Going Half Fast!

Semi-Displacement Boats: An Alluring Compromise

by Charles Neville

IN RECENT YEARS HEAVY-DISPLACEMENT TRAWLERS HAVE become icons of free-spirit invoking images of foreign ports and exotic adventures. For many, however, the 8-knot lifestyle is something they cannot (or do not want to) reconcile with other aspects of their lives, such as houses, businesses, kids, grandkids, etc.

By the same token, for many (especially ex-sailboaters) the need for speed isn't in their genes. For them, the thought of a high-speed boat doesn't suit. This quandary has made the middle range of semi-displacement boats more and more popular, especially with boaters not really interested in crossing oceans.

Semi-displacement boats are half-breeds: vessels that can move faster than their displacement brethren but cannot quite match the performance of speedy planing boats of equal length. The allure for owners is obvious. In return for sacrificing some of the economy and offshore sea characteristics of displacement boats, semi-displacement versions seem to reward owners with that extra bit of speed to get home or to a safe port more quickly.

Many consider this a valuable tradeoff. The combination of features has value, and the marketplace, never one to miss an opportunity, has responded by offering these potential buyers an ever-expanding array of new semi-displacement cruisers.

Do semi-displacement boats really offer the best of both worlds, or the worst? Some insist that these craft provide little of the performance of planing hulls with less economy of displacement ones. The truth probably lies somewhere in between. The fact remains that semi-displacement cruisers will continue to be an attractive option for many boaters. A better understanding may help to demystify the breed.

It is easy to get confused when discussing these boats because even those in the trade can't agree what to call them. Terms used

The Grand Banks 46 is a quintessential semi-displacement cruising boat. The traditional GB line can run fast or at displacement speeds, depending on power, and its popularity proves the long-held benefit of the semi-displacement trawler type.

include "fast displacement," "semi-displacement," "semi-planing," or the old favorite of technical journals, "pre-planing." All of these are largely interchangeable. I'll stick to "semi-displacement."

Speed Is Key

Semi-displacement is less a boat type than a speed range. All boats can be positioned on a straight line that represents an endless range of speeds from the slowest to the fastest. The position each boat occupies generally is a function of its hull shape and power. Because the whole range is seamless, comprehending the proper place of semi-displacement boats requires a good understanding of how they fit in the continuum between displacement and planing boats.

U.S. NAVY PHOTO BY PHOTOGRAPHER'S MATE 2ND CLASS SHANE T. MCCOY

USS Winston S. Churchill (DDG 81) making a high-speed run in the English Channel. The Arleigh Burke-class destroyer with the Aegis weapon system is 510 feet long and carries 380 crew. This ship operates well beyond traditional speed-length ratios.

This concept may be more easily understood if we temporarily set aside the concept of hull speed for heavy cruisers. The notion of a speed-length ratio suggests that displacement-speedboats cannot be powered beyond 1.34 times the square root of a boat's LWL (load waterline length.) It is the speed at which the hull makes a wave as long as its waterline.

But this notion is not completely true. Destroyers, for example, routinely are powered to speed-length ratios of 1.6 to 1.8, though at speed their motion in a seaway reportedly can be daunting. Other efficient displacement hulls also can be pushed beyond the supposed limit.

You can even ignore the efficiencies of form in the following extreme example. At least in theory, the bulkiest of tugboats could be propelled to reach planing speeds (stability and practicality aside). It largely is a function of the power installed. Clearly, we don't do so with tugs because of the absurd amount of power required, the lack of available space to put that power, significant control and stability issues and, most important, the obvious insanity of doing so.

Strictly speaking, then, a hull speed of 1.34 is not an impenetrable barrier. Like the sound barrier, it is one founded to a great extent on economics and practicality. Designers have come to understand a need to adapt hulls in various ways to minimize, or take advantage of, the way a boat and the water must interact as speed increases.

What's Happening?

At the lowest of speeds all of a boat's weight is supported by buoyancy of the water. The power needed to move a boat forward generally is that required to overcome friction. Most of the friction to be overcome is caused by the

COURTESY OF ISLAND PACKET YACHTS

Newer to the scene, cruisers such as this 360 Express from Island Packet, show that planing hulls also can make fine cruising boats, trading long-range tankage and extra accommodations and storage for efficient speed. Such a boat proves that all types have their place in the cruising-under-power community.

disturbance of the water rather than between a boat and the water. A boat rather successfully pulls a thin layer of water along with it. That initial layer, however, tries with decreasing success, to bring additional layers of water along for the ride, resulting in friction.

