HOME

2000-#3

DIY boat owner

the MARINE MAINTENANCE MAGAZINE

COLUMNS

SHOPTALK

WOODEN RAILS MADE EASY: Worn or damaged rubrails and toerails shout "neglect" and detract from your boat's value and appearance. Replacement isn't difficult if you follow these steps from a pro.

By Gary Grinnell

ELECTRONICS

WHAT YOU SHOULD KNOW ABOUT RADAR: Choosing a radar set with the correct output performance and features are just a few of the many details you'll need to consider when purchasing and installing a radar system. If radar is in your future, read on.

By Larry Douglas

SAILBOAT RIGGING

THREE RS OF RUDDER REPAIR: Wet, soggy rudder? If your boat is one of many with a hollow rudder, here's how to remove, rebuild and reassemble it before it fails.

By Martin Parker

DIY PROJECTS Mini-Tank Propane Holder; Silencing A Noisy Hatch; Mast Deck Support.

GOOD BOATKEEPING

HOLDING TOOLS: Is finding good storage places for tools driving you crazy? Here are three ways to separate, stow and conquer the tool box blues.

By David & Zora Aiken

DIY MECHANIC

OUTBOARD MAINTENANCE & TROUBLESHOOTING

With the right tools and a few basic skills, you can perform most outboard maintenance and troubleshooting jobs yourself. Here's how.

MAINTENANCE

A BOAT OWNER'S GUIDE TO PREVENTIVE MAINTENANCE

Are you interested in preventing breakdowns and saving money? This specialized maintenance program is designed to maximize the performance and reliability of your boat's engine and all onboard mechanical equipment.

By Robert Hess

FIBERGLASS CLINIC

REPAIRS YOU SHOULDN'T IGNORE

Despite the fact that fiberglass boats appear to last forever, poor construction and reckless use result in flexing of many hulls and decks. Find out why your boat is flexing, how to survey the damage, then effectively repair it to prevent recurrence.

THE GOOD, THE BAD, THE UGLY

Delamination can occur in a solid fiberglass laminate or cored hull, between the inner or outer glass skins, in bulkhead tabbing fastening interior structures, in deck cores and in rudders. If you own an older fiberglass boat or are looking to buy one, here's how to diagnose the condition and some methods to cure and prevent it.

By Nick Bailey

Departments

Q&A TalkBack: Hull Cracks Offer Failure Clues; Add Alignment to Annual Service; Orange Peeling on Gelcoat; Troubleshooting a Stalling Outboard; Leave the Cowhide Ashore; Easy Dual Battery Conversion; Reduced Engine Life at WOT; Leak Check a Gas Tank

DIY TECHNICAL HELPLINE

Tech Tips: A collection of boat-tested tips.

Talkback Q+A

Hull Cracks Offer Failure Clues

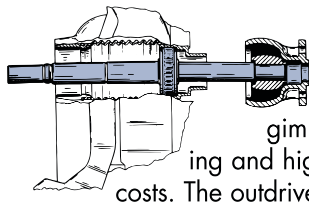
Q: Our boat's 7.4L engine mounts on a teak block integrated into the hull. Cracks in the hull are visible inside the engine compartment but not on the outside. Are these cracks of no concern or do they warrant attention?
Mary Ambrose, "Lunar Rose," Honey Harbour, Ont.

A: If your hull is a fiberglass composite, either a cored or solid laminate, cracks indicate movement that is flexing the laminate beyond its elastic limit (see "Fiberglass Clinic" on page 40). This is a bad sign. If the cracks are concentrated around the engine mounts, this could indicate that engine torque exceeds the mount's ability to restrain engine movement. This should be corrected before the engine rips itself right out of the boat. Cracks in the middle of a large flat laminate panel indicate panel flex. Since there is no indication on the outside of the hull, it's likely that the inner laminate is failing in tension. This may be only in the very last laminate, which is often a chopped strand mat rolled on for cosmetic purposes. Have a surveyor check your boat and determine whether cracks are superficial or there's widespread laminate failure.
— *Wayne Redditt*

Add Alignment to Annual Service

Q: In my owner's manual, it says to check engine alignment at the 20-hour service. What exactly are they referring to on this 3.0L engine?
Bob Forsyth, Lake Grapevine, Texas

A: The three components in a stern drive — engine, transom assembly and stern drive (or outdrive) — must be in alignment (perfectly parallel). If it isn't, you get engine knocking in corners and dramatically shortened life span of the engine coupler, driveshaft splines, U-joint and gimbal bearing and high repair costs. The outdrive is removed and an alignment tool (about $150) is inserted from outside the boat into the gimbal bearing then into the coupler and engine mounts adjusted as needed to maintain alignment. If you don't have the proper tool, skills or knowledge (you'll need a repair manual), take your boat to an authorized marine dealer. Alignment should be performed every 20 hours, the maximum recommendation, or annually. MerCruiser recommends doing this work during decommissioning so you'll beat the spring rush. Removal and replacement of the stern drive takes about 2.5 hours to do an efficient job.
— *Jan Mundy*


MERCURY MARINE

Orange Peeling on Gelcoat

Q: The gelcoat of my 1987 6.7m (22') Celebrity hull has a smooth finish but has a textured orange-peel appearance. There is still ample gelcoat, so compounding is not a problem, but is there another method of refurbishing the gelcoat more efficiently?
Jason Pitman, "Pile "o" Ship," Lake Simcoe, Ont.

A: A factory finish would not exhibit the orange-peel surface you describe. At some time the boat has been refinished, likely sprayed with gelcoat or paint, and sanding it smooth requires plenty of elbow grease. The easiest method involves using an air tool known as a D/A (double orbital or double action) sander with Stikit pads of 320 to 400 grit to smooth the surface. After removing the orange peel, wet sand with 500-, 600-, then 800-grit papers on a hand 1/4-sheet sander until the surface is uniformly smooth and glossy. Buff using a coarse (1,000-grit) compound, followed by a fine compound. Now wax the boat. You could also try some of the new 3M Stearated Stikit disks that go up to 800 grit on the D/A instead of hand sanding. Either way, it's a ton of work. Make sure the finish is gelcoat before you do any work. Paint will also orange peel if it's not thinned properly, or if it's applied with a roller. Buffing paint with fiberglass compound is usually a disaster.
— *Wayne Redditt*

Troubleshooting a Stalling Outboard

Q: I have a 1998 Mercury 225XL factory-installed on a 7.9m (26') Rennell. The engine runs perfectly for about 30 minutes then stalls and won't restart. The problem has been troubleshot by technicians but without results. The last time a technician supposedly fixed the engine we were stranded at sea for four hours.
Adal Medina, Yabucoa, Puerto Rico

A: Intermittent spark is normally a temperature-related failure, either electrical temperature of components or ambient temperature because the powerhead is too hot. To determine the cause, you need to first duplicate the failure at the dock. Securely tie the boat to the dock and start the engine and run in forward gear until it fails. At that point diagnose the engine system. Normal engine operating temperature is 48°C to 60°C (120°F to 140°F). An engine running at abnormally high temperatures, say 87°C (190°F), is not hot enough to activate the overheat audio alarm but hot enough to affect resistance of electronic components. If it's an OptiMax engine, it has self-diagnostic capabilities easily scanned by a dealer equipped with the proper electronic diagnostic

equipment. An engine with electronic (EFI) or direct fuel injection (DFI) also has self-diagnostic capabilities — circuit failures are recorded by the ECU "black box" and easily identified by a technician with the proper diagnostic equipment. It's possible that electrical connections could also produce an intermittent spark. With EFI or DFI, electrical continuity and cleanliness of all circuits and operation of the alternator are all critical parts of the system. A bad electrical connection, (i.e. corroded continuity to ground) causes voltage misreading and malfunctioning of the intelligent ignition system. Inadequate water cooling and overheating, caused by water pump or impeller weakening or failure, also affects spark. Check the water pump and impeller, and install a water-pressure gauge (refer to DIY 1996-#2 issue for step-by-step installation) that constantly monitors these components.
— Jan Mundy

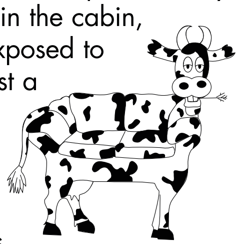
Leave the Cowhide Ashore

Q: We are considering installing two chairs in our main cabin and want your opinion on leather as a suitable covering. This area has lots of humidity and we don't want to encourage mold growth.
Sheila Lewis, Yarmouth, Nova Scotia

A: The concern with using leather for upholstery in a saltwater environment is not moisture but salt. On those hot, humid-free days when everything dries out, the salt

Q+A

crystallizes and when sat upon easily cuts the fabric. There are some very durable, near-leather vinyl fabrics available. Mobern makes a fabric called Alante, an expanded vinyl that when used in the cabin, where it's not exposed to UV light, can last a lifetime. Not cheap, though it's much less costly, as much as five-times less, than leather. LeatherTouch makes Ultra-Soft Touch, Bonanza and various other leather look-alikes. These are easy to clean and easy to maintain.



ALISON HOOD

— *Jan Mundy*

Easy Dual Battery Conversion

Q: I would like to convert from a single battery 12-volt system connected to a master switch to a dual battery system. How do I wire such a system?
Andy Potter, Odessa, Ont.

A: Assuming that you have a "1-2-Both-Off" switch, conversion is easy. Wire the positive terminal of the existing battery bank onto the contact for position "1" on the switch. Wire the positive terminal from the new battery bank to position "2" on the switch. Take all your charging sources and loads from the common terminal on the switch, and they will be directed to whichever battery bank you select (1, 2 or Both). The disadvantage of this system is that you have to constantly choose where the charging current goes and the load current comes from. There are several options that would allow you to have two battery banks but eliminate or reduce the amount of switching you have to do. If the battery banks are of equal size, a battery combiner would allow charging current to go to both batteries as needed. If one battery bank is a smaller starter battery, then a Heart Echo-Charge is the answer. With either of these systems you can use the switch or not depending on how you arrange things.
— *Kevin Jeffrey*

Reduced Engine Life at WOT

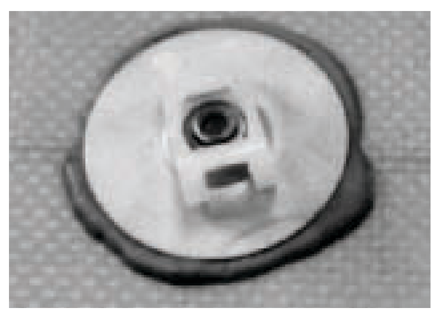
Q: One of two 7.4L/454CID engines on our 9.7m (32') Baja blew a camshaft after running for 5.5 hours and at full throttle for 10 minutes. I thought marine engines were designed to handle this?
Elaine Shapiro,
Westfield Center, Ohio

A: Without knowing your boat's history, engine model, year and usage, there are a lot of factors that must be considered. No engines are designed to run at wide-open throttle (WOT), not even the space shuttle! Rather they run on a prescribed duty cycle. (You'll find this described in your owner's manual.) Typical duty cycle for most marine engines is 50% to 75% of WOT for a maximum duration of three hours at one time. WOT is recommended for emergency situations only. The average life of a marine stern drive engine that has been professionally maintained and commissioned is 2,000 hours. Ordinarily, if you have premature engine failure (before the 2,000 hours life expectancy), one of three things failed: the maintenance program, commissioning program or duty cycle. Newer engines (i.e. post '94 carbureted and EFI MerCruiser) have an engine control module (ECM) that provides the dealer with complete operational history, such as number of times the engine hit the rev limiter, number of times exceeded 2,000 rpm in reverse, etc. The camshaft controls the valve timing. An engine that runs the first 10 hours without failure, a camshaft breakage may indicate that something else is wrong. A camshaft failure in a big-block engine after the 10-hour break-in period is normally caused by excessive operation beyond the duty cycle. When maintenance, commissioning and duty cycle are strictly adhered to, then it's possible that engine failure is a symptom of another problem.
— *Jan Mundy*

Leak Check a Gas Tank

Q: My boat's aluminum gas tank doesn't have a leak, yet, but it's 21 years old and foamed into place in the belly of the cuddy cabin. Is there an easy way to check for leaks?
Dale Hubbard, Boston, Mass.

A: Should your tank develop a leak, fuel will quickly dissolve the foam, loosening the tank. While underway, you'll likely hear the tank moving in the bilge. Fuel tanks can be pressure tested with a gearcase pressure tester to a maximum of 3psi and you'll need to cap off the vent and fill, and remove the anti-siphon valve. If the tank is large, pressurizing will take a very long time, so the best time to pressure test is when full, otherwise you'll have to occupy all the air space with pressure. Tanks are not structurally designed to be



pressurized from the inside out, so do this carefully and no higher than 3psi. (Refer to DIY 2000-#1 issue for how to diagnose and repair leaking tanks.) If the problem is a small leak, confirm the leak location. To do this, purge all fumes from the tank, plug the vent, fill and pick-up fittings and using a pressure tester, inflate the tank to 3 psi, the recommended minimum test pressure. Apply soap and water to the outside and check for bubbles. A single pinhole leak is easily fixed by the DIYer with a Click Bond, an aluminum self-adhesive patch used by the aircraft industry.
— *Jan Mundy*

Tech Tips ✓

LIGHTWEIGHT CEILING PANELS: Art board, a "plastic" cardboard with a corrugated core sandwiched between smooth skins makes a cheap, waterproof and lightweight headliner. They are available in 4'x 8' sheets from specialty art suppliers. Buy 6mm- (1/4"-) thick boards and attach with cleats screwed to the deckhead. Cover seams between panels with 6mm by 38mm (1/4" by 1-1/2") varnished wood strips.
Ron Plosnak, Chicago, Ill.

HOSE GUARD: Make a shield hose, using half a short piece of same or larger diameter hose and wrap over primary hose, to protect from kinking, puncture and abrasion.

BILGE PUMP MINUTEMETER: Purchase a common 12-volt truck timer used to clock accumulated engine running time and mileage (CDN$10 at Princess Auto Parts), and add some wire and connectors. To install, tee off the power from the switch to the bilge pump, wiring the grounds correctly. Don't install it in series with the bilge pump.
Dave Mount, boatless in Pickering, Ont.

