Competition Composites Inc.

Foil Design Tips

The information found here is a collection of tips to help with your foil design, whether you are starting from scratch or modifying a pre-existing design. This will not make you an expert, but should help you understand some of the tradeoffs in foil design (all designs are a compromise after all, as for any given boat there is no one perfect design for all sailing conditions and sailing styles).

While foil design may in fact be rocket science, don't be afraid. Yes, there are a number of specialized foil design software programs and books on the subject available for those who are truly interested in the subject. But a conservative design of simple planform and foil section, built smooth and fair, will be fast and work well in all conditions.

I've taken a fairly simple approach to these subjects, but if you spot any glaring errors feel free to drop me a line.

Common Subjects

Rudders

Centerboards

Common Subjects

Terminology

- angle of attack - the angle the foil faces to the flow of water over it (this varies on rudders as you steer the boat).
- aspect ratio - the comparison of the length to the width of the planform of your rudder or centerboard. High aspect ratio foils are long and skinny while low aspect ratios are short and squat. Boats with higher maximum speeds are more apt to use high aspect ratio foils (think of the fin on a sailboard as the ultimate example of this) while slower boats are more suited to lower aspect ratio foils.
- chord - the distance from the leading edge to the trailing edge.
- ellipse - a 'stretched' circle (oval). An important shape in planform design.
- foil section - the cross-sectional view of your rudder or centerboard (Similar to the cross-section of an aircraft wing [airfoil] but nearly always symmetrical from side to side).
- NACA 4 digit series (NACA0008, NACA0010, etc) - the most popular foil sections used in sailboats. The first 2 digits ('00') indicate that the section is symmetrical, and the last 2 digits ('08', '10' etc) define the maximum width of the section as a percentage of the length of the chord. In other words, a NACA0008 foil is 8% as thick as the foil is wide. The maximum thickness on these foils is found at a distance 30% back from the leading edge.
- planform - the outline of your rudder or centerboard when viewed from the side
- spline - a curved line that is defined by a number of points that it passes through (or close to) - think of flexing a thin piece of wood around those points. There are several different mathematical forms of splines with different properties.

Planform

First of all, the obvious: the planform you design must fit within your fleet's class rules. Some fleets offer complete freedom in this, while others may force you to fit within a few mm tolerance of their official dimensions.

The simplest planform is the simple rectangle, and will give good performance while also being easy to fabricate.

A performance increase can be had by going with an elliptical tip - this can be done with either an elliptical leading edge or trailing edge while keeping the opposite edge straight (or the tip can be fully elliptical). The performance increase comes from the increased lift and reduced drag from this shape - with a rectangular tip, water can 'escape' by going around the bottom of the foil rather than across the chord, while with an ellipse** its always a shorter path across the chord than it is around the bottom.

If choosing between an elliptical leading edge / straight trailing edge, or straight leading edge / elliptical trailing edge, the former of these is mechanically stronger (this may not be an issue if your composite layup is sufficiently strong).

A few other notes - when an elliptical foil stalls, it stalls all at once. By comparison, a foil with a squared off tip will have the tip stall first - if the helmsman feels this flutter they may be able to correct in time.

(** If you want to split hairs, what's really important is that the pressure differential over the foil have an elliptical distribution - this doesn't necessarily require the planform be semi-elliptical.)

Rudders

Thickness

The thickness of a rudder (as a percentage of its chord) will be greater than the thickness of a centerboard. Why? Because thin foil sections stall at lower angles of attack than thick sections. Centerboards may be thin because they always travel in the same direction through the water as the boat hull. But rudders sweep through the water as they steer the boat.

Tradeoffs:

- thin foils give lower drag, but less lift, and they stall at lower angles of attack.
- thick foils have higher drag, but more lift, and they won't stall until higher angles of attack. Thick foils are also mechanically stronger, all else being equal.

Considerations:

- if you steer aggressively in waves, then consider going for a thicker section.

The NACA0012 section (12% as thick as its chord) is a good compromise.

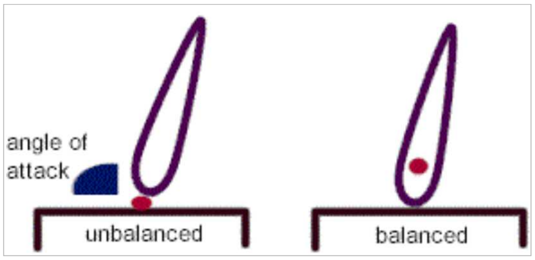
A final performance tweak is to make the cross section of the rudder thinner at the waterline - this yields another drag reduction. The trade off is one of mechanical strength, as this is a very high load area to begin with.

