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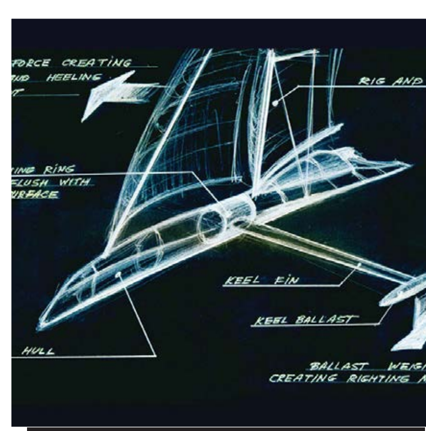

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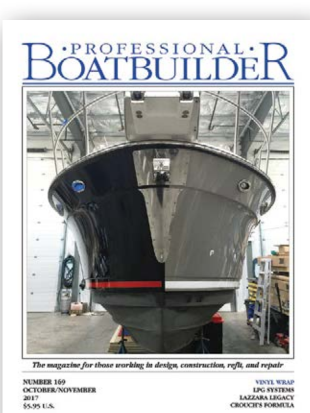


On the cover: This 28′ (8.5m) 2012-vintage Cutwater cruiser appears to have a split personality at the halfway point during application of a new Boat Blue high-gloss vinyl wrap finish by Wrap Boats of Vancouver, British Columbia. The original gray gelcoat, badly discolored from exposure to ultraviolet light, could no longer be renewed by polishing. The full hull wrap refinishing took a three-person crew 32 hours, including preparation and cleanup. Story on page 28.
Photograph by Tammy Charles.

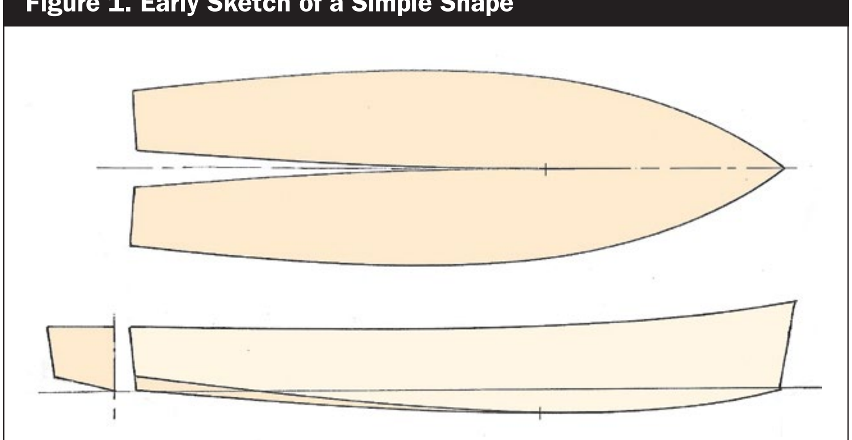
W17: Can Simple Hull Shapes Be Supported by Science?

When creating the hulls of a small trimaran, naval architect Mike Waters drew on his extensive experience designing large ships and on a lifelong desire to combine efficient performance with simplicity of form and construction.

Text and graphics by Mike Waters
(except where noted)

I have always been fascinated by things that work really well yet are simple in concept or execution. This immediately created an appreciation of hard-chine boats, and my first design, now 65 years ago, was like that. Even before that, the first boat I built had a bottom formed from a flat sheet with a long, gently curved cut in the center from the stern. I thought it was pure magic the way it took an attractive bottom shape by simply pulling the rear end together and closing the V at the transom, adding both rise of floor and a gentle rocker at the same time. I loved to cut out paper reproductions to demo this to my young schoolmates (see **Figure 1**).

