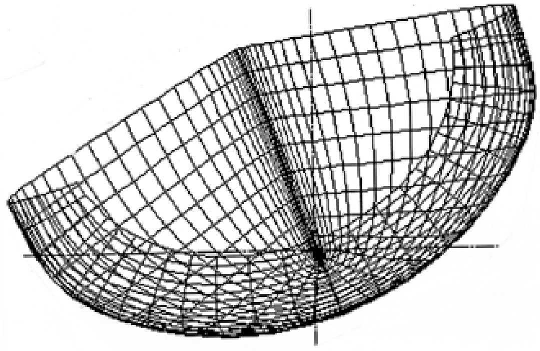
TOC

Last Chapter

Next Chapter

Help!



CRUISING DESIGN

Efficient cruising is one of the great pleasures in life. When the rig, fins, payload, and hull shape strike an efficient balance, the boat has an extra "sweet" feel. This extends to efficiency in the interior, as well as to hull form and lifestyle trade-offs. Finally, an efficient set of systems will add the polishing touch to a perfect passage.

Yet with so many hydrodynamic and budget trade-offs, it's rarely possible to find the perfect yacht. Personal needs and goals change, and as you gain experience, what you once saw as "the ultimate combination" suddenly looks a little dull. There's always another, better way to do it.

Linda and I have tried in the following chapters to outline the basics of hull design, rig engineering, systems, and interior layout. We hope that after reading this, you'll make up your *own* mind about what constitutes the optimum yacht.

DEFINING NEEDS

The key to putting together a successful yacht is to be realistic about cruising plans. For most, cruising means daysailing, weekend sails, and maybe a couple of weeks spent on the boat during the summer. If your sailing is limited to Long Island Sound or Catalina Channel, it doesn't make sense to equip for a circumnavigation, or to make the trade-offs that make the hull capable of handling a survival storm.

On the other hand, if you plan to go offshore, seakeeping abilities are high on the list of priorities.

Synergism

There's a certain beauty when the various elements of a yacht synergistically reinforce each other. Each decision, whether regarding refrigeration systems or roller-furling, has an interrelationship with everything else aboard. Consider *all* the ramifications of each decision, including those which apply to your own *unique* circumstances. As soon as you understand this, you're well on your way to successful cruising.

You don't need size to go around the world — what you need is a seaworthy design. We met this singlehander in Tonga. Jim, a containership master with P & O Lines, periodically takes time off to continue his cruise around the world in this simple yet elegant 26-foot (8 m) yacht.

How Small Can You Go?

You've read quite a few comments so far about going to sea in the biggest boat you can afford. For a lot of folks, that will tend towards the smaller end of the size range. Linda and I are frequently asked, how small is acceptable?

The answer to that lies in how adventurous you feel, and what sort of comfort level you require to enjoy yourself. We've seen many cruisers in far-off ports on the second, third, or fourth year of a cruise aboard 25-footers (8m). Yes, the boats are a little cramped, but the sailors are still having a wonderful time. Passages on a small boat are bouncier, and probably longer, than passages on a large yacht; but as we've said before, you spend a very small percentage of time at sea.

We've seen several converted lifeboats and whale boats cruising in remote areas. These vessels — in the mid 20-foot (6.8m) range — are typically quite spartan, but in each case their crewmembers seem to be enjoying themselves immensely.

Sure, the risks may be higher on a small boat than if you wait for the budget for a larger vessel. But life is full of risks. You never know what's coming around the bend.

The key is to *go cruising*. Sitting around and dreaming doesn't count for much. If you have the desire, go *now*. You'll encounter many new and wonderful experiences to offset the occasional discomfort of a small boat.

OFFSHORE PERSPECTIVE

Later we'll get into the details of choosing a boat or evaluating your present vessel's cruising capabilities. For now, some comments on the offshore perspective are in order.

If you plan to sail in protected waters, along a coastline with generally good weather and plenty of harbors of refuge, you won't need certain design characteristics that would be desirable offshore.

If you're headed offshore, however, it makes sense to go in the most suitable vessel your budget will allow. This may involve some trade-offs in interior volume or in superstructure. In the end, you'll find comfort in the knowledge that you have the safest possible vessel, able to handle heavy weather as well as to provide a comfortable ride in pleasant conditions.

Because so many different ingredients go into the makeup of a "seaworthy" yacht, we thought it would be best to start this section with an overview of the basic factors as they apply to *extreme* wind and sea conditions. You can then weigh these factors when choosing and equipping a yacht for your own style of cruising.

STEERING CONTROL

In our opinion, the single most important heavy-weather issue is ability to steer the boat in big seas. This is critical at high speeds as well as when going slow, whether sailing upwind or down. Steering ability affects comfort during moderate passages. It impacts the power required to run the autopilot, and determines whether you need a big windvane. Boats that are easily steered have far less motion, especially running in the trades, making rest easier for the crew.

The issue of steering is surrounded with all kinds of debates. For almost 40 years we've been working on ways to make boats steer more easily — and we still learn something new each time we go to sea. Still, many (not all!) sailors agree on a few basic issues:

Helm versus Waves

Before we get into design details, let's look for a moment at the two major factors that affect your need to steer.

The first is the relationship between the rig, hull, and fins. As true wind angle and speed change, or as the sailplan is modified by adding or reducing sail, the helm-balance relationships vary. Your choices regarding sail size, where sails are flown, and how they are trimmed offer a great deal of control over the balance issues.

With most boats, most of the time, you can eventually get hull and rig into balance. Once this is achieved (if the wind direction and velocity remain more or less constant, and if you're in smooth water) the boat will stay on a straight course. But then along comes a series of waves, hitting you on the bow, the stern, or amidships, and imparting huge amounts of force. The size of the waves, where and at what angle they hit is a constantly changing equation affecting the boat's ability to stay on track.

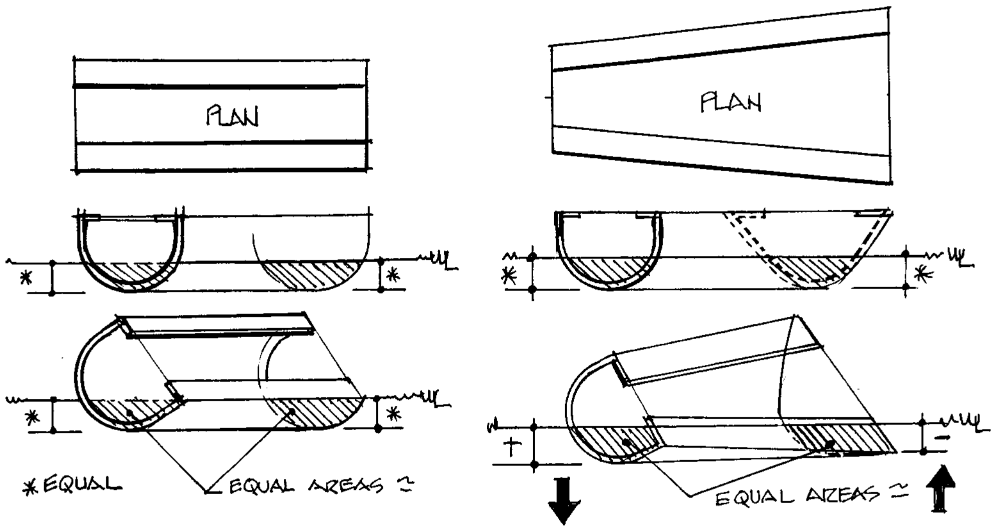
On a yacht used for coastal cruising, you need be concerned only with hull and rig balance and with the steering forces needed to overcome any unbalance. For offshore work, however, the focus shifts to recovering from or avoiding the course disruptions brought about by the seas. This is a more difficult challenge.

Hull Balance

How a hull maintains or changes balance with heel has a major impact on the tendency to head up into the wind when a gust hits or when slapped by a wave.

Ideally, the various hydrostatic relationships remain constant as you heel through a normal sailing range (except for prismatic coefficient, which we'll discuss later on.) But for a variety of reasons, this goal can be difficult to achieve. A hull with good balance may lack physical space on the interior or may not comply well with a particular handicap rule.

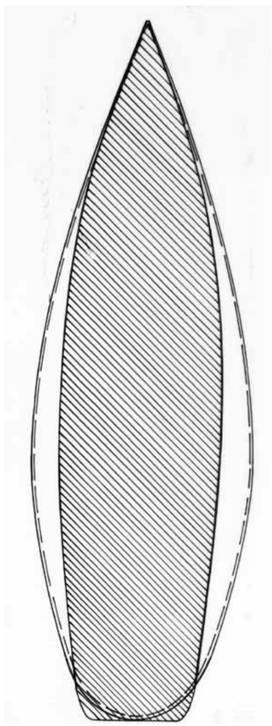
Consider a hull shaped like a pipe cut in half length-wise. As it rolls over, the shape always looks the same to the water (i.e., it has the same cross-sectional area whichever way it is turned).

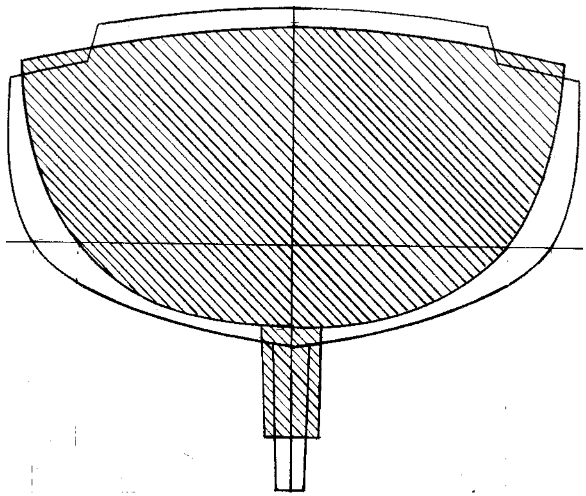


Two views of hull balance and heel. On the left is what happens if you heel a section of pipe (or a barge). The fore-and-aft distribution of volume stays the same with heel. On the right is an unbalanced shape. The bow pitches down and the stern up with heel. In addition, the centerline of the hull rotates so that the keel is crabbing, which creates very high levels of drag.

This is a balanced shape. Of course, this shape might be tough to live in and will lack stability. On the other hand, picture a floating hemisphere. Again you get perfect balance with heel angle, this time with problems pushing the shape through the water. A rectangular barge is third example of a balanced hull form.

To get the hull to afford a livable interior requires some length and beam. Beam is also necessary for upright stability. To get through the seas, the hull needs some sort of a point on one end. The problem is how to balance these needs against steering.





A comparison of a design with a 4-to-1 length-to-beam ratio, and a design with a 3-to-1 ratio. The skinnier boat will track better and develop less helm with heel.

The shallower, flatter midships section is a more effective end plate for the keel. The end plate and shallower bilges make possible less draft, while the keel maintains comparable lift-to-drag characteristics with its keel as well as with the deeper but fatter hull.

TOC
Last Chapter
Next Chapter
Help!

TOC
Last Chapter
Next Chapter
Help!

Length-to-Beam Ratio

The first key to this design conundrum is having a hull that is substantially longer than its beam. The greater the length-to-beam ratio, the easier for the designer to work out a shape with good heeled balance.

Over many years we've found that length-to-beam ratios of around 4-to-1 (or higher) work well. If you can reach 5-to-1, so much the better. *Sundeer* and *Beowulf* are close to 6-to-1.

With larger vessels — those above 45 feet (14 m) — this doesn't have much of a negative impact on interior living space. On smaller yachts, however, the interior starts to get cramped.

So, with smaller boats we immediately get into a major trade-off: Do we sacrifice interior room for seaworthiness?

Curve of Area

Many yacht designers use "curve of area" — a plot of how volume is developed in the hull — as a primary design tool. This plot illustrates the submerged portion of the hull when upright and shows how the hull looks at various heel angles.

The relationship between bow and stern areas determines upwind/downwind speed relationships, as well as the relative hull speed in light or breezy conditions.

If the hull shape is balanced with heel, you can take the upright and heeled curves of area, overlay them, and they will fit on top of each other.

There are many ways to work up a curve of area that stays constant with heel. One is to draw a true double-ender. Another, used in many of the wide BOC designs, is to draw an elliptical shape.

Each option, however, is associated with problems. The true double-ender has a hard time releasing its quarter wave at any significant speed — so it is efficient only in light airs. The BOC shape, at the other extreme, lifts so much of the stern out of the water that a centerline rudder is useless — hence the development of twin rudders. Twin rudders have their trade-offs, too, which we'll discuss later.

For most cruising situations, the optimum lies somewhere between these extremes. The better the beam-to-length ratio, the easier to draw a balanced curve of area.

Bow Shape

Another important issue is the bow shape when looked at in section (i.e., from the forward part of the boat looking aft). Designers often refer to this as the "dead rise" angle.

Walk around any boat yard and you'll see all sorts of bow shapes. Some are deep and V-shaped, while many modern boats are extremely flat up forward.

If you only consider steering control, flatter is preferable to a V shape. The flat shape does not lock into the water as does the V, so it is more easily turned (with less immersed area under the water there is less resistance to turning — just the opposite is the case with a V-shape).

Five different approaches to bow shape. The top two hulls are heavy-displacement designs with quite deep bow sections. The middle two are moderate-displacement bows. All four of these vessels are about 40 feet (12.3 m) in length and have 24-degree entry angles. Compare this to the two views of the Whitbread 60 at the bottom. This is a very light-displacement hull shape, combined with a narrow 16-degree entry angle. Even though this is the flattest of all the hulls, it also yields the smoothest ride, as the entry angle is so narrow.

A traditional hull design based on 19th-century whale boats. This hull shape achieves its balance with heel by having lots of volume forward. This works but does present a bluff bow to the waves which makes for a bouncy, slow ride to weather.

There is one small drawback, however. If you're not careful, that flat bow will pound so hard when sailing to windward that the noise and motion will be unbearable.

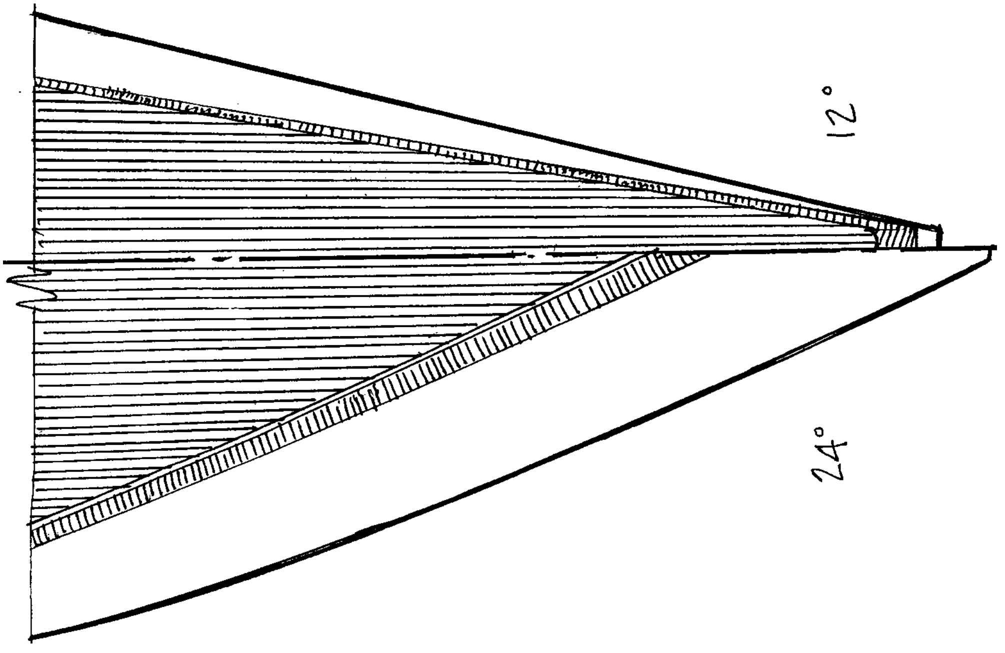
For work in smooth water, deeply V'd-shapes are fine. The fact that they lock in provides a degree of directional stability, and they cut better through the chop going upwind. But once you head offshore, you have to deal with those waves banging into the hull. And there is *nothing* you or your designer can do to avoid being turned this way and that by the waves. The V-shape will hold you on course once the wave has helped you establish a new direction, but it won't stop the wave from making that change.

The concept of "directional stability," no matter how well executed, can do little to hold you on course in heavy conditions. Rather, it makes it harder to get back on course after the boat has been turned by the seas.

Therefore, we prefer for offshore work a bow shape, keel, and rudder combination that steers easily, returning the boat to its course after the wave has finished its work.

Half-Entry Angle

So far we've talked about bow shape in a two-dimensional context, looking at the shape up forward. Nevertheless, the bow is a three-dimensional object. Pounding is determined by both the shape when looking from the bow aft, and by the plan view when looking up from beneath the boat.



Here is a comparison of a traditional 24-degree entry angle and what you are starting to see on some of the higher performance boats where waterline is not rated — 12 degrees. The lined area represents a cut through the waterplane of each at the waterline. The solid perimeter represents the deck edge. Obviously the finer entry, longer waterlined shape will cut through the waves more easily.

TOC
Last Chapter
Next Chapter
Help!

An extremely V'd bow with a wide plan shape may pound more than a flat shape with a narrow entry angle.

As the waterline is lengthened relative to beam and displacement, this entry angle (viewed from below) becomes much narrower. That's another reason boats with favorable length-to-beam ratios steer more easily.

This angle is usually measured from the centerline at the waterline. Most cruising designs with short waterlines have a half-entry angle around 22 to 24 degrees. Many high-performance IMS boats are down to around 16 or 18 degrees. The Sundeer Series of yachts we've done in the last few years have typically come in with half-entry angles in the 11-to-12.5-degree range.

Upwind Issues

Now let's consider how the bow interacts with waves when heading to windward. As the bow and head sea first collide, the bow begins to slice its way through the wave. The wave, of course, is trying to hold the boat back. As the drive of the rig and momentum of the hull force the bow deeper into the wave, forward energy is transferred from boat to wave. The more bow for the wave to grip, the more energy lost. You decelerate, and the bow begins to lift in the wave.

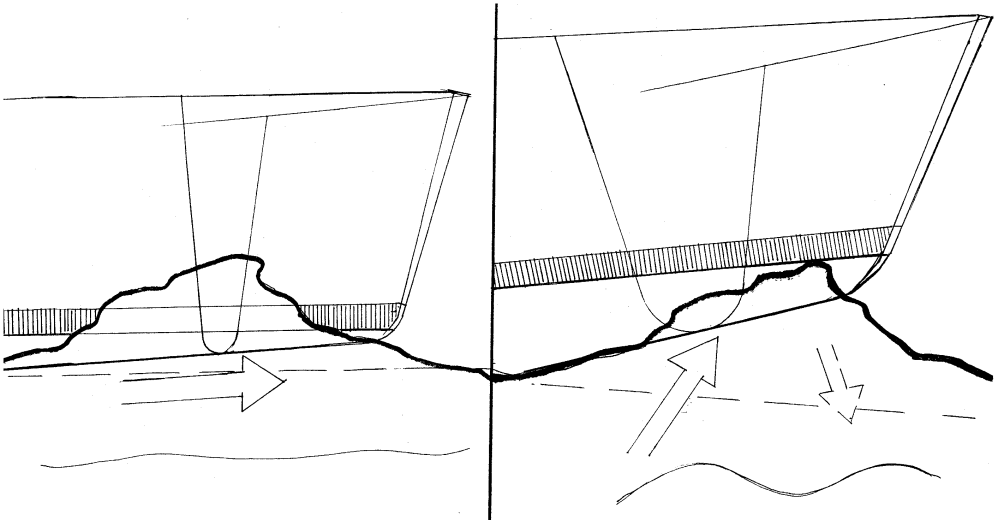
The fatter the bow — whether through waterline beam or topside flare — the more resistance through the wave.

It's pretty obvious that the finer the bow, the easier to get through the wave, and the faster and smoother you'll sail upwind.

Once the bow is through the wave, if the sea is steep enough and there's nothing on the back side of the wave to support the bow, you drop into the trough. This is where that annoying slamming occurs.

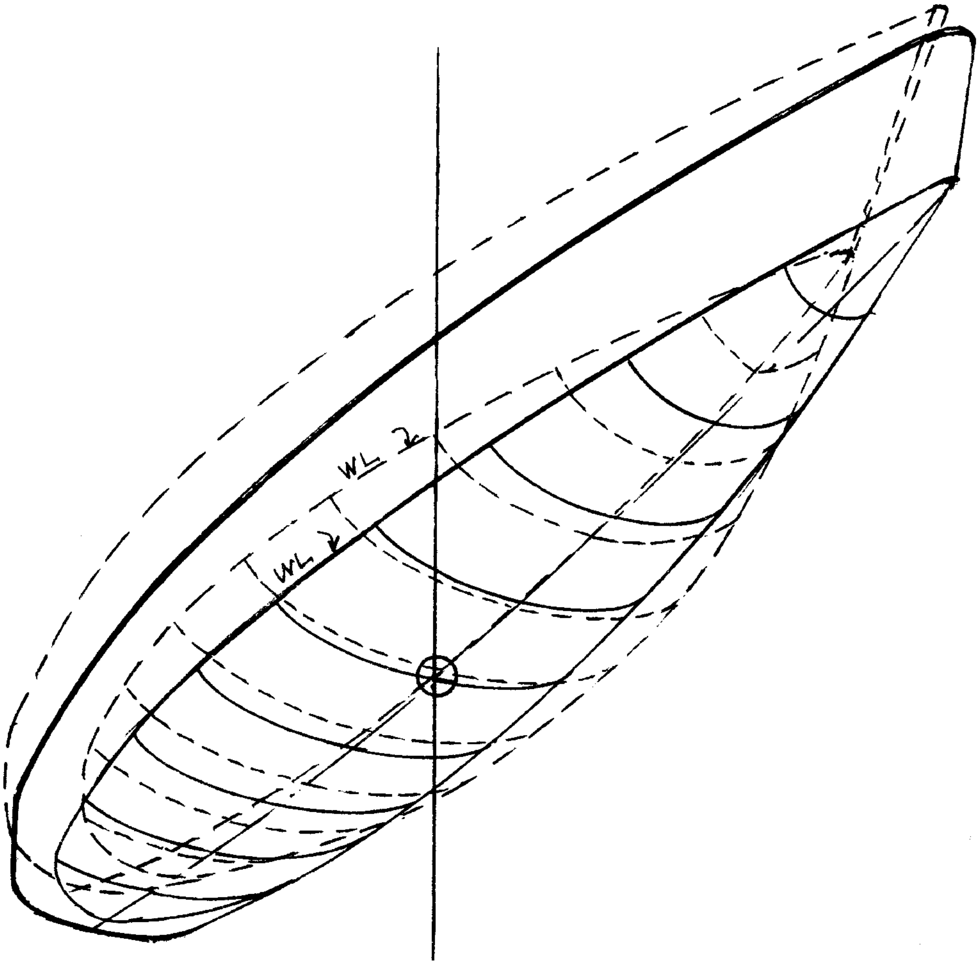
The magnitude of the slam is a function of boat, wave speed, wave angle, and the shape of the hull (especially when it is heeled) as it hits the oncoming wave. You can modify the slamming impact by changing course, changing tack, speeding up or slowing down, or increasing or decreasing heel.

