Aerodynamics of the mast/sail combination

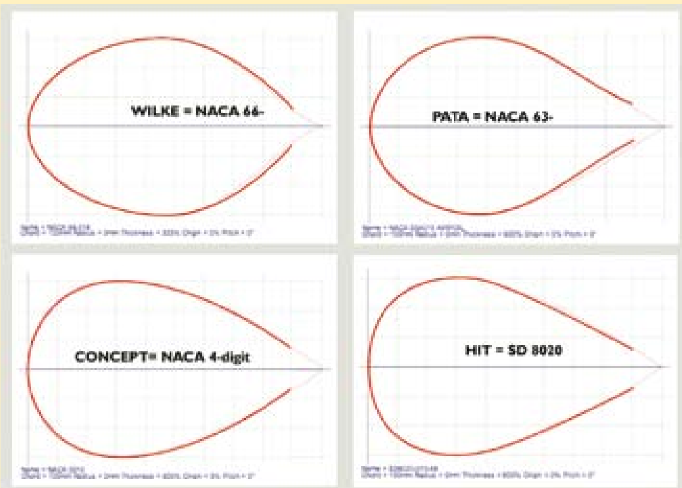
The aerodynamic shape of the Finn mast has been an intriguing subject since the rule change after the 1992 Olympic Games in Barcelona, allowing for carbon fibre and a wing shaped mast.

WB-Sails has a long tradition in shaping masts, too: During the years, we have designed mast profiles for the Europe, Finn, 470 and Star classes. Our first Finn mast was in 1995 for Freddy Lööf, who won the Savannah Pre-Olympics with it. After Savannah Luca Devoti's Latini wing mast was to take over the market.

We had a chance to revisit the Finn mast recently within a development project assigned by the French Sailing Federation (FFV). Besides FFV, the project also benefitted from the support of Paul Iatchkine, head of R&D at the ENVSN (Ecole Nationale de Voile et des Sports Nautiques), Illy Brummer Design and Transmer Assurances (financial support). To begin with, the most popular existing masts were Laser-scanned at ENVSN in Quiberon, with a hand held apparatus about the size of a football. 'Painting' with the laser you can see the 3D-model of the mast forming on the computer screen. Scanning a complete mast takes about an hour. At the end of the day, it was perhaps surprising to see how different the Wilke, HIT, Pata and Concept mast are in shape. In the past, this kind of analysis has been performed on a 2-dimensional section of the sail and mast. This investigation was performed on a 3D-model of the mast with the complete sail behind it. For meaningful results, a 3D-analysis is necessary, with the plenty bent and aft raked mast of the Finn mast/sail interaction

The mast-sail combination is all about interaction, not only when it come to the mechanical properties or bending of the mast, but also when it comes to the aerodynamic interaction between the two. For understanding the aerodynamics, it is perhaps best to think of the mast as part of the sail area. In fact, the mast is very efficient sail area: In light winds, up to 8 per cent of the driving force (the force in the direction of the motion of the boat) comes from the mast.

Scanning the mast with a laser scanner. Inset: A 3D-model of the mast being formed on the computer screen in real time. Photo: Paul Iatchkine, ENVSN.

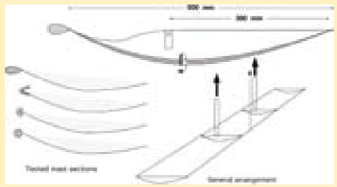


A cut from mast scans about 1 metre above the boom. The profiles are surprisingly different from each other, but on the other hand, each one of them corresponds closely to well known aerofoils. Clearly, the designers have done their homework. All but Pata are maximum length to the rule, and close to minimum thickness.

In medium and heavy air, the contribution of the mast decreases, as the sail is feathered more and more, and especially the top part starts to slow down rather than drive the boat forward. Nevertheless, even in medium-heavy airs, 5-6 per cent of the effective drive comes from the mast. The lateral area of the mast is about 0.5 sq metres, and the sail is 10.8 sq metres, so the mast represents about 4.5 per cent of the total area. Considering its efficiency, no wonder its shape should be of interest.

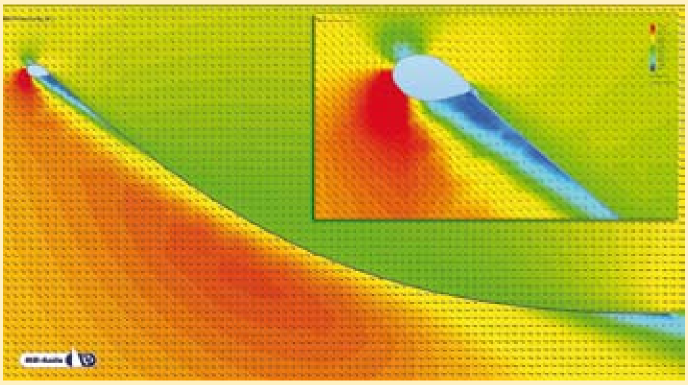
CFD analysis of the mast-sail combination

However, there's a downside to the efficiency of the mast: It disturbs the flow over the sail, especially on the leeward side. The airflow

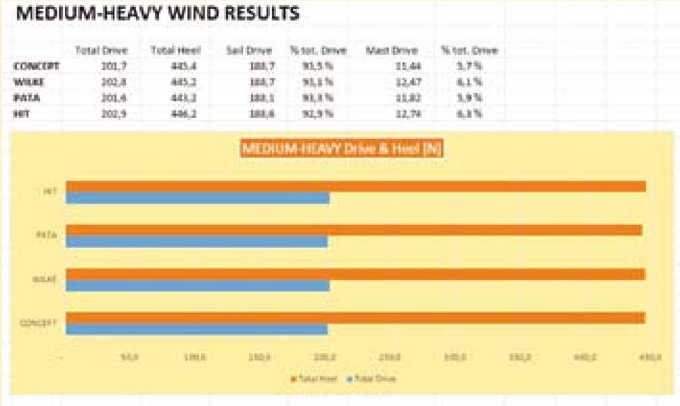


Above: Wind tunnel testing Finn mast profiles in mid-1990s. The wing mast profile was the best, while the recessed C-profile (second from top) was the worst.

