Sailing Cruiser Design

History, hydrostatics, and art, PART 1

In Part 1 of his two-part series, Tad Roberts analyzes four small cruising sailboats he has designed. In Part 2 of the series he will analyze the designs of four larger cruisers.

Purpose and sailing ability should define any sailboat. Intended use—daysailing in protected waters, coastwise weekend cruising, or ocean voyaging—helps define the overall character of a boat; it plays a part in the choice of hull and appendage form, arrangement, construction method, rig type, and budget. Use also affects choices concerning sailing ability, seaworthiness, comfort, safety, and maintainability. But there is another key element in the development of a boat's character—romance. For me, cruising under sail is a romantic notion, conjuring up the image of a deserted tropical anchorage, the doughty little ship at rest with lines ashore and baggywrinkle in the rigging, drying out after a month at sea rolling down the tradewinds.

Let's take a look at eight small sailing cruisers I have designed as examples of offshore and coastwise cruisers. History, hydrodynamics, art, and romance influence and inform the other constants in their design. We'll discover the historic precedents for each boat, and we'll explore rigs and their effect within the context of the different vessels and their intended use. I will also talk about the art of tying all this together.

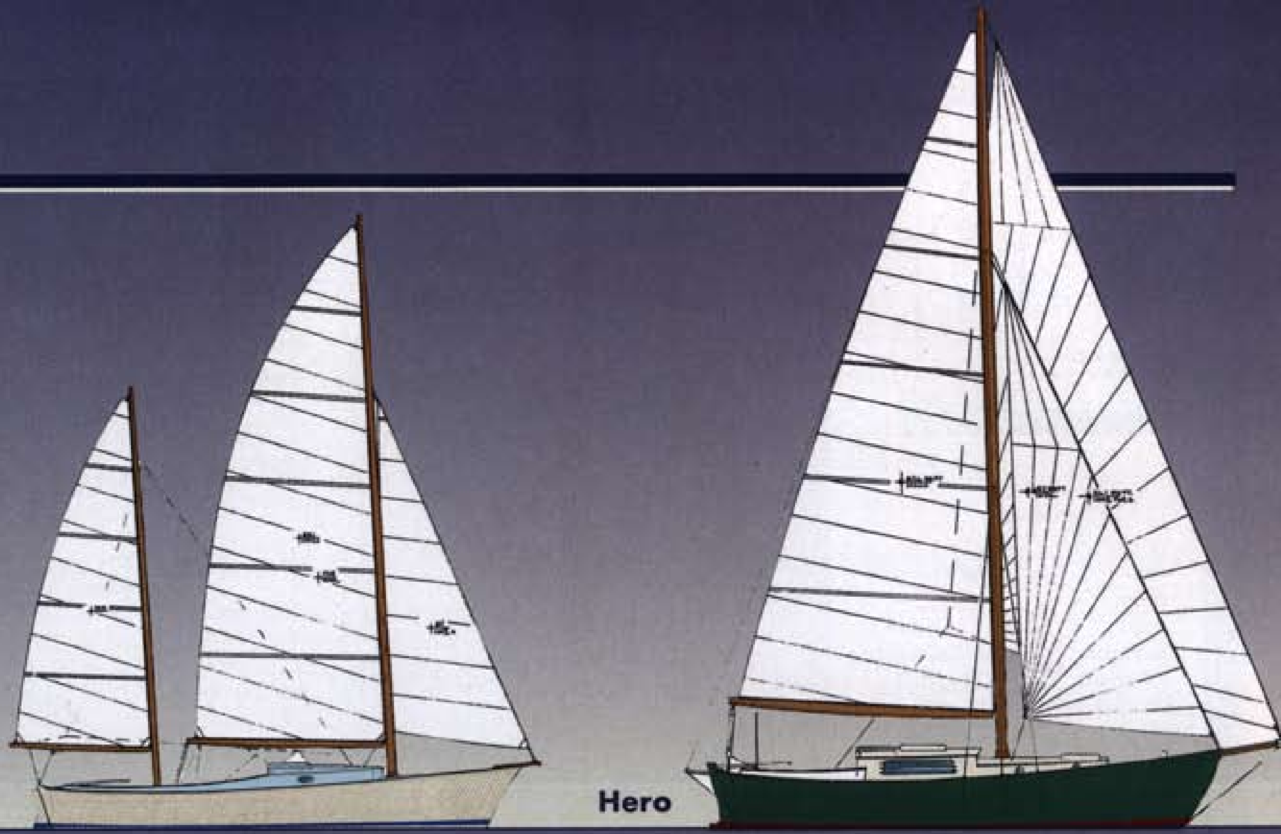
The boats fall into two main types, coastal cruisers and offshore voyagers. The boats are presented according to their lengths, with the shortest overall in Part 1. However, as we'll see, length does not correlate with seakeeping ability. Captain Flint and Ratty should certainly stay near shore, but Hero, a relatively short boat at 29′6″, is meant to go anywhere. Two longer but less ocean-capable boats, Tilikum and Flash, will be presented in Part 2, along with a pair of larger bluewater cruisers, Wizard and Wildcat. The displacement figures given are "half load" condition, that is, the boat is complete and ready for sea, but with only half the crew, stores, and liquids aboard. Boats are always sailing at something other than design displacement. If my design targets are in the middle of a cruiser's displacement range, design parameters remain valid.

Displacement/length ratios are an easy way to categorize and compare a diverse group of boats. For the purposes of this discussion we will consider any boat with a D/L over 300 a heavy-displacement boat: 160 to 300 is medium; 100 to 160 is light; and anything below 100 ultralight.

Captain Flint's displacement/length ratio is 220, about the middle of medium. Let's keep that in mind while we look at the reasoning behind his length, hull form, rig, and how they relate to balance.

