Big steering wheels work well if you want to finesse a boat to weather when sitting on the rail — but the ergonomics are not always the best when standing at the helm, especially for shorter crew members.

Linda is at the helm of *Intermezzo II*. She holds onto a 48-inch-diameter (1.2m) wheel, the bottom rim of which is mounted 2 inches (50 mm) off the cockpit floor. She is 5 1/2-feet (1.7m) tall; this is the maximum arm height at which she can efficiently exert pressure when steering in heavy conditions.

TOC
Last Chapter
Next Chapter
Help!

STEERING SYSTEMS

On a yacht bound offshore, the steering system should be designed so that the weakest crew-member can handle steering if necessary.

An efficient steering system is a key ingredient in how easily your boat handles at sea. It affects power consumption for the pilot as well, and also affects how well you cope with changing conditions in heavy weather.

Obviously, reliability is a key issue.

STEERING STRUCTURE

There are all sorts of ways to decide how to go about engineering a steering system. The typical approach is to allow for the sailing loads, with a factor of safety thrown in.

These loads are transmitted from the rudder blade to the rudder shaft, then distributed with bearings into the hull. How the loads are dealt with varies with builders, construction materials, and rudder configuration.

When rudders fail under sail, it is typically in one of three weak areas. The first is the outer shell of the rudder itself. Although the shell is not highly loaded, it is made from two halves that are not always bonded well together. Failure typically starts with a small, innocuous-looking crack on the leading edge. With water pressure, it begins to open. Once there's enough surface area on the crack, the water pressure just peels the skin off.

The second weak spot: Most fiberglass rudders transfer skin loads to a stainless-steel framework, which is welded to the rudder stock. As contact points with the rudder stock are highly loaded, the welds can gradually fail over time. The first failures are not noticeable, since the other welds carry the load. Soon, however, they are overwhelmed, and a catastrophic failure occurs.

The third area for problems is the rudder shaft itself. If this is undersized for the loads, or if there is a local stress riser (such as a hole or bearing crease), the shaft begins to deflect so far that the elastic limit of the rudder stock is exceeded and it does not return to its original shape.

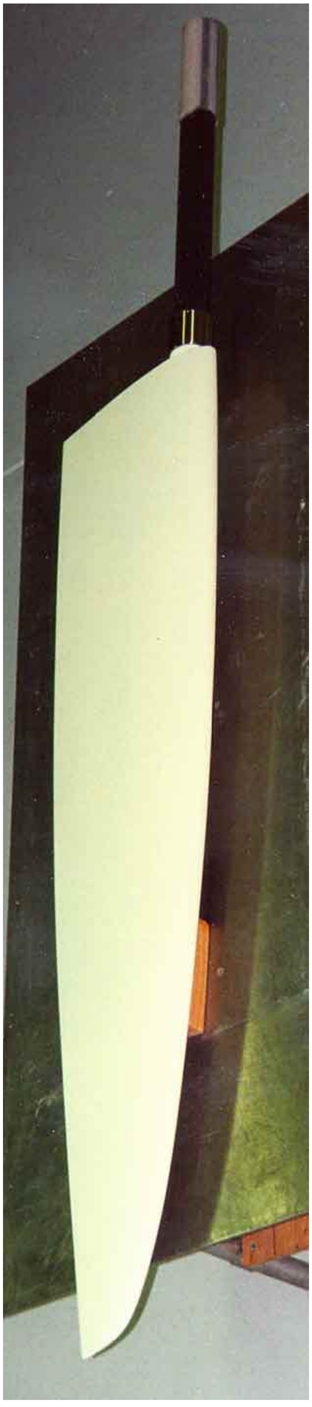
Fortunately, steering failures at sea are relatively rare. Where they are more common, and where the loads really build up, is when you are aground. Here, impact and bending loads come into play, depending on the grounding situation.

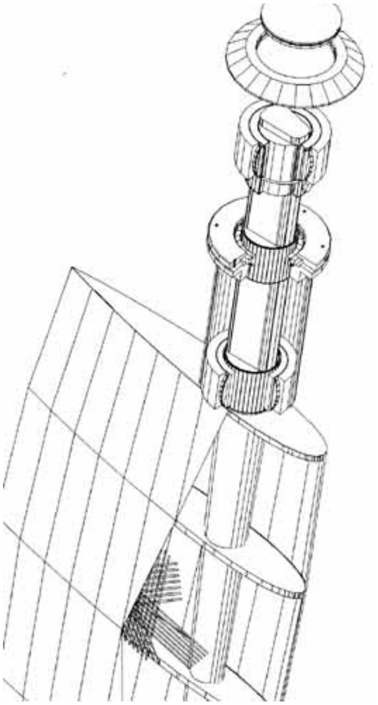
Factors of Safety

Over the years we've based our rudder-design calculations on the ABS formulas. However, in general we feel they are too light for long-term use, where you need a bit of abuse tolerance.

We've found that using twice the ABS recommendations works quite well. With the exception of a sheared key on the 69-foot *Wakaroa*'s quadrant (after hitting a whale) I can think of no failures using this approach.

This probably means we've beem a little over-cautious — but then, losing your steering is a good way to ruin an otherwise lovely passage.





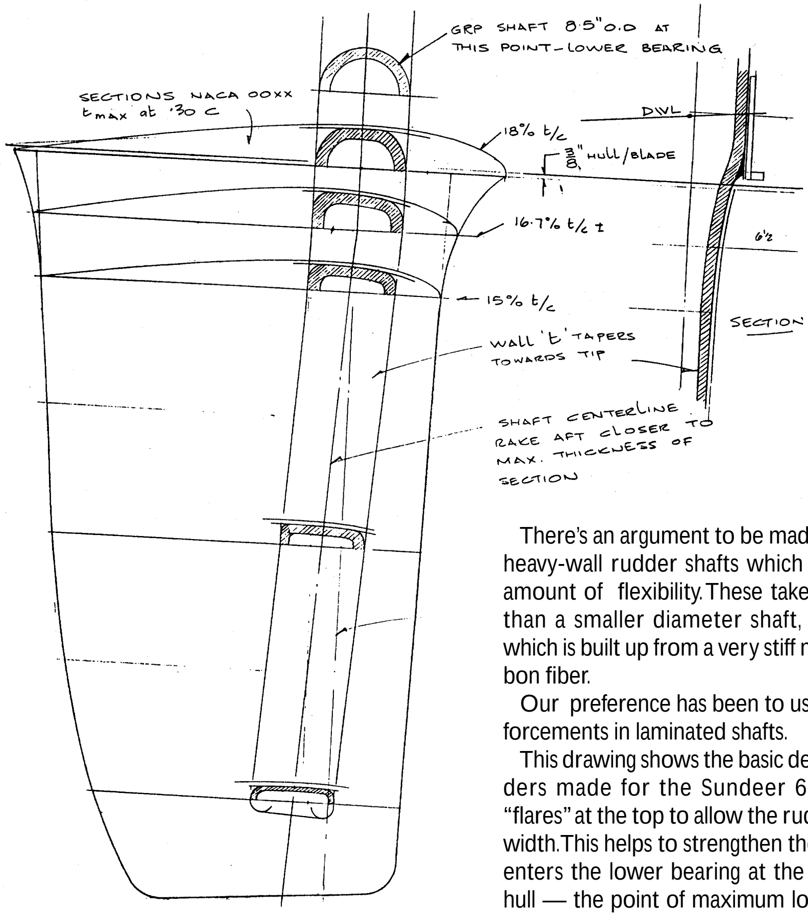
The rudder is one of the areas in which a high-tech approach sometimes makes sense. Using carbon fiber, as shown in the finished blade on the left, allows the rudder-shaft diameter to be reduced. This in turn allows the top of the blade to be thinner and more efficient. The very high aspect-ratio plan form shown here will generate lots of lift from a relatively small blade. This means reduced wetted surface.

This approach has two negatives. One is cost. These rudders are expensive to fabricate, although they provide a lot of joy when hand-steering.

The second issue is the damage resistance of carbon fiber. It is extremely strong but does not have much elasticity, and so is not good at taking shock loads when you go aground.

The illustration above shows a typical Advanced Composites rudder and bearing system.

(Photo and illustration courtesy of Advanced Composites.)



There's an argument to be made for the use of heavy-wall rudder shafts which have a certain amount of flexibility. These take impact better, than a smaller diameter shaft, especially one which is built up from a very stiff material like carbon fiber.

Our preference has been to use "S" glass reinforcements in laminated shafts.

This drawing shows the basic details of the rudders made for the Sundeer 64. The rudder "flares" at the top to allow the rudder shaft extra width. This helps to strengthen the shaft where it enters the lower bearing at the bottom of the hull — the point of maximum loading. The drag on this shape is a little higher than on a thinner shaft. But these are cruising boats and the most important issue is keeping the rudder shaft in one piece, even after a moderate collision.

