas which the forces act upon. This is where the term "self-volume" is created.

The diagram of our rudder with the trim tab attached, looked something like the following sketch:

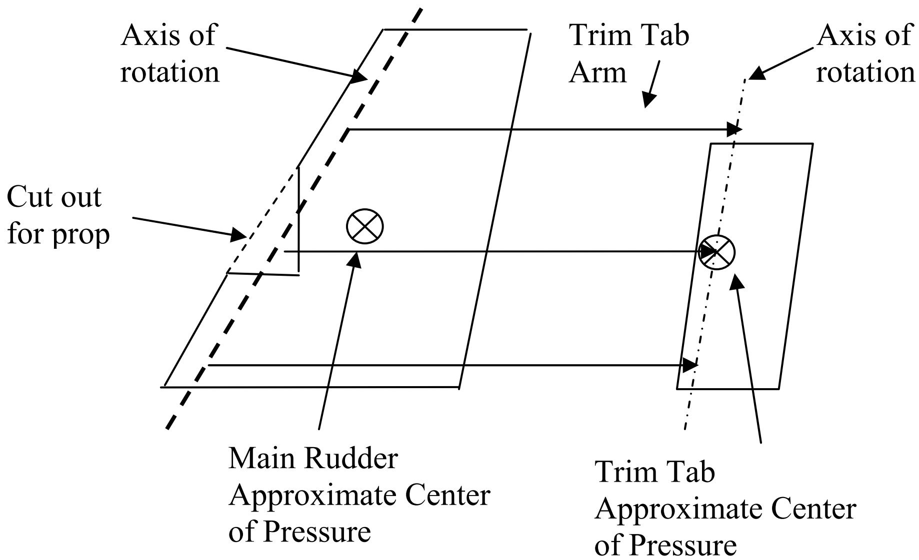


Figure 3: Rudder Self-Volume

There is a cutout for the prop in the main rudder, and the tab is mounted aft with the arrows showing the distance from the axis of the main rudder to the axis of the trim tab.

The process of computing the self-volume includes finding the surface area and then the distance between the gudgeon pins and the center of pressure. The center of pressure can be difficult to estimate. For a rectangular shaped foil, the center of pressure is about 27% of its width, or chord (which is explained in the next section), from the leading edge, but for our main rudder with its funny shape, it is difficult to estimate. A figure between 25% and 27% of the width are typical estimates. For odd shaped rudders, this process is less clear because the width is often asymmetrical. We'll cover this after finding the surface area.

The first step is computing the surface area. Often odd shaped structures can be sub-divided into rectangles and right triangles. This makes estimating the surface area easier. Notice the following drawing of the Mariah's rudder and the sections that it was divided into.

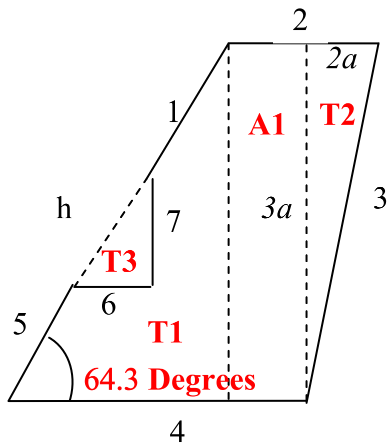


Figure 4: Computing Surface Area

Three right triangles[3] can be constructed for our rudder, T1, T2, and T3. Notice that T3 is actually a cut out section of the area T1, so the solid area of T1 will actually become T1 minus T3. The angle between sections 5 and 4 was measured at 64.3 degrees. The following table shows the physical measurements of each segment as it was measured in the yard.

Rudder as measured in yard	
Segment	in feet
1	1.5
2	1.667
3	4.58
4	2.667
5	2
6	0.5
7	1.5
Angle	64.3

Table 1: Measured Dimensions

Once the base segment measurements are known, the other segments such as 2a and 4a can be computed. First we have to compute h, using the hypotenuse formula.

h = square root (segment 7 * segment 7 + segment 6 * segment 6)
h = square root (1.5 * 1.5 + 0.5 * 0.5) = 1.5811

Also, by knowing the angle, we can directly compute 3a using the Sine formula:

[3] A right triangle must have one side that has a 90 degree angle. See the Appendix for some basic formulas for right triangles.

3a = segments(5+h+1) * sin (angle)

So, pulling the measurements from the table:

3a = (2 + 1.58.11 + 1.5) * sin(64.3) = 4.5785

This allows us to calculate the area T1

Area T1 = 0.5 * (segment 4 * segment 3a)
Area T1 = 0.5 * (2.667 * 4.5785) = 2.5578

To compute A1 and T2, the segment 2a must be computed using the hypotenuse formula again:
2a = square root ((segment 3 * segment 3) – (segment 3a * segment 3a))
2a = square root ((4.58 * 4.58) – (4.5785*4.5785)) = 0.1173

Now A1 and T2 can be computed. A1 is calculated by the formula for a rectangle, using 3a and the difference between 2 and 2a:

A1 = segment 3a * (segment 2 – segment 2a)
A1= 4.5785 * (1.667 – 1.173) = 7.095

T2 = 0.5 * (segment 2a * segment 3a)
T2 = 0.5 * (0.1173 * 4.5785) = 0.2685

The total area is T1 + A1 + T2

Total = 2.5578 + 7.095 + 0.2685 = 9.9216

But we have to remove the area of T3 because it is a cut out for the prop.

T3 = 0.5 * (segment 7 * segment 6)
T3= 0.5 * (1.5 * 0.5) = 0.375

So the final answer becomes (Total Area – T3):

Surface Area = 9.9216 – 0.375 = 9.5466

Finding the center of pressure for a rudder that is a strange shape is not a simple task. Designers do this with scale mock ups, or it is computed numerically with the aid of 3-D fluid calculations.

There is no easy way to find the center of pressure. Some books recommend building a scale model and testing it in a river. (?!) We estimated where the 25% point was along the chord and used this for our center of pressure. I estimated it to be 7.25" back from the point where the gudgeons mounted to the rudder. Thus the rudder arm would be 7.25" (or 0.6 feet).

Using this number for the rudder arm, the self-volume = 0.6 * 9.55 = 5.73 feet.

Determining the Self-Volume of Your Trim Tab

Now that we know the size of the main rudder, the next step is to design the trim tab. A full power trim tab needs to have the same self-volume as the main rudder, in our case, 5.73 feet. The ideal trim tab will have a 1:1 relationship with the main rudder. This means that for a 5 degree turn on the tab, the rudder will turn 5 degrees the opposite direction.

