Perfect pitch

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T-foil rudders are revolutionising many high performance dinghy classes, **Kevin Ellway** explains all…

As part of the development of the new SK4 skiff and E5 Cherub designs – both 13-14ft high performance skiffs – a considerable amount of technical research was undertaken. This involved developing a VPP (velocity prediction program) for high speed skiffs and extending this to account for the effects of T-foil rudders. This research showed that T-foil rudders can greatly enhance the speed of high performance dinghies in medium winds and more. Besides improving performance they also make some classes, particularly short boats, easier to sail as the wind and sea state increases. T-foil rudders do, however, diminish the light wind performance of dinghies.

How do T-foil rudders work?

A rudder T-foil has three basic effects on the way your boat sails: they reduce the displacement of the boat, recover some of the wave energy of the boat, and finally change its pitching stiffness and centre of pitching.

1) Displacement reduction

Figure 1 shows the resistance of a 4m long (13ft) skiff as a function of speed. The all-up weight is assumed to be 200kg. The sailing weight is supported by the hull at all speeds. If we divide the resistance by the sailing weight, we then have the drag:lift coefficient of the hull – shown in Figure 2.

Also shown in Figure 2 is the drag:lift coefficient for a T-foil attached to a rudder. It is assumed to be inclined to the flow at 4 degrees. This angle of attack is close to optimum in giving the least drag for a given lift.

It can be seen that below a speed of about 6 knots, the hull gives a lower drag:lift ratio. This means that the hull is more efficient at supporting load than the T-foil. So, below a boatspeed of 6 knots, the T-foil will be slightly detrimental to performance. Above 6 knots, however, the T-foil has a lower drag:lift coefficient than the hull. The T-foil rudder can thus reduce the overall drag of the hull if it is used to carry some of the boat's weight. Practically, this means setting the T-foil to produce lift, and moving the crew's weight aft so that some of the weight is taken from the hull and supported on the foil. This action of the T-foil is to make the boat lighter, not longer, as is often suggested.

Although the graph is for a 13ft skiff, it can be applied to a skiff-type hull of any length by using Figure 3. Here, the speed in knots has been divided by the square root of the waterline length to produce the so-called speed:length ratio (SLR). We can see from Figure 3 that the T-foil is of benefit at a SLR of about 1.7. If we had a 36ft-long skiff, a T-foil should be of benefit at and above the same SLR ratio; i.e. above a speed of 1.7 x square root of 36, i.e. above a speed of 10.2 knots, assuming the skiff had a similar displacement:length ratio.

Figure 4 shows a skiff's drag with and without the T-foil. The reduction in drag is very marked above a SLR of 2.