As the speed slowly rises, other things begin to happen. With more speed, the whole boat is pulled or sucked down almost unnoticeably into the hole in the water it has created. The primary cause of this is water entering at the bow, racing under the curved hull and returning up to its original position near the water's surface.

Like an upside-down airplane wing, this action produces an area of reduced pressure under the hull, causing it to be pulled down ever so slightly. A low-pressure area created by the propeller that also increases downward suction near the stern exacerbates this downward pull.

To move forward, the boat has to push the water out of the way. As a result, a small pattern of waves is formed along the length of the boat. Their length becomes longer and the number (along the hull) fewer as speed increases. The length of these waves between any two crests is directly proportional to the speed the boat is traveling: the relationship to speed-length ratio. Another series of waves also is generated by the vessel's stern.

With an increase in speed, the boat is pulled down more and more while at the same time waves generated along the length of the hull become longer and longer. At some indeterminate speed the bow-generated wave will synchronize with the stern-generated wave in a way that the bow wave will be at its highest point while the stern wave is at its lowest. The bow wave will neutralize the stern wave and the vessel will be operating at its highest efficiency. A typical displacement hull will meet this condition when traveling at a speed-length ratio of approximately 1.0.

As speed continues to increase, waves generated become an increasing problem with more and more of the boat's propulsion power siphoned off, producing ever-larger waves. The hull is sucked down still farther. This combination of events causes the boat to experience trim changes as the bow rises and the stern gradually falls or squats. If the hull form is of a purely displacement type, the boat appears challenged with an unlikely task of trying to drag itself up over its own ever-larger bow wave. Generally, this point is assumed to occur at the speed-length ratio of about 1.34, the so-called hull speed.

Other Limits

Beyond this, many elements conspire to limit ever-increasing speeds. Trying to overcome these with brute force makes the condition even worse. The stern wave is left behind leaving the vessel's aft end largely unsupported. As a result, the stern squats dramatically as the bow rises uncomfortably.

Allowed to continue unabated, the power required would become outrageous. The boat's safety and stability also could be jeopardized because of the greatly exaggerated trim and violent wave pattern created. Something needs to change. More power and less weight might make the boat go somewhat faster. But what really is called for is a re-evaluation of the hull shape. The boat needs to be optimized to go over the next speed hurdle and move into the semi-displacement range.

To accomplish this, the combination of friction and ever-increasing wave-making resistance must be overcome while still allowing water to flow efficiently around the hull. The most effective method of doing so is to rearrange the underwater hull shape in a way that reverses (and gradually eliminates) that downward pull we have been talking about. That downward pull is lift (as in an airplane wing). Up to now it has been pulling in a negative direction.

Lift, however, has two major components. The first involves shape (the camber of an airplane wing).

The second is angle of attack, or the angle that the fixed shape makes with the oncoming flow of air or, in the case of a boat, water. If we can get this so-called dynamic lift to work in our favor, the boat gradually will begin to pull back up vertically with less friction, leaving less boat in the water to create waves.

Working Favorably

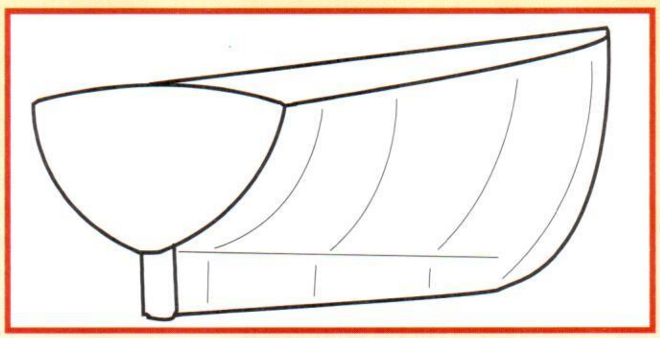
How do we make the angle of attack work favorably? The bow comes up as the angle of attack increases. To make that change in trim generate vertical lift, the stern also must be shaped to resist being pulled down in the water and to assist in inducing lift. In simple terms, the stern must be broader. At the same time, however, the stern should not be too deep.

We still, after all, want the water to close back in around the boat as it moves forward. Making this happen most likely will require the center of gravity to be located farther aft than might be expected for a boat operating at purely slower speeds. Keeping the boat lighter also becomes increasingly important.