Earlier we found the main rudder arm to be 6" from the center of pressure to the axis. For the trim tab, its arm is the distance from the tab's center of pressure to the axis on the main rudder. Since the trim tab is designed to be balanced, the distance between its center of pressure and axis is essentially zero. So for all intents and purposes, the trim tab arm is strictly the distance between the axis of the main rudder and the axis of the trim tab.

You can vary three parameters to achieve this self-volume, the chord, the span and the rudder arm. Of these three parameters, the rudder arm has the biggest effect on the self-volume calculation. The further aft you place your trim tab, the larger the self-volume becomes, allowing you to reduce the size of your trim tab. The next section will help you design a trim tab to the size which you feel is strong enough, yet small enough for your application. From there, you can then calculate the required rudder arm distance. You might find you'll have to go back and forth between these two steps to find a solution you like.

We over designed our trim tab because we didn't have time to correct it if the design turned out too small. Our final finished cut design after installation was about 7.11 cubic feet for the self-volume.

Determining the Chord Length and Span

The next step, now that we know what the self-volume needs to be, is to come up with some physical dimensions. But before we go into that, here are a few basics about foil shapes.

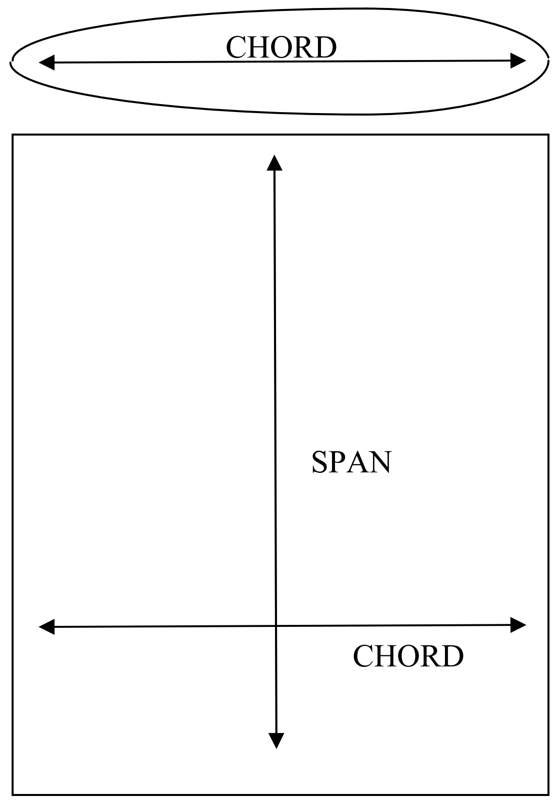


Figure 5: Chord and Span

The span is the length of the foil, and the chord is the width. Together these parameters define the foils aspect ratio:

ASPECT RATIO = (SPAN * SPAN) / CHORD.

The aspect ratio helps determine the amount of lift or force that your trim tab will generate when moving through the water. A higher aspect ratio will generate more lift, but it will stall faster. This means that as the angle of the trim tab increases, it will reach a high turning force quickly, then it will stall and the force will drop more dramatically as the angle is increased further.

If you want to look into this more closely, Letcher's book has some nice graphs and explanations on pages 96-99.

For our design we chose an aspect ratio of about 10. This is a very high aspect ratio, and in retrospect, I would probably choose about 5 to 7 just to make the span smaller because our final self-volume turned out to be oversized.

To define the physical dimensions, pick a chord and span that gives you the area you need, and the aspect ratio you desire.

In our case, we started with a 10" chord and a 3' span. This works out to be 2.5 square feet for a surface area. Then use the information about your main rudder's self-volume to see how far back you need to set the trim tab. Remember, that the further back you place the tab, the smaller you can make it.

So, for our design the required trim tab arm is calculated as follows:
Rudder Self-Volume = 5.73
Trim Tab Arm = (Rudder Self-Volume)/(Trim Tab Surface) = 5.73 / 2.5 = 2.29 feet.

So in our case the axis of the trim tab must be about 2.29 feet from the axis of the rudder. Since the rudder is slanted, we tried to design the shaft of the tab to angle inwards so it meets the top of rudder at 90 degrees (see Figure 16) to make connecting the controls easier. This meant that the tab was at a different angle from the main rudder axis. I computed the average trim tab arm and added a little extra distance of 6" to insure the tab had enough force.

When designing the trim tab arm, keep in mind the clearance required for turning the trim tab. Our tab was designed so that it could spin 360 degrees making rudder stops unnecessary.

Figure 6 and Table 2 show the physical parameters for our trim tab's arm.

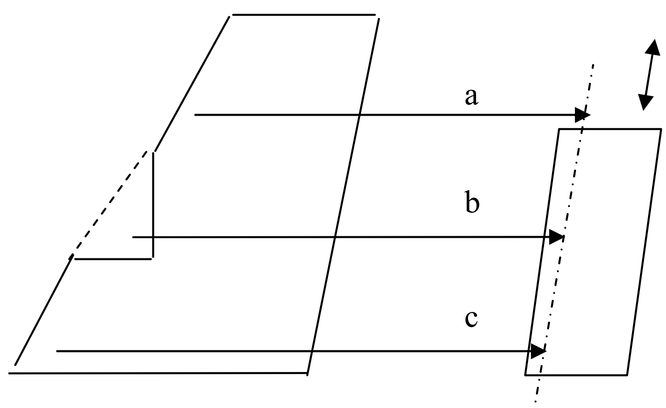


Figure 6: Trim Tab Arm

Final measurements, after everything was assembled, for a, b, and c are as follows:

tab arm	Feet
A	2.5
B	2.92
C	3.33
average	2.916667

Table 2: Trim Tab Arm Measurements

*After everything was fitted and attached, 2.92 was the average arm length, which may not be very accurate because the forces aren't averaged, but it was a good starting point. The self-volume ended up being 2.92 * 2.5 = 7.3 cubic feet on paper. After all the construction was done, some of the final dimensions were slightly different for the span. The span ended up at 9.75" and the final self-volume was 7.11.*

This is a little more power than we need and it might cause the tab to over-steer, but in the control part of the design, we can add damping to easily reduce the feedback.

Computing the Physical Design Profile

Now that we know the chord and the span, we can begin designing the foil. The first step is to compute the wing shaped curve.