Modern yachts with narrow bows and flat or U-shaped bottoms present a softer face to the wave when heeled. On the other hand, older designs, with lots of topside flare forward, have a large flat area in the bow when heeled. These tend to slam less, if kept upright where the V-shape can soften the impact.



With a sharp bow shape (left) you can penetrate waves more easily. There is less volume for the wave to grab. This is important at all angles of sail (up and downwind) and when motorsailing to windward. A bow with more volume gives the waves a better hold on the hull. The wave can then exert more force to shove the bow up and start a pitching motion, while retarding forward progress.

TOC
Last Chapter
Next Chapter
Help!



The real test of a cruising hull comes downwind in heavy weather. Here you need volume and, if you are fast enough, dynamic lift to keep the bow from burying as you surf down steep waves. As the waterline lengthens, even though the bow is drawn narrower, you can actually end up with more fore-and-aft stability, as is shown in this drawing.

The dotted line represents a typical, modern cruising hull with quite a bit of overhang at the ends. The solid line is more like one of our Sundeer Series. Because the waterline is so long, even though it is narrower in the ends, there is more net volume (and planing surface at high speeds) to keep the bow high and dry as you accelerate down wave faces. A good comparison would be the Sundeer 64 and a Swan 65. The Sundeer has almost 50% more longitudinal stability. When you add to this a very narrow shape, that easily enters the wave without undue resistance, you have the best of both worlds: A soft ride and dry decks — in both directions.

Downwind Issues

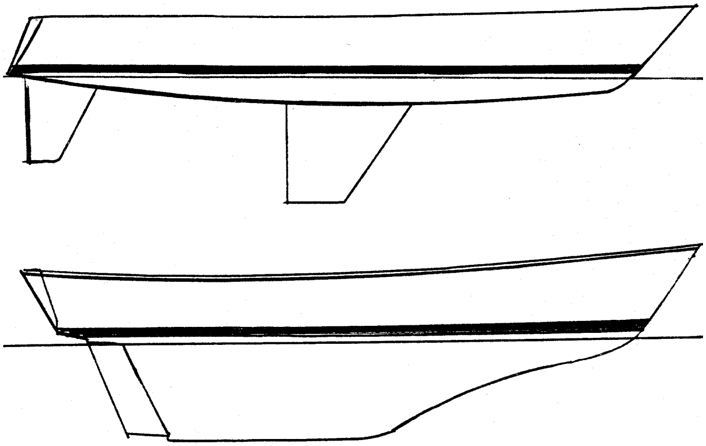
The issues are somewhat different when headed downwind. No longer do you worry about penetrating the waves — unless you're sailing an extremely fast boat and overtaking the seas. Nevertheless, if you push the boat really hard (i.e., surf down waves), a certain amount of buoyancy is required to support the bow as it reaches the bottom of the wave. This support prevents the bow from burying at the end of the surf.

Here we have two diametrically opposed requirements: one, a fine bow for heading uphill, and two, a full bow to provide buoyancy downwind.

Racing boats are always drawn with fine bows, since races are typically won or lost on the windward legs. A cruising boat, however, should be able to be driven hard downwind in heavy weather.

Although you can never entirely escape this trade-off, a longer, narrower boat will reduce the differential between upwind and downwind shapes.

TOC
Last Chapter
Next Chapter
Help!



The hull, if balanced, will tend to stay on a straight course until upset by a sea. Once off course what you want is the most efficient steering system.

This is provided by a separated keel and rudder — the more separation, the better. The keel provides a pivot point about which the rudder turns the hull.

TOC
Last Chapter
Next Chapter
Help!

Keel Plan

Since we're talking about steering control we need to briefly discuss keels.

Our experience over the years has been that keels play a small part in the steering equation. In a steering context, we believe their primary steering function is to act as a pivot point about which the rudder turns the hull.

Anything beyond the minimum fin area is a definite negative. Fin area should provide lift when beating into headseas, as well as a place to store ballast, and support while hauled or aground.

What about all those stories of full-keeled cruisers? Yes, a long keel provides directional stability in smooth water. The problem is that the keel does little to offset wave impact on the bow or stern. A long keel only makes it more difficult for the rudder to get the boat back on course.

Over the years, we've designed shorter and shorter keels, while our boats have become easier to steer and more comfortable.

Rudder and Hull Interaction

In order to be most effective the rudder must be totally immersed — meaning the top of the rudder cannot pierce the surface of the water. An immersed rudder will generate twice the lift, for a given amount of drag, of a surface-piercing foil. This is due to the end plate effect of the hull, doubling the effective aspect ratio of the rudder.

The minute the rudder pierces the surface, however, induced drag doubles and lift (steering force) drops precipitously.

If your hull shape stays in trim in a fore-and-aft plane as the boat heels, and if the beam aft isn't too great, the rudder will remain immersed as you heel through normal sailing angles. This is assuming the rudder is immersed when the boat is upright.

But with a wide stern, or if the hull tends to trim bow down (and therefore stern up) with heel, you must watch steering control carefully in heavy conditions, as the rudder will tend to ventilate very quickly with heel.

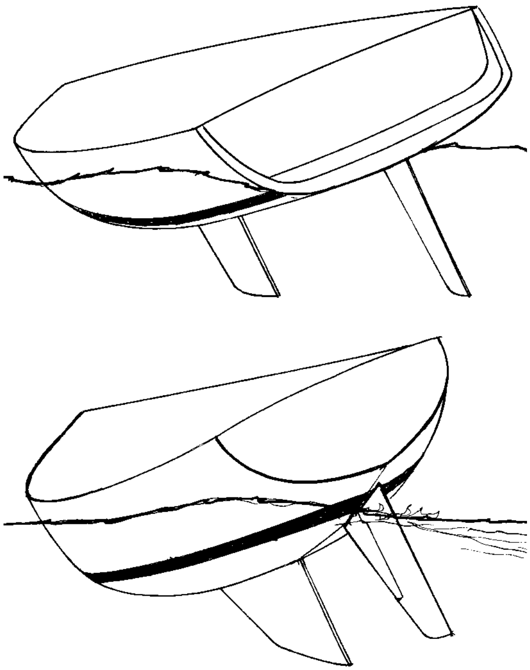
You may be okay if the rudder is just barely free of the water surface at rest. In many situations, the quarter wave follows the hull aft to the transom, providing a seal for the rudder.

Rudder Stall

Requiring rudder force to change or hold course increases the rudder's angle of attack — or, the angle of the rudder to the centerline of the boat. The lift generated by the rudder is directly proportional to this angle of attack. Lift increases with the square of your boat's velocity. A rudder with a given angle of attack that generates 100 units of force at 6 knots will generate 156 units of force at 7.5 knots.

For most steering conditions, you need turn the rudder only a few degrees off-center. A common mistake is to turn the rudder too far when you think you need a lot of help steering. There is a point at which the rudder can no longer generate lift, and the flow on the foil begins to separate. At this point, the rudder stalls. You can tell you've just stalled the blade if you have good pressure on the wheel (when turned), and the helm suddenly goes mushy, sometimes accompanied by a whooshing noise from the rudder. At this point you lose control of the boat. Aside from getting the hull and rig back into balance, and/or reducing heel angle, the only solution is to wiggle the rudder back and forth in quick strokes, trying to get flow to reattach.

If you operate the rudder close to the stall point, and if the hull heels a bit more, breaking the end-plate effect of the hull, the top of the rudder will begin to ventilate. This causes the rudder to stall immediately.



Correct rudder-and-hull interaction is a critical factor in steering control. As long as the hull provides an end plate effect for the rudder, the foil is efficient. The minute the top of the rudder lifts clear of the surface, the end plate is broken and aspect ratio is halved, drag increases dramatically, and steering power is lost. All hulls, at some point, lift their rudders clear with heel. The trick is to delay this as long as possible.

The top drawing shows a wide stern design with minimal stern overhang, and the rudder is well covered. This requires balanced lines so the stern does not lift with heel.

The bottom drawing is a boat with longer overhangs and a finer stern. With this hull shape the rudder will uncover at early angles of heel. You could move the rudder forward to maintain the end plate, but this would reduce the leverage that comes with distance from the turning center provided by the keel.

What we are trying to show is that you cannot stereotype hulls. Many people claim that the conditions should be the reverse of what is drawn. However, careful attention to how the bow and stern sections are drawn can make it possible with either type to keep the rudder covered through the normal range of sailing angles.

Reducing Rudder Stall with Design

A number of things can be done to the rudder shape to defer stalling. First is thickening the foil shape of the rudder. Thicker foils are less sensitive to stall than thinner foils. Of course, thick foils also have more form drag and are slower at low-to-medium speeds. We typically favor foil sections in the 12 to 14 percent range for the bottom of the rudder, and usually around 19 to 22 percent at the hull where we need space for the rudder shaft.

Aspect ratio is important. Deep rudders with short chord (fore-and-aft) dimensions are more efficient at generating lift than shallow fins. Deep rudders also leave more blade in the water as the boat heels. However, deep rudders are difficult to protect and engineer.

The most important issue is blade area. A bigger rudder generates the same lift as a smaller rudder at a lower angle of attack. Since excessive angle of attack is what causes stall, big rudders generate more turning force before stalling. Yet these rudders are slow in normal sailing conditions.

A cruising yacht is better off with a rudder that is slightly oversized for everyday sailing, giving some insurance in a blow. This also pays dividends when maneuvering in tight quarters, whether under sail or power.

Rudder Configurations

The three basic rudder configurations are keel-attached, skeg-mounted, and spade. The spade rudder is by far the most efficient, the skeg-mounted rudder second, and the keel-attached rudder least effective.

Of course, structural issues should be evaluated. Consider how the rudder works at sea, as well as what would happen to it in a grounding.

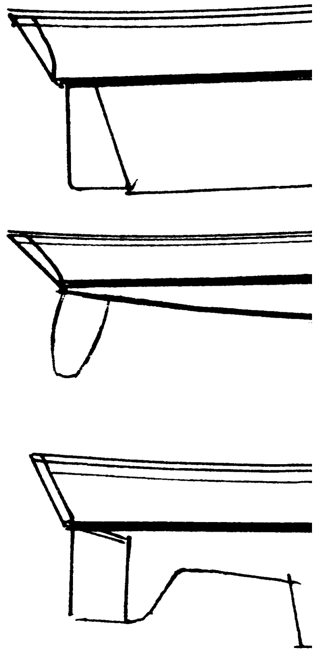
The most important thing to consider is how well the boat handles in heavy weather. In this situation the spade rudder wins hands down, both in terms of steering effectiveness and the power the spade requires to be exerted to keep your boat on course (for crew or self-steering).

TOC
Last Chapter
Next Chapter
Help!

"Traditional Yacht" Steering Characteristics

What about all the wonderful traditional yachts in the old days — the ones with the long keels and attached rudders? Those vintage yachts that steered so well were extremely narrow for their length (typically 5- or 6-to-1 on length-to-beam ratio) and had beautifully balanced hull lines. As a result, very little steering force was needed to keep them on track in smooth water. That's a good thing, since you can't force a boat back on course with a barn-door rudder attached to the keel.

Offshore in a blow, traditional boats were a real handful to steer and had to be slowed down due to the risk of broaching. The boats were much harder on their crews and much slower than well-designed modern yachts. And short-handed passagemaking? Forget it. A typical 50-footer (15.4m) carried four experienced crew.



Keel-attached rudders (top) generate the least turning force for their size. Skeg-mounted rudders (bottom) are a big improvement. However, balanced spade rudders (middle) are by far the most efficient at generating good steering control with minimum input from self-steering gear or helmsman.

Rig Factors

The center of lift in the sailplan has a clear relationship to the hull/keel combination. In theory, the rig's center of lift should be just behind the center of lift of the hull and keel. (Actually, in modern yachts you typically ignore the hull and use the center of lift for the keel only.) This creates a touch of weather helm, which is considered good.

I would be less than truthful, however, if I claimed to understand the details of this phenomenon. Yes, our yachts tend to balance beautifully, and we have certain formulas that predict where to put the keel. But think about the following situation: You're close-reaching, the wind is blowing, and you spot some chafe on the seam of the mainsail. You furl the mainsail and continue under jib alone — you've probably done this before. Logic would dictate that the boat develop a huge amount of lee helm. The center of effort of the sailplan is far forward of the center of effort of the hull/keel. Yet as you may know if you've tried this, you will have a balanced helm, developing weather helm as big puffs develop.

Another scenario: You're sailing with a reefed main and working jib. As the breeze increases, the boat heels and weather helm builds up — unless you've got those balanced lines. So you furl the jib and put up the staysail. Now the area of the forward triangle is reduced, so the center of effort in the rig moves aft. Logically, the weather helm should increase, but just the opposite occurs — as heel angle eases up, weather heel is reduced.

When beating or reaching on ketches like *Wakaroa*, *Beowulf*, and *Sundeer*, we sail with main and jib, with mizzen and jib (without the main), or bareheaded with just the main and mizzen — without making a big difference on helm!

Sail Shape

Sail shape does, however, impact helm. More efficient jib shape and main shape create less weather helm. When beating or reaching in heavy conditions, the right shape makes a huge difference in helm load.

For both main and jib, this means a relatively flat sail, with the pocket as far forward as is practical. For headsails, having the sheet lead far enough aft helps to flatten the foot of the sail and allows the head to twist open. If the lead is too far forward, just the opposite happens, increasing drag, heel, and helm.

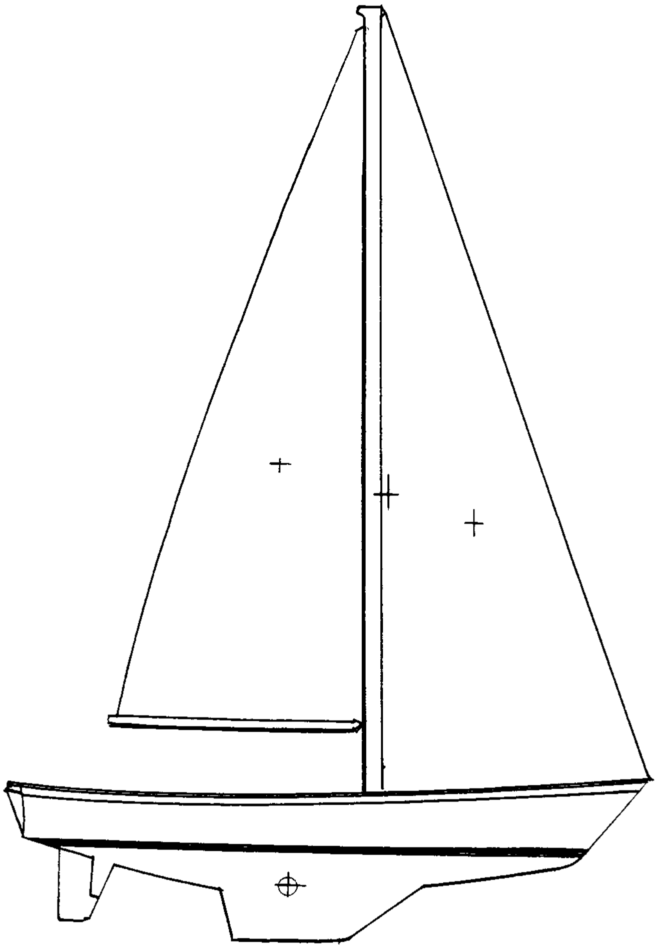
Aging sails tend to become drafty, and their pockets typically move aft. Both factors increase weather helm.

TOC
Last Chapter
Next Chapter
Help!

Self-Steering Power

We discuss self-steering at length in the preparation section. However, I'd like to reiterate the importance of powerful self-steering gear in the context of both comfortable cruising and heavy weather.

A boat that is easy to steer in a given set of conditions will need less power to get the job done. This applies to windvanes as well as to autopilots. When it's blowing hard, a servo-pendulum type of vane will probably be stronger than any crewmember. Yet the tendency with pilots is to go with drive motors sized for normal conditions. This is exactly what you don't want to do. Size the pilot drives for gale forces. The motor with the bigger drive will only use more power when it needs to work harder. In more moderate conditions, power consumption will be the same as the smaller drives. And you'll have fewer maintenance problems.



This drawing shows the traditional method of calculating rig-and-hull balance, a system that has been in use for several centuries. Start by calculating the geometric center of each sail, and then find the center between the two sails. Next, calculate the center of the underwater hull shape and fins. The center of the rig area is then placed somewhat forward of the center of the underwater areas.

What is so interesting about this approach is that you normally end up with weather helm (which, to a degree, is desirable), even though having the sail area ahead of the hull keel area should result in leeward helm.

Enter the computer. About fifteen years ago we (and several other designers) began to use the computer to calculate "lift" centers for the rig and keel. Once a lift-prediction program is dialed in, it can be used with some degree of accuracy to predict smooth water unheeled forces.

With the computer as a tool we now put the aerodynamic lift center of the rig *aft* of the hydrodynamic lift center of the keel. This does, as you would expect, produce a degree of weather helm.

Evaluating the Boat

How do you know if a boat will steer well offshore in a seaway or in heavy weather? The first thing to do is to talk to folks in a similar vessel who have been caught in weather offshore. Ask what sort of sail configurations they used, how well the self-steering worked, and at what point they had to take over and hand-steer. Find out how the boat handled in the trades. Did it tend to roll, swinging its bow back and forth, or did it track straight down the seas? How often were they forced to shorten sail or slow down because they couldn't control the boat or it tended to broach?

An even better plan is to head offshore for a good shakedown cruise. Hang out until you find boisterous winds and, even more important, good-sized seas. Push the boat hard, carrying all the sail you can manage. This will teach you what to expect when sailing with a more conservative rig in really bad wind and seas.

TOC

Last Chapter

Next Chapter

Help!

SURVIVING A KNOCKDOWN

With good steering control and reasonable seamanship, a knockdown should be a rare occurrence. Still, when heading offshore the risk exists. It's important to evaluate your chances of finding yourself with the spreaders in or under the water.

Wind-induced knockdowns are frequent in the racing fraternity, typically the result of pushing too hard with a spinnaker. They are so common, in fact, that unless the chute blows or the mast comes down, nobody thinks much about them.

While getting flattened in this fashion is rare for cruisers, it's worth checking out the mechanics. A knockdown is basically a function of too much wind force on the rig and not enough righting moment (restoring force) in the hull and keel.

As the boat heels over, the sails recline at an ever-increasing angle, and the wind has less to push against. At the same time, the righting moment of the hull is increasing steadily with heel (most yachts have a maximum righting moment at around 60 degrees of heel).

At some point the force of the wind is no longer strong enough to overcome the restoring force of the keel, and the boat hangs at whatever angle it has attained.

When the wind drops, the boat comes back upright to the point where the rudder can get a grip on the water, sending you on your way.

Absorbing Wave Impact

We are more concerned about wave-induced knockdowns when cruising offshore.

In this situation, the breaking crest of a wave hits the topsides, imparting energy to the hull. This works very much like the punching-bag toys we used to play with as kids — only now, the punching bag is the boat, and the breaking crest of the wave does the punching.

The magnitude of wave energy imparted to the hull and how the hull deals with that energy determines how far the boat will heel.

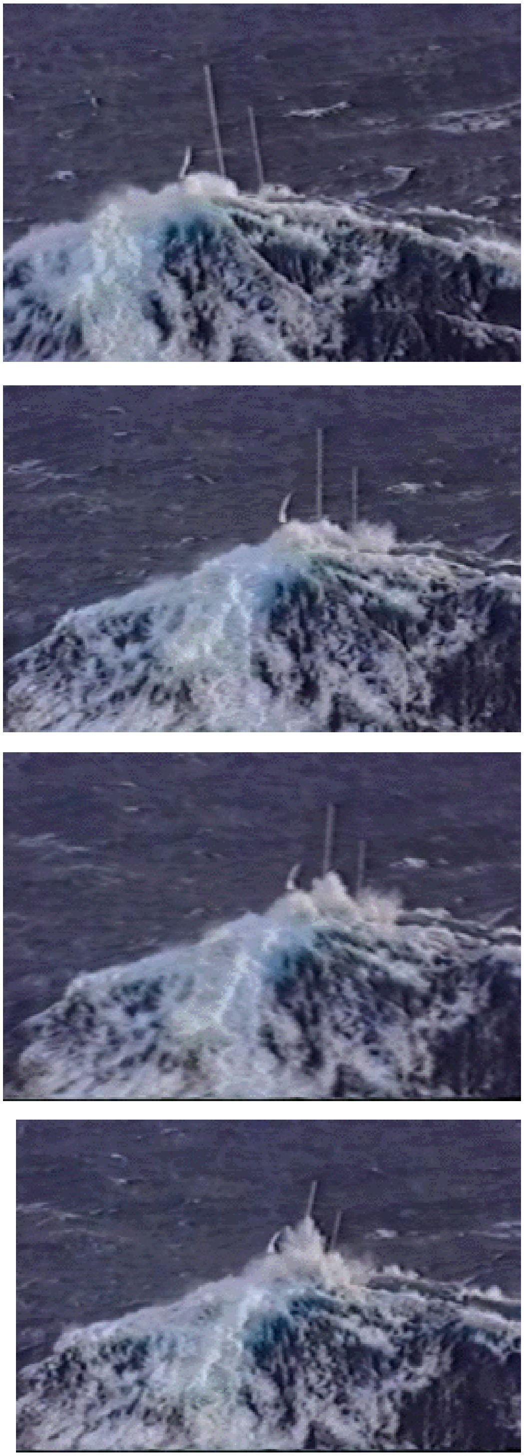
The following 13 photos were lifted from U.S. Coast Guard video footage shot in a Gulf Stream gale. The entire sequence takes place in less than 5 seconds. The vessel involved, a Morgan Out Island 41, is a shallow-draft centerboard design. The shallow canoe body combined with the high freeboard of the flush deck hull, offers good *skid* characteristics. The ketch rig increases polar moments, another positive feature. On the negative side, this hull is beamy with a shallow rudder and is difficult to control in big seas.