Figure 5 shows the predicted change in upwind

Fig 1 - Speed Vs drag graph

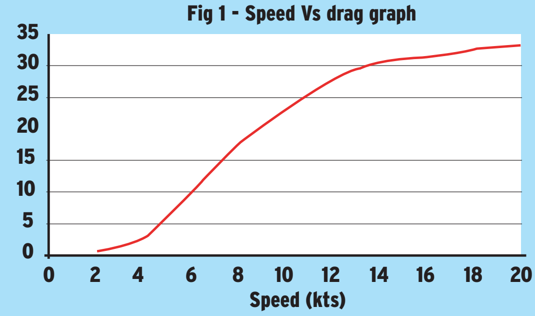


Fig 2 - Drag: lift ratios of a 4m skiff hull and T-foils

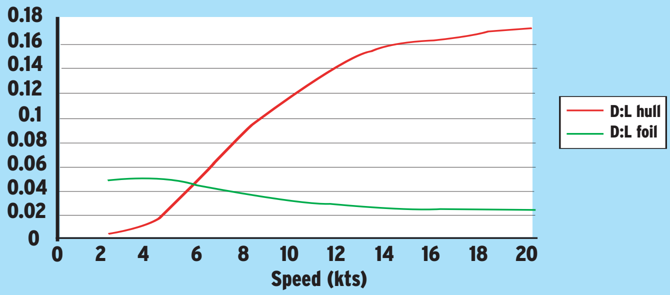


Fig 3 - Drag: lift ratios of a versus speed: length ratio

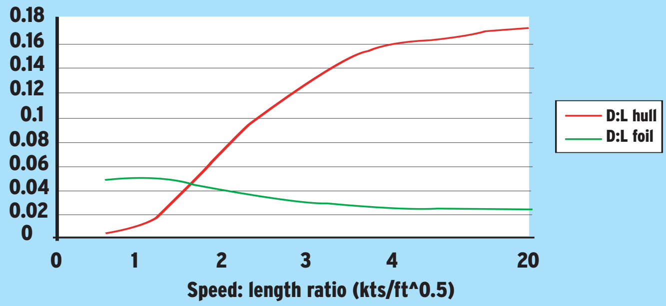


Fig 4 - 4m skiff drags with and without T-foil

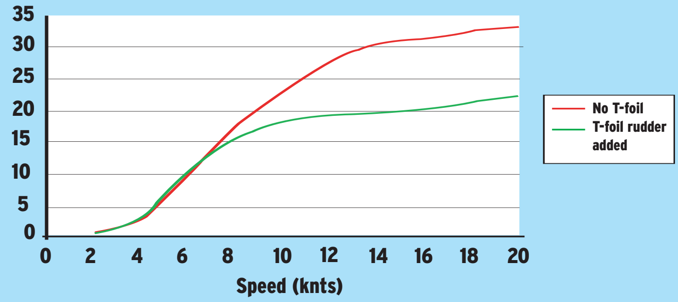
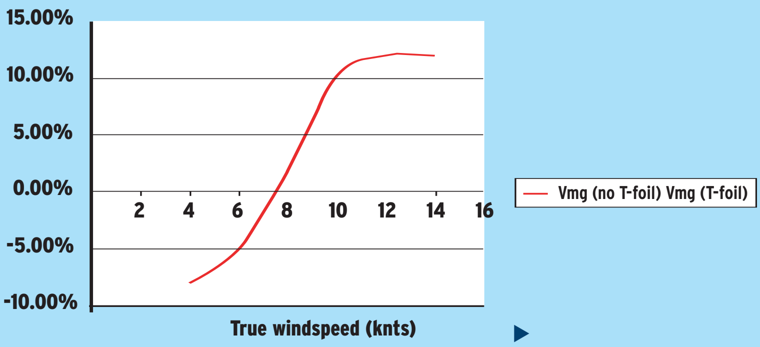


Fig 5: Change in upwind vmg produced by rudder T-foil



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Top **The closer the foils are to the top the more energy is recovered – but they have to stay submerged.**

Above **The International Moth class has used foils to great effect – this is a prototype Bladerunner rudder.**

VMGs (velocity made good) due to the effect of the T-foil on a Cherub Daemon. It can be seen that the T-foil makes the boat about eight per cent slower in winds of only 4 knots, but up to 12 per cent faster in winds above 10 knots in flat water. This is a massive gain in performance and accounts for around 70 PN points.

The predicted changes in performance agreed with speeds recorded using a GPS on both the SK4 skiff and Cherub dinghies sailed with and without T-foils.

2) Energy recovery

The T-foil rudder was originally developed for the International 14 by renowned yacht and dinghy designer Paul Bieker. Bieker's idea was to use the T-foil to recover some of the wave energy produced by the hull as it passes through the water.

The waves produced by a boat have a wavelength which varies proportional to the boat's speed. When the hull travels at a speed of approximately 1.3 x square root of LWL (waterline length) the wavelength is equal to one boat length. This is the so-called 'hull' speed. The action of the waves trap the hull in the trough and cause a steep slope in the resistance curve at a SLR of 1.3 (see Fig 6a).

At SLRs greater than 1.3, the second wave crest is behind the transom of the boat. It gets progressively further behind the boat the faster the boat sails. At a SLR of about 1.7, the crest of the wave is 0.6 boat lengths behind the transom and the boat is in semi-planing mode. At a SLR of 3, the crest is four hull lengths behind the boat. At this speed length ratio, the boat is fully planing.