EASY NONSKID REPAIR: To patch a hole in textured nonskid, paint a non-blemished area larger than the hole to be patched with light grease. Trowel on a layer of silicone caulking (or dental impression material), press a piece of thin cardboard or heavy paper into the silicone and allow to cure overnight. Pull off the "mold" and wash off grease. Use and reuse this mold after coating with wax, silicone spray or mold release, then laying it on fairing compound and weighing with sand in a plastic bag. Be sure to orient the patch with the existing texture pattern (this is difficult).
John Brooke, "Petrel," Boston, Mass.

DONUT GUARD FOR WIRES: To prevent cables, hoses and wires from chafe where passing through bulkheads, wooden or metal frames, wrap the opening with a piece of hose that fits snugly in the hole.

STAIN BEATER: For all but the most stubborn stains on fiberglass, try Lysol Tub and Tile in a spray applicator. Be sure to rinse thoroughly after use.
Lorne and Tracey Sinclair, "Gossip," Victoria, B.C.

FABRIC GLIDE: Upholstery covers are often difficult to slip over foam cushions. Dusting the cushions with talcum powder makes them slide in much easier and they smell fresher.

NEGATIVE GROUND CHECK: An electronic device (in my case a trim-tab motor) that fails to operate is easily checked with a multimeter, provided you use the proper ground. Connect the positive probe to the unit's positive and the negative probe to the unit's ground. If you connect the negative probe to a "good" common ground you'll get a 12-volt readout and replace a perfectly functioning electronic device (my trim-tab motor) with a new one that gives the same reading on the multimeter and won't work either until the unit's "real" ground is fixed (I had inadvertently disconnected the ground to the trim-tab motor).
Michael Myers, "Wendy Lynn," Baton Rouge, Louisiana

QUICK TEAK FIX: When you don't have time to prepare new teak for application of a coating, and don't like the look of oxidized (gray) teak, sand lightly and apply an exterior semi-transparent oil-based stain. As the wood weathers, the stain can be used as a touch-up to keep the color fresh.

TAKE GREAT BOATING PICS: To prevent blurred photos when taking pictures onboard, "stabilize" the scene by always using fast film, ISO 400 or faster, and shoot with the fastest shutter speed you can.

DISCLAIMER: DIY boat owner is not accountable for any products or procedures that appear in this column.

Tech Tips welcomes contributions from readers. If you have a boat-tested tip you'd like to share, send complete information along with your name, boat name and home port to:
DIY Tech Tips
P.O. Box 22473
Alexandria, VA 22304

E-mail: info@diy-boat.com

ShopTalk

WOODEN RAILS MADE EASY

Rubrails and toerails help to visually define the most important lines on your boat. Worn or damaged wooden rails shout "neglect" and detract from your boat's value and appearance. Replacement isn't difficult if you follow these steps from a pro.

By Gary Grinnell

Replacing rubrails and toerails is, for the most part, fairly easy. Most of the time the rubrail and toerail will be attached with screws or nails covered with wooden bungs. In addition, adhesive sealants, such as 3M 5200, have been used in recent years.

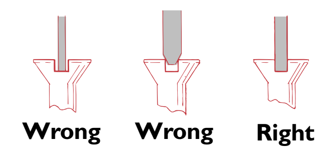
The first step is to remove the old rail. Should you decide to save the good parts of an otherwise bad rail, keep in mind that bending the new piece to fit on a tightly curved area makes it difficult to obtain smooth seamless joints.

Now lay out the joint with a sharp pencil, bevel gauge and square. Tape old newspapers, thick cardboard or thin plywood to the surrounding area to protect the hull (or deck) and cut to the line. A dovetail saw is perfect for this. Stop your cut about 15mm (1/16") short of going all the way through and finish the job with a sharp utility knife.

Use an old screwdriver or a narrow chisel to pop out the old bungs. Do this with a minimum amount of damage to the surrounding wood on rails you plan to reuse. The next job is to remove any glue (or varnish) residue from the screw heads then remove the screws. An old ice pick works well for cleaning the screw heads. If you can't find one, file a large nail or nail set to shape. Take extra care to remove all glue or the screwdriver won't seat in the slots and you'll strip the heads. Be sure the screwdriver you use fits the slot (**Figure 1**); try different ones and file as needed for a good fit. Use lots of pressure and a slow torquing motion to back out the screws. If the screw won't budge, split apart the rail with a sharp chisel and twist out using Vise Grips. If you're saving the rail try drilling out the screw. To do this, tap the screw head with a prick punch and drill first with a small diameter, sharp twist bit, then use larger bits until removal of the screw head is completed. The idea here is to remove the entire head so the rail lifts off easily.

Figure 1

DAVID AIKEN



For maximum torque and to prevent stripping heads when removing old screws (or installing new ones), use a screwdriver of the correct width.

Once all screws are out you need to pull up the rails. Use a thin, flat bar and a block of wood. Newspapers or cardboard underneath will protect the surface. (Stanley Tools makes a small cabinetmaker's prybar that is excellent for this job on all but the largest boats.)

If the rails were bedded with 3M 5200 (or other polyurethane sealant) this won't work and you'll have to cut the rails off with a chisel or use a hacksaw blade to cut through the adhesive. Protect the hull (or deck) with wide masking tape and newspapers. Some people report success using Anti-Bond 2015, a product formulated to remove polyurethane adhesives. Label each piece's location as it's removed — if any questions arise later you can reconstruct things from the original parts.

Now, write your shopping list. Determine the number of screws, bungs (wooden plugs) and liner feet of wood you'll need. Don't forget glue, bedding compound, varnish, tape and brushes.

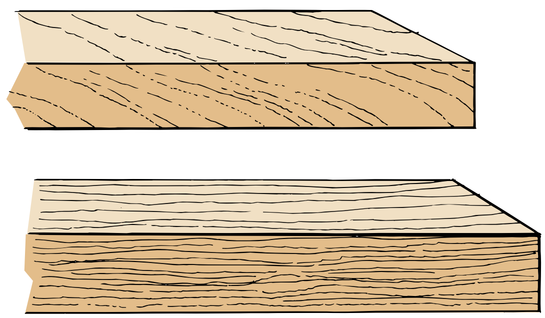
If you decide to duplicate the original rail use a sample piece of the old material. Should you desire to change the shape or are building from scratch, make up some prototypes from scrap wood and place them on your boat. If you're uncertain of the shape and size, examine other boats of similar design. Be aware that the larger the rail, the more difficult it is to bend into place.

Make a drawing of the rail, showing dimensions and length. Add a couple of extra pieces for breakage. Don't forget to add extra for the width of the saw blade and material lost to planing.

Construction and Refit

Mahogany, oak and teak are the standard woods for rails but almost any good quality lumber can be used. Select wood free of knots, cracks and worm holes, commonly found in mahogany. Less obvious is grain run out: select wood with grain that is perfectly straight and follows the sides of the board (**Figure 2**). Avoid pieces that have "figured" or rippled-looking grain. Sight along the edges to check for trueness and pass up any severely curved or twisted lumber. Color is also important. You don't want mahogany rails of multiple shades. Perfect wood exists largely in the imagination so be ready to accept small pin knots or slight curves.

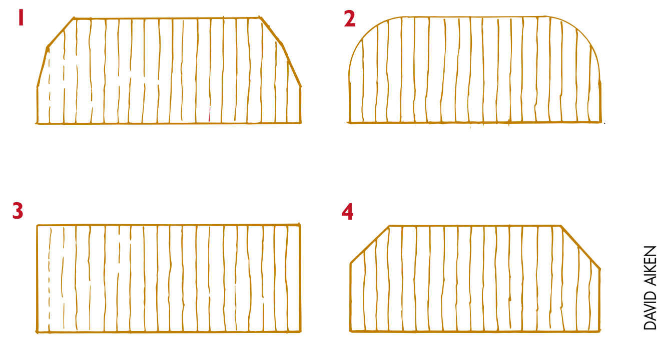
Figure 2



(top) Example of grain run-out that breaks easily; (bottom) Wood with good grain structure.

Now the fun begins. As in any woodworking project you must start with a true straight edge. If you have the luxury of a jointer, you have it made. If not, snap a straight line using a carpenter's chalk line or monofilament fishing line and plane or cut with a skill saw. Next, rip the wood, leave extra for planing. When cutting long lengths I find it helpful to put the waste piece between the blade and fence — if the board shimmies a little bit you haven't chopped too much stock off. Check and double check the measurement before cutting.

Figure 3



Stages in Cutting Rubrails.

Most of the time you'll be cutting at least one bevel (**Figure 3**). I like to set the table saw blade with a piece of the old stock or sample. It's more accurate than a bevel gauge which can get whacked and change its setting. Again, check the angle and width before cutting.

With rail stock all cut and beveled, now cut the bevel at the bow where the toerail meets the bow chock, or stem on a wooden boat. Use a bevel gauge to pick up the angle or use a steel rule and measure off the distance at each corner. Cut the angle with a sharp handsaw, check the fit and recut as needed.

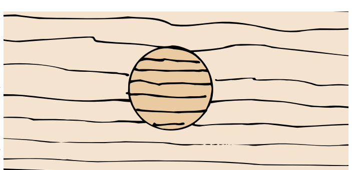
I prefer to predrill most of the stock before attaching it to the boat. But before drilling the entire rail, first consider the screw pattern, allowing for joints, especially when using butt joints, and scuppers (a.k.a. drain holes). It's unlikely that your rail is one long length so plan your joints so they land on a relatively straight section. Equally space screw holes and use a drill of the proper size so the screw shank is a loose fit in the counter bore. You may also want to drill starter holes on the hull (or deck), beginning at the bow, to check that your first few screws aren't going through some undesirable place. You don't need a row of fasteners projecting from the headliner waiting to scalp someone.

You may want to glue the rails together beforehand to ensure a smooth, fair line. Check all joint surfaces with a straight edge, then dry-clamp the rails before permanently connecting with waterproof glue (use an epoxy glue.) Use lots of clamps and check for straightness before leaving them to cure.

Stagnant water sitting on deck causes rot, discoloration and paint loss. Cut openings for scuppers at the lowest point on the sheer where water collects. Holes should be large enough to drain water with minimal clogging, but small enough so the rail doesn't crack.

Some boats have high, massive toerails. These will need to be beveled on the bottom edge that meets the deck. To do this, use a bevel gauge and a level to duplicate the angles. Mark bevels on the rails in 2.5cm (1") sections, every 45cm (18") or so. Carefully cut to the lines then connect the small cuts with a batten, mark the wood and cut to the line with a draw knife and plane. Check for trueness with a straight edge; any weird bumps will produce an ugly gap. At this stage you may want to dry-fit the rail. If your boat has extreme curves, it may be necessary to prebend the rails using steam or hot water, but I consider this a last resort. [Ed: An easy steam box is made by placing the stock in an ABS pipe of the correct diameter and length, and standing it upright over a water-filled electric kettle at the bottom, sealing the gap with wet rags and stuffing one into the pipe top. It takes numerous refills of the kettle and about 30 minutes to soften 2.5cm (1") square stock to where it bends easily.]

If you have time, it's a good idea to finish the mating surfaces with varnish. This discourages rot, and as untreated wood tends to absorb oil from the compound, it also helps the bedding compound remain intact longer.


DAVID AIKEN

Plug holes with wooden bungs, lining up grain with surrounding rail.

Recheck to be sure that all old bedding compound and screws are removed. Clean the hull (or deck), vacuuming to remove all residue then wipe with solvent. Using a putty knife, smear an even coat of bedding compound over the surface where the rail installs. I like Interlux bedding compound because it works, it's easy to use, it won't make you sick and it looks suspiciously like peanut butter. Start fastening at the bow and gently bend the rail around to the stern. Use shores and wedges to hold things in place. Plug the screw holes with plugs (bungs), matching the grain of the surrounding wood. Clip the bungs with a sharp chisel, cutting against the grain, sand and varnish.

About the author: Gary Grinnell operates a mobile wooden boatbuilding and repair business based in Townshend, Vermont.

Radar Electronics

WHAT YOU SHOULD KNOW ABOUT RADAR

Choosing a radar set with the correct output performance and features, locating a convenient location for the display, avoiding interference with other electronic equipment, mounting the scanner to avoid inhabited areas — are just some of the many details you'll need to consider when purchasing and installing a radar system. If radar is in your future, read on.

Story and Photos by Larry Douglas

It's hard to avoid noticing that most serious cruising boats over 7.9m (26') have a radar set. Unfortunately, there are a substantial number of installations that probably don't meet the owner's expectations. Some scanners are placed where they are significantly blocked by metal structures. Others are placed so low that their horizon is much too limited to be very useful — and sometimes the transmitted signal is nearly in line with the helmsman's head; not a safe installation at all. Likewise, balancing the need to keep the display away from the compass and other electronic equipment but still visible in poor weather conditions can be extremely difficult.

Power or Sail: Selecting a System

A radar set consists of two main components, the scanner and the display unit, connected by a special multi-conductor cable. In all of the smaller systems the cable carries power from the display unit to the scanner and information to the display unit from the scanner, while the larger antenna systems usually require a separate power cable for the antenna motor.

Modern radar systems use one of two display types. One type is the cathode ray tube (CRT), which is much like your desktop computer display. The other option is a liquid crystal display (LCD) screen that often seems to have less contrast and a narrower effective viewing angle. It does, however, draw less current, which may make the difference between using it or not in doubtful situations. It should be said that for most purposes either will serve well, and a decision for one or the other should be made only after viewing both types from a range of suppliers and under a wide range of lighting conditions. My personal preference is the CRT, but having a powerboat there is adequate DC power available for most electronic accessories. A sailing vessel having limited battery power available might prefer the LCD display.

Radar systems are sold complete with electronic components but you'll need to purchase brackets, clamps, watertight fittings, cable ties, sealant, additional power cable, fuses and wiring connectors.

Scanners also come in two versions, the dome and the open array. Both the dome and the open array include the antenna and drive motor plus transmitter, receiver, and antenna position sensor(s). Dome antennas tend to be less than 66cm (26") in diameter and 4kW peak (transmit) power or less. Open arrays are usually larger and more powerful.