Even though we've used these photos to show good skid characteristics, this yacht was never designed or built with offshore work in mind.

You can see the boat (upper right) in a dangerous attitude to the seas. She is almost beam-on, and any wave impact will very efficiently impart a rolling moment to the hull. If she were bow or stern to the wave, there would be significantly less tendency to knock the boat down. The crest is just starting to form.

In the lower two photos, the wave is forming a nice crest and is bearing down on the hull to leeward. The bottom right photo shows impact just beginning to be made by the crest. Notice that the hull is already sliding to leeward as the mast begins to heel.

TOC
Last Chapter
Next Chapter
Help!



The four photos above show the hull reacting to wave impact. The hull seems to almost make it over the crest, before being pushed back to leeward. By the third photo, about 50 percent of the hull has been hit by the crest and in the fourth photo the wave has broadsided the entire hull.

If you get hit by a breaking sea, two things will get the adrenaline pumping: The first is the E-ticket ride upon which you are about to embark. The second is the question of whether a second wave is about to pop you when you're down, thereby inducing even more heel angle.

A series of factors control how your vessel reacts in this situation.

Skid Factor

If the boat skids to leeward with the wave while heeled, the hull and rig have more time to *absorb* and *dissipate* wave energy. The longer this takes—and we're talking about a second or two one way or the other — the better your chance of keeping the spreaders dry.

You don't want the boat to sit there like a rock in one place, as that forces the wave energy to be absorbed by the hull. When this happens, most of the wave force is turned into heeling energy, and over you go.

If the hull begins to skid to leeward as it heels, there is more time to absorb wave energy.

Several key design issues will help you to skid. First, you want the keel to come clear of the water as early in the roll as possible. With the keel out, there isn't much lateral force trying to hold you in place.This makes it easy for the hull to slip to leeward with the wave energy.

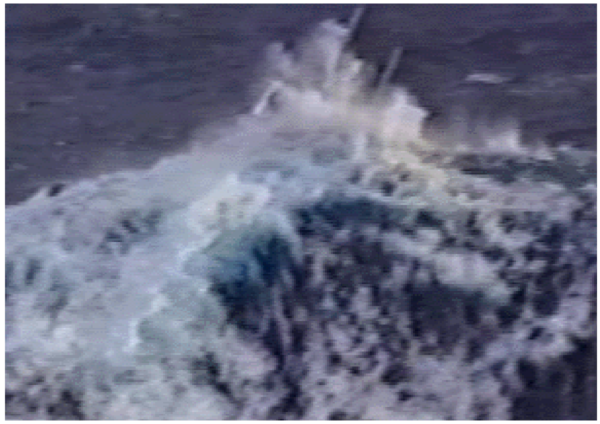
If you have ever raced dinghies or small catamarans, you know that a common technique when overpowered on a reach is to raise the centerboard, or the leeward board on a cat. When a gust begins to heel you over, the board no longer holds you in place, and the boat just shoots to leeward, relieving the force. Once the gust dies down, you continue on your way.

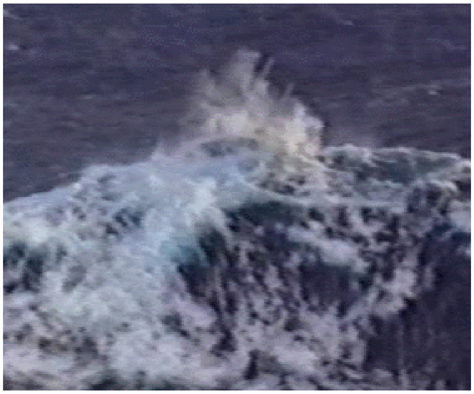
We're looking for the same thing with a cruising keel in a knockdown situation.

The second design factor is how your boat floats when heeled — i.e., what sort of a shape does she present to the sea as she's being knocked sideways?

When well heeled, heavy boats with low freeboard tend to float with much of the deck awash. At the other extreme, light boats with high freeboard heel way over before getting the rail or coamings wet. With more deck in the water, you have more of an edge trying to hold you in place (while wave energy is dissipated). Thus it stands to reason that lighter boats with higher freeboard skid off to leeward more easily. This also comes into play when you look at what happens to the keel. The heavy, low-freeboard vessel will float lower in the water when knocked down. This keeps more of the keel immersed. On the other hand, the boat with more topsides on which to float lifts her keel out of the water sooner.

TOC
Last Chapter
Next Chapter
Help!





At this point, the hull has absorbed all of the wave energy. The top right photo shows the reaction of the crest from hitting the topsides as it climbs the rigging. In the photos to the left, the wave has pretty much spent its energy.The hull keeps sliding to leeward as its momentum continues the heeling action. A hull shape like the Morgan Out Island 41 typically reaches maximum stability at around 65 degrees, so from here on it will require less energy to continue the rolling.

With stability dropping off at these great heel angles, the hull continues its roll down to about 80 degrees.

If a second wave were in the equation, hitting the boat now that it has started to lose stability due to excess heel, the next knock could result in a roll-over.

This is why it is so important in a knockdown situation to quickly get back on your feet and headed into or away from the seas.

In the left middle photos you can see that the wave impact has now passed. However, the hull continues to leeward.

In the bottom left photo, the keel is again taking over and bringing the boat back upright. The last photo, bottom right, shows the boat heading downwind and away from the next wave.

Okay, the excitement is almost over. With no second encounter this time, the boat is coming back upright. In the bottom left photo, heel is reduced to where the rudder once again can be effective.

In the bottom right photo, you can see the crew beginning to run off. What is so interesting is that the boat is still within the white water of the broken crest. This is the best indication of how far they have skidded to leeward, and why we don't have even more spectacular images of the boat being rolled. Keep in mind that this entire sequence took less than five seconds.

TOC
Last Chapter
Next Chapter
Help!

We experienced a number of spinnaker knockdowns over the years on both our *Intermezzo*s. These were typically in moderate conditions at night, when we were caught flying too much sail with a combination of windshift and gust in a squall. The difference in the behavior of the boats was as dramatic as the difference in the hull shapes. The first *Intermezzo* would knockdown quickly until equilibrium was established, typically at around 65 or 70 degrees. Her drift to leeward was marginal in this attitude. *Intermezzo II*, with her high topsides, would start to skidding sideways by the time she had heeled to 35 degrees. Her spinnaker knockdowns typically stopped around 50 to 55 degrees, and by this time she would head to leeward at 4 knots or more!

How do you know your boat's reaction in advance? A good clue is to watch what happens with heel. If the decks stay dry until 30 or 35 degrees, you'll be in much better shape than if they start to get wet at 25 degrees.

Intermezzo would roll her cockpit coamings under at 35 degrees, while *Intermezzo II* wouldn't even get the deck edge wet until heeled passed 35 degrees.

In this next series of helicopter video shots, we see a U.S. Coast Guard surf-rescue boat during training exercises. These vessels are designed to skid. Their shallow, round canoe bodies, combined with plenty of buoyancy in the form of deck structure, will help get them right-side-up in a hurry should a capsize occur.

The surf boat is deliberately put into an almost-beam-on relationship with a breaking crest. Notice how the hull skids with the wave crest as it heels.

The crew must be wondering why they volunteered for this duty! The hull is almost locked into the crest as it skids to leeward. In the bottom photo, the deck edge creates lots of drag. If there were more heel at this point, the boat would be close to a true roll-over.

Considering that this took place in late fall — the summer is usually too calm — you begin to appreciate the dedication of these surf-boat crews. (USCG photos)

TOC

Last Chapter

Next Chapter

Help!

Polar Moments

Another equally important ingredient in this knockdown equation is what engineers refer to as the “polar moment.”

Polar moments describe the various weights of the boat, and their relationship to a central point. The further away from this central point — typically just above the waterline — the more powerful the polar moments. Distance is an important factor, since polar moments increase with the third power of their distance from that central point.

Because of this distance factor, rig and rigging weight are extremely important.

Polar moments act as a stabilizing force, slowing the motion of the boat when the wave imparts energy to the hull. A good chunk of that wave energy must overcome and accelerate polar moments to get the boat to heel. The higher the polar moments, the longer the time it will take for the heel to increase, and the more time the boat will have to (hopefully) skid sideways, further dissipating wave energy.

You’ve probably read about violent motion on dismasted yachts. This is due to reduced polar moments. Dismasted vessels are also far more likely to be knocked down or rolled as a result of low polar moments.

Polar moments help to soften everyday motion as well. Boats with more weight aloft tend to roll at a slower rate, and over a longer period, than comparable vessels with lighter rigs.

In fact, in moderate conditions, where a leftover sea makes the boat extremely uncomfortable, you can soften the motion by hoisting a bit of weight aloft — a ball of chain, for example. This was a common trick in the days of commercial sail.

However, there’s a problem with getting the polar moments too high, as this increases pitching upwind. Higher polar moments mean higher vertical center of gravity. Also, hull shapes react differently to variations on the polar-moment theme. Where one type of hull might do nicely with high polar moments, in terms of pitch, another would have difficulty.

Changing to a carbon-fiber rig, for example, benefits a CCA-type design with long overhangs (and therefore lower longitudinal stability to resist pitching) much more than a long-waterline vessel.

Limit of Positive Stability

The limit of positive stability, or “LPS,” is the point at which the hull and keel stability can no longer bring you back right-side-up. At this point, the boat continues to rotate under water until it pops back to the surface having completed a 360-degree circle.

LPS is expressed in the form of degrees of heel or is shown in a curve. Twenty-five years ago the typical cruising yacht had an LPS of 135 to 140 degrees or more. This meant it could still recover (and not roll) after a knockdown where the mast reaches 45 or 50 degrees below horizontal.

The LPS also indicates how quickly a capsized vessel will return to an upright attitude. The higher the LPS, the quicker you’ll come back upright. If you are on deck and harnessed to the cockpit when rolled, the time to find out about your limit of positive stability is not while you’re holding your breath!

Consider for a moment the statistical issues of breaking seas. It may be one wave in 100,000 that meets with your topsides at the right place, time, and angle, with enough power to induce a capsize. With a really good LPS, it may only take one wave in 100 to have the energy to knock you back right-side-up. But if you are short on LPS, the boat may be almost as stable upside-down as right-side-up. In this case, the boat will require as much energy to get back as what knocked it down. You could be waiting a long time for that second big wave. You want to be as *unstable* as possible when you upside-down, so that the time required to get the boat back with its mast in the air is kept to a minimum.

We can investigate this issue by first looking at the curve of stability, then comparing the areas enclosed by that curve when the vessel is in upright and upside-down attitudes. A ratio of at least 2.5 times as much upright stability as capsized stability is best.

The LPS is a function of hull shape, freeboard, deck shape, superstructure, and the vertical center of gravity of the entire vessel’s structure.

Narrow beam, high topsides, and the coachroof or pilothouse add substantially to the boat’s ability to right itself quickly. On the other hand, low freeboard, wide beam, lack of deck structure,

TOC
Last Chapter
Next Chapter
Help!

and high center of gravity hinder that return to an upright position. If the internal payload shifts from the bilge to the deck head, this will reduce LPS — so make sure payload is secure.

There isn't much you can do about the design factors, but you can do a lot about your vertical center of gravity.

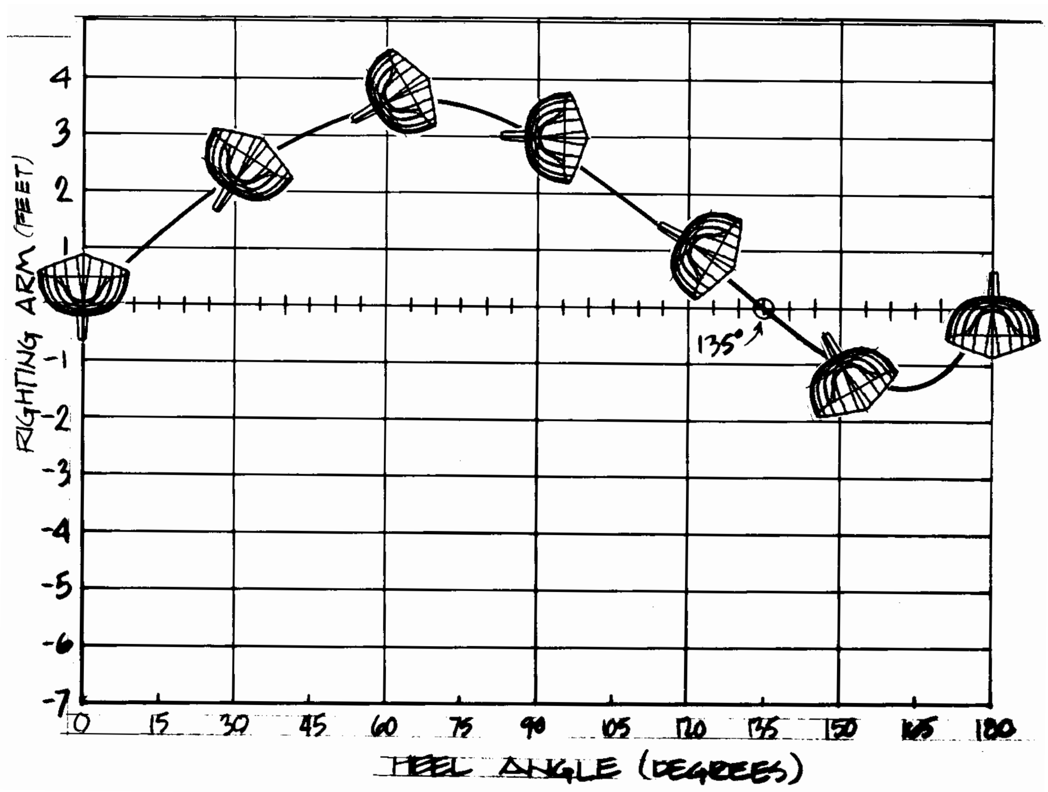
Calculating LPS

LPS is such a critical factor in a seagoing vessel that you'll want to know just where your boat stands. An easy way of getting a feel for the equation is to check with the U. S. Sailing Association. As part of the IMS handicap rule, LPS is calculated based on the hull shape and vertical center of gravity. While your own vessel may not have a rating, a sistership may. Of course, you could also have your boat measured.

There are a couple of caveats here. The first is to compare your vertical center of gravity with the purported sistership. If you have roller-furling and an in-mast mainsail, and the sistership doesn't, you could easily lose 10 degrees in LPS. Second, be aware that IMS data does not take deck structure into account. A long trunk cabin can easily add 7 or more degrees to LPS. A medium-sized pilothouse will add 10 degrees or more to your figures.

Cockpits reduce LPS, so if you have a large, deep cockpit on a flush deck yacht, your LPS will be less than the U. S. Sailing Association curves show.

The IMS rule measures center of gravity with sails on the main-saloon sole — not a very realistic expectation. If you have roller-furling, think about the sails on their headstays with the mainsail hoisted. This will reduce the IMS LPS calculations by 5-to-10 degrees.



LPS for a modern 35-footer (10.76 m) is typically about 135 degrees. The shape of the curve of stability also has an impact on motion. Older designs tend to be less stable initially, and then firm up as they begin to heel. This is much more comfortable at sea than a vessel with a high initial stability (which has a quick motion in waves).

You often read magazine reviews wherein the writer states that a certain vessel is initially tender. Since these reviews are typically conducted in smooth-water conditions this should not automatically be construed as a negative for cruising designs (although it would not be good for a racing yacht).

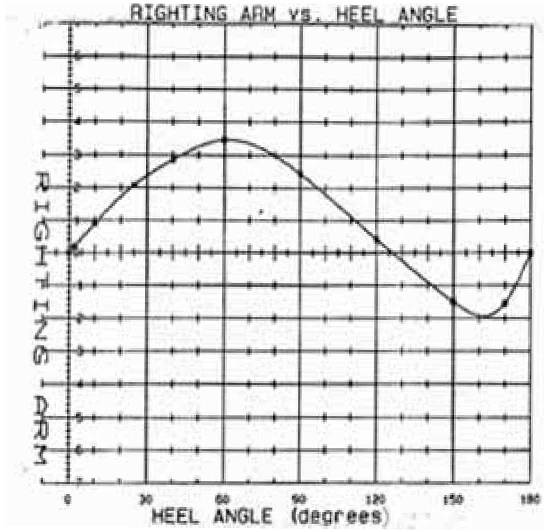
TOC

Last Chapter

Next Chapter

Help!

Another approach is to go to a service like Peter Schwenn's Velocity in Annapolis, Maryland. Peter can digitize a set of your hull and deck lines (obtained from your builder or designer) into his computer. With the freeboard measurements, he can calculate displacement, and with a simple inclining test, you can tell him your boat's righting moment. This data reveals your LPS — and also provides a set of VPPs with which to tune the boat. Peter can then easily predict the impact of adding weight aloft, both on performance and LPS.



The stability curve for *Sundeer.* The initial slope is quite gradual for a soft motion. The limit of positive stability occurs at 126 degrees — a number that is reasonably conservative for a vessel of this size — but would be tight for a smaller boat. This curve is done without deck structure or curvature. If that were included, the LPS would jump to about 133 degrees.

Watertight Integrity

It's important to maintain watertight integrity in order to reach maximum LPS. If your companionway washboards are damaged or drop out, or if a cockpit locker opens, allowing water to flood below, LPS can be significantly compromised in a matter of seconds. Everything possible must be done to preserve your boat's watertight integrity and prevent this down-flooding. It goes without saying that storm shutters and companionway locks should be in place before they're needed.

What's the Right LPS?

Steering control and most other design, rig, and system questions can be debated, and a case can be made for going to sea for just about any configuration of vessel. When it comes to LPS, however, there are no shortcuts.

Don't head offshore if LPS is insufficient. The risks in heavy weather are just too high.

What's the right LPS? That's one of the toughest questions in yacht design. Size is probably the most important issue. Big boats, with their inherently high gyradius and polar moments, can absorb more wave impact without getting into trouble than small vessels. Therefore, smaller cruisers need a higher LPS.

Skid factors are important. A boat that skids well after impact can get away with a lower LPS. Compare a centerboarder with a shallow fixed keel to a sistership with deep draft; the centerboarder will always do better in absorbing the wave impact, assuming the board is up. The centerboarder would get away with a lower LPS than the fixed-keel sistership.

Length, in and of itself, is not a fixed criteria either. Compare two 40-footers (12.3m): one weighing 14,000 pounds (6,400 kg), and one weighing 20,000 pounds (9,100 kg). The heavier boat will have higher polar moments and so theoretically will better absorb wave impact. Yet if the hull of the heavy boat sits low in the water, with a deep keel, while the lighter boat floats higher, with a shallow keel (thus skidding better), the lighter boat might react better, getting by with a lower LPS.

There is simply no pat formula to determine what is or is not a good offshore boat. It is necessary to look at all the factors.

In the end, one of the best ways to find out if you have the right boat is to see how others like it have done offshore, in heavy weather. If the design has a history of dealing successfully with heavy weather, your boat is probably going to be okay.

Cut-Off Numbers

Now I will propose some rough LPS numbers, with the caveat that this is just a start in the evaluation process. These numbers are suggested on the assumption that we're talking about moderate-displacement designs, with average freeboard and conservative cruising rigs — meaning

TOC
Last Chapter
Next Chapter
Help!

relatively high polar moments. This also assumes that deck structure, coamings, and cabins are *included* in the calculations.

Factors that indicate numbers should be higher: low freeboard, deep draft, light rigs, and poor steering control. Factors that indicate the numbers could be a bit lower: high freeboard, heavy rigs, shallow draft (or centerboard configuration), and good steering control.

For 25- to 30-footers (7.7m to 9.2m) I'd like to see 135 to 140 degrees.

For 30- to 35-footers (9.2m to 10.7m) this could drop to 132 to 137 degrees.

For 35- to 40-footers (10.7m to 12.3m) a minimum LPS would be in the range of 130 to 135 degrees.

You could probably take an additional 2 degrees off for 5 feet (1.5 m) of increased length, to a minimum LPS of 125 degrees.

The above figures represent an educated guess for average cruising conditions, *where the likelihood of severe weather is rare*. If you are heading into areas known for breaking seas, add some insurance to these heel angles.

Over the years we have built boats with relatively high LPS figures — especially considering the fact that they steer so well; have small, shallow keels; and skid nicely on their topsides. Our smaller vessels, in the 57-foot (17.5m) range, typically come in at around 130 degrees. Larger designs, 65 feet (20 m) or above, are usually around 125 degrees. While we've experienced a number of spinnaker knockdowns and have been flattened a couple of times by big breaking seas, we've never had one of our own boats put its spreaders underwater. As far as we know, none of the other boats we've built has ever been partially or totally rolled. Given the numerous circumnavigations and ocean passages these vessels have made, there is reason to believe that these LPS figures work well for these types of designs.

Vendee Globe Lessons

As we are heading to the press with this book, word has been filtering back from the Southern Ocean about numerous problems with the Open 60s being raced by the Vendee Globe contestants. Aside from the structural problems, what is most troubling is the capsize of one of the Group Finot designs, *Pour Amnesty International*, and its failure to recover.

The vessel in question lost its rig in the capsize although it should have had an LPS of around 140 degrees. However, it did not right itself, according to skipper Thierry Dubois, despite being at various positions to the waves over several days.

The Open 60s have very wide decks, devoid of camber or deck structure. Even though this deck shape/structure is a factor in calculating the LPS, its lack may be a contributing factor to the lack of righting.