Rudder-Shaft Construction

There are several approaches to rudder shafts. Stainless steel is frequently used and has the advantages of being weldable and moderate in size for its stiffness. Being reasonably corrosion-resistant, it provides a long-term, clean-running surface for your bearings. It's important to be sure that the rudder-skin loads are evenly distributed into the shaft and that welds on ribs are well-made and of a large area.

Of course, with aluminum yachts, the norm is to use an aluminum shaft. The shaft will be larger in diameter than stainless, since aluminum is around one-third as stiff as stainless. However, it is also lighter. You'll probably end up a little lighter on the shaft —and you won't have a problem with electrolysis between dissimilar metals.

Carbon fiber is the ultimate rudder-shaft material. Very stiff and light, it offers the best shot at a moderate-sized shaft for reduced rudder thickness. Of course, a carbon-fiber rudder shaft will run two to three times the cost of aluminum or stainless steel.

You're probably wondering about reliability with carbon fiber. If properly engineered, it is just as reliable as any other material. Jay Hlavety's company, Advanced Composites in Santa Cruz, California, has been making carbon-fiber rudder stocks for racers and cruisers for over ten years. In the more than 450 rudders he has supplied, he hasn't had a failure.

TOC
Last Chapter
Next Chapter
Help!

TOC

Last Chapter

Next Chapter

Help!

These two *Beowulf* photos were taken in New Zealand, where line boring is a common practice. When the hull was built in Truckee, California, the builder had never heard of this process. Trying to weld bearing carriers in alignment is almost impossible. We ended up trying to put the bearing carriers in place with epoxy, but they were not very well aligned.

Notice the temporary welded lugs in the right photo, supporting the machinery base. In the left photo you can see a mid-span temporary support as well. The bottom support is not visible.

Line boring is the only certain way to get the rudder and prop shaft bearing carriers in line. The process involves what is in effect a portable lathe. A base is set up, usually on top, and a shaft is run all the way to the bottom of the hull. This shaft is fixed at the same angle as the rudder shaft. A cutting tool is then used to mill out the interior of the bearing carriers, as well as any flanges which may be in use. (Kelly Archer photos)

This is an aluminum bearing carrier welded to the bottom of one of our hulls. The hull plating in this area is double the rest of the hull bottom, and the aluminum carrier is slipped down and through the hull. This makes it possible to weld both inside and out. The gussets spread the load into the hull plate.

The same logic is used on fiberglass hulls. Core, if any is present, is left out in favor of a beefed-up solid laminate. Gussets are used to spread the load.

The thin bearing shown is Turcite.

TOC
Last Chapter
Next Chapter
Help!

Rudder-Shaft Alignment

For a rudder to steer easily under load, the rudder shaft must be carefully aligned with the bearings through which it passes. Imperfect alignment causes tremendous amounts of increased friction between the rudder shaft and the bearings in which the shaft is carried.

When a fiberglass vessel is laid up, the rudder-bearing carriers are typically inserted with a steel aligning jig. This jig is removed once the secondary bonding that holds the carriers has set.

If the hull and/or deck don't change shape when the boat is launched, and if the job has been done correctly, everything will be fine. Unfortunately, this is frequently not the case.

In metal boats, where bearing carriers must be welded into place, virtually nothing can be done in the way of jigging to keep things in alignment.

Potting in Bearings

One approach to this alignment conundrum is to make the bearing holders oversize. The bearing and bearing holders are then coated with a resin and microballoon mixture. Next, the bearings are slid into place, using the rudder shaft as an alignment jig. The bearings will be in alignment once the resin matric cures — assuming the bearings have a close fit on the rudder shaft.

Line Boring

Line boring is a much more accurate approach. With this technique, a long boring tool is used to cut away a small amount of the lower and upper bearing holder. The cutting tool is held in alignment by a long rod running the distance between bearing holders. This ensures everything will be correctly aligned.

Rudder-Shaft Deflection

It is not at all uncommon for a rudder shaft to deflect (bend) under load. As you can imagine, it doesn't take much of a deflection for carefully installed bearings to be out of alignment

With a used boat, there's not much to be done about this, besides being aware of the risk. With new construction, however, you can do away almost entirely with deflection by specifying higher strength rudder shafts.

RUDDER BEARINGS

The next key to efficiency is the rudder bearings. The difference between efficient and inefficient bearings can mean a factor of three or more in steering effort.

The impact of bearings on your steering system is also a function of rudder loads. On a spade rudder, the loads will be very high. A skeg- or keel-mounted rudder will have lower loading on the bearings.

Compressive Yield

When looking at bearing materials, there are five properties to check. The most important by far is compressive yield. This is the ability of the material to withstand pressure before it begins to deform. With plastics, this deformation leads to what is called "cold forming." The material changes shape, allows the bearing to become misaligned, and dramatically increases friction.

This is a real problem with many commonly used plastics under load. Compressive yield is also directly related to the ability of a bearing to wear over time.

Hydroscopicity

It's also important to determine hydroscopicity, or the tendency of the material to absorb water. Most plastics absorb small amounts of water when immersed. This causes the bearings to expand and bind on the rudder shaft.

Thermal Stability

Thermal stability is another issue. Most plastics move around as the temperature changes. If bearings have been machined in cold weather, and you're cruising in warm weather, the expansion may be enough to bind on the rudder shaft.

Physical Properties of Plastic

	TEST METHOD						
PROPERTY	ASTI	NYLON 101	NYLATRON GS	MC NYLON	TEFLON	ACETAL	UHMW-PE
Specific Gravity	D792	1.14 - 1.15	1.14 - 1.18	1.15 - 1.17	2.1 - 2.3	1.41 - 1.42	0.94
Tensile strength, 73°f, psi	D638	9 - 12,000	10 - 14,000	11 - 14,000	1,5 - 5,000	8,8 - 12,000	4 - 5,000
Fensile Modulus of Elasticity, 73°f	D638	250 - 400,000	450 - 600,000	350 - 450,000	50 - 90,000	410 - 520,000	80 - 100,000
Elongation, 73°f, %	D638	20 - 200	5 - 150	10 - 60	75 - 350	12 - 75	200 - 450
Flexural Strength, 73°f, psi	D790	12.5 - 14,000	16 - 19,000	16 - 17,500	NO BREAK	13 - 15,000	-----
Flexural Modulus of Elasticity, 73°f, psi	D790	175 - 410,000	400 - 500,000	-----	90 - 110,000	375 - 550,000	75,000
Shear Strength, 73°f, psi	D732	9600	9,5 - 10,500	10,5 - 11,500	-----	7,7 - 9,500	3,500
Compressive Strength 10% Def., psi	D695	12,000	12,000 - 13,000	-----	-----	16,000 - 18,000	2,500
Compressive Modulus of Elasticity, 73°f, psi	D695	-----	-----	-----	95,000 - 115,000	-----	-----
Coefficient of Friction (Dry vs. Steel) Dynamic		.17 - .43	.15 - .35	.16 - .25	.04 - .1	.15 - .35	.09 - .12
Hardness, Rockwell, 73°f	D785	R110 - 120	R110 - 125	R112 - 120	R10 - 20	R119-122	R64
Durometer, 73°f	D676	D80 - 85	D80 - 90	-----	D55 - 70	2.3	-----
Tensile Impact, 73°F, ft. lb./sq. in.	D1822	90 - 180	50 - 180	80 - 130	30 - 200	40 - 90	1000
Water Absorption Immersion 24 Hours, %	D570	.6 - 1.5	.5 - 1.4	.6 - 1.2	.00 - .05	.12 - .25	< .01
Saturation, %	D570	7 - 9	6 - 8	5.5 - 6.5		.8 - .9	-----

John Newton at Tides Marine in Fort Lauderdale, Florida, was kind enough to send us this chart showing the different properties of various plastic materials. The two plastics most commonly used in the marine business are Nylatron GS and UHMW. The Nylatron has much better mechanical properties than those of UHMW. However, the coefficient of friction is only half as good. The biggest problem with all forms of nylon is the fact that they absorb water, causing them to expand according to temperature. A nylon-based bearing needs a lot of slop going into the water to allow for clearance after it has absorbed its share of water.

Coefficient of Friction

Last, look into coefficient of friction. All other things being equal, you want this to be as low as possible. The problem is that some of the materials with the lowest coefficients of friction also have problems with compressive yield, hydroscopicity, and thermal stability.

Engineering Issues

Once a rudder has been designed and the shaft size has been decided, it is time to look at what sort of bearing system to employ. Calculate a total load for each bearing, then check the characteristics of various materials available.

The stronger the bearing material in terms of compressive yield, the shorter the bearing can be. A shorter bearing has less surface in contact with the rudder. Since total friction is a function of the coefficient of friction, load, and contact surface area, sometimes a harder bearing material with a higher coefficient of friction will actually have less overall friction than a softer, more slippery material.

One caveat: Avoid the tendency to make bearings longer than necessary. Too much bearing surface increases friction.