Captain Flint
A 17′ Cat-Schooner

Captain Flint is a 17′ schooner-rigged flatiron skiff intended for protected waters. This limitation on cruising range is due to the fact that this is an open boat. A self-bailing cockpit or watertight cabin closure would ruin him for the role of family camping cruiser by dividing an already



Text and drawings by Tad Roberts

small boat up into several cramped areas. The price paid for this open space is that volume under side decks and in the ends should be given over to positive flotation in case of swamping. Open floorboards are fitted over the frames, and this low sole (bottom boards) means low seats with decent backrests for comfort and that feeling of being "in" rather than "on" your little ship. This brings us to the essential character of this boat, that Captain Flint is the biggest boat possible in this length. Minimum overhangs, wide beam, and two-masted rig all add up to a "big" little ship.

When considering any design, the first major factor that comes to mind is length. If we're of a mind to impress, we talk about overall length, sparred length, or length on deck, but the most important length is the length of the waterline. Captain Flint's waterline length is 16′3″, almost 96% of the overall length. Why?

Boats, especially sailboats, are of similar proportions; the simple length number gives us a good idea of the overall size and capabilities of a particular hull. Most boats are roughly a third as wide as they are long on the waterline, and depth (main deck to keel rabbet) is about half the beam. The 28′ Teazer has almost three times the internal volume of the 17′ Captain Flint. Although length (LOA + LWL/2) has increased 1.59 times, beam and depth have increased 1.14 times and 1.51 times, respectively. Captain Flint's cubic number (length × beam × depth) is 269, while that of Teazer is 743, about 2.76 times the size of Captain Flint.

Captain Flint will take about 400 hours to build, while Teazer would consume 1,100 to 1,600 hours. I arrive at these numbers by taking the boats' total weight (design displacement) and deleting the payload (people, stores, and liquids), to arrive at a "light-ship" weight. You can figure construction hours by the pound. I base the calculations on 3 lbs per hour; but the rate can range anywhere from 3 to 5 lbs depending on finish level, construction method, and work habits. For Captain Flint's calculations, I subtracted 900 lbs from the 2,100-lb displacement to account for people, stores, sails, outboard, and gear. Then I divided the remaining 1,200 lbs by 3 lbs per hour and arrived at total of 400 construction hours. If you double the construction hours and multiply by the hourly shop rate, you will have a rough value for the boat's total cost.

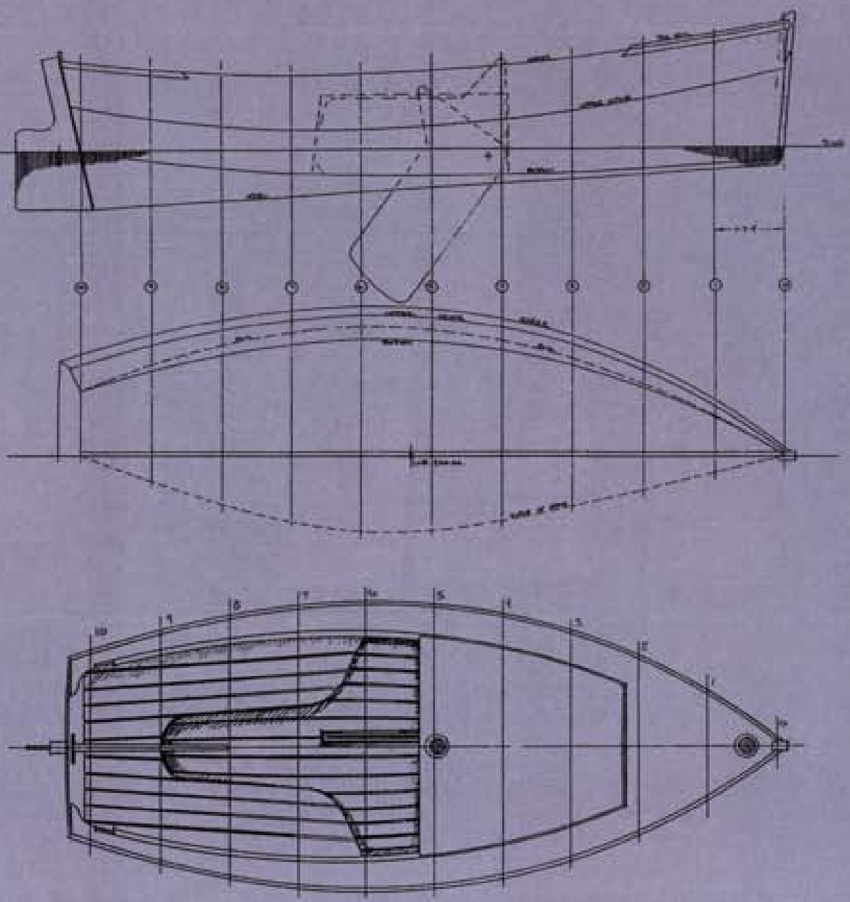
Let's go back to Captain Flint's hull, which is dead flat athwartships, with shallow fore-and-aft rocker. The flat bottom promotes the idea that this boat would be simple to build, while the rocker has a hydrodynamic reason for being. It keeps the hull volume concentrated amidships and minimizes the waves created while underway.

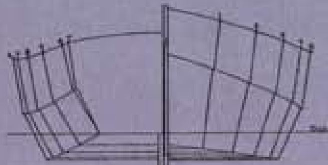
One thing that's a bit different about the Captain's hull is the knuckle in its topsides, which visually breaks up an otherwise large, flat area. The tapered shadow line gives the Captain a traditional air. The narrower panels also make better use of the sheet-plywood construction material. A straight-sided version might have more initial stability, but it would appear too boxy for my taste.