Another issue may be lack of downflooding. The Open 60s are well sealed and divided into at least three watertight sections. Most conventional yachts suffer significant water ingress when rolled. This of course has a major impact on stability. It just may be a contributing factor to self-righting which in the past we have not considered closely enough.

Isabelle Autissiere's swing-keel design was knocked down with the keel apparently in the centerline (running) position. Her vessel would not right itself until the swing keel had been canted, after which the boat came quickly upright.

You can be sure that there will be lots of analysis of the data by designers and yacht clubs around the world. We do know that these vessels are being sailed single-handledly in some of the roughest seas in the world. And this race in particular had more wind and breaking seas than had been previously encountered.

A number of experienced Whitbread sailors have indicated that they felt the Whitbread 60s would not recover from a full capsize, and that the only reason disaster had not struck before is that they are always carefully (if agressively) sailed downwind, with the best helmsman driving.

As a designer, all of this data is very concerning. We know that the Open 60s are extreme in terms of length-to-beam ratio and lack of freeboard. The fact that they are frequently under auto pilot command or being sailed by a very tired seaman in horrendous conditions must also factor in. Is there a lesson for the rest of us here? I am not sure, but I am less comfortable with some of the numbers we've been using in the past than I was a month ago.

TOC
Last Chapter
Next Chapter
Help!

STRUCTURAL INTEGRITY

Most cruising designs will cope with the elements as long as they remain structurally sound. The crew may be tired, the boat may have some blown sails or mechanical problems, but the boat will make it to port on its own as long as the key structural elements hold together. However, compromise the structural integrity of any of the key components, and you can quickly find yourself in trouble.

On Deck

Under most conditions, deck-and-cabin structure carries very light loads. Yet, if the boat drops off the face of a steep wave or rolls over, the loads on the deck and house become enormous. Once the deck structure is breached, staying afloat will be difficult. The need for good structure seems so obvious that you would think everyone would want to keep this area really strong.

However, during the 99.99% of the time that the deck is not working hard, that weight up high costs stability, slows the boat, and makes it tender. There is a temptation to build light for performance, and maybe to save money. Sailing inshore, this may be a logical argument. But for offshore work, it does not make sense.

How to tell if a deck is strong enough? Flexing under load is a good way to check. If you hop down into the cockpit and the sole drops while the sides flex in, imagine what will happen if your weight is replaced with a couple of tons of water. Stress cracks in the laminate around hatch corners or coaming edges are another indication of potential trouble — cracks in gelcoat are typically not a problem, as this usually is caused by a pooling of the gelcoat in the mold, leading to a brittle concentration of resin.

Look carefully at any sort of hull or cabin window. If you fall 20 feet (6.1 m) off the face of a wave, landing flat on those ports, will they take the load? Opening plastic ports are rarely strong enough and should be replaced with metal for offshore work.

How about deck hatches and the coamings to which they are attached? Hinge and hold-down hardware must be strong and attached in a manner that won't work loose under load — through-bolting is always preferable to screwing. If the hatch is a composite timber/plastic construction, are the corners reinforced?

Keel Attachment

Under most sailing conditions, the keel structure carries a predictable amount of load, typically handled with ease. But long periods of pounding, severe knockdowns, and groundings raise the loads enormously. It's important to carefully check keelbolts — the way in which they are bedded into the ballast itself, and reinforcement where they come into the interior. Also check the structure that spreads the keel loads into the hull. These athwartships beams (called floors) are critical to dissipating keel loading.

The most efficient keelbolts are the farthest athwartships from the centerline. More keel bolts spread the load concentration throughout the hull structure, so if there's a choice between a few large bolts or several smaller ones, you will be better off with the larger quantity of smaller diameter bolts.

Assuming the boat has some miles, and perhaps a grounding or two, in its history, you can get a feel for how the keel structure is doing by looking at the floors. If they are all intact, if fiberglass bonding is well secured, and if keel bolts are tight, these are all good signs.

But if one or more of the keelbolts leak, there are broken floors or broken floor to hull bonds, or you can flex the keel when the boat is hauled, these are indications of a structure that is tired or not getting the job done.

Another opportunity to check keel structure comes when you haul out. Check to see if the hull bottom deflects upwards as the Travelift sets the hull down on the keel, before the hull props have been snugged. Ask the travelift operator to loosen the slings a hair, so that all the hull weight rests on the keel. This is a good test of the floors.

The distance between deck and keel should remain constant. The easiest way to measure this is by placing a pole inside the boat when she is still afloat. It should be held in place with a bit of tape, with a small gap at the top. If the gap closes you know the boat has settled down on the keel and that the hull and floors are deflecting.

TOC
Last Chapter
Next Chapter
Help!

The Erickson 41 *Windshadow* reaching in the Virgin Islands after her circumnavigation. *Windshadow* was from the same design era as *Intermezzo* and drawn by designer Bruce King to the CCA racing rule. The long overhangs contribute very little to effective waterline when this type of design is heeled (due to the low prismatic coefficient of the overhang area when it begins to immerse).

At the other end of the design spectrum is this very nice Chuck Burns light-displacement cruiser, *Naiad*. This 38-foot (11.7m) hull has a higher effective waterline length than the much-larger *Intermezzo*. It is almost as long in an absolute sense, and when you add to this the much higher prismatic coefficient, the effective waterline is going to be very long. (Tim James photo)

Steering System

A boat that loses its steering in moderate conditions can usually find a way to steer using sails or a sweep of some sort. But in heavy weather, the situation quickly becomes unmanageable. A vessel headed offshore needs a secure steering system. Also, the crew needs to understand all elements in the system from a maintenance standpoint.

Rig

The last critical element in the offshore boat is a structurally sound, abuse-tolerant rig. If the spar is lost in the trades, you can usually jury-rig something from what's left to get home. If severe weather intervenes, however, rig loss and the attendant reduction in polar moments could turn an otherwise seaworthy hull into a configuration ripe for a rollover.

Almost all rig failures could be prevented. A spar rarely goes over the side without first giving some warning. Careful checks before each passage, as well as while under way, will go a long way toward eliminating this problem.

DESIGN CHARACTERISTICS

So far we have discussed the design criteria affecting performance in heavy weather. Of course, the percentage of time spent in heavy weather is small. Chances are good you could sail around the world and never worry about LPS or the structural integrity of the deck.

How these design characteristics affect your own cruising plans is a function of the type of boat you like to sail, the weather you expect to encounter, and how quickly you will reach for the starter button on the engine.

Performance Orientation

A naval architect uses many hydrodynamic concepts to determine the best range of performance for a given design. Unfortunately, one has to decide where strengths should lie. To be especially quick in light airs, you'll suffer at higher speeds. Conversely, a design with good top-end speed will be somewhat slower in light wind ranges.

Boats that are quick in light airs tend to be more tender than more conservatively rigged boats. Still, you can always reef down or fly smaller sails when the breeze comes up.

As long as you are comfortable handling the rig, and as long as you are not totally dependent on a specialized furling system to deal with the rig, the light-air orientation makes sense. Yet at some point, rig size and sail handling cross a threshold where the light-air rig is no longer prudent for the crew in question.

For offshore work, with a short-handed crew the orientation needs to be more toward reducing the sail change and reefing frequency, which means giving up some light-air performance.

Powering Ability

Your vessel's capability under power, especially range, also affects decisions on light-air abilities. With good range under power, light-air capability is not as critical. But if powering range is limited, as on many boats, you'll want to make good progress under sail in all weather conditions. (Most cruising takes place in less than 10 knots of wind.)

Windward Ability

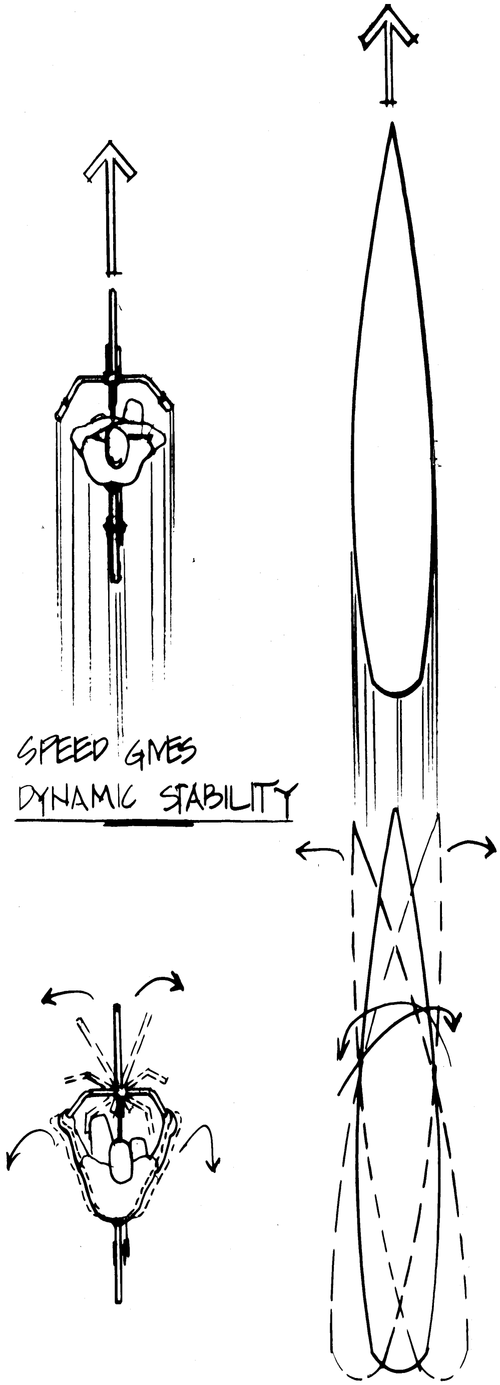
Going to windward is an important part of cruising abilities, but don't sacrifice everything on its altar. At some point a *reasonable* turn of speed uphill is reached, and sailing faster means a rougher ride if the seas are making up, which in turn means you're probably going to slow down anyway. So having a reasonable turn of upwind speed is a good thing, but carrying extra draft or a higher-aspect ratio rig that can't be used on most offshore passages may not make sense.

Speed-Length Ratio

The speed-length ratio (SLR) is a term used to express how fast a boat is moving in relation to the square root of its waterline length. For a 36-foot waterline (11.1m) — the square root of which is 6 — an SLR of one would be 6 knots. At 8 knots, the SLR would be 1.33 (or 8 knots divided by 6). As higher SLRs are attained, wave drag increases dramatically, which is why it's so easy to get that first bunch of knots, but so hard to reach the last couple of notches on the steam gauge.

The SLR is a really good predictor of how a boat will do in moderate breezes on a passage-making basis.

Precisely because of the relationship of speed-length ratio to wave drag, vessels with longer waterlines are much more efficient at maintaining a given speed. Suppose that instead of a 36-foot (11.1m) waterline we had



Speed brings with it dynamic stability, somewhat like riding a bike slow or fast. At low speed, you wobble back and forth and it is hard to control yourself. As you speed up, the bike steadies down and control becomes easier.

As long as you can maintain good steering control, it is almost always more comfortable (and safer) to go fast rather than slow .

TOC
Last Chapter
Next Chapter
Help!

one that was 49 feet (15.1 m). With the square root this time being 7, you can see that at the same speed as the shorter waterline, the longer boat is operating at a *lower* speed-length ratio. At 8 knots this would be an SLR of 1.14 compared to the SLR of 1.33 on the shorter design.

Since the wave drag at 1.14 is about half of 1.33, guess which boat is going to take less horsepower (sail or engine) to maintain the 8 knots?

This is such a potent phenomenon that it's common for large cargo ships, after being lengthened, to carry substantially more payload while burning less fuel.

The SLR that a yacht can hit varies with factors such as displacement-length ratio and prismatic coefficient (which are discussed next). In general, heavier boats will sail at a maximum SLR of about 1.3. As the prismatic coefficient goes up and displacement-length ratio drops, SLRs of as high as 1.6 to 1.8 can be attained without surfing.

As a general rule, most cruisers maintain an average speed-length ratio of around 1.00, or 144 miles a day, for a vessel with a 36-foot (11.1m) waterline in moderate tradewind conditions. *Intermezzo* averaged closer to 1.12, or 167 miles a day, because we pushed her really hard. In fresh trades she'd do a steady SLR of 1.25, or 180 miles a day, but we worked for it!

Sundeer would average an easy 240 miles per day in moderate trades, with little effort on the part of the crew. She sailed at an SLR of 1.25 with less effort than *Intermezzo* because of her more efficient hull form. She gave us many days at SLRs of 1.4 or above (270 miles), but we had to work for those.

Beowulf holds the record, however, for ease-of-handling at high SLRs. On her maiden voyage from Los Angeles to New Zealand, she *averaged* an SLR of 1.35 (286 miles per day) for the entire trip, and this with a very relaxed crew.

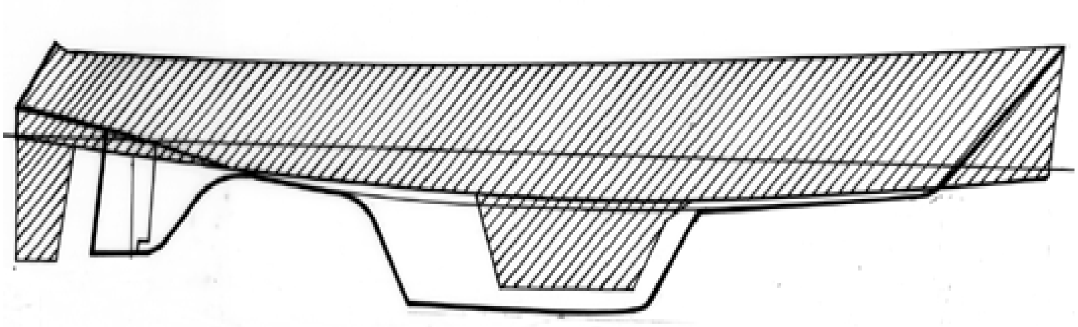
Light or Heavy Displacement?

The definition of displacement is one of the trickier areas of the design question. You can quite easily have a *heavy-displacement* yacht that is very lightly constructed and carries a small payload, and a *light-displacement* cruiser built like a tank, that carries lots of gear.

The problem comes in the formula typically used to define heavy or light displacement. This is called the displacement-length ratio (DLR).

To calculate DLR, take the weight in long tons (2,240 pounds/ton) and divide it by the length of the waterline *cubed* and then divide the entire thing by 0.000001. For *Intermezzo* it would work as follows: 37,000 pounds/2,240 = 16.51 (long tons). Her 36-foot waterline cubed (36 x 36 x 36) is 46,656. Now divide the long tons by WL cubed and then by 0.000001, and you will get a DLR of 354.

That would be considered moderate to heavy. And she was heavily built and carried a lot of payload.



Here's a comparison of a full-waterline hull and a shape that has long overhangs. The long-waterline vessel can have a much finer entry forward and still have good downwind stability. Because it is much faster, the keel can be smaller and still generate the same lift. The rudder can be located farther aft and still be covered with immersed hull, giving it a longer moment arm with which to turn the boat.

TOC
Last Chapter
Next Chapter
Help!

TOC

Last Chapter

Next Chapter

Help!

Now let's try a little experiment. Suppose we take the same boat, leaving everything (scantlings, rig, ballast, payload) the same, but change the hull shape to shorten the overhangs. Using the same heavy fiberglass layups, we pull the waterline forward at the bow and depress the hull aft to shorten the counter. The new waterline is 47 feet, leaving the stern just touching and the bow with an IOR-looking 37-degree rake. Because we've added a few square feet to the hull laminate our weight is going to increase, perhaps to 37,600 pounds.

Calculating now, we get a DLR of 161, which might make our *new* boat a light-displacement vessel.

But is this new boat any lighter? Her actual displacement has gone up. She has increased her ability to carry payload. After all, adding extra weight on a 47-foot waterline is bound to be more efficient than on the old 36-foot waterline.

What we're trying to show you is that one can't simply go out and say, "I'd like a heavy-, medium-, or light-displacement design." In the cruising context, the real equation is more complicated.

You need to look at scantlings, stability, payload, and hull shape to evaluate the proper yacht for your needs.

Generally, DLRs drop as vessels get larger. They carry a smaller percentage of their displacement as payload and are more efficient, weight-wise, at fitting in basic systems.

Within certain limits as the DLR drops, the design in question is able to sail at higher speed-length ratios, with better control. This means that in heavy airs, especially downwind, you're better off typically with lower DLRs.

Of course, there are some trades to be taken. If two vessels of *identical* waterline length are compared, the one with the heavier displacement (and therefore higher DLR) is going to have a softer motion and carry its payload more easily. But then the crew, sails, and engine are going to have to work a lot harder to maintain the same passage times as the lighter boat.

If you go back to our example, keep displacement and length overall constant, and simply make the waterline longer, the configuration with the lower DLR will be faster as well as more comfortable.

Consider the Sundeer 56 for a moment. Most of these boats probably passage at around 42,000 pounds (19,000 kg), allowing for lots of cruising gear and half tanks. With a waterline of 56 feet (17.23 m) they have a DLR of 106. Now, most folks would say this is a light-displacement boat, maybe it would even warrant the appellation *ultralight*. But she carries half-a-ton of batteries, over 300 gallons (1,150 L) of water, has a range under power of well over 1,000 miles, and is built like a brick. The keel structure is four times the ABS rule, and the rudder stock is twice ABS. The Sundeer 56 has a far more conservative structure than many "heavier" cruising designs with higher DLRs.

How do we get this to work? The answer is simple. Add waterline, but keep other factors like rig, ballast, interior, and systems constant (i.e., resist the temptation to load the longer waterline).

The result is a boat that is easily driven and that can maintain high speed-length ratios at sea with minimal effort on the part of her crew.

What I am trying to convey here is that defining a boat as a light-displacement design or medium- or heavy-displacement based on its DLR doesn't really convey any useful information.

It is much more important to look at how the boat is built — the systems, rig, etc. — to see if she's suited to your needs. *Don't rule out (or in) any particular vessel based on its displacement-length ratio*.

Sail Area

The sail area-to-wetted-surface ratio is a good indicator of how you will do in light airs. *Intermezzo* had a ratio of 2.65-to-1, and in light airs, with everything flying, she could hang out a ratio of 6-to-1. And she was very quick in light airs.

If you study the sail area-to-wetted-surface ratios of known performers, you can set them up as objective criteria at which to aim. With a moderate-displacement vessel in the 40-foot range, a good rule of thumb is 2.25 to 2.50 square feet of measured sail (main and foretriangle) for every square foot of wetted surface.

Beowulf, at the other extreme, has a ratio of just 2.4-to-1 going to 5.5-to-1 off the wind.

Intermezzo at "speed" in the Torres Straights between Papua New Guinea and Australia. She is reaching here at about 7.25 knots or a speed-length ratio of 12. The bow wave has a fair amount of magnitude. Note the large hollow in the area of the keel that then flows up to the beginning of the quarter wave aft. This hollow is quite typical of heavy designs with deep canoe bodies amidships. Of particular interest is the quarter wave and where it forms and then leaves the stern. It has started separation well before the end of the hull. Compare this to the photos of longer waterline designs, and you'll see a considerable difference. Ideally, this quarter wave would not start to even form until it was on the very end of the hull.

As you'd expect from these numbers, *Intermezzo* in smooth water would be faster than *Beowulf* in drifting conditions. If there were a chop around, the contest would go the other way due to the much greater stability of the larger vessel which would result in less shaking of the rig and sails.

Sail area-to-displacement indicates the rig power relative to drag at higher speeds (which is displacement-related). However, these numbers are only a reliable indicator *between similar designs*.

The three views of *Intermezzo* out of the water give you a feel for her hull shape. She was a flier in light airs because she had a minimum wetted-surface hull. The keel was very inefficient by today's standards, and if there was any sort of sea running and our speed dropped, the keel would begin to stall and *Intermezzo* would slip to leeward. So she had to be kept up to speed when sailing upwind. The huge spade rudder kept her on course, but with any other form of rudder she'd have been very difficult to control in heavy airs.

Looking at the bow you'd think it would slice through the waves. However, when *Intermezzo* heeled in the breeze she presented a very flat topsides to the waves and would pound hard as she dropped onto a wave.

SA-D numbers around 16 to 17 are considered middle-of-the-road for moderate-displacement cruisers. Much below 16 indicates a sluggish performer until the breeze really comes up. A number above 17 indicates good performance, but unless there is stability to go with it, you will be doing a lot of reefing.

Intermezzo came in around 17.5 while *Beowulf* had an SA-D of 21 in cruising trim. You would think these numbers indicate *Intermezzo* would be much stiffer than *Beowulf*, but the opposite was the case. That's because of the very powerful hull shape on *Beowulf* and her saltwater ballast as compared to *Intermezzo*'s light-air hull orientation which made her quite tender. As we said in the beginning, these ratios are only good indicators between vessels of like types.

TOC
Last Chapter
Next Chapter
Help!

Prismatic Coefficient

The prismatic coefficient (PC) is a mathamatical expression of how volume is distributed throughout the hull. This is one of the first things a designer decides upon after calculating displacement. PC is calculated as follows: Multiply beam waterline by hull depth, and multiply that number by waterline length. This gives you the theoretical potential volume (if the ends of the hull weren't tapered). Now, take the *actual* hull volume and divide that number by the theoretical volume.

Surprisingly, most PCs fall into a very narrow range, between 0.52 and 0.57. The actual number used on a given design is usually a closely guarded secret. When the designer goes into his drag curves, he sees that for slower boat speeds the lower PC is best; the opposite being true at higher speeds.

The PC also affects your displacement-length ratio and/or *effective* waterline length. Boats with higher PCs have longer *effective* waterlines than those with lower PCs (even though the measured waterline is the same).

To confuse matters a bit more, you need to break down the PC into aft and forward components. A hull with an upwind orientation will have a higher forward PC while the aft PC is reduced (i.e., more hull volume in the bow and less in the stern). Just the opposite is the case for off-the-wind performance, although aft PCs are always higher than forward PCs.

