The yacht that turned to port

Kim Klaka PhD MRINA

Have you ever wondered how accurate the section of a keel or rudder has to be? I have, so I did some background reading to find out. It all started a couple of years ago when my 10m sailing yacht showed a tendency to turn to port and had an appalling tacking angle of nearly 100 degrees. That's the subject of a long and slightly different story, suffice to say I had narrowed it down to a hydrodynamic cause. So I set to making templates for the fin keel and spade rudder to rectify the problem. Before doing this I had to satisfy myself that I could fair the keel to the required accuracy, which begs the question: what is the required accuracy? I am not talking about surface roughness (that is well understood and widely known), but larger scale undulations – waviness, lumps and hollows.

As is so often the case with foils, the best experimental work is usually to be found in the archives during the period 1930-1960. This instantly leads to three reference points – Abbott and von Doenhoff (originally 1949), Hoerner (originally 1958) and the suite of NACA technical bulletins from that era. Sure enough, they did not disappoint.

Abbott and von Doenhoff comment mostly on surface roughness and transition, but in part 7c of their 1959 edition they do provide the following delightfully simple and practical advice about waviness:

"*For the types of waves usually found on practical-construction wings, the test of rocking a straightedge over the surface in a chordwise direction is a fairly satisfactory criterion. The straightedge test should rock smoothly without jarring or clicking*".

Similar advice is often given by good shipwrights. To find out what happens to performance if you don't achieve this level of smoothness, I had to refer to NACA technical notes.

Powell (1954) tested helicopter rotor blades with and without fairing filler. The maximum variation in thickness was 0.13%, which resulted in 6% more power required to rotate the blades. However, the test conditions were rather different from the flow round a yacht keel.

Ward (1931) compared foils that were not exactly wavy, but they differed slightly in local thickness. For example, he tested a NACA 0021 section against a subtle variant, the NACA 100. The greatest thickness difference between the two sections at any point along the chord was 0.35% chord i.e. for a typical keel of chord 650mm, this is a section thickness variation of 2.3mm. The wind tunnel tests showed, with all the usual caveats about two-dimensionality, Reynolds number and pressure gradients, that this modest difference caused a 9.4% drop in maximum lift and 2.3% drop in max lift/drag ratio. So we now have a rule of thumb:

Every 1mm of waviness decreases lift-drag by 1%.

Is it correct? I didn't have a wind tunnel handy so I reverted to very coarse full scale measurements. I measured the profiles of my keel and rudder, and found out two things:

- Firstly, the maximum thickness port and starboard differed on average by about 5mm over a chord length of 1400mm i.e. 0.35% of chord.

- Secondly, the thickness deviations from a NACA 630-series section were about 2mm i.e. 0.07% chord.

After two weeks of sanding and fairing, I had reduced the asymmetry and unfairness to about 1mm worst-case (0.007%). The boat now tracks in a straight line and tacking angles are back below 90 degrees, saving me about 5 minutes in a 2-hour race. So I conclude that waviness of more than 1mm makes a significant difference in performance.

References

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