Figure 1. Early Sketch of a Simple Shape

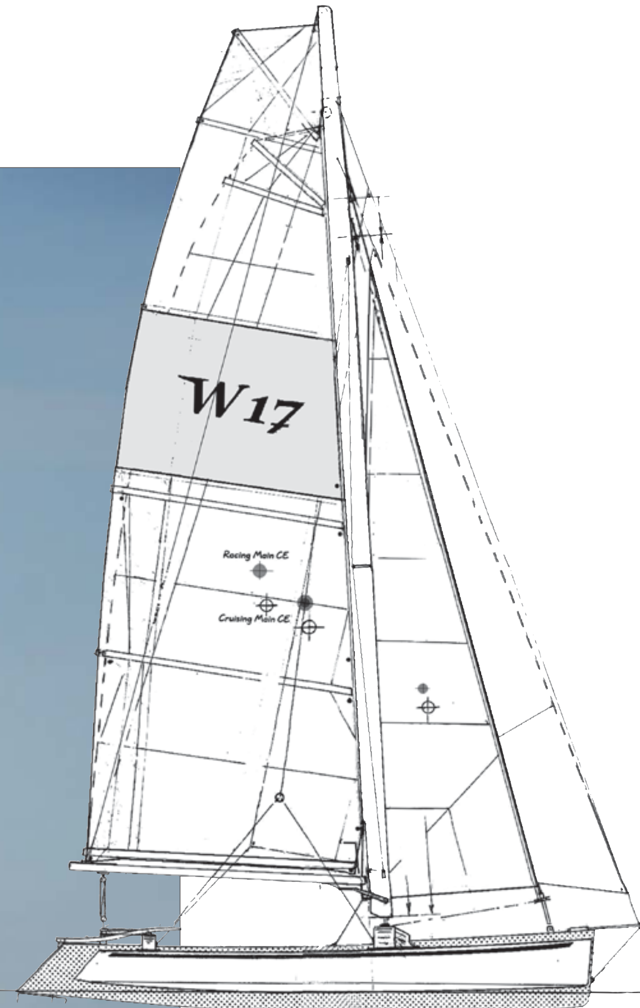


Fast-forward 35 years, when I was immediately drawn to the work of Jim Brown, Norm Cross, Lock Crowther, and Dick Newick, as pioneers in designing more efficient trimarans. One design in particular stirred the early juices of my youth, as it was called SIB for "Simple Is Beautiful." Since then, I have continued to dabble with new designs based on the SIB principle, with just two factors overriding simplicity: *efficiency to achieve design objectives* and *symmetry of design*…as I am still reluctant to compromise efficiency for ultimate simplicity.

Faced with the central challenge for all designers—where and how to compromise—my priorities lead to the question, "Can really simple, easy-to-build shapes *also* yield high efficiency?" I recently had a chance to answer that while developing hull shapes for the W17, a 17′ (5.2m) trimaran. (For more on Waters's background and how the W17 came to be, see the sidebar on page 108.)

I started by defining performance and efficiency as applicable in this case. This led to studying the hullform and how this might affect the creation of

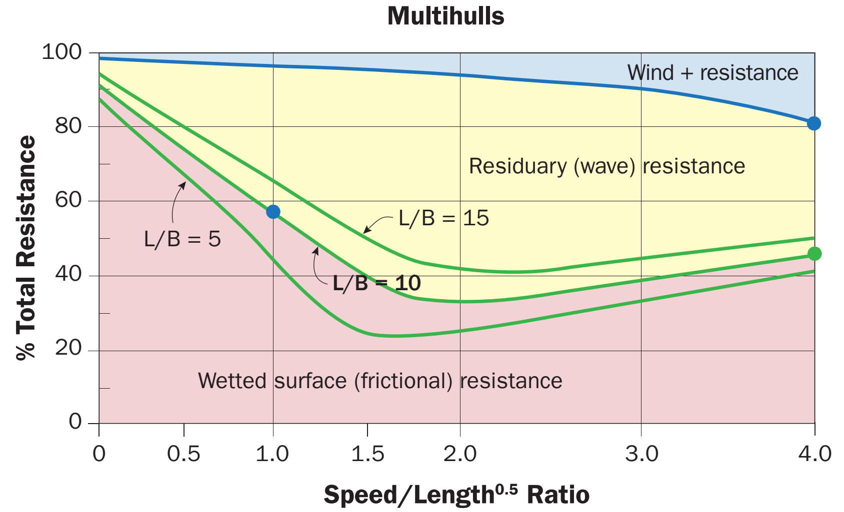
GEOFF KERR



__Left__—The development of the W17, a 17' (5.2m) trimaran, was the author's attempt to prove that simple shapes could also be efficient using proven hydrodynamics. W17's performance on the water (shown here on Lake Champlain) demonstrated that achieving both did not have to compromise either. __Above__—Two options for the sail plan's rotating wing mast: a basic 167-sq-ft cruising rig (shown in the dotted lines) with 24' (7.3m) mast made of glass-sheathed wood and plywood, and a carbon wing mast for a 200-sq-ft race rig.

waves that can, in turn, create more spray, which will make the boat wetter to sail. Frictional resistance needed to be assessed also, but placed in proper perspective with wavemaking, because lowering one can raise the other. Then there are side effects such as resistance (or not) to leeway that feeds into overall performance for a sailboat; and also the effect of pitching that not only adds to resistance through the water but also noticeably affects the efficiency of the sails by creating erratic airflow high up. There are certainly more variables to consider, but these four were the main measures of performance and efficiency I examined when designing the W17.

