PROPULSION SYSTEMS

Mechanical, plumbing, and electrical systems are some of the most intriguing aspects of evaluating, equipping or designing a new cruising yacht. There are so many ways to go — different choices, combinations, direct and indirect relationships to consider.

The outcome of this decision-making process will have a substantial impact on your cruising success, the resale value of your vessel, and costs of ownership, not to mention your frustration level.

BASIC RULES

A few rules to bear in mind:

Be clear about needs. Try to get the job done with the minimum required gear. Keep everything as simple as possible —although, as we've said, simple is a relative term!

Don't crowd equipment into tight spaces. This leads to enormously increased installation costs and future maintenance problems. If it can't easily be seen, touched, and removed, think twice about the installation.

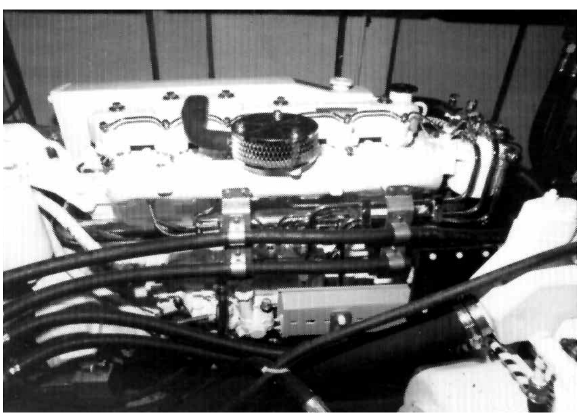
Consider carefully the integration of the various bits and pieces. How does all of this gear work together? Can you scavenge a pump from the saltwater washdown system to use with the fridge compressors? Will the DC alternator on the genset fit on the main engine?

The last thing to weigh is changing technology. The marine industry keeps growing, with new and better ideas always coming forth. What seems like a great way to go this year may be antiquated in a year or two. Stay alert to any changes that might bring aboard more efficient, easily maintained lifestyle-enhancing gear.

At the same time, be wary of the traps posed by untested equipment, and by the normal desire to have the newest and best aboard. Nothing is more frustrating than spending part of your precious freedom chips on a new gadget that doesn't work as advertised, takes up valuable space, and worse, keeps you at work in unpleasant conditions trying to effect repairs, while your anchorage neighbors are having a good time ashore. If you have an already-equipped vessel and are thinking about making changes to enhance cruising plans, hold off until you've had a chance to use the boat for a while. Whatever you think you want to do today will change once you have had some real cruising experience.

An efficient engine room needs plenty of space around all machinery so that you can see what is happening and deal easily with maintenance.

Hoses and wires should be carefully supported to avoid chafe. Aesthetics are important as well. It is much easier to spot trouble early in a clean, neat engine room.



Aesthetics

This may sound like a funny topic in an engine-room section, but it's important. A good-looking engine room or engine space not only makes you proud, but is an indication of the care with which things are installed and maintained.

Equipment placed in a neat, functional manner, with hoses and wires aligned and protected against chafe,

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is easier to work on. Keeping equipment clean is another part of the equation. A clean engine and engine compartment minimizes noxious odors and dangerous fumes, keeps the bilge clean, and makes it easier to spot incipient trouble before it reaches the crisis stage.

Keeping gear (especially the engine) painted is a simple chore if done on a *timely* basis. With metal, the thicker the paint film, the longer it will last, preventing rust in the process. Taking an hour or so, three or four times a year, to touch up bad spots really pays dividends.

Fasteners

One of the major battles to be fought with moving machinery is keeping the nuts and bolts tight. This can be achieved in any number of ways.

The simplest is with brute force. Put plenty of torque on a nut and flat washer — say, 120 foot pounds — and it will probably stay put until hell freezes over. But I've always been a little leery of this approach.

The next step up is the lock washer. In many areas, if used with lots of torque, these will do a good job.

Then there are lock nuts. These are nuts that have been scored or that have nylon inserts. The one drawback is that it takes forever to back them off, since a wrench must be used all the way.

In some applications, adhesives such as Loctite will be valuable. Here, it's essential to be sure the bonding surfaces are clean and the proper type of adhesive is used. Be careful not to use permanent adhesive if you expect to remove the nut without a major hassle. About the only way to break Loctite is with a torch.

Finally, critical fasteners can be drilled and wired or fitted with cotter pins. This is the usual approach on prop-shaft couplings and the prop itself.

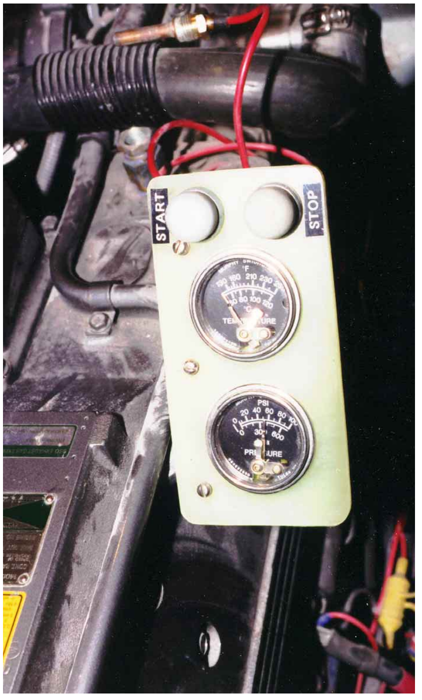
On the other side of the coin is removal of fasteners during maintenance procedures. Items such as pumps, which may require frequent service, should use fasteners that are easy to remove. My preference here is sheet-metal screws with large, quick-acting threads.

It's a good idea to use Never Seize compound on all metal-to-metal fasteners, as well as any that will see moisture. This ensures your ability to break them free years down the road.

A light gray or light blue is the best choice for color, as it won't show much of the normal oil film, yet will show leaks of fuel or oil. Dark colors should be avoided, as they make it more difficult to spot leaks.

Chrome plating and galvanizing not only look great, but also reduce paint chores. I like to chrome valve covers, air cleaners, and any other easy-to-remove, large covers. However, avoid the temptation to do the fuel lines or other bits of plumbing. Otherwise, repainting around the chrome will be a time-consuming chore. Large steel brackets made up for mounting accessories can be galvanized to prevent rusting. Both chroming and galvanizing are cost-effective.

Finally, look at the possibility of putting drip trays under the diesel engine, as well as under fuel and oil filters. A good drip tray will save hours of work in the bilges and will keep them smelling fresher in the process.



We make it a habit to start and stop the engine in the engine room, with control buttons mounted right on the engine. This allows us to give the engine a once-over, checking oil, coolant, belts, and generally looking for incipient problems.

We mount mechanical "switch" gauges, manufactured by the Murphy Gauge Company, in the same location. These not only tell us how the engine is running, but are used to trigger an alarm if the engine starts to run outside closely set parameters.

These gauges allow you to adjust the exact temperature and oil pressure at which they will send a signal.

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THE ENGINE

The first consideration in choosing or evaluating an auxiliary diesel engine is the horsepower requirement. This is a complex question, since horsepower needs change so dramatically with wind and sea conditions.

If the wind is calm and the sea is smooth, you'll require very small amounts of horsepower to run at low speed-length ratios. Aboard *Intermezzo* we used about 15 horsepower to cruise at 6 knots (with her 36-foot /11m waterline, this was a speed-length ratio of 1). But as the wind starts to build, so does resistance. Ten knots of wind can increase your horsepower requirements as much as 30 percent. Throw in 3 or 4 feet of chop and another 10 knots of wind and you'll increase horsepower needs 150 percent to 200 percent.

In smaller yachts, and when the engine is installed where its noise, heat, and vibration are obnoxious — like right in the middle of the main saloon, as it was on *Intermezzo* — you're going to sail whenever there's a breeze. This being the case, the weight and expense of an overly large diesel doesn't make sense to me.

Intermezzo was quick enough in light airs that we didn't need to use the engine unless it was almost flat calm. We weren't trying to keep a tight schedule — just stay out of the way of bad weather and get passages over with as expeditiously and comfortably as possible. From this experience I decided that engines were useful primarily as generators, and secondarily for use in propulsion. After all, if there's a breeze, even dead on the nose, we'd rather sail than listen to the bloody engine roaring right under our feet.

When we specified the 85-horsepower Perkins 4-236 for *Intermezzo II*'s aft engine room, we did so because of resale value. I figured a 30-horsepower engine would do just fine but didn't think anyone would agree with me when the time came to sell her. The first time I had cause to think differently was on the New River in Fort Lauderdale, Florida. We were heading back to our dock from the boatyard, running downriver with the ebbing tide through a series of narrow bridges. Under the Inland Rules of the Road, vessels running downtide always have right-of-way, but as we began to head through a just-opened bridge, a sport fisherman on the other side decided he would speed up and try to beat us through. There wasn't enough room for both of us between the bridge pilings, and we were headed for a collision. I jammed the wheel hard over to starboard and gave *Intermezzo II* full throttle. We just barely made the turn without being pinned by the current against the bridge. Without extra horsepower available, we would not have made it.

I figured we'd just saved ourselves enough damage to pay for the extra iron in the engine room.

Our next lesson started in Acapulco, Mexico, on our way home from Panama. We put in 365 gallons (1,414 liters) of diesel fuel for just US $75. That $75 was enough fuel to get us all the way back to Los Angeles, and with a long beat ahead — with all the attendant coastal-navigation problems, not to mention relative discomfort — it was easy to say, "Let's power all the way home." Well, we did — we made the trip quickly, painlessly, and managed to finish a book manuscript in the process. This was made possible by the extra horsepower, coupled with isolating the engine in our aft engine room, where its noise and heat couldn't annoy us.

When we decided to build *Sundeer,* we concluded from the beginning to make her as efficient as possible under power, with the ability to punch our way through just about anything going uphill. That last trip up the coast on the old boat had really opened our eyes. We ended up with a 150-horsepower Isuzu engine with enough muscle to allow us to do whatever we wanted.

Smaller cruisers don't usually have fine-enough hull shapes forward or enough displacement to fight their way upwind against adverse seas with the engine only. This was the case with our 50-foot (15.4 m) *Intermezzo*. If this is your situation, putting lots of power under the floorboards may not make sense. Another factor to consider is your boat's handiness under sail. If she's a good sailor in light airs, weatherly, and able to tack out of a tight spot in plenty of wind, you won't use your engine as much as a less-efficient vessel would.

Next is handling in port with a small crew. Here, the larger the vessel and the smaller the crew, the more important it is that you can force the boat to do your bidding, as opposed to finessing things. Maneuvering in a tide-against-wind situation can call for lots of reserve horsepower, typically more than under normal passaging. Of course, when in doubt about a tight squeeze, you can always anchor out and move in close later when conditions are more favorable.

How do you know what size engine to look for? The best bet is to try a comparable boat out and see how its setup works. Check performance in smooth water, then in adverse conditions. The same holds for maneuvering in close quarters. You can also calculate, with modest success, what

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will be required. There are formulas in *Skene's Elements of Yacht Design*, or a good prop shop will be able to do calculations for you. But be clear about what speed you want to make under what conditions. Finally, as discussed in the next section, propeller choice and efficiency will play a big part in your power requirements.

Horsepower Ratings

Most marine engines come with several different ratings. There will be brake horsepower figures, which indicate what the bare block, without accessories, will do; and shaft horsepower, which is what the engine will net out at after deducting for a water pump, alternator, and transmission.

Then there will probably be an intermittent rating as well as a continuous rating. While it's nice to know what the short-term usable power is, you'll want to do your calculations based on the continuous rating.

Finally, many marine engines carry service ratings. Typically these are for high-speed yachts, heavy yachts, and commercial vessels. In each successive case the engine is de-rated, so that the top rpm is limited. Sometimes the fuel pump settings and/or injectors tips will be modified as well. The lower the rating, the longer the engine will last.

Detuning

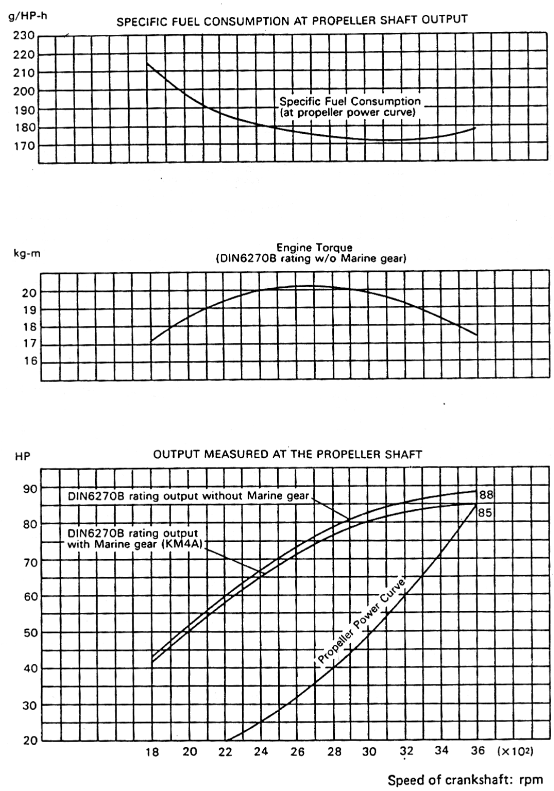
If you happen to find an engine you really like, but it has far more power than necessary, it may be possible to get the factory to detune it for you. There will frequently be special settings for the engines used in generating sets or other auxiliary applications. The fuel pump will be removed and reset to lower the engine rating and injectors or injector tips may be exchanged. The advantage of this approach is a better torque curve at low rpm and lower fuel consumption.

Two-Cycle or Four?

In diesel engines you have a choice between two-cycle (where each piston fires every second revolution) and four cycle. I prefer the four-cycle since it's quieter and somewhat more efficient on fuel. GM diesels, known as "screaming gimmies" (for good reason — you can hear one coming miles away on a calm day!) are the only two-cycles available nowadays.

Injection Systems

There are two styles of injection systems. You have direct-injection engines, where the fuel goes directly



Here are a set of performance curves for an 88-horsepower Yanmar four-cylinder diesel. This is a quiet, smooth-running engine available in 50- to 100-horsepower configurations.

The top graph indicates fuel consumption based on horsepower taken per the bottom curve of usable propeller curve. If you are using more power, the engine will be somewhat more efficient.

Engine torque is shown on the middle graph. Note how it is relatively flat between 2,400 and 3,100 rpm's. This corresponds to the best spot on the fuel consumption graph.

The bottom graph shows available power. Ignore the top curve as this is without transmission losses.

The bottom curve is indicative of the amount of power you can put into the water with a prop that is small enough to allow the engine to come up to maximum rpm. For a powerboat, most of which operate at around 80 percent of available power, this works well. But for sailboats, where powering loads vary so widely, this is not very efficient. However, if you want to have a warranty on your engine you must follow these recommendations.

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into the cylinder, and indirect injection, where it goes into a pre-ignition chamber. In the latter case, some claim a smoother running engine, and until a few years ago most marine conversions of auto diesels fell into this type. However, they're somewhat less efficient on fuel and require the assistance of glow plugs when starting.

Glow plugs can be a real pain if you're in a tight spot and need the engine quickly, as they typically take 15 to 20 seconds of preheating before the engine will catch. On several occasions I have wanted the engine in a hurry, and that 20 seconds of waiting seemed like forever. We learned to pre-start the engine and let it warm up if we thought it might be needed later. Once a glow plug–equipped engine runs for a few minutes, it will crank right over without the glow plugs the next time.

Today, a number of small direct-injection marine engines are on the market, so the choices are getting easier. I would definitely choose a direct-injection engine whenever possible.

RPM Range

Next, consider the rpm range of your engine. High-speed engines develop more horsepower per pound than their slower counterparts, but they tend to be noisier, use more fuel, and don't last as long. A typical high-speed engine will turn 3,600 to 4,500 rpm at peak output, while moderate-speed engines turn over at about 2,800 rpm. Slow-speed diesels run at 1,600 to 2,000 rpm.

Longevity isn't a major factor on most cruisers — it's rare to use an engine more than 500 hours per year. At this rate, with good maintenance, a high-speed engine will last 10 to 15 years.

Of course you have to look at the engine's horsepower curve to see at which rpm you have the needed horsepower and torque. Ideally, the engine should develop the horsepower you've decided upon at its maximum torque point, which usually corresponds to minimum fuel consumption. This will usually be about 20 to 25 percent under the max rpm/horsepower point on the curve, so you have some reserve left and aren't pushing the engine to its limit all the time. While looking at the horsepower and torque curves, try to pick an engine with a flat curve that's efficient over a wide range of rpm settings. This makes for better fuel efficiency since it will be difficult to predict the exact rpm at which you'll be running.

Boosting Power

You may also be looking at turbochargers and aftercoolers that increase efficiency and available horsepower from a given size engine block. The turbos used to be a lot of trouble, but today they seem reasonably reliable. The only major hazard is with fire, and that seems to be pretty rare. If the turbo fails, the engine still runs, just at a slightly lower efficiency level. A nice factor with turbos is that they quiet the engine somewhat. Intercoolers are pure net gain. These cool the incoming air with a heat exchanger run off the seawater cooling system. A good intercooler can increase horsepower 10 percent or more, with almost no gain in fuel consumption.

Parts Availability

Availability of spare parts is certainly a consideration, although not as big a consideration as in years gone by. Since most marine engines are reincarnated truck, tractor, or taxi engines, parts today are pretty well-dispersed worldwide.

Marinization Details

Look carefully at the marinization package. The heat exchanger on the engine and transmission should be made from Cupro Nickel, which doesn't corrode as fast as plain copper. Easily reached sacrificial zincs should be in all heat exchangers, including the exhaust manifold. The saltwater pump installation should be scrutinized for maintenance and type. Some engines use belt-driven impeller pumps, while others are gear-driven. V-belts are a pain, but if a leak develops on the shaft it won't fill the crankcase with salt water, so they're my preference. With a gear-driven pump, if a leak develops in the shaft seal, you can't run the engine — period. Yet if your belt-driven pump fails for some reason, it's usually possible to jury-rig something to keep going.

Location of the starter and alternator is important. Hopefully they'll be up high, away from bilge water. Then you need to think about bleeding the injectors, changing fuel and oil filters, and adjusting belts. One engine design may be a lot better in this regard than something else. Also, ask about the ability to take horsepower from the front of the crankshaft to run accessories. Most engines allow about 25 percent of the rated horsepower at any rpm to be taken off in a sideways direction. But some, because of front-bearing limitations, restrict belting on accessories.

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Spares

While you're thinking about the cost of the engine, also consider the spare-parts inventory. It's not unusual for a good set of spares to run 20 percent of the cost of the engine itself, and pricing policies vary from one manufacturer to the next.

Here's what we carry for offshore work, where I want to be able to deal with almost anything: A full gasket set, shop and overhaul manuals, complete injector set, high-pressure fuel lines, four sets of sacrificial zincs, V-belts, two salt-water pump impellers, pump-overhaul kit, and occasionally a complete salt-water pump, starter solenoid, thermostat, set of glow plugs, freshwater-overhaul kit, set of freeze plugs (if the engine is a few years old), fuel lift pump, alternator, and regulator. Fuel and oil filters will vary with the secondary systems, but I like to have at least a year's supply aboard.

Making Choices

The true marine engine used to be a rarity. Almost all of our choices were converted industrial engines. We've used a variety of engines with success. These include the Perkins 4.236, Isuzu QD150, and Mercedes 120-horsepower marine engine. In the last few years, however, we've been using Yanmar engines from 88 to 170 horsepower.

These are definitely high-speed engines, although amazingly well-balanced and quiet. We've had a minimum of warranty issues with them, and from a maintenance standpoint they are nicely designed.

Finally, they're amazingly compact and lightweight. We haven't used them long enough to know firsthand how much time between overhauls we'll get, but from what we've been told by other users, we can expect 5,000 to 10,000 hours, if they are well maintained.

THE DRIVE LINE

The drive line is made up of a series of elements connecting the engine to the propeller. This gear sees tremendous load — abuse in many cases — and the failure of any element in the system will quickly turn you into a sailboat.

Design issues used to be clear-cut with limited choices. Now we have a whole collection of gear to choose from, so the decision-making process is more difficult.

Overall Efficiency

There's a certain amount of loss from every element in the drive line. The greatest will be at the transmission, each bearing, and even the packing gland rob you of power. When we realize that this loss is multiplied by the prop efficiency (or lack thereof), it takes on added significance.

Let's assume you have a prop efficiency of 40 percent — not too bad. If your drive-line losses are 10 percent, about average, you'd have a total propulsion efficiency of 0.40 percent less than 10 percent drive-line loss, or 36 percent. If you have an average 40-footer with a 32-foot waterline, odds are you will need about 14 horsepower in the water to move at 6 1/2 knots. That doesn't sound too bad until you realize that you must divide the 14 horsepower by the 0.36 efficiency. This means the engine has to deliver 38 horsepower to the transmission in order to net out the 14 you need to push the boat!

Obviously, you want to be as efficient as possible all the way down that drive line.

Reliability

Reliability in the drive line is typically a question of proper installation, timely maintenance, hours of use, and how hard a given piece of gear is working relative to its rating. The importance of this will depend on where you cruise and how dependent you are on the engine.

For most cruising, with low hours of usage, close to home where expert assistance is available, you can operate near the top of the allowable load range. But as you journey further afield, it becomes prudent to reduce working load levels.