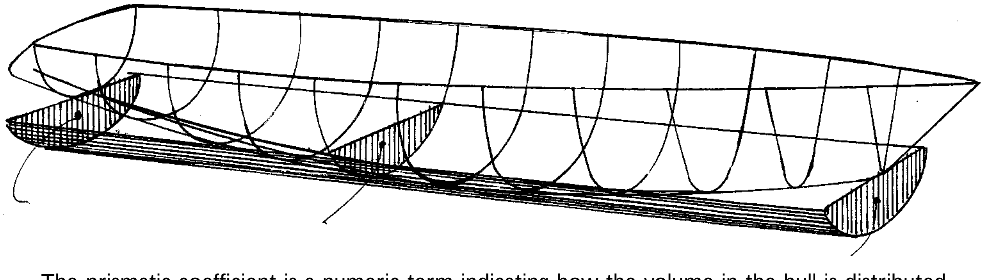
Of course, the ideal situation would be to have the PC increase with speed and heel. And if it's the aft PC that's going up, so much the better.

To do this, designers add volume to the counter stern and topsides in the aft quarters of the hull, widening the transom in the process. While this sounds easy, it is very difficult to achieve in the real design world. In fact, many designs have their PCs drop with heel — just the opposite of what you want!

If the designer is successful, then as the boat heels, this stern quarter digs in, increasing the aft (and overall) PC. This is fast in a racing context. The only problem is that unless you are very clever, this extra volume aft tends to push the bow down, messing up trim and making the boat hard to steer. The centerline rudder also begins to lift out and ventilate, reducing its effectiveness.

By today's standards the Bill Lapworth-designed Cal-40 is a pretty tame-looking boat. But when she was first introduced in the mid-1960s she was considered radical (and worse) by a lot of the establishment. With a relatively long waterline for the CCA era, a high prismatic, and light displacement (today it would be considered on the heavy side of medium), this boat blew the doors off the opposition.

And it was a wonderful sea boat, mild mannered, easy to handle in a blow, and a real ball to sail.



The prismatic coefficient is a numeric term indicating how the volume in the hull is distributed between the center of the hull and the ends. Start with the position of maximum cross-sectional area in the hull (the widest *and* deepest part of the hull), usually a little aft of center. The dimensions of this point are then multiplied by the waterline length. This gives you the volume of the shaded area above. The volume of this area is compared to that of the actual hull shape. This ratio is the PC.

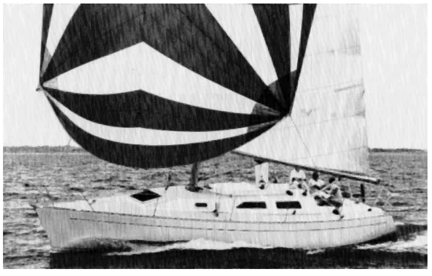
TOC

Last Chapter

Next Chapter

Help!

Take a look at the bow and stern waves in this photo of a Cal-40 reaching. She is sailing at a speed-length ratio of 1.15, or about 6.5 knots. Because of the high prismatic and medium-displacement ratio her *effective* waterline is longer than the actual measured length so her effective speed-length ratio is actually less, compared to a design like *Intermezzo*. This accounts for the relatively small bow and stern wave you see in this photo.



This Oyster 39, built by Oyster Marine in the UK and designed by Carl Schumacher, is an excellent example of a modern light-displacement cruising design. At 39 feet (12 m) in length and displacing just 12,000 pounds (5,440 kg) the boat is easily driven. Note how small bow and stern wave are here, even though the boat is sailing at a speed-length ratio of above 1.25.

You can get away with these characteristics in smooth water with a careful driver, but offshore and short-handed, they create undesirable handling characteristics.

PCs have trended higher in the last decade. Designers have learned to coax more light-air speed from their designs, despite higher PCs (with better sail-area-to-wetted-surface ratios and more efficient fins).

The higher PCs have a cruising advantage. As more hull volume is pushed into the ends of the boat, better use of the interior can be made for accommodations.

Assuming moderate displacement-length ratios, here are some generalized PC numbers: If you are optimizing for a speed-length ratio below 0.80 (light airs), a PC of 0.52 to 0.53 is usually chosen. At a speed-length ratio of 1, the PC will move to about 0.54. A speed-length ratio of 1.2 usually brings with it a PC of 0.55, and if you are optimizing for high speeds, with a speed-length ratio above 1.3, the PC can go as high as 0.57.

Beamy boats tend to have lower PCs to reduce the volume in their ends, so they can get through chop better. Narrower boats tend to have higher PCs, as they can tolerate the end volume better in terms of pitching. (This is especially true of the forward sections, which on a narrow boat are much finer than on a fat boat, and hence get through the waves better.)

Wetted Surface Drag versus Wave Drag

There are two primary forms of hull drag. How they interact is a function of the speed of the boat relative to its waterline (speed-length ratio), the prismatic coefficient, and the displacement-length ratio.

In general, wetted-surface drag constitutes the majority of the speed restraint below a speed-length ratio of one. As the SLR increases wave drag begins to dominate, until at SLRs above 1.3 it constitutes the vast majority of drag.

Displacement-length ratio changes the way these ratios work. As the DLR is reduced, so is wave drag as a percentage of the total restraining forces. Of course, as the DLR goes up, wave drag becomes more predominant.

As we've already discussed, vessels with high DLRs (heavy designs) quickly reach a speed-length ratio limit which they find difficult to exceed. The wave drag builds up too big a hill for the boat to climb.

On the other hand, if the DLR is low enough, wave drag is such a small component that very high speed-length ratios are easily attained.

Where a vessel with a DLR of 350 will have trouble exceeding an SLR of 1.3 to 1.35, a design with a DLR of 100 can easily sustain speed-length ratios of 1.6 or more.

It would seem obvious that all yachts should have low DLRs so as to be fast. The only fallacy in this argument is that to support a given amount of displacement, the shorter waterline design (the one with the higher DLR) is going to have a lot less wetted surface in the water.

This means that at slower speeds it will have a better sail area-to-wetted surface ratio and that means boat speed in light airs.

TOC
Last Chapter
Next Chapter
Help!

The boat with the higher DLR will also tend to have more upright stability since with a shorter waterline it will tend to be beamier on the water.

Freeboard

Freeboard involves a lot of trade-offs in design evaluation. Windage at sea and at anchor are negatives lined up against an increase in range of positive stability (where increased freeboard has a major positive impact), improved skid characteristics in a knockdown, and interior space.

Another important consideration is the ability to get back aboard if you've fallen over. I remem-

Here's a Norsemen 447 (left and above left) sailing at a speed-length ratio of 1.05. At rest the stern is about 6 inches (150 mm) clear of the water. At this speed the quarter wave has climbed the counter and is exiting cleanly. As speed increases this type of shape will be reasonably efficient.

With the wind and sea on the beam you would not expect to see a lot of motion. In the left photo the bow wave is moderate in magnitude, indicating an efficient hull shape for this speed. If you were to get rid of the bow overhang, pull the cutwater forward, reducing the entry angle by 20 percent or so in the process, most of the piled-up wave under the bow would disappear.

TOC
Last Chapter
Next Chapter
Help!

Here's a nice-looking hull sailing a little faster than the vessel on the previous page, or at a speed-length ratio of about 1.1. If you look closely at the stern in the top and middle photos you will notice the quarter wave climbing the transom. This indicates a problem with the hull shape at this speed (and probably higher as well as somewhat slower speeds). This could very well be caused by the boat being overweight or trimmed too far down at the stern at rest. Or it may be a problem with the curve of area of the hull.

Notice the large hollow indicated amidships in the top photo. Part of this is due to a bit of sea running, but part is the normal trough found between bow and stern waves on moderate and heavier displacement designs.

The magnitude of the bow wave also indicates the boat is tending toward heavy.

Compare these photos to those on the preceding page. This hull shape will require more power to move it through the water

ber my first time aboard a modern IOR boat (a Columbia 43) at Catalina Island. (That will give you some idea of how long ago "modern" was to me!) It felt as if I were on a stepladder looking down at the water. At that point I said I would never go to sea in a boat that I couldn't climb back aboard unaided.

But transom steps, well-rigged (permanent) boarding ladders, and swim steps take the curse off this aspect of high freeboard, and on balance it works out to be an acceptable compromise.

High freeboard generally makes a boat drier. Furthermore, it makes a world of difference down below. In a moderate-displacement hull with shallow bilges, to get headroom, the topsides must go up. As long as this height is in proportion to the overall boat and you have the ability to get uphill against the windage, you're okay.

This leads directly to the question of trunk cabin versus flush deck as a way of achieving desired headroom. The flush-deck vessel is cheaper to build and safer at sea. A trunk cabin or doghouse can allow more light inside and has the supposed advantage of letting people in the raised area see out. And in many cases it looks more traditional.

A flush-deck vessel's hull is much stiffer than her trunk-cabin counterpart. The deck forms a continuous web between the gunnels, helping prevent the hull from bending and twisting. If you open a huge hole in that web for the trunk cabin, the hull is going to work more freely. At sea in heavy weather, not having to worry about stoving in a cabinside is a comfort.

If you detect a bias here in favor of flush-deckers, you're right. Over 40 feet (12.3 m) they're definitely the way to go. Smaller vessels don't have the option because of headroom necessities, and must stay with the trunk cabin.

TOC

Last Chapter

Next Chapter

Help!

Where the rules of the sea or economics are paramount, you will see little or no overhang.

One of our early Deerfoot 74 designs with a very short stern overhang. This is a faster shape in light airs under sail than a transom which touches as there is less wetted surface. But it is slower under power and at speed under sail because the effective waterline is shorter. It also forces you to a less favorable distribution of buoyancy throughout the hull shape.

Overhangs

If waterline equals efficiency and good seakeeping, why would anyone give it away in the form of a bow or stern overhang?

Let's look at the bow first. On the average 40-foot (12.3m) cruiser, the difference between an almost straight bow and a "traditional" 35-to-40-degree bow is roughly 3.5 feet (1.1 m) in waterline length. If you keep all other design elements constant (same rig, engine, interior, keel, and rudder) all an almost straight bow will do is significantly drop the displacement-length ratio, substantially narrowing the entry angle of the bow in the process. This gives you a much more efficient hull form in any sort of a breeze, one with a very fine bow that will weave its way through headseas much more easily than the vessel with the shorter waterline.

What about that fine bow digging in down wind in a blow, you may be wondering? What keeps the bow on its lines downwind is longitudinal stability. This is a function of the total volume in the hull and how it is distributed longitudinally (fore and aft). Assuming that the displacement (and therefore the volume) of this hull has stayed constant, the only change in the ability to resist bow burying is the fact that the volume of the hull is spread out over a longer distance. With a constant displacement and longer waterline, the longitudinal stability increases dramatically.

Almost the same issues are at play in the stern. Getting rid of overhang and redistributing volume along a longer waterline brings nothing but benefits.

There is, however, one issue in the stern that is different. This is the way the stern wave reacts with the transom.

As we've already discussed, the higher the displacement-length ratio the more wave drag you have at any given speed. What you want to do hydrodynamically is get that stern wave as cleanly away from the hull as possible. If you have a very flat run aft with no stern clearance, the stern wave may actually climb the transom at low speeds. When it tries to shear itself away from the transom to leave the boat, it creates a lot of drag.

As displacement-length ratio drops the stern wave also gets smaller in magnitude, so the problem is not as great in boats which are lighter for their length.

What this adds up to is the fact that heavy boats need a certain amount of stern overhang to help with achieving a clean release of the quarter wave. Lighter boats can get away with less.

TOC
Last Chapter
Next Chapter
Help!

The amount of overhang is also a function of the speed length ratio at which the boat is designed to operate. As the displacement-length ratio drops there is a tendency for the stern wave to move off the hull itself and behind the boat. This can actually be controlled to some degree with how the curve of area is developed in the hull shape.

The question of overhang then becomes a direct trade-off between low-speed and high-speed performance. At low speeds there is added drag if the wave does not depart cleanly. But at some point the stern wave naturally moves aft of the transom and there is no longer an issue of transom drag. At this point any overhang is a negative in terms of performance.

Why would anyone want overhang? That's a good question. For one, our eyes get used to a certain look. What we think of as aesthetically pleasing is typically what we are used to.

If it takes a lot of curves at the end of your yacht to give you pleasure, there is no reason why you should not go this route. It may even be fast in some conditions. But it makes sense to be realistic about penalties you are paying for the right look.

The Dry Bow

There is no such thing as a dry bow. However, there are certainly degrees of wetness. My own experience working at the mast and forward is that it is not so much the amount of water a bow throws in any given condition as *where* it throws it that is important.

A bow that shears spray and wave tops cleanly, sending them immediately to leeward well forward of the main mast, keeps the aft crew dry.

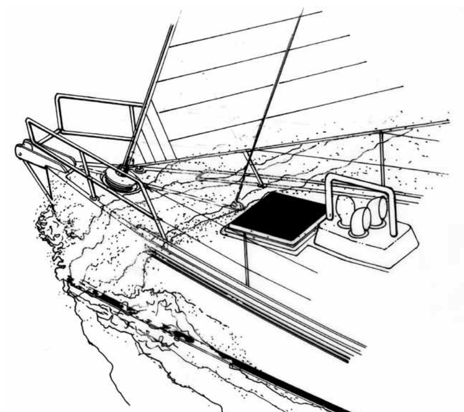
On the other hand a bow that shoots its spray aft as well as to leeward is going to make you a lot wetter.

What appears to be the case, at least with our boats, is that those with the narrowest bows and the least amount of topside flare get their water to leeward the quickest. The designs we've built with more volume forward tended to push the water out, allowing the wind to take it some distance aft before sending it off to leeward.

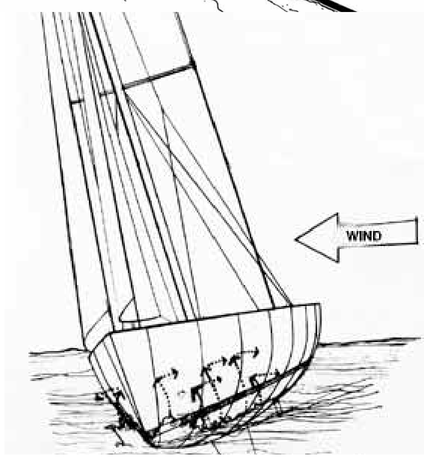
Sundeer power-reaching on the way to Hawaii with wind and sea abeam. This is one of the wettest sailing angles.

We've found that very fine entries, with little topside flare tend to quickly shear bow spray across the deck. It is very wet forward of the cutter stay, but you can stand at the mast in these conditions and stay dry.

Our experience is that flared bows with lots of reserve buoyancy tend to chuck the water aft, closer to where the crew is working.



The drawing to the left shows schematically how water shears across the deck.



When you have flared topsides, the spray is knocked back to windward from whence it blows aft, getting the crew wet (left).

TOC
Last Chapter
Next Chapter
Help!

Pounding also has an impact. A boat that pounds or hobby-horses as she works through the waves (like *Intermezzo*!) throws a lot of spray vertically. This gives it more time to work aft and get the crew wet.

Reaching Spray Patterns

As the wind and seas move aft, the wind tends to carry whatever water the bow kicks up more quickly to leeward. What now conspires to get you wet are the beam seas.

When the hull bottom is smacked by even a small wave top, what happens to the resulting spray is a function of your heel angle and bottom shape.

If the boat is relatively upright and/or the hull is deep, with a lot of bilge curvature, the spray is likely to climb the topsides and come pouring down your neck.

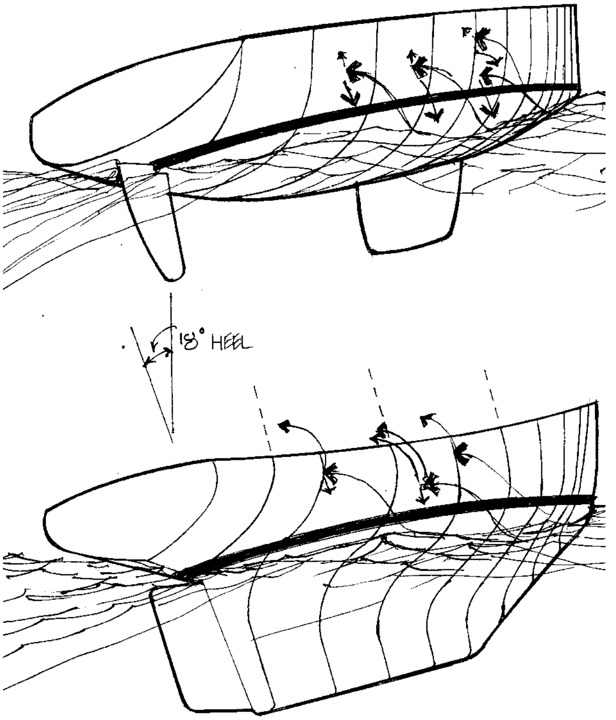
On the other hand, with flatter bottoms with a defined turn to the bilge at the topsides, the wave frequently hits below the topsides and is deflected downward.

Freeboard also plays a part in reaching wetness. The more freeboard you have, the drier you'll stay.

Stern Slap

One of the annoying characteristics of stern overhangs, especially on modern yachts, is that they slap when any sort of chop hits them. If an outboard throws a wake up against the counter, it explodes like a cherry bomb. This resonates through the interior and is startling to say the least. Should you perchance be docked so that your stern faces the prevailing chop, the situation can become unbearable.

If you get rid of the overhang, you eliminate this problem. The alternative is to have a very steep exit angle on the hull shape aft (typical of heavier displacement vessels).



When reaching, modern hulls with lots of flare aft tend to be drier. The flare knocks the wave tops back down, rather than up, as is the case with the vertical topsides more typical with heavier designs.

Freeboard is another factor. Higher freeboard means the seas have to be splashed higher before they can clear the shear and sweep into the cockpit area.

A major annoyance with counter sterns is wave slap, especially at anchor or tied to a dock. A small dinghy passes with a very short wake, and when the stern wave hits your counter, it sounds like someone lighting a cherry bomb down below!

TOC
Last Chapter
Next Chapter
Help!

Racing-Rule Influence

Cruising-yacht design has for the most part been dominated by racing-rule influences. Designers typically make their reputation with race victories. People then want designs that look like the winning boats for cruising.

Because these victories are typically won on handicap, and the handicap rule always has biases built into it, cruising yachts end up looking like handicap winners.

The Cruising Club of America (CCA) rule dominated racing and cruising design in North America from the early 1940s through the mid-1970s.

The CCA handicap was what is called a "waterline rule". Waterline length was a major component of predicted speed. As a result designers tried to find hull shapes that had short measured waterlines (so they rated slow) but sailed faster than the measurements indicated.

This lead to the long fore-and-aft overhangs with which we are all so familiar. Graceful to look at? Yes. Efficient in an absolute sense? No. Along with these short waterlines went a relatively narrow beam.

In the early 1970s a new rule, the International Offshore Rule (IOR), was adopted. This handicap system was a negotiated compromise between the CCA adherents and the folks in Europe who raced under the Royal Ocean Racing Club (RORC).

The compromise IOR rule initially offered big advantages over the CCA and RORC handicaps. Waterlines were lengthened, freeboard went up, beam increased, and the boats got lighter.

There was a lot of grumbling from some quarters, but the early IOR boats were a wonderful advance in terms of performance, ease of handling, seakeeping ability, and interior living space. In short, they made for much better cruising boats.

Tumblehome, (topside area beyond the toerail that projects outboard of the rail) was a favorite rule-beating device in the early 1960s. From a cruising standpoint there are a number of disadvantages. First, hulls drawn this way tend to be less balanced with heel. Second, when you lay against a sea wall or pilings it is very difficult to protect the topsides with fenders.

As designers learned more about the IOR rule they found loopholes, which in turn the rulemakers tried to plug. The designers would then find more holes in the rule. Over time the boats got faster and faster relative to their handicaps, but the hulls and rigs became very lightly constructed and difficult to steer in any sort of a blow. These later IOR yachts definitely were not good cruising boats!

About the time the IOR was getting a real foothold, development work started on a new rule, which attempted to eliminate all biases. The hope was that this handicap would enable CCA, IOR, and non-rule boats to compete on handicap on an even basis.

While the handicap portion of the rule has had a checkered career in assessing totally different types of designs on a racing basis, it has fostered a new breed of wonderful yachts.

This International Measurement System (IMS) allows vessels with moderate beam and plumb bows to sail competitively — a first for handicap rules. The result is that almost all new racing designs and many cruisers influenced by the IMS handicap rule are much faster, more easily driven, and better sea boats than anything that has come before.

TOC

Last Chapter

Next Chapter

Help!

BOC Influence

The BOC singlehanded around-the-world-race is as simple a rule as you can get. There are two classes, one for 50-footers (15.4m) and a second class for 60 footers (18.5m).

The only rule on performance is that the boats cannot exceed these lengths overall and that shiftable ballast systems cannot heel the boat more than 10 degrees at the dock. Any hull shape, rig configuration, keel type, and rudder system is allowed.

Considering that these yachts are driven by a single person around the world in some of the roughest conditions imaginable, you would think the design evolution would provide some lessons. And they have.

First, nobody gives away waterline length. These vessels all have vertical bows. Second, they have transoms that barely clear the water at rest. Many incorporate fore-and-aft ballast tanks (in addition to hull-side ballast tanks) to change fore-and-aft trim. In light airs and upwind they trim bow down, lifting the stern clear. Off the wind and in a breeze they trim stern down.

To generate power to carry enormous rigs, the fastest boats have tended to be extremely wide aft, using the conical sections we discussed earlier to maintain a balanced hull with heel. However, this only works if you have very light structure (as it adds lots of surface area to the hull and deck) and twin rudders (as a centerline rudder would be lifted clear of the water with any sort of heel), so the application to cruising of these shapes is limited. It is interesting to note that one of the competitors, Luc Van Den Heede, has always sailed on vessels with very moderate beam. While he has not won, he has placed in the top three in the last three races and never more than one percent or so off the pace overall (and typically faster upwind and in heavy downwind conditions).

Two photos of the BOC 60 *Coyote*. These designs tend to be perfectly balanced with heel as their sections are cone-like. However, as they heel they begin to lift the centerline well clear. This has led to the dual-rudder system now so prevalent. The weather rudder quickly lifts out of the water while the leeward rudder is deeply buried. Because the leeward rudder is close to vertical and buried, it can be much smaller to get the job done than a single centerline rudder would need to be.