The trim tab we made follows a formula characterized by the NACA0010 standard. NACA denotes a standard family of foils devised by the U.S. National Advisory Committee for Aeronautics. The "00" in NACA0010 represents the percentage of its symmetry (or camber, 00 is symmetrical) and the "10" is the percentage of the chord length which is the maximum thickness. If this is confusing, you'll see how this works in the following tables.

If the foil is a NACA0010, the thickness is 10% of the chord length. If it is a NACA0015, then the thickness is 15% of the chord length. A foil that is 0015 will have more lift than a 0010 foil, but it will also stall out quicker. Typically on sailboats, either the NACA0010 or the NACA0015 are used.

The following is a table of nominal factors I've pieced together from different sources for building a NACA0010 foil.

Position (fraction of chord)	Thickness (fraction of the chord)
0	0
0.0125	0.30615
0.025	0.04340
0.05	0.05900
0.075	0.07000
0.1	0.07800
0.2	0.09600
0.3	0.10000
0.4	0.09700
0.5	0.08800
0.6	0.07600
0.7	0.06100
0.8	0.04400
0.9	0.02400
1	0.00200

Table 3: Nominal values for a NACA0010 foil

Using the table above, we can compute an example foil. Let's say that after calculating the required self-volume needed for our trim tab, we determine a span of 2 feet and a chord length of 10 inches is required.

We go to the table and begin to multiply out the columns by the chord length. For our example, the resulting table would look like the following:

Position	Thickness
0	0
0.125	0.314
0.25	0.434
0.5	0.59
0.75	0.7
1	0.78
2	0.96
3	1
4	0.97
5	0.88
6	0.76
7	0.61
8	0.44
9	0.24
10	0.02

Table 4: Example of a NACA0010 foil with a 10" chord

So if you look at a cross section of your newly designed foil, at 0.125 inches along the chord, it is .314 inches thick, at 1 inch along it is 0.78 inches thick. This thickness is the *total* thickness, by the way. If you want to look at just ½ of the profile (which is how you'll need to calculate it for building a mold or template), just take the thickness numbers and divide them all by 2. The resulting ½ profile looks like the following, using our example numbers of a 10" chord.

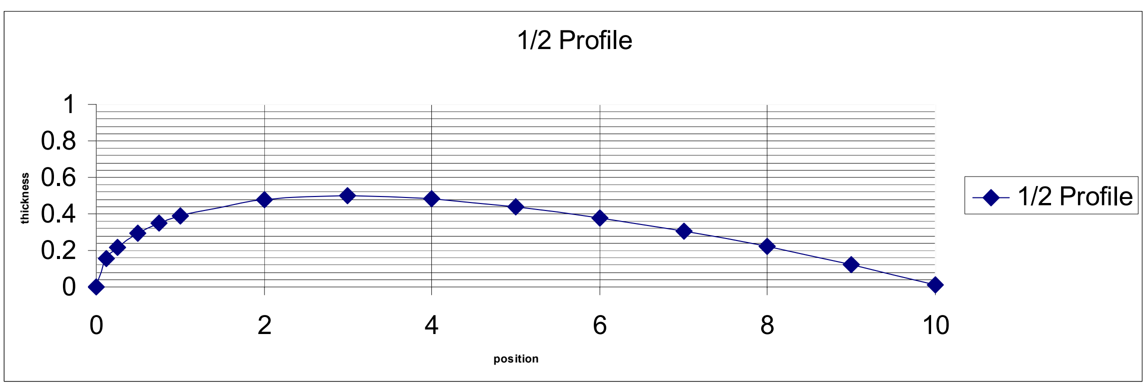


Figure 7: Profile of half of the trim tab foil

Sometimes we need the foil to be a little bit thicker for strength purposes. I found a fudge factor that can be applied to the foil to thicken it for strength. If you want to increase the thickness for strength, modify the table by the following multiplier:

MULTIPLER = (MIN. DESIRED THICKNESS) / CHORD * 10

So if you want the same 10 inch chord as in the above example, but want it at least 1.5" thick, your multiplier is 1.5/10 * 10 = 1.5. (The result seems trivial only because of the number chosen for the chord in this example).

Your new table would then be the previous table, with all the thickness values multiplied by 1.5, like below.

Position	Thickness
0	0
0.125	0.471
0.25	0.651
0.5	0.885
0.75	1.05
1	1.17
2	1.44
3	1.5
4	1.455
5	1.32
6	1.14
7	0.915
8	0.66
9	0.36
10	0.03

Table 5: Example of 10" chord, with a 1.5" minimum thickness

Our final design ended up with a 1.75 minimum thickness, a 9.75" chord and is shown in the following table.

Position	Thickness
0	0
0.121875	0.5495
0.24375	0.7595
0.4875	1.0325
0.73125	1.225
0.975	1.365
1.95	1.68
2.925	1.75
3.9	1.6975
4.875	1.54
5.85	1.33
6.825	1.0675
7.8	0.77
8.775	0.42
9.75	0.035

Table 6: Sarana's Actual Trim Tab Foil

Before building your trim tab, there is one final check you should perform. The effectiveness of the main rudder is reduced by the trim tab, because they turn in opposite directions. The moment, or forces, about the rudder axis is static when the forces are equal. This can be expressed as:

Tab lift * Tab Arm = Rudder Lift * Rudder Arm

Solving this equation for the Tab Lift and assuming the rudder lift is constant, the effectiveness of the rudder is reduced by the rotational moment related to the tab arm and the rudder arm. It can be expressed as a percentage as follows:

Reduction in Effectiveness (%) = Tab Arm / Rudder Arm * 100%.

For example, a rudder arm of 0.33 ft and a tab arm of 2.66 ft will produce a reduction in efficiency of the main rudder equal to .33/2.66 * 100% = 12.5%. As a rule of thumb if you keep this below 15-18% you shouldn't notice any difference in how the main rudder steers the boat when the trim tab is driving it.

Building It

There are several options for building the tab. You can build it out of wood and call it done, or laminate it with fiberglass, or make a mold from the wood model and build the entire foil with a cored fiberglass structure. It's your choice.

Materials

We used iroko wood for the foil, Silicon Bronze Metal, and thermoplastic bearings with glass balls below the waterline and stainless steel thrust bearings in a thermoplastic race above the water line. The shaft was ¾" solid silicon bronze, the supports below the waterline were 1/8” thick silicon bronze, and the support strut, trim tab arm and trim tab lock above the waterline were made from ¼” thick silicon bronze. The threaded rod for the trim tab lock was also silicon bronze.