Bearing Clearance

Another factor to determine is bearing clearance. Requirements vary with the material characteristics. With many plastics, it is more of an art than a science to know just how much allowance to make for hydroscopicity and thermal expansion.

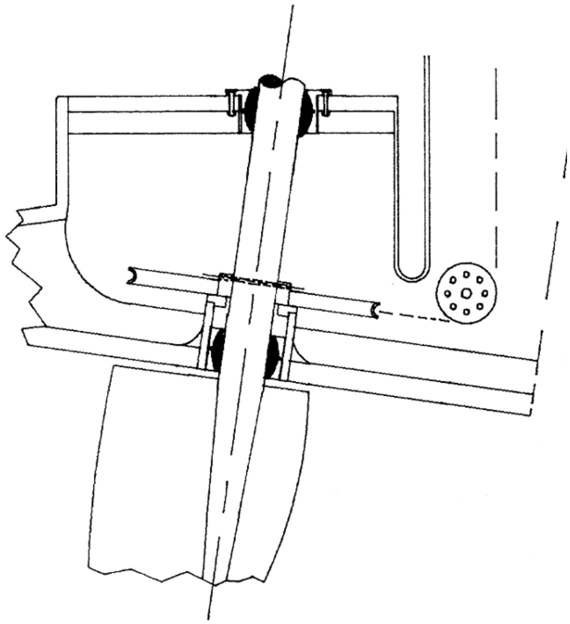
The ideal situation is to start on the tight side and, after a period of time, use a cylinder hone to ream out the bearings to the right tolerance. The only problem with this approach is that the boat

TOC

Last Chapter

Next Chapter

Help!



Self-aligning bearings allow for misalignment between the top and bottom bearing, as well as for deflection of the rudder shaft under load.

must be hauled and the rudder dropped before the process can begin.

Why not just make the bearings oversize in the beginning? The answer is that beyond a nominal amount of clearance, the bearing begins to lose its precise fit to the rudder shaft, increasing friction.

Bearing Materials

Over the years we've used all sorts of materials for bearings. Bronze is common in older boats. While stable and wear-resistant, it has a high coefficient of friction.

Nylons, Teflons, UHMW (ultra-high molecular weight), and Delrin are also commonly used. All of these suffer in a variety of ways from the engineering problems discussed above. Of the four, UHMW has the best track record.

Jay Hlavety of Advanced Composite Concepts has been supplying us with rudder bearings for years. Whenever we are doing a new boat project, I always check with Jay to find out the best material available.

For the last few years he's been supplying us with a material called Turcite. This is a filled, reinforced polyester, with excellent mechanical properties and good friction characteristics to boot. For example, the compressive yield on Turcite is 15,000 psi — compared to 2,000 psi or less for most plastics and 5,000 psi for Delrin. Turcite is relatively stable thermally and has almost no tendency to absorb moisture.

Fixed Bearings

The simplest and most common bearings are sleave-like in configuration. These will be held in place in the bearing holder either with set screws or with a small amount of adhesive. Fixed bearings are the simplest to execute in terms of machining, but as we've been discussing, must be installed to very close tolerances.

TOC

Last Chapter

Next Chapter

Help!

Needle Bearings

On many of the yachts we've built over the years we've used needle bearings. In this case, a series of vertical rollers is held in a cage between rudder shaft and bearing housing. Needle bearings are typically very efficient in terms of steering loads.

However, they do take quite a bit of space around the rudder shaft and require a lot more maintenance. In recent years we've stayed with either UHMW or Turcite.

Self-Aligning Bearings

One of the ways around the alignment problem is to use self-aligning bearings. In this case, the bearing in contact with the rudder shaft is spherical in shape on its outside edge, and is held in a carrier that allows the rudder bearing to move as required for alignment.

This is particularly helpful where the rudder shaft itself is deflecting — a common problem in racing boats.

Bearing Longevity

Where we'd expect a Delrin or UHMW bearing to last perhaps 8,000 miles, needle bearings typically last less than 5,000 miles before needing work. On the other hand, we've had Turcite bearings go 20,000 miles.

Regardless of what type of bearing material you use, when you are having a set machined for the first time (or as a replacement), have a spare set made at the same time. Most of the machining costs are a function of setup. The actual costs for a second set are negligible compared to those of the first set.

Bearing Cleanliness

Before going further we should chat for a minute about bearing cleanliness. Nothing ruins a bearing faster than dirt. The dirt can come from the air, from something kicked up in the water, or more commonly from chips of metal or plastic that find their way into the bearing during boatbuilding or maintenance procedures. Whenever possible, make sure your bearings are covered or sealed.

Bearing Lubrication

Some bearing materials require lubrication, while others do not. If a lubricant is desired, make sure that what you use matches the needs of your bearing material. In many cases, the wrong lubricant will turn into a sticky gum, increasing friction.

RUDDER PACKING GLANDS

The last item which bears on the rudder shaft and is therefore a consideration for friction is the packing gland. This device keeps the water from coming up the rudder shaft into the boat.

With a modern canoe-body style of hull, the odds are the gland will be above the at-rest waterline. However, dynamic pressure generated by the rudder and prop wash will quickly find any weaknesses in the gland once you are up to speed. On most older designs, the top of the bottom bearing is below the waterline

Rudder glands vary from bronze with a square packing (just like on your propeller shaft) to devices that depend on O-rings or lip seals.

In all cases, it is important to provide just enough pressure on the adjusting nut to prevent the ingress of water. Remember, the tighter the packing gland, the more friction on your steering.

To find out how much of a difference this makes, try your steering with the gland backed off, and then again with it really tight. You will be amazed at the difference.

If the top of the bottom bearing is above the waterline, you can eliminate the rudder gland by clamping a rubber boot around the bearing carrier. This provides a dam to retain any water that comes up the rudder shaft, allowing it to drain back out when pressures are reduced. We've used this system on many of our boats — it works well, causes no friction on the rudder shaft, and there's no maintenance.

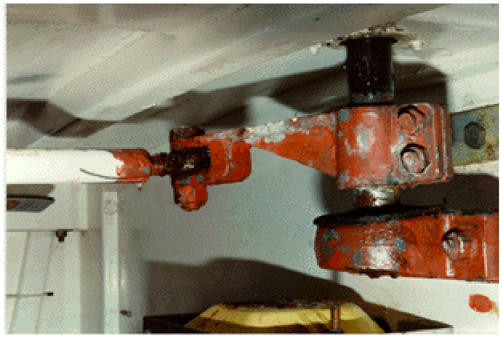
TOC
Last Chapter
Next Chapter
Help!

TOC

Last Chapter

Next Chapter

Help!



A classic-looking cutter with a traditional long tiller attached to a keel-hung rudder (upper left).

With no counterbalance possible on the rudder, steering forces can become very high — hence the long tiller, which provides additional leverage. Equally important in this equation is the ability to comfortably brace your body. This is necessary in order to be able to exert force on the tiller, pulling it to weather (it will go to leeward all by itself!) and to keep your body jammed into position if the boat rolls.

In the lower left photo you can see a number of good possibilities for bracing your feet to leeward. But the coamings will be hard on your back after a while. A coaming twice as high would be more comfortable to lean back against.

Sometimes the rudder shaft is not in the ideal spot to attach a tiller. The upper right photo shows a very simple method of transferring the load.

The bottom right photo shows the rudder head, with a short tiller (or more properly, a bell crank) bolted to the top of the rudder stock. A rigid rod connects this to another bellcrank further forward. This is in turn attached to another vertical shaft, to which the tiller is affixed in the cockpit.

TILLER STEERING

The simplest and most elegant solution for steering is the tiller. You get rid of a whole bunch of potential problems, eliminate all of the friction inherent with wheel steering, and most important, get to feel the boat. When the tiller is not being used, it can be stored in a vertical position, leaving the cockpit more open.

Of course there are some negatives. The first comes with steering load. The amount of leverage a tiller can exercise on the rudder is limited by tiller length — as opposed to wheel steering, which has a geared ratio. This in turn limits the size of vessel in which a tiller is effective — typically

TOC
Last Chapter
Next Chapter
Help!

This bronze quadrant was custom cast for our production Sundeer series by Edson. For cable-steering loads, the bronze is overkill, but when the quadrant has to act as a rudder stop it begins to make sense. Note the hydraulic ram for the autopilot attached to a lug on the back side of the quadrant. Triple cable clamps, attached to a threaded eye bolt, provide connection for the steering cables.

something under 40 feet (12.3 m), although steering characteristics bear directly on the size of vessel that can use a tiller.

In a cruising context, you need to look at the tiller as it links to the self-steering device. The tiller is much easier and more efficient to connect to a wind vane than is a wheel system.

The pilot has two possibilities. The first is an external system. The alternative is to fit a short tiller arm to the rudder stock and connect this to your pilot drive. This latter approach, if coupled with a powerful pilot, makes the most sense to me. This makes the tiller available for fun and for emergencies, even though most of the time it will be vertical and you'll be steering with the pilot.