RPM Versus Torque

A key element to understand is the relationship between rpm and torque. For a given amount of power, the higher the rpm, the lower will be the loading on the various elements. If a 50-horsepower engine runs at 3,000 rpm with a 3-to-1 reduction gear turning the shaft at 1,000 rpm, you might do well with a 1 1/4-inch (32mm) prop shaft. If that reduction gear changes to 2 1/2-to-1, and prop shaft rpm goes up to 1,200 rpm, a much lighter one-inch (25mm) shaft would do the job. This relationship holds true all the way down the drive line.

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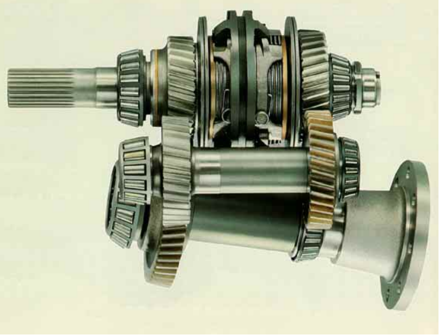
TRANSMISSIONS

With transmissions, a variety of configurations, ratings, and design philosophies are available. As you look into this field, you will want to consider several issues beyond those initially discussed.

Most important is the desired reduction ratio. This is a complex issue involving the drag characteristics of your vessel, the engine you want, propeller options, and your evaluation of the various trade-offs in powering versus sailing performance. Each time you change one element, it affects everything else.

Mechanical versus Hydraulic

One of the early decisions you will make is whether to use a hydraulic or mechanical box. In smaller engines, typically below 80 horsepower, there are a number of mechanical options, the best known made by Hurth in Germany. These boxes are very efficient, typically costing less than one percent in loss through most of their operating range.



A cutaway drawing of a Hurth mechanical transmission. Mechanical transmissions are always more efficient than hydraulic designs within the horsepower range where they can be utilized. In larger boxes, however, be sure to check the force required to shift the transmission in and out of gear.

The only negative with mechanical boxes is they are more difficult to shift than their hydraulic counterparts. However, with smaller engines, this is not an issue.

With a hydraulic transmission, a hydraulic pump creates hydraulic pressure to operate a series of clutch plates. These clutch plates transfer the power of the engine to the reduction gears and handle the shifting between forward, neutral, and reverse.

Transmission Efficiency

Mechanical boxes typically lose one to two percent of their power to friction. These losses are constant across the entire rpm/horsepower range.

Hydraulic boxes are less efficient. First you have an “overhead” figure required by the pump, whether or not the engine is doing any serious work. This figure can be as high as 4 or 5 horsepower on some of the older transmission designs. To this you have to add more loss that occurs as the transmission starts to do work. These losses will run from 7 to 15 percent.

The killer, though, is that initial loss. Look at it in the context of the 14-horsepower example we used earlier. There would be another 5 or so horsepower down the drain, and that’s a huge chunk.

If you are looking to make your overall system more efficient, or replacing an existing transmission, look at the efficiency figures carefully.

Power Ratings

Transmissions typically have pleasure-boat and work-boat ratings. Pleasure ratings are okay for short-term use close to home, but for long life and or hard work it is better to use the commercial ratings.

Also make sure that the transmission can handle your reverse loads, as some gears have a lower rating in reverse than forward.

Reduction Gear

Once the transmission has transferred power from the engine through its clutch mechanism, the energy travels through a reduction gear where the engine rpm is reduced by something between 1.5- and 3.3-to-1.

Optimizing the reduction ratio is a key element in making your overall propulsion system as efficient as possible. In general, if you have the room to swing a good-sized prop, the deeper the reduction ratio (the slower the prop will turn), the more efficient will be the propeller. Of course, as you slow down the prop shaft, the torque goes up — so the prop shaft, prop hub, and couplings all have to go up in size.

When researching transmission choices, be sure to look at available reduction ratios, as some companies have a better selection in your horsepower range than others.

In-Line Configurations

There are three typical in-line transmission configurations. The first set of choices deals with the relationship of the output coupling to the crank shaft of the engine. There is typically a moderate amount of offset, the transmission output being lower.

Dropped-output configurations are also available where the output flange of the transmission is as much as 8 inches (200 mm) lower than the engine's crankshaft.

Angled outputs, typically 7 degrees, are also available.

Both the output angle and the output flange height should be matched to where the propeller shaft is located, if you are repowering. When building new there is more flexibility, and the decision on what configuration to use will typically be made based on keeping the engine as low as possible in the bilge.

V-Drives

If your engine ends up fairly far aft, a V-drive is unavoidable. This allows you to have the transmission facing forward, with the engine facing aft, and to then bring the shaft all the way under the engine for attachment to the transmission.

Watch for several problems:

First, access to your shaft coupling and stuffing box. Since they'll be under the engine, be sure to get to them for general inspection and repair work. There will frequently be structural engine bearers running fore-and-aft in close proximity to the engine pan. Generally, there is little room between these two elements to get at the gear under the engine.

Next, make sure there's plenty of space for proper alignment. Nothing will ruin a transmission faster than a misaligned shaft. I prefer to avoid a V-drive where possible because of the increased friction represented by changing direction and the access problems, but sometimes the trade-offs in other areas make this unavoidable. We used Borg Warner CR72 Vs on both *Intermezzo II* and *Sundeer* because of their aft-engine-room layouts. At the time these were the only boxes available in the horsepower range we required. Today I'd use a Hurth 600 series V, which is more efficient and reliable.

If you have a special situation and need to remotely mount the engine from the V-drive, check out the Walthers transmissions.

The Borg Warner V-drive (above) has been a standby for years. However, they are heavy, relatively inefficient, and expensive. We prefer Hurth V-drives where we can use them. Note the flexible coupling between the output flange of the tranny and the prop shaft input flange.

The Stillet Sonic Sail Drive (below) has been used on a number of race boats. It will accept mechanical or hydraulic input and is very clean in terms of sailing drag.

Sail Drives

Sail drives have been around in one form or another now for 20 years. In that time they've had their share of problems, but currently seem to be okay for smaller engines. They offer advantages in underwater drag, vibration isolation, and installation cost.

Be sure they are properly installed, and keep a very close eye on the zinc anodes.

Cooling

Almost all transmissions generate heat while working and so have an oil cooler, typically plumbed in series with the engine's heat exchanger. It is not uncommon to have pin holes develop after time in the heat exchanger. This leads to a loss of coolant (you'll see an oily slick in the exhaust water). It may also allow the incursion of sea water into the transmission, creating an awful mess with the oil. It turns to a Vasoline-like substance and you have to tear down the box.

The best way to avoid these problems is to keep a close eye on heat-exchanger zincs. Checking the transmission oil each time you check the main engine also helps to avoid problems.

Get-Home Capability

Some transmissions also have a "get home" option that allows you to lock the box into forward in the event of a general failure — an excellent feature. If all other things were equal, I'd go for the transmission with this option.

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Power Takeoff

Another consideration is the availability of a power takeoff option on the transmission, typically for a hydraulic pump. This is common with some larger gears. There is typically a standard mounting to which many different types of pumps can be easily mounted.

This is a simple way of getting power off the engine, although it involves the use of hydraulics.

Propeller Impact

When you shift from ahead to astern, there's a significant impact on the drive line from the change in direction of the propeller. If you happen to have a feathering propeller like a Maxi Prop, the shock loads get even higher.

This needs to be taken into account when choosing a transmission and other drive-line components.

Dampener Plates

While diesel engines appear to rotate smoothly, in reality the rotation of the crankshaft is a series of explosive jerks as each cylinder fires. If this motion were transmitted directly to the transmission, the transmission wouldn't last more then a few hours.

When you shift the transmission, especially when a feathering prop is involved, there are other shock loadings to be absorbed between engine and transmission.

As a result, almost all diesels have a dampener plate bolted to the flywheel, which is connected to the transmission with a spline gear. This dampener plate has a series of springs around the perimeter to smooth out and absorb the shock loadings.

Now to make things complicated, different engines have different pulsation (or "torsional," as the engineers refer to them) characteristics. Of course, so do transmissions. So the choice of the proper pressure plate can get quite complex.

If you're using an engine/transmission combination that's been in use for a long time with a similar propeller, everything should be fine. But once something changes, a new engine, different gear box, or different type of prop, the dampener characteristics may need to be modified.

I am sorry to report that this frequently requires trial and error.

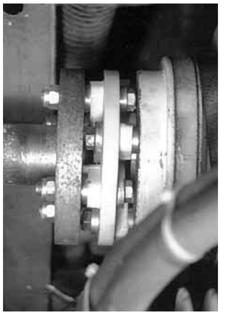
One caveat: Bigger is not necessarily better. If you're having problems with the pressure plate failing, it doesn't automatically follow that you need something "stronger." By simply going up in size to cure the problem, you'll pass it along to the next weak link — something in the engine or transmission. When you're changing dampener plates, keep capacity in the proper horsepower range, then work on the dampening characteristics.

Engine Mounts

Your engine mounts play an important part in keeping the engine aligned with the prop shaft, while isolating some of the noise and vibration from the hull. If they're more than five years old, you should think about replacing them, as the rubber tends to wear with age and exposure to oil and diesel fuel.

Ideally, your mounts will be as soft as is allowable while still keeping the engine within alignment tolerances. The softer the mount, the quieter the engine.

Some engines, such as Yanmar, require specialized mounts. In some cases Yanmar engines come with three different mounts.



Flex couplings will reduce wear on your transmission bearings and provide you with a quieter running engine. However, they do not remove the requirement for a well-aligned prop shaft.

Flexible Couplings

One way to increase mount softness and reduce required shaft alignment tolerances is with a flexible coupling between the prop shaft and the transmission. There are many types on the market. If you go this route, remember to buy the best quality coupling available, and still try to keep the engine aligned right on the nose. Carry a spare — preferably two —and be sure you have the tools to change the coupling.

Prop Shafts

First, some basic prop-shaft engineering. Stiffness is a function of the cube of diameter. A very small increase in shaft diameter has an enormous impact on stiffness. Shaft stiffness has a lot to do with cutlass-bearing wear and shaft noise transmitted into the boat. When in doubt, go bigger.

If you're limited in shaft size, you can improve the situation by using high-strength alloys like Nitronic 50 or something in that range. This won't have a major impact on stiffness, but it will on net strength.

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The connection of the shaft to the transmission, via the coupling on the end, has to be treated carefully. There are tremendous forces at work on that coupling, especially when you go from forward to reverse. If a keyway is used in the coupling, be sure the proper type of key is used, and carry several spares. These will typically be a high-strength bronze alloy or stainless steel. With a clamp-style coupling, as well as with keyway-style, check the bolts periodically to be sure they're tight.

If starting from scratch, consider going a notch or two oversize. This will reduce the possibility of bending the shaft when you wrap a sheet around it. If we're doing shaft calcs and see that a 1 1/4-inch (32mm) shaft would normally be used, we typically go up to 1 1/2 inches (38 mm).

Support Bearings

Your shaft will be supported in one or more places by a bearing, typically a cutless bearing, with a fluted rubber or plastic inner liner surrounded by metal or fiberglass. Be sure you know how to change this bearing, and carry several spares. It'll be necessary to remove your prop, and having a prop puller on board is a good idea anyway. If the bearing is in a P-bracket you'll need a tool to push it out. Otherwise, you'll have to remove the shaft to do the job.

You'll come out ahead on the cost of these tools the first time you're sitting in the yard, paying $60 an hour, while the mechanic messes around all day pulling your shaft because *he* doesn't have the right equipment!

If you have interior support bearings they should be split so they can be changed without pulling the shaft. The halves are driven out and drop off the shaft.

Sometimes shaft length makes it necessary to have a bearing close to the transmission. In this case, you'll have to be very careful with alignment between shaft and transmission. Otherwise, there will be substantial transmission bearing and shaft-seal wear. This type of installation will require firmer motor mounts.

If you end up with two cutless bearings, have the outer diameter of the forward bearing turned down a hair, so it will slip through the P-bracket without force.

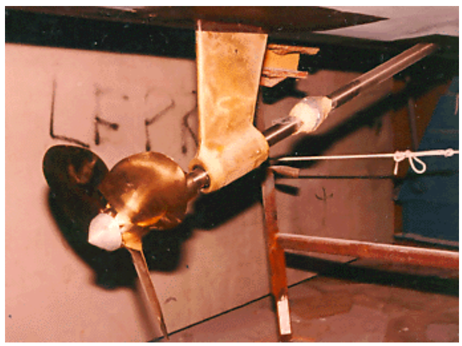
Prop-Shaft Brackets

At the end of the prop shaft some form of support is necessary. Depending on horsepower and prop diameter this will take the form of either a P- or a V-bracket. The former is a single strut with a casing for the cutlass bearing welded or cast on the end. This is commonly seen on small sailboat installations.

But as the loads increase it's necessary to go to the V-bracket, which offers greater stiffness, except with a lot more drag. Most powerboats have this type of bracket, and more sailboats should use it to reduce prop-shaft vibration and noise.

Keep substantial reinforcements on hand in the hull area where the bracket is attached. There are enormous loads on the fasteners, as well as lots of prop-wash vibration to be dealt with. If the area isn't well-reinforced, the shaft support bracket will vibrate. This tends to enlarge the bolt-holes over time, causing leakage and transmitting noise to the interior. Ideally, along with a thickened hull, several large frames will be worked into the area as well.

Remember, the shaft support bracket needs to handle the long-term torsional loads of the prop and the short-term loads that occur when a jibsheet or dinghy painter catches in the prop.



We've found that making the prop-shaft support bracket substantially oversized pays big dividends in reducing noise and vibration. Our approach is to go three to four times what is considered normal. The bronze bracket above is on a Sundeer 64 and is rated for a 400-horsepower engine — although the 64 has a 140-horsepower Yanmar.

Below is a V-strut on one of our large motorsailers. Once you reach a certain prop size you are forced to use a V-structure. This is good for the prop and shaft, but very high on sailing drag.

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SHAFT-PACKING GLANDS

The prop shaft–packing gland is one of the major potential trouble spots on the boat. While it is working correctly, you don't think about it. If it starts to leak, however, it can make a mess out of the surrounding area, as well as add significantly to the bilge-pumping load.

Common Gland Issues

All of the various forms of stuffing boxes (or packing glands, as some call them) serve to keep water out of the boat, the shaft properly lubricated, and to give long life. How well they achieve these aims is subject to several issues. First is shaft/engine alignment. If everything is properly aligned, and the shaft is running true, you will see no apparent movement when the shaft is turning, other than the shaft rotation itself. If the gland or the hose attaching it to the stern tube appears to be wobbling, this is an indicator of alignment problems. This will make the job of any packing gland difficult.

All systems rely to some degree on the shaft being smooth. Scratches or scoring where seals or packing material are in contact with the shaft promote wear on the seals or packing, and make it difficult to achieve a good seal.

Good lubrication is another factor. This is typically achieved with water (although oil is occasionally used). If the lube system doesn't function correctly, failure will quickly occur.

Finally, all packing materials have difficulty with dirt, especially with sandy grit. Keep an eye on this when getting free of a grounding and when powering in water affected by river outflows.

Maintenance

There are several maintenance issues you will want to consider as you think about the correct packing gland for your situation. The first is access. Hopefully the packing gland will be out in the open where you can easily reach it. However, this is frequently not the case. If you don't have good access, consider what sort of routing maintenance your system will require, and how this will be achieved.

Next, if the packing-gland system requires major maintenance, you will want to think about how this is achieved in the space available. Can it be achieved with the boat still in the water, or will a haul-out be required?

What about catastrophic failure? What elements in the system could fail in such a way as to put your vessel in peril?

Finally, do you have the correct tools aboard to do whatever maintenance is required?

Shaft-Gland-to-Stern-Tube Connection

The shaft gland is connected to the stern tube with a piece of hose (which should be double-clamped at each end with high-quality 316 stainless-steel hose clamps).

The more flexible this hose is, and the longer it is, the better job the shaft gland will do of working in a slightly misaligned situation.

Use only the very best quality hose. Stay away from hose with mild-steel reinforcing wire.

Conventional Stuffing Boxes

Conventional stuffing boxes use an impregnated flax-like material (or more modern material) to form a seal between the prop shaft and stuffing box. An adjustable nut on the end presses the packing onto the shaft, thereby limiting the ingress of water.

If this adjustment is correctly made, the shaft log will be dry when the engine is off and will have a slight drip while the engine is running.

The drip is an indicator that the shaft is being lubricated by seawater. If that lubrication is not present, the packing will be scorched (thereby losing its effectiveness) and there is a possibility of the shaft being scored.

Lip Seal–Based Glands

The crankshaft on your engine and input/output gears on your transmission use lip seals to contain lube oil, so why not use them on the shaft to keep seawater at bay? In theory this makes sense. However, over the years a variety of systems have been tried without long-term success on cruising yachts.

The maintenance problems with these systems have been primarily due to misalignment between engine and shaft. Any sort of whip in the shaft would quickly chew up the somewhat-delicate edges of the lip seals, after which the shaft would start to leak.

John Newton's Tides Marine has partially solved this problem with a clever design. John's approach is to create a lip-seal carrier that also acts to keep the seal in alignment with the shaft. Picture a long shaft bearing, floating with the shaft, to which the shaft seal is attached. As the shaft whips or wobbles, the bearing and lip seal stay with it.

We tried one of John's seals on *Beowulf* and have been pleased with the results.

The question then arises about maintenance. Seals are subject to wear, need lubrication (supplied by a tap on the engine cooling water), and are adversely affected by dirt and silt. The answer is to slip a couple of spare seals over the shaft between the gland and coupling for future use. When the installed seal goes bad, cut it out and press in one of the spares. John figures a seal is good for several thousand hours in the average installation.

Oil-Lubricated Systems

The traditional approach with commercial vessels is to use two lip seals, and then fill the chamber so formed with oil. This has a major advantage if you are running in silty water, in that the oil lubricates while keeping the dirt carried with the water outside.

However, these type of systems require perfect alignment. If running in silty water is not a problem, then water-based systems are a better choice.

Spring-Based Seals

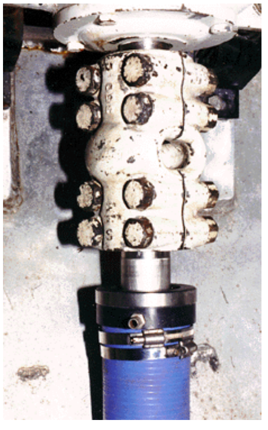
The French developed a system in the 1980s called LASDROP that used a unique approach to eliminating shaft leaks. The concept is pretty simple. Attach a stainless collar to the shaft using an "O" ring seal between collar and shaft. This provides a sealing face or edge on the inboard side. Then clamp a spring-loaded bellows to the stern tube, the forward end of which has some form of low-friction long-life plastic clamped to it. The forward pressure of the bellows keeps the two surfaces in contact, theoretically eliminating any drips.

A number of companies now make these seals. We've used both the French seals and those supplied by PYI under the label PSS.

You will want to carry spare bellows, O-rings, and rub plates. Major maintenance may require a haul-out or that the shaft be sealed underwater where it exits the hull.

There are all sorts of shaft seals, most of which will do a good job. The LASDROP and PSS seals (upper left and middle) are quite trouble-free. The Strong Seal (upper and lower right) uses a traditional lip seal held in place with a spring. Where this system varies from the past is in the lip-seal holder, which acts like a cutlass bearing around the shaft, thus keeping the lip seal always in perfect alignment with the shaft.

All shaft stuffing boxes will, at some time or other, leak. It is better to face this inevitability in front. Enclose the seal with a self-draining box, with a plastic lid, so you can see the leak when it starts. This keeps the surrounding area clean and dry.



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SCATRA

The SCATRA system is the ultimate in flexible couplings. Developed in Sweden in the early 1980s, it employs a combination of thrust bearing at the forward end of the propeller shaft with a CV axle (similar to a universal joint).

The thrust bearing takes the forward and reverse prop shaft thrust through a rubber-mounted bearing, minimizing the prop-shaft vibration which is transmitted to the hull.

The CV axle has a ball-based universal joint at each end and can be angled up to 8 degrees.

Because of the CV axle's ability to misalign, it reduces the problems associated with transmission-to-prop-shaft alignment.

This in turn allows you to use extremely soft engine mounts. These soft mounts do a better job of keeping engine noise off the hull surfaces.

Alignment Issues

In spite of the fact that the CV axle allows misalignment, the better job you do in aligning the engine, the longer the CV axle will last. There's a direct relationship between alignment, angular offset, horsepower, rpm, and longevity.

CV axles are frequently used to lower the engine closer to the hull. In many of the yachts we're involved with, we use a 7-degree-down-angle transmission and 8 degrees of angle on the CV axle, to allow us to have an engine parallel with the waterline, hooked to a 15-degree prop shaft.

There is one key element, however. When aligning an engine and prop shaft with an angle taken up by the CV axle, a line projected from the flanges of the transmission and prop shaft must meet in the center of the CV axle.

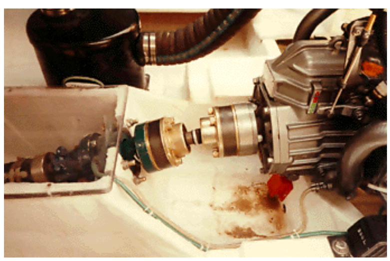
This is actually much simpler than it sounds. You can make or buy a simple jig to facilitate this alignment.