Wood Foil

We made our trim tab out of two pieces of laminated Iroko wood (which is similar to teak), saturated it with epoxy, and then used 2 coats of Interprotect 2000E barrier coat and a bottom paint coating. If we would have built if from all fiberglass, it would have been much lighter, but we were constrained by time.

The more laminations you use, the stronger the foil will be and the less likely it will warp over time. We only used two pieces of 1” thick wood to make our tab. When you laminate the pieces together, make sure you have plenty of extra length in both the chord and span; you’ll want an extra margin for error. I suggest at least 2 inches of extra width and 12 inches of extra length. If you use our table saw technique described below for cutting the foil, it helps to have about an extra inch of wood on each side of the chord for stability when running it through the saw.

To begin with, look closely at the pieces you plan to laminate. Study the grain of the wood. Have them planed if they are warped or rough. Where the grain is closer together, the wood is stronger. Try to design the lay-up so the area where the grain is tighter is on the trailing edge of the foil where it will be thinner. Also, I suggest you laminate the wood so the grains are in opposition to each other as illustrated below, this will keep them from warping in the same direction.

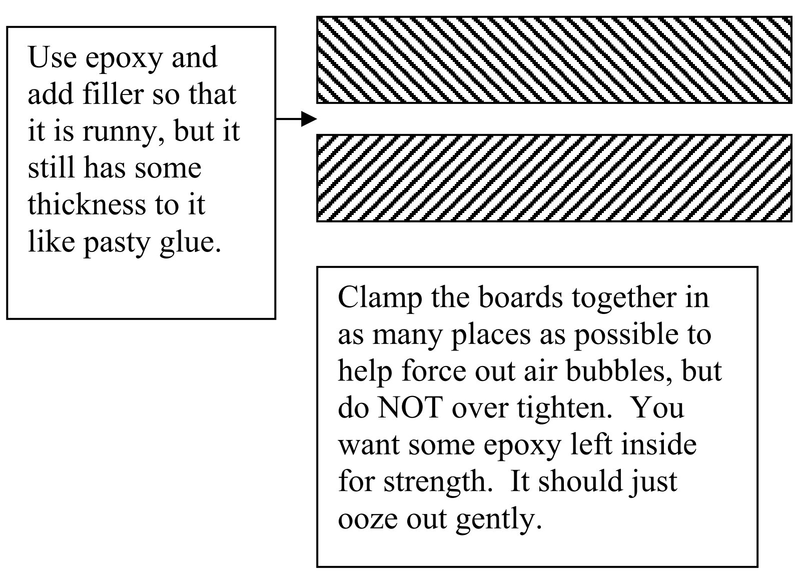


Figure 8: Diagram of wood grain and epoxy lay-up

The purpose for adding filler to the epoxy helps fill in voids, dents, groves inside the wood. It provides a better bond than just straight epoxy.

Allow the lay-up to cure overnight. Then plane the board down to the maximum thickness you want to use for your trim tab. In our case this was 1.75”. If you don’t have a planer, then you could rescale your numbers to the thickness you ended up with after the lay-up cures. Make sure that your surfaces are not warped! If they are you’ll need to plane them.

Make a Template

Create a template for cutting the foil shape on a table saw. The profile has to be reversed to know how much material to remove for creating the foil shape. This is done by computing a set of offsets based on the profile of the foil. To compute each cut depth, subtract your desired maximum thickness of the foil from the profile thickness at each position of the foil. Since we are working on one side of the foil at a time, the numbers should all be based on ½ thickness.

The template for the 10” chord, 1” maximum thickness example becomes:

position	thickness	1/2 Thickness	depth to cut (½ max thickness – ½ thickness)
0	0	0	0.500
0.125	0.314	0.157	0.343
0.25	0.434	0.217	0.283
0.5	0.59	0.295	0.205
0.75	0.7	0.35	0.150
1	0.78	0.39	0.110
2	0.96	0.48	0.020
3	1	0.5	0.000
4	0.97	0.485	0.015
5	0.88	0.44	0.060
6	0.76	0.38	0.120
7	0.61	0.305	0.195
8	0.44	0.22	0.280
9	0.24	0.12	0.380
10	0.02	0.01	0.490

Table 7: Example of a Template for a 10" chord with 1” max thickness

Now take a 2x4 that is about 6 inches longer than your chord, and carefully mark the position lines and the depth to cut from one edge. Make sure you use a nice 2x4 that has clean edges.

The 2x4 template should look something like this (but better than this poor illustration):

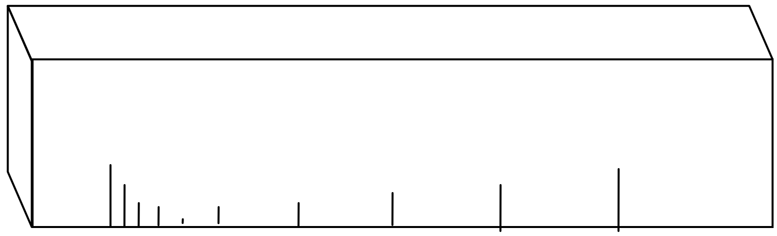


Figure 9: A 2x4 template with the depths marked

Now that you have drawn the depths on the board, carefully connect all the endpoints on the lines to make a nice dark shape of your foil. This template will be your depth gauge for setting the saw blade depth on your table saw.

Begin by laying the template on the table saw and adjust the blade height so that the deepest cut into the wood matches the outline of the profile. When you are sure things look right, make a cut into your template with the table saw.

Check the cut on the template to make sure you did not cut past your profile. It is better to be a little shallow than too deep. An error in either direction can be cleaned up later, but a cut too deep will require using a faring compound to fill it in.

Once you're sure the cut is right, run the laminated wood for your trim tab through the table saw making the same profile cut. Turn the board over and make the same cut on the opposite side of the cut you just made. This insures the foil will be symmetrical.

Repeat this process for all the marked points on the board, then start cutting all the points in between. Leave small comb teeth of wood about 1/8" or so in between each cut. This helps keep the board on an even plane while running it through the saw. Always make sure to test each new cut on your template before cutting your trim tab, going back and forth between the two.

When you're done, the board should look like a two sided comb with a foil shape in between.

Chisel and Sand

The next step is to chisel out the foil, removing the comb's "teeth" pieces, and then cut off the excess material on the chord (you may need to run it through the table saw to clean up the edges).

Now you can sand it smooth with a belt sander, being careful to sand it evenly and not hold the sander in one spot. A trick a shipwright told me once was to take a pencil and scribble on the surface of wood you want to sand smooth. The pencil marks are a good visual indicator of how much material you've removed and where. Sand it evenly and smoothly with decreasing grits of paper. Do a final sand with a palm sander and a fine grit.