Left: Wind tunnel testing Finn mast profiles in mid-1990s.



A cut plot of the Pata mast 0.5 metre above the boom in heavier winds. The blue area represents the separated flow behind the mast. The area would be larger in light winds.



MEDIUM-HEAVY WIND RESULTS

	Total Drive	Total Heel	Sail Drive	% tot. Drive	Mast Drive	% tot. Drive
CONCEPT	201,7	445,4	188,7	93,5 %	11,44	5,7 %
WILKE	202,8	445,2	188,7	93,1 %	12,47	6,1 %
PATA	201,6	443,2	188,1	93,3 %	11,82	5,9 %
HIT	202,9	446,2	188,6	92,9 %	12,74	6,3 %

Results from medium-heavy wind runs, showing the drive and heel as well as the separate values for the mast and sail. The differences in the total drive are small enough and disappear in the analysis uncertainties. In different winds, the ranking between individual masts may vary, but the pattern where a good mast disturbs the sail and vice versa remains.

separates from the mast about where the wind is tangential to the mast surface (or a little earlier), to re-attach on the sail surface 20-40 cm later. A lot of beneficial suction on the front part of the sail is lost - especially beneficial for driving the boat forward, when we remember that pressure always acts perpendicular to the surface and the luff of the sail is thus best oriented to drive the boat.

The area with separated flow is often called a separation bubble, even if in case of a mast and highly 3-dimensional flow, calling it a separation vortex would be more appropriate. In fact, on the leeward side behind the mast, the air is slowly ascending in a spiral motion up from the tack towards the head of the sail.

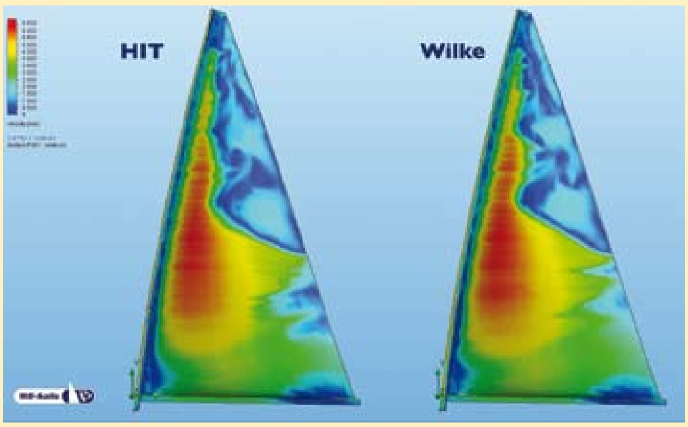
From the CFD (Computational Fluid Dynamics) analysis of the four mast profiles, we found out that there are indeed differences in drive efficiency. The masts were analysed in combination with the sail, and as a full 3D-model including the boom but neglecting the boat and the sailor - their effect could be assumed similar on all of them. The HIT mast would be a winner, with about 9 per cent more drive in light airs than the Concept or Pata.

In medium and heavy airs, the difference persists, while Wilke starts to get close to HIT. But these numbers are only for the mast. When you add the driving forces (and heeling forces) of mast and the sail together, the differences between all the masts more or less vanish. There are minor differences in ranking when it comes to light, medium or heavy air, but in general, you can say that all the masts, attached to the same sail, perform similar. So, by what you gain by shaping the mast, you tend to lose in a larger disturbance over the sail, reducing the effort to nil. One could say that what did you expect, we know from practice that with any of these masts you could win the Finn Gold Cup. This amply explains why we never found an advantage in all the work we have done on 470 or Star mast profiles either. The mechanical properties of the mast – bending characteristics – are much more important than the profile shape. The HIT-mast, being thicker in front, causes a larger separation area on the front part of the sail than Wilke or Pata that have a finer entry.

As a footnote, the drive of the boom is nil - taken separately; it does not contribute to the forward motion of the boat at all. This may seem surprising, as it is still nicely angled between the wind and the direction of the motion of the boat. The boom is not useless, however, even from the aerodynamic point of view only. It powers the foot of the sail, which would be less efficient without the boom underneath.

As a second footnote, maybe equally surprising, when sailing upwind the Finn hull has very little air drag. The hull drag is close to nil and always only a half or less of the air drag of the sailor hiking out. A reason is that close to the water surface and between the waves, the wind is much weaker. Note that in this discussion, with drag we refer a force opposing the direction of the motion of the boat, not a force in the direction of (the apparent) wind, as sometimes is referred.

Text and graphics by Mikko Brummer/WB-Sails.
For more information go to www.wb-sails.fi



Plot of the surface velocities on HIT and Wilke in light wind. The differences are subtle but enough to compensate what the HIT gains in the mast forces in Wilke's favour when it comes to sail pressure. The blue-green area behind the mast corresponds to the separation vortex. The flow over the cambered and rather low aspect sail is highly 3-dimensional, so it is necessary to analyse the whole mast-sail combination, not just some horizontal cuts of it, like the habit has been in the past.