Figure 2. Approx. Ratio of Resistance Types to Speed/Length Ratio



Shading shows the approximate relationship when considering hull(s) of L/B = 10. Hulls that are slimmer (L/B = 15) or broader (L/B = 5) will move the dividing line, as wave-related resistance is even more predominant on broader hulls.

But before diving into the detail, let's revisit some important background for all ship designers. In the 1850s, when civil engineer Isambard Kingdom Brunel was preparing to be the first to design and build iron steamships to cross the Atlantic, he asked an engineer working for him to look into any potential stability issues. That engineer, William Froude, made some fine wood models for performance testing, but realized he needed a reliable way to upscale resistance figures for full-size ships. So he convinced the British Admiralty that a long test tank was needed. This was approved, and public money built the first-ever ship test tank near his home in county Devon, United Kingdom.

During the 1860s, Froude soon realized that hull resistance was split into two main factors that varied quite independently of each other, and that their "upscaling" from model to a large ship must be separately assessed and calculated. More experiments followed; and Froude discovered that, while the frictional part varied with surface area, surface roughness, and speed, the wave-resistance component varied close to the length of the wave the boat or ship created. A controlled series of tests followed and were so meticulously executed that the factors and formulas produced are still valid today, despite all the refined testing since. Froude's tests for friction produced tables of data showing factors for roughness of different surfaces, as well as showing that longer surfaces (or ships) showed a slight overall reduction (up to ~10%) relative to shorter ones.

Further, for wavemaking resistance, his tests proved a simple, basic relationship now called a Froude Number (F_n). The initial formula, simply $F_n = V/L^{0.5}$, with V in knots and L in feet, has since been known as the Speed/Length ratio. Froude also noted that wave resistance was most dominant when his F_n equaled 1.34, which equated to a wave equal to the length of the boat, as shown in the **photo below**. (Because some countries use metric units, the formula now exists in a non-dimensional form, but for this article, the original ratio will be used and simply called the SLR.)

So with that perspective from the past, let's look at the graphic in **Figure 2**. This is particularly of interest for slender hulls like multihulls, because it combines the relative distribution of frictional and wavemaking resistance, as discovered by Froude, with the modifying effect of the length-to-beam (L/B) ratio. While such distribution will vary somewhat with different hullforms, the information is close enough to see what's typically happening as the SLR varies, and is therefore valuable in assessing the relative importance of one resistance to another for specific cases. (Note that "wind + resistance" is assumed in this case, to include resistance of appendages, such as foils, rudders, etc.)

This photo shows a monohull at near maximum speed with the wave almost equal to the length of the boat, the state at which wave resistance is most dominant (F_n 1.34).

The main hull of the W17 has a L/B ratio of 9.5, so the L/B = 10 curve is very close. The relative speeds in knots for the SLR given, as they apply to the W17, will therefore be:

SLR 0.5 Speed = 2 k
SLR 1.0 Speed = 4.1 k
SLR 1.5 Speed = 6.15 k
SLR 2.0 Speed = 8.2 k
SLR 3.0 Speed = 12.3 k
SLR 4.0 Speed = 16.4 k

So what can we learn from these curves that might help guide our design?

At 2 k, about 70% of the resistance is frictional and related mainly to the wetted surface. (This might remind you to pull out the daggerboard when going mostly downwind in light air.)

At 4 k, nearly 40% is wavemaking, so form is starting to be a serious factor. At 6 k, about 55% of the resistance is wavemaking, and at 8 k (a common speed for this boat), wavemaking peaks at about two-thirds the total. As the speed increases to 12.3 k, the wavemaking is still more than 50%; and at 16 k, which would be a maximum for a W17 of designed weight, the wavemaking component is now about equal to the frictional resistance, which is rising again at the higher speeds.

From this, it is clear that from 5 kts to 16 kts, wakemaking resistance will have the upper hand compared to skin friction and therefore justifies priority attention during the design under consideration.

So let's consider how form can have an effect on wavemaking. First of all, it's important to appreciate that wavemaking occurs at the surface, at the interface between water and air. As water is effectively incompressible, underwater waves cannot exist in the same way, and this is why only friction, form, and appendage resistance affect submarines. So what will cause surface waves and added resistance? For one thing, a typical rounded monohull cannot avoid them, as beam is required for stability. This results in the typical banana-shaped buttock lines (a lengthwise off-center slice down through the boat) that all monohulls have.