CABLE STEERING

Obviously wheel steering is more complex than a tiller-based system. The problem comes with all of the pulleys, gears, corners, bearings, cables, and chains. Each element has separate maintenance issues, and the failure of any single item can lead to embarrassment or worse.

Cable steering is by far the most common system found on smaller cruising yachts.

There are a series of issues affecting steering efficiency and maintenance.

The Quadrant

Quadrants carry a substantial amount of reversing load over long periods of time. This means that unless the quadrant is engineered conservatively, fatigue can become a problem.

This quadrant has been prefabricated from aluminum plate. There are four 1/2-inch (12.6mm) bolts on each side, holding it to the stainless-steel rudder shaft.

A turnbuckle has been used for cable adjustment. This looks quite neat but severely reduces the amount of flexibility in cable length, as the turnbuckle body takes up so much room compared to a threaded-eye bolt.

This quadrant is sitting right on top of the rudder-packing gland. Some clearance would be better. This would make it easier to keep an eye on the quadrant.

Points that need attention are the flanges that clamp on the rudder shaft and the attachment points for the cables. Pay particular attention to the alignment of cables with their eyebolts.

The pull should be directly in line. Avoid any bending, as this will, over time, lead to a failure of the eye bolts.

Where the cables run over the quadrant, the surfaces should be smooth and fair. If there is going to be a problem, it typically occurs where the cable makes its bend to attach to the eye bolts. Watch for broken wire strands. These are an indicator of a cable that has begun to fail.

Turning Blocks

The cables will probably run over a series of four or more turning sheaves — two at the base of the steering pedestal and two outboard that lead back to the rudder quadrant. These sheaves should be a minimum of 25 times the diameter of the steering cables.

Since they are a significant source of friction, ideally they will have needle bearings to reduce energy loss.

Some of these bearing require lubrication. If they are easy to reach, you'll want to make sure that the grease nipples are placed so they are handy. If they are difficult to reach, running a remote grease-gun attachment point may make sense.

Because of the high loads and the fact that the loads are reversing, the bolts that fasten down the sheaves tend to work with time. Keep a close eye on them.

Finally, you will want to be sure that your steering sheaves are aligned with the cables and with the grooves in the steering quadrant.

Cables

Steering cables are the weak link in the steering system, due to fatigue over the years. If the turning sheaves are not large enough, the inner wires on each turn tend to compress, while the outer wires are stretched. After a few thousand cycles around a sharp corner, the individual wires start to fail, creating "meat hooks."

The best way to get around this problem is to use larger-than-normal cables with commensurately oversized sheaves. However, going up in size on the cables without increasing sheave size is counterproductive — the new, larger wire will be under greater stress due to the smaller relative diameter of the existing sheaves.

Stainless-steel 7x19 wire is the typical choice for steering cables. Cable clamps are usually used at one end (typically three) with a swaged fitting at the other end. It is always a good idea to carry a spare set of steering cables.

If your steering pedestal is some distance from the quadrant, and if the cables become longer than normal, you will need to increase size to compensate for stretch.

Steering Chain

To connect the efforts of the helmsman turning the wheel to the rudder, use a piece of stainless-steel chain, running over a toothed sprocket (see below). Stainless is a must for the compass to read with any degree of accuracy.

The chain needs to match the sprocket carefully, or the links will tend to break down.

Over time, you may find that cracks begin to develop in the side plates of the chain. Keep a careful eye on these. You can always replace an individual link once a single link has begun to fail, but this is a good indicator that the rest of the chain is tired as well.

Chain Sprocket

The shaft to which the steering wheel is attached transmits steering energy to the chain with a toothed gear called a sprocket. The number of teeth on the sprocket are one of the key elements in your steering ratio.

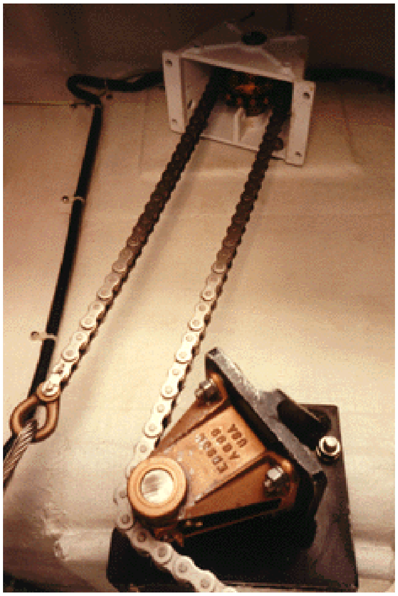
In most cases it's easy to exchange the sprocket for one with more or less teeth. Having more teeth decreases your hard over to hard over turns, while having less teeth increases the turns, reducing steering loads.

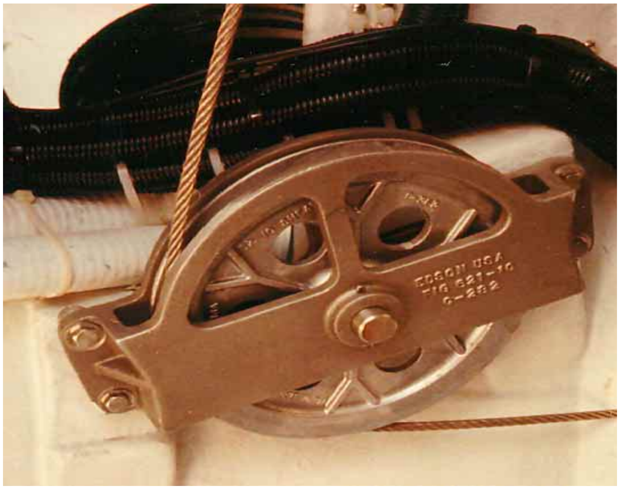
TOC

Last Chapter

Next Chapter

Help!

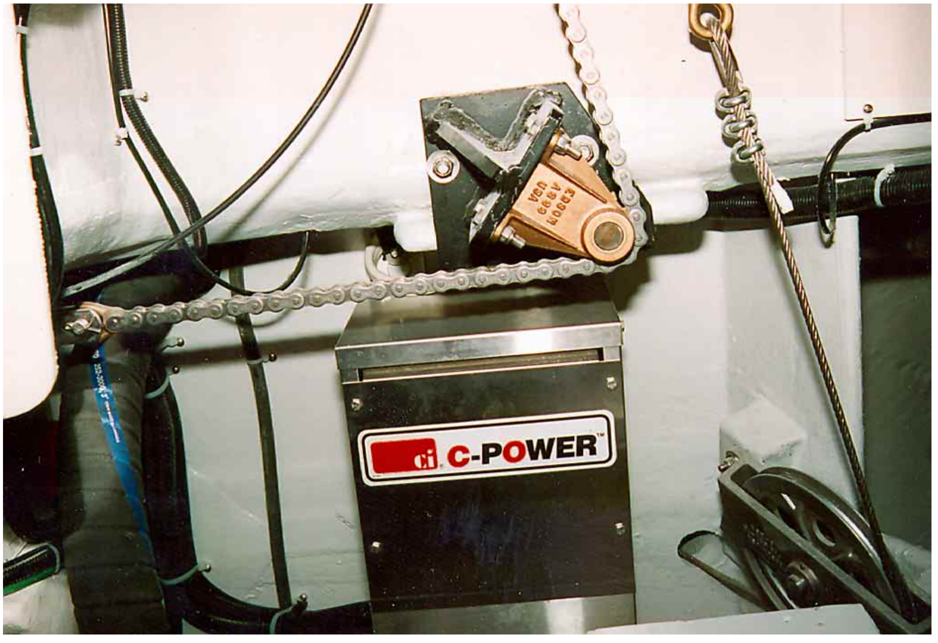




Each time the steering cables change direction (above left), friction is added to the system. Using large-diameter sheaves reduces the wear on cables and helps cut down on friction. Equally important is the bearing material between sheave and its axle (above right).

Most sheaves have an oilite (impregnated bronze) bearing. If you upgrade to needle bearings, friction will be reduced by as much as 50 percent.

Always be sure the bearings are well lubricated.



With dual steering wheels, you must connect the two wheels together. This necessitates an extra idler gear for each helm, over which a piece of chain (or in some cases cable) runs. The top left photo shows the port helm idler, while the photo above is of the starboard idler. At the top of the photo you can see the backside of the helm sprocket and bearing.