Why did I give Captain Flint a schooner rig? It's different, it fits with my desire to create a salty character

Particulars

LOA	17′0″
LWL	16′3″
Beam	6′10″
Draft	1′4″ board up
Sail area	155 sq ft total
Mainsail	72 sq ft
Foresail	83 sq ft
Displ.	2,100 lbs
Ballast	500 lbs





Captain Flint—A camp-cruiser intended for use on protected waters, this cat-schooner is the biggest boat possible for its length.

in the Captain, and it's practical. The two-masted rig means short masts, which keep sail centers of effort low and this means shorter heeling moments. The short masts can be unstayed, simplifying construction and cutting cost. The masts are in the right places to work well with the interior arrangement: the foremast is out of the way, and the main is amidships, properly braced by the after end of the cabin. The mainmast will be on the boat's centerline, and we'll build the centerboard trunk clear of the mast on the port side of the keel.

With a schooner rig, the center of effort ends up farther aft than it would in, say, a sloop or ketch. This is what happens when you put the big sail in back. I compensate for this by giving the keel lots of drag. Note that the deepest point is at the heel of the rudder. I also move the centerboard aft, but not too much because its center of area moves aft as it pivots upward. This brings us to balance, the tricky art of trading off the heeling and driving forces of the rig against the lifting and directional forces of the hull and its appendages. There are many opportunities to adjust the balance of Captain Flint. We can adjust the center of lateral plane forward or aft by lowering or lifting the centerboard. The center of effort also can be shifted by changing the rake of the masts, and sail sizes and sheeting can be adjusted as well.

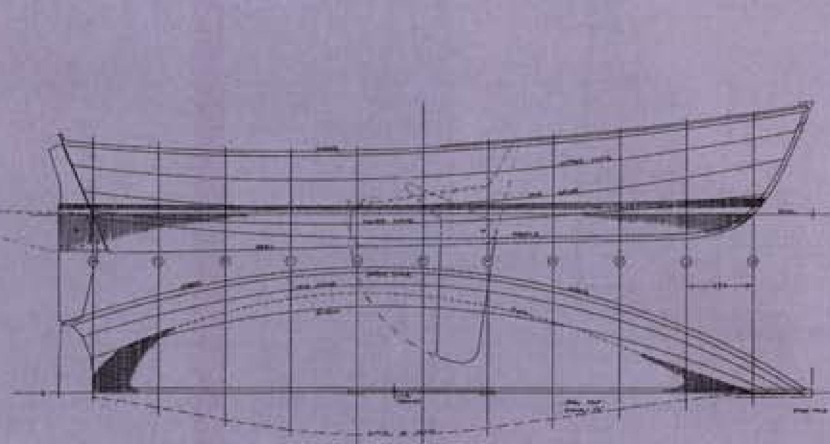
Now we need to look at how length relates to speed, resistance, and displacement. Ratty will be a faster boat than Captain Flint, and we'll see how weight (displacement) affects hull form, sail area, wetted surface, and cruising range.

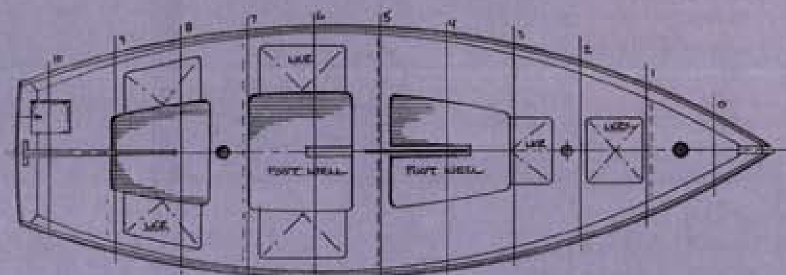
Ratty
A 20′ Cat-Ketch

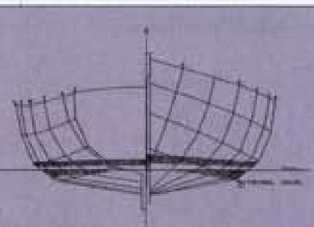
Ratty is bigger than Captain Flint, but he is also lighter. If length says something about the physical size and room available in a particular boat, it also tells us a great deal about the potential performance. Aside from weight, length is the most important factor determining the ultimate speed of any displacement (i.e., non-planing) hull. This speed/length-of-waterline relationship has to do with wavemaking. As a hull moves through the water, the bow creates a wave by splitting apart and pushing water upwards (technically, it creates a pressure difference). The stern creates another wave where the water exits from under the hull. These waves start out as ripples at low speed, but as the hull moves faster they separate into bow and stern crests with a single big trough between. If the

Particulars

LOA	20′0″
LWL	17′6″
Beam	6′8″
Draft	1′0″ board up
Sail area	174 sq ft total
Mainsail	122 sq ft
Mizzen	52 sq ft
Displ.	1,350 lbs
Ballast	350 lbs







Ratty—Bigger, lighter, and more lively than Captain Flint, the Rat exemplifies a light displacement, form-stable boat that relies on hull shape for its stiffness.

hull is forced to go any faster, the stern wave moves out from under the transom, the stern drops into the hole, and the boat bogs down while trying to climb the after face of the bow wave.

With crests at bow and stern, we have a wavelength roughly equal to the waterline length of the boat. As it turns out, most water waves move at a speed equal to approximately 1.34 times the square root of their crest-to-crest length. Ratty's design waterline length is 17.5′, and the square root is 4.18; multiply this by 1.34, and we have a theoretical hull speed of 5.6 knots. With a high sail area/displacement ratio and suitable hull form, Ratty can exceed this speed under the best conditions. But only in short bursts. Average cruising speeds will be closer to a speed/length ratio of 0.9–1. Captain Flint's waterline length is 16.25′, and the square root is 4.03; multiply 4.03 by 1.34 to equal 5.4 knots. As the Captain is a displacement vessel, having neither light enough construction nor high enough sail area/displacement ratio to plane, this is about his maximum speed.