Cut the span of the foil to its finished length, and keep the leftover chunk as it will be handy for making templates or shaping metal later.

Epoxy Seal

If you're going to laminate it or use it as a mold for a fiberglass rudder, your construction process will differ slightly from here.

If you want to follow our method, we heated the board up above a baseboard heater for about 5 hours, then we used epoxy thinned with acetone and coated the board. As it cools the epoxy will be pulled into the pores of the wood. Several coats and plenty of curing time are also recommended.

Next, mix up some epoxy with fairing filler in it and coat the board. This will fill in any grooves left by the saw or chisel, or a wild sander. Once it cures, gently fair the board back to its original shape. Add another coat of penetrating epoxy (epoxy thinned with acetone, about 60/40 of resin to acetone, mixed and then catalyst added to match the amount of resin used).

Trim Tab Installation

Now that the basic tab is shaped and finished, you have to connect it to a shaft and support struts on the main rudder. We used silicon bronze and bought the raw metal from a local metal supplier. For sources on bearings, shaft collars and example part numbers see the Appendix or follow this link: http://www.mcmaster-carr.com/

We used a piece of copper pipe and built two mock mounting struts out of 2x4 sections for our template. We cut 12" deep V-shaped grooves into the 2X4's that would fit over the aft section of the main rudder which was the appropriate distance for our trim tab arm. The bottom strut was longer than the top strut to compensate for the rake of the main rudder and the hull so that the top of the copper pipe was perpendicular to the top of the rudder. The copper pipe was inserted through holes drilled in the 2x4's and screwed into place to keep them from turning while we were fitting everything.

We plunged this template into the water, positioning it over the rudder where we wanted the struts, or gudgeons to be mounted. We modified it a few times to get the shape and the angles to fit correctly and even dove with it a couple times. Trying to get the right fit with the boat in the water was difficult at best. If you have the chance to haul out to make these measurements, your measurements and templates will take much less work.

From this, we went on to make some mechanical drawings of the struts, the shaft and the caps for the trim tab.

The shaft should be attached at the center of pressure for the tab to be properly balanced. On this type of foil, this is approximately 27% of the chord length. To be safe, use 24% to 25% to make sure you don't end up with an unstable unbalanced trim tab. We used

24% and in the case of a chord of 10” this means the shaft should be at 2.5” from the leading edge. *If in doubt move the shaft closer to the leading edge.*

We designed end caps for the trim tab out of 1/8” silicon bronze, which we secured to the trim tab ends with 3M’s 5200 sealant. They are also positively held in place by the squeezing effect of the bent 1/8” silicon bronze which was tightly shaped using the excess chunk of the trim tab foil trimmed off earlier.

The following photograph shows the end results, before the barrier coats and bottom paint. The purple color is the fairing compound that remained in the groves and dents of the surface.

Figure 10: Sarana's Entire Trim Tab Assembly

Figure 11: Sarana's Trim Tab

The structure of the man rudder struts is 3" wide plates with two 2" support plates brazed to them. The 3" plates were cut to fit the shape of the main rudder, as determined by our exercises with the 2X4 templates. The support plates flare out around the shape of the main rudder and are thru-bolted with silicon bronze bolts and bedded heavily with 3M's 4200 fast cure.

The shaft is ¾" silicon bronze and is welded to the top of the cap on the trim tab with a ¼" thick plate welded under it for additional support. The welder has done a lot of marine construction and felt that this heavy weld would not fail under pressure. A photograph is shown below of the top strut and the weld.

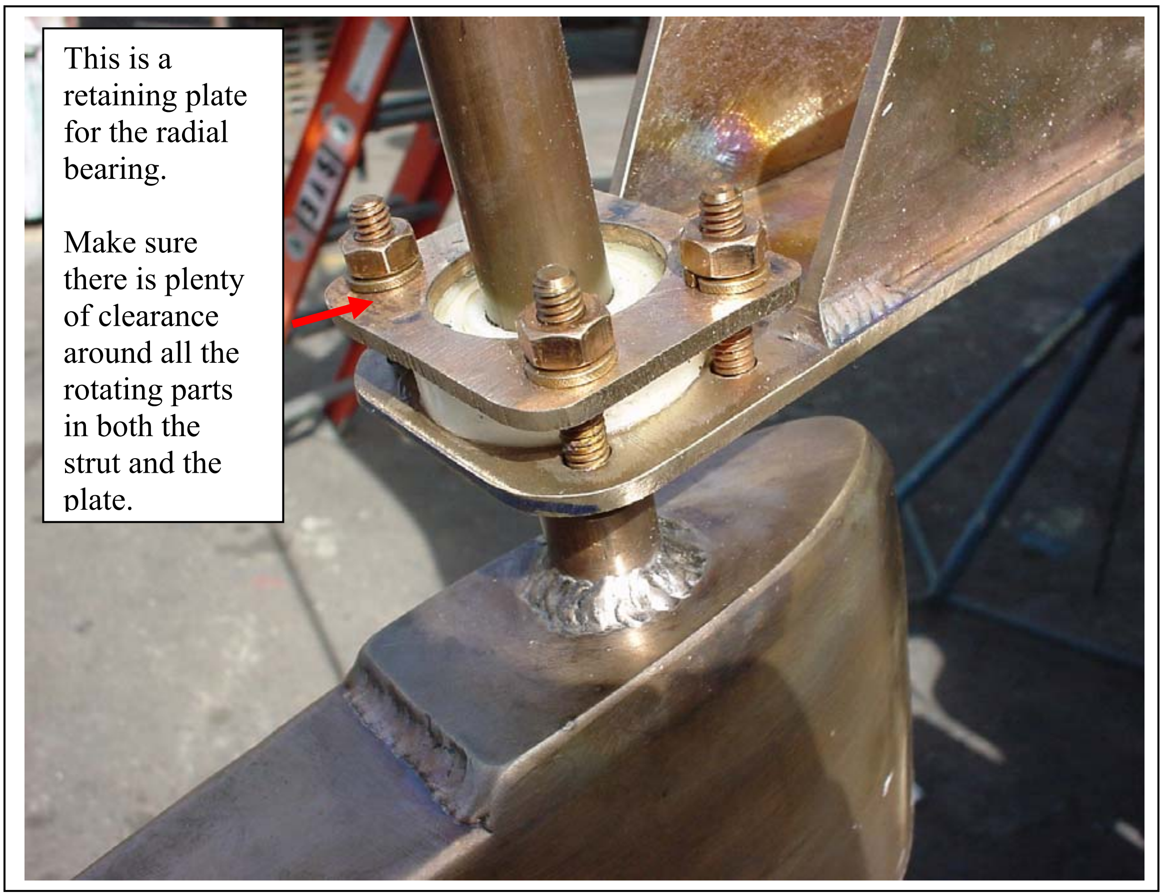


Figure 12: Upper Strut Support

Both the top and bottom sections of the shaft are welded in the same manor. The retaining plate you see in the above photograph holds the radial bearing in place. There is some slop in the alignment of the holes for the plate to allow for aligning the shaft. Clearance should be allowed for the bearing to rotate freely and without binding.