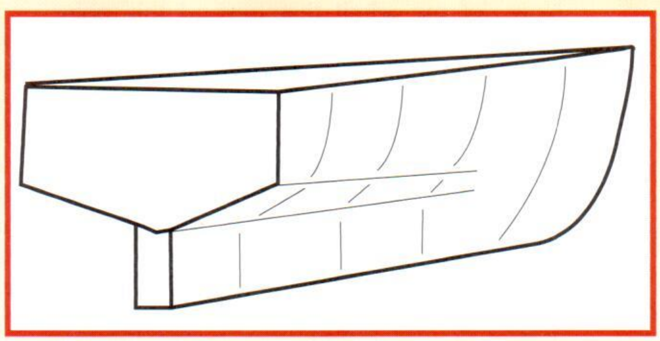
If the shape is successful, here is what happens. Instead of continuing to be sucked down farther, the boat will begin to rise as the lift generated overcomes effects of the

The differences in underwater form are evident from this hull shape illustration.

This full-bodied form carries the most weight, in terms of long distance stores and fuel, and is the best for offshore, trans-ocean passagemaking.



This hull shows the flatter chines and reduced volume typical of semi-displacement vessels. For many, this is the form of choice, offering a good mix of performance.



Planing hulls have the least underwater shape, and use forward motion to get up on top of the water, with flat underwater sections and often with a deep-V entry.

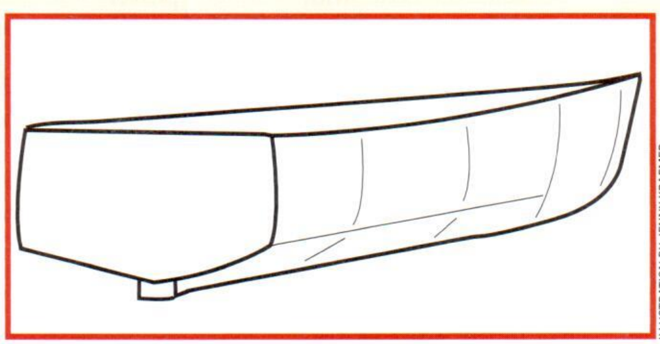


ILLUSTRATION BY JENNY KRAEMER

The full-displacement Nordhavn 40. Pushing a displacement hull beyond hull speed becomes an exercise in horsepower management. It takes enormous power to drive such a hull shape beyond a 1.34 S/L displacement range.

downward tendencies previously in play. Properly done, the stern rises faster than the bow and the extreme trim angle begins to reduce. The stern wave gradually is left behind.

Speed increases, lift increases, and slowly the boat pulls itself back to the same vertical position it occupied at low-speed conditions. In this situation, hydrostatic forces and dynamic lift share support of the boat equally. The approximate speed-length ratio where this condition occurs is around 2.0.

Now, let me admit that beyond this point, where the boat begins to rise above its original static-trim position, some books will refer to the boat as planing or at least, "pre-planing." More accurately, the boat is in a partial planing state. At the risk of criticism, and to avoid clouding the message, I'm going to continue to call this a semi-displacement regime because hydrostatic forces remain in play.

Continuing To Rise

A suitable boat with enough power will continue to rise beyond this point of equilibrium. Downward forces diminish as lift continues to dominate. If a boat has sufficient lifting or planing surface, it will continue to rise out of the water until it is supported entirely by the dynamic forces of lift skimming over the water's surface. The point of this transition is at speed-length ratios of approximately 2.5 to 3.0. The transom would be running dry leaving little stern wave and the chines would be running clear of the water below.

Both friction and the hull-induced waves would be minimized because so little of the boat is in the water. The boat is operating in a full planing condition. This point often is called "hump speed," referring to the pronounced hump shown in a classic speed vs. horsepower performance graph. For a brief period the boat is capable of increasing its speed with little additional power. As it comes "on plane," it is not uncommon for a slight power reduction to be possible and still keep the boat on top.

For the true planing hull, additional speed still is an option. The transom is likely deeper and the run of the chines and bottom surface is close to level with the water surface as it runs aft. Deep-V sections also often are used to improve performance in a seaway. Speeds above this are limited only by the amount of available power, and the stability and control requirements necessary to keep the boat from becoming an uncontrollable projectile.