Planform

How big should your rudder be? Rudders contribute to both lift and lateral resistance, and this is taken into account by the boat designer when determining foil sizes. If designing a new rudder for your boat, keep the underwater surface area approximately the same as that of your original rudder (even if changing its shape). If you don't know this measurement, then a good rule of thumb is to have the surface area of the rudder about 1/3 as large as the surface area of the centerboard.

Aspect ratio: if you've ever had the experience of going really fast downwind in your sailboat and had the rudder feeling just 'go away' (it feels like there's nothing back there) then you're a good candidate for a higher-aspect ratio rudder blade. A high aspect rudder has a more sure feel to it at higher speeds, but with the trade off of losing steerage earlier in light air. High aspect ratio rudders also have to be built stronger - the longer blade has more leverage and is more likely to break if it loads up (if a rudder is going to break, it usually breaks where it enters the headstock).

Balanced or not?: a rudder that's leading edge is forward of its pivot point is said to be balanced, and requires less effort to steer. Balanced rudders are more common in keelboats, but are also possible in dinghy's.

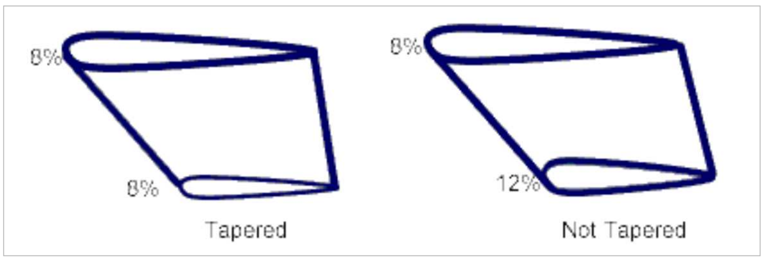


Centerboards

Thickness

The angle of attack is low for a centerboard (its the same as the leeway of the boat... about 3 degrees). This allows a thinner foil section to be chosen than you would use for a rudder. The thinner section gives less drag, and you don't have to worry about the board stalling the way a rudder will. An 8% thickness-to-chord ratio (like the NACA0008 section) is a good general purpose starting point for your design.

Tapered or not? Some builders taper the absolute thickness of their boards as the chord shortens towards the tip. This maintains the same relative thickness and ideal foil section as the board narrows. Others do not taper, with the result that the relative thickness at the tip is much higher than the thickness at the hull. Why? One reason not to taper is to achieve mechanical strength - remember, you have to be able to stand on your centerboard if you capsize - but this comes at a cost of having a higher drag foil section at the tip. How to decide? If you specify a cloth layup over the core of sufficient strength, then go ahead and taper to maintain your ideal foil section. But if, for example, you are building a board out of mahogany with no covering, then don't taper it - it won't be strong enough.

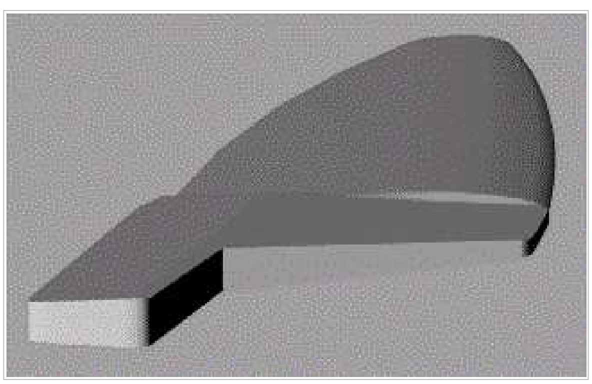


One other consideration - sometimes your class rules will prevent you from having a thick enough board relative to its chord where it exits the hull. If for example your maximum centerboard slot is specified as 30mm, but your board must have a chord of 500mm where it exits the hull, then the most you can achieve is a 6% foil section. In this case keep the board at 30mm thickness until it tapers to the point where the ideal foil section is achieved (375mm chord for an 8% section at 30mm) and then begin tapering it from there.

