Don't Get the Hump

The name van Oossanen is a highly respected one in naval architectural circles. The firm's founder, Piet, devised the appendage that changed the face and location of the America's Cup forever and brought the Auld Mug to Australia when his winged keel on the 12-metre yacht Australia II *won in Newport In 1983. Here his son, Perry, explains the firm's proposal for a new type of hull form for semi-displacement yachts: one that allows the rather uneconomic semi-displacement yacht to green up a bit for the current climate and to help conserve the future one.*

HULL FORM DESIGN FOR THE DISPLACEMENT TO SEMI-DISPLACEMENT SPEED RANGE

Recent developments

Van Oossanen & Associates (VOA) have been involved in the design of superyachts for more than 15 years, either as primary naval architect, or as a design consultant, with a particular focus on the hydrodynamic and performance aspects of the design. In recent years, we find there are two important trends in the design briefs we find on our desks. First of all we find the yachts increase in length and, second, we often find that for one and the same length, the speed requirements are set ever higher. These trends have implications for the design of the hull form of such yachts and, especially, of semi-displacement ones. First, let us look at the differences between displacement and semi-displacement yachts from a naval architect's point of view.

Hull types

The first difference to make between the two is obvious: speed. Basically, there are three speed regimes: displacement speeds which are at the lower end; the planing speeds at the higher end; and, in between, the so-called semi-displacement or semi-planing speed regime. Put in numbers, displacement speeds are up to a Froude number of 0.5 and fully planing speeds are above a Froude number of 1.0 (see our article on Froude on page 94). The in-between speed range is that of semi-displacement hulls.

The next major difference comes as a result of this difference in speed: the hull form. A typical displacement yacht will have a round bilge hull, often with a bulbous bow, and

Image: istock.com

upwards-sloping buttocks behind the maximum section. Hulls for planing speeds are typically of the hard-chine type, featuring one or more pronounced spray rails over the entire length of the hull. Since in these cases the transom is usually deeply submerged they will often have tunnels in the aft ship to give some extra space to the propeller. From a hydrodynamic point of view, displacement hulls are totally carried by the volume of water they displace, while planing hulls are carried – for a large part – by hydrodynamic lift, which a hard chine hull produces at high speeds. Historically speaking, the semi-displacement hull form is derived from the planing hull and is very similar, although often slightly less extreme in its features.

A third important difference is in the weight of the yacht: displacement yachts will usually be built in steel, often the super structure is built in a lighter material such as aluminium or composites, and semi-displacement or planing yachts will often be built in aluminium or composites, in order to save weight and so reduce the required engine power to achieve the high speeds they are designed for.

Longer and Faster?

As stated in the introduction, there is a clear trend in the design briefs for larger yachts. The fastest growing market segment is the market for yachts between 40 and 50 metres, and the number of over 50-metre yachts is increasing too. This length increase is also seen in semi-displacement yachts. Where a semi-displacement yacht would have been typically 30 to 40 metres 10 to 15 years ago, nowadays we see them quite often at around 50 metres or higher.

What is striking in the semi-displacement segment is that although the length of the yachts increases, the speed requirements often do not. Some 15 years ago, a 30–40-metre semi-displacement yacht would have had a speed requirement of something in between 25 and 30 knots; nowadays, a 55- or 60-metre semi-displacement one will still have the same speed requirements of between 25 and 30 knots. This actually means that the speed relative to the hull length, the Froude number, has decreased.

In fact, a 30–40-metre semi-displacement yacht with a maximum speed of, say, 28 knots (or a Froude number between 0.8 and 0.9), comes quite close to her fully planing counter parts. A 50- or 60-metre yacht doing the same speed (a Froude number between 0.6 and 0.7) comes a lot closer to a displacement yacht than a planing yacht. This, of course, should have implications to the design of the hull form.

THE SEMI-DISPLACEMENT HULL FORM

One striking disadvantage of semi-displacement yachts of the hard chine type is the inability of a pronounced hard chine yacht to run efficiently or comfortably at

TANK TESTS

The Wolfson Unit has conducted towing tank tests on a large number of round bilge/semi-displacement motoryacht forms and hard chine forms since 1968. A database has been compiled containing the resistance and powering data for the majority of the tested motoryacht hull forms which calculates a comparative performance coefficient for each resistance data point which relates the speed, length, displacement and effective power. This then allows direct comparison with the other tested hull forms at discrete Froude numbers. For example, if hull efficiency at the cruising speed is the main design driver then the designer should be looking for a hull form that is placed high up in the rankings at that particular Froude number. The rankings are expressed as a percentage at each Volumetric Froude number increment, 0% being the least efficient and 100% being the most efficient.