The SCATRA system (left) includes a CV axle between engine and prop shaft, and a large, rubber-mounted thrust bearing that couples to the end of the propeller shaft.

The CV axle can be angled up to 8 degrees.

Sizing SCATRAs

Sizing SCATRA units is a function of taking the drive-train characteristics, then looking at what you consider an acceptable CV axle life. We find that based on the normal SCATRA data we get around 2,000 hours of running time from a CV axle before it needs an overhaul. We always suggest that our owners carry a spare.

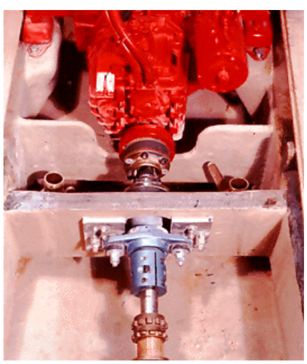


One key to a good SCATRA installation is a secure location for the thrust bearing. Considering that a prop can develop as much as 25 pounds (11 kg) of thrust for each horsepower available, you see that forces can get high. The usual method is to weld or fiberglass in a structural floor, tied to the engine stringers.

Another approach (middle left) is to build a self-contained box girder all the way around the area where the prop shaft enters the hull. A lid on this will also help contain any prop-shaft leaks.

Maintenance

We've found over the years that SCATRAs are quite reliable. Keep a careful eye, however, on the bolts. Even when installed with Loctite, they tend to work loose over time. We recommend checking the flange bolts every 100 hours, and before any use of the engine where a drive-train problem would compromise vessel safety.



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PROPELLERS

We started this section talking about how much power is needed for various conditions. What we didn't tell you was the propeller's *inefficiency* at delivering the engine's power to the water. The typical sailboat prop is lucky to get 30 percent of the power actually into the water, and efficiency levels below 20 percent are not uncommon. So, if it takes 15 horsepower to actually move you through the water, and you have a 25-percent prop efficiency, the engine must deliver 60 horsepower to the prop just to net out the 15 horsepower required for forward motion.

With this in mind it becomes quickly apparent that one of the best ways to improve powering performance is not by increasing engine power, but by making the prop better. Going from a 25-percent efficiency factor to a 50-percent factor will have the same effect as doubling the engine's power, with the extra advantage of reducing fuel consumption and extending range at the same time. It makes sense to do everything possible to have an efficient prop.

Propeller Engineering

A series of factors affect prop efficiency and cruising speeds. Foremost amongst these is blade loading. Within certain parameters, the more blade area you have per horsepower of work you are doing, the more efficient the propeller, since the blades are under less load.

The prop, however, must be able to slip a bit to do its job, and it must allow the engine to attain enough rpm so that the engine can develop the horsepower required to turn the prop.

Propeller Matching

To get the right combination of prop and engine characteristics you also vary the reduction gear ratios between engine and prop shaft. In some cases you may use a 2-to-1 reduction, in others maybe 2.567-to-1. The key is to develop the correct relationship between the prop and the engine output curve. A prop that is too large, putting too much load on the engine, can be as bad as one that is too small.

Sizing

Blade diameter is a major prop variable. This is a function of the factors already discussed, in addition to space available, and the form drag you are willing to tolerate under sail.

First, diameter is most important. The bigger the blade and the slower it turns, the more efficient will be your system. *Sundeer* and my dad's *Deerfoot II* have the same engine. But while my dad has room to throw a 32-inch, three-bladed prop using a 3-to-1 reduction gear, we're limited to 26-inch and a 2-to-1 reduction — our aft engine location just doesn't allow the room for a larger diameter wheel. As a result, he puts 25 percent more power into the water per gallon of fuel than we did.

However, as we've already said, blade diameter has to be matched to the engine's rpm and torque curve and to the reduction gear. Having too big a prop, which will limit engine rpm, can be just as bad as too small a prop, leading to engine damage.

Swept Area

Another consideration is blade area. Up to a certain point, typically 50 to 55 percent (of the circle swept by the blades), more surface area in the prop is better. Swept area varies tremendously among manufacturers.

Pitch

The next consideration is prop pitch (or blade twist). The more pitch you have, up to a point, the more the prop will push you ahead with each revolution. Pitch is limited by cavitation on the blades, and by the engine's ability to push the boat as fast as the prop would like it to go.

Blade Shape

Although there are as many debates about this issue as about anything else to do with boats, there are a few generalities. Blades with a twisted shape, like a conventional prop, are more efficient than straight blades, like some of the low-drag racing props. The area close to the hub doesn't do much work, while that near the tips is highly efficient. Blade shape affects noise, cavitation, the ability to reverse easily, and of course, overall efficiency.

How Many Blades?

Two-bladed props are theoretically the most efficient configuration. However, it is tough to get sufficient diameter to put enough blade surface into the water with just two blades, so three blades often end up on the most efficient sailboats. On powerboats, five- and even six-bladed props are not uncommon! Three-bladed props are better balanced, so are quieter underway as well.

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Feathering props without blade camber (twist) tend to be noisy, so require greater tip clearance to reduce noise coming into the boat.This Max Prop has a heavily built support bracket, allowing for a 30-percent clearance between the edge of the blade and hull bottom.

Tip Clearance

Tip clearance — the distance between the hull and the outer edge of the blade — is an absolute situation in which more is better. However, the ideal minimum varies with hull shape and propeller design. A flat bottom with a flat-bladed prop should have about 30 percent tip clearance, but the same hull with a more efficient twisted blade might get away with a 15-percent tip clearance. A 30-percent tip clearance with a 24-inch (600mm) prop would be about 7.2 inches (180 mm).

When you begin to cheat on tip clearance, two things happen. First, the prop wash gets noisy, and that becomes annoying inside the boat. Second, you start to get cavitation off the prop tips, reducing efficiency.

Now, you're sitting there thinking: I want the biggest possible prop, but need lots of tip clearance, and I only have so much room — so what do I do?

Experiment. As we said in the beginning, it's tough to calculate all of this on paper.

Apertures

Another consideration is what sort of opening your prop sits in. If it's a modern canoe body, with the prop sitting happily in open water, you're fine. But if you have a propeller that sits in a cutout between keel and rudder, knock off a few more efficiency points. If the keel area ahead of the prop isn't faired to a nice clean edge, go back another couple of notches.

Overpropping

Engine builders typically want to see the prop/reduction gear setup allow the engine to come up to its full speed. The problem is that with the typical cruising sailboat, you spend most of your time running at a much lower spot on the rpm gauge. As a result, the engine spends most of its life lightly loaded, which diesel engines do not enjoy.

One answer is to overprop — that is, use a prop/reduction gear design oriented toward a lower operating engine rpm. This is much more efficient for the prop and the engine. Fuel economy improves, the engine is happier running at a higher load, and the boat is quieter.

Sounds like a slam dunk, right? The problem is that if you try to run the engine higher than the prop will allow it to turn, all kinds of bad things happen to the engine. The engine builders really don't like to see this type of approach employed. However, if you are careful with engine management, it makes a lot of sense. We've been doing it for years with our custom boats, as well as on all our personal yachts.

The key is to be sure to always run at no more than 80 percent of the engine's available power. There are two ways to check this. One is by measuring exhaust-gas temperature, comparing it to the published engine data (engine exhaust heat corresponds closely to the engine loading). The second is to keep an eye on your exhaust color and rpm.

Here's how this works. You want to momentarily find the point at which the engine begins to "lug," or becomes overloaded. The two indications of this are sluggish response or no response to the throttle and/or a dark smoke from the exhaust (unburned fuel). Once this point is established, back off 20 percent on rpm ,and you'll be at about the 80 percent point on available power.

When in doubt, err on the side of caution. Reduce revs a little more.

Any time you see prop turbulence at the surface like this, you know a lot of power is going to waste.

Measuring Efficiency

How do you know how efficient your present setup is? First, measure your fuel consumption in smooth, windless conditions. Diesel engines burn about 0.4 pounds of fuel per horsepower per hour, or about one U.S. gallon for every 18 horsepower used. Armed with

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your consumption/horsepower calculation, go to *Skene'sElements of Yacht Design* and calculate the required horsepower to move you at the speed you were traveling. With that and the actual horsepower the engine used, you can arrive at prop efficiency (plus or minus 5 to 10 percent). It's an excellent way to jump into this whole area and will give you a baseline for comparison when deciding what, if anything, you want to do.

Cruising Considerations

There are a series of issues to be addressed as you figure out how to deal with this propeller conundrum. First is the relative importance of sailing (and maneuvering under sail) as compared to powering.

You may find youself where you want both at different times during your cruising. Since fixed props are typically fairly reasonable in cost (especially reconditoned), some cruisers carry a sailing and a powering prop.

When you consider powering, you need to decide if speed or range is most important. If you plan to short-hop, and schedule is important, then a prop allowing the engine to come up to full rpm and to develop full power will be a better bet than overproping, which is more efficient but limits top speed. If you expect to be powering to windward or motorsailing upwind, you'll require more prop efficiency than motorsailing downwind or powering in smooth conditions.

Also consider control under power. Some props have better stopping power than others, and some display less stern "walk."

Trade-Offs

Of course there have to be some trade-offs in all of this. On one hand, we are talking about sailboats — and the bigger and more efficient the prop is, the more drag it will have under sail. That drag can be enormous, costing as much as 15 to 20 percent of boatspeed to windward, plus slowing down your tacking to a point that might get you into trouble in close quarters.

In deciding which way to go, there are some other considerations. If you have plenty of power available in your engine, and lots of fuel capacity for your needs, prop efficiency won't be as critical. On the other hand, if you feel your boat is underpowered in some conditions, or if your range under power needs boosting, it may be a lot less expensive to work on prop efficiency rather than adding tanks or a new, bigger engine.

Remember, going from a 25-percent efficient prop to a 50-percent efficiency is the same as doubling your range or engine size!

Fixed-Blade Sailing Props

The simplest and least exspensive solution to the sailing issues is to use a two-bladed prop of cutdown area. This reduces drag, but prop efficiency suffers as well. In best cirucmstances, one of these props will put maybe 25 percent of the engine's power actually into the water.

Folding Propellers

Twenty-five years ago Walt Beck pioneered the folding propeller at Martec. These were initially used on race boats and gradually began to find their way onto cruisers. These props fold into a streamlined shape when sailing and open under centrifugal force when the engine is on.

Both Martec (top) and Gori (bottom) make reasonably efficient folding props for forward propulsion. However, neither of these works particulary well in reverse, a key handling consideration.

We used a Martec folder on *Intermezzo* and found that the sailing difference between it and our fixed three-blader, which we carried as a spare, was about 20 miles a day in the southeast trades. We put the fixed prop on for better control running the passes in the Tuamotus, but *Intermezzo* felt so sluggish under sail that we changed back right away. From a safety standpoint I felt it was better to be able to sail and maneuver in tight spots at maximum efficiency rather than be forced to depend on the diesel to get us out of a sticky situation.

But the Martec type of wheel doesn't have enough blade area to be very efficient, and they are not extremely strong in reverse.

Maxi Props

We saw our first Maxi Prop in the late 1970s in Cape Town, South Africa. It was streamlined when feathered, and seemed to have enough blade area to offer some advantages under power. I

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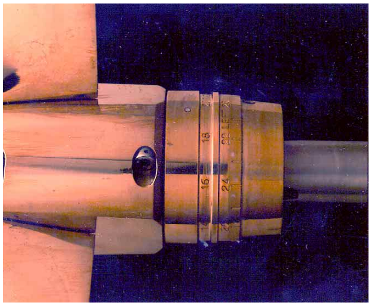

Maxi Props are now available with an external pitch adjustment. All that is required to change pitch is a quick swim and a turn of the pitch collar ahead of the hub. This makes it possible to optimize pitch for likely conditions — more pitch for motorsailing, less for banging into head seas.

particularly liked the feature that allowed one to disassemble the prop and change the pitch.

The only question I had in my mind was would it stand up?

Well, that was 16 years ago. Since then we've used over 44 Maxi Props on boats we've owned or built for others, and they've been remarkably trouble-free. We even once had one of our 74-footers pick up a piece of 1/2-inch (12mm) chain on the prop, wrap it around the hub, and break the chain, with only superficial damage to the prop.

Because the blades feather and are symmetrical (i.e., there is no twist), they are as efficient in reverse as forward. This gives excellent stopping power, aiding maneuverability in tight spots. Because the thrust is symmetrical they also exhibit less sideways torque, making it easier to control direction in reverse.

Where they fall down is in efficiency. That lack of twist reduces prop efficiency in most cases to around 40 to 45 percent. You may hear higher numbers, but we've tested Maxi Props extensively and have found that overall this is about where they fall. Compared to a small-bladed sailing prop or a folder, this is quite good.

If you are looking at a Maxi or similar style of non-twisted prop, give your propeller-tip speed careful thought. We've found that at up to 95 feet (30 m) per second they have reasonable efficiency. However, above this prop-tip speed, their efficiency diminishes rapidly and the prop appears to cavitate excessively.

To keep tip speed down, you need the biggest reduction gear possible, so that the blade turns slowly, and as much swept area as you can get (largest hub), which allows you to reduce diameter a bit, thereby reducing tip speed. The smaller the engine you are using, and/or the less horsepower you need to get into the water, the smaller the prop, and again, the lower the tip speed. As boats and horsepower requirements grow, the Maxi Prop becomes a less favorable choice.

You will also want to look at the swept-blade area. For a given diameter, the swept area varies with hub diameter. Larger hubs (with stronger gears) have more swept area and hence are more efficient (but they cost more!).

Luke Propellers

Luke props feather and offer the efficiency and quiet running of cambered blades. However, they have higher drag under sail.

The original Hyde feather prop, made for the last 30 or so years by Paul Luke, is also a feathering prop. However, these props have twisted blades, so they are much more efficient. In the correct situation they can range from 45 to 55 percent in efficiency — with a couple of drawbacks. First, they have a large hub, which when combined with the twisted blades adds to sailing drag. They are not nearly as draggy as a fixed prop, but neither are they as good under sail as a folding or untwisted feathering propeller. They also share the same (negative) traits as fixed props in reverse. Still, if you want good powering and are willing to give up some sailing performance, one might make sense for you.

Controllable-Pitch Props

Another approach is a controllable-pitched prop. You can get small CP wheels from SAAB, and larger ones from Hundestadt. These have the advantage of allowing a large-diameter, three-bladed wheel that can be feathered when sailing. Additionally, you can adjust propeller pitch for conditions encountered — lots of pitch and slow rpm when motorsailing and more RPM and a flatter pitch when punching into head seas.

These props can be very efficient under power. We've had real-world experience with a VP2 Hundestadt on *Beowulf*, averaging better than 60 percent efficiency.

In addition, the propeller pitch can be reversed so that when you put the transmission into forward, the prop pulls you astern (and vise versa). This in turn reverses the direction of prop "walk" — a huge advantage. This stern torque can be used to pull the stern in either direction, allowing

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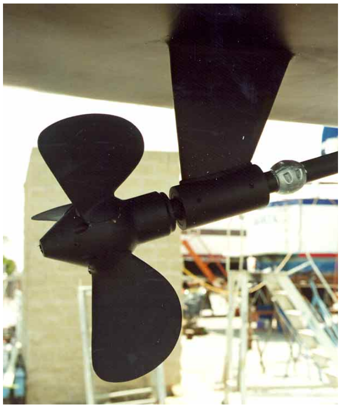
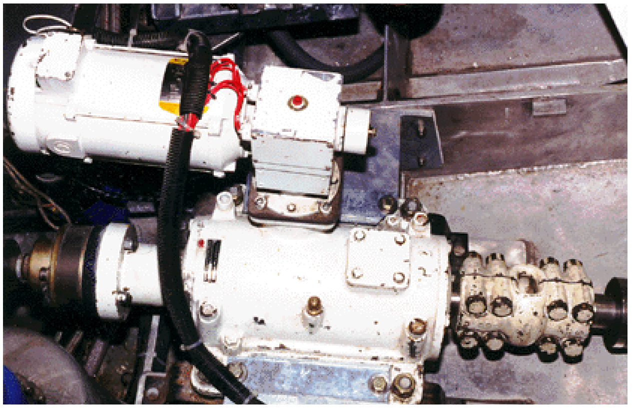


Beowulf's VP2 Hundested (above) and the VP4 on *Galatea* (below) — highly efficient under power, but approximately 75 percent more drag under sail than a comparable Maxi Prop with streamlined blades.

The Hundested gear is robust and heavy. This VP2 in *Beowulf*'s engine room (below) weighs almost 200 pounds (91 kg). The electric motor in the upperleft corner of the photo controls pitch setting. In an emergency you can easily crank in pitch by hand.

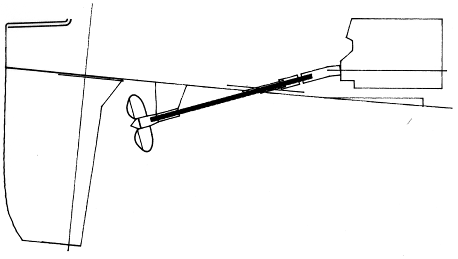


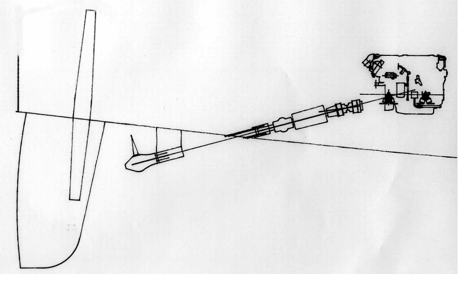
you to pull the stern toward or away from the dock, going to port or starboard. When trying to reverse directly out of tight spot, reducing pitch also reduces stern walk, so that it takes less distance before you are moving in a straight line. And, if you are trying to use prop walk to rotate over, pitching increases the prop torque and pulls you around faster. With these abilities you can maneuver under power into some unbelievably tight spaces.

The one negative with CP props is the drag from their large-diameter hubs and twisted blades. When we did the prop engineering for *Beowulf* we estimated that the sailing drag from this prop would double compared to a Maxi Prop. We estimate that this costs an average of a couple of miles a day. But, the powering advantages — and more important to us, the maneuvering advantages — make it worthwhile.

Another negative with CP props is that they have a gearbox that goes after the engine, adding substantially to the drive line length. Also, they are heavy. Still, if you want efficiency and good control when maneuvering, they are wonderful.

If you decide to go this route, consider how to control the pitch. If the transmission is close by the cockpit, and you are using the pitch control to optimize cruise efficiency, you can get by with a manual control. This is typically a small-diameter handle that can be rotated in one direction or the other to control pitch. There is usually a stop at the feathered position. Keep track of how many turns gets you to the normal pitch setting, then optimize from this using your exhaust gas temperature as a guide.





One of the biggest hurdles with a Hundestadt system is the extra length required for the gear. The upper sketch shows the engine/prop shaft relationship in the Sundeer 64. The lower drawing is with the same engine, and comparable rudder relationships, but using the Hundested gear (a VP3). In order to fit in the Hundested you need to add almost 3 feet (0.9 m), plus raise the engine.

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The Autoprop is a clever approach to automatic pitch control and appears to work well. However, check relative noise levels with this prop on your hull shape. Some folks have found them to be quite noisy under certain conditions.

However, when you want to use the prop to help in maneuvering, you need faster action. If this is the case, Hundested offers an electric control along with analog pitch meters. Mounted close to the helm, these make handling a dream.

Autoprops

The Autoprop works on a different principle than the rest of the propellers we've been discussing. The blades are oriented around a pivot axis and automatically assume a natural, theoretically efficient angle of attack. The blades set themselves to the correct pitch for the required sea state and boatspeed.

The reports we have read indicate that they offer a large improvement over fixed props and folding props. I suspect that they will power better than the Maxi Props as well.

Gori Props

Gori, a European company, has developed an interesting new design — a folding prop (for low drag) with three twisted blades. On paper it looks excellent. They also have an overdrive feature whereby the blades are over-rotated for motorsailing or powering at slower speeds.

We tested one of these props when doing powering trials on the early Sundeer 64s, and found it to have forward ability comparable to the Maxi Prop. Where it fell down in our trials was its reversing ability. It was not nearly as efficient going astern.

We were one of the early testers of the Gori prop and I'm sure they've learned a lot since then. I'd seriously consider it and the Maxi for one of our future projects.

Getting It Right

If you are a little confused by all of this prop stuff, you're in good company. Everyone else in the marine field is, too — it doesn't help to be the U.S. Navy, or to have the most powerful computer in the world. In the end, what works best for everyone is cut and try.

Do your engineering to hopefully get you into the ballpark — then test in the real world. This provides a benchmark from which to do your fine tuning.

So, unless you are working from a known sistership, expect to do a bit of experimenting!

This is not as bad as it sounds, since prop pitch and diameter are easily modified by a local prop shop. And in almost all cases, props can be easily changed in the water.

Propeller Protection

If you intend to spend much time powering in logging country, or where extensive fish traps are used, some form of propeller protection may be in order.

On commercial fishing boats, various sorts of cages are constructed around the prop to keep nets clear. This same approach is easy to execute on most yachts. Using steel or aluminum piping, a removable cage can be fabricated for well under $1,000 on most vessels. The key is attachment to the hull. If you have a metal hull, welding on a tab or two is quick. With fiberglass or timber, a through-bolted mounting pad will be necessary. Usually the cage will run on each side of the prop and under the bottom.