The water flow near the surface, at SLRs of more than 1.4 and less than 2, has an uphill slope (see figure 6b). A T-foil, placed close to the surface, produces a lift perpendicular to the flow and a drag parallel to the flow. From Fig 6c, we can see that these forces produce a net forward force in the boat's direction of travel. The T-foil is thus converting some of the wave energy into a propulsive force as well as reducing the

Figure 6a

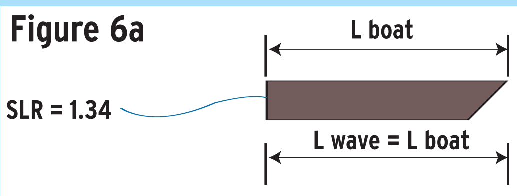


Figure 6b

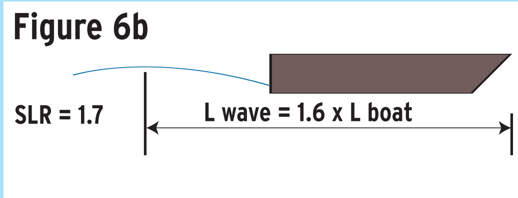
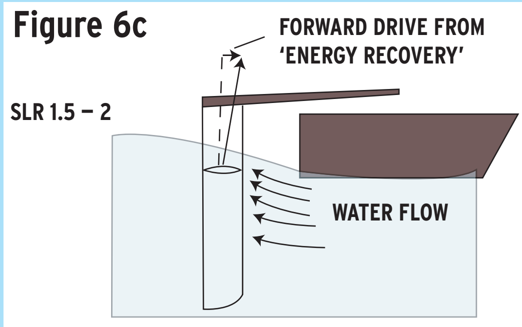


Figure 6c



displacement of the boat.

This mechanism will only work if the foils are close to the surface. What's more, it will work best if the combination of boat speed and distance from the bow correspond to a SLR of between about 1.5-2. On an International 14, the foil is about 15.6ft from the bow. It should have maximum 'recovery' effect at a speed of about 6-8kts, which Bieker says is the typical speed of an I14 upwind.

3) Pitching control

A boat pitches about its centre of floatation. Without a T-foil, this is roughly 55 per cent of the way back from the stem. The action of the T-foil moves this centre aft. The boat tends to pitch almost around the T-foil. The boat, at least in terms of pitching, thus behaves as though it is much longer. This is a big advantage on short boats with tall rigs and improves performance in chop.

What should I put on my boat?

Will a T-foil rudder make my boat go faster?

In order to benefit from the actions of displacement reduction and energy recovery, the boat needs to be sailing at a SLR of around 1.7 or more for appreciable benefit. For a 'typical' boat of around 14ft waterline, this is a speed of more than 6.5 knots.

High performance boats, which are both light and have lots of leverage, will easily exceed this speed upwind. Few sitting out boats (the B14 excepted) will go fast enough upwind to benefit. Many boats will go fast enough downwind to benefit from a T-foil, but the foil will almost certainly be of detriment upwind.

In summary, T-foil rudders, if allowed in the class rules, will mainly benefit high performance dinghies.

Where is the best location on the rudder blade for the T-foil?

For energy recovery, the foils want to be situated as close to the surface as possible. It is important that the tips of the foils stay immersed when you heel. If they break the surface, the rudder will ventilate and there is a fair chance you'll break the foils off.

For displacement reduction at high speeds, then the foils are best at the tip of the rudder. The further they are from the surface, the greater their efficiency (improved lift:drag). They also increase the lift:drag ratio of the rudder blade by forming an end plate. The end plate stops flow beneath the top from the high pressure to low pressure side. The increase in efficiency means you may well be able to shorten the rudder blade length, saving some wetted area.

What are the best foil shapes?

The planform of the foils should ideally be elliptical. A good approximation is to make the foils trapezoidal with a taper ratio of 0.5 – i.e. the chord at the tip is half the chord at the root.

The aspect ratio of the foil (length squared divided by area) should be eight or more to minimise the induced drag. Induced drag is that produced as a direct consequence of producing lift.

The T-foils operate at low Reynolds numbers: this means that the water flow over them is laminar. To minimise profile drag (the drag at zero lift angle) the thickness to chord ratio needs be around 10 per cent or less.