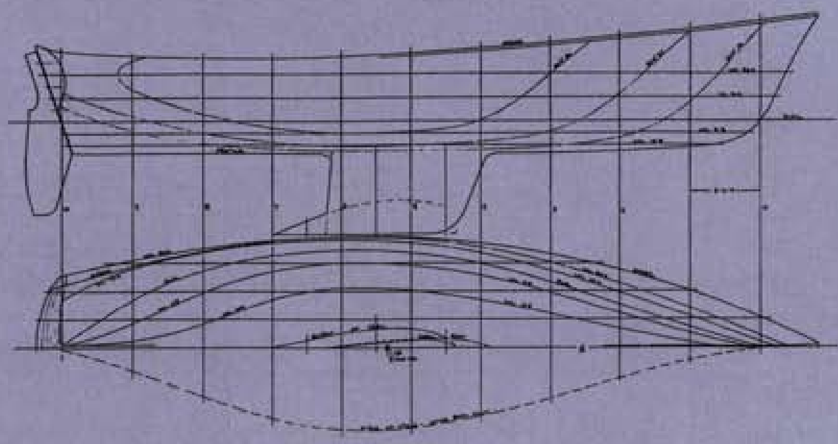
The other major component of resistance is frictional drag, which is mainly dependent on wetted surface but also includes hull-form drag or eddymaking resistance. Frictional drag makes up the largest part of total drag at low speed (depending on hull form, up to a S/L of 1.2–1.3). As speed increases, waves start to form and wavemaking resistance increases. At a speed/length ratio of 1.34 (theoretical hull speed), resistance is about half wavemaking and half friction. But beyond S/L 1.34, wavemaking increases dramatically (see WB No. 137, page 79).

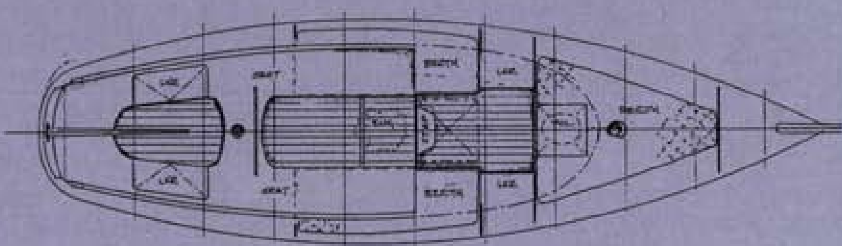
Examining the above, we find that the longest waterline is the fastest. For a given midsection, the longer the waterline, the easier the entrance and exit, thus minimizing form drag and eddying. Is maximum waterline length good? As we discussed concerning low speed, resistance in light air is mostly dependent on wetted surface, and wetted surface increases rapidly with length, but only slightly with weight. A narrow, deep, rounded hull will have less surface area than a wider, flatter hull of the same weight. Ratty is an attempt at getting the best of these opposing requirements. It has a long waterline and a flat high-speed hull, and we can remove the appendage drag by lifting the centerboard up into its case. We will explore this problem further in the next issue when we talk about a boat called Flash.

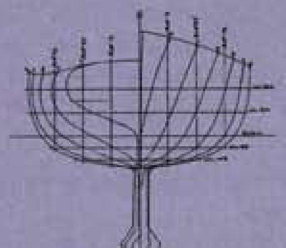
As you can reasonably set only so much sail from a given hull length, a sailboat's driving power is limited. That's where Captain Flint will be a bit deficient, with a

Particulars

LOA	28′0″
LWL	25′0″
Beam	7′10″
Draft	4′0″
Sail area	405 sq ft total
Mainsail	221 sq ft
Mizzen	100sq ft
Jib	84 sq ft
Displ.	5,600 lbs
Ballast	2,500 lbs







Teazer—This boat combines design elements from traditional coastal cruisers (ketch rig; classic sheer; and a low, rounded house) with a fin keel and spade rudder.

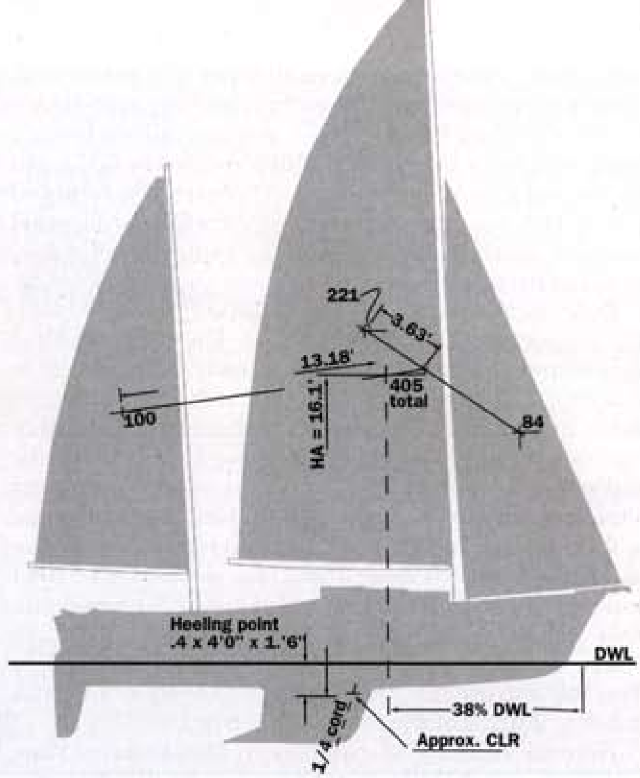
sail area/wetted surface ratio of 2.16. If the Captain were 3′ shorter at 13.25′ waterline, the SA/WS ratio would be 2.34, which would be an improvement. Without a large light staysail set from the mainmast, the Captain will be underpowered in a light breeze. With Ratty I have gone to a taller rig, with more "horsepower" per pound of boat. Ratty has 1 sq ft of sail for each 8 lbs of design displacement, while Captain Flint has 13.5 lbs of boat per square foot of sail.