Basic radar sets start at around $750 for a 7cm (6") LCD display, a 30cm (12") dome with 1.5kW output and 16-mile range, and features such as waterproof display, automatic tuning and power-saving mode. Of course if you have the room, the DC power and budget, you can easily spend over $8,000 on a 96-nautical-mile (nm) system that has a 30cm (12") CRT display and 1.8m (6') antenna. However, most, if not all, features are available in smaller systems at half the cost.

Choosing the right radar set for our boat was a matter of selecting the appropriate CRT display size (I needed to see it from about 1.2m/4' away), with the features I wanted. These features included an easy-to-read display (very subjective, so I had to look at every model that I could), chart plotter available as an option (maybe to be added later), and multiple target tracking. I decided on a

Raytheon R80 series which has a 25cm (10") CRT display. As for the antenna, a 21cm (24") dome with 4kW output and 48nm range is a more-than-adequate system for our purpose. It was also easy to mount on the front of our mast using a Scanstrut mounting bracket. Cost is always a consideration, but a properly installed, high-quality radar unit should last well over 10 years, so dividing the purchase price over a 10-year period makes the yearly cost less than one fuel fill-up for my boat.

How Large and How Powerful?

Other specifications notwithstanding, the ability of a radar set to find a target mostly has to do with output power and antenna size. As with most marine products, it's important to select the compromise that works best for your needs. Owners of smaller sailboats tend towards a LCD display and a 2kW or 4kW dome. Powerboaters will select either a dome or an open array, with the size and power more limited by space and the pocketbook than anything else. There are, however, important reasons for considering more power and a larger antenna. Any radar set will (or should) show you the supertanker 5km (3 miles) to port; at the same distance, it takes more power to locate that harbor entrance buoy in heavy rain.

Also significant is the ability to precisely locate a narrow channel opening. The larger the diameter of the antenna, the better its ability to display the opening as it really is, or to separate two objects (such as a tug with one or more tows) rather than painting them as one larger target. This ability is usually specified as horizontal beamwidth, and is inversely proportional to the size of the antenna. The narrower the horizontal beamwidth (and larger the antenna), the better you will be able to distinguish between two objects located close to each other. Another important issue often overlooked is the angle the radar antenna makes with the horizon. For best performance the antenna should be parallel to the horizon, certainly within half the vertical beamwidth specification. Since powerboats squat (ride bow high when underway) and sailboats heel, keeping the antenna horizontal becomes a real problem. (Nautical Engineering's powerboat mount has a fully adjustable mounting angle from vertical to horizontal.) Sailboat owners should consider a gimbaled mount that compensates for heel such as those made by Performance Marine (Waltz Radar Leveling System), Questus, Stainless Outfitters and others. If you use your radar while under sail, you really should consider installing it on a self-leveling mount. Powerboats that squat under way should position the antenna so that it's horizontal at normal cruising speed.

Scanner must be securely mounted but and high enough to keep the transmitted energy safely above an area where people may be and above other antennas: (top) Fixed bracket-mounted antenna on short mast on author's Tollycraft; (center) Edson NavCom Tower Systems provide a single mounting pod for radar, GPS or VHF antennas, flood lights and other accessories; (bottom) Gimballed, self-leveling sailboat bracket mounts pole connected to the backstay.

Installation Checklist

While the above characteristics and features are important, don't neglect your specific needs (or wants) when selecting both parts of a radar set. You may, for example, want a chart plotter option, a second display or target tracking ability (sometimes known as ARPA for Advanced Radar Plotting Aid). Any or all of these features are available, but not in all brands, models, sizes, and price ranges. With most suppliers it's possible to match two or more display models with two, three or more scanners to give you exactly what you need.

Installation is not difficult if the instructions are followed and adequate planning precedes the actual installation. After you open the boxes and before you drill any holes, pull any wires or mount any equipment, there is one very important thing you need to do first: Take the time to plan the installation in every detail! Failure to do this is probably the most common reason for problems during and after the installation. It's a certainty that you will need things that are not included in the kit such as brackets, clamps, watertight fittings, and such. Don't forget cable ties, sealant (3M Marine Sealant 101 or other polysulfide sealant), additional power cable, fuses, and connectors either. Tools needed include drill and bits, 1/2" brad point drill bit, 3/4" and 7/8" holesaws, various screwdrivers, wrenches, wire crimping and stripping tools. If the supplied multi-conductor cable is not long enough, have the extension or longer cable (usually special-ordered from the distributor) on site before you start the installation.

Antenna Height

Since radar waves are "line of sight" only, the higher the antenna, the longer the range. In reality, most radar systems are rarely used above the 20-km (12-mile) range, so height is not all that critical. On our boat we use the 3- and 6-mile ranges, with occasional scans at 12 miles in limited visibility to check for large ships. Most of the time we use the radar set to obtain the range to a buoy or mark and the target is less than 8km (5 miles) away. From radar horizon calculations, if your antenna height is 3m (9.8') and the target height is 3m (9.8'), the theoretical maximum radar range is 7.8nm. Raising the antenna height from 3m to 5m (16') while keeping

Placement of the display is important for comfortable and convenient use: (top) CRT display mounted to the overhead in the forward cabin of author's tri-cabin cruiser; (bottom) Pod-mounted LCD screen in sailboat cockpit.

the target height the same only increases the range to 8.9nm, so it's not usually worth the effort to get a slight amount of additional height. The one reason to add height is to keep the beam away from people. A typical antenna has a vertical beamwidth of around 10° to 15° above and below the horizontal plane (20° to 30° total spread). Since continuous exposure to ionizing radiation (such as radar) is harmful, it's wise to keep the beam well clear.

Locating the Scanner

On our tri-cabin powerboat, the scanner ended up near the top of the mast just below the level of the bimini frame. I put it there since the frame is made of 25mm (1") stainless-steel tubing and can interfere with the radar signal. Although this is in the danger zone of anyone standing at the upper helm station, the radar is never permitted to be on when we're driving from above. On our boat, radar is not used during fair weather cruising. (Of course, we do practice using it during good weather but only at the lower helm station.)

Positioning the Display

Operating a boat under poor visual conditions while navigating and searching the radar set for targets can be done, but it's tiring and not much fun. For this reason, a radar display should be located within the helmsman's line of sight, but in such a way that someone else can operate the set and keep track of any targets or navigation aids. That may mean adjusting the distance and/or viewing angle as well as the height. Keep in mind that the display and wiring may have minimum safe distance requirements to the magnetic compass and other electronic equipment (radar is capable of interfering with SSB and VHF radios, autopilots, depthsounders and other electronic equipment). Check the manual for specific warnings and instructions.

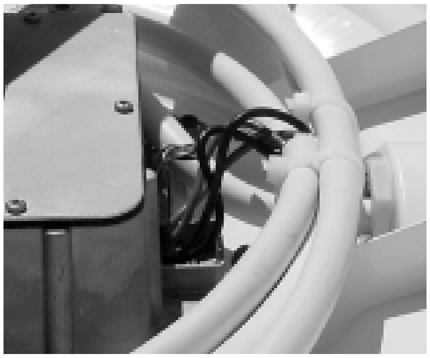
On our boat, I secured the display to the overhead in the forward cabin, taking the place formerly occupied by a color depthsounder. The unit's mounting bracket easily bolted to the existing supports and the existing DC power cable was amply sized. To install, cut the DC power cable to a convenient length, terminate it with an appropriate connector and/or terminal block, then use the larger cable and an appropriate fuse. Remember that fuses protect wiring, not electronics, so install the fuse at the panel, not at the equipment!

Inside view of a dome scanner shows the antenna, drive motor, transmitter, receiver and antenna position sensor.

Sailboat installations are as individual as the sailors that use them. Some like to have the display located near other instruments and housings are available for that purpose from suppliers such as Edson. Others mount the display just inside the cabin but still visible (more or less) from the wheel.

Cable Routing

Installing a modern radar set is quite simple, especially since the multi-conductor cable often has plug-in connec-



Never cut or splice the multi-conductor antenna cable; instead coil extra cable in the base of the dome.

tors at both ends, and most, if not all adjustments consist of following setup menus and using either a push button or a trackball. Generally the most difficult part of the installation is pulling the multi-conductor cable. Once the equipment is secured and the cables are run, the only other wiring required is the DC connection and perhaps the scanner motor wires. Of course that can present a problem as any holes needed to allow passage for the multi-conductor cable often need to be drilled oversize to permit the connector(s) to pass through. For example, with the installation on my boat, the cable diameter was about 12mm (1/2") but the minimum hole size had to be 19mm (3/4") because of the connector size. Also, plan to pull the multi-conductor cable from the display to the scanner, not the other way around. Most display end plugs are over 25mm (1") in diameter. In case of a routing mistake, back up and start over. Don't even consider cutting and splicing the multi-conductor cable! Allowance must also sometimes be made for extra cable. Most instructions suggest coiling extra cable in the base of the dome or, in the case of an open scanner, coiling it loosely in a protected area. In both cases be sure to properly secure it from unintended movement. Another caution is to avoid sharp bends and chafe points. The minimum bend, unless otherwise specified, should be at least 25 times the cable diameter, and more if possible. Don't forget to install the watertight bulkhead fitting, and file or sand well all ungrommeted holes to avoid chafing the cable.

Since the mast angles slightly aft, the dome's mounting bracket could not be installed so the dome is level while under way, which it needs to be for maximum range and sensitivity. For the short term, I decided to tilt the dome forward using stainless-steel washers as spacers at the back between the dome and the bracket, using the dome's two rear bolts to hold them in place. (I'll have a proper flange made that will better position the dome.)

Once the cable was run and the dome mounted it was time to connect the cable. I fed the cable into the dome via the watertight connector (remembering to install the cap and grommet), winding the excess cable around the bottom of the dome. Plugging the cable into the dome's connector and connecting the two motor wires to their terminals completed the wiring terminations. The last task was to secure the cable against movement (you don't want it interfering with the rotating antenna) using cable ties secured to the various mounting screws inside the dome. Re-installing the dome's cover (loosely until initial tests are complete) finished the installation.

Routing the cable was the most difficult and time-consuming part of the installation. Beginning at the overhead in the forward cabin, taking care to keep it as far as possible from the compass at the lower helm station, I drilled a 3/4" (19mm) hole through the wall next to the lower-helm station so the cable traveled

Antenna cable leads through the cabin wall via a water-tight fitting to the dome mounted on the mast.

TIPS

SHORTER IS BETTER

If you need to lengthen the DC power cable, start by shortening it! Some furnished DC power cables are just adequately sized for their length versus allowable voltage drop. [Ed: Refer to "Boat Wiring Handbook" in DIY 1998-#4 for voltage drop tables.] Any longer and they may not have enough voltage at the rated current available to the internal power supply.

back and up into the overhead, aft inside a conduit, then through another 19mm (3/4") hole in the top rear corner of a galley cupboard and out through the aft end of the main saloon. The cable was secured using 12mm (1/2") nylon clamps every 40.6cm (16") or less. A grommet was installed at every drilled hole for protection from chafing. At the exit from the main saloon, I installed a watertight fitting over the cable, securing the fitting to the outside of the cabin wall using the supplied hardware. Outside, the cable runs up inside our mast, entering and leaving through 22mm (7/8") holes. A word to the wise: If you plan to use O-rings or a similar sort of anti-chafe material when entering and leaving a mast, purchase them first. You may have to adjust the size of the holes to the available size of the O-rings. As an alternative, purchase windshield gasket material from an auto shop (or window supplier) and cut it to size. Depending upon the thickness of the metal mast it might even be a better option.

Tests and Adjustments

After plugging the cable and DC power connectors into the receptacles at the rear of the display, pushing the power button brought the set into the standby position with the internal timer counting the warm-up delay until the transmitter was ready. Preliminary checks were quickly completed using the instruction manual. Unlike older sets that often required numerous trips back and forth between the scanner and the display, most sets now allow necessary adjustments, such as range calibration and heading alignment, to be done from the front panel. Since our slip is in an enclosed marina without useable range or bearing calibration points, we'll leave final adjustments until we're at another port.

About the author: Larry Douglas is an electronics consultant based in Bellingham, Wash.

DIY MATERIALS AND LABOR

MATERIALS

Prices in U.S. funds and do not include tax or shipping.

Raytheon RA84H radar, 10" CRT display with 24" 4kW dome	$3,580
Scanstrut dome mounting bracket 24" dome	$279
Watertight bulkhead fitting for radar cable (Blue Seas #1002)	$14.75
19 12" nylon cable clamps	$3.80
19 #8 by 3/4" oval head stainless-steel screws	$2.28
8 #10 by 3/4" oval head stainless-steel screws	$1.20
8 1/4" stainless-steel washers (spacers)	$.80
3 3/4" by 1/2" O-rings	$.45
2 7/8" by 1/2" O-rings	$.80
1 3 oz. Tube 3M 101 white polysulfide sealant	$7.99
6 10" nylon cable ties	$.72
Miscellaneous wire connectors, fuse, etc.	$2.75
Total	$3,894.54

LABOR

Times are approximate and in hours. Not included are multiple trips to the store, rest breaks, cleanup, spouse diversions, etc.

Mount display 1
Mount dome bracket on mast 1.5
Drill two holes in mast 1
Run cable, including inside holes and all mounting inside the cabin 3
Install dome and terminate cable 1.5
Final installation; DC wiring, unit testing and dockside alignment 2

Total (estimated) 10

Rigging Sailboat

THREE Rs OF RUDDER REPAIR

Wet, soggy rudder? If your boat is one of many with a hollow rudder, here's how to remove, rebuild and reassemble it before it fails.

Story and Photos by Martin Parker

In the 1980s many rudders on production sailboats were designed as hollow, watertight constructions. The shell was manufactured of fiberglass and the rudder shaft of 316 stainless steel, but internally the tangs were commonly mild steel, sometimes surrounded by fiberglass. Providing no water leaks in, this design is fine. But after a couple of years water inevitably seeps in due to the joint breakdown between the rudder shaft and the fiberglass. Corrosion weakens the welded joints, a process particularly accelerated in saltwater, and if the weld between the rudder shaft and the tang breaks, the shaft will slip round in the rudder — no more steerage.

After listening to a fellow sailor who opened up his rudder on a Sabre 27 to find one of three tangs was rusted through, I was even more worried about the condition of my boat's rudder. It leaked about a pint of water from the bottom of the rudder when the boat was laid up at the end of the season. (Ed: For boats winter-stored in cold climates, freeze damage can blow apart a water-filled rudder resulting in major repairs.)