When compared with other round bilge hull forms at speeds in excess of 15 knots (cruising speed) and up to 44 knots (almost planing speed) the tested motoryacht's ranking is typically around 100–140% indicating that the design is currently ranked as the most efficient in the Wolfson Unit's database. When compared with hard chine forms the ranking increases to around 100–200%.

Dickon Buckland, Wolfson Unit MTIA

Speed in knots	Length on the waterline in metres: 30	35	40	45	50	55	60	
10	0.30	0.28	0.26	0.24	0.23	0.22	0.21	*Displacement*
15	0.45	0.42	0.39	0.37	0.35	0.33	0.32	*Speeds*
20	0.60	0.56	0.52	0.49	0.46	0.44	0.42	
25	0.75	0.69	0.65	0.61	0.58	0.55	0.53	*Semi-Displacement*
30	0.90	0.83	0.78	0.73	0.70	0.66	0.64	*Speeds*
35	1.05	0.97	0.91	0.86	0.81	0.78	0.74	
40	1.20	1.11	1.04	0.98	0.93	0.89	0.85	*Planing*
45	1.35	1.25	1.17	1.10	1.05	1.00	0.95	*Speeds*

The speed-relative-to-length is expressed by naval architects as the Froude number, which is calculated by $F_n = V\ 9.81 \cdot L_{WL}$. In this formula, V is the speed of the yacht in metres per second and L_{WL} is the length of the hull on the waterline in metres. The table above gives Froude numbers for a range of lengths and speeds, for quick reference.

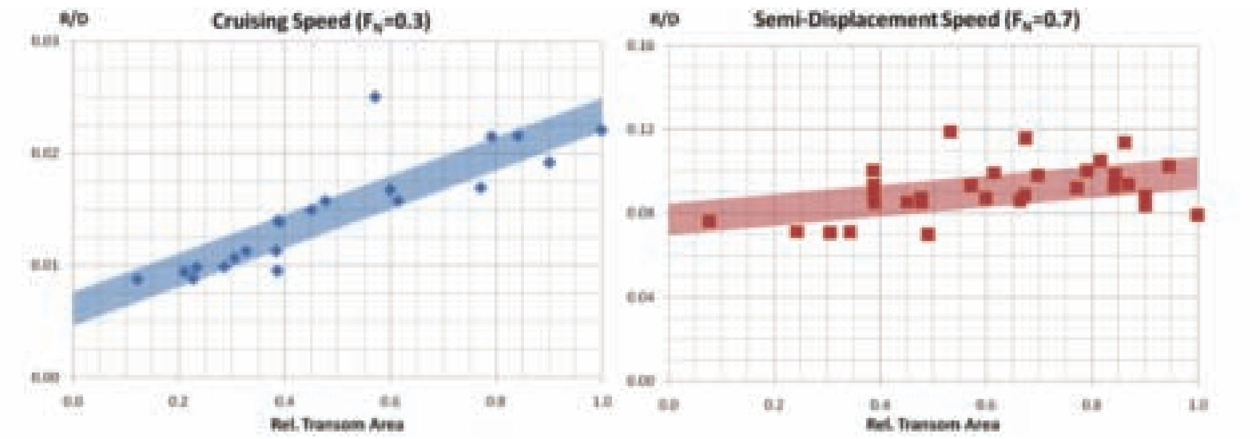


Figure 1. Dependency of resistance on the immersed transom area at FN_L = 0.35 and 0.60. The vertical scale displays the hydrodynamic resistance-per-ton of displacement and the horizontal axis shows the relative area of the transom below the water.

speeds other than close to her design speed. The hard chine hull will, when speeding up, first drag along a large dead-water area behind the transom, causing a lot of resistance. Then above a certain speed, when the transom runs dry, the yacht will create an enormous transverse wave behind her and the trim angle will increase significantly. The bow will come down only once the aft part of the hull starts to generate some hydrodynamic lift; which is only at high speeds. Only then will a hard chine hull start to run efficiently.