So, you say, that's a nice snapshot of a day in the life of a boat, but how does it help to identify the semi-displacement boat you might be considering? Unfortunately, it's not easy. The difficulty is compounded by at least two other simple details.

First, there are technical definitions of a semi-displacement boat, and second, are the overall characteristics of just about any planing boat.

Broadly speaking, you can define a boat operating in the semi-displacement speed range as one that is partly supported by both hydrostatic and dynamic forces (that is, lift). Unfortunately, in the real world, identifying one that is doing so is virtually impossible when looking at or even riding on it.

The second accepted definition of a semi-displacement hull is related to the rise and fall of the boat as speed increases (waves not withstanding). This definition is more a benchmark relating to how a boat reacts to its interaction with the water around it. It is most easily understood by picturing a simple graph noting the position of the center of gravity (CG) of the boat as it travels through the range of speeds. The CG is simply the combined center of all of the vertical and horizontal weights aboard. Think of it as the balance point of an unequally loaded teeter-totter.

From speed zero, the CG is sucked down by hydrodynamic forces, discussed above, to a point that approximates a speed-length ratio of 1.34. (Figure 1.) At that point, lift joins the equation. The CG and the vessel begin to rise until hydrodynamic and lift forces are approximately equal, at a speed-length ratio of about 2.0. At this point, lift overpowers hydrodynamic forces and the boat rises out of the water as speed and power increase. This process continues until at a speed-length ratio of around 2.5 to 3.0. Here the boat lifts out of the water with virtually all of the support for the

Figure 1

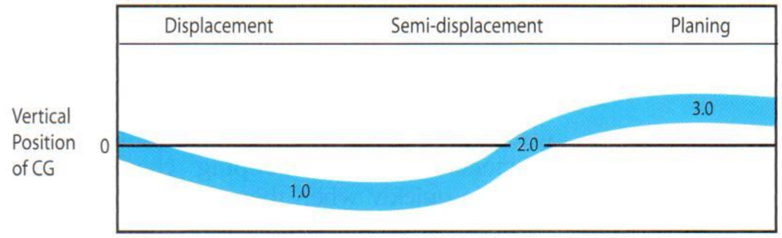
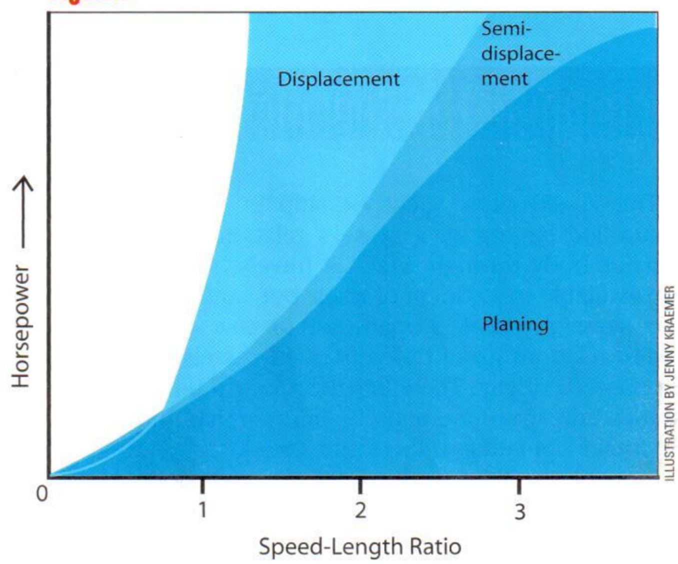


Figure 2



Some trawler yachts, such as this Mainship, are squarely in that murky middle range of hull shape, where it is the amount of horsepower that determines the performance of the boat.

vessel provided by dynamic forces. Unfortunately, this definition also is virtually impossible to perceive or easily predict.

Planing boats can operate at all of the speeds discussed. Clearly, however, their performance, efficiencies and sea-keeping characteristics degrade quickly when they operate below full planing speeds. Often their sea-keeping characteristics also are extremely uncomfortable at high speeds. Still, this ability to operate at all speeds allows planing hulls to masquerade as boats with slower speed potentials.