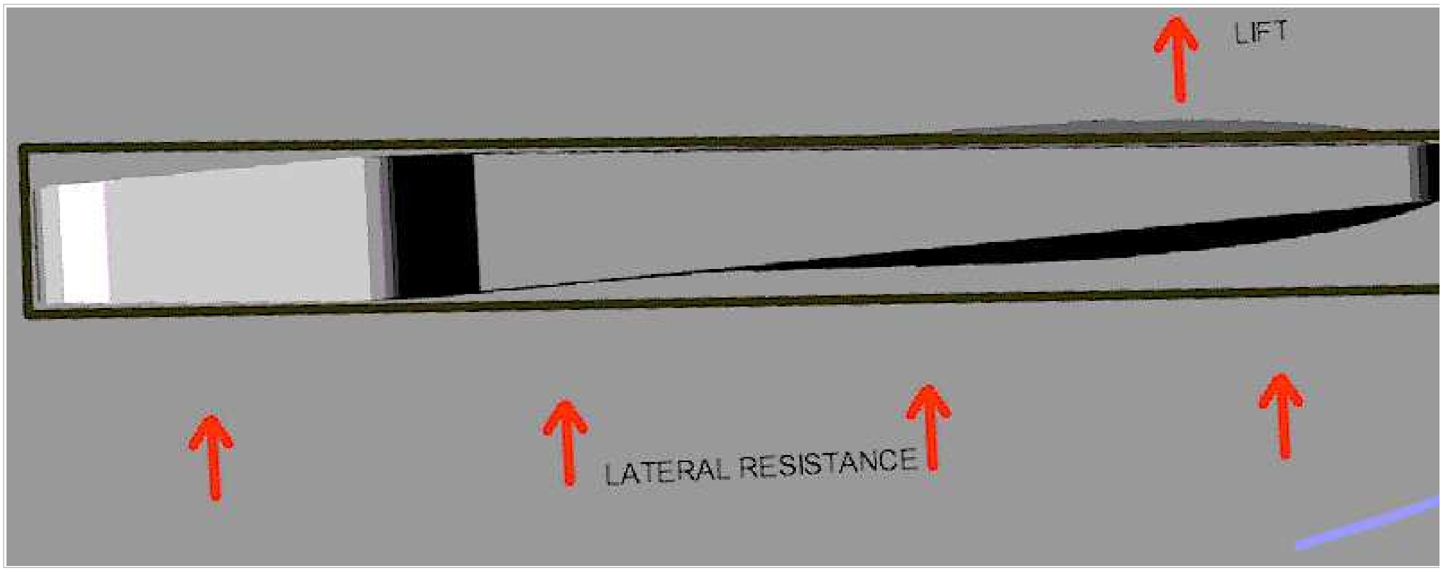
Stiffness: can a centerboard ever be too stiff? Yes! What happens when you're sailing along and a gust hits? Answer: the boat heels. A well rigged boat will be optimized for crew weight so that when the gust hits, the mast tip bends off to shed power, and the boat heels less and squirts forward rather than slipping off to the side. In a similar fashion, if your centerboard flexes when the gust hits, this will also reduce the amount of heel and contribute to forward motion. So ideally the stiffness of your centerboard is tuned to your crew weight and the amount of sail power that you can carry. Racing sailboarders are probably at the leading edge of this, selecting their fins according to their weight and aggressiveness.

Gybing Heads

Some boats use what is known as a "gybing head" design. If you look at the following picture, you can see that the head is trapezoidal in cross section, rather than the more typical rectangular.



What this does is allow the centerboard to pivot inside the centerboard trunk (rotating about the point of maximum thickness of the head). The forces causing the board to pivot are (1) the lift being generated by the foil, and (2) the lateral resistance from the foil preventing the boat from slipping sideways through the water. Usually you can view the lift vector as being concentrated at the 25 % chord, while the lateral resistance is more or less evenly distributed across the foil. If the pivot point is greater than 50% back from the leading edge of the foil, then the forces will cause the centerboard to be pressed against the side of the trunk, and it is "gybed" into position. Typical centerboard gybing angles are about 3 degrees. The centerboard only gybes when it is all the way down - as soon as you start to rake it back in the trunk, the fat leading edge of the foil will jam enter the trunk and cause the centerboard to jam in a straight fore-aft position.



Why do you want a gybing centerboard? By the board rotating to windward, you increase the angle of attack of the centerboard with respect to the centerline of the hull, and therefore generate more lift, all else being equal. In practice this means you can steer the boat slightly lower and sail with a fuller jib for increased power while maintaining the same leeway angle as a similar boat with a non-gybing board. That's the theory - some fleets like them, some don't (and many one-design classes don't allow them). Frank Bethwaite in "High Performance Sailing" claims they are a bad idea as the rudder may end up directly in the disrupted flow from the centerboard.

Click here for a short overview of the fabrication process.

More to come...

If you want to learn more, there is a wealth of information on the internet. I won't include the links (I don't want to maintain links, and that's what search engines are for!) but some of the pages worth looking for include:

- Design and Construction of Centerboards and Ruddersby Paul Zander
- Aerodynamic Forces on the Hobbyinc page
- Rudder Strength by Richard Hinterhoeller on the Shark class home page
- Emergency Rudder Design and Construction by Paul Kamen
- Foil Design Parameters and Performance tutorial on David Vacanti's page
- The Totally Free Foil Primer by John Dreese
- 5o5 Fins by Bransford Eck on the Int'l 5o5 class page

Hardcover references on my bookshelf include:

Aero-hydrodynamics of Sailing by C.A. Marchaj

High Performance Sailing by Frank Bethwaite

Marine Composites by Eric Greene Associates