This behaviour has its downside not only on comfort and usability, but also on the economic efficiency of the yacht and her carbon footprint. Long passages and cruises are never made at semi-displacement speeds, but rather on a moderate cruising speed of 12 to 15 knots.

The less-favourable aspect of hard chine semi-displacement yachts comes to the fore when interpreting the results from towing tank tests. In Figure 1 (above), the results of a number of tank tests carried out for superyacht projects are shown. In this figure, the blue chart shows the resistance (per ton of displacement) at a typical cruising speed and the red chart shows the resistance (per ton of displacement) at a semi-displacement speed. The influence of transom area on resistance can be clearly seen: at cruising speed there is almost a factor of 3 in the difference in resistance between a hull with no transom immersion (say, a sailing yacht) and a hull with full transom immersion (say, a planing yacht). At the shown semi-displacement speed, the influence of transom area is less apparent, but a favourable trend towards a small transom area still exists.

THE FAST DISPLACEMENT HULL FORM

Triggered by the desire to develop hull forms which are efficient over the entire speed range and not only at a chosen design speed, as well as by the current trends in the market, we developed a new, hybrid, hull form concept, called the 'Fast Displacement Hull Form(patent pending)' or FDHF. The concept is based on a number of standard features which are not entirely new to ship or yacht design; but here, combined in a special, well-balanced, state-of-the-art design a surprisingly efficient hull form is obtained. The development of this hull is rooted in numerous experiments and calculations and evolved over many different designs and over the course of a number of years.

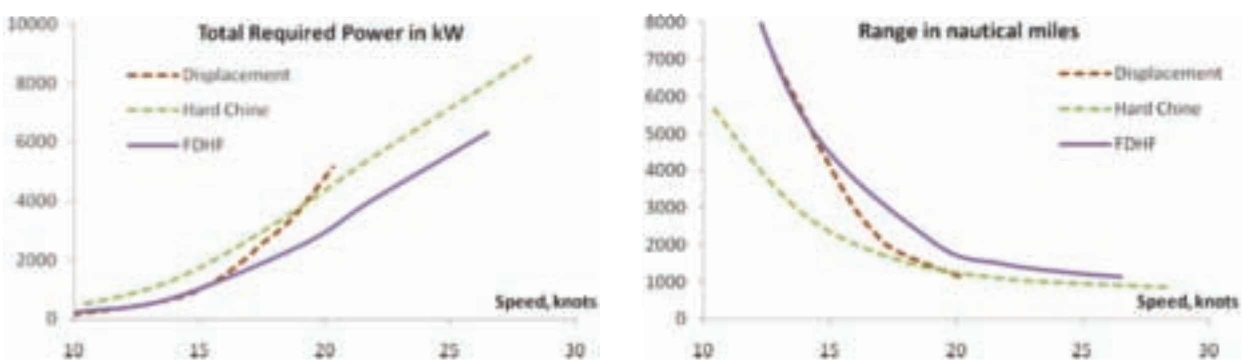
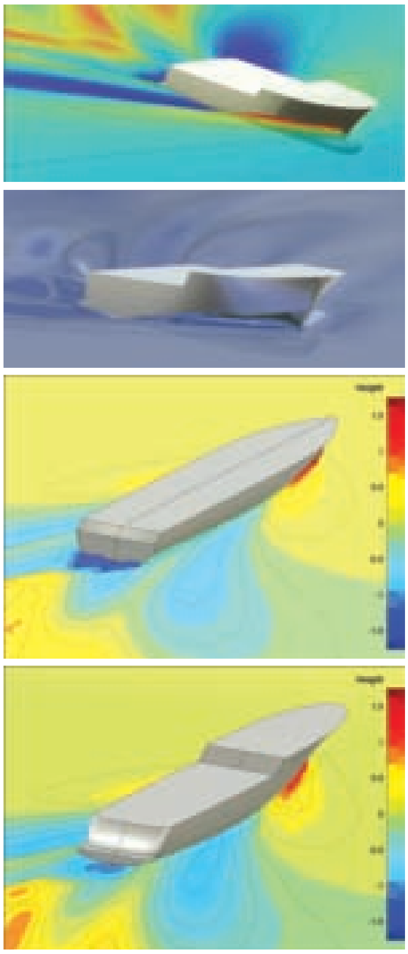