The Ugly Truth

Although many types of boats can operate at a range of speeds, the differing efficiencies of displacement, semi-displacement and planing hulls can be seen easily in a graph of horsepower required as a function of speed-length ratios for the three typically designed hull types (Figure 2). At lowest speeds, the performance of all the candidates is similar. But this changes rapidly. Up to a speed-length ratio of 1.0, the displacement boat clearly is the

Untangling The Specifics: Speed-Length Ratio

The speed of a yacht or ship is governed and controlled largely by a vessel's relationship with the viscous body through which it travels: water. Vessels are available in a variety of sizes, but water always has the same physical properties. For that reason, the speed relationship of different-sized vessels cannot be compared directly. The efficiencies of a 300-foot vessel at a certain speed are entirely different than those of a 30-footer operating at the same speed.

Consider a 300-foot freighter cruising along at 20 knots in the scenic channel in Lake St. Claire, north of Detroit. Looking closely at the scene, ignoring some minimal froth, the bow wave generated would appear negligible. The stern wave also would show little fuss even at close range.

Now imagine our 30-foot cruiser running right alongside at the same speed. The smaller boat would be churning up a mess of water as it struggled to keep up with the metal giant. The bow would be high and the wake would be substantial. One of these vessels appears to be out for an afternoon stroll, while the other seems to be running for all it's worth.

Since the late 1800s, methods have been developed to help us understand and evaluate differences between various-sized boats. These generally are related to the interaction between the waves created and a boat's waterline length. This relationship, again, stems from the predictable way waves are generated along any boat or ship of a given length.

The most common format for quantifying this relationship among yachts is called the speed-length ratio (s-l ratio). It is popular for a number of reasons, not the least being the fact that it's easy to understand and easy to determine with any calculator equipped with a square-root key.

The equation for this method is: s-l ratio = $V \div \sqrt{LWL}$, where V = speed in knots and LWL = load waterline length.

Armed with the variables of boat speed and length, you can calculate the speed-length ratio yourself. By comparing that speed-length ratio with generally accepted numbers you get a pretty good idea of the speed category in which a given boat is operating.

Here is a list of the speed-length ratios for various hull types:

Full displacement: 0 to 1.34.

Semi-displacement: 1.35 to approximately 2.4 to 2.9.

Full planing: Approximately 2.5 or 3.0 and above.

(Numbers are inexact because of variations in performance of different hulls.)

By rearranging the above equation, you also can easily figure speed at any given speed-length ratio: V (speed in knots) = (s-l ratio) x $\sqrt{LWL}$.

Some other notes that might help:

Chine Or No Chine: Semi-displacement boats can function well with either rounded hull or hard chines. Boats with rounded bilge sections, like lobster-boat hulls, often reach into the planing region if kept light enough. Yacht versions, however, likely are heavier and are more apt to top out at semi-displacement speeds. They may not be carrying fish, but they are carrying much larger deckhouses and extra equipment.

The rounded-hull shape can offer a softer ride in heavy seas than one with hard chines. On the other hand, the hard-chine boat likely will be more maneuverable and faster, pound for pound. Remember, though, hard chines deliver a stiffer ride.

Bow Shape Forward: To allow a boat to break through oncoming waves, a sharper V-shaped bow is more efficient. Above-the-water flared sections and other elements such as spray chines will help a boat shed water. Without this help, water coming aboard can make these boats wet at higher speeds.

Waterplane Shape Aft: The shape of the boat aft (say within the last third of its length) becomes critically important when shooting for semi-displacement speeds. Imagine looking down at the outline of the hole in the champion for efficiency, with planing hulls bringing up the rear.

At slightly above a speed-length ratio of approximately 1.2, everything changes again. The displacement-boat curve begins to reach for the sky leaving semi-displacement boats to show the best efficiency. At some point above 2.0, however, planing boats begin to come into their own. Beyond speed-length ratios of 2.5 to 3.0, only true planing shapes and raw power control the limit.

So here's the ugly truth. There are three primary ways of achieving semi-displacement

water created by the boat. This is called the shape of the waterplane.

The waterplane for a semi-displacement boat would be more wedge-shaped, but tucked in a bit at the stern. The transom width (at the water surface) might be about 85 percent of the overall waterline beam. The same aft shape for a displacement hull would be closer to that of a watermelon, or the same fruit shape with just a bit of the aft end cut off. For a planing cruiser, the midship beam would be the same, running straight all the way to the transom.

Weighty Issues: Weight is not the entire answer, but it is a big factor in the equation. Semi-displacement boats must be kept light to reach higher speeds efficiently. This is especially important if a round-bilged hull form is chosen. Weight is the most common reason that many boats with a clear planing shape get relegated to semi-displacement speeds or below.

