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Why do yacht designers fit T-bulbs to the keels of modern racer-cruisers?

Perhaps some of your readers can enlighten me. The answer to the title question that might reasonably be expected is: “because T-bulbs are faster”, but that is perhaps too simplistic….

The question arose when I started investigating entanglement of yachts with craypots. This has become a serious problem on the west coast (and elsewhere), so we are exploring different strategies to manage the risk. I have been keeping a log of entanglement incidents, with over 30 recorded to date. Whilst most of those incidents are snags of pot lines on the rudder or prop, about a third seem to be snagged on the keel bulb when yachts are under sail. There is a performance trade off between any hydrodynamic or stability advantage of the T-bulb, and the time lost disentangling. In order to find out where that trade-off lies, we need to know three things:

1. The likelihood/frequency of entanglement.
2. The time taken to disentangle.
3. The performance advantage of the T-bulb compared with a less “catchy” L-bulb.

Likelihood of entanglement

This is clearly highly variable, but for many races it is close to one entanglement every 24 hours. Here are some informative extracts from reports of yachts entangled whilst racing

Race 1

“On the <overnight> feeder race. Calm weather, 10 knots, night (of course) we caught 4 pots and one cray pot line with 3 floats that was just floating around. The 4 pots stopped us and we lost around 1.5 hrs clearing all of them thru the night we reckon. The loose line dropped our speed and then we had to physically pull the line in to free us. We reckon caught on keel (T keel!!). Action to remove- manoeuvre until free, sail backwards etc. no cutting of anything. No damage sustained.

Race 2

Same on recent <overnight> race, same conditions early am, dark etc but only caught one. There was a line of pots set for some miles in a north south line off the coast which we caught one on the way up. On the way down we were in day light so could avoid them”

Race 3

“<overnight> Race. Most yachts also reported becoming entangled in craypot lines during the race, the long floating lines creating a constant hazard at night.”

So it would appear that the likelihood of entanglement on an overnight race is nearly 100%! Let's say that only a third of them are around the keel, then we could estimate there is a 30% likelihood of entanglement around the keel on an overnight race. It could be 10%, it could be 50%, but it's somewhere in that ballpark.

Time taken to disentangle

Estimating the time taken to disentangle has an even wider range of uncertainty than estimating the likelihood of entanglement. The first of the above reports quote 1.5 hours which is a severe case but the minimum time lost in stopping the boat, backing it up and (hopefully) freeing the pot must be at least a couple of minutes, probably a lot more. So let's say the average time lost is 5 minutes per entanglement. It is somewhere between 2 minute and 90 minutes.

Performance gain of a T-bulb

This is where the naval architects start to get excited! My first thought was to go to the regular fall-backs of Hoerner (1965) and Hoerner (1975), expecting to find something useful about aircraft wing tip tanks or similar. Nothing! That's the first time they have failed me. An initial cursory internet search didn't reveal anything useful either. The next step was obvious – phone a friend. Whenever there is an intriguing design problem I turn to model yachts to see what they do. They use T-bulbs and have problems catching weed in some ponds. Luckily a friend of mine is a professional model yacht designer who has been looking into fins and bulbs, but with a very different approach to what I expected.

Fin twist

His research revealed that the flexure of the fin affected performance – especially twist induced by the longitudinal position of the bulb. An L-bulb has its centre of gravity well behind the twist axis of the fin, so will induce twist. A T-bulb on the other hand has its centre of gravity close to the twist axis of the fin, so the amount of twist, if any, will be small.

The twist changes the angle of attack of the fin along the span, which in turn alters the lift distribution and vertical centre of pressure. The optimum spanwise lift distribution is usually (but not always) elliptical, but the notion that this is generated by an elliptical profile (Spitfire wing), has long ago been proven incorrect when the waves on the free surface are taken into account. Also, a bulb will increase the lift at the fin tip, which can move the distribution away from optimum, but it also has a pseudo-endplate effect, which alters the optimum distribution from elliptical towards uniform. Hmmm…

Twist (positive) will produce more lift near the tip which will create a higher heeling moment. It will reduce the leeway angle of the hull, and here is the design dilemma – most hulls are very inefficient sideforce generators, so reducing hull leeway angle should increase overall lift-drag ratio. However, whilst that might be true for a fat or deep hull, it is rather less so for a slender hull. So the benefit or drawback of twist depends on the hull slenderness.

Let us assume though, that twist is detrimental to performance. Given the difficulties in quantifying its effect, I have taken a different approach. Let us suppose we wish to reduce the twist angle on a keel by, say, half. What is the increase in fin thickness required to achieve this, and what is the resulting drag increase and speed loss? To halve the twist we must double the polar inertia, which varies roughly as the cube of section thickness. So a 26% increase in section thickness will halve the twist. From Marchaj (1979), achieving this by increasing the section thickness from a NACA 0012 to NACA 0015 will increase the section drag coefficient by 11% at Reynolds numbers typical for yacht keels. What contribution does this make to total drag? Using convenient published data for the YD-40 in Larsson and Eliasson (1994) the section drag contributes about 11% of total drag at 6kn boat speed and 6% at 8kn. Let's call that an average of 8% around the course. So the increase in drag due to increase in keel thickness is 11% of 8%, which is a 0.9% increase in total drag. Next, let us make a wildly hand-waving approximation that drag varies with the cube of speed, then we have a 0.3% drop in speed due to the increase in keel thickness required to halve the twist angle. For a 24 hour race this corresponds to a time loss of just over 4 minutes.

Fluid flow
Now let's get back to bulb longitudinal placement itself. A nicely packaged piece of research from Chalmers University (Axfors and Tunander, 2011) examined the hydrodynamic differences of several keels, all with the same draft and righting moment. The results were then put into a VPP and they got some interesting answers. A well-designed T-bulb (a craypot catcher) is faster than a well-designed L- bulb (a craypot dodger), but not by much. (Interestingly, the study found a conventional non-bulb fin was even faster that the T-bulb, though they qualify that statement with reasoning that is not very convincing in my view.) Taking the average of the VPP results for true wind speeds of 8, 12, 16 and 20 knots, over a range of wind angles representative of an Olympic style race course, the T-bulb averages 2 and a half minutes faster than the L-bulb over 24 hours of racing (it's nearly 6 minutes faster in 8kn of wind and just 30 seconds faster in 20kn).

Overall speed effect.

Taken over a 24 hour race, if we add the 2.5 minute speed loss due to L-bulb position and the 4 minute speed loss due to increased keel thickness, we have a total speed loss of about 6.5 minutes for the L-bulb compared with the T-bulb. Our earlier estimate of likely time lost due to a keel entanglement in an overnight race was around 5 minutes, with a 30% chance of it occurring. In other words, the T-bulb is only faster if you are sailing somewhere where the likelihood of entanglement is low (and the typical wind speeds are low).

So there we have it – the benefit of the T-bulb on a race course along a lobster-friendly coastline is marginal at best, and they are a big nuisance when cruising; designers please take note!

My next task is to investigate ways to reduce the likelihood of craypot entanglement with the prop and rudder. Some cruisers fit a wire from the keel trailing edge to the bottom of the rudder(or skeg if they have one). It is easy to calculate the drag increase (from data on towed umbilical cables e.g. Erdsal, 2004), but do those wires actually reduced the likelihood of entanglement? Any feedback?

References

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