There's one final point we should discuss before leaving length. Inertia of waterplane is a main factor in low-angle (up to 10°–15° or so) stability—longitudinal as well as transverse.

A boat's waterplane is a horizontal cut through the hull at its waterline. Inertia of the waterplane depends upon the distribution of its area around a geometric center—the more area farther away from the center, the more the damping action. Therefore, the longer the waterline, the greater the pitch damping, and the smoother the sailing will be. If Ratty's waterline were only 14′0″ and the rest of his length were overhang, the boat would have to pitch that much further before any hull was immersed to damp the motion. We'll take another look at waterplane in Part 2.

How is it that a bigger boat is of lighter displacement? Well, hang on a minute; Ratty is just a *longer* boat. Overall length has increased 3′, waterline 1.25′, but beam is 2″ less, and depth is also about 2″ less (that is Ratty's beam and depth are both 97% of Captain Flint's). Recall the scaling we did between Captain Flint and Teazer. In this case, Captain Flint's L = 16.62′, and that of Ratty is 18.75′, an increase of 13% (in other words Ratty's length is 113% of the Captains.) This means our scaling factor between the two boats is $L \times B \times D = 1.13 \times 0.97 \times 0.97 = 1.06$. For Captain Flint, I have allowed 700 lbs for the structure. Using our 1.06 scaling factor, Ratty's structure would weigh 742 lbs if built in the same manner. But it is not.

Ratty's "sailing weight," or half-load displacement, is 1,350 lbs, which gives a displacement/length ratio of 112, about half that of the Captain. This reflects my thought that Ratty will be a more lively sailer. So the payload allowed is smaller as well—500 lbs instead of the Captain's 900 lbs. With 350 lbs of ballast, this leaves 500 lbs for the structure: hull, bulkheads, seats, spars, and sails. The Captain is built using relatively heavy plywood over solid lumber frames. Ratty's construction is a stitch-and-tape plywood skin over an egg-crate internal structure of slotted-together and epoxy-filleted plywood. All this effort and expense is aimed at keeping the trailer weight under 1,000 lbs so the boat can travel behind a small car. Trailer



The Davidson Laboratory (calculated) center of effort of Teazer's sail plan is located above a point that is 38% abaft the bow along her designed waterline. The cutter-rigged Hero's calculated center of effort is farther forward.

weight is also the reason for the minimal ballast. Much of Ratty's stability while sailing depends upon the crew, and this boat will be less able to look after itself at sea.

I allowed 500 lbs of payload for Ratty, but what will happen if the little cruiser is loaded down by three adults, a dog, stores, and camping gear for five days? It adds up to a load of 1,380 lbs, about equal to the Rat's normal sailing weight. We said payload would be 500 lbs when floating at designed waterline. For this trip we are 880 lbs over that, and the boat is now displacing 2,230 lbs and sitting lower in the water.

What will this added weight do to the boat's behavior? First, let's look at the waterplane. Floating at his designed waterline, Ratty's waterplane area is 65.4 sq ft. With the extra 880 lbs aboard, the hull will float 2.5" below the designed waterline. (Waterplane area = waterline length × waterline beam × 0.70.) Once waterplane area is known, we can calculate sinkage: area × 64/12 = 348 lbs per inch immersion. And 880 divided by our 348 lbs-per-inch means the boat sinks 2.5".

Obviously this means an increase in wetted surface—that 2.5" strip all around the boat. In a cruising situation this amount of wetted surface is of little import. Because of the veed sections (have a look at the body plan), waterplane area will increase rapidly as Ratty sinks. The 2.5" of sinkage will bring the waterline up to about the middle of the boottop. If we could keep the vertical center of gravity (VCG) the same, this sinkage and increase in waterplane inertia would mean an increase in stability. But, alas, because this small, light boat is floating on top of the water, almost all increases in weight will raise the VCG, and stability might suffer. Cruising speed is another measure of the type of boat we are looking at. Ratty's designed waterline length is 17.5' and the maximum S/L achieved while cruising would be 1.34 or 5.6 knots. But that is a maximum, and obtainable only under ideal conditions. Ratty has a low D/L ratio (112) and fairly high sail area/displacement ratio, so we expect generally good performance. In reality you will average an S/L of about 1.0 for a day cruise in this boat. For an eight-hour sail with a good steady breeze, that amounts to about 33 nautical miles over the bottom in a day! Ratty might make 15–20 miles up the coast in a long day on the water. That's a nice day cruise, but you are not getting far in a weekend.

Ratty is a rigged as a cat-ketch. There are reefpoints in both sails, plus a third maststep about 3' abaft the mainmast. These various combinations can handle everything up to a fresh gale. After that it's time to take the masts down and lay to a sea anchor.

Now let's look at how a longer waterline means more range, how hull form and displacement affect motion, and at how Teazer's deck layout and rig will affect her use. Teazer is also the most delicate of these designs, and that plays a part in her use as well.

Teazer

A 28' Coastwise Cruising Ketch

We can think about cruising farther in Teazer, which is intended for coastwise daysailing and overnighting. With her 25'0" waterline and a cruising S/L of about 0.9, she will cover 36 nautical miles in an 8-hour cruising day. This lower S/L reflects a more relaxed attitude to sailing the boat; you still have to pay attention, but it will be much less work to sail Teazer than it is Ratty. First she is larger, about four times the displacement, and so all motion will be slower. Teazer is a ballasted keelboat, and in comparison to the Rat, where the crew is most of the ballast, she will be quite stiff. Slower motion and less worry about trying to keep the boat upright means better-rested sailors at the end of the day. Teazer also has a cabin and dodger to protect the crew should the weather turn against them.