Figure 2. Power and range curves for the comparison

The development started with the first application of a round bilge hull form for semi-displacement yachts, experimenting with various bulbous bows at higher speeds, and testing the impact of different hull characteristics using Computational Fluid Dynamics (CFD) and towing tank facilities. A number of yachts with features of this concept, designed by VOA, have already been built, resulting in good performance and a pleasantly behaving vessel over the entire speed range, such as the Cyrus 33-metre yachts (below).

The main benefit of this hull form is the performance. At cruising speed, the performance of the FDHF equals a very well-designed displacement hull form. Due to a small immersed transom area, a well-designed section shape and optimised dynamic trim control, the transverse wave system is kept to a minimum, and the transom runs dry at very low speeds.
The improvement, however, is not only at lower speeds, but also in the semi-displacement speed range; a major improvement in resistance is found. The resistance values displayed by the FDHF are 15–20% better than those of well-designed hard chine hull forms, over a major part of the semi-displacement speed range. Comparison of model test results for the FDHF with those of numerous hard chine models show that only at a Froude number of 0.95 (which is nearly at 'fully' planing speed) a single hard chine hull is more efficient than the FDHF (see the statement from the Wolfson Unit, on page 107).

As the FDHF is purely a displacement-type of hull form that does not rely on hydrodynamic lift for efficiency the trim angle is almost indifferent to the speed. This is one



Top image: 3D view of the computed wave elevations around the FDHF at semi-displacement speeds. The colours indicate the wave height, red being the highest value and blue the lowest.

Second from top: Rendered view of the computed wave elevations around the FDHF at semi-displacement speeds.

Lower two images: Computed wave elevations around a Hard Chine form (top) and the FDHF (bottom) at semi-displacement speeds. The colours shown indicate the wave height, red being the highest value and blue the lowest. It can be clearly seen that the wave patterns especially differ aft of the transom, where the hard chine hull creates a very deep and steep wave trough, while the transom wave aft of the FDHF is much less pronounced.

Fansea *and* **Cyrus One***; both are yachts of a series of 33-metre round bilge semi-displacement yachts, built by Cyrus Yachts in Turkey. The yachts show excellent performance and high comfort levels. (The FDHF is also featured on a new Heesen 65m design see rendering [top image]; a short spec of that will be released in April and the design hard launched during MYS 2010 – Ed.)*

of the reasons that makes it possible to run efficiently at low, high as well as at intermediate speeds.

The round bilge hull form of the FDHF also has an advantage in the behaviour of the hull in waves. In scientific literature, it is commonly accepted that round bilge hulls are superior at displacement speeds when it comes to comfort, and that at semi-displacement speeds, there is no major difference between the different hull forms. At those speeds, dynamic effects have a much larger influence on the seakeeping behaviour than the actual section shape of the hull.

RESISTANCE ANALYSIS

As an example, let us compare the design of a 50-metre yacht according to the FDHF concept with a displacement of 375 tonnes, to be built in aluminium. A round bilge displacement hull and a hard-chine semi-displacement hull, which have been tested in the tank, are chosen as a reference. Figure 2 (on page 108) shows power and range curves for the designs, determined using tank tests and CFD calculations, carried out by VOA (using ISIS-CFD). For determining the range, 60 tonnes of fuel has been assumed.

At cruising speed, it can be seen that the FDHF performs equally to the displacement hull form (both have a range of just over 4,000nm), and both are significantly better than the hard chine hull form, which has a 40% smaller range. When approaching the hull speed, just under 20 knots, the required power for the displacement hull form increases rapidly, while the required power for the FDHF increases much more slowly. To obtain a maximum speed of 25 knots, the FDHF would require about 5.500kW, while the hard chine hull needs more than 7.100kW. This is a difference of more than 20%.

REFERENCES

Perry van Oossanen, Justus Heimann, et al. (2009). 'Hull Form Design for the Displacement to Semi-Displacement Speed Range'. Royal Institution of Naval Architects, Proceedings of FAST 2009, Athens, Greece.

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