Another approach for repelling lines and nets is a set of spurs. This is like a Cuisinart blade which slips on the prop shaft ahead of the propeller and just aft of the support strut.

There's a penalty in form drag that needs to be weighed against the trouble of going swimming from time to time to cut a sheet or lobster-pot pendant free.

Keep It Clean!

Having dug through all of this data on prop efficiency, there's one more issue about which you ought to be aware. Prop efficiency is drastically reduced by even a thin coating of slime. Six to eight weeks after cleaning in the tropics, there will be enough growth on your prop to cost you an easy 10 percent. Allow a light scale to build up and that loss will jump to 20 percent. If the prop has been sitting around for a year or so, and there's 1/4 inch (6 mm) of crustaceans along for the ride, you will be lucky to get any forward propulsion. Keep it clean!

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POWER TAKEOFF

In most cruising installations, accessories are run off the front of the engine (the PTO pulley). You may be turning a damage-control pump, fridge compressor, and one or more alternators. Odds are you will want to turn these at a higher speed than the engine, requiring a large-diameter pulley.

A whole series of factors should be carefully considered. Get them right, and you will have years of trouble-free service. Otherwise, these accessories and their belt drives will be a source of continuing frustration.

Brackets

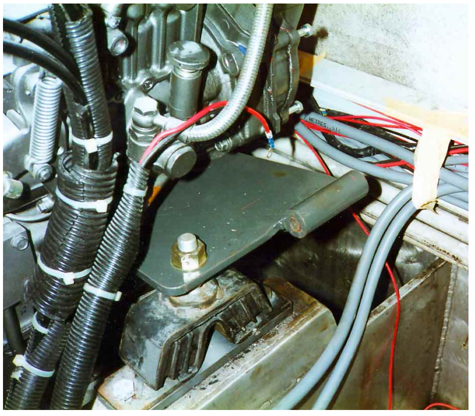
Brackets are subject to many hours of vibration and bending loads and should always be made from heavy-gauge steel. Aluminum, although lighter, does not stand up well to vibration.

The vibration is a function of the engine balance, the natural tendency of a diesel to create “torsionals” with each power stroke in the individual cylinders, and the load placed by the accessories themselves.

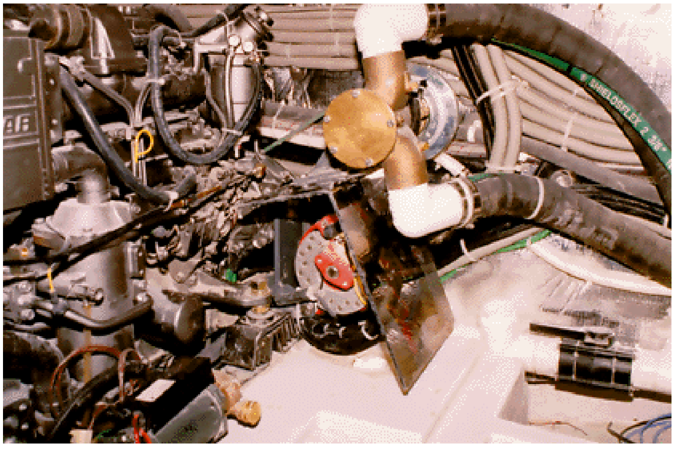
The brackets need to be strong enough not to bend under load.

An example of the loads felt by brackets: watermaker pumps and fridge pumps use between 1.5 and 2.5 horsepower each; and a good-sized 12-volt alternator will consume 6 to 8 horsepower, with 24-volt alternators taking 50 percent more.

Finding a place to attach brackets is often a problem. It is always best to find a dedicated bracket mounting point, such as an unused motor-mount pad on the engine block. Avoid sharing attachment points with other accessories. Brackets mounted off the engine are rarely successful, as they tend to transmit noise to the hull — and since they do not vibrate directly with the engine, they put excess loads from vibration on the accessories.



Generally, the best way to attach a bracket to the engine is to bolt it onto the motor mount pads on the engine block and then pick up the edge with a motor mount, as shown here. (The alternator is not yet mounted).



The starboard-side bracket on the Sundeer 64 was a real challenge. It had to deal with a large alternator that required up to 9 horsepower, plus a heavy-duty damage-control pump that would take 4 horsepower. Needless to say, the bracket was a very heavy weldment.

Note the plastic drip shield between the damage-control pump and alternator, just in case the pump springs a leak.

Alignment

After having a strong bracket, making sure that the drive and accessory pulley are exactly in line is the next key issue. These two pulleys should be as close to exactly on as you can get. Even a 1/16-inch (1.5mm) misalignment will cause havoc with belt wear.

Belt Tensioning

Proper belt tension is critical to good performance. If the belt it too loose, slippage will create heat (in addition to belt wear), and that heat eventually affects accessory bearings. In higher power applications you simply will not be able to transfer power from the engine to the accessory without proper tension.

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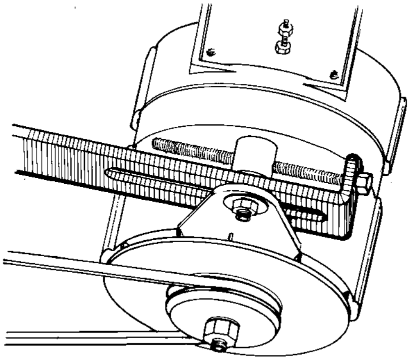

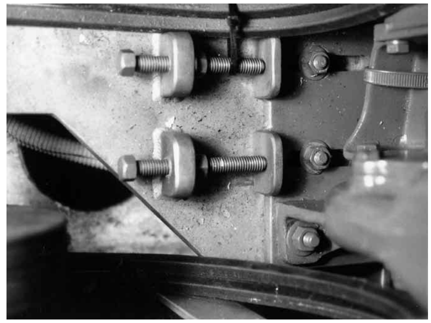

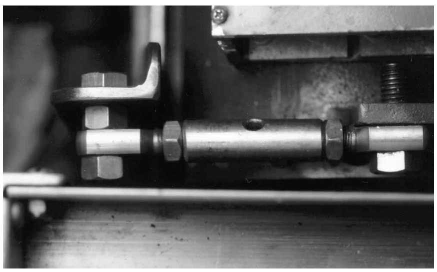

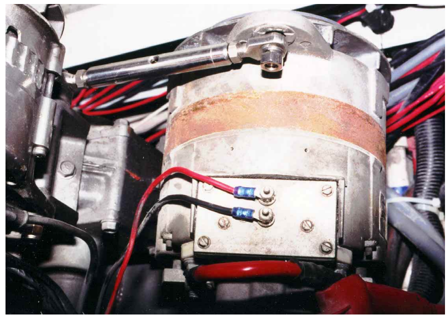

There are many ways to build in a belt-tensioning device.The simplest is to use a bolt to pulley the alternator away from the engine (upper left illustration). If the device in question is base-mounted (the way a fridge compressor is typically installed), then bolts can be used to push (top right) or pull the accessory into the correct tension.

Or, as is shown in the two lower photos, a small turnbuckle can be worked into the mix.

The typical method of tension is to use a long screwdriver or chunk of pipe as a lever, then brace yourself for a real effort. With lower power accessories, this will work. But as power requirements increase, so does belt tension. At some point it becomes nearly impossible to attain the right amount of tension.

This is where some form of screw adjuster comes into play. We have used a variety of schemes over the years, typically employing a simple threaded rod with a nut bearing against the accessory in question. These are easy to make up and save a lot of trouble over time.

PTO Capacity

You will want to check the PTO capability of your engine against the power needed to run your accessories. The engine manufacturer will advise you of their limitations. PTO capacity is typically a function of how the PTO pulley is attached, engine rpm, crank-shaft size, front-bearing capacity, along with the weight and size of the drive pulley.

Most small engines afford 3 or 4 horsepower at low rpm without complaint. As you get into larger alternators, you need to watch these factors.

Engine Loading

No diesel engine likes to run for long periods in a relatively unloaded state. The bigger the engine, and/or the higher the performance of the engine, the less it likes this situation. Running the engine for long periods like this causes glazing of cylinder walls and rings, as well as excessive carbon buildup. Of course, this is exactly what most of us do for a majority of the hours on the engine. So what can be done to mitigate the damage?

The first thing is to periodically run the engine hard under full load while powering. We typically try to get in 15 to 20 minutes of high-load powering for every five or so hours of charging. This reduces glazing and blows out built-up carbon. Note that this means running the engine hard, right up near max rpm, with engine heat up at the top end of the operating range.

The second thing to do is to adhere strictly to an oil-maintenance program. Using some of the high-tech oil-treatment systems discussed later will also help.

Drive Pulley Design

The relationship of the PTO drive pulley to accessory pulleys is determined by several factors. First, you need to determine what the ideal high speed idle rpm will be for your engine. Then, look at what rpm range you want a given accessory to run.

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Say you have a fridge compressor that you want to turn at 3,000 rpm, and you want to run the engine at 1,000 rpm at anchor. This gives you a 3-to-1 drive ratio. Since the clutch pulley on the fridge compressor is probably 6 inches (150 mm), this would require a drive pulley with an 18-inch (450mm) diameter. That's not practical, so the fridge compressor will be limited to about 2-to-1 at best.

Alternators are easier to deal with, however. With a 12-inch (305mm) drive pulley, the odds are you'll be using a 3-inch (75mm). This would give you a drive ratio of 4-to-1, so that at 1,000 rpm the alternator would be spinning at 4,000. Since most alternators begin to hit their stride at around 3,500 rpm, this seems ideal.

However, you need to look at what happens when the engine is up to speed, as all accessories have an rpm limit, above which they become very unhappy.

Since most alternators are limited to between 7,500 and 10,000 rpm, if you were using a high-speed diesel that cruised at 3,300 rpm, the 4-to-1 ratio would have the alternator turning at 13,000 rpm! The 4-to-1 would work with a low rpm engine, but with higher top speed, the drive-pulley diameter would have to be reduced.

The more accessories you run on the front of the engine, the deeper the drive pulley will be. The problem here comes with bending load on the crank shaft. The loads that are taken at the end farthest away from the engine's PTO have the highest bending "arm."

To minimize this load, arrange accessories so that the highest power requirements are dealt with closest to the PTO, and lightest loads at the end of the drive pulley.

Pulley weight, balance, and finish are all important to belt life, engine front seal, and bearing wear. The drive pulley should be as light as possible, polished carefully, and balanced perfectly.

Lay Shafts

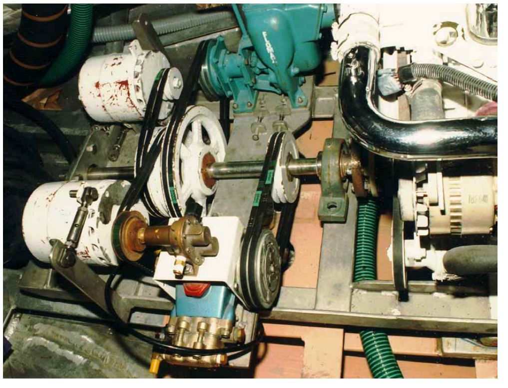
Lay shafts sound wonderful in theory. The PTO is used on the main engine to drive an intermediate shaft. To this shaft are connected a number of accessories like fridge compressors, alternators, pumps, and maybe a dive compressor. To get really sophisticated, a smaller diesel can be used to power the lay shaft from the opposite end, in which case clutches are required to disconnect the engine not being used.

In the real world, however, there are some problems. To begin with, lay shafts tend to be heavy, expensive, and excessively noisy. It is not uncommon for lay shafts to be noisier than the engines to which they are attached. And, heaven forbid, should a belt ever fail, you may end up with a huge project to get new belts into place.

On the other hand, they do allow a lot of accessories to be run of the main engine.

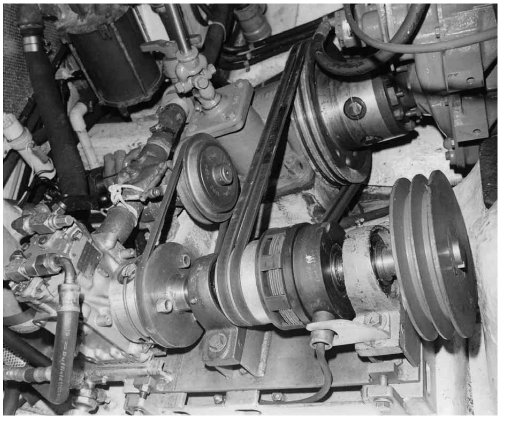
We've fitted lay shafts to a number of vessels over the years, including one of our own (which we later removed). My feeling is that once you understand the true costs of the lay shaft, not to mention the noise issues, other means of achieving the objective become more palatable. Perhaps a small genset, or changing a couple of accessories to DC drive, will eliminate the need for the lay shaft.

If you go with a lay shaft, there are several issues to take into account. Alignment between the drive and lay-shaft pulleys must be spot-on. Belt engineering should be conservative. The lay shaft and related brackets must be tied to the engine mounts so that the two entities vibrate together. Mounting the engine in one spot and the lay shaft elsewhere — unless a CV axle is used — will result in premature bearing and seal failure on the driving engine.



The lay shaft on *Sundeer* lasted less than a year before I changed to engine-mounted alternators and damage-control pump and put a 24-volt DC motor on the watermaker. The new system was lighter, more efficient, and left more space in the engine room.

Jim Schmidt uses a lay shaft to drive all of *Wakaroa*'s accessories. It can be run with either the main engine or a small auxiliary engine.



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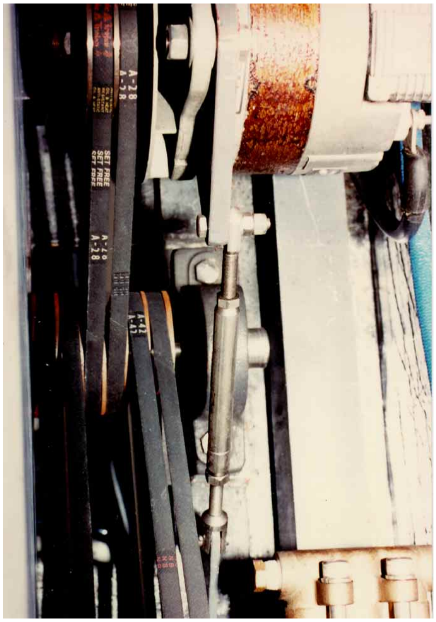
V-BELTS

Next to pumps, V-belts cause the most annoying maintenance problems when cruising. If they are the right design for the job, properly installed, and correctly tensioned, they will give you thousands of hours of trouble free life.

But since this is not typically the case, be prepared with lots of spare belts!



Most cruising yachts today have a large selection of accessories attached to the main engine.The belts driving them are frequently the weak link in the system.

How They Work

V-belts transmit power with their *sides*, not their bottom. They depend upon a certain amount of contact area with the pulleys to get the job done. This brings into play several factors.

The first is belt wrap. Under ideal conditions, with a 1-to-1 pulley ratio, each belt will wrap around 180 degrees of pulley. However, with a stepped-up system, as we normally use on boats, the belt wrap will be greater on the drive pulley and less on the accessory pulley. This degrades the performance of the belt. One way to mitigate the belt-wrap problem with the smaller pulley is to move the two pulleys further apart, as this reduces angular change between the two.

Another way to make the belts more efficient is to increase the size of both pulleys. There are, of course, some practical limits with drive-pulley size and weight. Also, check on maximum allowable belt speed. Belt speed is a function of engine rpm and pulley circumference. For a given rpm, as diameter and circumference increase, so does belt speed.

Types of Belts

There are literally dozens of types of V-belts — all sorts of designs, constructions, power ratings, and configurations. Two similar-looking belts may have vastly different power ratings.

The typical automotive belt, which you'd buy in an auto parts shop, may be able to handle 3 horsepower. If you step up a grade and go to an industrial belt, such as the Gates High Power II, for a couple of dollars more, you'll double that rating. It's usually necessary to visit an industrial belt distributor in order to obtain higher rated industrial belts.

Belts are typically sold in cogged and smooth designs. Cogged belts generally have higher power ratings and grip the pulleys better.

You can also buy adjustable belting, which can be used at any required length. This works great in a pinch, but only for low-power applications.

Horsepower Ratings

If you consult an industrial belt engineer about your application, he'll run your system through a computer program. He'll want to know the rpm at which the belt is expected to operate, required power, pulley diameter, and the distance between the pulleys.

The engineer will then specify several belt types, In the process, he'll predict how many hours of operation to expect.

It is amazing just how much power you can transmit. With high-quality cogged belts, using a 2-to-1 pulley ratio and belt life of around 1,000 hours, a single belt will handle close to eight horsepower. However, to do this, belt tension and alignment must be exact! We've found (the hard way) that for most people, this situation is too aggressive, and it is better to de-rate the belts down to the 4-horsepower range.

Belt Tension

We've now mentioned belt tension, which is critical to long life, a couple of times. The problem comes in determining the correct tension. Your engine manuals may indicate tension requirements. Belt engineers can also offer figures.

Our experience with large alternators and their high power requirements has been that a new belt should start life at around 75 to 80 pounds (34 to 36 kg) of tension. After the initial break-in period where the belt is stretching, this tension should drop to the 50-to-60-pound (23 to 27 kg) range. Most industrial belt suppliers have inexpensive and easy-to-use devices for measuring belt tension.

Before we leave this subject, be aware that overtightening can also be a problem, leading to premature bearing failure.

Dusting

All belts make a certain amount of dust when running. However, if the correct belt is being used, if it is set at the proper tension, and if pulleys are correctly aligned, dusting should be minimal. More than a small amount of dust is cause to investigate.

One Belt or Two?

If you have a minimum of accessories, it makes sense to transfer power with dual belts. Thus loads are split, and most of the time, belts can loaf along.

With multiple accessories, however, using dual belts makes for a large, heavy drive pulley. This puts more load on the engine PTO, front bearing, and front oil seal. Over the years we've found that with multiple accessories, it's better to work hard to make the single-belt systems efficient, thereby reducing PTO loading.

Multi-Belt Systems

Odds are you'll have a bunch of belts on the front end of the engine. When the time comes to change a belt, Murphy will make sure it is the innermost belt — meaning you have to remove all the outer belts to get to that inner belt!

The one way around this is to put on an extra set of inner belts. Tie them out of the way so they are available when needed.

Dealing with the Unexpected

Over the course of cruising, all sorts of problems may crop off with your V-belts and related accessories. It may be that you cannot find the correct length of replacement belt, or that your own belts are on their last legs. Perhaps the bearings are going out on one of the accessories.

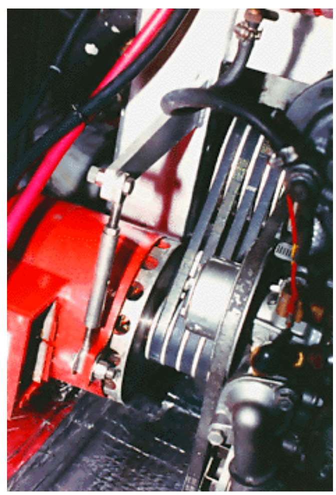
There are a variety of things you can do to keep going. One is to carry some "belt dressing." Available in solid and spray form, it increases the friction between belts and pulleys. If a belt has stretched too far to tighten properly, sometimes a little belt dressing is just enough to get the job done — but do not make a steady habit of using it.

If a bearing is going, reducing belt tension will often help delay the point of total demise.

You can also reduce the power requirements of your accessories by reducing output. With alternators, cutting back on the regulator reduces the load on bearings and belts at the same time.

It is usually possible to tie off a second set of belts on the front of the engine or at each accessory on a lay shaft. This makes it much simpler to change a belt!

When you cannot find the correct belt length, or have an inside belt that needs changing and not enough time to do it right, adjustable belting will provide a temporary fix. However, watch tension carefully, and reduce loads if possible, as these belts don't handle the same horsepower as regular V-belts.



There is a relationship between pulley diameter, horsepower, and rpm. When the loads get really high, it may be necessary to go to multiple belts. In this photo, we are turning a 9kW DC alternator that requires 20 horsepower.

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EMERGENCY STARTING

Since much of the systems logic to be employed later in this chapter depends on engine reliability, a word is in order on how to start a balky engine.

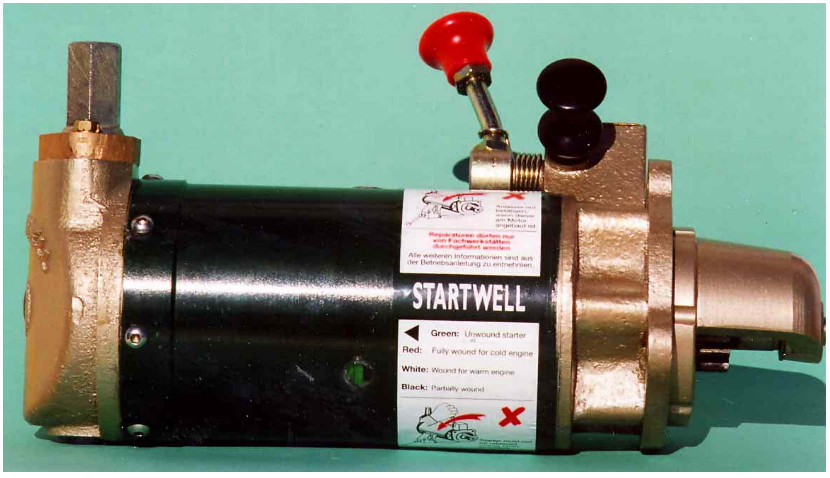
The nice thing about a diesel engine is that there's very little to go wrong with it. If you can get fuel to the engine, and get the engine to turn over, it will start. The difficulty comes in cranking speed. To get those first shots of diesel to explode under compression, a cold diesel needs a good turn of speed from the starter to generate enough heat. When there's a problem starting a diesel, it's usually electrical in nature. It's possible that the batteries are low, or there may be a wiring problem, or perhaps the starter solenoid or starter itself is bad.