Now, throughout this review, it's important to remember that boats move forward through the water and to consider how they displace water in their way. In general, we do *not* want the hull to move sideways. Even heeling over is generally negative, although this can be a way to actually lower resistance on some boats (more on this later). So, considering this forward motion, what happens in the area of these typical "banana" buttocks?

Figure 3. "Banana" Buttock's Effect on Surface Water

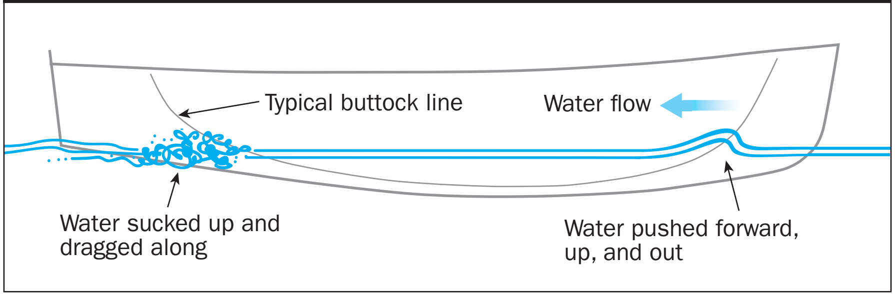


Figure 3 shows that the forward slope pushes water ahead of it as well as up and sideways. At the stern, the lifting buttock line will start to suck the water up and the boat down, further adding to drag and resistance—the principal reasons a displacement monohull struggles to exceed a SLR of 1.4. (See again that **photo** of a boat-form wave on page 106).

We must also consider the waves caused by the wind, and how they might react to the hull shape that is being driven through them.

As boats are a mix of shapes, let's consider them in their simplest form and compare their attributes relative to waves and resistance (**Figure 4**). All three shapes shown here will support the same weight or static buoyancy.

The **V shape** is often applied to bow sections to cushion the ride, but there are issues, especially for a sailboat. For one thing, its wetted surface is the highest in relation to its volume, almost 19% more when compared to the curved hull section. The other characteristic that concerns me is that it tends to "pump." By this I mean that as it rides up and down, it also forces surface water out horizontally. That's a lot of work and energy being expended and in a direction that does nothing to help forward motion. Additionally, hull buoyancy increases quickly with immersion, which aggravates pitching significantly, launching the bow in the air until it loses support and then allowing it to plunge back down with little initial resistance. So this is not one of my favorite "simple surfaces," despite being perhaps the best for directional stability.

The **semicircle** clearly has the least wetted surface in relation to volume, so it offers a clear benefit for a SLR of less than 1. While that speed range may be perfect for some manually propelled craft, a sailing multihull with efficiency perks like a rotating wing mast will be far less in that range. The section itself offers virtually zero form resistance against roll and little form stability, so it would have to be distorted to a more U shape to succeed in that way. This compromises the surface area, but there's little option for a boat that relies significantly on hullform for stability, as do most monohulls. Multihulls are different though, as their stability comes from multiple buoyant hulls. Either way, the rounded bilge offers little

Journey to the W17

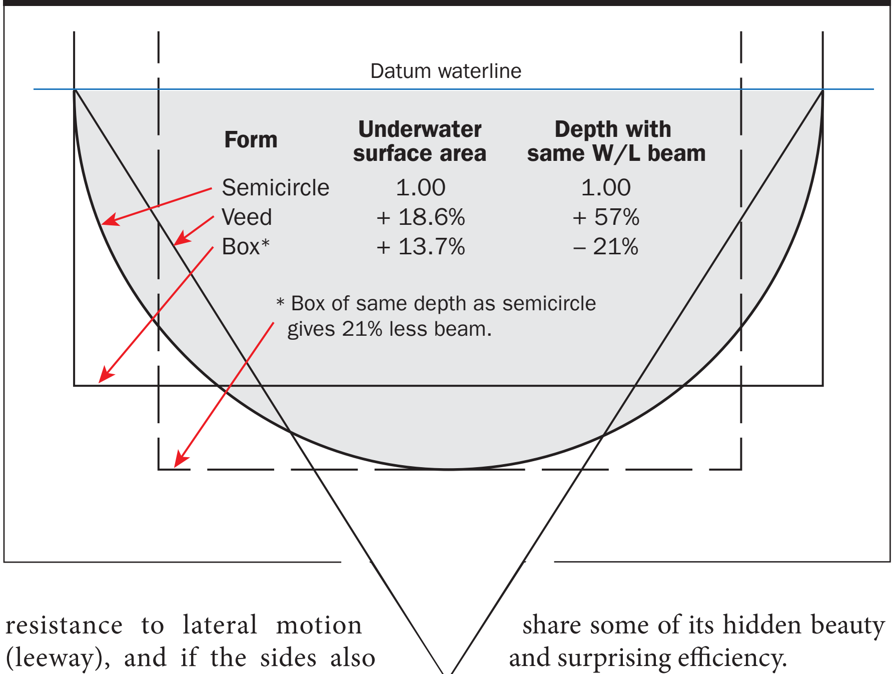
The W17 is a return to small boats for Mike Waters, who worked as a naval architect of big ships for more than four decades. During those years, he often tank-tested ship models to assess the performance of the full-size vessel. When asked to explain the similarity between designing a 600′ (183m) ship and a 17′ (5.2m) dinghy, Waters said that the models tested for both were typically in the 12′–20′ (3.7m–6m) range, and that there are known and calculable relationships between the model and the finished hull, whatever its size.

