

PRINCIPLES OF NAVAL ARCHITECTURE

When it comes to selecting a boat, many prospective buyers have a difficult time understanding the parameters of yacht design and are oftentimes confused by the complex jargon of naval architecture. The differences in the various hull shapes dictate that, for the same engine power, vessels will obtain different performance. So, for a better understanding, and in preparation of what to expect during the buying process, we have outlined some of the basic formulas used to estimate a yacht's performance.



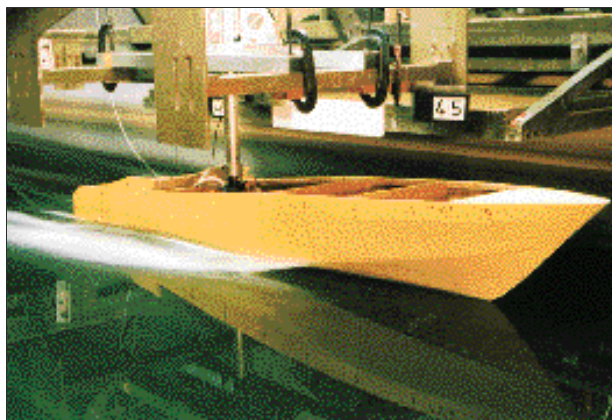
The procedure is rather simple: all you will need is a good calculator and a little concentration. But hopefully this exercise will help clarify some of the most disconcerting principles of design and in turn, help in the buying process by assessing the displayed performances of some of the hull types. A boat yard is the best place to observe and study the various hull shapes. The mindful observer will immediately notice the difference between hard chine and round bilge hulls, variations in the geometry of the sections, longitudinal distribution of volumes, and shape and depth of sections and transoms. All of these elements influence the total resistance and thus the speed and fuel consumption of a yacht.

Technical File...

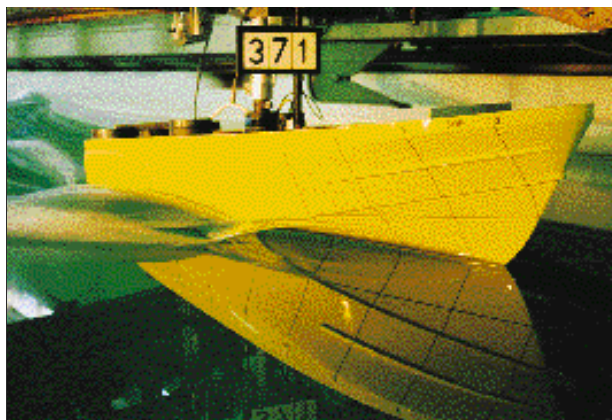
Motor yacht hulls are classified into three categories: displacement, semi-planing (sometimes called semi-displacement), and planing hulls. The differences between displacement and planing hulls are fairly easy to identify. The semi-planing hull particulars are not as widely understood, however, and there are a lot of misconceptions about their hull geometry and performance. A semi-planing hull is not just a displacement yacht with more powerful engines: it takes more than just installing larger engines to gain a few knots. The operating speeds and handling of a yacht not only vary according to its weight, waterline, length, and beam, but also depend on its hull geometry and longitudinal distribution of its underwater volume.

Naval architects define the characteristics of a yacht with several basic dimensions and coefficients which are used to classify hulls. The first of these coefficients, known as Taylor quotient (Tq) or speed-length ratio (SLR), is derived from a formula by the well known British Naval Architect William Froude. This quotient is the ratio of the speed in knots, divided by the square root of the waterline length in feet. Daniel Savitsky, a hydrodynamics specialist, internationally known for his work on planing hulls, divides the various operational speeds into categories based on this ratio. The hulls with a quotient below 1.34 are classified as displacement hulls. The semi-planing hulls have a coefficient between 1.34 and 3. For typical planing hulls, the coefficient has values above 3. For instance, the 70 ft Ghibli has a Taylor quotient of 3.74, calculated as follows: 28 (speed in knots) divided by 7.48 (the square root of its 56 foot waterline length).