The following is a photograph of the lower radial bearing.

Figure 13: Lower strut support

A 2” section of shaft was welded onto the bottom of the trim tab, assuring perfect alignment with the main section of the shaft at the top. The bottom strut was then attached to this with a radial bearing and retaining plate, same as for the top trim tab strut.

The support strut that is above the waterline, near the top of the main rudder, was made with ¼” silicon bronze, as opposed to the 1/8” used elsewhere. This increased the strength of the support, and made sure that if anyone climbed on the rudder, it would hold without deforming.

Figure 14: Above water support strut

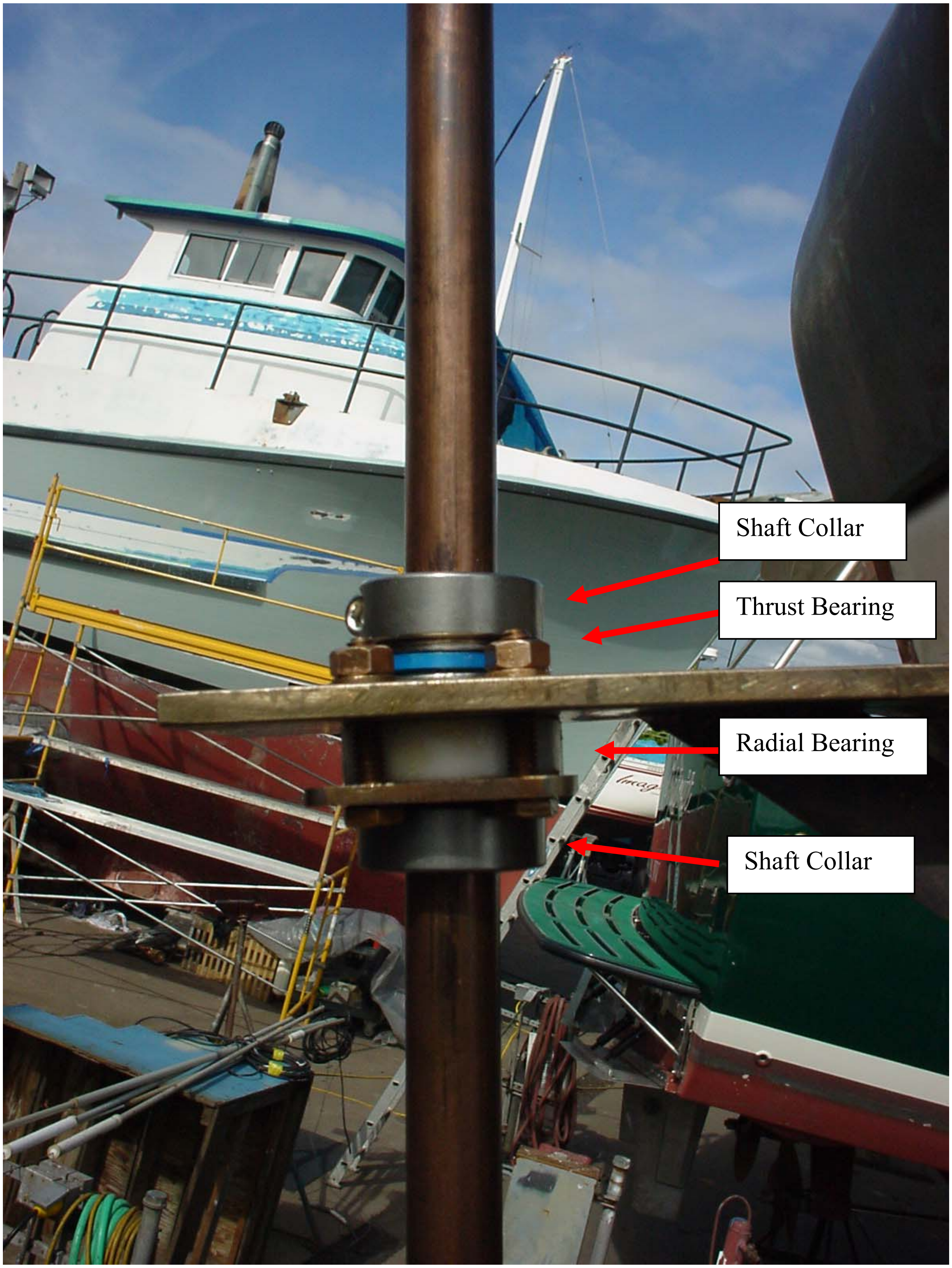


Figure 15: Bearing details of the above water support strut

The upper support holds the weight of the entire shaft and trim tab. The shaft collars prevent up and down movement of the shaft. The thrust bearing holds the weight of everything and consists of stainless steel balls in a delrin race for low corrosion and high strength. The radial bearing takes any of the side forces and keeps the friction low. We used radial bearings with glass balls and delrin races for no corrosion above and below the waterline.

The last piece of the trim tab puzzle is the trim tab control arm. We made ours out of two oversized nuts with an inner diameter slightly less than the ¾" shaft and a piece of ¼" silicon bronze.

The nuts were threaded onto a bolt and brazed together, then bored out to ¾" inner diameter. They were then brazed to a ¼" plate that has a 3/8" continuous grove cut into it for the control attachments. The final part is shown in the following photograph.