In a cruising context, however, there are two problems. First, the rudders are vulnerable to damage since they are not protected by the keel. Second, under power you do not have the advantage of prop wash blowing against the rudder blade. (North Sails Rhode Island photo)

The BOC boats have all gone to large-roach mains for drive and efficiency. This rig is typical of the BOC in that spreaders are only modestly raked to hold up the mast. In this case, running backstays are necessary for holding the mast in the boat when sailing off the wind. If spreader rake were increased to 25 degrees, the running backstays would not be required. But then how far out the main could be eased when running would be limited. (North Sails Rhode Island photo)

"Traditional" Cruisers

I am never sure what people mean when they discuss the merits of the "traditional" cruising yachts of yesteryear.

Are we talking about Joshua Slocums's *Spray*? He'd be the first to tell you this was an awful sailing vessel, ponderous, hard to steer, and a handful. Or maybe the genre is defined by the Scandinavian double-enders originally designed as rescue craft?

TOC
Last Chapter
Next Chapter
Help!

TOC

Last Chapter

Next Chapter

Help!

Being true double-enders, these designs had balanced lines. And with their full keels and extremely heavy displacement when sailed by a large, experienced crew, they would take anything nature threw at them. But for short-handed cruising they are a handful.

How about John Alden's lovely schooners and ketches? I grew up on Alden designs and can attest to their grace under sail. But it took a lot of crew to achieve that grace. And while they'd handle heavy weather, you had a lot less room for error in severe conditions than with modern designs.

Do these designs make any sense today? If you love the look and feel of one of these graceful old ladies, if they make your heart sing as you recline in the cockpit and look at all the Clorox bottle–style modern yachts, of course they make sense.

But be aware that they will take more careful seamanship and that they tend toward wet, bouncy rides offshore, especially upwind.

Bob Perry popularized this style of canoe stern years ago with his Valiant 40 design. It was an attempt to take the sharper ended "traditional" canoe stern and give it some of the hydrodynamic qualities of a proper transom stern.

At the time the Westsail company was making big noises, selling lots of boats with a more traditional double-ender approach.The Westsails (referred to by many as "Wet Snails") were very slow, and the Valiant 40 blew the socks of them in any sort of sailing competition.

This led to lots of requests to draw more boats with the "Perry" stern.

At low speed-length ratios this type of shape is efficient. But as boatspeed increases this shape makes it difficult for the stern wave to cleanly depart from the hull, so it is very slow once the breeze comes up. Add to this a lack of storage and deck space aft and you will see why even Bob Perry will tell you a transom stern makes more cruising sense.

Shibumi is a Bruce Roberts hard-chine hull, reminiscent of Joshua Slocum's *Spray*.

Because the lines are so boxy or barge-like, they are actually quite balanced with heel. However, the beam-to-length ratio of 3-to-1 makes for difficult steering in big seas.

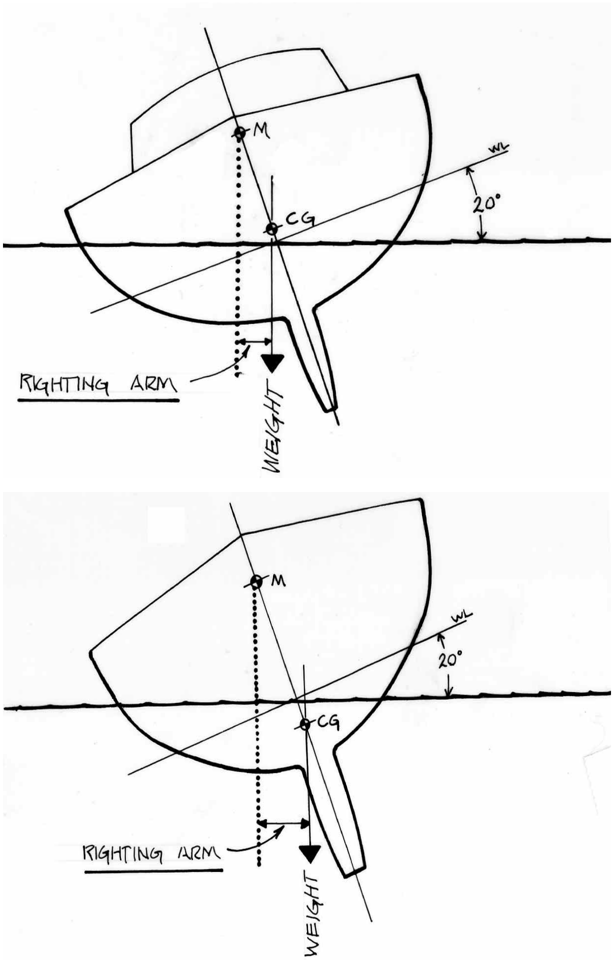
SAILING STABILITY

Sailing stability (as opposed to range or ultimate stability) is the single most important ingredient in boatspeed (once the breeze comes up), all other things being equal. The more stability there is to oppose the overturning force in the rig, the more upright you sail and the more sail area you can carry to provide driving force.

When you are reaching or beating, where the keel is providing lift, the induced drag on the keel is directly related in a quasi-geometric form to heel. Past an initial few degrees, induced drag on the keel escalates rapidly.

As you know, stability is a major component in how comfortable (or uncomfortable) a yacht will be at sea.

How stability is developed in the design process is full of trade-offs. The interplay between hull shape and ballast is complex. What works well for a racing boat does not necessarily do as well for a cruiser, as the penalties we are willing to pay in terms of hull shape, draft, and motion are quite different than what a racer will put up with.



Upright stability is a function of form stability from hull shape, expressed as the metacentric height (indicated by the letter "M" in the two drawings) and the vertical center of gravity (CG in the drawings).

As the boat heels, the horizontal distance between these two functions increases, adding to your stability. Look at the difference in the two identical hull shapes that have different CGs. The lower drawing has a normal CG, as the designer intended. The upper drawing represents what happens after adding roller-furling jibs, a new heavier spar, and deck gear. The righting arm is much shorter, reducing stability. This is less comfortable and can be dangerous in a rollover situation.

Hull-Form Inertia

Hull shape plays the biggest role in providing stability. This is referred to as hull-form inertia. And beam is the biggest component of hull shape stability.

In a strictly performance context, for light- to medium-airs and smooth seas, the ideal is to develop the maximum hull-form inertia with the minimum amount of hull sitting in the water. This is most easily accomplished with beamy boats that have pinched (narrow) ends.

Because hull-form stability is so high with this type of shape, the amount of ballast required can be reduced. You end up with a powerful, light boat that can be very fast under some conditions.

But as you reduce the ballast, a watchful eye must be kept on the range of positive stability, as this type of beamy hull requires a very low center of gravity to maintain an acceptable limit of positive stability when knocked flat by wind or wave.

TOC
Last Chapter
Next Chapter
Help!

For smooth-water sailing, where upwind speed is paramount, this approach works fine. But this type of hull shape tends to be harder to steer, pitches in a sea, and will not be nearly as fast or comfortable off the wind.

When you go for a narrower hull form, you have a lot less hull-form inertia with which to work. This forces you to lower the center of gravity with a shorter rig or more ballast, or combination of both.

Of course, as we've already discussed, the narrower boat, coupled with the lower vertical center of gravity (VCG), has a much better range of stability, allows for better bow shape and wave penetration, and will be faster off the wind. But in smooth water, sailing upwind, the beamier boat will win because of its greater initial stability.

Vertical Center of Gravity

Of all the factors under your direct control which affect comfort, safety, and speed, none is more important than the VCG in terms of sailing stability and your limit of positive stability. (The VCG is the point about which all the weights in the boat — rig, keel, hull, etc. — are centered.) The lower the VCG, the stiffer the boat and the better the range of stability in a capsize.

Most yachts 25 or 30 years ago had a VCG 2 to 6 inches (50 mm to 150 mm) below their floating waterline. Today, most cruising yachts have a VCG at or slightly above the waterline.

It is possible to get away with this from a design standpoint because hull forms have more inertia (beam) for sailing stability, and higher freeboards to help with range of stability, than they did a decade or two ago.

It is important to ascertain what the designer allowed for in terms of payload CG and if he calculated in roller-furling headsails or in-mast furling.

Any change in rig weight has a big impact on VCG. If the boat is not designed for a heavier roller-furling rig from the beginning, you may need to add ballast to bring the VCG back down to the design point after re-sparring. Just adding a couple of roller-furling jibs will have a big negative impact.

Weight on deck also affects VCG. As you start to add dinghies, anchors, windlasses, and jerry jugs filled with fuel or water, up creeps the VCG.

This increase in VCG will be felt initially in a reduced ability to carry sail in a breeze. Okay, the boat's a little more tender so you reduce sail sooner. After all, you're cruising, right?

But where it really hurts is in heavy weather when you are trying to claw off a lee shore, or get knocked down by a big sea. Adding the weight of two roller-furled jibs, and a deck load of gear to the average 35-foot (10.8m) yacht will cost you 7 to 10 degrees in range of stability.

Metacentric Height

In the final analysis, the stability of the boat is derived from the "metacentric height" and its relationship to the VCG. This fancy-sounding engineering term is really quite simple. The metacenter of the hull is a function of the waterplane inertia (or hull shape as it cuts the water when looked at from the deck down). The higher this inertia (hull-form stability), the higher the metacentric height.

You now introduce the vertical center of gravity into the equation. The lower the VCG, and the higher the metacentric height, the more stability you have.

With the boat upright, these two factors are aligned on top of each other. As the boat heels, they begin to diverge. This divergence is the righting moment lever arm. The longer that arm is, the stiffer your boat.

To establish righting moment at any given heel angle, you multiply this righting arm by the total weight of the boat.

The Curve of Stability

If you plot the righting arm against heel, you end up with a curved shape. The shape of this curve at low heel angles (below 10 degrees) has a big impact on your motion at anchor and at sea.

In a cruising boat it is better to have a stability curve, that builds up gradually, as this provides a much more comfortable motion than one which rises abruptly. The gradual buildup translates to an easier or slower motion. A quick rise in stability creates a fast, jerky motion.

On the other hand, from a performance standpoint, you want all the stability you can get, as fast as you can get it.

Heel Angle and Comfort

The relationship of heel to comfort is quite amazing. At 10 degrees of heel you hardly know you are sailing. Fifteen to 18 degrees lets you know you're sailing and having fun. And it is not too bad a heel angle for long periods of time. But as the heel angle begins to climb to 20 degrees and above, it becomes difficult to move around or stay in your bunk.

These higher heel angles are fine for daysailing, but for passagemaking they tend to wear the crew out rather quickly.

MOTION

Before we go further, let's take a moment to look at how some of the factors we've been discussing affect motion at sea and at anchor.

Downwind

The most uncomfortable motion, to us, is rolling downwind. This is a function of wind angle, wave patterns, and the design of the vessel. One can always mitigate rolling by heading up a bit on course, sheeting the main toward centerline, and *carrying more sail*. A further substantial reduction in downwind roll can be had by *increasing boatspeed*. Even small increases in speed, up to a point, can yield very large reductions in rolling. As a result, higher-performance cruising designs are generally more comfortable off the wind than heavier, slower designs.

When you travel faster, downwind dynamic stability increases (it's the same as riding a bike — when you go slowly, the bike wobbles. Speed up and you are nice and steady). The rudder is also more effective at keeping you on course, as its lift or control ability increases with the square of your increase in speed. And finally, the waves overtaking you have less impact as their apparent speed of closure is reduced by your increased speed.

Another major issue in downwind motion is steering control, whether by crew or self-steering system. The closer you stay on course, the less yawing you do, and the more comfortable you are.

Reaching

Comfortable reaching is primarily based on the stability curve of the boat. A stiff boat that sails more upright is going to be a lot more comfortable than a boat that leans. However, you want to be sure there are no hard spots on the stability curve which would cause a jerkiness in the motion.

How your boat responds to wave impact is the other major criteria, and this is almost solely a function of polar moments (and therefore yacht size).

Upwind

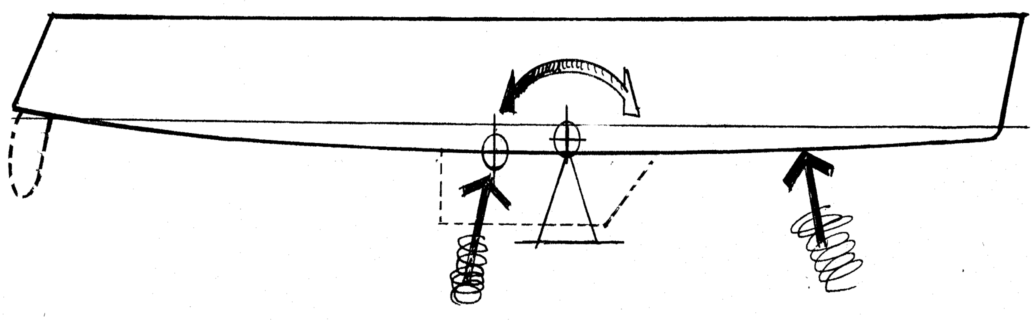
When going to windward, other factors enter into the equation, the most important of which is hull shape in the forward third of the boat. There simply is no substitute for a *soft* bow when you're plugging uphill.

Stiffness also plays a big part. Stiff boats, sailing more upright, are easier on their crews.

Another factor is the tendency of the boat to pitch or hobbyhorse. The more longitudinal stability (i.e., fore-and-aft hull resistance to pitching) that you have, the less your boat will oscillate when heading into the seas.

Weight aloft and weight in the ends of the boat also contribute to pitching (although by adding to the polar moments, this weight does slow down the pitch period).

TOC
Last Chapter
Next Chapter
Help!



The spring effect comes from a misalignment of the center of buoyancy and the center of the waterplane area. The further apart these two factors, the more a hull will tend to bob up and down after a wave passes by. The closer these two measurements are to each other, the less "couple" there will be between them, and the smoother the ride into headseas.

The Spring Effect

Any time you are sailing into waves, there is the potential for a spring effect to take place. This is where a wave accelerates the hull vertically, and then the motion seems to take a life of its own, and even after the wave has passed you continue to hobby-horse.

The major cause of this is the relationship of the longitudinal center of buoyancy of your hull (the point at which the entire floating hull volume is centered) and the center of your waterplane area (i.e., the geometric center of the hull at the waterline).

In an ideal world these two positions would be right over each other. When this occurs, there is no spring effect. However, they are frequently separated by some distance. When this is the case, once the bow is accelerated by a wave there is a spring or pendulum effect caused by the misalignment of these two factors which will keep the hull hobby-horsing until the energy is finally spent.

If another wave comes along at just the right time, off you go again. This is one of the main reasons a lot of yachts have so much trouble making progress uphill.

It is not at all unusual to find these two elements separated by as much as 10 percent of the waterline length. Five percent is a much better figure. In our own designs, we always try to keep this number under 3 percent.

At Anchor

On the hook, a rolly anchorage brings another type of motion. If you spend much time in California, Mexico, the Galapagos, or Hawaii, you will be an expert on this.

The rounder the hull shape, the softer the side-to-side roll will be. Flatter bottoms will roll less, but when they hit a certain stability point, there will be an annoying jerk in the roll.

As polar moments go up, with a heavier rig, for example, it tends to dampen sideways motion (just as it absorbs wave impact), making life more comfortable at sea and at anchor.

Finally, there is the center of gravity. With a highly ballasted design there may be a tendency for a hard spot or quickness in motion. This is, of course, blended with polar moments and the form stability, which comes from the hull shape.

Generally speaking, for a given size, highly ballasted boats with rounded hull forms and heavy rigs have the softest motion. On the other hand, for a constant displacement, a larger vessel will have a more comfortable ride than a smaller one (there's nothing like waterline length).

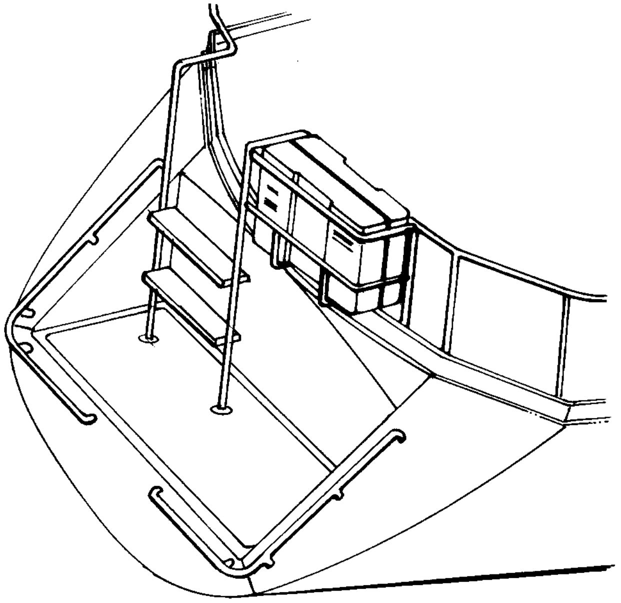
TOC
Last Chapter
Next Chapter
Help!

TOC

Last Chapter

Next Chapter

Help!



An early schematic drawing for the Sundeer 64 swim step. The step is wide and deep, allowing plenty of room for a couple of people. The ladder is set off to one side, with the steps held close to the transom so there is room to walk aft of the ladder. Handrails run down the side and across the back, providing a variety of hand-holds for folks in the dink, and a grab spot for a swimmer or person who has fallen overboard.

SWIM STEPS

Almost 20 years ago, when we started to work on our first "ultimate" cruising design, the one problem that bothered both Linda and me was the recovery of a person who'd fallen overboard. We knew that getting back was tough, but even harder was getting a person back aboard, especially if the person was injured. With *Intermezzo*'s relatively low freeboard I felt I could get Linda back, and knew I could pull myself aboard (on the lee side) if I was uninjured — I was in good shape in those days! But on a more modern design, with shallower bilges and increased freeboard, this was not going to be an option.

Aside from increasing lifeline height to 32 inches (812 mm), the best thing we could think of was a stern extension.

Over the next few years, as we realized what a great boon to cruising these extensions were, we worked on improving the design. Gradually, over a number of boats, we worked out a set of basic principles.

First, the swim step should be about 24 inches (609 mm) or more long. It should be high enough to create a small transom for plumbing exhausts, and to keep your feet dry when standing on it waiting to get into, or out of the dinghy. We've found about 12 inches (304 mm) of height above the water works pretty well.

You need to have handrails on the edges that are convenient for controlling the dink when you come alongside.

The ladder is usually best positioned to one side or the other, leaving as much room free for people getting on or off the platform.

A two-door "garage" was incorporated into the transom on this Deerfoot 61 design. It housed dive gear, outboard fuel, propane, and all sorts of other odds and ends. The ladder folds down for swimming

The one shortcoming of this swim-step design was its height above water level. It was a hair low, and you tended to get your feet wet if there was any chop in the anchorage.

Reality turned out to be slightly different. The handrails were made up in three sections, with a break left to port. A swim ladder was fitted in this break on most of the boats.

The swim step on the Sundeer 56 (above) followed the same pattern as we established for the Sundeer 64. Note the outward splay at the top of the transom ladder to allow shoulder room when you pass through the pushpit.

The Deerfoot 72 *Locura* (above) had an interesting aft arrangement. Note the man-overboard pole tube and built-in spot for life ring. The two large grills are engine-room air intakes.

You don't need a wide transom to make a swim step work. Take a look at what's been done on this Canadian design (right). Although small, it will still work for getting into and out of the dink, and for swimming.

The disadvantage would come in man-overboard recovery. For this, you need space to brace yourself while pulling the person in the water onto the step, and then maneuvering them to the deck.

Mayer and Kathryn Page's 60-foot (18.5m) Bill Dixon design *Lady Kathryn* had an interesting step with dink and davits (above and below). There was just enough room to scrunch aboard under the dink onto the swim step. Of course, when the dinghy was in the water it was a breeze getting on and off. Rather than using a transom ladder, they had steps leading to the main deck built into the corner of the transom.

The Farr 55 *Amazing Grace* (above) had an aft owner's cabin, with a window right through the transom. The standing backstay makes a great hand-hold. This step would work better if the ladder to the deck were moved as far to starboard as possible.

TOC
Last Chapter
Next Chapter
Help!

Four other Canadian approaches to adding a swim step (above, below, and two right photos), here in the form of horizontal platforms. While this does not help sailing length, it is a simple method of adding a swim step to a transom-stern design.

A simple ladder (left two photos) can help a man overboard get back aboard if he's able to help himself. But if you have to get down and work with the overboard person, you need space in which to stand.

Alternate boarding solutions. A traditional side-boarding ladder (above left) is great for dinks and swimming, as long as the vessel is not moving. These ladders tend to be heavy and difficult to stow. By the time you get through buying it and doing the installation, you have just about paid for a stern platform, which does not need to be stowed and has some safety value.

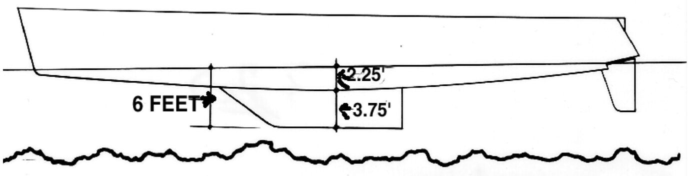
You don't see many stern boarding ladders (above right) set in Tonga in the South Pacific. But, it is a good example of how they work. This one is supported by a mizzen halyard.

TOC
Last Chapter
Next Chapter
Help!

KEELS

Before we get into the various design aspects of the keel, perhaps it would be a good idea to look at what a keel has to do.

First, it must provide enough lift to oppose rig forces, in an efficient enough manner to allow you to work to windward under a variety of conditions. (The keel also works when reaching, but not as hard.)



There's a big difference between draft, per se, and an efficient keel foil. You have to look at how much of the draft is taken up by the canoe body and what's left for the keel. In the drawing above, with a 6-foot (1.84m) draft vessel, if the canoe body takes 2.25 feet (0.7 m), then there's 3.75 feet (1.15 m) left over for the fin. Compare this to the photos of *Intermezzo*'s fin. Her canoe body was so deep that even with 7 feet (2.15 m) of draft she had barely 2 feet (0.6 m) of fin left for lift.