Electrical difficulties normally develop over a period of time. The engine appears to take longer to start each time it's used. Perhaps there's a bad cell in the battery bank and the entire bank is flat. When you get to the point where there may not be enough punch left to get the engine to fire, there's a short-term solution. Give the engine a shot of ether. The ether speeds up the combustion process, and a diesel that wouldn't have a prayer of starting normally will fire right off with ether. This gives you a chance to get the batteries charged and/or sort out the other problems.

But ether must be used carefully. Too big a dose can damage the valves or pistons. And a messy dose, if sparked off, can damage *you*. You can hold a rag, soaked in ether, at the air vent, or give a squirt from an aerosol can. A one-second burst from the aerosol can should do the trick. A diesel mechanic I know also recommends using WD40. It's less volatile and therefore less likely to damage the engine if too much is used.

If you have a mechanical transmission (as opposed to hydraulic), the engine can be started by sailing. Many diesels will start at five or so knots of boatspeed (just like pushing a car when you were a kid!). Some smaller diesel engines have the option of hand-crank starting. It's really nice to know that regardless of what happens to your electrical system, the engine (or generator set) can be fired off with a little arm muscle.

However, there are a couple of major considerations to make this a feasible alternative. First, you need room to swing the crank. As self-evident as this may seem, probably two-thirds of the boats we've seen with hand-crank capabilities can't benefit from it, as the crew can't get into a reasonable position to exert leverage. Second, there will usually be a pressure-relief valve for the cylinders. Actuating this valve allows the crew to spin the engine, getting the flywheel up to speed without having to fight compression. Obviously, access to the compression relief must be good.



Startwell Engineering in the UK make a spring starter that can be bolted onto the engine when the batteries (or the electric starter) die. A small crank is used to wind up the spring, using the shaft at the upper left of the photo. The red handle is then pulled to release the spring and spin the engine. At around $700, this may make more sense than carrying a spare starter motor.

A key consideration will be access to the starter motor.

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FUEL SYSTEM

Feed a diesel clean fuel and it will run forever. But let a small amount of water or dirt get to the injection pump and you're in for some headaches.

Filters

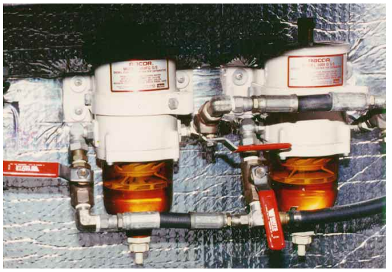
Most fuel filters use paper cartridges to take out contaminants down to a 30- to 40-micron size, or about the size of a typical blood cell. You can get even finer filters, but they clog up more quickly.

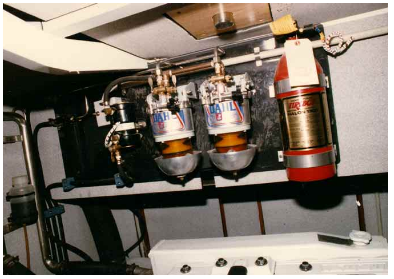
The engine will usually have a fuel filter mounted right ahead of the lift pump. You should have larger-capacity filters in the line to augment the system. Size and types vary, but it's best to go with large filters. The bigger they are, the more capacity before they need changing, and the finer screen size they can have.

You may want to use two filters with a "Y" selector valve. This allows a quick changeover and a leisurely approach when it is convenient to changing the dirty cartridge. Having a vacuum-pressure gauge mounted in line will let you know when the fuel filters are dirty enough to change, but before they begin to starve the engine. Racor and Dahl are two of the more popular filters available today — both work well. On *Sundeer* we experimented with industrial-type filters made by the Electrolube Corporation. These are so efficient they get down to particles as small as three to five microns. Using a hybrid filter material with a variety of ingredients and more surface area than other types, they don't plug up as quickly. They even have a biocide to kill diesel bacteria when it's present. Conventional filters don't tackle bacteria.

While we've rarely had problems with fuel over the years, we still like to have as much protection for the engine as possible. So, when the time came to specify a system for *Beowulf* we went with a dual-manifold Racor system with 30-micron filters as a primary, and a 2-micron Racor filter as a secondary, both ahead of the day tank. These get a single shot at the fuel. The engine's fuel filter is continuously working on the day-tank fuel as the excess fuel is recycled back and forth between day tank and injection pump.

You'll want to know if the fuel filters have a bypass to allow fuel to flow when the filter itself is plugged. There are two schools of thought here. One says you don't want the engine to quit, or be starved for fuel if the filter is plugged. (In a diesel engine, the fuel actually provides a substantial amount of the cylinder cooling, more so than even the salt water in the heat exchangers — so running a fuel-starved engine can lead to serious damage.) The other argument is that you don't want to let dirty or waterlogged fuel into the engine, since it will do other forms of damage. I think the best compromise is two filters, a selector valve, a vacuum gauge with which you can keep track of filter condition, and a non-bypass filter design.





The ideal fuel-filtering system is to have two filters selectable with a Y-valve. Thus, when one unit needs to be replaced, you can keep the engine running with the other. You can plumb this yourself (top photo) or get a pre-plumbed system from Racor or Dahl.

Changing filters can be messy. Using a plastic bag (above) or having a drip tray (below) contains the spilled diesel or lube oil.

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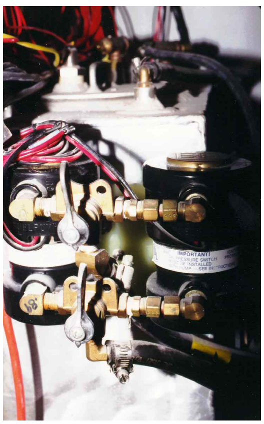

An aluminum day tank with fuel filters and lift pumps mounted alongside. This tank holds 20 gallons (77 liters). Either lift pump can be selected with the Y-valves.

Filter Installation

There are several installation considerations on fuel filters. First, if you spill fuel when removing the filter, where does it go? Is there room for a bucket or catch tray under the filter? If the spilled fuel ends up in your bilge, you'll be smelling it for months! How about access to get the filters in and out? It's a good idea to install a shut-off valve between filter and tank, and between filter and engine, so that when you break the fuel-line suction, a minimum of air is trapped. This makes it easier to bleed the system after you have replaced the filters.

While most modern filters remove dirt and water, some are specialized for one job or the other. Just remember that you need to remove both!

Day Tanks

A lot of experienced cruisers like to have a day tank in their fuel system, where several hours (or more) of fuel is fed periodically into a tank that will use gravity to feed the engine's lift pump. This way, you know that regardless of what happens with filters or the lift pump, there's always a certain amount of clean fuel ready to be used (assuming, of course, the low-level alarm in the day tank goes off when the clogged filters restrict fuel flow).

A day tank will typically be fed from your hull tanks with an electric lift pump actuated by some form of on/off float switch within the day tank. Or, if you have a larger tank, you can pump fuel manually or use a toggle switch to turn the electric lift pump on.

Where we've had a long lift from the fuel tanks to the engine, we've always used a day tank. However, they do take up space and are an additional system that can cause problems. If the engine isn't too much higher than the fuel source, when the fuel tanks are near empty I'd forget about the day tank.

If you do have an electric system to fill the day tank, actuated by a float switch, you can count the pump cycles to keep track of your fuel consumption. Ideally there will be float switches to turn the electric pump on and off, as well as to indicate high and low tank readings. This is usually best handled with a series of reed switches on a single shaft.

Fuel Lift Pumps

You may also want to consider putting an electric lift pump into the fuel line between the tank and engine. There are several good units on the market (made by Walbro and Stewart Warner) that reduce the hassle of bleeding air from the fuel system. They also lessen the load on the engine's mechanical fuel lift pump. The design of these pumps allows the engine lift pump to pull through them if they fail.

RANGE UNDER POWER

We should take a minute to chat about what "range under power" means. First, you have to determine your usable volume of fuel. This will be less than the theoretical maximum due to filling difficulties, and the inability (or undesirability) of drawing the last of the fuel off the bottom of the tank. With usable capacity in hand, we then proceed to consumption-per-hour at various speeds.

The only time we picked up dirty fuel during our circumnavigation was in Bali, from these drums. By leaving the last couple of inches (50 mm) in the bottom, you avoid most of the muck.

A Baja filter (left) has a series of very fine screens that remove water and dirt from diesel. However, since they do not remove bacteria, a biocide should be used whenever you pick up suspect fuel.

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Fuel-Consumption

Diesel engines are conveniently alike when it comes to fuel burned. They generally consume about four-tenths of one pound (18 grams) of diesel fuel per hour for each horsepower produced. (The actual figure will vary 10 percent one way or the other, depending on how an engine is being used and its efficiency at that point). Assuming your fuel weighs in at 6.7 pounds per gallon, that means for every gallon (3.875 liters) per hour burned, your engine is putting out 16.75 horsepower.

These consumption numbers are generally accurate, whether you're plugging into a headsea with the engine working hard or motorsailing along at a good clip with the engine barely doing any work at all. This is due to the nature of the fuel-injection pump on the engine; it provides just enough fuel for the engine to do the work required. If the load on the engine is less, fuel consumption will be less — although for any given rpm there is an optimum loading at which the very best fuel efficiency will be achieved.

Speed-Length Ratio

The speed at which you travel, or more correctly the speed-length ratio, will have a big impact on your range. The best mileage will be found at a speed-length ratio between 0.95 and 1.05 (to find your speed-length ratio, divide boat speed by the square root of waterline length — thus 6.6 knots on a 36-foot waterline would be 6.6/6, or 1.1. As the SLR goes up toward 1.3, powering range will drop as much as 70 percent.

Bottom and Prop Condition

While a small amount of growth on the bottom retards speed modestly, that same amount of marine life on your prop will have disastrous effects. Even a slight scale, which will find its way onto most props four to six weeks after cleaning, will knock efficiency by 10 percent or more. Give the prop another couple of months and you can kiss 25 percent of your speed and range good-bye.

The Right Prop

Most sailboat props will deliver between 20 and 40 percent of the engine's efforts to the water. If you're not getting the speed or range that you think you should be, one of the first problems to check propeller efficiency.

Measuring Consumption

The simplest measure of consumption is to check engine hours between refills, dividing quantity of fuel used by hours run. This is best done after a relatively long powering session with consistent apparent-wind and sea conditions. Obviously this can be done after a period of intermittent use, but for truly accurate data it's better to go out and run some tests.

Ideally, your test will be carried out first on a calm day. The fuel tank must be carefully topped off beforehand. Allow plenty of time for the diesel foam to settle down, so you can get that last gallon of fuel into the tank. Maintain constant rpm on the engine for a couple of hours at your normal cruising speed. Then refill the tank right to the top. The longer you run, the less filling variances will affect your final numbers. It many cases, it's easiest to carry a couple of jerry jugs aboard and refill from these.

To make shorter runs with better accuracy, disconnect the fuel line from the fuel tank and draw directly from a jerry jug, measuring by sight fuel consumed. Be sure the jerry jug is well secured!

Calculating Range

It's obvious that if you divide your fuel tank capacity by consumption per hour, you'll know how many hours (and at what speed) you can power. The tricky part is knowing just how many *usable* gallons of fuel there are.

To begin with, it's always a good idea to leave the last inch (25mm) or so of fuel in the tank as it's more than likely your tank will have some water from condensation at the bottom. There's also going to be some sludge or dirt at the bottom, unless tanks are periodically cleaned.

To figure out how large your tank is in gallons, multiply the area of the top by the height to get cubic feet. Then multiply the cubic feet of volume times 7.48 gallons per cubic foot for overall capacity.

Let's assume that there are 50 gallons of "usable" fuel in a 55-gallon tank. From our test run we know we burn 0.85 gallons per hour at 6 knots. Divide 50 gallons by 0.85, and you get 58.82 hours of running time. Multiply this by our speed, 6 knots, and you get 352 miles of range. Remember, however, that this is in smooth water with no wind.

Different Conditions

If there's a light breeze blowing and you can motorsail, it's possible to cut consumption by as much as 50 percent at the same or even slightly better speeds. On the other hand, just a 10-knot headwind can increase fuel consumption (and decrease range) by 15 to 20 percent. Make that 20 knots of head wind and throw in a head sea, and consumption will go up 75 to 100 percent. On the other hand, if you can motorsail to windward, using a flattened mainsail, perhaps reefed down and sheeted somewhat to windward, with a 20-degree apparent-wind angle, you can get consumption back toward the smooth water norm (assuming seas are not holding you back).

Ideally, we'd like to test each condition and establish some hard numbers for each. But this may not be practical. Still, if you keep your tank topped up as you find different conditions, and then top up again, you'll collect some valuable data. You can achieve similar results when powering over long periods of time with an accurate dipstick.

Aboard *Sundeer* we measured a 10-percent increase in consumption between flat calm and 7 knots of wind in a calm sea. When we experience 12 knots of wind and 2 feet of chop, consumption almost doubles.

So, when you're calculating your range, do it for calm as well as boisterous conditions.

Daily Charging Allowance

You'll also have to allow for the daily charging cycle in range. This is a little more exact, as the consumption on the genset or engine is pretty much standard, even though it will vary slightly with refrigeration and electrical loading.

Most small diesels burn between 1/4- and 1/2-gallon (1 to 2 liters) a day during charging.

How Much Range Do You Need?

How much range is enough? You can (almost) never have too much. If the fuel is carried low in the boat, well below the center of gravity, it will help stability so you won't pay a penalty for having lots of it aboard. If it's stowed under seats and bunks, you lose good storage space and add weight to the boat without really helping stability. Another factor is how unpleasant motoring really is. With a quiet, efficient engine room, you'll want to motor a lot more than if you're living right on top of a noisy engine.

Range under power can be a safety consideration when you're making long passages. If navigation is difficult or dangerous, the quicker you get through an area, the less time current and drift can affect your course. And the faster you get a passage over with, the less chance a weather system will have of catching you.

Intermezzo carried 150 gallons (580 liters) of fuel, which gave us a range of about 900 miles (1 gallon, or 3.875 liters per hour, at 6 knots). This seemed to work well, but then she was very quick in light airs and was unpleasant under power. *Intermezzo II* carried a little over 350 gallons (1,356 liters) of fuel and had a range of 1,700 miles (1.5 gallons, or 5.87 liters per hour at 7.5 knots). I couldn't imagine needing more fuel, but when we built *Sundeer* we went to 620 gallons (2,400 liters) of fuel. This allowed us to travel faster and farther — 2,500 miles at 8.5 to 9 knots or 1,500 miles at just under 10 knots. *Beowulf* carries even more fuel — 800 gallons (3,100 liters). At 10 knots she has a range of well over 3,000 miles.

On the other hand we've had many friends who have made do with a few hundred miles of range. Is there a happy minimum medium somewhere? Yes. If you can power 400 to 600 miles at 4 to 5 knots, that's probably enough to keep you out of trouble in really light airs and through reef-infested areas.

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The chart at right gives basic horsepower data for several different types of vessels. Data is based on the following: a clean bottom and propeller, smooth water (no wind), and moderate drag from appendages (keel and rudder).

The data is presented for six different waterline lengths. The displacement (Disp) for each is shown as well as the displacement-length ratio (DLR). Horsepower requirements go up or down pretty much in proportion to displacement, so if your displacement is above or below these numbers, you can adjust accordingly.

In the left-hand column of each is the speed-length ratio (SLR) for each of the speeds shown. As discussed in the design section, the SLR is a key determinant of drag (and thus horsepower needs).

Effective horsepower (EHP) is shown in the third column from the left. This is the force required to propel the vessel in question delivered in the water *(i.e., the actual thrust with which the propeller can push you forward, after allowing for all inefficiencies)*.

To get engine horsepower you need to adjust for propulsion efficiency. This includes transmission losses, and the losses from any support bearings, along with prop efficiency.

The three right-hand columns each show what horsepower would be needed based on propulsion efficiencies of 0.25, 0.325, and 0.4. For most sailboats with a feathering or narrow sailing prop, the 0.25 column is about right. If you have a really good prop, you might get to the 0.325 column. Very few yachts will net out at 0.4.

Let's say your waterline is 30 feet, and you have a displacement of 20,000 pounds. At a speed of 5.75 knots (SLR of 1.05), the data indicates an EHP of 2.10. You need to modify this for your heavier displacement (20,000/18,000=1.11). So 1.11 times 2.10 gives you 2.33 effective horsepower. Assuming an overall propulsion efficiency of 0.25, divide EHP by PE. (2.33/0.25 = 9.32 engine horsepower required to attain this speed.)

LWL=24'	Disp=10,000	DLR=325			
SLR	Knots	EHP	PE=.25	PE=.325	PE=.40
1.00	4.90	0.80	3.20	2.46	2.00
1.05	5.14	1.10	4.40	3.38	2.75
1.10	5.39	1.30	5.20	4.00	3.25
1.15	5.63	1.50	6.00	4.62	3.75
1.20	5.88	1.20	4.80	3.69	3.00
1.25	6.12	2.70	10.80	8.31	6.75
1.30	6.37	3.70	14.80	11.38	9.25
LWL=30'	Disp=18,000	DLR=297			
SLR	Knots	EHP	PE=.25	PE=.325	PE=.40
1.00	5.48	1.70	6.80	5.23	4.25
1.05	5.75	2.10	8.40	6.46	5.25
1.10	6.02	2.50	10.00	7.69	6.25
1.15	6.30	3.10	12.40	9.54	7.75
1.20	6.57	4.00	16.00	12.31	10.00
1.25	6.85	5.40	21.60	16.62	13.50
1.30	7.12	7.30	29.20	22.46	18.25
LWL=36'	Disp=26,000	DLR=248			
SLR	Knots	EHP	PE=.25	PE=.325	PE=.40
1.00	6.00	2.60	10.40	8.00	6.50
1.05	6.30	3.40	13.60	10.46	8.50
1.10	6.60	4.00	16.00	12.31	10.00
1.15	6.90	4.90	19.60	15.08	12.25
1.20	7.20	6.40	25.60	19.69	16.00
1.25	7.50	8.60	34.40	26.46	21.50
1.30	7.80	11.60	46.40	35.69	29.00
LWL=42'	Disp=38,000	DLR=228			
SLR	Knots	EHP	PE=.25	PE=.325	PE=.40
1.00	6.48	4.10	16.40	12.62	10.25
1.05	6.80	5.40	21.60	16.62	13.50
1.10	7.13	6.30	25.20	19.38	15.75
1.15	7.45	7.80	31.20	24.00	19.50
1.20	7.78	10.10	40.40	31.08	25.25
1.25	8.10	13.50	54.00	41.54	33.75
1.30	8.42	18.40	73.60	56.62	46.00
LWL=48'	Disp=47,000	DLR=190			
SLR	Knots	EHP	PE=.25	PE=.325	PE=.40
1.00	6.93	5.50	22.00	16.92	13.75
1.05	7.27	7.10	28.40	21.85	17.75
1.10	7.62	8.40	33.60	25.85	21.00
1.15	7.97	10.30	41.20	31.69	25.75
1.20	8.31	13.30	53.20	40.92	33.25
1.25	8.66	17.90	71.60	55.08	44.75
1.30	9.01	24.30	97.20	74.77	60.75
LWL=54'	Disp=60,000	DLR=170			
SLR	Knots	EHP	PE=.25	PE=.325	PE=.40
1.00	7.35	7.40	29.60	22.77	18.50
1.05	7.72	9.60	38.40	29.54	24.00
1.10	8.08	11.40	45.60	35.08	28.50
1.15	8.45	13.90	55.60	42.77	34.75
1.20	8.82	18.10	72.40	55.69	45.25
1.25	9.19	24.20	96.80	74.46	60.50
1.30	9.55	32.90	131.60	101.23	82.25

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LWL=30'	Disp=18,000	LR=297		Fuel Burn	Total Hours	Range in	Range in	Range in
SLR	Knots	EHP	PE=.25	Per Hour	40 US Gal.	Smooth	Medium	Rough
1.00	5.48	1.70	6.80	0.39	102.94	564.12	394.88	282.06
1.05	5.75	2.10	8.40	0.48	83.33	479.17	335.42	239.58
1.10	6.02	2.50	10.00	0.57	70.00	421.40	294.98	210.70
1.15	6.30	3.10	12.40	0.71	56.45	355.65	248.95	177.82
1.20	6.57	4.00	16.00	0.91	43.75	287.44	201.21	143.72
1.25	6.85	5.40	21.60	1.23	32.41	221.99	155.39	111.00
1.30	7.12	7.30	29.20	1.67	23.97	170.68	119.48	85.34

Let's take this a step further. Assume you have 40 U.S. gallons of diesel fuel, and want to know what your range under power will be. Most diesels burn about 1 gallon for every 16 horsepower they use. So first we need to convert horsepower to gallons-per-hour.