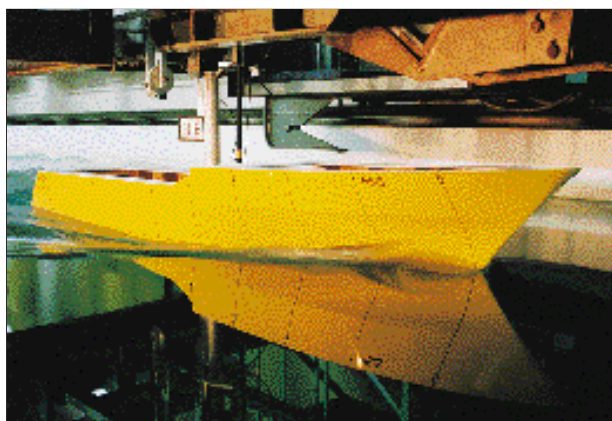
It is obvious that the weight or the displacement of a yacht has a tremendous influence on the performance. Since only the weight, and not the displacement in cubic feet, is normally published by the builders, a simple formula can be used to convert the weight into a volume. The displacement of a boat in cubic feet is simply the weight in tons multiplied by the density of sea-water, (35 lbs/ft³). Since Ghibli has a published weight of 49 tons, its displacement is 1715 ft³. This important parameter is used in several other formulas and ratios. It is even more important to relate the displacement of a vessel to its waterline length. To do so, naval architects and designers are using a so called "slenderness" or length/displacement ratio to classify boats. It is the ratio of the waterline length in feet over the cubic root of the displacement in ft³. There are limiting values to this ratio, for instance, it would be unrealistic to try to classify a boat with a slenderness ratio over 5 in the category of



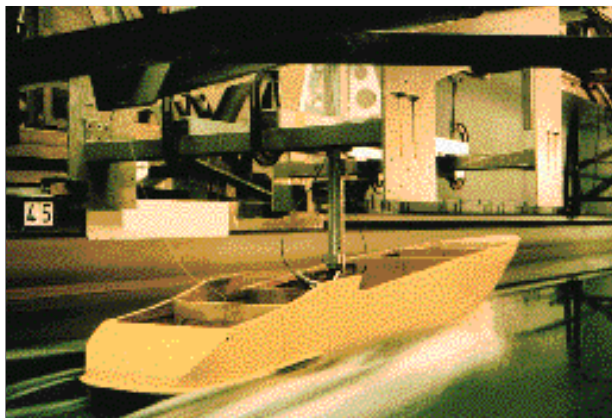
The planing hull generates a flat bow wave.



The semi planing hull leaves a deep wake.



The forefoot of a displacement hull does not come out of the water.

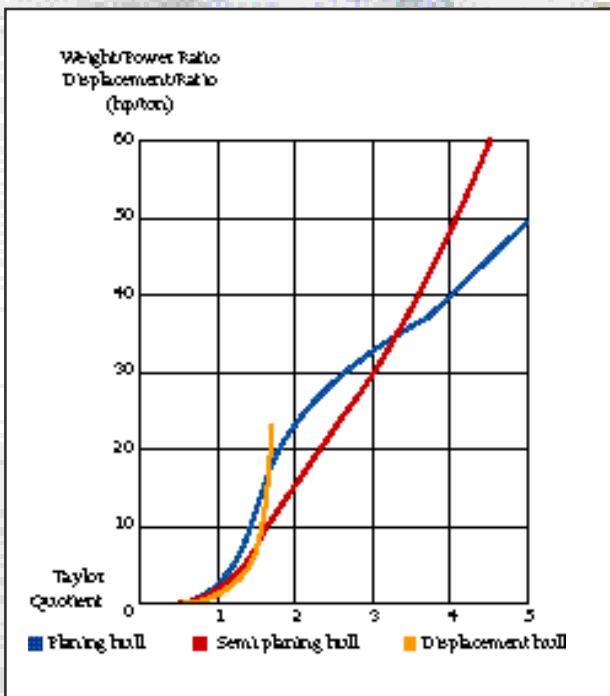


Testing of a planing hull in a towing tank.

the planing or semi-planing hulls and this, even by doubling the engine horsepower. Again looking at our sample boat, the 70' Ghibli, the slenderness ratio calculation is as follows: 56 (waterline length in feet)/11.97 (cubic root of 1715 ft³). Therefore, the slenderness ratio is 4.71, which is typical for semi planing hull.