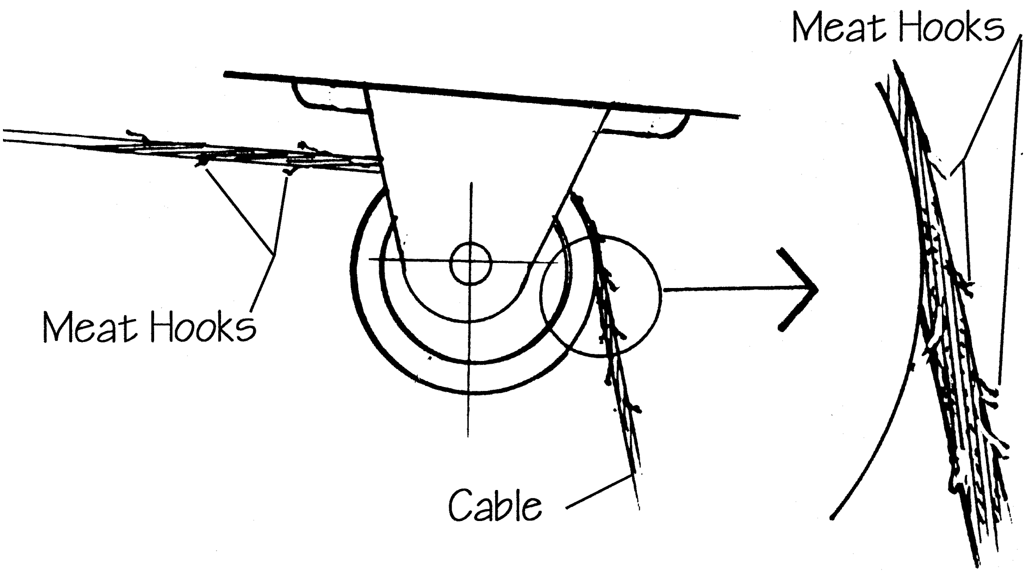
TOC

Last Chapter

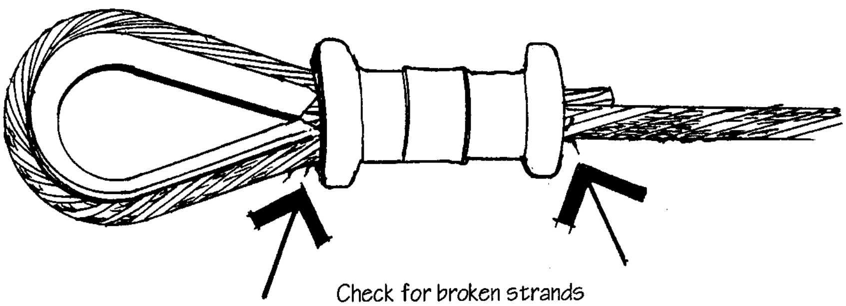
Next Chapter

Help!

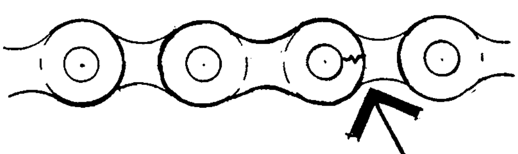
TOC
Last Chapter
Next Chapter
Help!



Meat hooks (broken cable strands) typically form where the steering cable runs over sheaves. How long before this happens is a function of wire diameter and loading and the pulley diameter over which the wire must run. The cable sheaves should be at least 25 times the diameter of the wire.



Nicopress fittings can also develop broken strands, especially if they are subject to bending back and forth. It's a good habit to periodically check each side of the Nicopress ferrule for broken strands.



Of all the parts in the steering system, the one most subject to failure is the chain that runs over the helm gear. Chains usually fail by small cracks turning to large cracks over time. The cracks normally form on the links where they join the various segments. You can spot these when they first start, if you are looking.

TOC

Last Chapter

Next Chapter

Help!

HYDRAULIC STEERING

Hydraulic steering has a series of advantages. Gone are all of those cables, pulleys, and chains, so it is probably more reliable than cable. The helm can be located a long way from the rudder without worrying about how to route the cables. It's easy to tie in an autopilot, and installing a second inside steering station is simple. The wheel will not turn when the pilot is operating, and feedback (the tendency for external forces to turn the helm) under power or in big seas is eliminated.

On the other hand, there are some serious disadvantages. All feel is lost. If the boat has excessive weather helm and needs a change in sail trim the only way you'll know is by looking at an electronic rudder-angle indicator (or by taking a look aloft).

Even more serious, there is no "king spoke." Since there is always a bit of slippage you cannot mark the wheel on center and expect that to be the center the next time you use the wheel.

This becomes a major problem when you are trying to steer aggressively with a spinnaker up or when sailing in storm conditions.

I have had hydraulic steering on several of our own boats, each time swearing it would be the last. *Beowulf*, our most recent creation, has hydraulic steering!

Helm Pumps

The first element in the hydraulic steering system is a helm pump to which the steering wheel is attached. Each turn of the helm pump pushes a certain amount of hydraulic fluid through the lines to the steering cylinder. The bigger the helm pump, the faster your steering response will be.

Helm pumps are available with variable displacement. You can actually change the amount of fluid displaced with each turn so that gear ratios are adjustable.

Helm pumps are typically very reliable. The only thing you need careful about is bearing and seal wear from large wheels. From 36 inches (900 mm) and down, this is typically not a factor. With larger wheels it is. You may want to go to a larger sized pump so there is a larger bearing in the pump to take wheel loads.

Cylinder Size

Cylinder size is based on the rudder loads. With most systems you do not want to exceed a working pressure of 900 pounds per square inch (psi) as the maximum operating pressure. Once your steering loads are calculated you can then pick the correct cylinder to do the job.

It never makes sense to scrimp on cylinder size. There's not a lot of difference in cost or bulk.

However, the larger the cylinder, the slower the steering response (unless helm pump capacity is increased). You feel this as more turns of the wheel for hard over to hard over. This does have the advantage of increasing your leverage over the rudder.

The base of the steering cylinder carries the full load of your entire steering system. This is usually four 3/8-inch (9.6 mm) or 1/2-inch (12.6 mm) bolts. With the load reversing thousands of times on a passage, these bolts and the base to which they are attached are going to get a real workout.

That base needs to be extremely stout. The bolts must be torqued right to their limits. Be sure to use lock washers, lock nuts, or some form of Loctite. *And check the bolts before every passage*.

You will want to make sure that the cylinder is carefully aligned with the steering arm and that you have equal movement of the rudder either side of center.

We have installed systems where we used two hydraulic cylinders working in parallel to carry the full load. If you have a shut-off valve on one of the cylinders, in light airs and/or in tight quarters in which fast helm response is desired, shutting down one of the cylinders cuts the steering ratio in half, giving you a helm repsonse that is twice as fast (but with half the mechanical advantage).

How do you figure out the correct size of cylinder for your boat? There are a variety of formulas that various manufacturers use that can give you a starting point. Speed, rudder efficiency, counterbalance on the blade (or lack thereof), rudder size, and vessel displacement all enter into the equation.

The best approach is to find a boat similar to yours and ask the owner how his system works. A good indicator of sizing is if the operating pressure is below 900 psi in all but the worst of load situations.

Over the years we've typically used Hynautics K-3 cylinders on our larger boats (ranging from *Intermezzo II*, to the Sundeer 64 and 67, and including the 79-foot *Beowulf*). On *Intermezzo II* and *Beowulf* the cylinders were used for both wheel and pilot steering. The other vessels were for pilots only. The Sundeer 56 was fitted with a K-2 cylinder for the pilot.

Steering Tiller

The force of the hydraulic cylinder is delivered to the rudder shaft via a short tiller arm that is clamped to the rudder shaft. The length of this arm and the length of the hydraulic cylinder's piston combine to determine how far the rudder will travel before the steering reaches its maximum angle.

Shorter tiller arms give you more rudder angle. We always try and have several holes so that the amount of rudder angle can be adjusted (a longer tiller arm also gives you more leverage).

On most of our hydraulic systems we've typically used an 8-inch (200mm) tiller arm.

This tiller obviously must be immensely strong, with large bolts and heavy clamping flanges.

Keep a close eye on the clamping bolts.

Plumbing

With operating pressures at or below 900 psi, you have a wide variety of plumbing materials from which to choose.

High-pressure copper tubing (not refrigeration tubing) can be used if you are careful with the end fittings. However, we prefer to use stainless tubing if the system is going to be hard plumbed, as it has a much longer life.

If you do hard plumb, you will need some flexible hoses between the hydraulic cylinder and hard plumbing. If the hoses are short, you can get away with material rated at 2,000 psi (which typically has a burst strength of 6,000 psi). The issue here is not the strength of the hose but how much it expands under load.

If there is much expansion going on then the steering will be mushy.

For longer runs we typically specify 5,000-psi hose.

Hydraulic Fluid

The use of the correct hydraulic fluid is critical to the long-term well-being of the many seals in the system. Be sure and follow the manufacturer's recommendations. And just in case there's a leak, carry an extra gallon of hydraulic fluid.

Accumulator Tank

Most hydraulic systems include an accumulator tank or reservoir. This should be mounted as high as possible in the system, where the fluid level is easy to read with the sight glass, and where it is easy to fill. Remember to leave enough space between the filler and top and deck head for small funnel and a quart (liter) container of oil.