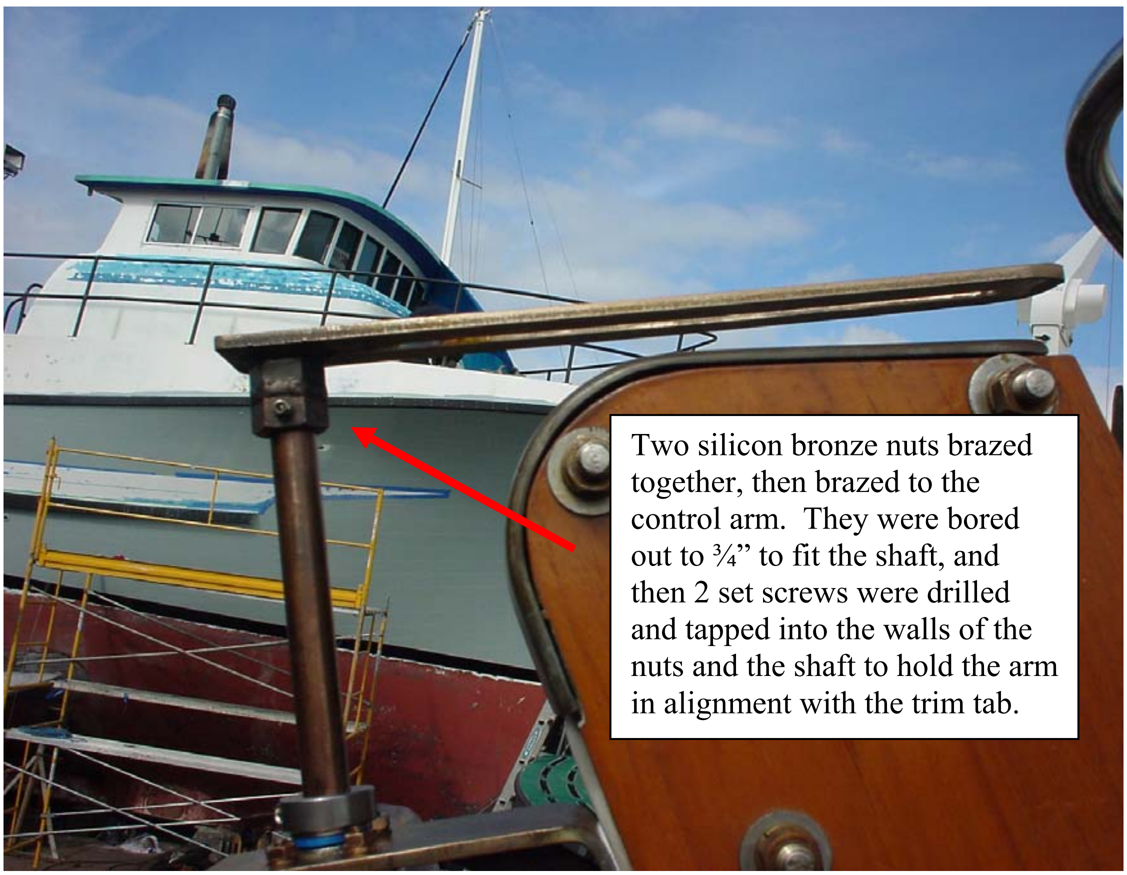


Figure 16: Trim tab control arm

One very important aspect in choosing the length of the trim tab control arm is to make it longer than where the axis of the main rudder crosses it. You can find the axis by standing over the top of the rudder while swinging it back and forth. Look for the point where there is no rotational movement and mark it. This is where the axis of the rudder is located. You need to make sure your tab arm slot goes slightly past this point for maximum control range.

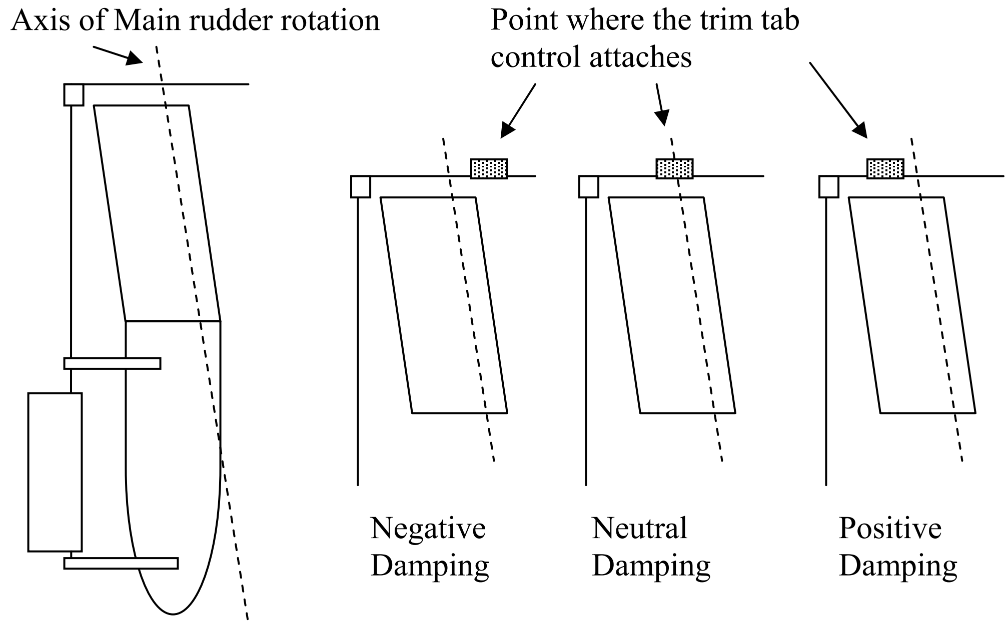


Figure 17: Control arm attach points

You can configure your controls to have negative, neutral or positive damping depending on where you set your controls on the trim tab's control arm. Having positive damping is vital if the boat is in heavy waves or swells. For example, if a wave pushes the main rudder to starboard, positive damping will apply the opposite force via the trim tab and the main rudder, which would normally swing hard over, will only slightly deviate to starboard before the trim tab corrects it. The great advantage of positive feedback is it requires no input to the trim tab to keep the main rudder stable in large waves. So, whether it is connected to an autopilot or a wind vane, the boat's main rudder is corrected before a course error occurs without having to apply hardly any force on the trim tab control arm.

If the sea state is fairly calm, then the control can be moved to a more neutral position for a quicker and lighter response to the controlling device (either an autopilot or a wind vane).

I doubt you would want to move to the negative damped condition, unless you like to watch your equipment work hard to try to constantly correct itself and over steer its course.

Trim Tab Lock

Another key feature to your trim tab is a locking device. You'll need this for when you want to back up, or just steer the boat in your regular old fashioned way.

Our lock was overbuilt, but it works. We used two pieces of ¼" silicon bronze, 3/8" threaded rod, some 3/8" nuts and a bolt. We found a plastic handle for locking it down and the final results looked like the following photograph.