When looking at the drawing, the first clue to her intended use is the huge cockpit with a short cabin trunk forward. I have taken her strongest elements from traditional cruising designs: classic sheer, the low, rounded house, elliptical transom, and ketch rig. Modern touches are the short overhangs, fin keel and spade rudder, and tight bilge radius with flattish sections amidships. The wild card in this styling mix is the slight reversal in the stem profile. I think the slight clipper bow balances the short stern nicely and gives Teazer a distinctive look. She is no longer trying to look like a Herreshoff but has developed her own character.

The next feature that tags Teazer as a daysailer is her large rig; the tall, unstayed spars set 405 sq ft of sail, which gives a sail area/displacement ratio of 20.5. This is performance cruiser territory. Having this much sail area coupled with her low wetted surface means she will really move under working sail in light air. In very light air you could set a mizzen staysail, adding another 130 sq ft.

Let's look at a way to compare various boats' behavior under sail. This is a measurement called the Dellenbaugh angle, which is the approximate angle our boat will heel when sailing to windward in a 14-knot breeze. The

Dellenbaugh formula uses a mathematical constant multiplied by sail area multiplied by a heeling arm (HA = distance between CE of sail plan and an assumed heeling point, arbitrarily $0.4 \times$ draft). This is divided by GM times displacement. GM is the distance between the center of gravity (G), and the metacenter (M), which is the point on the centerline about which the center of buoyancy moves as the boat heels.

Every boat's stability is related to the length of GM. The longer it is, the stiffer the vessel. There are two basic ways to increase GM. The first is to lower G, by adding or lowering ballast, so-called "weight stability," typical of meter boats and offshore cruisers like Hero. The other method of lengthening GM is to raise M by making the hull wide and shallow. This is "form stability" and is most often associated with modern hulls. Weight-stable types, such as Teazer and Hero, are characterized by narrow waterlines and fairly deep draft. They are initially tender and have high angles of heel when sailing but good ultimate stability. Form-stable boats are initially stiff. Ballast is less, so they are of lighter displacement, stand up to their sail and are fast, but generally have lower ultimate stability. Ratty is of the form-stable type.

Here we continue to compare Teazer, Captain Flint, and Ratty using Dellenbaugh angles. At the designed weight and waterline, Ratty's Dellenbaugh angle is 26°. This is a high angle for cruising but is about average for this size of boat and reflects the idea that under sail G will shift to the weather side as the crew move outboard. With the extra 880-lb full-cruising load aboard, the Dellenbaugh angle comes down to 17.5°. Even though G goes up, the increase in displacement and waterplane inertia makes a big difference. Teazer's Dellenbaugh angle at design weight is approximately 20°, so we'll be reefing in about 15 knots of wind. By way of comparison, Captain Flint's Dellenbaugh angle at design displacement is 17°, reflecting heavy displacement and a short heeling arm for its size.

We now have an idea of how much Teazer will heel under sail, but what about movement in a seaway? At sea a boat is free to move in six directions; to surge, sway, heave, roll, pitch, and yaw. The first three are straight-line motions in the three directions, and the second three are rotational around the three axes. Pitch and heave are important because they add resistance depending on how pronounced they become. If a boat is heeled in calm water and then let go, it will roll past the vertical to a heel angle opposite and then back, and so on until the rolling is damped and the boat comes to rest. This also holds true for pitching. The rhythmic rolling/pitching period is called the "natural frequency." High-inertia modern boats that sit on top of the water have a small frequency and short, snappy roll and pitch. If you get into a situation where waves are hitting your hull at its natural frequency, the boat can amplify the motion to a dangerous condition. The easy way out of this is to change course, or speed, to alter the frequency of meeting waves.

Stability is also affected by passage through waves. Because you end up with either a crest or trough amidships, waterplane inertia increases and decreases with each passing wave. We often see boats heel over as they reach a wave crest. This is not just from the increased wind pressure, but from the loss of stability as well. Stability can drop to half of that in calm water on a wave top, then increase to half as much again in the trough.

What does the shape of the boat have to do with all this? The boat pitches about its center of gravity, and we can say that as the hull moves forward, the forebody starts the pitching and the afterbody damps it out. To minimize the tendency of the forebody to pitch, we can make it fine at the waterline and flaring out above, gradually increasing buoyancy. To maximize the damping of the afterbody, we can make it wide. Because waves can come at the boat from odd directions and in odd shapes, we need adequate freeboard and reserve buoyancy. Therefore we shape the boat with flare in her sections, especially forward, where there is danger that the fine bow will dive under a wave. This would be a very bad thing in the open Ratty. A decked-over boat such as Teazer is more forgiving in this respect; she can be knocked down but will not fill and sink.

Teazer is a coastwise sailer; most of her use will be daysailing, with very occasional overnight trips. Her arrangement is centered on a cockpit more than 12′ long, and this will comfortably accommodate at least six people. She is not an ocean cruiser, so cockpit volume is of no great concern. There are six large drains, and that is adequate for her use near shore. The cabin is small and simply appointed: there are four berths, a portable toilet, and lockers port and starboard. Cooking and eating will be done with portable equipment in the cockpit. A tarp over the main boom doubles accommodation space.

Now that we have considered some moderate-displacement boats, let's go on to a heavy-displacement, full-keeled hull and see what this means for performance and interior volume. Ease of construction is also a consideration, and see how displacement relates to structure. Also, I want to look at sailing balance and how the rig and hull are matched.