This shallow-draft design draws about 6.5 feet (2 m), the majority of which is taken up by canoe-body depth, leaving about 40 percent of the total draft for the fin. The resulting long, low-aspect keel will hold the ballast efficiently, but won't be of much help hard on the wind or close-reaching. If the waterline of the hull were longer (i.e., if she gave less hull away in overhangs) the canoe body would naturally become shallower, allowing more vertical span for the keel. Since keel efficiency goes up with the square of the aspect ratio, even small changes in keel span yield huge performance benefits.

Here's a different approach to the fin. This heavily swept leading edge will shed kelp and weed (not usually a big problem) and reduce impact loads at the tip. However, the steep leading-edge sweep angle is inefficient upwind and, because the tip of the keel is so small, forces the ballast package higher up, raising the center of gravity.

Boatspeed and Lift

Here we get to the first critical factor — speed. The lift the keel produces is a function of boatspeed *squared*. A very small increase or decrease in velocity makes for a big change in lift.

Now we get to the tricky area. Boatspeed obviously varies with wind and sea conditions. In moderate winds, with a smooth sea, you go like a bat and the keel works wonders. But throw in some headseas and increase wind velocity a bit, and the keel must generate more lift (to handle the increased wind loads) at the same time it is going slower due to wave interaction with the hull.

Angle of Attack

In order to generate lift, the keel must have an angle of attack. You notice this in the form of leeway, which is in effect the boat crabbing sideways through the water. The leeway or crabbing is what creates the angle of attack necessary for the keel to generate lift. The more leeway you make, the more lift there is. Because lift is a function of boatspeed squared (as we've discussed above), the faster you go the less leeway you need to generate the required lift. Conversely, slow down a moderate amount and the leeway angle must increase dramatically to still enable the keel to generate the required lift.

When you think about the hull going through the water at a sideways angle, you begin to visualize just how inefficient leeway is. The form drag on the hull resulting from leeway is significant.

One also has to consider tacking under adverse conditions. Each time you tack, the boat slows down and the keel really loads up. That's why a lot of boats seem to mush through their tacks, taking a long time to go from a sideslip to forward motion.

TOC
Last Chapter
Next Chapter
Help!

The answer might seem easy — more keel area. Adding to keel area, either in draft or horizontally will (to a degree) allow the keel to produce more lift. But what happens to the oversized keel, producing more lift, when going upwind in ideal conditions? Some of that lift is converted to *heeling* force, which tends to make you sail more on your ear.

So there's a very delicate balance between having too little area for adverse conditions and too much for nicer weather.

Ballast

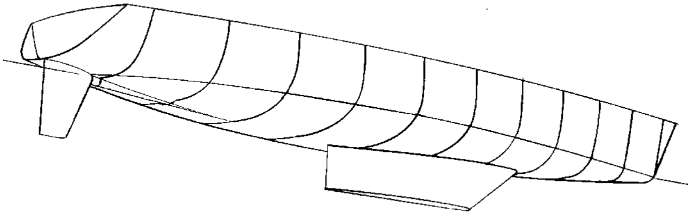
Next, the keel must contain your ballast, hopefully as low as possible. This means that what might be an ideal shape for pure sailing may have to be modified to allow the volume required to get all the ballast into place in the most efficient configuration.

The keel should provide a large sump for bilge water. This becomes more critical as your hull shape flattens out. It may also be a repository for fuel and water tanks and batteries.

A cruising boat should be able to balance easily on its keel when hauled, sitting on a grid, or aground. This means that the trailing edge of the fin must be aft somewhat of the longitudinal (fore-and-aft) center of gravity.

A typical early-1980s fin keel on-board the very first .Deerfoot. The leading edge sweep was thought to reduce tip turbulence. It probably doesn't do this at all, but it does help shed weed and reduce impact loads during a grounding.

Compared to the keel on the preceding page this would be very efficient. However, by today's standards it is a bit of a clunker. The same negative applies here with ballast. Because tip volume is reduced, the lead is forced up into the part of the keel closer to the hull. This reduces the lever arm of the ballast, mitigating its effectiveness.



One of the problems you run into with modern designs and their shallow bilges is where to put the fuel and water. We solved this problem initially by making keels which were a hair oversize and then putting all of the liquid into them, on top of the ballast. The design above is from the mid 1980s, a Deerfoot 2-62. We paid a modest performance penalty for this approach, but got to carry lots of liquid for better range under power and nice long showers!

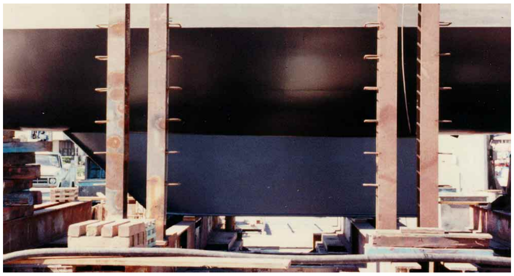
Finally, the keel provides some tracking or direction-stabilizing tendencies. However, it's very inefficient at doing this, and beyond a certain nominal point, it's better to look to hull balance and the rudder for tracking. Another interesting part of this equation is hull depth. Within a fixed amount of draft, the hull with the shallower canoe body will have more room for a higher aspect-ratio fin. *Sundeer*, although she draws a foot (300 mm) less water than *Intermezzo*, actually has a somewhat higher aspect-ratio fin, because of the shallower hull to which the keel is attached.

Draft

From a strict speed standpoint, a deep-draft boat will go faster to windward than a shallow-draft design. But it's possible to get a boat with moderate draft that performs well to windward, and the question of draft goes way beyond speed uphill. Accessibility to shallow cruising grounds is a major concern in areas like the Bahamas, the Inland Waterway, and the Chesapeake. On the other hand, besides the U.S. East Coast and adjacent Bahamas, the rest of the cruising world isn't that shallow. *Intermezzo* drew just over 7 feet (2.15 m) when fully loaded, and only once during our circumnavigation, in a lagoon on Moorea, were we denied an anchorage we would have liked. So strictly from an anchorage standpoint, a preponderance of good spots around the world have plenty of water.

Another aspect that must be carefully considered is hurricane holes. In many parts of the world, the best protection from cyclones or hurricanes is up a river or deep in a mangrove swamp. Here, draft becomes critical. Guam, in the central Pacific, is a classic example. It can and does get

TOC
Last Chapter
Next Chapter
Help!



Sundeer's keel (above and below) is very small, just 12 feet (3.7 m) long at the tip. Yet it did a better job than the longer keels because *Sundeer* could move quickly upwind, even in a chop, and her increased boatspeed generated huge increases in lift.

Her keel was 3 1/4 feet (975 mm) deep below the canoe body.

cyclones virtually any time during the year. There are some excellent rivers that give protection, but 6 1/2 feet is the draft limit when crossing the river-entrance bar.

Underwater obstructions are another factor. There's a direct relationship between draft and the likelihood of hitting (or just missing) a given coral head or shoal patch.

When the time came to decide on *Sundeer*'s keel, Linda and I went back and forth on these same draft questions. Our decision-making process was further complicated by the ability to quantify with our computer the various performance trade-offs. We tried the boat with everything from 5 to 8 feet of draft. I had several conversations with our more experienced friends. They all said the same thing: "Keep it as shallow as you can."

In the end we opted for a 6-foot, 2-inch draft at full load. It was a little slower uphill than a deeper fin would have been, but we wanted to be able to do the Chesapeake and Bahamas without too many restrictions. And just in case we were caught by a hurricane, those mangrove swamps looked pretty inviting.

On the other hand, when we did the design work for *Beowulf*, we ended up going with a 7 1/2-foot draft. We figured that *Beowulf* would spend most of her life in the Pacific, and this draft was shallow enough to allow us most of the anchorages we would likely visit.

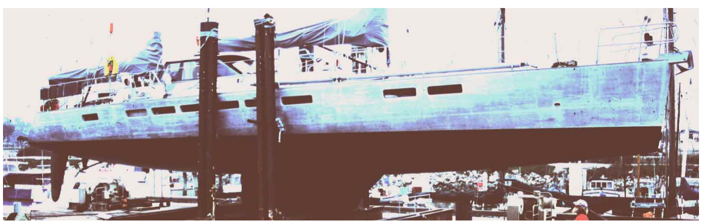
Along with anchorage restrictions, you also need to be realistic about windward performance. The more efficient your rig and hull shape and the better your powering ability, the less dependent you will be on the upwind ability of your keel.

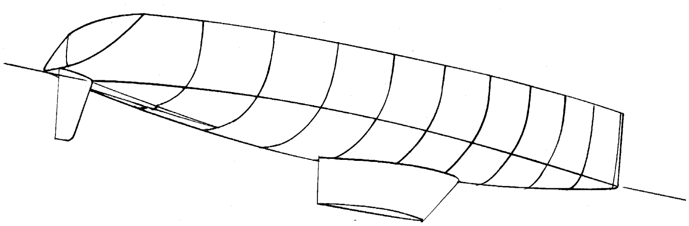
On the other hand, if your rig has a lot of windage, your forward sections tend toward full (so you hobby-horse going to weather), so the keel is going to be a lot more important.

Draft in Soft Mud

In many cases, there will be a shallow area of soft mud which you can push your keel through. For example, when we were last in New Zealand with *Beowulf* we wanted to visit some friends who lived up a deep river. The only problem was an area of shallow water about halfway up.

Between *Beowulf*'s relatively narrow keel tip and her





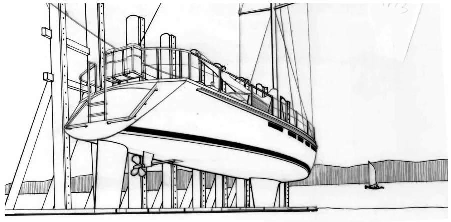
Two views of the canoe body and fins show just how short the keel on *Sundeer* really is. Yet *Sundeer* is faster to windward than any of the other boats we designed up to her time, including the single stickers with a foot (300 mm) more draft. That's because of loading on the rudder. The rudder probably looks a little wide at the top. This helps carry the very substantial rudder shaft (8.5 inches / 216 mm in diameter), and gives us more area for the prop to work against when maneuvering under power in tight quarters. If we were concerned only with sailing performance, we'd probably make the rudder somewhat narrower at its root. Remember when looking at the keel and rudder that *Sundeer* draws just 6 feet, 3 inches (1.9 m) at full load.

TOC
Last Chapter
Next Chapter
Help!

powerful engine, we were able to shove the keel through better than 2 feet (600 mm) of mud.

The issues that control this ability are keel shape (the shorter and thinner the better), and your ability to deliver power via your prop to the water. How hard or soft the bottom is will directly impact your ability.

However, there are a couple of caveats. One is that the longer and harder you push, the more bottom paint you'll remove from the keel (or the cleaner it will become). Second, if you hit a spot like this with a head of steam, make sure that the tides on succeeding days are increasing. Otherwise, you could be stuck for awhile!



Gridding is a common practice wherever tidal range allows. To make this possible, the keel needs to project aft of the center of gravity and have enough strength to take the localized loads that will be imparted to the bottom of the keel.

Aspect Ratio

Aspect ratio, or the relationship of keel depth-to-width (in a fore-and-aft direction), is the single most important criterion in keel performance. The keel's ability to generate lift efficiently goes up with the square of the aspect ratio, so a modest amount of increase in fin depth has a large impact on performance.

At the same time, there's a point of diminishing returns as you lengthen a keel in a fore-and-aft direction (thereby lowering the aspect ratio). At some point, wetted surface and form drag increase with length faster than lift, so that the increasing area that comes with lengthening the keel just slows you down.

Another impact on aspect ratio is the type of hull shape the keel abuts. A flat bottom will provide a better *end plate* than a highly V'd hull. For a given fin shape, the one with the better end plate will provide better lift.

Foil Shape

The foil chosen for the keel on a cruising boat should be picked for two characteristics: first, the ability to carry large volumes, and second, resistance to stalling. Volume is important because for a given size of keel you want to get your ballast stored as low as possible, helping stability, with maybe something left over for tankage or a sump. The ability to withstand stalling at large angles of leeway helps tacking and rough-water performance.

Laminar-flow shapes, sometimes used on racing boats, have a very narrow operating groove. Within the groove they can be fast, but they require constant attention to both their surface condition and to how they are loaded by the rig. A better choice for cruising is one of the NACA 0010 sections. These are highly tolerant of poor surface finish and stalling, and have the highest volume for a given amount of wetted surface of any of the standard fin shapes.

The next question is one of foil thickness. The thicker the keel (within reason), the better the stall characteristics and better the volume. However, thicker foils have higher form drag.

We've found that about a 15 percent bottom (tip) section and 12 percent hull (root) section is a good compromise. Above these figures form drag increases dramatically, and below them the keels become stall sensitive.

Vacanti Keels

Dave Vacanti is an aero- and hydrodynamics expert working with Boeing in Seattle. Over the years, Dave has consulted on all sorts of racing fins and on quite a few cruisers, too. We frequently get Dave's assistance on our projects.

Some years ago, he developed a new series of foils that hold more volume for a given amount of wetted surface than any other of which we are aware. At the same time they are reasonably stall-tolerant. They do have hollow trailing sections similar to many laminar shapes, but they do not seem as cranky in a cruising context as laminar foils.

We've used Dave's foil series on all of our Sundeer series designs and found them a good compromise for obtaining low center of gravity for ballast, while providing storage area for our battery banks and other gear.

Keel Area

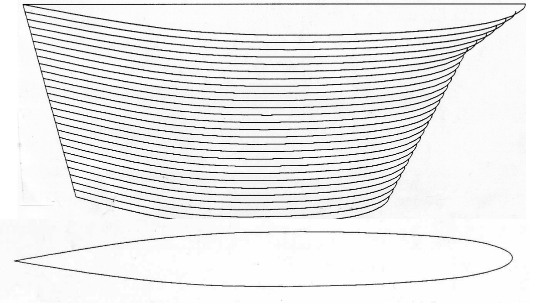
Having defined the geometric variables, the last question is keel area. This is usually expressed as a percentage of your sail area. However, a percentage that works in one configuration may not be so good in another. Higher aspect fins obviously generate more lift than shallower fins, so they can be smaller in area relative to the rig. Stiffer boats can get away with smaller keels, and the more efficient your rig is, the less keel area is required.

Most cruising boats have keels that range from about 3 1/2 to 6 percent of sail area.

TOC
Last Chapter
Next Chapter
Help!

Stalling

Keel stalls are caused by the same factors that make a rudder stall. They are trying to do too much work without enough area, aspect ratio, boatspeed, or some combination thereof. As the keel load increases (for any reason), the keel compensates by forcing the boat into more and more of a leeway angle. Finally, the flow on the keel can no longer maintain its attachment; the keel stalls, and the boat begins to mush sideways. The feeling is distinctive, and if it occurs in relatively smooth water you'll see the boat slipping to leeward.



Two views of the Vacanti foil used for the Sundeer 64 and (in smaller scale) the Sundeer 56. Note the very long, flat middle section and slightly hollow trailing edge. We chose these fins because they have good lift/drag characteristics and, for a given amount of wetted surface, very high volume. The high volume is important for getting the ballast low while leaving space on top of the lead for our "traction" battery banks.

In many small yachts, the need to fit in ballast dictates a minimum keel size which is more than sufficient for most sail load conditions, so stalling is rarely a problem. But as yachts get larger, their rig loads higher, and their hull shapes deeper, the same draft limitations are still in place (the big guys want to tuck away into those cozy, shallow anchorages, too). This forces the designer to make a longer and longer keel, reducing aspect ratio in the process.

It is a lot easier to come up with a 6-foot (1.85m) draft for a 36-foot design (11.1m) than for a 65-foot (20m) design.

As a result, for a given draft limitation, the larger yacht is going to have more of a keel-loading problem and be more prone to stalling.

If you assume from the beginning that keel stall will be a problem under some conditions, you can take design precautions to help the situation. One of the things we've tried that tends to work well is to increase chord thickness a bit. Another, suggested by Dave Vacanti, is to incorporate a "knuckle" at the leading edge of the keel where it intersects the hull.

One interesting fact we've discovered over the years that our shorter chord keels recover more quickly from a stall than do the fins with longer chords.

Grounding Loads

The keel structure and the keel/hull joint must be able to take severe groundings, like hitting a rock or coral head at a pretty good clip.

The load on the structure is a function of how deep the keel sits below the bottom of the hull (the lever arm) and how long the keel is where it intersects the hull. The shallower the keel is, the shorter the lever arm and the less load there is to deal with.

The same is true for the root chord length. If the keel is lengthened where it intersects with the hull, there is more structure into which the load can be spread.

We frequently splay the trailing edge of our keels aft at the hull to reduce grounding-load concentration into the hull and floor structure at this point.

Keel Tanks

Using the keel for fuel and water tankage can make a lot of sense, especially if you have a modern yacht with shallow bilges. The alternative is giving up storage space under bunks and seats.

You may need a fin somewhat thicker than might otherwise be the case, or even a little longer. But the increase in fuel and water capacity can be an excellent trade-off. All the Deerfoot yachts have used this approach with some degree of success.

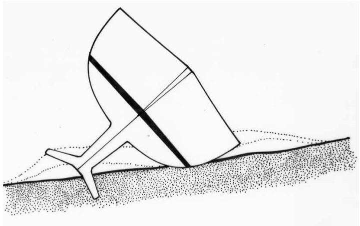
There is a negative, however. When the tanks are empty, the buoyancy of the keel floats the boat higher, reducing stability. And the larger keel adds to drag.

Ballast

A variety of materials are used for ballast. Concrete with iron punchings, cast iron, and lead are all seen at one time or another. Of all the materials, lead, usually alloyed with about 3 percent antimony for hardness, is the best. This is because of its superior density, about 700 pounds-per-cubic-foot, as compared to 430 for cast iron. This results in a lower center of gravity with less volume (leaving more space for tankage or a thinner keel).

Ballast inside a fiberglass shell is easier on maintenance, has no keelbolts to leak and, if prop-

TOC
Last Chapter
Next Chapter
Help!



The one big problem with winged and bulbed keels comes when you run aground. These keel bottom protrusions can act as an anchor in the seabed or in rocks and coral. The results could turn an otherwise mundane grounding into a disaster.

Bill Cook changed one of his centerboard designs to a winged keel and reports that at comparable draft, the boat sails better than before the wings were added. Getting rid of the centerboard slot is a help, and center of gravity is lowered with the lead wings. (Bill Cook photo.)

Bulbed fins are now very much in vogue for racing yachts and some cruisers. They have the advantage of a substantially lower center of gravity, while at the same time allowing a thinner, more efficient foil.

This type of keel, because the lead is so concentrated, puts much higher stresses on the intermediary keel structure and hull bottom.

When used with a cruising boat, very careful structural consideration has to be given to grounding loads and how they are to be distributed.

erly encapsulated and reinforced at the upper edges where the keel joins the hull, makes a stronger installation than outside ballast fastened with bolts.

On the other hand, outside ballast, if it is lead, will absorb the shock of a hard grounding. Another advantage is the possibility of jettisoning outside ballast in case of severe grounding.

This last feature isn't to be dismissed lightly. If the keelbolts are run from the inside out to nut plates molded into the *top* of the ballast, it's possible to withdraw the keelbolts from inside the hull. If you're hard aground, and it's not possible to refloat your boat as she lies, the keel can be removed, allowing her to float free or be dragged off.

Intermezzo had internal ballast. On three occasions she had severe run-ins with rock or coral. The bottom of her fiberglass keel looked like a cheese grater, but aside from some abrasion, she seemed not to have suffered unduly, and she never leaked.

Keel Appendages

There are all sorts of appendages bandied about these days to improve shallow-draft performance. There's a choice between Scheel keels, bulbs, and wings, not to mention various canard configurations. Quite a few computer simulations have been done, models have been tank-tested, and there have been a number of full-scale tests between sisterships with a variety of keel configurations.

From our observation of the development and testing, two factors stand out: First, you can't beat a conventional deep fin for all-around ability. Second, the various appendages are essentially a means of getting the lead lower and improving vertical center of gravity; the appendages themselves may or may not provide additional lift. But to the extent they do, the advantage is often counteracted by extra drag inherent in the concept.

There's also a major drawback to any sort of a protrusion on the bottom of the keel: What happens to the wings when you smack a rock going at hull speed? Or worse, suppose you're caught on a reef at the surf line. Any protrusion from the side of the keel is going to act as an anchor and prevent the boat from being thrown up and out of the surf line. As we've previously discussed, if a boat is trapped at the surf line, it usually means the end of the dream.

Centerboards

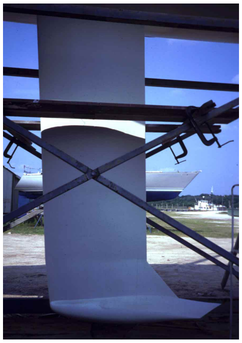
Centerboards are great in dinghies. In cruising boats, they bang, rattle, and jam with coral. They also make trouble with their winches and pendants. But moderate-displacement boats that need shallow draft and still want to go to weather need centerboards. It's interesting to note, however, that most cruising boats with centerboards rarely use them.

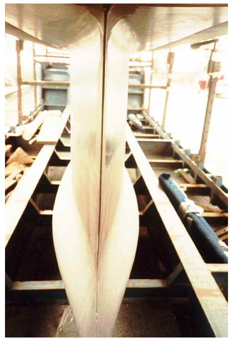
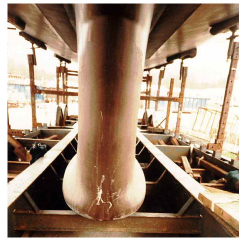
Rusty and Lorraine Johnson on *Aventura* are a good example. With a Hinckley Bermuda 40, a fairly deep board and very little keel to hold the boat, they rarely found it necessary to use the centerboard. Of course, when going to weather it had to cost them a lot.

Carl and Jean Moesley on *Rigadoon* had a more modern hull shape. With a long waterline, *Rigadoon* had a stump keel about 2 feet (609 mm) deep in which her centerboard was housed. She did okay uphill without it, although her performance improved when it was down.

TOC
Last Chapter
Next Chapter
Help!

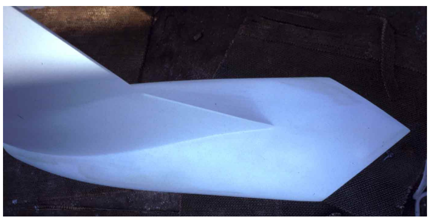
TOC
Last Chapter
Next Chapter
Help!