Relief Valves

All hydraulic systems incorporate a relief valve to relieve pressure in the event they are overloaded. These are typically set at around 900 to 1,100 psi. Although the cylinders typically will not fail until four times this rating, the manufacturers like to have a high factor of safety.

If you are steering in heavy weather or maybe making a fast turn under power, you may feel the wheel get unresponsive if the relief valves are popping. They also typically make a slight screeching sound.

If this occurs frequently, your hydraulic cylinder is undersized. If it happens on occasion, most relief valves can be adjusted upwards. We've set our own at 1,200 psi.

Bleeding

To operate properly a hydraulic steering system must be completely free of air or the air will compress under load, making steering mushy. You can tell if you have air in the system by turning the wheel until the rudder hits the stops. The wheel should then be firm. If you can move it more than an inch (25mm) or so there is air somewhere in the system.

Getting rid of air takes time. It will move around the system, becoming trapped at high spots and fittings.

The solution is to bleed each of the fittings in turn, while someone keeps a load on the steering wheel. It's not unusual to have to go around the entire system four or five times to get rid of all the air.

TOC

Last Chapter

Next Chapter

Help!

TOC
Last Chapter
Next Chapter
Help!

Hydraulic Leaks

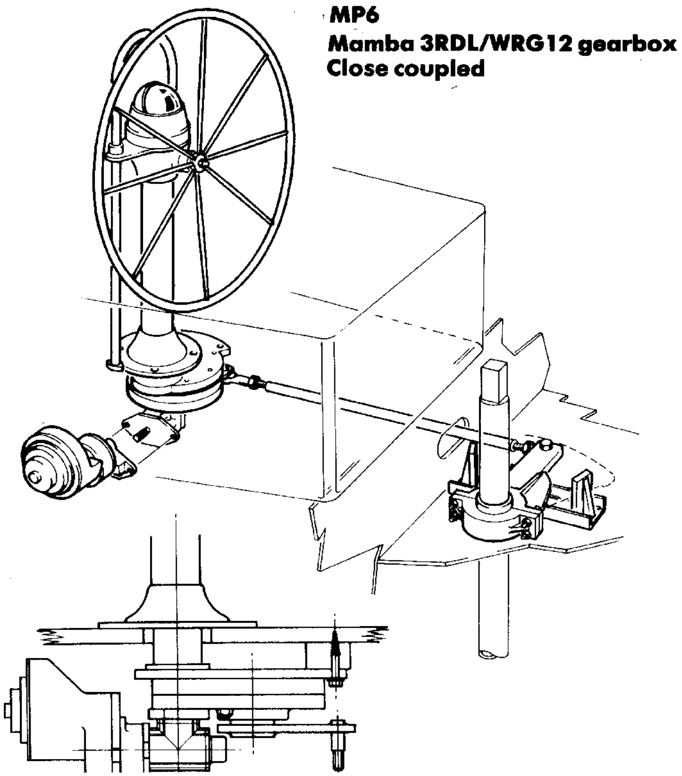
Over time there are going to be some leaks. These will most likely be at the helm pump and hydraulic cylinder from seal wear. Plumbing fittings should not leak if they are properly tightened.

You will want to keep the areas where leaks might occur clear of anything you wouldn't want hydraulic oil to drip on.

Installation Issues

The most important issue with hydraulic systems is keeping them clean. Even a tiny piece of dirt can lodge in a check valve, causing the system to malfunction. When you are assembling or maintaining the system, make sure all pipes and fittings are kept sealed. As each section is assembled, blow it out with compressed air.

Do not use Teflon tape with fittings. Pieces of it can break off inside the system. If you do need a thread sealant, use one specifically made for hydraulic systems.



The Mamba mechanical steering system, made by Whitlock in the UK, is a very efficient way of transferring torque from helm to the rudderpost.

The wheel, via torque tubes, turns a gear mounted under the helm, which, in turn, rotates a torque tube running back to the rudder post, at which point another gear (or transmission) changes this into a radial motion and adjusts a short tiller bolted to the rudder post.

For difficult installations, where cables would have a problem with slack or directional change, these systems work really well.

MECHANICAL STEERING

A number of companies offer mechanical steering systems where gears and torque tubes take the place of chain and cable or hydraulics.

These systems can be very efficient and can in some cases help with installations where cables would be impractical.

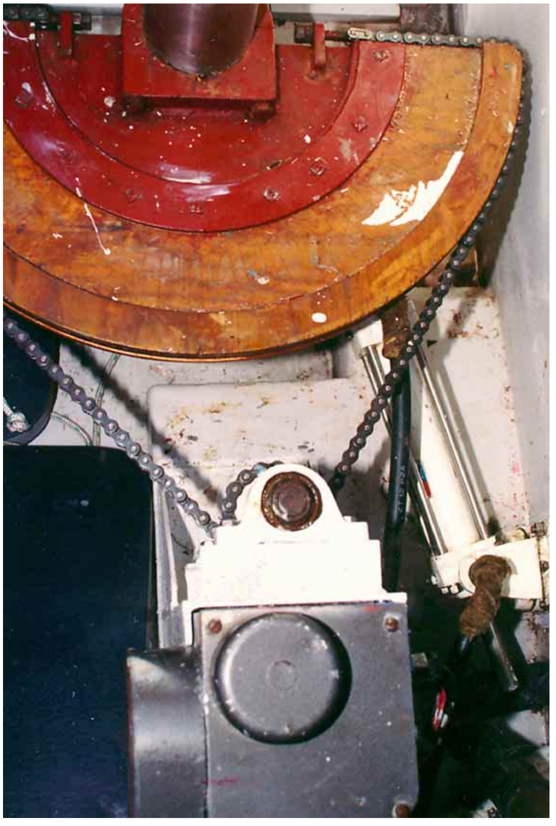
While we've never used a mechanical system on one of our projects, we have looked at it several times.

WORM GEARS

Worm-gear steering systems were quite common 30 years ago, especially where barn-door rudders attached to keels were used.

Worm gears have two advantages. First, they are compact. Next, they do not transmit rudder loads to the helm. With a barn-door rudder (keel attached), this can be a major issue in heavy weather.

They do suffer from significant friction and are quite costly, so it is rare to find this type of steering on a modern yacht.



This is an interesting quadrant system — a small steel center that clamps onto the rudder shaft. This is enlarged to an appropriate diameter with a fiberglassed plywood spacer. Steel roller chain is then used to transfer torque from a drive gear to the quadrant. This drive gear is in turn connected to a chain from the steering wheel, which makes a 90-degree bend over gears housed in the black box at the bottom of the photo.

On the right you can see a small white hydraulic cylinder attached to the steel center section. This is the autopilot drive.

STEERING DETAILS

Regardless of the steering system you decide to employ, you will need to look at a series of details that are common to all systems.

Tying in the Pilot

The first issue is tying in the autopilot. Cable steering typically allows for two approaches. One is to lengthen the steering chain so that the pilot drive motor engages the chain. This is quite common and easy to execute. Unfortunately, it means using the same steering system for manual and autopilot, so that one cannot back up the other. We prefer to design the system so that the autopilot drives the rudder shaft by means other than the cable system. Hence, each backs up the other. This can be achieved by using a separate tiller (e.g., the hydraulic cylinder tiller), or, alternatively, by tying directly to the quadrant (only if the quadrant is quite robust).

With a hydraulic pilot, you also have two choices. One is to "T" into the main hydraulic system. This is quite simple to do and relatively efficient but, again, puts all the eggs in one steering basket. If you take this approach, we suggest mounting a second cylinder that can be attached to the opposite side of the steering tiller. If the main system fails, this cylinder can then be used with a backup pilot.

Combination Steering

The most powerful pilots are hydraulically driven. If you have mechanical or cable steering, how do you integrate the two?

The solution is two-fold. First, connect the cylinder to the quadrant or a steering tiller. Then, allow for a "bypass" valve in the hydraulic plumbing. When you want to hand-steer, this valve is opened, recirculating the hydraulic fluid in the cylinder. The valve is closed to use the pilot. Note that in the closed position the manual steering will not work.

Obviously you will want the bypass valve located where it is convenient to operate. If this is not practical, you can operate it with a remote cable.

Electrically operated solenoid valves are available but add to power consumption and unnecessarily increase complexity.

Steering Ratios

The correct steering ratio is a bit of a conundrum. A fast-acting helm is best for good feel in light airs, as well as for maneuvering under sail or power in tight quarters. On the other hand, when steering loads are high, and when you are steering for hours on end, more leverage is going to be required.

Assuming for a moment that you have to pick a single steering ratio, how do you decide?

The first thing is to decide which is more important — offshore or close-in work. Smaller vessels with good maneuverability will probably be less concerned with tight quarters work and

TOC
Last Chapter
Next Chapter
Help!