The foil profile should ideally be suited to laminar flow, which predominates at low Reynolds numbers. It can either be symmetric or asymmetric. A suitable asymmetric foil is the Speer H005, as used by Fastacraft for their Moth hydrofoils. A suitable symmetric foil would be a NACA 63 series.

The area of the foil is boat-specific – a bigger area will give more lift, but will cause more drag at low speeds. It may also be difficult to control the boat at high speeds.

How do I use a T-foil?

A hull has an optimum fore and aft trim for any given speed. For skiff-type hulls, this is typically with the bow well immersed at low speeds, the knuckle of the bow at water level at semi-planing speeds (speed: length ratio 2-2.8) and with the bows clear of the water and a bow up trim of 4-5 degrees at planing speeds (SLR greater than 2.8). The precise trim is hull and sea-state specific.

It is important that when the T-foil is used, your weight is shifted aft to compensate for the lift so that the boat is still sailing at optimum fore and aft trim. Essentially, you are shifting your weight off the boat and on to the T-foil.

Common faults when using a T-foil are to use it to attain an excessively bow-down trim, or to try to stand too far back with insufficient lift from the T-foil so the boat sails transom-down. A further common mistake is to try to use the T-foil in light winds to lift the transom instead of just moving your weight forward.

It's useful to consider some basic physics: for a given angle of attack of the foil to the water, the lift is proportional to the boat speed squared. So if your speed increases from 8 knots to 12 knots, the lift from the foil will more than double. You will need to move aft quickly to compensate for this extra lift.

The lift from the foil is also approximately proportional to the angle of attack in degrees of the foil. So, again imagine your boat accelerating from 8 to 12 knots. At 8 knots, the boat is in semi-planing mode with the bow just kissing the water. Let's say the boat is at zero trim angle and the foil is at 4 degrees. At 12 knots, the boat is now planing and will require a more bow up trim angle of say 2-plus degrees. The angle of attack of the foil thus increases from 4 to 6 degrees due to the boat's change in trim. This alone causes an increase of foil lift of 50 per cent. The increase of boat speed from 8-12 knots causes the lift to double. So the action of an increase in speed and increase in boat trim causes a corresponding increase in foil lift of 300 per cent! So it is important not to use too much foil angle downwind when large changes of speed are likely.

One final consideration is that the lift from the foil will begin to approach its maximum value at an angle of attack of 7 degrees. At greater angles, the lift will not increase (it may even fall) and the drag will increase dramatically. This is because the foils will begin to stall – another reason for not using excessive foil angles when large changes of boatspeed are likely.

Final points

At speed:length ratios of less than 1.7 (about 6 knots for a 13ft hull) the T-foil is less efficient at supporting your weight than the buoyancy of the hull at these speeds. So the T-foil should be operated at near zero lift. For a symmetric foil, this is at zero degrees to the water flow. For an asymmetric foil this will be at about 3-minus degrees. Do not use the foil in lieu of moving your weight forward to lift the transom.

At speed:length ratios of 1.7-2.8 (i.e. semi-planing upwind for 14s and Cherubs) the T-foil should be used somewhere near maximum lift (about seven degrees from the zero lift position). The crew weight should be moved aft so that the boat's correct fore and aft trim is maintained.

At speed:length ratios of more than 2.8 (fully planing) the T-foil angle generally needs to be reduced from the semi-planing position to account for both the increased speed and the more bow-up trim of the boat. Crew weight should be moved well aft (but not quite as far back as possible) to maintain the correct boat trim. The resistance curves of flat-rockered hulls gets very flat at these speeds, so big jumps in speed are likely to occur when a gust hits. It is important, therefore, that you still have scope to rock your weight farther aft in the gusts to prevent the T-foil overly lifting the stern and slowing, or pitch-poling the boat through too much nose-down trim. ■

PHOTO GARY BLAKE

Left The International 14 class has been successfully using T-foil rudders for several years – here at the 2003 Europeans.

Further reference:

CA Marchaj 'The Aero-hydrodynamics of sailing'
Tom Speer at www.tspeer.com