New stainless-steel tangs.

Only one tang held the rudder. It was mild steel and badly corroded, and replaced with a stainless-steel one.

A look inside: The rudder was split as shown to make it easier to dig the mild steel tang out of the fiberglass and to ensure the added metal work could be properly glassed in and aligned with the tiller.

Removal and Dissection

It's no joke removing a rudder on sailboats and my 7.9m (26') Colvic Sailer was no exception as about 1.06m (3'6") of the rudder had to be withdrawn from the hull. The most common way to do this is to dig a very deep hole. If you're on concrete, you'll have to lift the boat instead! As my boat was on a trailer, I used a combination of jacking and a 61cm (2') hole to achieve the necessary drop clearance.

Once out, you need to select the cut line around the rudder. It's important to get this right — splitting it in the wrong place could make it difficult to realign the shaft on reassembly. I decided to cut out a segment, making the first cut about 12.7cm (5") from the top, and then the rest was split down the middle. An excellent tool to do this is a sabre saw; it has the reach to cut through the fiberglass skin and any internal filling. Someone not so long ago had filled the rudder with foam, making it difficult to split and clean out.

Inspection

After removing all the water-logged foam and fiberglass filler surrounding only one mild steel tang, it was clear that water had penetrated down to the weld, although it wasn't ready to break off yet! There was a fair amount of corrosion present, but to counter act this, there was a large weld area giving it many more serviceable years. The remaining shaft section was marred by crevice corrosion, particularly at the bottom where it passed through the rudder skin, but with some cleaning it could be reused again.

Finished rudder, except to apply the gelcoat. Split joint was ground out and filled with chop strand mat and filler.

Metal Repair

To reinforce the rudder and ensure it's longevity, I replaced the one mild steel tang and added two more made of 316 stainless steel, all welded with 316 rods and bonded to the inside. This rudder probably doesn't need the middle tangs but they were added as "belt and braces." Great care was taken when aligning the rudder to the tiller, as there is no adjustment here after fiberglassing all tangs in place. Once positioned, a small self-tapping screw in both tangs locked the assembly solid, which also stopped the rudder case from distorting. The top and bottom tang were well bonded in to support the shaft better and possibly reducing the risk of leakage. All other welds and metal components were coated with a thick layer of resin (I used polyester but you could use epoxy) for additional saltwater protection.

Reassembly

To reduce the weight of the rudder when it does leak, (you don't want it full of water) I fitted some shaped blocks of closed-cell foam bedded in with a thickened resin mixture (i.e. colidical silica mixed into epoxy). More of this solution was liberally applied to all surfaces when the two halves were

After four years of service the sacrificial anode is being eaten away, while the custom deflector has protected it well.

mated back together again. When set, the split joint was ground with a grinder to form a hollow that was filled with chopped strand matt and smoothed with filler (i.e. bedding compound, 3M Marine Premium Filler). Finally, two layers of gelcoat (only compatible with polyester resin) were applied in a warm atmosphere, to fully protect it from the sea's hostile environment. [Ed: Alternatively, if using epoxy resin, apply five coats of unthickened epoxy and finish with a polyurethane paint.) I pity anyone who wants to get this rudder open again, it will be difficult!

Anode Protection

Because the end of the rudder shaft looked as if metal-eating worms had been boring into it, I decided to add an anode to protect it. Incidentally, this was a typical example of crevice corrosion in stainless steel that tends to follow the grain of the material.

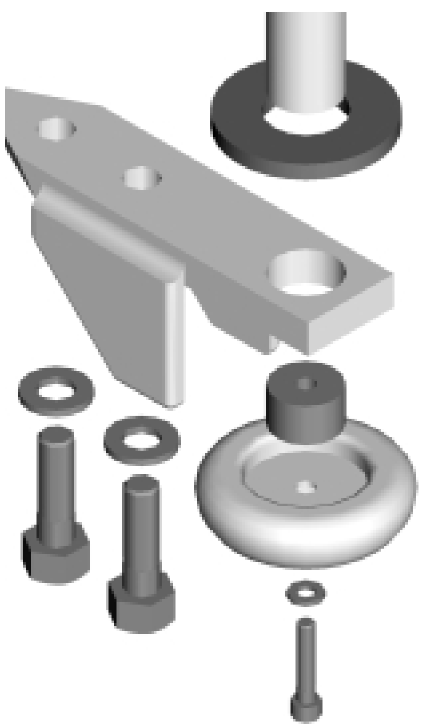
The anode was attached by filling the damaged end of the shaft full of weld, then drilling and tapping a hole for an M6 stainless-steel, cap-head machine screw. When the rudder and anode assembly was fitted back onto the boat, it was clear that debris could lasso the protruding anode. The solution was very simple: two shaped wings of stainless steel were welded to the rudder's bottom pivot to provide a deflection for stray ropes or weed. Luckily, it also has the strength to support the weight of the stern, which stops the anode from being crushed when the boat dries out on a hard surface.

When I split the rudder there was no danger of it breaking, but who knows how sound it would be in a few years. Just for peace of mind, this job was worth it!

DIY REPAIR BILL

The approximate cost was just under $100 plus lots and lots of time. The 316 stainless-steel strap 50mm by 5mm by 1.5m long (1-7/8" by 3/16" by 59") and everything else that I used, I had lying around in the garage.

Fiberglass, resin, filler and gelcoat	**$65**
Stainless-steel welding rods (10)	**$15**
McDuff anode	**$17**



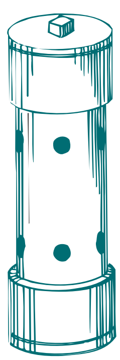
Customized anode mounts to bottom of rudder shaft and is protected by a keel-mounted bracket.

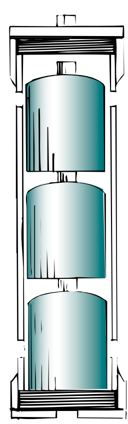
About the author: British writer Martin Parker is a mechanical engineer who in his spare time has rebuilt various boats from a small clinker dinghy to a fiberglass cruiser.

Projects

MINI-TANK PROPANE HOLDER

Propane is a dangerous fuel on board boats. Since it's denser than air, any leakage inside the hull ends up in the bilge where an explosion can result. Laws require that propane tanks and enclosures be vented overboard. Many boats carry the larger 5- and 10-lb tanks on swim platforms where any potential propane leaks dissipate safely. But what to do with the small propane canisters used on small barbecues and lanterns? These canisters are more prone to leakage than larger tanks and many people carry them in available storage bins on board.





White PVC sewer pipe, 10cm (4") in diameter, is the perfect solution to contain three canisters. Cut off a 61cm (24") length (each canister is 20cm/8" tall), add a cap on one end and a threaded female adapter with threaded plug on the other. Drill three or four equally spaced 9mm (3/8") holes around sides, top and bottom to vent any propane leakage. Drill a 3.8cm- (1-1/2"-) diameter hole in bottom cap to permit pushing out a canister should one happen to jam.

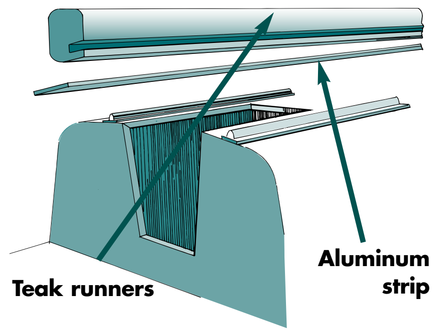
To use, just open cap, reach in and pull one out. If you make the container longer to hold more cylinders be aware that your arm may not be long enough to reach the bottom cylinders requiring you to upend the holder to get them out. Mount it on the swim platform strapped to a fender holder, railing or other hardware onboard and secure with bungy cords.

— *Mel Smith, "Archimedes," Port Whitby, Ont.*

SILENCING A NOISY HATCH

When sliding the companionway hatch on my 1979 Cal 29, it scrapes the cabintop resulting in a terrible noise (like fingers scratching a blackboard). The fiberglass hatch runners had apparently worn down the fiberglass hatch covers. I tried various lubricants, including soap and suntan oil, but to no relief. The only solution was to rebuild the hatch.

First, I removed the interior ceiling and teak trim to gain access to the original fasteners and remove the teak hatch runners. Original holes in the coach roof were filled with an epoxy-glass fiber paste and new ones drilled. Screw holes in teak runners were plugged with hardwood bungs set in wood glue. Placed under the teak runners were 6mm by 2.54cm (1/4" by 1") aluminum strips, predrilled to match new hole pattern on coach roof and holes countersunk for screw heads. I decided not to fabricate strips of teak due to the slim size and the difficulty in obtaining a flat, evenly planed surface. Aluminum strips were then screwed to teak runners. New fastening holes were filled with silicone sealant and



Details of squeal-proof hatch runners.

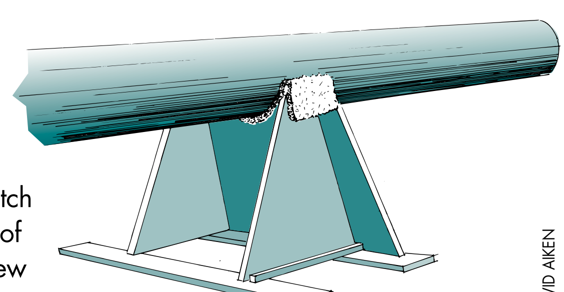
underside of aluminum strips bedded in sealant, then the new hatch runners placed on the coach roof and fastened from below using screws and oversize washers.

This has raised the hatch combing 6mm (1/4"), but the hatch cover and factory combing around the hatch should protect any gap I created from rain and spray. I now have a quiet hatch, though boating in saltwater I'm concerned about aluminum and electrolysis. Time will tell if I messed up.

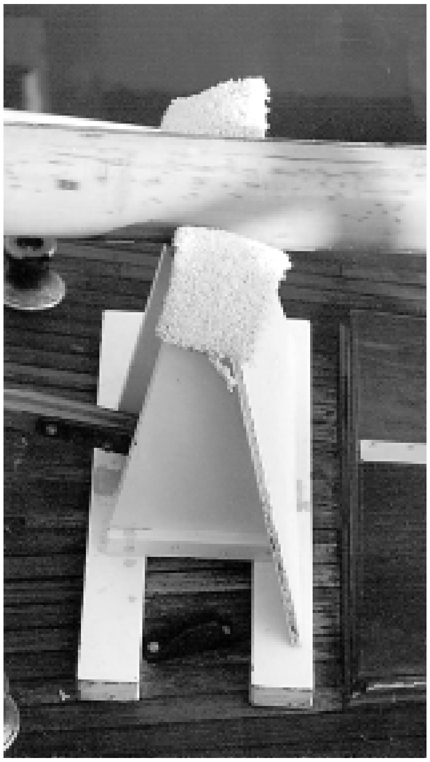
— *Jim Norwood is an avid DIY reader, "…even read the powerboat stuff," and moors his Cal 29, "In the Mood," in Port Author, Texas.*

MAST DECK SUPPORT

I've built myriad mast cradles and scanned other boat owner's creations, from the ever-popular



DAVID AIKEN



X-shaped tripods to step- and pulpit-mounted brackets. While all supported the mast above deck, few provided a completely stable, rigid mounting. I discovered this design on a boat in a yard in Michigan City, Ind. Made of 16mm (5/8") plywood or waterproof StarBoard, its wide 61cm (24") base delivers a secure footing for masts up to 30-footers. Heavy or longer masts may require 19mm (3/4") or thicker plywood and a wider base. Three pieces make up the front and sides. The front is sloped at a slight angle and notched to fit the mast then carpeted. Individual preference determines the finished height off deck. Solid wood cleats screwed to bottom sides offer extra vertical support and increase the mounting surface to the bases. Note footpads under bases (not shown in illustration); heavy masts may also require a center-mounted footpad and these could be padded with carpet to protect the deck.

— Jan Mundy

DIY MECHANIC

A USER'S GUIDE TO OUTBOARD MAINTENANCE

With the right tools and a few basic skills, you can perform most outboard maintenance and troubleshooting jobs yourself. Here's how.

Story and Photos by Jan Mundy

TOOLS

Service Manual
Socket set and
  12" drive extension
Combination wrench set
Spark plug socket or
  13/16" wrench
Spark plug gap tool
Slot and Philips screwdrivers
Ball-end Allen wrench set
Diagonal side cutters
Long nose pliers
Ball-peen hammer
Insulated spark-plug wire pliers
Grease gun
Vise grip pliers
Wire brush and Toothbrush
Fuel filter wrench
Gear lube hand pump
Wire stripper, crimping tool
Dental pick or ice pick
Multimeter
Battery hydrometer
Timing light (optional)
Compression gauge (optional)
Flywheel puller (optional)
Spark checker (optional)
Prop wrench (optional)
Prop pliers (optional)

In the mid-80s, two-stroke outboards took second place to stern drives, but with the introduction of direct fuel-injected outboards, they've regained popularity. They offer better weight-to-horsepower ratio and are much easier to maintain.

All two-stroke outboards operate using the same basic principles and theory, although the appearance of component parts may differ. Maintaining top operating performance and correcting problems before they occur, minimizes your chance of major engine breakdowns. And when components fail, a properly maintained outboard will cost much less to repair.

Before undertaking any work, be sure you have the mechanical skills and knowledge to accomplish the job proficiently. Purchase a service manual for your particular motor. An invaluable tool, manuals contain information with regards to tools and equipment required, tear-down procedures, inspection and cleaning, and reassembly procedures. It's strongly recommend that repairs involving fuel and steering systems, and remote controls be done by an authorized marine mechanic. Both are critical safety elements and are two areas you shouldn't mess with!

When doing any servicing, carefully follow directions. Purchase products recommended by your engine's manufacturer, read labels on containers and apply as specified; otherwise, you risk damage to your engine.

"There's no reason why an outboard can't last indefinitely," explains Warren Mills, owner of Gannon Narrows Marina (705/292-5695), a full-service marine facility located on the Trent-Severn Waterway in Ontario. "They wear out and get thrown away because owners don't maintain them." A former small engine apprenticeship instructor, Mills knows a lot about outboards and gladly offered to share some of his expertise.