Another Sundeer quadrant and pilot installation. The small bronze arm attached to the fiberglass rudderpost is for the rudder-angle sensor. The hydraulic ram (a Hynautics K-2 cylinder) drives the back of the quadrant. The attachment of the base of the ram must be very secure. As the boat travels, the load reverses itself every time the pilot tells the rudder to change direction. This reversing load tends to loosen bolts. The steering-system bolts (including quadrant, pilot connections, and cables) must be continually checked for correct tightness.

If you look at the forward center of the quadrant you will see a block of aluminum connected with five bolts. This acts as a rudder stop, limiting how far the rudder can travel. It is designed to impact two hard rubber pads mounted to the fiberglass gussets (port and starboard), one of which is visible in the closest corner of the quadrant.

TOC

Last Chapter

Next Chapter

Help!

more worried about offshore conditions. On the other hand, with larger vessels frequently what happens in tight quarters is of major importance.

The larger the wheel, the more leverage you have, so fewer turns are needed.

The bearings are another issue. Do they stick under load? If so, you will need more leverage when sailing in order to get the rudder to move that first fraction of a degree — after which it should move much more easily.

There are no hard-and-fast rules.

On our 50-foot (15.4m) *Intermezzo*, we had a 36-inch (900mm) wheel and 3-to-1 cable steering.

Intermezzo II, at 62 feet (19 m), had hydraulic steering with a 4-to-1 ratio, with a 4-foot (1,200mm) wheel. This made steering easy but really slow in port.

Sundeer, at 67 feet (20 m), was steered with a 1.75-to-1 ratio and a 4-foot wheel. The logic here was to maximize the ability to handle the boat in tight quarters. In light-to-moderate sailing load conditions this was fine, but in a real breeze could be a handful for Linda. In this case, we really relied on our dual autopilots to steer the boat offshore.

With *Beowulf*, at 78 feet (24 m), we went with hydraulic steering. Using a 40-inch (1,016 mm) wheel, she had a 4-to-1 steering ratio. Although this was the best we could do with hydraulics, it was far too slow for maneuvering. As a result, we always used our pilot when docking.

Rudder Stop

Some form of a rudder stop is required to take the load of the rudder, in case you lose control of the wheel in reverse or get thrown backwards by a big sea.

Since this typically happens quickly with high shock loads, the rudder stop must be extremely strong and heavily attached to the boat — it will see potentially higher loads than anything else in the steering system.

The stop itself works best with some form of hard rubber bumper between it and the quadrant or tiller arm.

TOC

Last Chapter

Next Chapter

Help!

Sarah (left), at age eight, surprised a lot of older folks with her feel for the boat, especially surfing with a spinnaker set. By standing on the deck just behind the wheel, she had a good view of the seas ahead, and could get her body strength into the wheel rim.

Having a place to step up onto for better visibility also works for older folks. This is particularly true when entering crowded harbors.

Lisa Miller (right) at *Locura*'s 5-foot (1.53m) wheel on a cold California day. In order to keep the rim of the wheel down at a level where the helmsman can get some armpower into it, the helm is sunken into a trough in the deck.

Wheel Diameter

Large-diameter wheels are very much in fashion. In some cases they make sense — for example, on racing boats where you want to be able to sit on the weather rail and watch the waves. But for cruising, the priorities are different.

Number one, the wheel needs to be efficiently sized for the shorter members of the crew. He or she should be able to comfortably hold the rim with arms bent at right angles at the elbow. With an excessively large wheel, you end up steering with your hands held high, making it tough to get good leverage. Large wheels also take a lot of cockpit space, are difficult to maneuver around at sea, and become a real nusiance in port. Of course, you can always remove the wheel in port.

Wheel Construction

The steering wheel should be constructed with enough strength so that it can survive even if a crewmember is thrown against it. With most destroyer-type stainless-steel wheels, strength is not a problem. Some of the higher-tech carbon and aluminum wheels do not take so well to abuse.

Wheel Brakes

Some form of a wheel brake with cable steering is helpful when anchored. This can be as simple as a piece of line tied to a winch or shroud, or it may be a built in friction break.

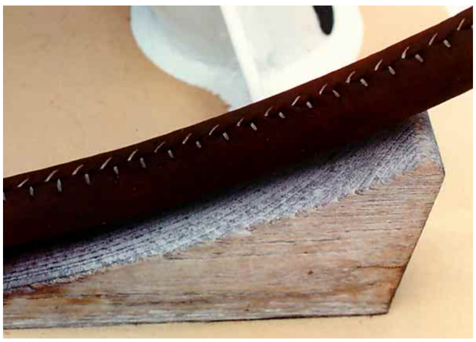
Single or Dual Wheels?

Single-wheel steering is lighter, simpler, less expensive, easier on maintenance, and has much less friction than dual-station steering.

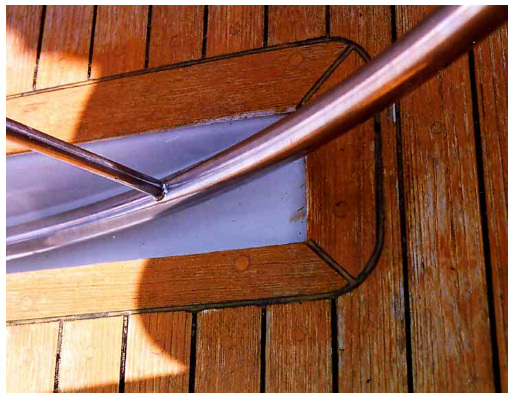
However, dual wheels look neat, provide a pathway through the cockpit, and give better visibility when sailing and docking as you move to the side deck.

Compare the ergonomics of this wheel with that on *Locura*'s wheel on the preceding page.They are both the same diameter, the difference being the amount of sinkage into the cockpit sole.

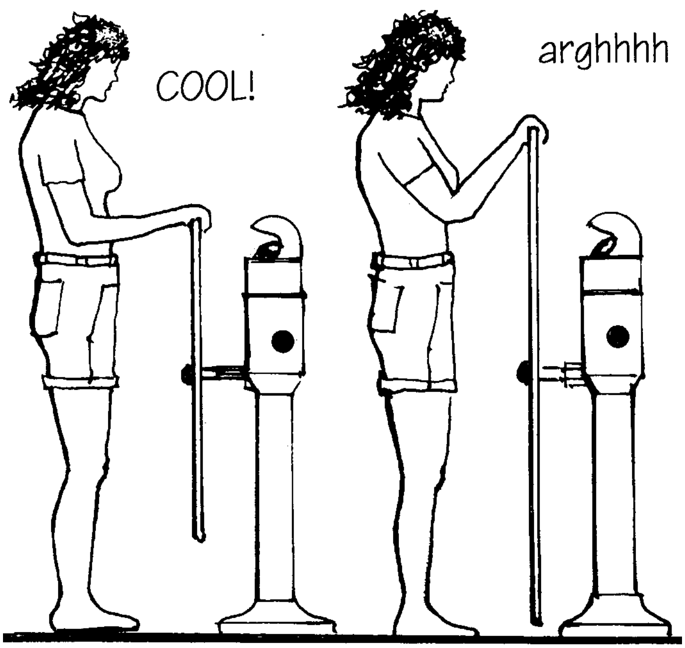
If you spend many hours at this helm your arms will be much more fatigued than if the wheel were a bit lower.



When the helm almost touches the deck, a block can be incorporated to keep your feet out of the way.



When a wheel is let into a trough or comes close to the deck, some means of keeping feet from jamming beneath is a must. If the trough is done properly, there will be no way for the helm to get a good bite on a foot and drag it.



The drawing to the left gives a feel for the ergonomics of steering. The helm should be set up so that the *weakest* member of the crew can deal with steering chores in heavy weather.

If the helm is too large in diameter and therefore too high off the deck, you cannot get your shoulder muscles into action efficiently.

TOC
Last Chapter
Next Chapter
Help!

TOC
Last Chapter
Next Chapter
Help!

Pedestals

When sailing in big seas and hanging onto the edge of a large-diameter wheel, the loads on the pedestal will be substantial. This is why the pedestal should be heavily constructed, with plenty of support under the cockpit sole.

Next comes the issue of engine controls. If you can reach over the wheel (not through it!) to work the controls, they can be mounted on the pedestal. My preference, however, is to mount them so that they can be operated by your foot, leaving your hands free to spin the wheel when maneuvering in tight quarters.

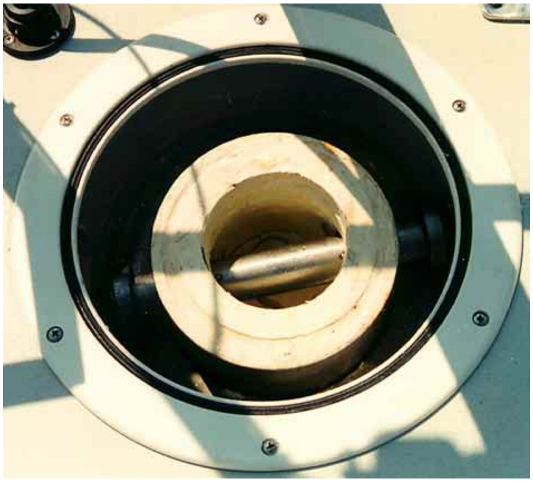
You will see many boats with all sorts of electronics and electrical controls clustered around the pedestal. This looks nice, but we've found it much more practical to keep electrical gear out of the weather if at all possible. Sailing instruments are much better mounted forward in the cockpit, where they can be seen by the crew as well as by the person steering.