In this case, let's go with the 18,000-pound displacement in the chart above. At an SLR of 1.10, or 6.02 knots, we see we need 10 horsepower at the engine if our propulsion efficiency is 0.25.

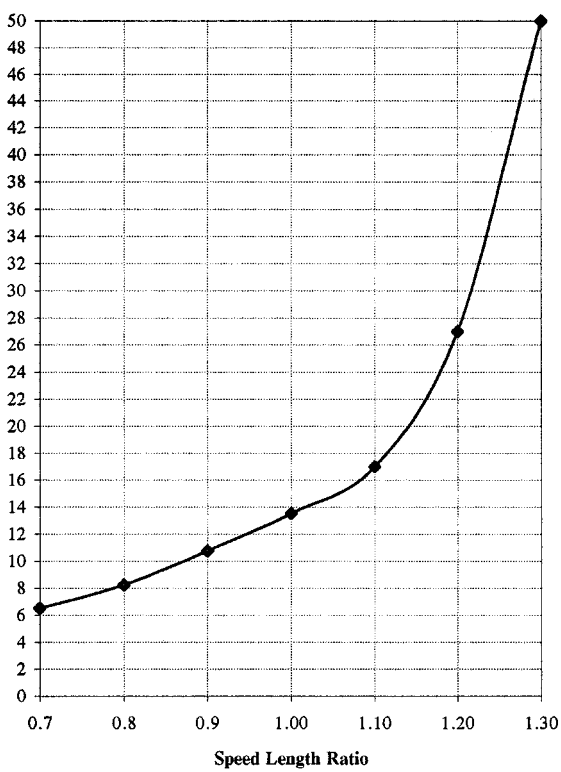
If you divide the power required from the engine by 16 to get gallons-per-hour, you will come up with 0.57 gph. Now take the fuel capacity available, in this example 40 gallons, and divide it by the fuel-per-hour burned (40/0.57=70 hours). Next, multiply the hours by the speed (6.02 knots times 70 hours = 421 nautical miles) to get your range under power.

Keep in mind this is for *optimized* conditions, with the hull and prop clean as a whistle. It is also a smooth-water no-wind scenario, which is not very realistic.

The following step is to make a "guesstimate" of how much fuel consumption will increase and range decrease should conditions deteriorate. For moderate conditions — say, 10 knots of true headwind and a 1-foot wind chop — your drag and fuel consumption will probably increase 30 percent. To get the modified range, multiply existing range by 0.7. In rougher conditions — say, 14 knots of headwind and a 2-foot chop — fuel consumption and drag will probably double. Therefore you multiply your smooth-water range by 0.5.

It would be rare to find a boat that fit any of this data exactly. However, if you can find a single realistic reference point for your own vessel, by checking fuel consumption at a given speed (and speed-length ratio) you should be able to interpolate up or down based on the numbers presented here.

A few caveats: First, drag at higher speed is very much a function of displacement-length ratio. The data in these tables is for moderate-displacement vessels. If you are much heavier for your length, the drag will be higher at higher SLRs. Conversely, if you are quite a bit lighter for your length, drag will be less at higher speeds.



Here's another approach to calculating required power. This will require some simple math.

First, calculate the weight of your boat in long tons by dividing total displacement by 2,240. If your boat weighs 20,000 pounds, this would make her 8.92 long tons (20,000/2240=8.92).

Next, pick a speed-length ratio. Let's say that your waterline length is 30 feet. The square root of 30 is 5.47. And we want to operate at an SLR of 1.1 or 6.02 knots (5.47 x 1.1 = 6.02 knots).

In the adjacent chart, find required thrust per ton on the left-hand side for an SLR of 1.1, or 17 pounds per ton. The thrust required will be 17 times 8.92 for a total of 152 pounds.

The formula for required horsepower (EHP) is resistance times speed in knots, multiplied by 0.003. For the example above, this works out as follows: 152 pounds times 6.02 knots (at our SLR of 1.1) times 0.003 or 2.74 horsepower.

Next, we have to calculate in the losses due to the drive train and prop. We'll assume a prop efficiency of 30 percent. Therefore, for required horsepower we take 2.74 and divide by 0.3, for 9.15 horses. Then we have to make allowances for the transmission at about 10-percent loss, as well as for a shaft bearing with another 2 percent in loss. So 9.15 divided by 0.88 gives a final requirement of 10.4 horsepower.

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FUEL TANKS

Diesel fuel is extremely viscous, much more so than water. As a result, the manufacturing of diesel tanks can be difficult. The sulphur in diesel fuel can combine with moisture in your tanks to create real corrosion problems — just as with engine oil.

Tank Materials

As a result of these two factors, choosing the correct material for tanks is somewhat complex. Black iron was favored for many years because of its apparent resistance to acids. But black iron rusts and is difficult to keep looking nice. Stainless looks better but has to be used in heavy gauges in order to last a reasonable length of time. Fiberglass should be ideal because of its resistance to acids, but is difficult to really get tight enough to prevent minor diesel leaks. (Diesel will leak through watertight surfaces!) Aluminum tanks, properly welded, seem to be more resistant to the acids than stainless and don't have the appearance problems of black iron.

You can see right away that you should be able to remove your tanks without tearing the boat apart, should the need arise. The only time I would be happy with built-in tanks is in a metal boat, where they're welded to the hull.

Buying New

If you're buying new tanks, they should be pressure-tested regardless of material. The procedure goes like this: Attach all fittings, covers, etc. (sealing off pipes where required), and apply 5 psi air pressure. Then go over all fittings, welds, and joints with soapy water and check for air leaks. After these have been found and repaired, reapply the air pressure and check again. If the leaks appear to be stopped, leave the 5 psi in the tank with an air gauge in the line. Turn off the external air pressure. Come back in 24 hours to be sure you still have the 5 psi air pressure.

How can you check if the tanks that are already installed are good? One way is with the air pressure test just mentioned. However, it may be that your tanks aren't strong enough to take the 5 psi pressure. Another approach is to use a lot of head pressure. First, try filling the tanks right up to the top of your fill, allowing time for all the foam to settle out. This means it may take a couple of hours of slow-filling at the end to get the fill pipe right up to the top. Then, double-check fittings, access ports, etc., for leakage or weeping.

Condensation

All fuel tanks have some condensation. Keeping tanks filled all the time will reduce condensation, but not completely. To get rid of the condensation, there are two approaches. The first is a small sump at the bottom of the tank, which you can periodically drain from the bottom. Since water is heavier than diesel, it will always be found at the lowest point of the tank. The second approach is to have a drain pipe through the top, leading right to the bottom of the tank, to which you can attach a small pump from time to time.

Your fuel *fill* pipe should go all the way to the bottom of the tank. This will reduce the fuel's tendency to foam, which can have a big impact on fuel capacity. I like to have a 2-inch (50mm) fill pipe to help reduce filling time.

The fuel-draw pipe, which leads to the engine, should have its pickup off the bottom a little bit. This way it stays out of any water that may accumulate at the bottom.

Separating air from diesel foam can be a headache. When we fill our tanks, the air vent is led to a bucket, so if there is any foam overflow it does not make a mess on deck.

Racor makes this clever fuel/air separator that does the job in a neater fashion, by returning the condensed fuel directly back to the tanks.

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Air vents must be placed so that chances of getting rain or spray into them are minimized. Coaming sides, and even the transom, can occasionally allow water into the tanks.

We've solved this problem in the past by bringing the air vents up through a lifeline stanchion (in this case through the push pit).

Air Vents

Getting air out of the tanks is difficult but necessary if you want to get full use of your fuel capacity. The air vent should be at least half the diameter of the inlet pipe, and led off the highest part of the tank. If the top of the tank slopes somewhat, so much the better. *It's critical that your air breather hose or pipe not have any dips in it.* It must run an upward slope to the vent point on deck. Any low spots will trap diesel, which will in turn block air flow. If this happens, it will be difficult to fill the tank and impossible to top off.

Clean Outs

Having a small access point above the low spot in the tank is a good idea for inspection and cleaning. The bolts holding this down should be blind tapped. If not, then bolts with O-ring seals around their heads must be used to prevent leakage up the threads. "Buna N" rubber must be used for the gasket. Other rubbers, like neoprene, tend to deteriorate under the influence of diesel.

Bladder Tanks

Heavy-rubber bladder tanks can be used for augmenting your fuel supply if they're well-fastened, carried low in the boat, and chafe protected. However, I haven't seen any bladder tanks I would be happy with for long-term usage.

Return Fuel Circuit

All diesel engines pump far more fuel than they burn. The excess fuel is used to cool the injection pump and provide a form of lubrication. As a result, there is a fuel-return plumbing circuit running from the engine back to the tanks. You usually have the choice of returning the fuel to the tank from which it was initially drawn, or to another tank. Be careful with this approach, as it is possible to overfill the lazy tank, in which case the excess will overflow.

Fuel Transfer

If you wish to transfer fuel from one tank to another, the overflow from the engine (as mentioned above) can be used, or you can fit a fuel transfer pump.

Because diesel is so hard on rubber, you must choose a pump that has been rated for fuel service. While a water pump could be used once or twice, the rubber parts would quickly be eaten by the diesel fuel.

Most fuel transfer pumps run quite slowly. A couple of gallons (8 liters) per minute is the norm for the medium-sized units.

ENGINE OIL

There's probably no aspect of diesel-engine maintenance more misunderstood than the importance of clean engine oil. If your engine oil is not treated properly, it will substantially shorten the life of your diesel.

The problem comes with the normal usage that a diesel auxiliary gets in a sailboat installation. The engine runs for a short period, maybe doesn't even get hot, then is shut down for a day or even a few weeks (this is especially true of lightly loaded gensets). This on/off short-cycling leads to condensation in the engine. When the engine cools down, a vacuum forms in the crankcase and pulls in the moist outside air. This condenses moisture, combining with the sulphur present in the oil or with particles in the oil that are the residue of the combustion process, and forms sulfuric acid. That acid then goes to town on the soft metal in your bearings, rubber parts inside the engine, and even the block.

So, rule number one is: Don't start the engine and then turn it off without letting it run for a while. Let it heat up and burn off some of the condensed moisture.

Next, change your oil often — not based on how many hours the engine has run, but on time between changes. Most experts suggest every six months. The less you run the engine, the more acid there will be. Check the color of oil on your dipstick frequently. If it's black and shiny, you're generally okay. But with any sign of moisture — usually a brownish tinge — change it right away.

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Engine lubricating oil comes in a variety of classifications, grades, and viscosities. Using the correct type of oil is important. The appropriate oil type varies with temperature and engine operating conditions. Check the owner's manual for the correct oil to be using in your conditions, and be alert to the changes required as you move the boat to different environments or change the operating conditions.

Classifications

CC: American Petroleum Institute (API) classification for lube oil to be used in heavy-duty gasoline and diesel-engine operation. This is formulated to protect engine from sludge deposits (from stop-and-go operation) and provide protection from high-temperature operation, ring-sticking, and piston deposits.

CD: Designed for heavily loaded diesels, with extra detergent to provided additional protection.

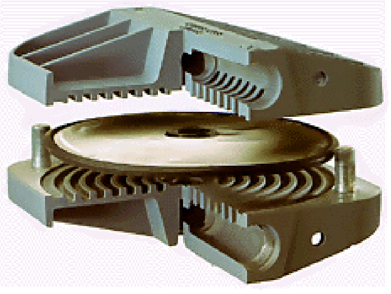
SC, SD, SE: Specifications designed by Automobile Manufacturers Association that require a sequence of tests for approval. Designed more for lower temperature operation.

Right class for your engine? CC is usually used for light-duty stop-and-go for naturally aspirated engines. Turbo-charged engines need CC/CD and sometimes a combination, since turbo operation is harder on engine and oil.

Sarah checking the oil on *Sundeer*'s Isuzu diesel. We make it a habit to check all liquid levels on the engine before starting the engine each time, and every six hours when powering for long period.

Spectographic Analysis

For roughly $25 you can send a sample of your oil out for spectographic analysis of what it contains. You will get back a report on engine wear, moisture, and other contaminants. The analysis can help you evaluate how the engine is doing and catch small problems before they become real headaches. This is also a good way to get a handle on a used engine.



Racor has come up with a fine-screen oil filter, replacing the paper element. Periodically you remove the screen and clean it. This means you don't have to carry spare filters or dispose of them. It also means the filter can be remotely mounted in a location where it is easy to access!

Bypass Oil Filters

Most marine engines use bypass filters to clean their oil. These filters typically take out particles down to about 30 microns in size. They do so by passing oil over a paper element. As the element becomes clogged, the flow shifts to another (now smaller) area of the filter. Eventually the filter becomes fully clogged, and the oil simply goes through a pressure-relief valve in an uncleaned state.

Of course, the buildup of particulate matter in the oil is one of the major causes of engine wear, so it is important to change the oil filter on a regular basis, *before* it goes into the bypass mode.

Special Filters

You may want to consider some help for your oil filter. Several companies make special additional filters to attack the acid and dirt problems (Electrolube, referred to in the section on fuel filters, and Refineco are two we've used). These have extremely fine filters (usually 3 to 10 microns, compared to the 30 to 40 microns of the normal engine-oil filter) and a heating element to boil off the moisture in the oil. This latter aspect is especially important, as it gets rid of one of the key ingredients of the sulfuric acid.

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We tested a centrifuge on *Sundeer* for a while. However, the oil flow was insufficient to get the unit up to proper operating speed.

These systems can add substantially to engine-oil life, but the filters should be changed on a regular basis, as they help absorb and/or neutralize the remaining acids. In sailboat applications, with light loading, these type of systems can add greatly to engine life as well as reduce the need to change your bypass filter since they have a much finer element. However, the bypass filter should be changed at least annually just to make sure the paper element doesn't fall apart from old age.

Centrifuges

If you have enough oil flow and pressure, a centrifuge is the ultimate oil-cleaning system. Centrifuges will remove contaminants down to 1 micron in size. But to do this they usually require an oil flow of around 10 gallons (38 liters) per minute.

Preluber

Mechanics claim that most wear on a diesel occurs in the first few seconds after starting, before oil has had a chance to circulate through the block. A simple solution to this is the Preluber. This is a high-pressure oil pump that runs for a couple of minutes before the engine is started, forcing the lube oil throughout the engine.

Equally important, it runs when after the engine is shut down, circulating the oil and allowing it to gradually cool down. This minimizes "coking" (the creation of sludge from oil throughout the block). The Preluber also acts as an oil-change pump.

Oil-Changing Systems

Having just lectured you (and reminded myself) about the importance of clean oil, I must admit that of all the chores on a boat, the absolute worst is changing the engine oil. I used to do this with a portable pump attached to my drill motor. It made such an awful mess that our interval between changes was much longer than it should have been. As I learned the importance of frequent changes, I decided to plumb in a permanent oil-changing pump to make life easier.

Groco makes a good pump, or you can use Preluber. I open a valve, put the exhaust hose into a jerry can, and turn on the switch. Note — it's very helpful to heat up the engine before changing the oil. Hot oil pumps more easily.

AIR SUPPLY

If the engine and/or generator are in an enclosed engine room, a sufficient supply of air must be provided. Otherwise, the machinery will smoke, lose power, and run hot. The problem is not so much in allowing air in, as it is in keeping out water and reducing noise transmission through the air ducts.

If the interior of the air duct is lined with sound-absorbing foam, noise transmission will be reduced substantially. Another approach is to use a series of baffles, either in the air duct itself or in the dorade vent on deck, to prevent sound from escaping.

The air intake should be placed in such a way as to minimize water incursion during a knockdown or rollover. This can be helped by running the duct deep into the bilge and to the opposite side of the centerline from the intake. On most modern designs, if the end of the duct is positioned properly, it will always be above the waterline, regardless of heel angle.

Air Cleaners

If the air cleaner isn't kept clean, the engine will be starved for air and won't run properly. Without a good filter, all sorts of dirt and abrasives will end up inside the engine. Furthermore, a good air cleaner can substantially reduce engine noise, since about a third of all engine noise comes out of the air-intake pipe. When there's room, we like to mount an air silencer in lieu of a conventional air cleaner. These units have substantially more capacity than regular air filters and are designed to reduce engine noise at the same time. Solberg and Donaldson are two of the largest makers of air silencers, with a range of sizes and shapes available. For offshore work, consider a washable filter instead of a paper cartridge. This saves a substantial amount of bulk storage space!

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CRANKCASE PRESSURE

During the combustion cycle in the cylinder, huge forces are built up as the fuel explodes. The piston rings and valves are supposed to seal all of this pressure, which is relieved by forcing the piston down, which turns the crankshaft. However, a small amount of pressure always escapes past the piston rings and finds its way into the crankcase. This causes positive pressure in the crankcase, which is vented to the outside, usually via a crankcase vent.

Two issues are raised here. One, with an open crankcase vent, as the engine cools, moist air is drawn in, and as we've already discussed, the moisture eventually condenses inside the engine, forming harmful acids. Second, the vented gases, called blow-by, are laden with oil from the crankcase, and eventually create a fine mist of oil all over the engine compartment.

Many modern engines have a hose running from the crankcase vent to the air intake of the engine. This is partially effective in reducing the blow-by.

Racor Crank Vent

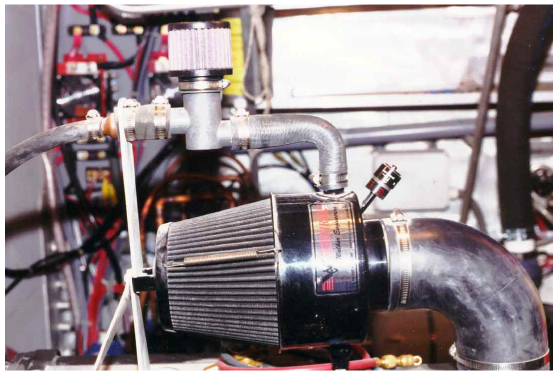
Racor produces a device called the Crank Vent. This is connected to the crankcase, and acts as a conduit for the blow-by pressure to release itself. Inside the crank vent is an oil trap. This precipitates oil out of the blow-by, which is returned to the engine oil sump. The exhaust from the Racor unit is plumbed back to the air intake of the engine.

Walker Air Sep

Once your engine reaches a certain size, approximately 140 horsepower, it is possible to use a Walker Air Sep unit.

This works somewhat like the crank vent, but on a more sophisticated basis. Crankcase pressure is taken across a low-pressure grid, and oil is precipitated out. The low pressure is formed by the flow of engine intake air over a special filter.

The Walker Air Sep has proven itself to be extremely valuable in reducing engine wear, cleaning up engine rooms, and reducing noise. We've fitted these to a number of our larger yachts with excellent results.

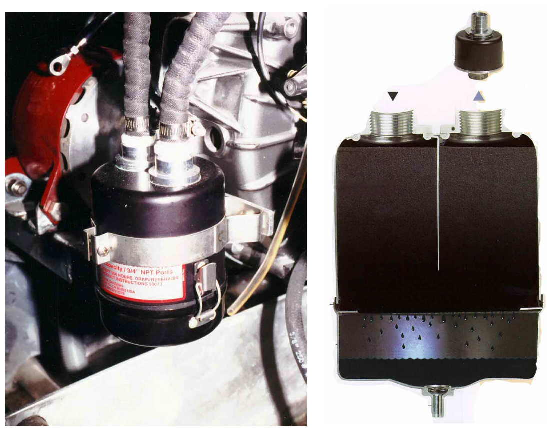


We tried out a Walker Air Sep on *Beowulf*'s turbocharged 170-horsepower Yanmar. The results were remarkable — almost no oil anywhere in the engine room.

ENGINE ROOM BLOWERS

While the engine or generator is running, it's constantly pulling the air from the engine room and replacing it with cooler outside air. But when the diesel stops, it radiates heat from its block and there's no exchange of air. If an exhaust vent is added, with a squirrel-cage blower, the hot air can be removed. Another approach is to put the blower into the incoming duct, reversing its direction depending upon whether incoming or exhaust air is required.

Squirrel-cage fans are extremely noisy and require careful installation. Because of this, and the fact that our own engine rooms have always been sealed from the living area, we haven't used exhaust fans.



A Racor Crank Vent mounted on a 50-horsepower Yanmar diesel (left). The drawing (right) shows the foam-like media used to precipitate oil out of the crankcase emissions.

Where tight bends are required on the exhaust line, fiberglass elbows can be used. Double hose clamps, of the highest quality, should be used on all exhaust connections — *not* as shown here!

Long exhaust pipes help keep the transom clean from smoke and water staining. However, you do have to take into account the presence of a dinghy aft. A flapper valve over the end of these pipes would make them less susceptible to following seas.

EXHAUSTS

The engine exhaust system has to do several important things. Foremost is to keep following seas from flooding the exhaust line and, hence, the engine.

If you have a deep hull and your engine is mounted low, this can be a serious problem, especially if the design of your vessel doesn't lend itself to surfing — because larger seas will give your transom a good pop now and then.

To protect the engine, you need a loop in the exhaust to the highest point possible in the boat. Before this loop you'll need a valve to shut off during heavy sea conditions, unless you have a modern, high freeboard boat that surfs easily, in which case a valve may not be required.