Routine Checkover

Before every trip, put engine in neutral, then remove the cowling and give everything a visual once-over. Look for oil leaking into the pan underneath the engine; outboards contain many plastic parts, such as the hose fittings on oil reservoir and trim pumps which often crack. Check for loose or missing nuts and bolts, abraded hoses and wires, and leaking hose connections. Examine trim gauge sender and wires. Operate trim, throttle and shifter. If boating in saltwater, apply a light spray of a moisture-displacing lubricant over the powerhead. Carefully replace cowling: when reinstalling on our boat's Mercury 150hp, it's easy to jam the trim motor's negative wire and ground out the system.

Start the engine and let warm up before leaving the dock. Observe the flow out of the cooling-water exhaust outlet and carefully check the temperature with your finger; it should be warm, not hot.

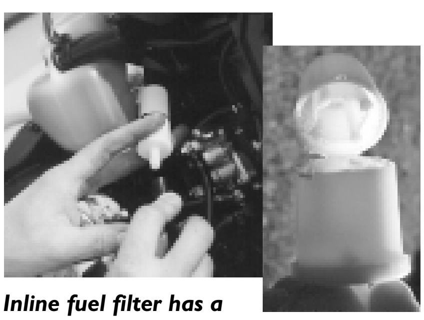
While underway, continually scan all gauges and monitor the telltale stream of water out the exhaust outlet.

After use, remove the cowling (remember to shift into neutral when working on the engine), rinse the powerhead with freshwater to remove salt residue (where applicable) and respray with lubricant. If needed, before replacing cowl, wax the housing and lubricate the rubber seal at the base of the cowling with a preservative. Always check the condition of the propeller and skeg, in case you unknowingly hit something. Flush engine with freshwater after every use in saltwater; do this periodically to freshwater-run engines to prevent silt buildup. Use flush ears connected to a garden hose or purchase a thread-on adapter (available for some engines).

Routine inspections before, during and after running your engine allow you to evaluate its condition and avoid potential costly repairs. Check your service manual to see what other routine servicing is required. If you suspect a problem beyond your mechanical skills, ask a competent marine mechanic to survey the engine and provide a repair estimate.

Troubleshooting: Fuel

Engines need three things to run: fuel, spark and compression. Should one of these systems fail, the engine either won't start or may cause it to miss, hesitate, lose power or idle rough. Diagnosing the problem requires a step-by-step systematic approach.



Inline fuel filter has a fine mesh screen that can become clogged. To clean, blow air through filter and reinstall. Replace if torn or punctured.

Beginning with the fuel system, check that you have fuel, that there is no water in the fuel and that fuel is getting to the carburetor. (Water in fuel shows up as beads on spark plugs or, if equipped, visible in a fuel-water separating filter.) Is the fuel hose connected backwards? Check the flow direction arrow on the primer bulb. Does the bulb maintain a firm pressure? This bulb houses a check valve that sometimes fails. Does the bulb go soft or collapse when running? A weak fuel pump is the culprit; depending on use and abuse (i.e. water in fuel, improper winterizing), a fuel pump will last 10 to 15 years, says Mills. With an inboard tank, often the fuel blockage is a clogged filter at the bottom of the fuel pickup tube. Best to remove filter before it causes problems. Is the engine's inline fuel filter clogged? Blow it out with compressed air, reinstall and check for fuel leaks.

To troubleshoot the fuel system, run the engine on a remote fuel tank.

When the fuel system checks out but your engine still runs at wide-open throttle for a few minutes then stalls, it may be the anti-siphon valve installed in the fuel hose. This device prevents fuel from draining out of the tank and into the bilge should the hose disconnect or develop a leak. Such devices are spring loaded and can restrict fuel flow, as much as 3 pounds of pressure. Low pressure creates a fuel restriction in the line which produces gas vapors. In extreme high temps, gas can bubble and a fuel restriction causes vapor lock. Attach a fuel pressure gauge in-line with the fuel system and note fuel pressure when engine stalls. You should have at least 3psi (value may vary with engine; check service manual for specs) at carburetor, below that the engine runs out of gas.

As a final check on boats with inboard fuel tanks, attach a portable fuel tank (i.e. 2-1/2 gal tank) directly to the engine. If the engine doesn't stall, this eliminates fuel system failure.

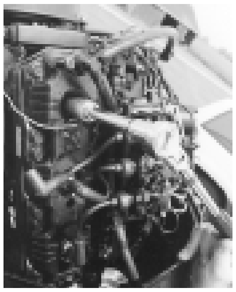
Troubleshooting: Spark

If the engine still won't start, check the ignition system beginning with the spark plugs. There are two types of plugs: standard with an adjustable electrode and surface gap (commonly used on Mercury engines) that cannot be set, are more expensive and typically need a high-energy ignition to function. Numerous types are available, so to be sure you purchase the proper plugs for your engine; for this you'll need to know your engine's serial number. (Also check service manual for recommended plugs.) Consult with an authorized marine mechanic to ensure you match the plug type to your boating usage.

Spark plug failure is usually caused by one of three things: using the wrong plugs for your engine or type of boating usage; improper installation of plugs; or fouled plugs. These conditions build up resistance and restrict amount of voltage produced.

Remove a plug wire by pulling and twisting on the boot. Never pull on the wire or the connection inside the cap may become separated or the boot damaged. Remove each spark plug (use spark plug wrench or 13/16" deep socket) by turning counterclockwise and arrange them in order of removal. The color and condition of the plugs is one of the best tools for analyzing your engine's health. A plug should be dry and powdery. A coffee- or gray-colored insulator indicates the plug is operating at the correct temperature and the air-fuel mixture is correct. If electrodes don't show excessive wear, clean with a wire brush or stiff toothbrush, gap the plug to specification and reinstall.

An insulator that is white or has flaking white blisters is too hot for your type of engine operation, namely high-speed running. Switch to a colder plug. Conversely, a plug with a black insulator indicates the



Use a spark plug wrench or 13/16" deep socket to remove each spark plug, turning counter-clockwise.

A good plug produces a crisp, blue-colored spark; if it doesn't, you've got an ignition breakdown.

Spark plugs are the best built-in engine analyzers. A dry and coffee-colored plug (left) indicates it's operating at the correct air-fuel mixture and temperature.

plug is too cold for engine operation that involves mostly idle, low-speed running or trolling. If this condition shows on only one plug, the cause is usually low compression in that cylinder.

Wet, black carbon fouling over the firing end indicates an improper carburetor adjustment and you're wasting fuel, a too-cold plug, incorrect fuel-oil mixture or poor grade oil, worn piston rings or a bad ground on the power pack (see below). Clean, regap and reinstall after correcting the problem. A water-logged plug, identified by water beads on the firing end, is an indication of water in the fuel.

A badly eroded electrode with a blistered white or gray insulator, indicates overheating or pre-ignition usually caused from a too-hot plug, overadvanced ignition timing, defective water pump, clogged water intake or incorrect prop (lugging engine).

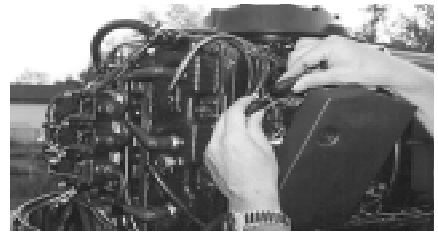
Hard deposits wedged between electrodes originate in the combustion chamber and are formed by excessive carbon in the chamber, use of incorrect oil, too much trolling followed by high-speed operation, and improper fuel-oil mixture. Operate at high speed to clean out engine.

Badly worn electrodes result in a wide gap that can become carbonized and cause the engine to misfire during acceleration, increase fuel consumption and poor high-speed performance. Replace the plug with a rating in the proper heat range and gapped to specification.

If the engine still fails to start, remove spark plugs. Attach a boot to one of them, hold the plug against the cylinder head and pull the recoil starter (or turn key switch). (Hold the plug wire with insulated pliers to prevent getting a shock.) A crisp, blue-colored spark should jump the plug's electrodes. An orange- or yellow-colored spark indicates a weak spark. If there's no spark, check the key switch (if equipped) and the ignition stop switch (a.k.a. kill switch) as they both cut off the ignition.

Also, check voltage at the coil by attaching a voltmeter. With the engine running, the meter should register voltage as specified in service manual.

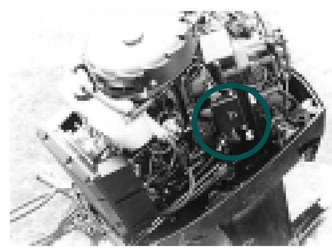
Another reason for no ignition when turning the key is a blown engine fuse. Located on the engine, this protects the key switch and gauges. A typical 20-amp, fuse-protected ignition system draws 6 amps, gauges draw 6 amps plus a 40% margin for resistance. If you tap into the engine-gauge wiring harness when adding a radio, horn, wipers, etc., the fuse often can't handle the extra voltage demands and blows to prevent melting the wiring. On our Mercury 150hp, this fuse blows every few years (usually at the ramp) from corrosion so we always carry a



Don't overlook engine fuse as a reason for failing to start.

spare. Check service manual for fuse location; on the 150 it's located behind the rear panel on the starboard side. Note: Never connect electrical accessories to the engine wiring harness; instead run dedicated 10-gauge wire from the battery to an accessory terminal block installed under the helm, and fuse each one.

Failure to start can also be caused by a faulty power pack or "black box" (larger engines have two). Mounted on the flywheel or side, this device controls spark to the cylinders. Before replacing the power pack (a very expensive part), check the ground: follow the orange



Location of power pack on 1990 Mercury 150hp.

TIPS

DON'T MESS WITH FUEL

Gasoline vapors are highly explosive. If you find a leak in the fuel system, take your boat to a qualified authorized marine engine repair center. Ditto if you need to make modifications to a built-in inboard tank as every part must be grounded to the battery to prevent static spark.

RELAUNCH GUIDE

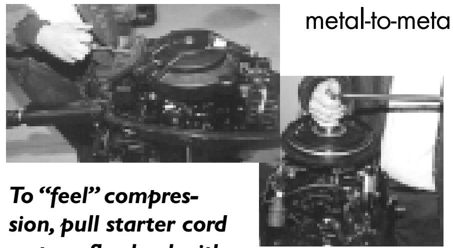
If you correctly prepared your outboard for storage, very little needs to be done for launching. First, check your list and service or replace as needed. With engine in running position, check the gear oil level: remove the air vent screw (top screw on the lower unit) and if oil doesn't trickle out, add gear oil until full and reinstall screw making sure O-ring or gasket is attached. There is usually oil loss due to evaporation during storage. Attach the fuel line to the engine (if portable tank) and use the primer bulb to fill the fuel system. Remove engine cowling and check for fuel or oil leaks (if equipped with oil tank reservoir). Replace cowling. Add an octane booster to fuel tank (check service manual for recommendations). Activate the choke, pull the starter handle three or four times and the engine should start. If it doesn't, follow the troubleshooting steps above. Run motor briefly to burn off fogging oil. Let motor cool down, put shifter in neutral, remove cowl and install new spark plugs after checking electrode gap. Replace cowling, start engine, check gears by shifting into forward and reverse, then go boating!

wires from the coil to the power terminal to remove corrosion, replace and start engine. If mounted on flywheel, you'll have to remove it.

Troubleshooting: Compression

If after you've checked fuel and spark your engine still won't start, you need to check compression. An engine with low or uneven compression between cylinders will not operate satisfactorily.

Compression is normally checked with a compression gauge, but Mills recommends turning the engine by hand, an easier and often more accurate method for DIYers. With the engine in neutral, disconnect spark plug wires (grasp the boot, then pull and twist) but leave plugs in, and slowly pull the starter cord until it grabs. On a healthy engine, you should feel two compression strokes in one revolution and they should feel identical; four strokes on a four-cylinder. On larger outboards, use a ratchet to turn the flywheel in the direction the engine runs (check service manual; most are clockwise, otherwise you'll flip impeller blades backwards) and turn one revolution; compression should be equal in all cylinders. A variation between cylinders may indicate worn, broken, or sticking piston rings or worn cylinders. If you feel metal-to-metal contact, pistons are likely scored. Further inspection and repair involves removing the head.



To "feel" compression, pull starter cord or turn flywheel with a ratchet, and turn one revolution.

Overheating

An overheating condition may be caused by a faulty water pump or impeller, blocked water intake, clogged water passages on the discharge side of the engine caused by hard water or salt build-up, or running the engine without water.

Never run an engine, regardless of size, without water circulating through the lower unit, either by submerging the lower unit or attaching flush ears. When water stops coming out the exhaust overboard or exhaust relief holes on older engines, or the overheat alarm sounds (which in some cases is too late to avoid engine damage) check the water intake. Often the intake grate becomes plugged with weeds, sand, plastic bags or other flotsam. To clear a blocked discharge line, ream out the discharge orifice with a stiff length of wire (a straightened paper clip works great). *(continued on page 26)*

30 STEPS TO OFF-SEASON STORAGE

Preparing your outboard for long-term storage isn't a hard job, nor is it expensive. Professional winterizing by a competent marine mechanic starts at $75, depending on engine horsepower, and may be a practical solution for some. If you decide to do the job yourself, materials will cost $40 or more and you'll need to reserve about six hours to complete all procedures outlined below.

Start with the boat in the water and engine in neutral, or place the motor in a barrel or use flush ears to supply water to the engine. Never start a motor without water! If using flush ears, always remove propeller to prevent injury. Remove spark plug wires before touching prop to avoid accidental starting.

1 Add a fuel stabilizer to your fuel tank and run your engine for at least 5 minutes. This ensures that the treated fuel goes through the entire fuel system. Better yet, remove the boat's fuel source and in a portable tank mix up 1-gal high-octane fuel (the highest available), fuel stabilizer and two-cycle motor oil at a ratio of 24:1 or 1qt to 5gals. Run the engine at idle for five minutes to distribute this "soup" through the system.

Add two-cycle oil to the fuel with the stabilizer then run the engine to coat the fuel injectors, carburetor, fuel pump, etc.

2 Remove the engine cowling and locate the opening of the carburetor(s); this may require the removal of the air box. To decarbonize engine, spray engine tuner (i.e. OMC Engine Tuner or Mercury Power Tune) into the carburetor air intake and run engine at fast idle for about 10 minutes. (This step is not usually needed unless you use bad oil and not always recommended so best to refer to your engine's service manual.)