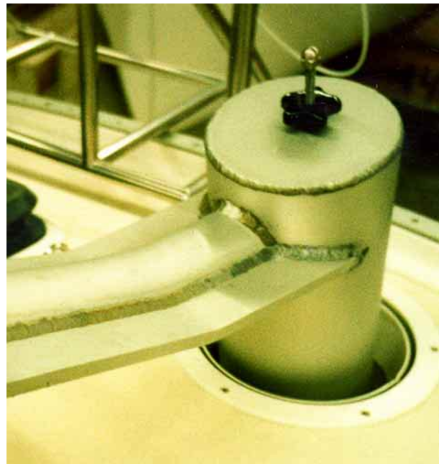
Corky Aucremen designed this clever guard rail/note board (above)for his Deerfoot 58 *Terra Nova*.The guard rail is about twice as high as the norm.This provides something better to hold onto and gets the note board up where it is easy to see.For writing down compass courses, bearings, times of hide tide, etc., this is ideal.

Pedestal development was pretty much static until a few years ago.Then someone came up with the idea of dishing the wheel and connecting it on the forward side (above). This allowed you to reach all sorts of buttons and controls without reaching around or through the spokes.

If you take this wheel-forward approach, be sure that the wheel projects far enough aft of the pedestal so that you can comfortably turn it without leaning forward (above).

The wheel shown here (below) is just a bit shy. The helmsman has to lean forward — a very uncomfortable position if you have to steer for any length of time.





TOC

Last Chapter

Next Chapter

Help!

Emergency tillers can be subject to extremely heavy loads, especially if in use for any period of time.

These three shots show the system for a Sundeer 64. A heavy chunk of schedule 40 aluminum pipe has a long gussett on each side for additional strength (top right and bottom left photos).

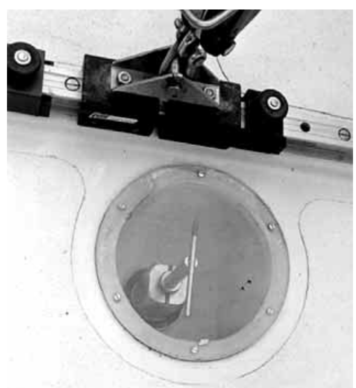
Where this is really needed is right at the rudder head. Note the holes at the tiller end for relieving tackles.

The upper left photo shows the top of the rudder shaft, typically hidden by a deck plate. The emergency tiller fits over the rudder shaft and engages the horizontal pin. That pin also carries the vertical weight of the rudder and is fitted with roller to reduce friction.

Emergency Tiller

Every vessel must have the means of fitting an *easy-to-use* emergency tiller. When evaluating this vital piece of gear, imagine how a sheet-to-tiller arrangement would be devised for self-steering. Be sure the emergency tiller can be rigged on short notice. Some set-ups require the removal of the binnacle before the emergency tiller can be shipped. Consider its strength as well. Emergency tillers are frequently too weak for the high loads they must withstand.

There should also be a means of rigging tackles to the end of the emergency tiller. The lines from these are then led to a convenient spot in the cockpit from which to steer. "Relieving tackles," as these are called, are just that — they relieve the strain of steering. We carried pre-rigged 3-to-1 tackles for both *Intermezzos* and 5-to-1 for *Sundeer* and *Beowulf*.

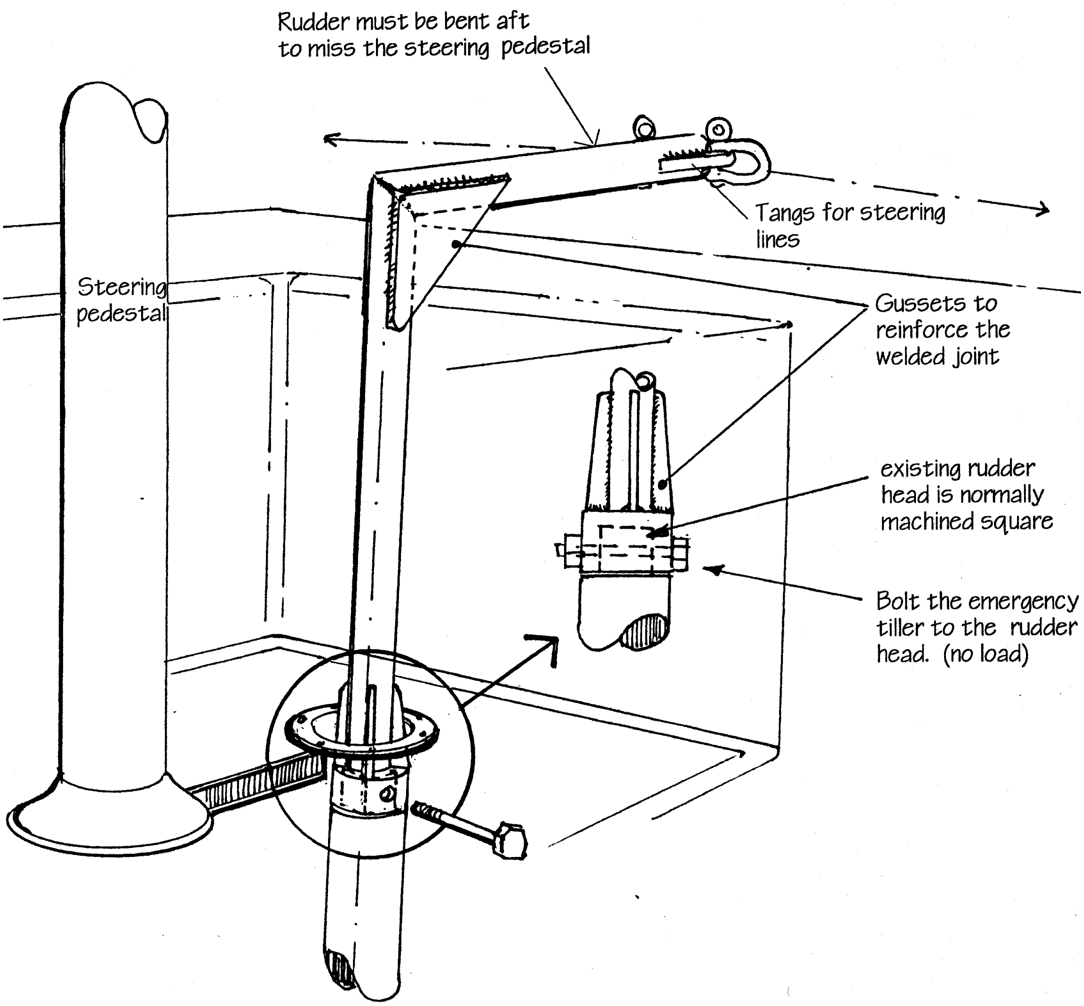


If your rudder head is exposed to view, it can make an excellent rudder angle indicator. Kelly Archer came up with this detail on *Wakaroa*.

Rudder-Angle Indicators

It is important to know the angle of your rudder, especially in heavy going. The simplest way to tell is to have a tactile indicator of when the wheel is at center. This is usually done with a

TOC
Last Chapter
Next Chapter
Help!



Emergency tillers are usually constructed to get you home from a weekend sail. They are typically built way too light for the rigors of a long passage, especially one which takes place in heavy airs.

The drawing above gives you the basics. First, a strong connection to the top of the rudder shaft is essential. The first place these tiller typically fail is where the vertical pipe comes off the attachment hardware. Gussets should be welded on four sides to reinforce this obvious weak spot.

Next, where the tiller makes a bend to face aft (as shown here) or forward is another weak point. Large angular gussets at this conner will help a lot.

Steering loads with such a short tiller are going to be very high. To handle these loads you need a set of relieving tackles, attached to the end of tiller, and then run down to the deck and forward to winches in the cockpit area.

You will want your emergency tiller to have welded lugs for these tackles to attach onto. The tackles should be handy. They don't always have to be used for this purpose, but you need to know where they are kept or being used, in case they are required quickly.

lashing of some sort. This way, when it is dark, and you are keeping an eye on the waves, you can feel where the helm is relative to center with the lashing passing under your fingers.

If you have hydraulic steering this tactile approach will not work, as the wheel loses its correlation to center with time. In this case, some form of a meter or the ability to look at the rudder head itself will do the job.

However, in really heavy going having to take your eyes off the path in front of you can be unnerving!