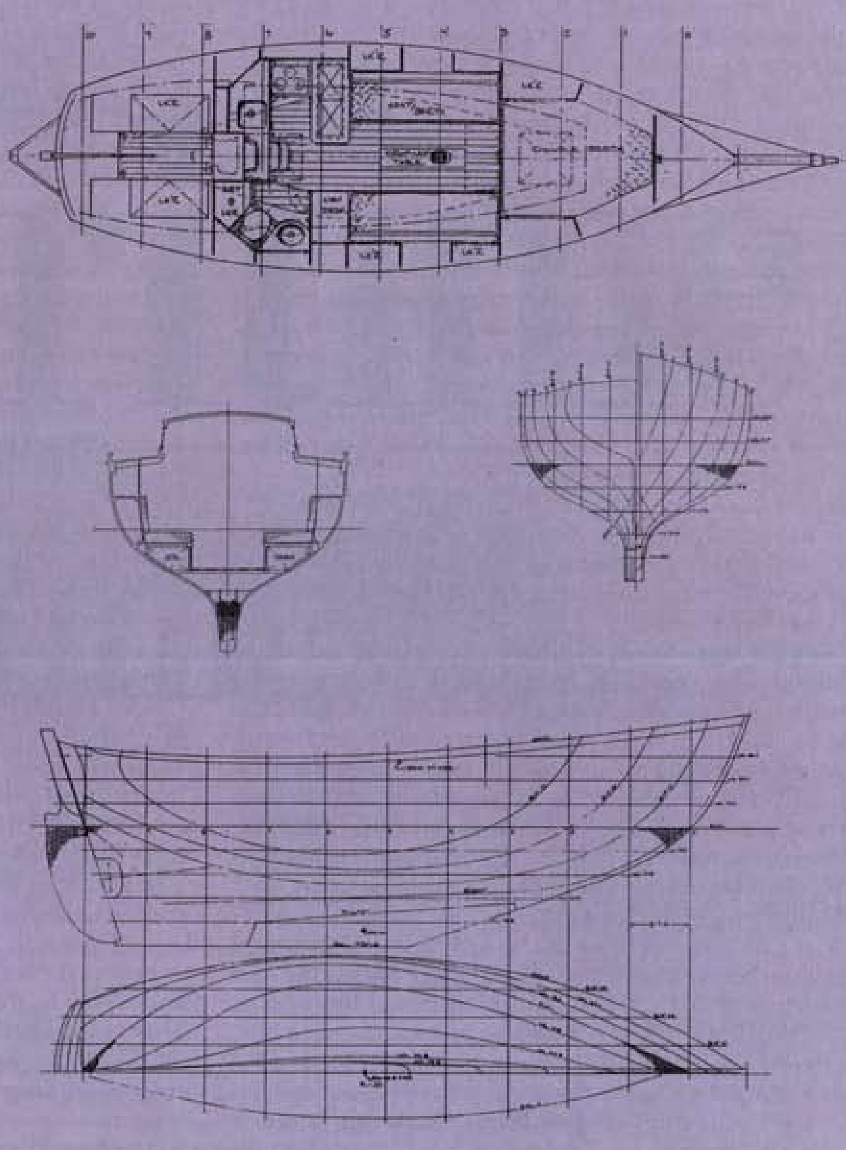
Hero
A 29′6″ Offshore Cutter

Now we look at a real oceangoing vessel. Hero is designed to go to sea and stay there. The quay punts of Falmouth, England, are the ancestors of Hero and of his close relatives such as Laurent Giles's WANDERER III, Lyle Hess's TALEISIN, and Billy Atkin's designs FORE AN' AFT, BEN BOW, and TALLY HO!. These boats were the principal characters in numerous cruising stories that I grew up with. For me, they represent the epitome of a small, self-sufficient offshore cruiser.

With Hero, I have chosen to compromise among these designs, with beam 17″ greater than that of WANDERER and 11″ less than that of TALEISIN. With a beam/length ratio of 0.33, Hero is close to the early Atkin boats. At 9′10″ this is right at the wide edge of the normal range of beam for keelboats of this length. Why not the wider and more roomy Hess version? In laying out the sheer in plan view, I just could not make a wider boat come out looking right. To me, Hero has a balanced-looking hull. WANDERER has finer lines than TALEISIN, but her interior appears cramped. As well as improving on WANDERER's accommodation, Hero's greater beam will provide decent side decks. The moderate beam also means a very high range of stability; Hero will still have positive

Particulars

LOA	29′6″
LWL	25′10″
Beam	9′10″
Draft	5′0″
Sail area	657 sq ft total
Mainsail	296 sq ft
100% Foretriangle	361 sq ft
Displ.	16,500 lbs
Ballast	6,300 lbs



Hero—This is a very heavy-displacement yacht, near the upper limit for a small ocean cruiser. The wine-glass sections increase stability rapidly as he heels.

stability upside down—at 180° of heel.

Hero is a very heavy-displacement yacht, the displacement/length ratio being 427. This is about the upper limit for a small ocean cruiser, though John G. Hanna's TAHITI is slightly heavier with a D/L of 438. TAHITI has a reputation for being slow, but I don't believe Hero will suffer the same fate. TAHITI is shy on sail area, with a SA/D of 10.6 with her coastal rig. Hero's SA/D ratio is 16.2, about average for a modern ocean-crosser. Next is draft: TAHITI's is 4′0″, Hero has another whole foot of depth, and as their displacements are similar, that extra foot is salient keel, which will really hang on as he works to weather. The last factor that tells for Hero's speediness is ballast. Hero carries 6,000 lbs of lead ballast outside. TAHITI is designed to carry 3,200 lbs outside. We can assume whatever further ballast was needed would be installed inside after the boat was launched.

The hull, deck, interior, machinery, and rig of Hero will weigh about 6,200 lbs. Ballast will total 6,300 lbs, fuel and water about 1,100 lbs, which leaves about 2,900 lbs for outfitting, crew, and stores. This will just bring Hero down to the designed waterline, and it will take almost 900 lbs more to put Hero down an inch below DWL. When sailing at design weight, Hero's Dellenbaugh angle will be 16.4°, average for this size cruiser.