3 To check water pump output, run engine at idle and at cruising speed and observe cooling-water stream exiting exhaust outlet. Carefully check the water temperature with your finger. It should be warm, but not hot. Service water pump and replace impeller every other year or when water flow is restricted. (For complete replacement instructions, see DIY 1998-#2). To readily diagnose the cooling system on larger outboards, install a water pressure gauge (You'll find how to do this in DIY 1997-#1.)

On older outboards, carefully drill screw holes through plate to line up with carburetor air intake. When need to fog engine, remove screws and insert applicator.

Fuel-injected engines are fogged by putting a 50/50 mix of fuel stabilizer and two-cycle oil into the fuel-water separator, then run engine only until it begins to stall.

4 With the engine running, spray fogging oil into the carburetor(s) air intake to "fog" the engine. Continue spraying ony until engine begins to stall.

5 Disconnect the fuel line (if portable tank).

6 To clean inline fuel filter (not usually necessary to replace), spray with compressed air, water or a moisture-displacing lubricant. Change fuel-water separating filter (if equipped).

Fuel-water separating filter keeps fuel system clean and free of water and other contaminants.

7 Remove spark plugs by turning counterclockwise and inspect, regap and clean with a stiff brush. If cracked or fouled, buy new plugs (see "Troubleshooting: Spark" on page 27). Spray fogging oil into cylinders. Turn flywheel 10 or more times. Reinstall spark plugs – finger tighten then use a torque wrench (typically 15 to 18psi) or give 1/4 turn with a wrench. To prevent stripping threads, lightly apply anti-seize lubricant to the plug before inserting. Dab dielectric silicone grease into spark plug boots.

8 Remove the boat from the water or remove motor from barrel or disconnect flush ears.

9 Remove the lower unit drain plugs with a slot screwdriver and drain and replace the gear oil (see "Lubrication" on page 31). Place oil into clear container and check for water or metal particles. Recheck oil level in spring and top up if necessary.

Water must always circulate through engine anytime the engine is running. Use a flushing device (a.k.a. rabbit's ears) or attach a threaded fitting to a garden hose.

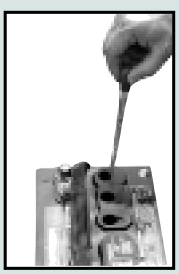
10 Remove tubing from end of speedometer fitting and blow air back toward the pitot to remove water to prevent freezing.

11 Examine skeg and repair if bent or broken.

12 Remove prop and inspect for dings and chips. Inspect prop shaft and seal for fishing line, weeds, etc., a common cause for water-contaminated gear oil. Lubricate prop shaft.

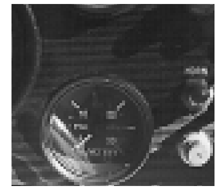
13 Clean all lubrication points and zerk fittings (as outlined in owner's manual) of old grease and reapply a quality waterproof grease.

14 Lubricate all moving parts, including shift and throttle cables. Check service manual for details.
15 Check zinc anodes and replace if worn to less than half of original size. Use a multimeter to ensure they are properly grounded: resistance should be zero when you connect positive probe to the anode and negative probe to an engine ground.
16 Retorque all bolts to factory specs (see service manual).
17 Visually inspect for all loose or worn hoses and wires, missing fasteners, corroded hose clamps, etc.
18 Lightly spray entire powerhead with a moisture-displacing lubricant. Coat rubber seal on cowling base with vinyl-rubber preservative, lubricate cowling latches, then replace cowling.
19 Clean and lubricate steering cables. To extend cable, turn steering wheel hard over to starboard, then apply grease. Clean and grease tilt tube.
20 For hydraulic steering, check fluid level in reservoir. To refill, turn wheel to port to retract cylinder rod to prevent an oil spill. With wheel turned to port, check port hose connections for leaks. Repeat with wheel turned to starboard.
21 Check fluid level in power trim oil reservoir and refill with proper fluid as needed. Check wires for chafe on trim gauge sender (commonly located on inside of a stern bracket).
22 Clean and lubricate pivot pins of the tilt cylinders.
23 Clean exterior and protect with a wax or spray-on, wax-based corrosion inhibitor.
24 Check housing for corrosion, chips or scratches and for any areas where paint has exposed metal, wet sand with 320-grit paper, mask surrounding area, then apply primer and spray touch-up paint. Don't paint anodes.
25 Fill up the fuel tank with fresh gas and oil (if mixed).
26 Inspect battery posts and terminals, and clean as needed. Disconnect terminals before cleaning. Check electrolyte level and add distilled water, as needed. Fully charge battery if leaving in boat.



An inexpensive hydrometer reads battery voltage of individual cells.

27 Send propeller out for repair, if necessary.
28 Make a list of what maintenance needs to be done, parts to purchase or repairs to make prior to launching. Update maintenance log.
29 Store engine in an upright position so gravity will drain all water out of the block. Loosely cover engine, allowing for ventilation to prevent moisture build-up.
30 Follow procedures in "Relaunch Guide" on page 29 when relaunching.



Left:When engine is running, water must always exit the exhaust telltale. Right: Water pump housing with worn impeller; unable to pump enough volume of water to cool the engine, this impeller caused overheating at WOT. Bottom: The only way to monitor water pressure is with a water-pressure gauge. If your boat is without, install one!

Have you serviced your water pump lately? Should it fail water stops exiting the exhaust and your engine overheats. Depending on the impairment, overheating often occurs during high-speed running when the pump can't pump enough volume to cool the engine. Servicing the water pump and replacing the impeller every two years is cheap insurance against an overheated engine. An impeller kit ($42) has everything you need to do the job.

The best way to monitor the condition of the water pump and impeller and detect a potential overheating condition long before the engine overheats, is to install a water pressure gauge. Few boats are factory-equipped with this gauge, yet it's arguably one of the two must-have outboard gauges (the other is a tach). Refer to DIY 1997-#1 issue for complete step-by-step installation.

Lubrication

Check your service manual for all the required lubrication points, type of lubricant required and frequency. Oil in the gear housing is normally changed every 100 hours or once a year before storing; more frequent users should change oil at least twice a season.

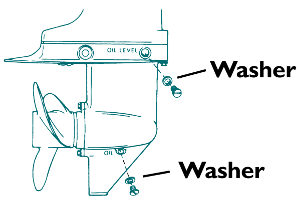
Changing gear oil is an easy, half-hour job. Tilt outboard up so that oil drains freely from housing. Remove drain/fill screw and washer (lower screw) and check for metal particles attached to screw. Metal particles may indicate gear wear and requires complete disassembly of the lower unit. Remove vent screw and washer (top screw) and let oil completely drain into a proper collection container. To refill, move outboard to fully trimmed in (operating) position. Insert oil tube into drain/fill hole. Add lubricant to gear housing until excess flows from vent hole. Drain about 30ml (1oz) from fill hole to allow for expansion. Install vent screw and washer. Remove oil tube and install cleaned screw with washer. To

Grease gun fits onto grease tube and makes easy work of lube jobs.

Changing gearcase lube is easy with a small hand pump. Insert hose into lower drain/fill hole and pump handle until oil spills from vent hole.

prevent water leaking into gearcase, be sure screws are installed with washers and replace worn ones. (Tip: Keep a supply of washers in your spares kit.) Never add oil without first removing vent screw or trapped air will prevent you from completely filling housing.

Before disposing of oil (take it to a recycling depot), place some in a clear container and let settle. Oil should be clear. Milky caramel-colored oil indicates a leak, meaning water entered the gearcase either through plug washers, stripped or cross-threaded plugs, or more likely worn prop, shift shaft or water pump seals. This requires immediate servicing — water can quickly rust or seize an oil-starved gearcase. A qualified marine mechanic can check condition of seals with a pressure gauge. Seals normally last 10 to 15 years but wear quickly in engines run in silt or sandy conditions. A replacement seal kit costs $36 and contains all needed gaskets, O-rings and seals. Burnt, blackish colored lube may indicate worn gears or bearings and requires disassembly of the lower unit.



Balancing the Prop

A propeller with dings, chips or running out of balance puts a lot of stress on the gearbox, driveshaft splines, pinion gear and other components, especially at high speeds. "Take a chip out of a helicopter blade and see how well it operates," exclaims Mills. Damage to gears can happen in a few hours or 50 hours, and result in a $2,000 or higher repair bill, depending on engine size.

Before servicing the prop, make sure the key switch is in the off position, disconnect the spark plug wires, remove leads from battery posts and shift to neutral. To prevent the prop from turning, place a block of wood between one of the blades and the anti-cavitation plate. Never pry on the edge of the propeller. Prop removal procedure varies with each engine brand; check service manual before proceeding. Procedure for a Mercury 150hp follows: Use prop pliers to bend back the locking tabs on the tab washer. Remove prop nut with prop wrench or socket, turning counterclockwise. Slide tab washer, splined washer, continuity washer, prop and forward thrust hub off propeller shaft. If the thrust hub is stubborn and refuses to budge, use two padded pry bars on opposite sides of the hub and work the hub loose. If the propeller is frozen to the shaft, apply heat, which also melts and destroys the rubber inside the hub. Do this carefully: as heat expands the rubber, the prop may be blown off the shaft. Cut or pull off the hub.

Inspect the prop for fishing line, weeds, etc. Check the prop seal. If damaged, gear oil leaks out only to be displaced by water. Clean the prop with steel wool. To reinstall the prop, apply waterproof grease to prop shaft splines to facilitate removal next time, slide on forward hub, prop but first align splines, washers and install nut. Place wooden block to hold prop and tighten prop nut to specified torque (refer to service manual) and bend down tabs on tab washer. (Again, check service manual for engine-specific instructions.)

Trim Tab Adjustment

The sacrificial zinc anode mounted on the anti-cavitation plate is also known as the trim tab. It protects the lower unit against corrosion and can be easily adjusted to correct steering torque or upgraded (i.e. longer tab) to match engine height and propeller configuration.

Does your boat pull hard to the right or left? Is there unequal wheel or tiller tension in each direction? To equalize steering pressure, remove the plug on top of the housing above the tab (removal procedure may vary depending on engine manufacturer). Loosen the screw or nut. If the boat turns easier to the left than to right, move the trailing edge of the tab to the left when viewing the motor from behind; move the tab to the right if boat turns more easily to the right. Since the exact adjustment requires experimentation, start with small corrections.

MERCURY MARINE

Before adjusting the tab, make sure the engine is centered and square on the transom and mounted at the proper height. For manually adjusted trim, the engine should be in the correct tilt pin hole. If equipped with power trim, position the engine at the optimum trim angle.

TIPS — A DEAD STOP

Carry a spare ignition stop switch (a.k.a. lanyard) or two. These could be a plastic prong clip or a rubber cap, depending on your engine, but all serve the same purpose: to prevent the engine from starting if not attached or shortout the ignition system if loose. Lanyards break, deteriorate or mysteriously disappear and without one, muscle power may be your only means home.

A BOAT OWNER'S GUIDE TO PREVENTIVE MAINTENANCE

Are you interested in preventing breakdowns and saving money? This specialized maintenance program is designed to maximize the performance and reliability of your boat's engine and all onboard mechanical equipment. It may actually help to reduce lifetime maintenance and operating costs as well.

By Robert Hess

Sudden engine failure is the concern of every boater. Despite the risks associated with engine failure and other marine gear, many owners continue to carry out only basic traditional maintenance work.

Most marine engine preventive maintenance programs still consist only of seasonal tune-ups and oil changes along with daily pre-start checks for loose belts and low coolant and oil levels. The skipper may also frequently monitor the engine and occasionally check a rudimentary set of analogue gauges and listen for changes in the sound of the engine exhaust or the feel of the engine vibration transmitted through the hull.

Take time to develop a maintenance program for your boat's engine and all mechanical equipment onboard and you'll spend more time on the water enjoying your boat and less time tied to a dock or on the hard.

Mechanical Actions

Modern maintenance programs should consist of a mixture of three basic strategies: run-to-failure, preventive maintenance and predictive maintenance. Programs based on one or more of each of these basic strategies are selected for each engine component in order to keep overall equipment lifecycle costs as low as possible while ensuring the equipment functions at peak performance.

Run to Failure is used for maintaining non-critical components that are allowed to fail without affecting overall equipment operation — the component can be changed quickly and it's possible to carry spares (i.e. battery powered tools, light bulbs), or there are dual or backup systems that allow equipment to continue operating without interruption (i.e. dual filter assemblies, back-up generators).

Preventive maintenance (PM) is the traditional maintenance program included in operators' manuals; usually a list of specific lubrication and adjustment work based on a time schedule (i.e. an oil change every 100 hours of engine running time). It's usually performed when equipment is not being used.

Predictive maintenance (PdM) measures and tracks the condition of equipment components that are considered to be capable of causing overall equipment failure. The estimated time of failure of each can be predicted and once determined, overhaul or replacement of the component or equipment is scheduled for a convenient time. This not only prevents failure, but also maximizes the service life of the equipment. Examples of PdM measurement are oil, vibration, lubrication and alignment analysis. PdM is usually performed when equipment is in use, in order to get accurate measurements at full load and temperature; there is no need to schedule shutdowns for PdM inspections.

These processes are referred to collectively as Reliability Centered Maintenance (RCM). Since different equipment, varying standards of component manufacture or quality and different operational conditions affect equipment reliability requirements, each case must be evaluated individually to select the most cost-effective program. Implementation of RCM isn't easy, until one becomes familiar with procedures and terminology.

Implementation Steps

When your PdM schedule is in the planning phase, a critical analysis called "rationalization" must be completed before implementation begins. Rationalization is a process to compare the time required to perform the inspections plus the estimated time required for the overhauls triggered by the PdM measurements plus the estimated time required for corrective maintenance to repair failures which

(*continued on page 31*)

ENGINES RCM (PM & PDM) PROGRAM

Root cause failure analysis data collection and most common causes of inboard engine failures.