Our benchmark to compare weight between boats of differing sizes is the displacement-length ratio (d-l ratio). The formula is:

$$\frac{\text{Displacement} \div 2240}{(\text{LWL} \div 100)^3}$$

Displacement-speed trawlers generally have d-l ratios of 300 and above. Semi-displacement speedboats are between 225 and 300. Planing boats need to be the lightest with displacement-length ratios typically between 225 and 220.

Sea Keeping And Boat Strength: Boats can be powered to hit a desired speed, but if the shape is inappropriate for sea conditions, the boat would be impractical in service day to day. Flat-bottomed boats may be exceptional performers in dead-calm conditions, but crew comfort in choppy seas may force the boat to travel well below its potential, if regularly used in rough service.

These same rough conditions also can put serious slamming loads on the hull and structure. Loads also rise rapidly as speed increases because hydrodynamic loading is related to a boat's velocity squared, not just the velocity itself. All of these loads demand complex structures when low weight also is an important necessity.

The full-displacement Krogen 39. An argument can always be made for displacement hulls, which remain composed when conditions worsen…up to a point.

speeds on the water. The first is to load up a displacement hull with excessive power. This technique usually is obvious because of huge wakes and radical trims these boats generally produce.

The second, and most difficult technique is to design a boat specific to the semi-displacement task. Often this means developing a relatively narrow, light hull with a fine bow. Such geometry results in a boat with less interior volume than others of a similar size, making it harder to sell.

The third method, and unfortunately the most common, is to take a typical planing hull shape, not worry too much if it gets significantly overweight, and pack in enough power to push it to whatever speed one believes customers will demand.

Of course, the purist in all of us would lean toward a true semi-displacement hull shape. Remember, however, that a good boat must be more than just a quality performer technically. Safety aside, the boat must do what the owners need it to do. In addition to a hull shape selected for speed, the boat must live up reasonably to an owner's arrangement requirements and equipment demands. As such, purist values aside, there is a definite place in the market for broad overweight planing boats that do semi-displacement speeds adequately.

Tradeoffs

The broader discussion, however, still is important to help folks focus on differences and tradeoffs to be considered by comparing all available options. I hope this explanation of the differences will help clear up two of the most obvious points of confusion that exist about speed ranges and boat types.

Buyer No. 1 decides he wants a typical 45-foot (LWL) displacement boat capable of 12–15 knots. Assuming a practical hull speed of 1.34, this means a true 9 knots. Even at an optimistic speed-length ratio of 1.42, it's still only about 9.5 knots. What this buyer really wants is a semi-displacement-speed boat.

A second buyer falls victim to the confusion generated when a boat is offered with a variety of engines for different speeds. Again, for a 45-footer this could be a 9-knot boat that's also available in a 12-knot version. The speed potential reveals that this is at least a semi-displacement boat that also is masquerading as a displacement type.

Similarly, this 45-footer could be offered as a 15-knot boat with horsepower options available for 20-knot speeds or beyond. Here, the speed potential clearly points to a planing hull that also is being offered in an underpowered version. Project all of the available possibilities, and one easily could suppose that both examples may feature the same full planing hull simply with smaller or larger power options designed to entice all available buyers.

Hulls are designed to match a speed potential. Whether an engine suitable of meeting that potential is provided is a secondary consideration, and one hopefully to be made by a reputable builder and an informed owner. The important thing to understand is the implication suggested when various engine combinations are offered. Also, remember the dominant factor that weight plays in determining whether or not the boat can achieve the speed goals you have set.

No one boat does a broad range of speeds well. A hull designed to go fast likely will be uncomfortable and inefficient at lower speeds. One designed to go slowly usually is terrible if pressed beyond its optimum. In that sense, a hull designed for the middle-speed range may be the right choice if those speeds best fit your needs. In choosing a boat, be sure you understand the compromises so the decision is an informed one.

Colin Mudie, designer, philosopher and author of the 1977 publication *Power Yachts*, expressed these thoughts with the dryness that only an Englishman would bring to the topic. He referred to the semi-displacement range as: "an unfortunate region full of hazards and disappointments for boat owners." In defending his placement of the topic within his book, he added: "We will include them with the displacement group as it seems more polite to consider them as rather overpowered-displacement vessels than as planing boats which could not quite make it."