Adding a flap to the exhaust pipe where it exits the transom will help reduce the tendency of waves to find their way into the engine.

Excessive exhaust-line back pressure will reduce the horsepower of your engine and reduce the engine's life. Turbocharged engines are especially subject to back-pressure problems.

Any restriction in the exhaust line creates back pressure, as does the length of the exhaust itself. Each radius, muffler, and Aqua Lift also contribute. Excessive back pressure can be reduced or eliminated by going up in size on the exhaust hose.

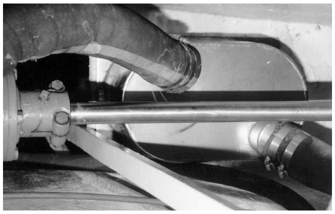
Aqua Lift

Since most diesels today inject water into the exhaust at the end of the engine's exhaust manifold (the water cools and quiets the exhaust gases), there will undoubtedly be an Aqua Lift in the system. The Aqua Lift is a tank that traps the engine exhaust water and then uses exhaust gas to force the water out through the exhaust line. (If the Aqua Lift is large enough, it will also collect small amounts of seawater, which might otherwise run back into the engine if a following sea catches you with your valve open. An oversized Aqua Lift, if there's room, is therefore a good idea.)

The exhaust gases are cool enough so that rubber, fiberglass, or PVC pipe can be used between the Aqua Lift and through-hull fitting.

If it can be squeezed in, I also like to fit a muffler to help quiet the engine down even more.

If the engine is located below the waterline, you will want to bring the exhaust water pipe up above the waterline in a loop, with a siphon break at the top of the loop. This loop should be at least a foot (300 mm) above the waterline. More is even better.



Aqua Lifts come in all shapes and sizes. And, if you cannot find the right configuration of inlet/outlet plumbing, they are easy to modify (left). Finding space for mounting down low is sometimes difficult. The middle photo shows an Aqua Lift installed below a prop shaft.

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Jacketed Exhaust

Some older boats, like *Intermezzo*, will have a jacketed exhaust. Here a flexible stainless connector between a steel pipe and the engine transfers the exhaust gases. The steel exhaust pipe is kept cool by pumping the engine's salt water around it. The problem with these systems is that salt and minerals gradually build up in the jacket, blocking the water flow. As a result, they haven't been used in many years. If you have an older yacht and it has a jacketed exhaust of any length, beware.

Hull Side Exhausts

With midships engine installations there's a tendency to exhaust out the side of the hull. This should be avoided if possible. The problem is in keeping the topsides clean. No matter what, there will be a long black smudge down the side after every passage.

Transom exhausts are much better. However, take extreme care with the exhaust line — keep it insulated from the surrounding hull and furniture to reduce noise transmission.

Mufflers

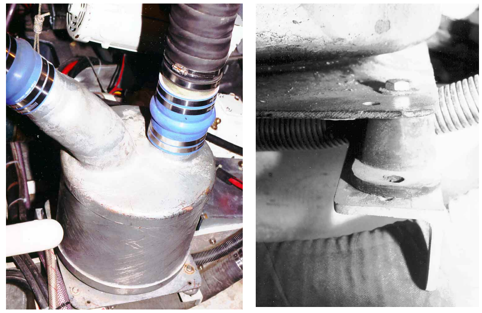
With naturally aspirated engines, which are not as bothered by back pressure as turbocharged diesels are, it is possible to fit a muffler in line after the Aqua Lift. This reduces exhaust rumble. Make sure that the muffler is not mounted — that vibration from the muffler cannot get into the hull.

Vibration

We've already mentioned exhaust vibration several times. Any vibration in the engine eventually finds its way into the exhaust system. To avoid imparting this annoyance into the hull, be sure that all exhaust elements, including the hose, are soft-mounted. If elements of the exhaust system lay on the hull, putting a layer of moderate-density foam beneath the items in question will sometimes do wonders for your noise and vibration problems.

Exhaust Hose

Exhaust hose, to last, must be of high quality. In many cases it is cost-efficient to use fiberglass pipe between sections of hose. Fiberglass is lighter than hose, lasts indefinitely, and allows you to see exhaust water flowing.

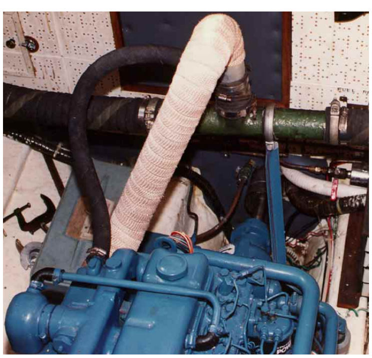


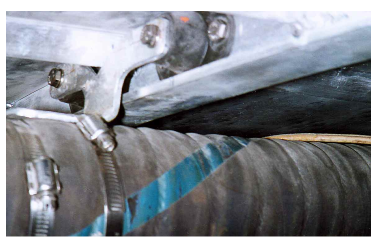
A substantial amount of noise and vibration can be transmitted from the engine to the Aqua Lift, and thus to the hull. To reduce transmission, we frequently use silicone rubber bellows (upper left) made by Trident Rubber. Mounting the Aqua Lift on soft rubber feet, such as the CalDyne mounts (upper right) provides effective isolation.

Most wet exhausts have an injection elbow just aft of the exhaust manifold (above). The salt-water cooling flow is pumped into the exhaust system at this point and carried away from the engine by the exhaust gases.

If you are cranking the engine without starting it (as in the bleeding process), turn off the incoming water so it can't run back into the exhaust manifold.

When a topside exhaust is underwater it creates back pressure and can be quite annoying if running in and out of waves. One way around this is to have exhausts to both sides, as shown here (right).





On *Beowulf* we used soft CalDyne mounts to attach exhaust hose to the hull (above).

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Halon-type extinguishers are typically mounted high, above the engine, with the fire-sensing device and nozzle pointed down.

At the bottom left of this photo you can see the wiring, which sends a signal should the fire extinguisher trigger. This signal is used to energize the engine stop solenoid, providing an automatic engine shutdown.

Intermezzo's engine was located under the floorboards in the keel sump, so the volume of the engine compartment was quite small. We used this portable halon extinguisher, which could be easily removed and used elsewhere should the need arise. However, this unit only worked with manual activation.

FIRE CONTROL

The only risk that really concerns me aboard is an engine-room fire. While it happens rarely, all the ingredients are there — heat, combustible materials, and the possibility of shorted electrical wiring, probably the number-one cause of engine room fires.

If a fire does start, a good fire-control system will be necessary. It's best to have an automatically discharging extinguisher with manual override.

Carbon Dioxide

There are several choices for materials. Originally, everyone used carbon dioxide. This has a smothering effect, denying oxygen to the engine as well as the flames. Unfortunately, carbon dioxide extinguishers are heavy and very large. However, they can be filled just about anywhere in the world and are extremely effective. If you have a small, contained engine compartment, carbon dioxide makes sense.

Halon

For many years halon has been the most popular material. It's an effective firefighting agent but will not shut the engine down. Instead, the engine will continue to run, ingesting the halon and eventually emptying the engine room of it — thus reducing or eliminating firefighting capability. As a result, the engine must be shut down whenever the extinguisher goes off. There are a number of automatic systems on the market that will engage the fuel-shutoff solenoid upon receipt of an alarm signal from the extinguisher.

A halon bottle takes less space and is lighter than carbon dioxide. The only problem is that it contains chlorofluorocarbons, which are now banned due to the hazard they pose to the ozone layer.

Several substitutes now on the market. These are less effective, so they take a larger bottle, and may not be refillable outside the United States.

Manual Engine Shut-Down

There are a number of good reasons for having a manual engine shutdown. First, it is usually necessary in the event of an engine-space fire. Second, in the event of a failure in the electrical solenoid (a not-infrequent occurrence), it provides a second means of shutting down the engine. Most engines are stopped by pulling a fuel lever mounted on the injection pump. Others simply have a butterfly valve in the air intake to shut off incoming air.

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ALARM SYSTEMS

One of the easiest ways to protect yourself, your machinery, and your boat against problems is with good alarms. Many reliable, inexpensive and easy-to-install systems are now available that will give you advance warning of engine trouble, fire, bilge level, battery condition, and other potential disasters.

Basic Engine Alarms

Let's start with a look at monitoring the engine. A low-oil-pressure alarm gives advance warning of impending trouble. Several types are available. The most commonly used are normally closed, or NC-type switches. Their contacts are closed if oil pressure drops below a set level, setting off an alarm bell and/or a light wired into the switch circuit. These are available in a number of settings, ranging from 3 to 20 pounds pressure. The 5-pound switches are most common, although some prefer higher setting for more advance warning.

Actual installation is quite simple. The sending units come with an 1/8-inch pipe thread stub, and most engines have a plug threaded into the pressure side of the oil system to accept this.

Monitoring the temperature of your engine is obviously important. A locked intake strainer or faulty impeller can reduce water flow to the point where the engine may overheat and seize. Engine temperature gauges have normally open (NO) contacts. When the temperature reaches the preset mark, usually between 190 degrees and 220 degrees Fahrenheit, the switch closes, sending an alarm. The sensing device can be installed into the freshwater side of the block at the hottest part of the head, or attached directly to the outside of the block. Sensors that read water temperature are quicker in signaling a problem.

While we're monitoring the engine room, consider a coolant-level indicator. This is a sensing device placed in the header tank to signal when engine water is low. There are pressure-differential meters that will tell you electrically when fuel filters need changing, and water-flow indicators that can be placed directly into the seawater feed to the engine's heat exchanger. There are also inexpensive monitors for water in the fuel filters and fuel-filter back pressure.

Alarm Sounds

The actual signal that will indicate a problem requires careful evaluation. I like to have three types of alarm sounds rather than a single, common one. If oil pressure is lost you have a few moments before the engine seizes. An overheated engine, on the other hand, can run for some time at reduced load without damage. Frequently, a diesel that has seized from overheating can be restarted once it has cooled down. A loud bell for oil, moderate horn for heat, and soft bell for other alarms will allow you to decipher what's wrong and decide whether to proceed or shut down.

Automatic Engine Shut-Down

If you have an electrically operated fuel solenoid on the engine, consider wiring it into your monitoring devices. That way if the engine is being used as a generator or if you're powering offshore, when a fault triggers an alarm, it will also shut down the engine. Be sure, however, to have a cutout switch to let you disable the shutdown system when maneuvering in tight quarters. If this last idea appeals but you have a manual cutoff, there are a number of fuel solenoids on the market that will, upon receipt of a signal, interrupt fuel flow and stall the engine.

The importance of this last feature was brought home to us some years ago in the Tuamotian atolls of the South Pacific. We were in the difficult process of exiting the lagoon of Takaroa, heading for the copra wharf of the village. *Intermezzo* needed all the maneuverability she could get from her engine as we battled a 35-knot wind with strong opposing current in the narrow confines of the pass. The engine heat alarm went off a quarter mile from the wharf. Without time or room to anchor we had no choice but to try to gain the security of the dock under engine. By reducing power and turning on the fresh hot-water system (which acted as a heat exchanger) we were able to get close enough to the wharf to throw a line. Our Polynesian friends lining the wharf had us secured quickly. Without the warning and the time it gave us to take temporary corrective action, we would have lost the engine and suffered serious damage against the coral walls of the pass. As it was, the engine was mildly seized, and two hours later, after cooling down, it started right up — to our everlasting joy and amazement.

"Murphy" Gauges

If you put a lot of hours on your machinery, or have generators that run without careful monitoring, you may want to consider "Murphy" gauges. These are analog meters that indicate the condition of your machinery while at the same time performing an alarm function. Their big advantage is that the alarm levels can be preset by the operator. If your engine normally runs at 65 pounds oil pressure, you can set the alarm at 55. This way you have early warning of any deviation from the norm. If your engine begins to get low on lube oil, the pressure will drop, maybe not far enough to trigger conventional alarms — but with these gauges you know right away something is up.

Multiple Alarm Signals

If you add up all the potential alarms for engine, generator, bilges, explosion, fire, performance instruments, and other electronics, it becomes quite an earful. All sorts of beeps, whistles, and bells fill the air on many modern yachts. Not only can this be annoying, but in emergency situations it may be difficult to tell which function is begging for attention.

One approach to dealing with this situation is to tie all the alarms into a single panel. Have one sound and a series of warning lights. When you're alerted by the buzzer, a quick glance at the panel tells you the nature and urgency of the alarm. The various lights can be color-coded for faster identification (red for urgent action, yellow for attention required soon, green just to let you know something is happening).

Tying one or more alarms to a single sound requires the use of diodes. These are small, inexpensive electronic devices that work like plumbing check valves — they only allow the electricity to flow in one direction. A diode is required on each signal function output wire. They're easy to solder in.

You may also want to have a switch in the circuit after each signal light to turn off the buzzer while you deal with the problem. If you switch off only the single function and something else goes off, the buzzer will sound again.

Intrusion Alarms

Most good cruising grounds are quite secure, especially in rural areas, and theft is rarely a problem. Still, you will probably venture to the big city from time to time. Here you may want some form of alarm system.

The question arises as to what level of alarm you feel is prudent. I am not as concerned with the sophisticated burglar as I am with the amateur. A professional will be able to defeat almost any electronic system and will have little difficulty gaining entrance to the boat.

It is usually quite simple to fit "reed" switches to the companionway and other deck hatches. The reed switch is a simple, sealed magnetic switch that closes when the paired magnet, holding the switch open, is moved. If someone slides your companionway hatch open, a signal is sent to the central control. When we install sliding screens on yachts, we typically fit reed switches to the screens.

You may also want to have a pressure-sensitive floor mat in the cockpit.

Proximity alarms are occasionally tried on larger yachts, but they always seem to have a problem with movement of sails and rigging, creating a lot of false alarms.

Once you have the signal, you then have a bunch of choices of what to do with it. The alarm control can be as simple as a relay triggered by the reed switch (or floor mat), which turns on a siren, horn, flashing spreader lights, or a masthead strobe.

Or the signal could be connected to any number of microprocessor-controlled systems. These can get quite sophisticated, with some able to dial an alarm-monitoring service or your home number.

Consider two wiring issues. First, many systems suggest reed switches be wired in series, like Christmas-tree lights. In this case, with a wire break or a bad reed switch, if you don't fix the problem, the entire system will be out of order. If the reed switches are wired in parallel, where each circuit has its own pair of wires, then you can disconnect a bad reed switch shorting the wires. This keeps everything else operating.

Next, you may want to consider a panic button like those frequently found in homes. Panic buttons, nothing more than normally closed switches, are easy to mount as required.

Finally, you will probably want to have the security system circuit run through your main control panel, with a circuit breaker to both protect the power supply and serve as an on/off switch. It's probably a good idea to label this something other than "burglar alarm," in case you encounter a persistent thief.

Flame Sensors

If a fire occurs on board, you only have a short period of time to get it extinguished. Once it begins to spread, the smoke will drive you out of the interior quickly, whereupon the interior, stores, and hull materials will provide plenty of combustion material.

Smoke detectors don't seem to work well on boats, as they are easily set off by cooking or the odd bit of warm oil vaporized by the engine or genset.

An automatic fire-extinguishing system for the engine won't trigger until the unit feels its trigger temperature. By this time the fire may be well established.

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It is far better to see the flame as soon as it starts. Fireboy and several other companies now sell an electronic eye which can see a tiny flame at some distance. For an engine compartment or engine room, this could allow valuable extra time to deal with the problem before it gets out of control.

Fire Control Circuits

If you use any form of halon or other inert-gas fire-quenching system, you will need to shut down diesel engines and exhaust fans as the fire-control chemical is released. Otherwise, the engine, generator, or diesel heater will simply ingest the fire supressant through its air intake and spit it out with the exhaust.

Fireboy makes a relay-control box that automatically shuts down devices to which it is attached, once it receives a signal from the fire extinguisher that it has started to discharge.

The wiring is quite simple. Run a pair of wires out from the relay box to the fire extinguisher for the alarm signal. Then, tap into the stop switch for each diesel. When triggered, a power pulse goes to the electric-stop solenoid on the diesels, shutting them down. For a diesel heater it is easiest to run the thermostat control through the normally closed relay on the control box. This will open with an alarm, allowing the heater to go through a cool-down cycle, but shutting down the boiler right away.

Carbon-Monoxide Alarms

Years ago, before we were married, Linda and I took a trip to Mexico with some friends aboard my Dad's catamaran, the *HuKaMakani*. We were tied up to the guest dock at the San Diego Yacht Club prior to departing for Ensenada on a cold winter evening.

The plan was to eat ashore, then turn in early for a before-sunrise departure. Five of us were seated in the main saloon. A lovely kerosene-powered Aladdin lamp provided heat and light. As we sat in the soft glow of the light, everyone became sleepy. We all began to doze off. A couple of minutes later a powerboat wake shoved us up against the dock, and I groggily got up to check the fenders. When I stepped outside, the night air smelled so sweet and I felt so strange. And then I realized what was happening. I rushed back into the main saloon, opened all the windows, and began to shake my friends. One by one, everyone came around. They hadn't dozed off for more than a couple of minutes. If that powerboat wash hadn't awakened me, we would have been on the front page of the *San Diego Tribune* the next morning, as another carbon-monoxide-poison statistic.

Today you can pick up sophisticated or simple carbon-monoxide alarms at marine stores or at your local hardware store. If you have any sort of open heat in the boat, or use your stove with sources of ventilation shut down, the carbon-monoxide alarm could save your life.

Bilge Alarms

Most boats today have at least one electric bilge pump, usually controlled automatically. If the pump is mounted out of the living area, or the engine is running, you may not hear it when it cycles. Since a cycling pump normally indicates a leak, it's a good idea to have some form of signal for the pump.

This can be audible, or a light, or both. The wiring is simple. Connect a wire to the pump device where it gets its current from the float switch. This wire is led back to the control panel and a signal light or soft bell.

If using a relay or solenoid to control the pump (activated by the float switch), pick up your alarm signal from the float switch trigger current — that is, the current used to turn on the solenoid or relay. This way if the solenoid or relay fails, you still have an indication that the float switch has been triggered.

Hooking a similar system into the freshwater pump lets you know when it's running.

As a backup, mount a float switch in the sump, and wire to a buzzer and/or light to indicate rising bilge water. If you have a modern, flat-bilged yacht, you may need port and starboard monitors.

Gas Sensors

Explosive-atmosphere sensors have become popular in recent years. These devices, with a sensing head mounted in the lowest part of the bilge, detect accumulations of gasoline or propane fumes. They also usually give warning of high water, although frequently ruining the sensing head. Check the sensitivity of the sending unit periodically with a propane lighter — and always rely on your own sense of smell as a backup.

The sensing heads seem to have a short lifespan and don't like to get oily from oily bilge water. Carry a spare or two.

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Overvoltage Alarm

Finally, if you have a high-output DC charging system, you may consider some form of overvoltage alarm to warn you if the alternator regulator shorts and goes to full field. While stand-alone alarms are available, many makes of sailing instruments have high/low voltage alarms built into them.

ENGINE INSTRUMENTS

Most of us are used to "idiot lights" in our cars to warn us when something is amiss. On a boat, you want to be able to monitor engine and generator vital signs continuously.

Engine-oil-pressure and water temperature are the two most basic instruments. Next would be a transmission oil pressure gauge.

A pyrometer mounted in the exhaust manifold is the best way of telling engine load. These are essential if you use a variable pitch prop.

While it's obvious that the watch should be able to monitor these gauges, I also like to have engine oil pressure and temperature instruments located where they're easy to see below.

TWIN ENGINES

There's something to be said for a dual-engine installation — and a lot of negatives, too.

On the plus side, is a built-in redundancy and the ability to use smaller diesels, resulting in better loading of the single engine when powering most of the time. The smaller engines also do better when used as a generator set. You also get a certain amount of increased maneuverability, although in a sailboat the props are so close together that the small advantage of their separation is largely offset by the lack of prop wash directly over the rudder.

The biggest drawback is lack of protection for the prop and running gear. A centerline wheel is protected by the keel. Once you are off-center, the prop has to contend with all manner of flotsam and jetsam. Nets and lobsterpot buoys are particularly troublesome. Then there is the problem of dual sets of running gear, as well as the added complexity and costs of the equipment and installation.

We considered a dual engine installation briefly on *Intermezzo II*, but abandoned the idea when I realized how little there was to be gained in our style of usage. The theoretical advantage of the second engine just didn't add up against our experience with reliable single-screw installations. And, after all, we were not totally at the mercy of the engine — we did have a sailboat.

But on a powerboat, the issue of a get-home system is more acute. With a single-screw setup, propulsion loss is much more threatening. Twin engines or some form of backup system could be a better trade-off.

If you opt for twin engines, be realistic about projected performance. It is rare that a displacement hull will gain more than 8 or 10 percent in cruising speed with the second engine turning over at full power.

GET-HOME SYSTEMS

There's a certain amount of emotional (as well as practical) benefit to knowing that regardless of what happens, you'll be able to make it home under your own power, if need be. The question of how to accomplish this, with a minimal complexity, takes some thought.

The first question is, at what speed and under what conditions can you expect the backup power to perform? The less horsepower required to do the job, the easier the solution will be.

The most popular strategy is to drive the main prop shaft via the auxiliary generator. This can be done mechanically with belts or with hydraulics. If you already have hydraulic capability, this is the easiest answer.