Another formula proposed by George Crouch and known as Crouch's formula, is widely used for estimating the speed of a planing hull. This formula integrates a constant "C" which generally ranges from 1.3 to 1.5 depending on the shape and the propulsion system used. The formula is : $V(\text{velocity}) = C \times 4 L \times P/D$. C is the constant which depends upon the hull form and the propulsion, L is the waterline length in feet, P is the power in hp and D the weight in tons. For Ghibli, the constant 1.4 is arbitrarily selected, which gives: $1.4 \times 4 \times 56 \times 2740/49 = 28.64$ knots, this value is slightly above the measured speed on the GPS during the sea trial. It simply shows that a reduction needs to be applied on the engine horsepower published by engine or boat manufacturers.

The more vertical the curve the more the hull hits a water wall.



Most data sheets do not take into account the various losses generated by gearboxes, shaft bearings and other hydraulic pumps. A reduction of about 10% of the rated power is not unusual. In this case, we obtain a predicted speed of about 27 knots which is a close match.



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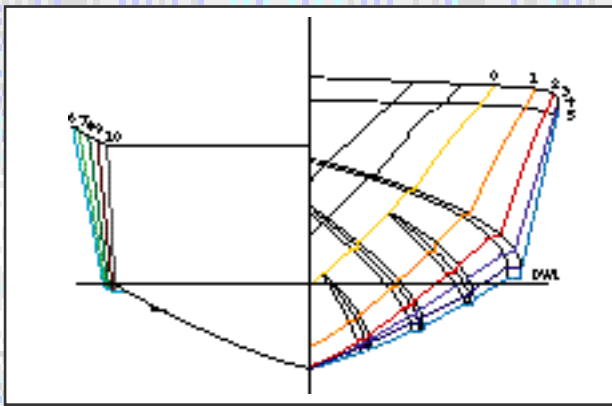
Another fundamental coefficient of naval architecture is the prismatic coefficient (C_p). It indicates how the displacement is distributed along the length of the vessel. If the value is high, the displacement will be distributed towards the ends, and more particularly the aft sections. The optimum prismatic coefficient increases with the Taylor quotient. Its determination is thus a function of the type of hull. For a displacement hull, the optimum coefficient is about 0.55 to

0.571; for a semi-planing hull, it varies between 0.60 and 0.70; and for planing hulls, it is often above 0.80. The formula is as follows: the displacement in cubic feet divided by the product of the waterline length in feet by the midship section in ft^3 . Once again, for Ghibli the prismatic coefficient is: 1715 (displacement in ft^3) / 56 (waterline length in ft) $\times 49.5$ (midship section area in ft^2) = 0.60 which is quite representative of this type of hull.

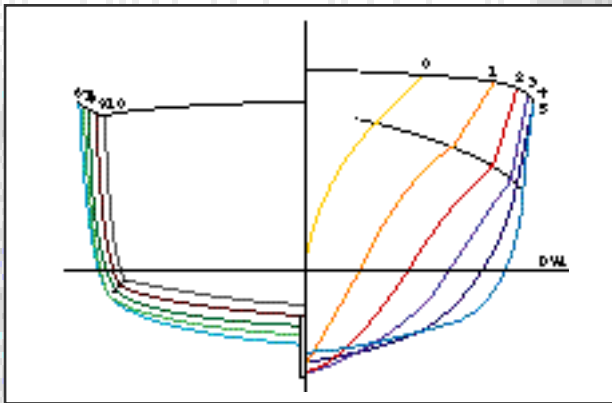
The displacement hulls do not generate hydrodynamic lift since they normally have round aft sections and canoe sterns. A planing hull typically has rather flat and wide aft sections with an immersed transom. These characteristics allow it to plane and thus reduce the total resistance to reach high speeds thanks to its hydrodynamic lift. On the contrary, a displacement hull does not plane and has to fight against the fluid through which it moves. In the case of displacement hulls, the hard bilge sections are inefficient even if some builders use them as they are easier and more economical to build. The slenderness of a displacement hull has a fundamental importance on the performance. This slenderness is simply measured by the waterline length/beam ratio (L/B). As an example, the performances of a displacement hull with a waterline length of 100 ft and a weight of 150 tons increase by about 12% when the L/B ratio increases from 3.33 to 5. In this case, the waterline beam is reduced from 30 ft to 20 ft with all the consequences on its livability and transverse stability. It demonstrates once more that naval architecture is the science and art of compromise.