Waters has been building, sailing, and racing small boats since he was 12. He sold his first design at 17, followed by a 14′ (4.3m) double-chine boat he built for racing and cruising in his native England. He also entered the famous one-time Coronation Dinghy Race around the Isle of Wight (about 70 miles), meeting with Ian Proctor, John Westell, and Uffa Fox, to check out their winning boats. One was Westell's Coronet, which later inspired the 505. To Waters, who was studying naval architecture at Southampton at the time, Coronet's extended gunwale flare made a lot of sense. "Extra beam for crew leverage but sailing on a relatively narrow waterline," he recalled. So that year, at age 19, he created a new design of International Moth, also with an extended flare, and formed a small boatbuilding company,

GEOFF KERR

Mike Waters, a big-ship naval architect, designed his first boat at 17, and at 19 he designed a new International Moth, which he sold through his small boatbuilding company, Singlehanded Products.

Figure 4. Comparison of Hull Shapes



resistance to lateral motion (leeway), and if the sides also have much flare, some of the same negative pumping as in the V-hull above will take place.

Finally, the **rectangular** hull section. Compared to the fine wineglass sections of yachts, this can look really ghastly at first glance, but allow me to share some of its hidden beauty and surprising efficiency.

First of all, boats need to travel most easily in a fore-and-aft direction. Think of this section as you might the stealth section of a 500-mph aircraft, as it also looks ungainly in section but streamlined in profile. (In fact, its speed relative to the difference in density of air and water is not so far apart.) The beauty of this section lies in the manner it does not disturb the critical water-surface interface, where waves are formed. The vertical sides virtually eliminate expenditure of energy on sideways pumping as the hull moves up and down relative to the water or, conversely, as the up-and-down waves move past the hull.

Compared to the other sections, it also supports its displacement farther below the waterline, where it is increasingly harder for waves to form. The vertical-sided bow also limits the exaggeration of pitching, as buoyancy increases more slowly with immersion than it does in a V or flared bow. This is more akin to the Hazelett mooring buoy, a small-diameter vertical tube or spar buoy of significant depth that is far less affected by passing waves than a conventional mooring ball (see "On the Rode," in *Professional BoatBuilder* No. 111).

If the shape permits a fine bow to be matched with a fuller stern, this asymmetry further serves to control pitching. In the case of a boat that heels,

Singlehanded Products, to build his new Flying Moth, and he received a dozen orders at the Earls Court Boat Show. At the same time, he raced his own Moth two or three times a week, crewed for a Hornet champion, and also cruised the coastal waters of the Solent between Weymouth and Gosport in the locally popular 14′ Lymington Scow.

He moved to Canada to design ships at an expanding Quebec shipyard in the '60s to the '80s, but always owned and sailed small boats, and in 1976 attended the first World Multihull Symposium, in Toronto. There he met veteran designers like Lock Crowther, Jim Brown, Dick Newick, and Norman Cross, and became a trimaran enthusiast.

As so often happens, Waters designed the W17 because he needed a boat. After owning three previous trimarans, he could not find the exact boat he wanted for his retirement. Waters said that all his life he has looked for ways to achieve "high efficiency with simplicity," and saw this as an opportunity to take on that challenge. According to a *Multihulls*

GEOFF KERR

*The cockpit **(below)** and main hull **(right)** under construction. Waters designed the W17 to combine advanced sailing with easy construction and maneuverability; special features include a pivoting daggerboard and hinged akas that bring the amas over the main hull for trailer transport.*

there is also more potential to lower the wetted surface with a flat bottom than with other shapes, so that at lower speeds, the potential negative effect of a higher wetted surface can be reduced by heeling and trimming forward.