Another approach, which is very easy to execute and makes a lot of sense, is to fit a transmission to the generator and power a second prop. We first saw this on a motor yacht in Capetown, South Africa. The owner had taken a Perkins 4-108 propulsion engine and installed it alongside his main Gardner diesel. A feathering prop was fitted to the backup shaft to reduce drag. The AC generator was mounted off the front end of the Perkins. For about half the cost of a hydraulic system he had a very efficient get-home system. The little Perkins produced 4 knots of speed as compared to his usual nine.

A better bet for the sailor is the dinghy outboard. With the dink tied alongside (using long, flat-leading bow and stern lines), a small outboard can do wonders in port. The 4-horsepower engine we had on *Intermezzo* would move us at 2 to 3 knots in smooth water. Elyse would sit in the dink operating the engine, while Sarah or Linda would relay my commands via hand signals.

The Schmidts went one step farther with *Wakaroa*. They made a mount on the transom for their 20-horsepower Mercury outboard. That engine would easily move the 69-foot *Wakaroa* at 5 knots.

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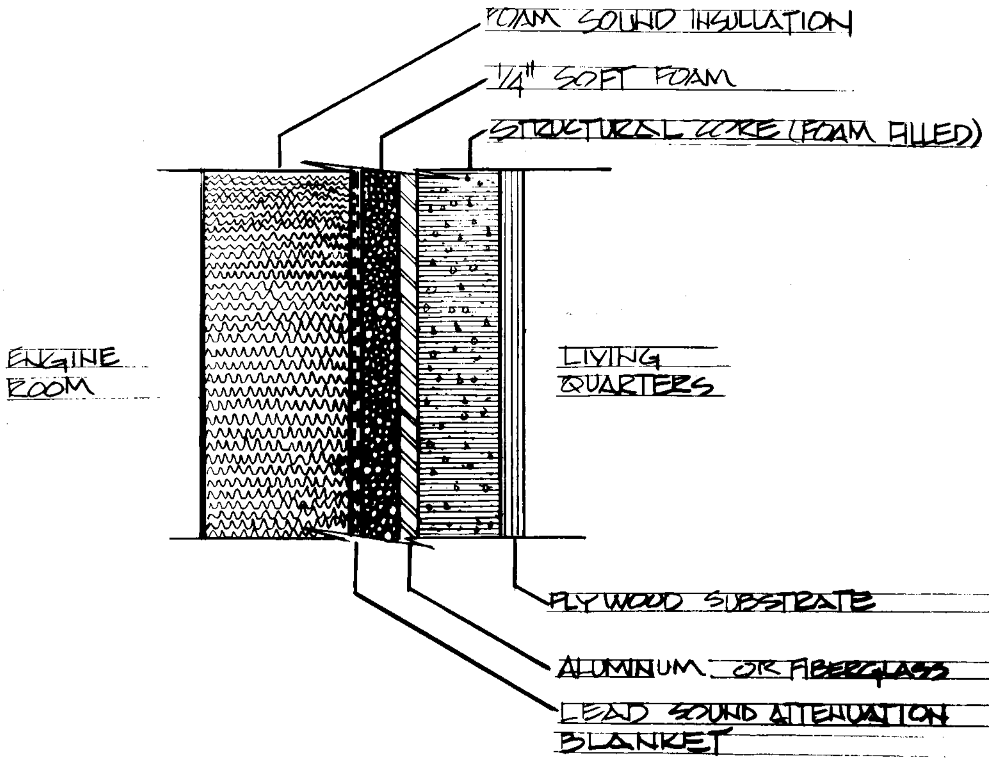
Numerous types of sound insulation are available. This one is covered with a mylar barrier, which keeps the foam sealed from engine-room liquids and is easy to clean.

SOUND INSULATION

Machinery noise is like water — it'll squirt through any opening between the engine space and interior. It will also set the hull and bulkheads to resonating on difference frequencies, transferring the noise to the interior in the process.

How do you mitigate the process? First, seal every potential outlet. Be sure that bulkheads are tight to the hull, and that hoses and wires go through sealed glands. If the engine is installed under the floorboards, or in an engine box under the companionway, use the stringers as part of the containment system and work up and around from there. It may not be possible to get 100-percent containment, but the closer you get, the lower will be the noise level inside the boat.

Next is the use of sound insulation materials. Today these take the form of a soft, open-cell foam (usually PVC or neoprene), which absorbs the sound and prevents it from bouncing off all the hard surfaces surrounding the machinery area.



When the time comes to insulate your engine space, the more room you allow for a barrier, and the denser the barrier is, the better will be the sound attenuation. For a modern fiberglass yacht, this illustration shows close to the optimum situation.

On one side you have a structural bulkhead — hopefully cored, which helps reduce noise transmission. On the machinery side there is a sound-absorbing foam, a lead or barium liner, and finally a "decoupling" layer of foam.

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This foam is frequently sandwiched around a thin sheet of lead or barium powder in a plastic matrix. This high-density material acts as a barrier to prevent the sound from penetrating the softer foam.

There are literally hundreds of types of materials and combinations available. The best for marine use are self-extinguishing in the presence of a fire, resistant to attack by oil, and have some form of protective cover on the surface of the foam. This protective barrier can be Mylar, or a vinyl fabric, or sometimes even perforated aluminum sheet. The protective barrier reduces the effectiveness somewhat, but is essential for keeping the insulation clean.

The thicker the foam and the heavier the barrier, the more effective the insulation. Most commercial grades are 1-inch (25mm) thick and weigh about 1/2 pound per square foot (3 kg/square meter) of barrier.

While we hate to give up unnecessary space and weight, over the years we've come to use 2-inch-thick (50mm) foam and 1-pound-per-square-foot barriers. It just does a much better job, and noise reduction is an important part of happiness aboard.

Since these foams are open-cell, they'll absorb moisture, at which point their effectiveness drops dramatically. So they can't be run into the bilge. However, there are other nonabsorbent materials that can get wet and even be walked on. These do well in the bilge area, especially in modern boats with flat hull shapes, which tend to radiate sound more.

If a complete job of sound insulation looks to be a major project, or not in keeping with your plans for occasional use, consider just doing the engine box or floorboards over the engine. Putting 1-inch foam/lead insulation directly over the engine reduces interior noise levels by close to 50 percent.

Sound Isolation

In order to keep the engine and engine room accessories as quiet as possible, isolate them from any surface that can transmit or resonate noise.

There are two approaches to this. First, avoid mounting noisy equipment on plywood bulkheads. If possible, mount it directly to the hull or topsides. If a bulkhead must be used, try to pick one that doesn't face an actively used living area.

Second, use the softest mounts available between the gear and the mounting surface. With the engine, as we have already discussed, there are strict limits on mount softness. However, from the generator on down there are some pretty squishy mounts available.

Some gear is annoying enough in its vibration to warrant a double set of isolation mounts. The first set is placed between the equipment and a base plate. A second set is then used between base plate and mounting point.

There's one other aspect to this question — that of gear you *do* want to hear running. The freshwater pump and bilge pumps, for example, should always be audible, although they don't have to drive you out of the boat.

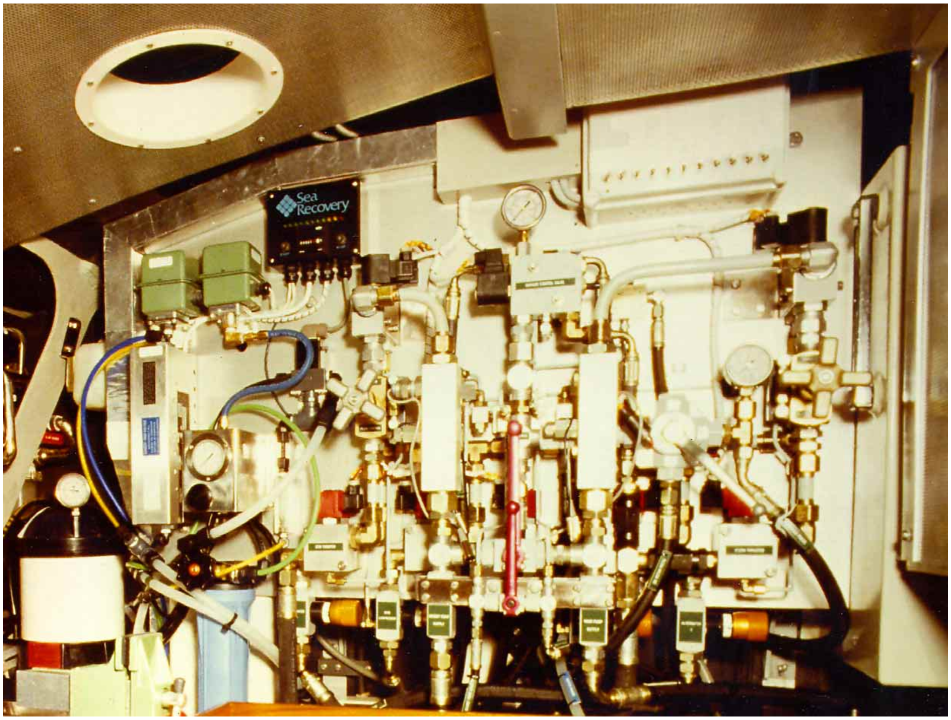
HYDRAULICS

Hydraulic systems work by the engine turning a pump, which then delivers fluid at high pressure to a motor, which turns the accessory in question. No electricity is involved, and in theory the system is pretty reliable. Just run your outgoing and return oil lines, tighten the fittings, bleed some air, and off you go.

In single applications, where the usage is relatively simple and straightforward, using a hydraulic drive can make sense. However, complex installations, where you are trying to do a lot of different things at once, tend to be heavy, expensive, unreliable, and generally difficult to live with.

Negatives

The first time I saw a marine hydraulic system, I thought, "Wow, this is the answer." However, now that I've put systems into a number of boats (and torn them out, too!) I am more realistic about the trade-offs.



A hydraulics engineer's dream — or nightmare, depending on how you look at it!
This system, on one of our 75-foot (23m) yachts, was designed to provide for an AC cruise generator, a large DC alternator, a watermaker, bow- and stern-thruster, plus the windlass.
We, and the owner, would have been much better off with a nonhydraulic approach to all of the applications, except for the thrusters.

To begin with, hydraulics produce a high-pitched whine that is almost impossible to isolate. Whenever a pump is being turned, even if no load is on it, you have that noise level permeating the boat. By putting a clutch between the pump and drive source, you can turn the system off, but this is an added layer of complication. And when the hydraulic motor is engaged there won't be any question about its running.

In addition, hydraulics are heavy. Yes, the motors themselves are lighter than comparable-power electric motors, but the plumbing and connections weigh far more than an electrical system, and you generally end up with significant weight increases.

In spite of what everyone claims, hydraulic systems leak. On a big system, there will always be a leak somewhere — which means hydraulic fluid, usually under pressure, making one hell of a mess.

There's typically a 15 to 20 percent power loss in the hydraulic equation, compared to the power efficiency of electrics.

If I haven't dissuaded you so far, read on.

System Balance

We've been involved in all sorts of sophisticated hydraulic systems, where everything from bow thrusters to cruise generators, with lots of in-between gear, is combined on one circuit. In the end there always seems to be a balancing problem between the needs of the different devices.

Most industrial hydraulic systems have one, or at the most, two, motors hooked to a single pump. With a whole bunch, it becomes an experimental operation — even for the pros.

If several motors are running from one pump, the plumbing and relative loads must be balanced carefully. Otherwise, one device under load will mess up the flow to the next motor. If automatic balancing valves are used, it's difficult to figure out what to do in advance. Be prepared to do a lot of plumbing while you try new gear.

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Applications

What applications are good for hydraulics? First, I'd say single-element systems, where there's just no other means to do the job. Perhaps you want to install a large cruise generator or alternator on your main engine and there's no space — or you want to run a lay shaft, but away from the engine. Okay, but keep it simple.

Lots of folks like to think about a hydraulic anchor windlass. The rationale is that you don't have to worry about the electrics up where they'll get wet. Nonetheless, most electric windlasses today are pretty reliable, and I don't think going to hydraulics is worth the trouble, unless your ground tackle is so large that you have no choice.

Operating Pressure

If you intend to use a hydraulic system, here are some things to consider: The higher the operating pressure, the smaller the hoses, pumps, and motors — but the higher the cost and the greater the maintenance problems. The systems we've been involved with have typically been under 2,000 psi in operating pressures.

Miscellaneous Requirements

Make allowances for a large accumulator tank. Size will vary with the system, but it's not uncommon to end up with a 10-gallon (38-liter) reservoir. You'll need a heat exchanger to cool the fluid, and possibly a pump for the water flow. You have to decide upon fitting types — aircraft grade, stainless, or mild steel (which are functional but rust quickly). Hose types vary all over the place. You'll want to have high factors of safety because a leak will cause a disastrous mess. However, high-pressure hose is really heavy.

Constant Speed Systems

Certain systems, which adjust oil flow, try to maintain regulated motor rpm as the main engine and its attached pump vary speed. These have some degree of success where they're only running *one* motor.

Still intrigued? The next step is to talk with a professional hydraulics engineer *who has experience in the marine field doing the type of system you want to use*. Then get some names of people using this gear, preferably commercial fishermen. If the fish boats are using it, you can be sure it's reliable.

We ought to mention one other application: Driving the prop shaft. If the engine ends up in a location where it's difficult to attach the prop shaft, a hydraulic drive may make sense. You lose about twice as much efficiency as with a normal transmission (hydraulic transmission, that is), but a flatter shaft angle, bigger prop, better reduction, etc., can all help to offset this. My dad used a drive like this on *Deerfoot.* It has stood the test of time and some 30,000 sea miles.

THRUSTERS

More small cruising yachts, both power and sail, have been fitted with bow thrusters in recent years. There's no denying that a good system will aid in close maneuvering, but the costs in space, weight, engine-room complexity, additional holes in the hull — not to mention greenbacks — are substantial.

There seems to be some sort of emotional appeal to the thruster concept. As a result, they've occasionally ended up on boats I was building despite my better judgement. Still, this gave me some insight into their use, and some of the parameters to be considered in the decision-making process.

Judging Need

How do you judge need? First, look at cruising grounds, the close-in maneuverability of your vessel, crew size, and your alternatives. Even if the boat is somewhat of a pig in tight quarters, you can always anchor out until conditions improve. In most cases, this is a better alternative to the complexity and cost of a thruster. After all, if you only really need a thruster once or twice a year, the inconvenience of anchoring and rigging out the dink is easy to swallow. However, if you have an extremely difficult crosswind home slip to deal with, that's a different equation. The bigger the boat and smaller the crew, the more sense a thruster makes.

If you are thinking of far-off places, and worried about the unknown, fear not. With the exception of a few spots in the Mediterranean, plenty of space is available.

Thruster Power

Okay, if you're still interested, here are some things to look at. Number one is power. If a thruster doesn't have the power to push you off a dock, or to rotate a bow against 20 to 25 knots of wind, it's not worth the trouble of installing it. This takes lots of horsepower. For a 74-foot pilothouse cutter, like the Deerfoot 74 *Interlude*, this means 30 horsepower taken from the generator set via hydraulic pump.

Then you have to decide how to power the thruster. Electric motors are used on very small thrusters, but the current draw is so high that special alternators are required to keep the batteries topped up. Some electric systems have short allowable operating periods due to overheating problems. However, assume the thruster will be in use for five or ten minutes at a clip for it to be of value.

Hydraulics are more commonly used. However, this gets you into an expensive, heavy, and bulky subsystem. A 30- to 40-horsepower hydraulic drive will end up costing more than the thruster by the time it's installed.

The next consideration is control. Most thrusters are a simple on/off, port/starboard affair. This means in light-load conditions the power has to be pulsed on and off — a sometimes difficult chore. At the same time the thruster is being maneuvered, the skipper will be dealing with the shift/throttle control of the engine and the wheel. This can occasionally resemble a one-armed paperhanger in action, and is the reason many thrusters, once installed, rarely see use. And if the thruster is powered hydraulically, via a pump on the engine, then the engine rpm will have to be coordinated with thruster needs. And if you have to slow the engine down to shift, thruster power is lost. For this reason it's better to power the thruster from the generator, if at all possible.

Controls

The thruster controls should be laid out so they're handy to the helm and engine controls. The best systems I've seen are run by foot-actuated switches (like electric-winch control buttons), placed port and starboard by the wheel. These leave the skipper's hands free for the wheel and engine controls.

If the sophistication is taken one step farther, the thruster can have a speed control to vary side force. This enables you to use a more deft touch in maneuvering, but adds a layer of complication and potential trouble to the system.

Another factor to look at is the inefficiency caused by the thrusters' hull openings. There will be a very large water inlet and two smaller thruster holes, or a large hole on each side of the hull in a tunnel thruster. These openings cause drag. It's not uncommon for a ship to lose as much as 5 to 10 percent of normal cruising speed to thruster openings. Some tunnel thrusters are more efficient than others with smaller openings.

DOING WITHOUT AN ENGINE

Does an auxiliary sailboat really need an engine? The unequivocal answer is — it depends. If your style of cruising requires a schedule, or if you sail in areas with light, undependable winds, an engine is necessary. But as the horizon begins to beckon and timetables are left behind, the engine's relative importance slips.

On two occasions when we were cruising aboard *Intermezzo* we had transmission problems that left us without diesel power at the prop. In each case we went a month or more as just a sailboat. True, trips required more planning and more work on the part of skipper and crew, but the level of satisfaction from a well-made passage was never equalled when the engine was available.

Of course, doing without an engine means your vessel must be a handy sailer. Light-air performance and weatherliness are critical components.

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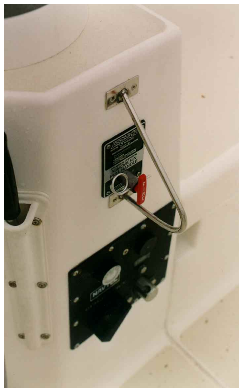
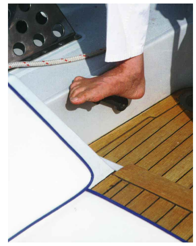
CONTROLS

The location of engine controls is always a trade-off between accessibility to your hands; foot operation (frequently necessary in tight docking); and keeping vulnerable control-handles free of sheet entanglements.

Controls are often mounted on the steering pedestal. This works fine as long as the wheel is not too large. But if the wheel is of such a size that you have to reach through it for the controls, look for a different system. In difficult maneuvering situations, where you are using short bursts of power and flipping the rudder back and forth, you need to be able to spin the wheel while adjusting the engine.





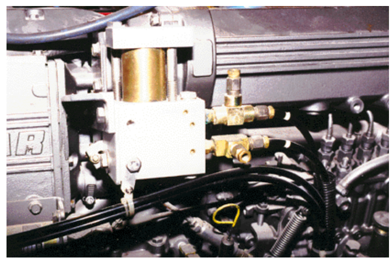
The ideal location for engine controls is where they can be operated by foot, leaving your hands free for the wheel.
Regardless of where they go, they need to be kept clear of sheets. If this looks like a problem, it may be possible to work in a guard (upper left photo).
It isn't unusual to find manual releases on fire control systems, engine shutdown, and auto pilots in the cockpit. These are typically controlled with Morse cables. They should be located where they will not foul sheets.

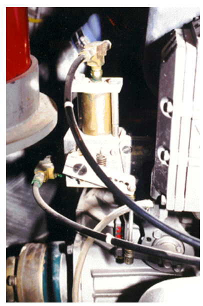
Control Systems

The single-lever engine control is by far the best choice. It puts shift and throttle in one unit and allows quicker maneuvering in tight spots. It also reduces shock load on the transmission, as engine rpm are automatically cut when going from one direction to the other.

The problem comes if you want to have single-lever control at two stations. Unless you go to a complicated and expensive control, you're forced to use separate shift and throttle linkages.

Hydraulic systems bear consideration if your controls are a long way from the engine room. These eliminate the hassle of running flexible Morse cables throughout the boat, and also eliminate noise transfer in the Morse-type cables. But hydraulic shifting systems, such as those made by Hynautics, are typically three to four times as expensive as mechanical shifters.





Hynautic hydraulic cylinders for controlling throttle and shift (above and left). These are very reliable, but costly to purchase and install.

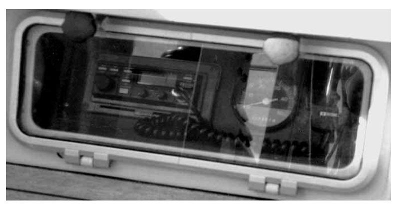
Instruments

Engine instruments should be located where they are handiest to the way you normally use the boat. If you usually steer in the cockpit with the engine on, the instruments should be easily visible from the helm.

The problem is that eye level is often quite far from the face of the cockpit well, where instruments tend to be located. There are two ways around this: One is to move the instruments some distance forward, to get some angle into the view. The other is to angle the instrument panel itself.

In most cruising situations, you don't steer with the engine on. You may be charging the batteries, or powering with the autopilot steering. When this is the case, the instruments are better located where they can be seen from under the dodger and without too much difficulty from down below.

For me, the ideal spot is at the forward end of the cockpit, facing aft, so that the larger gauges are visible from the helm.



Here are a couple of approaches (above and left) to protecting engine instruments from the elements. My preference is above, using an opening port to be sure of an absolute watertight seal.

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