Three views of the keel on *Hunter's Child*, designed by Lars Bergstrom. This is about as efficient as you can get, assuming draft is not a consideration (which it obviously isn't on a BOC racer). Most of the ballast is carried in the fin at the very bottom of the keel. Lift is efficiently provided by the very high-aspect-ratio plan form. Aside from the draft issues, the negative in this approach from a cruising standpoint is the sharp corner at the trailing edge of the fin. When you are hard aground, this will tend to hold you in place like an anchor.

One of the Sundeer 64s lived in shallow water on the west coast of Florida. It was about 6 inches (150 mm) too deep for the owner's dock. We shallowed up the draft and added this small bulb to the bottom of the fin. This allowed us to keep the same keel weight and vertical center of gravity. Performance off the wind felt the same or maybe a hair better, while there appeared to be some slight losses closer to the wind. The shape was designed to have minimum anchor effects when aground.



Warwick Collins invented the tandem keel a decade ago. It's now standard fare on a number of European production yachts. Aside from some claimed hydrodynamic advantages, it does have one big benefit compared to other winged designs: The leading edge slopes aft, which is much better for shedding weed and hitting rocks. Also, the canard in front helps spread the structural load along the hull. Most of the tandem keels have been cast from iron so they are quite a bit stronger than lead. The legs in the bottom photo are quite common in European areas with substantial tidal range. As you can see, they're ideal for drying out between tides. (Warwick Collins photos)

Full Keels

Some yacht builders still hold to the theory that one must have a full keel to be comfortable and seaworthy, or track well when sailing. Yet a full keel with an attached rudder is precisely the worst configuration for tracking and/or comfort.

Why then were full keels so popular on older yachts? Structure. Simply put, a long ballast shoe, shallow in depth, put a lot less structural load on the composite timber hulls, which used to be the norm. Hang a short fin with a low concentration of lead on an older timber boat and soon enough the garboard strakes would be leaking.

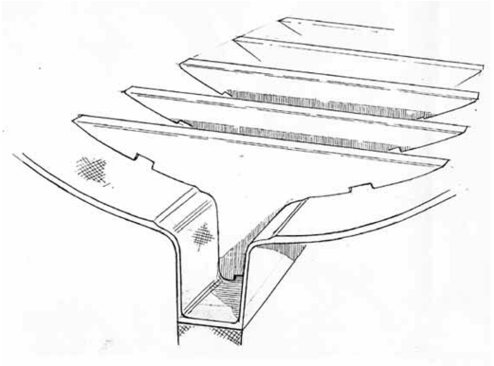
Of course, the long keel is nice when going aground. But this, at least for us, is not enough to compensate for the lack of performance and the attendant safety risks.

KEEL STRUCTURE

As we've already mentioned several times, the keel structure on a cruising yacht needs the ability to absorb punishment. If you do much cruising you will quickly find out what this means.

Many modern yachts are built so lightly that a moderate grounding results in severe hull and interior damage. This is simply not acceptable in a long-term cruising context.

Of course, it is hard to project just what the loadings are going to be in a given situation. It is a function of boatspeed (remember this is a square factor), displacement, keel shape, if you have exposed lead to absorb impact, the hardness of what you are hitting, and where you strike on the keel. Still, there are some design principles that we can apply to the situation.



Keel "floors" distribute the sailing and grounding load of the keel into the hull. When you hit a rock or shoal at speed, the loads tend to concentrate towards the aft end of the fin. In fiberglass hulls, the floors must be carefully bonded to the hull. Otherwise, the floors will delaminate from the hull when highly loaded.

Keels and the ABS Rule

Most modern yachts are engineered using the American Bureau of Shipping (ABS) rule as a guideline. The problem with this is that the rule only considers sailing loads, and if that is all you're shooting for, it does a reasonable job with cruising keels (but not with highly stressed racing fins).

With modern yachts, however, the rule severely underestimates the load in a grounding situation, as modern yachts typically have lighter keels than older designs and travel at much higher rates of speed. The lighter keel allows you to reduce structure. But the higher speed demands more of the boat when you collide with the bottom.

Over the years, we've found that by using the rule loads as a base, and then *multiplying by a factor of four*, we've gotten keel structures that stand up pretty well.

Keel Sump

In most yachts, the lead will come to within a a foot or two (300 mm to 600 mm) of the hull bottom. Between the hull bottom and the top of the ballast is a connection that forms a sump. This provides a convenient spot for collection of leaks and from which the bilge pumps can draw.

However, it is an inefficient structure, as you are asking the sump structure to first pick up the bending load of the keel (when heeled), transfer this into the bottom of the sump, then up the sides, and finally around the corner at the hull.

You can do this quite nicely with metal, but with fiberglass it is much more difficult. So the sump construction needs to be especially rugged.

Keel Floors

Because the sump structure and hull bottom are not efficient at spreading the keel load, structural members called "floors" are introduced. These floors run across the beam of the boat, dropping down into the sump where they cross. Along with the maststep and chain plates, these are the most highly loaded structures in the hull.

The deeper the floors are (i.e., the more space between the cabin sole and hull bottom), the more efficient they will be at carrying load. Since stiffness increases with the cube of the distance between sole and hull, small increases in the height of the floors yields huge benefits in terms of structural efficiency.

When a keel takes the ground at speed, the leading edge is forced aft. The keel then tries to pivot around its center, thrusting the aft end of the keel up (and forward end down) in the process.

If the after-keel structure is inadequate, the entire bottom of the boat will be deflected upwards. It is quite common for furniture around the aft end of a keel so deflected to be loosened from the hull or worse.

If you are serious about impact loads on your keel, you will want to be sure there is lots of extra structure at the aft end. This can be achieved by using a deeper floor (and stepping over it), or by adding additional floors in between the normal pattern.

You also have to look at how the load is dissipated at the end of these floors.

TOC
Last Chapter
Next Chapter
Help!

TOC

Last Chapter

Next Chapter

Help!

Drainage

With the keel sump being the natural repository for most leaks in your hull, drainage within the sump is a major design concern.

The first area to look at is the low spot in various levels of trim. Since most yachts trim down by the bow with increased displacement, will the low spot be forward?

One way of dealing with this in the design phase is to slope the bottom of the keel sump aft to make sure that regardless of trim, the water that collects will always run to the back end of the sump.

Next, you need to allow for limber holes in the floors. In metal hulls these should be at the outside corners to relieve the stress concentration from welding and to allow a continuous fillet to be run from one side of the floor to the other.

With glass sumps, however, the requirements of the bonding process will force you to have a central limber hole. *The limber holes should have a capacity at least as large as that of your largest bilge pump*.

Fiberglass Issues

There are several precautions that should be observed when fiberglass is used.

The keel sump must be heavily constructed, typically of a solid laminate (no core). This is not the area to save on weight or costs!

Care must be taken at the hull to sump intersection to make sure the laminate cleanly transitions around the corner, with good contact between layers, and no dry spots or resin pools. A moderate fillet radius, while structural, inefficiently helps the laminators with their job.

The bottom of the keel sump must be carefully laminated as well. As it is the low spot in the hull, resin will tend to drain into this area. This must be carefully watched, as resin-rich laminates can fracture later on under keelbolt loads.

In a fiberglass layup, the keel floors are going to be installed with secondary bonds. It is obviously necessary to ensure that these secondary bonds have the ability to carry the full load of the floor, past the point at which the floor will fail.

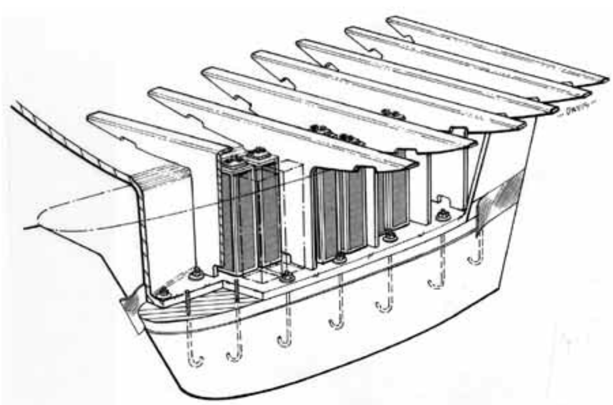
KEELBOLTS

Keelbolts are a key structural element in your seagoing security. If they start to work or loosen, maintenance considerations will put a quick end to your cruise.

From a structural standpoint, they take repeated reverse-cycle loading (as you pound your way upwind and then tack) and high shear loads when you go aground with any sort of speed.

Layout

The layout of the keelbolts has a lot to do with their level of stress. The farther off-center they are, the more efficient the loading. Narrow keels, with a single row of bolts, operate at much higher load levels.



A typical structural detail for one of the Sundeer production keels. A deep fiberglass sump is molded as part of the canoe body bottom. Heavy structural floors (athwartships structural members) are then bonded in place to spread the keel load into the surrounding hull area. Traction batteries are placed between the floors and add to the boat's overall ballast package. The external lead keel is bolted in place.

When keelbolts are on the centerline, they see a tension load from the weight of the keel, plus a bending load when heeled. This bending load reverses each time the boat rolls or tacks. After prolonged bending back and forth, all materials fatigue and will eventually reach a failure point.

When the bolts are spread across the keel, the bending load is replaced by tension and compression loading. This is easier to deal with structurally, and reduces or eliminates long-term fatigue concerns due to reverse-cycle loading.

The load decreases geometrically with separation, so anything done to improve the distance between the bolts (such as thickening the width of the keel where it meets the sump) pays big structural advantages.

From a bending standpoint, the more bolts are clustered around the middle of the keel, the better the job they can do.

However, when the time comes to transfer impact load in a grounding, you want fore-and-aft keelbolt distribution. Once again, more is better.

A final issue in keelbolt layout is proximity to the edge of the keel sump and the keel itself. You need to be concerned with creating stress risers with the holes if they are placed too close to the edge. This can be offset with a thickened structure, or the bolts need to be moved in between two and four times their diameter from the edge of the structure.

Materials

Stainless steel is typically used for keelbolts today. You will want to be sure it is a 316 or 18-8 alloy. Because stainless is subject to corrosion, the bolts need to be oversized for longevity and periodically inspected.

One problem that can occur with stainless bolts, if stainless nuts are used, is galling of the threads. A way around this is to use a monel-metal nut on the stainless bolt. The monel, being softer than stainless, will avoid galling.

Monel and bronze also make good bolt materials. They are less subject to corrosion than stainless and don't have the galling problems. However, having lower physical properties means for a given load they must be of larger diameter.

Attachment to Ballast

There are a number of different methods of making sure keelbolts stay attached to the lead ballast. The most common is to bend the keelbolt into a J or L shape. This hook on the end of the bolt, in conjunction with the threads of the bolt, keep it from withdrawing from the lead.

Another approach, which has been in use for close to a century, is to cast a pocket into the lead through which the threaded bolt protrudes. A heavy washer and bolt are then attached to the bottom end (as well as the top).

This approach has a number of advantages. First, keelbolt holes in the sump can be drilled after the keel has been aligned. This makes it possible to have very tight keelbolt hole tolerances. Next, you can withdraw the bolt when hauled for inspection. Third, changing a keel becomes a lot easier.

Another approach is to mold into the keel a series of thick plates. The keel is then fitted up to the hull, holes drilled, and the plates tapped to receive bolts. A true bolt is used with the head on the inside. This approach makes it easier to remove a keel or the bolt.

Installation

The actual installation of keelbolts is sometimes less than a precise affair. Conventional bolts cast into the keel may or may not be in line with the keel sump bottom holes. There is a definite tolerance issue with holes that have been drilled in the sump.

These holes should be as tight as possible. If a keelbolt is 1 inch (24 mm) in diameter, we like to see no more than 1/8 inch (3 mm) *total* clearance.

The more clearance there is, the tougher it is to keep the keelbolts tight and keep water at bay.

Sloppy installations usually show up after usage or a grounding.

Care needs to be taken when installing the nuts on the threads of the bolt. As already mentioned, galling can be a problem. For this reason, and to ease the torque loads required for tightening, we like to see the bolt and nut well-lubricated before installation. Nuts must be started carefully, so as not to cross thread.

Where the bolts bear down on the bottom of the sump in a fiberglass vessel, a bearing washer to spread the load must be installed under the nut. This needs to be thick enough so that it does not distort or bend under full load.

If the washer is too small a diameter, or distorts, the edges of it will tend to crush their way through laminate. This situation gets progressively worse until the nut pulls right through the laminate.

Bedding or Bonding?

The gap between keel and sump is going to be less than perfect. Some form of a seal must be made between these surfaces. If this is done correctly, a gasket will be formed around the edge of the keel (and keelbolts), preventing water from ever reaching the bolts.

Some builders favor a structural bond, using an epoxy or structural adhesive like 3M's 5200 for the job. In one case you have some flexibility for working. In the other, there's no give.

If you have a large keel, with lots of contact (and keelbolts) the rigid epoxy can be functional. However, if you expect any movement, a flexible bond is much better.

TOC

Last Chapter

Next Chapter

Help!

The advantage *and* problem with bonding the keel is that it is strongly fixed to the hull. The odds are that a keel with a reasonable amount of surface area could be held entirely with bond. The keelbolts are there to act as a clamp until the bond has cured.

The other side of this equation comes if you ever want to drop the keel. It becomes a horrendous, time-consuming, and expensive job.

The alternative is to use a flexible bedding material that does not form a structural bond. Here you are totally dependent on the keelbolts.

There are good arguments for both cases. In the end, I think I would come down on the side of a flexible adhesive for most applications. If you are not concerned with being able to easily drop the keel, go with a structural adhesive that has some flexibility built in.

Salvage Thoughts

As already mentioned, there are stranding conditions where it may not be possible to get yourself back to deep water without outside help, and that help will needs lots and lots of horsepower.

In some situations this may not be available, or if help is present, it may not have the power to get you and your keel back to deep water.

In this situation it could be very helpful to be able to remove the keel. This ability might make the difference between total loss and salvaging your home.

If this scenario is of concern, you will want to consider keel attachment in light of just how difficult it would be to remove your keel.

RUDDERS

Now we are getting into an area with a lot of debate. What's the best rudder layout for a cruising yacht?

The bottom hinge of a keel-attached rudder is vulnerable in a grounding. When this is loosened or broken, the rudder becomes useless (a not-uncommon occurrence with full-keeled designs).

Three types of skeg-mounted rudders. The left photo shows a bottom detail which will quickly fail in a grounding, leaving the boat without steering. If the rudder swings back and forth on the upper bearing, a hole is likely to be torn in the hull bottom, which could lead to a sinking if not quickly dealt with. The middle design is marginally safer. The right photo shows the correct detail with the bottom rudder hinge midway up the rudder. Also, the projection forward of the rudder shaft on this design will contribute counterbalance and reduce steering forces.

Keel-Attached

Rudders attached to the aft ends of full keels are the *least* efficient form of steering control. They are more like a landing flap on an airplane wing, and while they do exert some control on direction, it isn't a lot for the amount of effort which must be put into steering.

If you have a keel-attached rudder, you will want to be sure that your self-steering gear is heavily built with lots of gearing down to increase steering power for heavy-weather conditions.

Keel-attached rudders typically have a structural hinge point at the bottom of the keel, one midway up the keel, and a stuffing box and bearing where the shaft enters the hull.

If you spend any time on a reef, that bottom hinge is liable to be damaged. When this happens, it is not unusual to have the rudder jam.

If you do have a bottom hinge, consider moving it up the keel about a quarter of the keel depth so that a good chunk off the bottom of the rudder must be lost before you begin to interfere with steering.

TOC
Last Chapter
Next Chapter
Help!

Skeg-Mounted

Skeg-hung rudders are much more efficient than a keel-attached fin, but less efficient than a spade. They have a drawback under power: If the prop is ahead of the skeg (a typical situation), the rudder does not exert much directional influence over the prop thrust. This really cuts down on your maneuvering ability in tight quarters.

The bottom hinge of the skeg-mounted rudder needs to be up from the bottom of the skeg so that a grounding doesn't damage the steering system.

It goes without saying that the skeg must be extremely strong to take both sailing and grounding loads.

Spade

Spade rudders are by far the *most efficient* in terms of steering power. For the same depth and area, they are probably a quarter to a third more powerful than a skeg-hung rudder of the same size.

Seagoing damage has always been a concern, but if the spade rudder is conservatively engineered *and you devote the same amount of weight to it as the skeg hung assembly*, it will be just as strong or stronger.

In a grounding, you can chew away at the bottom of the rudder without affecting the rudder support structure.

Rudder Balance

Wherever possible you want the rudder to have some counterbalance — that is, area ahead of the pivot point. This forward area provides force to help with turning the rudder, reducing steering loads for the rudder. However, the issue of the correct amount of counterbalance is hotly debated.

If you have too little counterbalance, the boat is hard to steer. Too much, on the other hand, and the boat will tend to oversteer at high speeds. If you are surfing down a wave having a jolly time driving and the wheel or tiller suddenly takes a bite to leeward, it is very disconcerting!

For most of our spade rudders, we find that an offset of about 19 percent of the area head of the pivot point works pretty well. Note that this percentage varies with aspect ratio, rudder load, and rudder speed.

Skeg-mounted rudders can be counterbalanced by shortening the bottom of the skeg and then projecting a section of the rudder forward of the bottom hinge.

The only problem with this is that it will tend to catch nets and buoy lines.

Sundeer's spade rudder, a massive aluminum weldment, is capable of taking more grounding loads than just about any normal skeg.

Prop-Wash Considerations

The relationship of the propeller to the rudder is tricky. If the prop is close enough, the rudder can act as a thrust deflector, in effect a large thruster, to help with shoving your stern around in tight quarters.

The rudder can also act as a "stator" to straighten out the circular flow off the prop, increasing propeller efficiency in the process. On the other hand, if the prop is too close it will tend to shove the wheel out of your hands if you turn at high speed (from the prop-wash blowing against the counterbalanced portion of the rudder). Too much separation and you lose the thruster capabilities. Factors that go into the design process are prop size and type, clearance between hull and prop tip, rudder chord width, and amount of counterbalance. Get it all right, and it works great. We've found that we can use props as close as 75 percent of their diameter between the closest points on the prop and leading edge of rudder.

Twin Rudders

Twin rudders have been used with success on BOC-style yachts. The theory is that because they are well to leeward and angle outboard, when the boat heels the blade will be vertical, end-plated by the immersed hull, and very efficient. As a result, the rudder can be a lot smaller than a centerline rudder, which is uncovered and operating at a heel angle.

Meanwhile, the windward rudder is out of the water. Drag is significantly reduced.

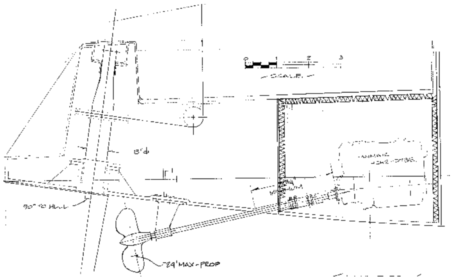
It makes lots of sense from a strictly performance standpoint. However, there are two drawbacks for cruising.

TOC

Last Chapter

Next Chapter

Help!



The relationship of propeller and rudder is critical for good maneuverability under power. Note how close this 26-inch (650mm) Max prop is to the rudder on the Sundeer 64. You don't want to be too close, or prop wash will tend to oversteer the boat radically when turning. On the other hand, getting the prop just right mitigates the steering problem and turns the prop into a wonderful thruster.

First, the outboard rudders are not protected by the keel. With a centerline rudder, if you whack a whale or log, the keel will typically deflect it away from the rudder. But an outboard rudder is sitting out there all by itself. Second, with a centerline propeller and outboard rudders there is no way you can get prop wash over the rudder to help with maneuvering. This makes the boat very difficult to handle under power in tight quarters.

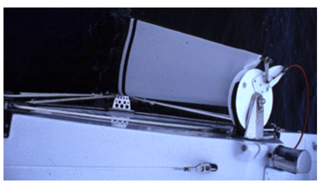
Transom-Hung

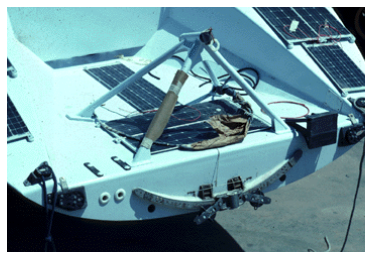
There are all sorts of designs with transom-hung rudders. Some are quite heavy in displacement, with long keels. Others are light-displacement fliers with short keels.

There are several major advantages to transom-hung rudders. First, everything to do with the steering system is very much out in the open. This makes inspection and maintenance easy. Next, a transom-hung rudder is easy to adapt a trim tab onto. They also make sense from a structural standpoint. You have a long "couple" between the top and bottom gudgeon. This is very efficient in terms of taking load. Next, the loads are taken in one of the strongest parts of the boat.

On the other hand, there are some negatives. The rudder is exposed when at anchor or in a Mediterranean-moor situation. Hydrodynamically, there is no end-plate effect, as most, if not all, of the rudder is aft of the end-plate afforded by the hull. Finally, they are difficult to work into a swim step (although we've seen several swim steps with V-shapes notched for the rudder.)

Naiad (above), a Chuck Burns design with a transom-hung rudder, is shown here in the most beautiful anchorage in the world, on the island of Fatu Hiva in the Marquesas. Although the blade is somewhat less efficient on the transom, since it does not have the end-plate effect of the hull to work against, it is so much simpler to maintain and has so many self-steering advantages that it makes a lot of sense for many boats.





Lars Bergstrom has come up with a very clever approach to the high-performance rudder that has real potential for cruising yachts. Lars's rudders pivot from side to side, so that they can be kept vertical when the yacht is heeled. This makes the rudder far more efficient. At the same time, when you are under power, the rudder is on the centerline so you have the benefit of prop wash to help you maneuver. He has used this approach on a number of his designs with great success. (Lars Bergstrom photos)

Lars designed this fin (left) for one of our Deerfoots. The rudder is buried under the hull so the actuating mechanism runs down through the center of the rudder shaft. (Lars Bergstrom photo)

TOC
Last Chapter
Next Chapter
Help!