This is how simply shaped scows and flat sharpies can perform remarkably well, and the narrower they are, the better. Even a scow with a round bilge can show a significant improvement in waterline shape when heeled a little, as seen in **Figure 5**. In fact, it would benefit all sailors to look at the waterlines of their own boats when heeled and trimmed, as they might discover much more efficient shapes are then available to them.

Figure 5. Flat Scow Heeled Slightly

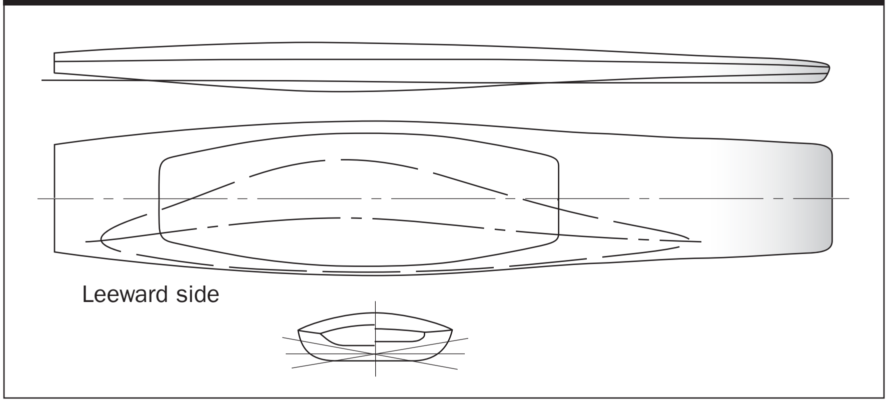
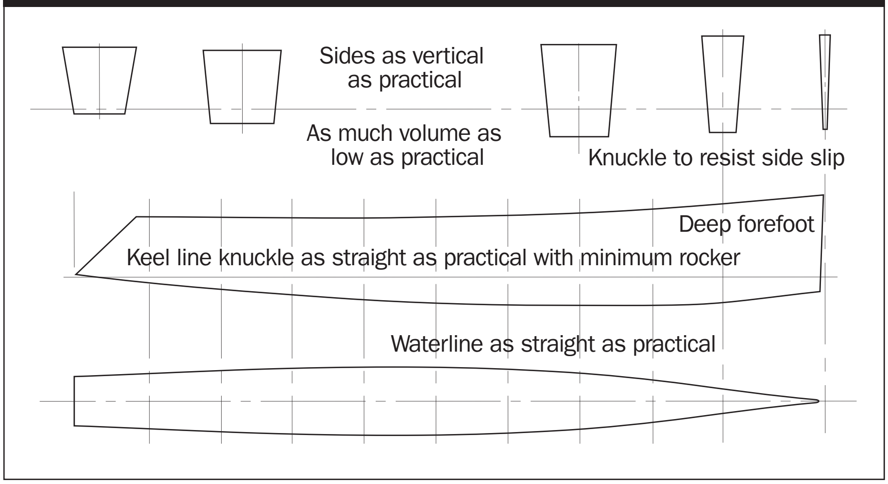


Figure 6. Sketch of W17 Central Hull



Nearly all lines, such as buttock, chine, and waterlines, are much straighter with this "box" form, and once the knuckle is below that critical water-to-air interface, the straighter the line, the less form resistance is created.

Here is a sketch of the W17 central hull (**Figure 6**), and by keeping the forefoot as low as practical, all the above positive advantages can be enjoyed. And there's yet another advantage. This shape has the highest resistance to side slip (leeway), which means a smaller board is required, further reducing drag.

Another interesting aspect is this: From the graphic of the three sectional forms (Figure 4), you will note that the box shape has 13.7% more wetted surface than the round bilge, indicating that the box gives more resistance when the speed is very low (or very high). But with the same draft, the beam of the box will be 21% less, so it causes far less surface disturbance and

Magazine article by Waters published in March 2016, other goals for the boat included: simple to maintain; easy to handle ashore; some rough-water capability; onboard storage; comfort; fully draining cockpit; feeling of security; relatively dry; sail and handle well; go to windward better than most; carry a rotating wing mast; not be expensive to build (it's now available as a kit); and above all, look really good.