Defective starting battery	**28.0%**
Out of fuel	**14.0%**
Unknown/undetermined	**16.0%**
Transmission or outdrive failure	**6.6%**
Electrical system failure (excluding starting battery)	**4.7%**
Overheating	**4.7%**
Fuel pump failure	**3.8%**
Starter failure	**2.4%**
Water pump failure	**2.4%**
Major mechanical failure	**8.9%**

To convert preventative maintenance (PM) frequency units from operating time (engine hours) to energy consumption (fuel consumed in litres) use these conversion factors:

GASOLINE ENGINES:

1 hp = .3L/hour; 15 hp @ 2,000 rpm under load = 4.5L/hour

DIESEL ENGINES:

1 hp = .2L/hour; 15 hp @ 2,000 rpm under load = 3L/hour

Work Order: Daily PM Checks

Each day of use before starting engine:

___ Drain water from fuel-water separator/filter bowl.
___ Check engine oil level.
___ If fitted, turn grease cup cap(s) 1/4 turn.
___ Check fuel level and calculate fuel requirements.
___ Check heat exchanger coolant level.
___ Check drive belt condition and tension.
___ Check engine for leaks and loose fasteners.

Work Order: Intermittent PdM Work

Monitor the following instruments:

___ Monitor oil pressure gauge reading within specification and stable.
___ Monitor coolant temperature gauge reading within specification and stable.
___ Monitor oil temperature gauge reading within specification and stable.
___ Monitor coolant pressure gauge reading within specification and stable.
___ Monitor transmission (marine gear) oil temperature gauge reading within specification and stable.
___ Monitor alternator charging amperage within specification and stabilize to match electrical load once batteries are charged.
___ Monitor alternator charging voltage within specification

and stabilize once batteries are charged.
___ Monitor fuel tank level gauge dropping slowly at normal rate.
___ Monitor hull vibration normal and stable.
___ Monitor volume of cooling water being ejected at the exhaust normal and stable.
___ Monitor exhaust smoke normal and stable.

Work Order: Scheduled PdM Work

Every 25 hours x engine hp x .3 gas or .2 diesel (litres):
___ Record oil pressure at full load.
___ Record coolant temperature at full load.
___ Record oil temperature at full load.
___ Record coolant pressure at full load.
___ Record cylinder head temperature at full load.
___ Record exhaust manifold temperature at full load.
___ Record intake manifold vacuum at idle and full load.

ENGINE RCM (PM & PdM) PROGRAM

___ Record exhaust back pressure at full load.
___ Record transmission oil temperature at full load.
___ Record engine starting battery load test voltage.
___ Record voltage drop from starting battery positive terminal and starter positive terminal, and voltage drop from battery negative terminal and starter frame.
___ Record alternator charging amperage at full charge.
___ Record alternator charging voltage at full charge.
___ Calibrate fuel tank level gauge.
___ Record propeller shaft vibration at full load and speed.
___ Measure hull vibration at full load and speed.
___ Measure volume of cooling water being ejected at the exhaust at full load.
___ Take engine oil sample and record analysis data.
___ Take transmission (marine gear) oil sample and record analysis data.

Work Order: Scheduled PM Work

Every 50 hours x engine hp x .3 gas or .2 diesel (litres):
___ Refill water pump grease cup. Clean sea water strainer.
___ Inspect engine for leaks and loose fasteners.

Work Order: Scheduled PM Work

Every 500 hours x engine hp x .3 gas or .2 diesel (litres):
___ Measure reversing gear adjustment and adjust if necessary. Wash carburetor flame arrester element.
___ Replace air filter.

Work Order: Scheduled PM Work

Every 750 hours x engine hp x .3 gas or .2 diesel (litres):
___ Adjust valve clearance.
___ Torque cylinder head.
___ Clean and service ignition system.

___ Clean and service fuel injection system.
___ Clean and service batteries.
___ Check and adjust engine and propeller shaft alignment.

Work Order: Scheduled PM Work

Every 1,500 hours x engine hp x .3 gas or .2 diesel (litres): Flush cooling system. Replace all rubber hoses.

Work Order: Seasonal PM Work

Before laying up boat for winter storage:

___ Add 1L of fuel stabilizer to gas tanks or 1L of diesel fuel conditioner to diesel fuel tanks and fill fuel tank with fuel.
___ Check and/or replace cooling system sacrificial anode(s).
___ Drain fuel filter housing(s) and replace fuel filter(s) element(s).
___ Change engine oil and oil filter. Change oil hot and run engine for 5 minutes with new oil to circulate clean oil through all bearings.
___ Connect seawater intake hose to a pail of non-toxic antifreeze and run engine to suck antifreeze into cooling system until it comes out exhaust.
___ Block exhaust outlet and tag engine with "Do Not Start."
___ Inspect water pump impellers and replace if necessary. Remove impellers from water pump until boat is returned to service to avoid blades taking a permanent set.
___ Lubricate control panel stop cable and ignition switch.
___ Check and clean, fill and/or charge engine starting and house batteries.
___ Drain carburetor float bowl and fuel pump sediment bowl.
___ Spray engine with rust preventative oil.
___ Remove spark plugs and/or fuel injectors and pour 1/8 cup of engine oil into combustion chamber.
___ Turn engine over by hand several times. Replace spark plugs and/or fuel injectors.
___ Clean, gap and replace spark plugs and/or clean and test fuel injectors.

occur despite the PdM program, with the actual work time available to do the work. If there is not sufficient work time available, contractors must be hired, or the PdM plan reduced, to make the plan doable. Skipping PM tasks or PdM measurements due to a lack of resources will result in increased failures and an increase in repair costs.

Regardless of the type or size of your engine or equipment, follow these 11 steps to implement your maintenance management system. To gain a better understanding of RCM, refer to the sample implementation exercise, "Example Of RCM/PdM Implementation For Engine" on page 38.

1 Standardize and define the following common operational and maintenance terminology.

Failure: Equipment or components break or stop working to specification.

Downtime: Equipment is out of service or not useable during normally scheduled operating time.

Corrective maintenance: Work to repair a failure.

Planned maintenance: Work to prevent failures from occurring.

Predictive maintenance: Work which gathers equipment condition data for use in predicting the time of failure, so rebuild or replacement can be scheduled to prevent failure.

Reliability: Average time between failures.
Availability: Percent of time equipment is out of service during its normally scheduled running time.
Maintainability: Average time to carry out corrective maintenance to correct a failure.

2 Identify and record a unique identification name and/or number (called the Equipment Number) for each piece of equipment and its components and record the make, model and serial number of each.

3 Decide on the primary operational performance requirement for each piece of equipment. Since the operational requirement for similar equipment can differ greatly depending on use, it's correct to assume that the goal is to minimize operational, depreciation and maintenance costs over the life of the equipment. In the case of critical equipment, the primary operational requirement will always be absolutely no breakdowns (total reliability). Other equipment may have very limited downtime (i.e. 5%), since it's very expensive to maintain such gear with the goal of absolutely no failures. Equipment that can be taken out of service to replace worn parts, for example, for short periods without causing a problem may have a primary operational performance requirement of downtime of less than 5% of scheduled operating time and life span of 10 years or longer.

4 Select the standard operational performance indicator(s) to evaluate the primary operational performance requirement selected. Confirm the operational data that must be collected to calculate them, and decide how it will be collected. Standard operational performance indicators are calculated statistics that measure the operational performance of equipment so the maintenance program can be constantly improved.

Once the performance indicators are selected, you'll need to record the data, namely Reliability, Availability and Maintainability that are required to calculate them in a daily log. Such calculations require the collection and recording of the operating time and number of failures and/or downtime due to failures.

The most important performance indicator used is Reliability, defined as the average interval between failures and calculated as: total operating time (in minutes) divided by the number of failures. A typical reliability calculation would be as follows:

Total operating time
= 80 hours x 60 = 4,800 minutes
Number of Failures = 4
Reliability = 4,800/4 = 1,200 minutes.

Availability is defined as the percentage of time the equipment was ready for service during its scheduled running time. It's calculated as: scheduled operating time (in hours) minus downtime due to equipment failure (in hours) divided by scheduled operating time (in hours) multiplied by 100. Optimum is 100% equipment availability during the scheduled operating time. A typical calculation with a total downtime of 5 hours would be as follows:

Total scheduled operating time
= 85 hours
Total downtime = 5 hours
Reliability = 80 hours/85 hours x 100 = 94%

Maintainability is defined as the average time required to return the equipment to service and calculated as: downtime due to equipment failure (in minutes) divided by the number of failures. A typical calculation with a 5-hour downtime, would be as follows:

Total Downtime = 5 hours x 60 = 300 minutes
Number of Failures = 4
Maintainability = 300/4 = 75 minutes

EXAMPLE OF RCM/PDM IMPLEMENTATION FOR ENGINE

Common Failure Description	RCFA	Key Component	Operational Performance	Key Measurement(s) to Predict Requirement	Measurement Point Failure	Measurement Instrument/	PdM--Work Measurement Tool (unit)	PdM- Frequency	Measurement Triggering Measurement	Measurement Triggering Scheduled
Defective starting battery 28%	Sulphated starting battery	Battery	Reliability=engine operating time (no downtime)	Battery load test & charge recovery test	Control panel wiring harness	Control panel starter draw ammeter, alternator charge ammeter, voltmeter	Measure starter draw voltage drop & battery charge recovery rate after start	Engine start	Voltage drop changes -.2 volts from normal = check charging system, if OK, replace battery; .5 volt change in battery charge recovery rate start & finish voltage or 2 minute change in time from start to near 0 minutes	Voltage drops to < 9.8 volts = check charging system, if OK, replace battery; 1 volt change in battery charge recovery rate start & finish voltage or 5 minute change in time from start to near 0 minutes
Out of fuel 14%	Insufficient fuel for completion of trip distance	Fuel tank/fuel tank level sensor	Reliability=Engine operating time (no downtime)	Fuel tank level & trip distance fuel volume necessary to reach destination	Fuel tank level	Fuel tank level sensor & gauge marked in units of boat distance capability	Monitor tank level and distance to destination	Constant	Fuel tank capacity gauge reading=distance to destination +10%	Fuel tank capacity gauge reading < distance to destination
Engine mechanical failure 8.9%	Crankshaft/ connecting rod/piston/ valve/camshaft fatigue crack leading to failure	Internal engine components	Reliability=engine operating time (no downtime)	Vibration, engine overspeed, overload, misalignment	Vibration analysis, engine speed/load measurement	Vibration, speed, alignment measurement tools	Measure vibration, speed, alignment, load	Engine fuel consumption or engine hours	Vibration, speed, alignment=maximum spec: schedule rebuild or repair	Vibration, speed, alignment exceed maximum spec: immediately rebuild or repair
Transmission/ outdrive mechanical failure 6.6%	Transmission/ outdrive bearing or gear wear or fatigue crack leading to failure	Shaft, bearings, lubricant	Reliability=engine operating time (no downtime)	Bearing wear: wear particles in oil	Oil analysis	Oil analysis tools	Take oil sample & send to oil analysis lab	Engine fuel consumption or engine hours	Low level of steel particles = check bearing axial play & end play. Schedule replacement if measurement exceeds minimum wear limit	High level of steel particles = check bearing axial play & end play. Immediately replace lubricant. Immediately replace bearings if measure-ment exceeds maximum wear limit
Electrical system failure 4.7%	Electrical system failure	Alternator, wiring	Reliability=engine operating time (no downtime)	Charge rate voltage OK & full rated alternator output	Distribution panel, battery, alternator	Voltmeter & adjustable carbon pile load with ammeter Ohmmeter Infrared scanner	Test alternator output Measure voltage drop to terminals Measure terminal temperature under full load	Engine fuel consumption or calendar days	Fail output test = check/adjust/replace alternator belt, if OK rebuild alternator Voltage drop >.01 volt=clean/repair terminal connection	Fail output test = check/adjust/replace alternator belt, if OK rebuild alternator Voltage drop >.1 volt = clean/repair terminal connection
Overheating 4.7%	Partially blocked heat exchanger and/or water jackets	Sea water strainer, heat exchanger water pumps, water jackets	Reliability=engine operating time (no downtime)	-.2 psi change in water pressure before pump, + .2 psi change in water pressure after pump	Seawater and engine-coolant pumps intake & outlet ports	Control panel water-pressure sensor or gauge (.1 psi scale)	Monitor water pressure and note change of +/-.2 psi or more	Constant (fixed sensor & warning indicator) or Operator monitoring 1/hour (fixed gauge)	+/-.2 psi change from normal	+/-.5 psi change from normal

5 Analyze the possible real causes of failure of each component using both past service records (called Root Cause Failure Analysis or RCFA) and predictions from experienced technicians and operators based on their experience with similar equipment. Identify at least one numerical measurement for each critical sub-assembly which can be used to verify that it's in good condition and monitored to track a deteriorating condition leading to the failures identified using RCFA (i.e. temperature, vibration, pressure, alignment, etc). Identify the appropriate meter or tool to take the numerical measurement (i.e. temperature gauge, pressure gauge, dial gauge, etc).

6 Prepare and implement a schedule of regular PdM inspections to collect the numerical measurements identified. Similar to a PM work schedule, it should be directly related to equipment wear and corrosion by using units linked to energy consumed (watts of electricity, litres/gallons of fuel), time (hours, days, months, seasons). An engine hourmeter, for example, gives only an indication of the time the engine was running, not the load it was under. Since most engine wear occurs as a result of load, a much better indicator of engine use is fuel consumption as the basis for engine PdM schedules.

7 Confirm how the data will be recorded and stored. The alternative to a regular measurement collection schedule is continual monitoring by sensors or warning indicators which are capable of detecting minor changes, such as an oil-pressure sensor.

8 Rationalize the maintenance plan by adjusting the inspection schedule so the plan is doable.

9 Once the data collection program is in place, regularly sort and organize the numerical measurements and analyze them to predict the failure time of each sub-assembly, so that repair, rebuild or replacement work can be scheduled before failure is predicted to occur. In most cases the best planning tool is a simple line graph, with the PdM scheduling unit (i.e. energy consumption) on the horizontal "X" axis along the bottom, and the PdM measurement unit on the "Y" vertical axis on the left side.

10 Carry out the scheduled repair, rebuild or replacement work.

11 Track the root cause of each failure or unplanned repair using RCFA and modify the PM inspection schedule and PdM data collection to ensure a similar failure never occurs again. ⚓

About the author: Robert Hess operates Atomic Four Engine Service in Vancouver, B.C., and specializes in sales and rebuilding of Universal gas and diesel marine engines.