The semi-planing hulls generally have a rather low L/B ratio and fine entries associated with aft sections that generate more lift, enabling these type of hulls to reduce the total resistance and installed horsepower for an operating speed that corresponds to a Taylor quotient of 1.4 to 3. The study of the total resistance, or more simply the weight/power ratio, curves as a function of the Taylor quotient, clearly demonstrating the differences between the three types of hulls. So a displacement hull will hit a wall when it reaches its hump speed. In simple terms, both other types of hulls reduce the water resistance thanks to their hydrodynamic lift, which allows them to plane. Where displacement hulls have evolved slowly over the centuries, planing hulls have undergone important developments during the last 50 years with various applications for military and offshore racing boats. In 1960, the designer Raymond Hunt revolutionized the geometry of the planing hull with the introduction of the so called deep V. It had been known for a long time that a planing hull, to be effi-

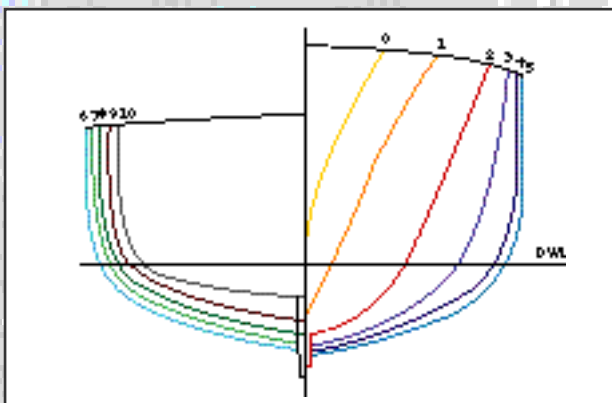
Planing hull.



Semi planing hull.



Displacement hull.



...naval architecture



The forefoot is totally submerged and the bow wave is quite aft: these are the highly visible characteristics of a planing hull.

cient, must have prismatic sections, that is to say a constant V from the middle of the hull to the transom. This type of hull, used by many naval architects and builders, associates remarkable sea-keeping characteristics with excellent performance. Several designers such as Don Shead, Jim Wine and Renato Levi have contributed to the improvement in performances of these hulls and in creating boats whose Taylor quotient is above 8, with speed of 50 knots for a waterline length of 40 ft. The optimum deadrise angle of the V increases with the speed. Renato Levi, for example, recommends the use of 18° angle for a Taylor quotient of 3.5 and a 25° angle for a Taylor quotient of 8.

The semi-planing hulls combine comfort, seaworthiness and stability of the displacement hulls with the good performances and better efficiency of the planing hulls at intermediate speeds. The modern design tools, such as testing tanks and numerical flow codes give the architects the tools to design and optimize high performance semi-planing hulls. Howev-

In rough seas, a planing hull must maintain very high or very low speeds.

er, these boats are extremely sensitive to weight. So a tremendous evolution has taken place due to the introduction of new light weight materials and modern construction techniques. British and Scandinavian naval architects have worked considerably on these types of boats to tackle the problem of speed in rough seas. The efficiency of these hulls can still be improved by the addition of wedges fitted on the bottom, forward of transom, to increase lift.

The semi-planing hulls have numerous advantages when they are designed by architects who clearly understand the basic principles and limitations imposed by this type of hull. Today, this type of design is found chiefly on yachts over 60 ft as it is associated with performance and livability. Although these semi-planing hulls seem to have reached their maximum potential, the future now lies in finding new solutions to maximize efficiency in performance and comfort.

By Eric A. Ogden

Photos : Michel Karsenti & Renaud Jourdon