According to a review, "The W17 Trimaran," by Geoff Kerr, in our sister publication, *WoodenBoat* (January/February 2017, No. 254), the final design successfully solves these apparent contradictions: "easy construction with sophisticated engineering, high speed with a boxy hull, and easy handling with high-tech sailing." Some of its unique features include a pivoting daggerboard that can be angled to reduce draft by 12″ (30.5cm) in shallow waters, and hinged akas that bring in the amas over the main hull, folding the boat to a size narrow enough (7′3″/2.2m) to be easily transported on a flatbed trailer.

There are two options for the rotating wing mast, both of his design: A 24′ (7.3m) glass-sheathed wood and plywood design for the basic cruising sail plan of 167 sq ft; and for the 200-sq-ft race rig, a carbon wing mast that Waters built on his front porch, demonstrating to potential home builders that advanced materials don't necessarily require special facilities if selected and employed correctly.

Interestingly, in April 2017, Classic & Vintage Racing Dinghy Association (CVRDA.org) reported finding "a rare, just discovered Moth-like dinghy that we all fell in love with, but no one can identify." It turned out to be one of the first Flying Moths Waters had built 62 years ago in plywood, which has now been restored and is sailing again.

—Melissa Wood, associate editor

This image of the W17 clearly shows that the critical surface interface suffers minimal horizontal "pumping." The hull slices the water so cleanly that it remains translucent enough to see the keel 7.9" (200mm) below, even at 9–10 knots.

wave. Now further consider this: the fine box section clearly offers less side slip than a rounded shape, and if one can sail to windward with 4° to 5° less leeway, one can totally make up for the difference in speed theoretically offered by the round hull. Admittedly, this is only when going to windward, but as we may spend 50% of our time in that mode, it's certainly worth factoring in to our overall review of performance. Tests have shown that by using the proposed hullforms, leeway is indeed significantly reduced, sometimes to zero.

Before leaving the main hull, a word or two about keel rocker. Experience has shown that less rocker typically contributes to more speed, although one generally has to balance that with the need for some rocker to aid maneuverability. But on a small hull like the W17, the stern run can be relatively flat, as the crew are mobile and can readily move aft to keep the bows up. But on a larger, heavier boat, crew weight will have less effect, so the ability to keep things under control with the bows up needs to be designed in. One way to do that is to build in a slight underwater bustle toward the stern. Then, when going too fast down a wave or trying to handle an overcanvased situation, this bustle will create a slight suction at speed, helping to slow a boat a little as well as lift the bow. I've long suspected that noted trimaran designer Ian Farrier knows this well, and although his boats are not hard-chined, they are still fairly flat at the stern. This bustle in profile not only adds more buoyancy under the cockpit for trimarans more than 20′ but also offers the safety aspect I mentioned above.

As the W17 is a trimaran, there's another hull to think about, the so-called ama, or outrigger. Its shape needs to be *very* different from the main hull. While the nearly vertical, straight sides and straight longitudinal lines are just as important, these hulls need to also work when pushed to the deck to leeward, as well as fly airborne just above the waves on the windward side. To achieve this mixed role for the W17, I developed a triform hull shape—a bottom with three different angles, each designed to suit a purpose.

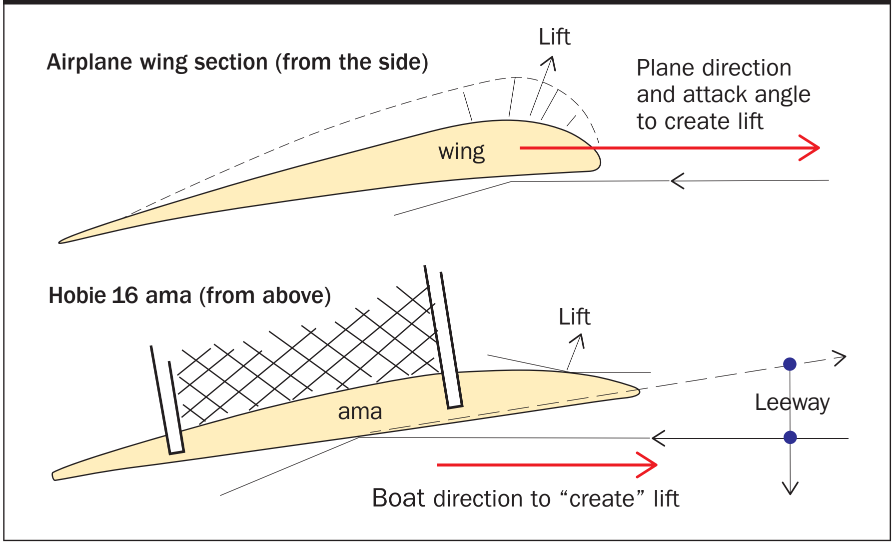
At the bow, the bottom panel all but disappears, but what remains is twisted toward the vertical, so the entry is fine and low. Amidships, the bottom of the ama frequently contacts wave tops on the weather side, so when the boat is sailing inclined at 15°–20°, the bottom is designed to a 60°–70° V to silently slice through them, without disturbing or slapping the crests and creating