Figure 18: Trim tab lock

The wing nuts on the side, allow you to fine tune the angle so you can adjust out any prop walk you might have on your boat.

The bolt that the handle attaches to is actually two nuts brazed together, then threaded onto the rod, with a bolt brazed to the top of the nuts.

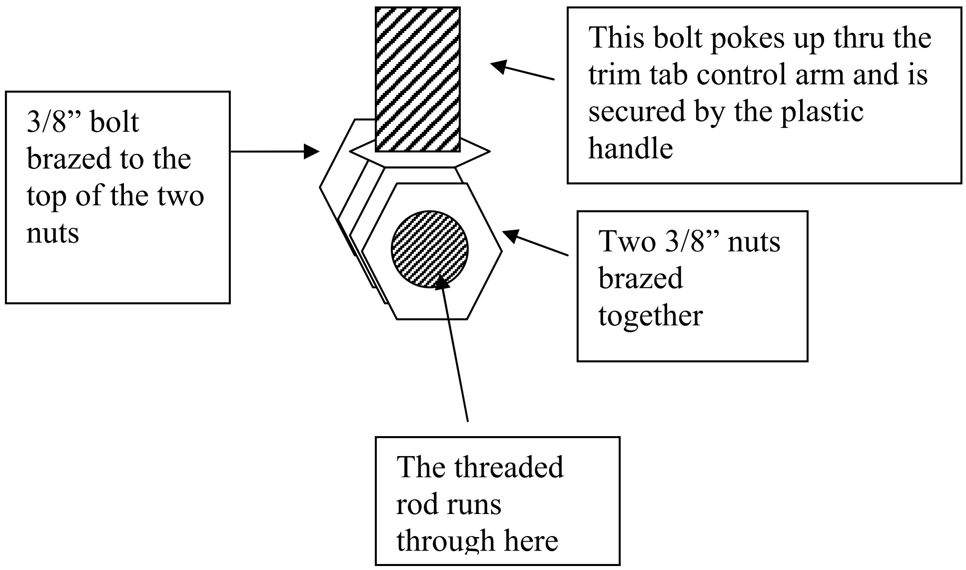


Figure 19: Sketch of trim tab locking device

To unlock the trim tab control arm, just unscrew the handle and push the bolt down out of the slot. We attached a small lanyard to the plastic handle so that it didn't accidentally get dropped overboard.

As a final check, make sure you have plenty of clearance for the tiller arm to swing around, and for the bolt to drop out of the way.

When everything is mounted and the boat's ready to go back into the water, coat the trim tab with barrier coat and bottom paint. *Do not apply bottom paint directly to the metal! You have to use some sort of barrier coat first otherwise the copper bottom paint will corrode the metal.*

Verifying the Trim Tab Design

With the boat in the water, lock the trim tab control arm in the center or slightly to port if you have a right hand turning prop. The first thing you may notice is the extra weight and stiffness of your tiller. It will feel different now that you've added more surface area to it. Be wary that you might have to fight the tiller in one direction or another until you adjust the tab lock into a nice neutral position.

Once you are in some calm open water, with no obstacles around, get the boat up to hull speed. Then put the engine in neutral and unlock the trim tab control arm while holding it in the neutral position.

The first test is for the trim tab's balance. Move the tab arm back and forth 3-4 degrees. Watch out, because the main tiller will swing around too, so try not to obstruct it or get hit with it. As you're doing this, note if it has a tendency to continue turning, resist turning or if the tiller is neutral. If it continues turning, then your shaft was too far back from the leading edge and you're going to have to start over. If it is neutral, congratulations, you'll have a low friction trim tab. If it has some resistance, but not too much, this is ok, but your wind vane might have to work a little bit harder.

The second test is for the proper self-volume. If you remember, there were some estimates that probably had to be made about the main rudder to calculate the trim tab's desired self-volume. This is tested by turning the trim tab arm by a fixed number of degrees and then noting how many degrees the main rudder turns. They should be close to 1:1. A 5 degree turn on the trim tab should produce a 5 degree turn (in the opposite direction) of the main rudder.

Don't worry if they are not exactly 1:1. If you're able to steer the boat using just the trim tab without any wild gyrations, you should be in good shape. It can difficult to steer the boat with just the trim tab arm, so practice it a little before trying to make any judgments.

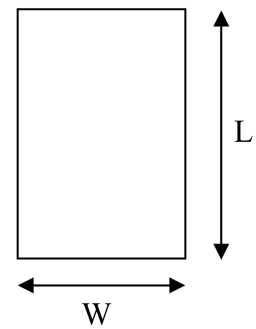
Also, make sure you lock the trim tab or have someone holding it before engaging the prop. The turbulence over the trim tab can throw it in funny directions and steer the boat wildly if the control arm is not being held. But you do have to have motion through the water to perform these tests, so either sail, or coast along in neutral.

Good luck on your own trim tab design. It is very satisfying when you have the finished product which was designed specifically for your boat, and it works great. And, you will know the workings and design of the trim tab inside and out, and be able to perform maintenance and repairs with relative ease.

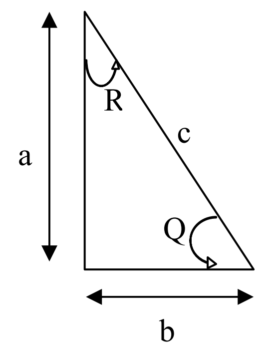
APPENDIX

Surface Areas

Rectangle
Area = Length * Width
A = L * H



Right Triangle
Area = 0.5 * Base * Height
A = 0.5 * b * a



Lengths:
c * c = a*a + b*b

Where c is the length of the hypotenuse, which can also be rewritten as any of the following:
c = square root (a*a + b*b)
a = square root (c*c – b*b)
b = square root (c*c – a*a)

If you know either, all three sides, or 2 sides and an angle, you can compute the missing dimension from the following formulas.
Law of Sines with angle Q in degrees:
R = 90 – Q
Sin(Q) = a/c
Cos(Q)= b/c

Sin(R) = b/c
Cos(R)=a/c

Sources for Bearings
The best deal we found for quality and inexpensive bearings was McMaster-Carr
http://www.mcmaster-carr.com/

Look for their Economy Ball Thrust Bearings, like part number 6655K39.
The radial bearings are Thermoplastic Semi-Precision Ball Bearings, like part number 6455K86. They also have lots of gears and other parts you might find useful for your project.