I have extended the forward overhang considerably from that of the plumb-stemmed quay punt derivatives, the Hess and Atkin designs. Hero is closer to the Laurent Giles model and has more buoyancy and deck space forward. It also moves the inner forestay forward, giving us a lower-aspect staysail. The spoon bow pulls the lines out and, in my opinion, gives the boat a more graceful and less dated look.

Looking further at Hero's lines, we spot a full keel with deep reverses in the sections down low. Why would anyone choose a full keel with its disadvantages of increased wetted surface and poor efficiency as a lifting foil? Granted there will be differences in performance compared to a fin-and-skeg model, but perhaps those differences make sense for Hero's intended use. The main advantages to the full keel are simple and rugged construction of the basic hull, a nice deep sump for the water that inevitably finds its way into the boat, excellent protection for the rudder and propeller, and a boat that's directionally stable. This deep body plan also allows a lower cabin sole, lowering the overall profile and CG of the boat.

Certainly a well-designed fin keel and skeg-rudder boat can be directionally stable, and I believe that Teazer (and Wizard, to be discussed in the next installment) are such boats. But the fin-and-skeg hull can also be very quick to change course with minor inattention by the helmsperson. This quick reaction makes perfect sense in daysailing or coastwise cruising situations, but offshore it is less desirable. The fin keel is certainly more efficient at developing the side force needed to counteract leeway and the driving force of the sail plan. But structurally, the attachment of a fin keel and, more critically, a skeg-type rudder, can be an engineering challenge.

In a wooden boat, the fin must be attached with bolts that extend up through the keel into heavy floor timbers that carry this load out into the hull planking. The higher into the hull these floors extend, the farther outboard they will reach—which better spreads the loads. I like to tie some of these floors to bulkheads, again to aid in distributing those keel loads. In small boats this often means structural members that have to project through the cabin sole. In my experience, skegs always need some reinforcing to counter tremendous side loads. Usually this means the complication of either fiberglass or directional laminations of wood on the skeg. So the fin and skeg push the cabin sole up and create a more highly stressed structure—both negatives in my quest for a simple, rugged, and beautiful small cruising boat.

The wineglass sections are beautiful, but they represent another compromise. Here I am balancing the requirement for cabin-sole width down low versus volume up high. The more volume up near the waterline, the quicker the center of buoyancy moves outboard as the boat heels. I want a cross between a flat dish and a deep Vee, and come out with this lovely shape that is much steeped in history.

Getting the center of effort in the right place, so that the boat is longitudinally balanced while sailing, is a big part of directional stability. On each of the sail plans in this article, I have indicated the area and geometric center of each boat's mainsail, mizzen, and foretriangle. From these geometric centers I calculate a theoretical center of effort using a method that originated at the Davidson Laboratory of the Stevens Institute of Technology. A total CE is calculated by loading the foretriangle by 1.7 times its area; the main is taken at 100% and mizzen at 50%. This seems reasonable; the headsail is certainly more efficient than the main, which is interfered with by the mast. And the mizzen is operating somewhat in the wake of the main plus the interference from its own mast. Wind-tunnel tests show that the actual CE of sails is much closer to the leading edge, but it moves around depending on heel and wind speed. So this is just an approximation that is useful for comparison with other boats.

If this DL-CE (for Davidson Laboratory) is positioned somewhere between 27% and 38% along the waterline from the stem, the boat should be well balanced when sailing. Hero's DL-CE is at 34% while Teazer is at 38%, reflecting the differences between a cutter and a ketch. Most sloops and cutters will fall in the 32–34% range, but in all cases this must be compared to previous designs that proved well balanced. (For more information on DL-CE, see *Sail Performance* by C.A. Marchaj, International Marine, 1996.)

The other half of this equation is that portion of the boat below water that resists the side force of the rig. The theoretical center of this underwater area is referred to as the CLR, or center of lateral resistance. Of course, this center changes as the boat heels and moves through waves, but the idea is to get it to directly oppose the driving force operating through the CE; then the boat is balanced. In the past this CLR was just the geometric center of the underwater plane, and designers acknowledged it meant little by introducing a fudge factor called "lead." This was a percentage of the vessel's waterline length, commonly 10%–20%, by which the CE was forward of the CLR. Again by testing, this time in towing tanks, we know this geometric CLR is a long way from the actual hydrodynamic center. For a modern fin keel, the center of pressure will be close to its leading edge, about 25% of chord length back from it. The fin keel will generate the largest portion of the lateral resistance, and so actual CLR will be close to the root of the keel at the quarter-chord line.

Most small boats are not tank-tested, nor are their rigs tested in wind tunnels, so we continue to rely on the old geometric comparison methods for most designs. Unfortunately, this means that sometimes things don't turn out perfectly and adjustments must be made to the rig or underbody, or both, after sailing trials.

Hero carries a cutter rig because it offers many opportunities to shorten sail while remaining balanced. The first sail taken in is the big genoa flying from the end of the bowsprit. Next the main is reefed; two reefs bring the head down to the staysail stay, which is backed up by the running backstays. We now have a short, all-inboard, heavy-weather, masthead rig. If the wind continues to build, we'll drop the staysail and carry on under main alone. In more wind and depending on the point of sail required, we'll use either the main trysail or the spitfire jib, or both.

Because Hero is designed to take two people anywhere in the world, his cockpit is small. If it floods, the extra weight won't sink the boat. Steering is with a tiller; a self-steering vane and trim tab can easily be fitted to the outboard rudder. Six of the eight boats we'll look at have outboard rudders. This gets the control surface as far aft as possible, which increases the turning moment. I also like its obvious simplicity and honesty.

Hero's form is steeped in history. For contrast, in Part 2 we'll look at a totally different form adapted from seemingly opposing traditions. With the light-displacement Tilikum we will again look at length, weight, and hull form. Also we will consider tandem centerboards and how this hull might match the Chinese lug rig.

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