Each of the three angles of the outriggers' hulls ***(far left)*** *serves a different purpose, allowing for greater efficiency when pushed to the deck to leeward as well as when flying airborne on the windward side* ***(inset).***

annoying spray. At the stern, the bottom is much reduced in width and further twisted to be flat yet tapered down to as close to a fishtail as practical for minimal resistance when submerged. This twist is accomplished by a slight keel rocker in conjunction with an outboard chine that's dead straight (see photo on page 105) and typically working totally under the water. The resulting ama hull is slightly asymmetric with the inside nearly straight.

This raises an interesting question. For many years now, catamarans, like the Hobie 14 and 16, have also had asymmetrical hulls, but these have been cambered in the opposite direction to the ama of the W17. In **Figure 7**, the lower image shows the asymmetrical hull of an early Hobie cat, and the sketch above it shows how it might relate to an airplane wing to create lift. The only way the Hobie cat can create the needed lift to windward to oppose leeway is to actually have some leeway in the first place! This means that its efficiency is very limited and will depend on maintaining good speed, so the angle of attack (the leeway) can be minimized.

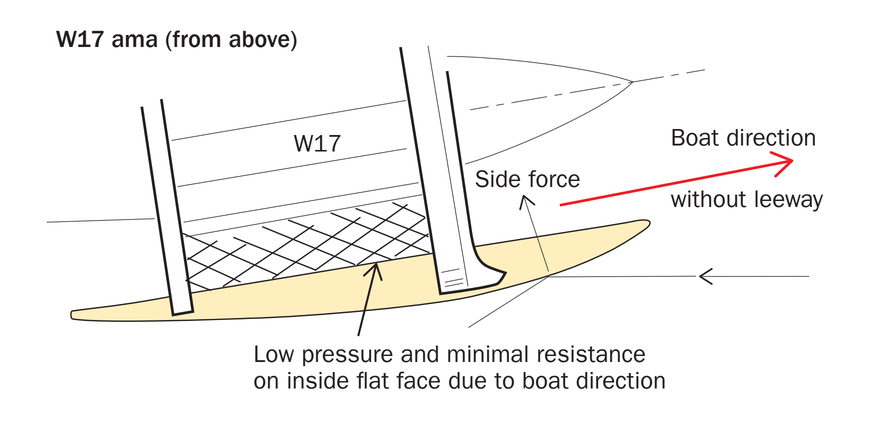
Figure 7. Creating Lift: An Early Hobie Cat



Now compare that to the reverse direction taken by the asymmetrical amas of the W17 (**Figure 8**). In this case, the forward motion will impose a positive pressure on the curved leeward side and literally push the boat to windward. This is further assisted by slightly toeing-in the two amas so this force to windward is raised and maintained. To give a simple example of this, imagine picking up the rear of any regular kayak so the deck is against your side. Now move the bow forward through the water, and you'll see the bow turn away from the rockered keel.

This design has yet another purpose

Figure 8. The W17 Ama Opposing Leeway



and advantage. The flow between the main hull and an ama is now far less compressed into a venturi, thus permitting the existing waves to pass without being further raised or in any way disturbed. Finally, it should be noted that the ama should not be too much shorter than the main hull, as on a heeled sailing trimaran, the ama's length is important for speed as well as providing important diagonal stability. It's not merely a stability/buoyancy pod.

Although this does not exhaust all the design aspects that simple forms can offer the designer, I hope it shows that they are not necessarily as much of a compromise as many would first think. In fact, the sparkling overall performance of the W17 has recently led me to consider a much larger trimaran of nearly double the length, because most of the above positives will equally apply, and the hulls will not only be easy to construct but will allow the boat to sit stably on its bottom without damage or heel.

Only by sailing the W17 can one really appreciate the effect of all these factors, but they *do* work. This quote from an e-mail I received sums it up: "I cannot ever remember sailing on a boat that felt just so damned efficient!" PBB

***About the Author:** In addition to his career as a big-ship designer, naval architect Mike Waters has spent 60 years sailing high-performance boats and 40 as a trimaran enthusiast. Learn more at www.smalltridesign.com.*