DIY Fiberglass Clinic

How To Survey, Repair & Prevent

REPAIRS YOU SHOULDN'T IGNORE

Despite the fact that fiberglass boats appear to last forever, poor construction and reckless use result in flexing of many hulls and decks. Initially, telltale cracking appears on the surface, and as it progresses, major structural failure can occur. In extreme cases, flex-related damage can sink a boat. Find out why your boat is flexing, how to survey the damage, then effectively repair it to prevent recurrence.

***DIY 1998-#1** issue reviewed the steps and techniques to do professional fiberglass cosmetic repairs. In this special section, DIY details structural defects — hinging, cracking and delaminating — in fiber-reinforced plastic hulls and decks: how to identify critical failures; execute repairs to damaged hulls and decks, and provide key preventive remedies. Whether you are making it a do-it-yourself repair or hiring a professional, this knowledge will help you make informed decisions that can add years to the life of your boat and dollars to its trade-in value. — JM*

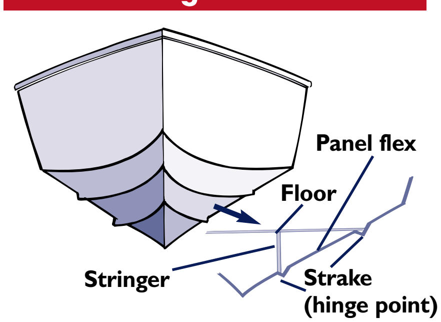
By Nick Bailey

Some years ago, our club's mark boat, a new 6.4m (21') center console runabout with a foam-filled double bottom, almost sank before the frantic operator was able to beach it. Just below the waterline forward, the bottom had split open athwartship and water pressure had torn the hull neatly along the center strake. This left a large panel of fiberglass flapping loose and exposed the foam-filled hull. The boat was a write-off. Apparently the builder, by then defunct, in a classic case of under-engineering, had skimped on the outer skin laminates and used flotation foam of inadequate density and strength. The usual pounding a powerboat hull receives gradually crushed the foam. This allowed the too thin fiberglass skin to flex until it cracked, the lip snagged the high-speed water flowing past the hull and suddenly ripped open. This sort of dramatic failure is rare in fiber-reinforced plastic (FRP) boats, but unfortunately cracked and leaking hulls are not, especially in powerboats with high-hours or older sailboats.

Flex-Related Hinging

In flex-related powerboat hull failures, initial stress cracks usually appear at or adjacent to where panel flex is restrained or limited by either internal structural members (i.e. bulkheads or stringers) and chines, running strakes or other external sharp corners

Figure 1

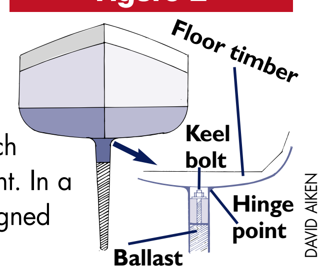


Flex-related hinging in a powerboat.

(**Figure 1**). This concentration of flexing stress at a hard point or corner radius may subsequently lead to failure. This is called "hinging," since the motion of the flexing panel rotates around the point of restraint where the crack appears.

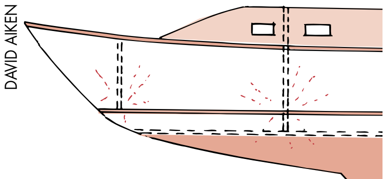
Running strakes, chines, steps, transom edges and all other sharp corners concentrate the bending stresses from wave pounding and bouncing along on the trailer. Such areas are the most demanding of careful workmanship. Fiberglass is reluctant to lay neatly into sharp corners in the mold: fibers get thinned out as they are pushed in with a lay-up tool, air bubbles remain and resin pools without much glass content. In a poorly designed and constructed hull, premature cracking and failure will begin at these locations; an experienced hull surveyor will look here first for signs of hull failure to come.

Figure 2

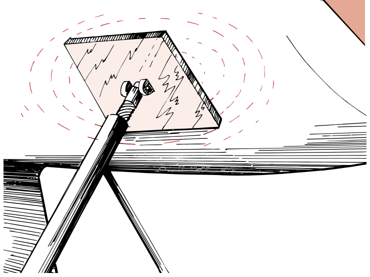


Hinging in a sailboat.

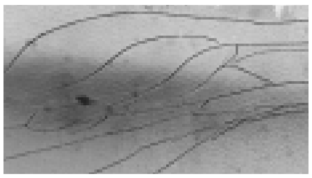
Hinging problems are also common in sailboats. Flex-related stress cracks often occur above the waterline in the relatively flat forward sections of the hull, usually along the line of a bulkhead or vee-berth top. Relatively flat hull panels tend to "oil-can" or pop in and out as the boat beats to weather. Due to a sailboat's lower speeds and correspondingly



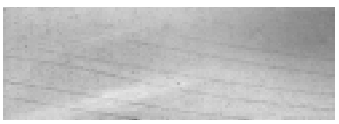
1



2

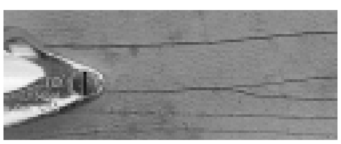


3

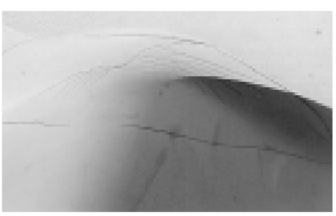


4

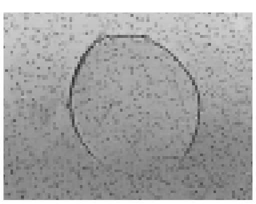
5



6



7



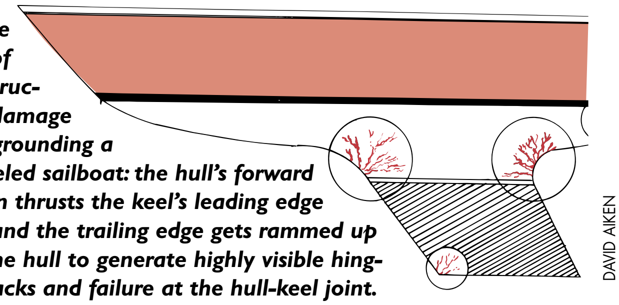
8

Structural Flex Cracks

Do not ignore these cracks: (1) Common stress cracks caused by minor hinging of flat panel at a bulkhead or vee-berth; (2) Hull deflection due to bad cradling; (3) Long random cracks wide enough to insert a penny; (4) A tight group of parallel cracks on runabout at bow indicates trailer damage; (5) Stress cracks at stanchion bases, (6) deck hardware and (7) corners at cabin-deck joint; (8) Concentric circular cracks on cored deck may indicate wet core.

lesser forces involved, these topside cracks are usually confined to the gelcoat layer and represent, for the short term anyway, cosmetic rather than structural problems. A surveyor will usually recommend rather than require repairs to be done "in the fullness of time" to these topside stress cracks.

Figure 3



Telltale signs of vast structural damage after grounding a fin-keeled sailboat: the hull's forward motion thrusts the keel's leading edge back and the trailing edge gets rammed up into the hull to generate highly visible hinging cracks and failure at the hull-keel joint.

A more serious problem sometimes occurs where an external fin keel is bolted to a hull extension or keel stub (**Figure 2**). The heavy side loads created when the boat is heeled can cause hinging to occur at the radius where the glass keel stub meets the hull. If the interior stringers, grid structure or floor timbers supporting the keel are properly engineered and constructed and subsequently remain undamaged, there are rarely any problems. If, however, the interior structure is damaged or the tabbing securing the structure to the hull is delaminated (typically by grounding), the keel stub can bend and flex freely. This concentrates stress at the stub-to-hull radius. The smaller the radius at this location the greater the stress concentration which can lead to serious cracking and delamination (**Figure 3**). [Ed: For how to diagnose and repair delaminated hulls and decks, refer to "The Good, The Bad and The Ugly" on page 46.]

The radius dimension at the top of the keel stub is an important variable in determining whether or not flex will eventually create a problem. Many well-built small- to medium-sized sailboats have very simple and shallow keel stub structures with a large stub-to-hull radius. In lieu of floor timbers or a grid structure they may have heavy solid, unidirectional glass reinforcement at the keel bolts. These boats have shown a surprising ability to bounce off rocks with only minor damage. Larger, equally well built boats (some from the same manufacturer), built to maximize performance often have a deep rigid keel stub with interior structural reinforcement and a relatively rigid cored hull. These stronger, more rigid and more complex structures fare less well when grounded, exceeding the loads they were carefully engineered for. Damage may not be obvious to the untrained eye and the boat continues sailing for several seasons, enduring broken tabbing, delamination, loose stringers and the resulting excessive flex, until it starts to sink. Haul out reveals a big crack that originated some time ago from a subtle stress crack barely visible through the antifouling. Repairing such severe damage is strictly the realm of the professional yard and often requires the input of a naval architect or engineer.

TIPS HARSH REALITY

A word of warning about cosmetic deck stress cracks around hardware and fittings. These are stressed and flexed during normal use and even if a perfect crack repair is done, the crack will likely return because the pattern of use and loading hasn't changed. Do cosmetic repairs like this just before you put the boat up for sale.

RESIN REPAIR SUBSTITUTES

One point to keep in mind when contemplating a repair to fiberglass (a.k.a. fiber reinforced plastic or FRP) structures is that the process of polymerization (essentially turning liquid into solid plastic) that occurs during boat construction is a non-reversible process. Once turned to solid plastic, there is no longer any chance to chemically bond a resin (regardless of its make-up) in the same way that the original is bonded.

Boat builders use a laminating resin during consecutive layering of reinforcements that retains an active surface for subsequent layers to bond with chemically. The final layer is put on with an air-inhibited resin that allows complete polymerization. When properly laid up, the surface is hard and tack free (see "The Good, The Bad and The Ugly" on page 46). At that point all further bonding is known as secondary, meaning the bonds are primarily adhesive in nature.

Whether to use epoxy, polyester or vinylester resin for secondary bonding is debated endlessly amongst professionals. Repair epoxies may be formulated to have extraordinary adhesive properties, but have difficult laminating properties. Most resins, regardless of type, are compromised in one category or another. Researching the chemical system that you intend to use is the crucial step in successful repair work. Virtually any resin system — epoxy, polyester or vinylester — may be made to work effectively, if you understand its application and limitations.

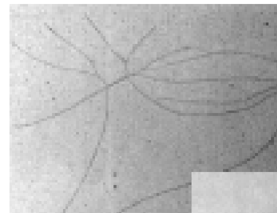
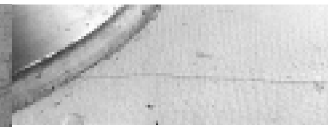
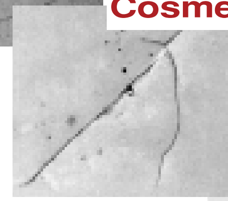
— Wayne Redditt

Repair Strategies

It's often not enough to repair the boat by simply rebuilding and relaminating the original structures using the original laminate schedule. Hull stiffness, particularly in an aging boat or one that was used for a long time with broken and loose interior structures, may have been affected throughout without showing any delamination or obvious problems. Repairing the boat by duplicating the original design may not solve the problem and reconstruction may require additional support structures or reinforcement to successfully return the boat to service.

Often the symptom is repaired without curing the disease. I have seen examples of this where delaminated tabbing at a bulkhead or stringer is repaired but fails again soon afterwards. The bond was subjected to greater stress than it was designed for and until the overall flexing or bending was reduced, it was impossible to bond the tabbing permanently without first doing some re-engineering and structural upgrades. (Most insurance companies and appraisers understand this necessity particularly if a yard is reluctant to warrantee the job without the input and direction from an engineer or naval architect as to the recommended course of repair.)

Non-Structural Cosmetic Cracks

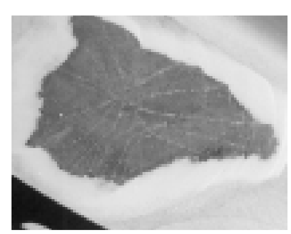

(Left top) Spider cracks not caused by stress; (right & middle) Single cracks caused by voids or bubbles; (bottom) Hairline cracks at deck hardware.

Crack Repairs

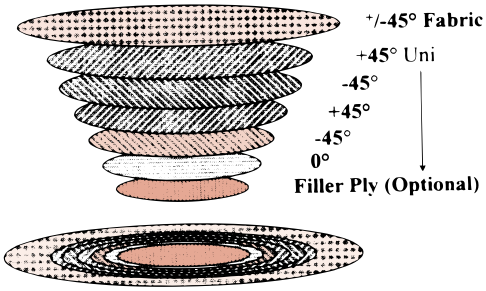
Suppose your hull has a significant crack that is getting larger or has started to leak. Prompt action is now required. If the hull is cored, the core is probably wet by now and the area of wet core will have to be cut out and replaced, a much more complicated procedure. Assuming a non-cored hull, the magnitude of the repair depends on the depth of the crack. If the crack is leaking water into the boat, it obviously extends through the laminate. Very subtle hairline cracks, however, are a cosmetic issue and can be left alone as they likely don't need any structural repair (see "Crack Analysis" on page 45). [Ed: For proper repair procedures, refer to "Fiberglass Cosmetic Repairs" in DIY 1998-#1 issue.] I don't recommend amateur repair of structural hull problems and neither will your insurance company. Here are the steps a professional repair would follow.

STEP 1 Prep Grinding

Use a feathering sander with a 40-grit disc to lightly remove gelcoat in the repair area to reveal the laminate. This is often the only way, without taking a core sample, to make an accurate assessment of the extent of damage. If the crack continues into the laminate and if there is "bruised" opaque milky white laminate nearby (indicating delamination) then a grinder is used to remove the cracked and delaminated fiberglass. This continues until only solid green or bluish translucent looking laminate is left. Edges of the repair area are feathered smoothly with a



Whitish cracks radiating outwards indicate damaged laminate. Grind the laminate to remove all delaminated glass and reinforce laminate.



Laminate patches replace original structure. Use additional patches on inside to stiffen repair where necessary.

grinder to an appropriate distance (approximately half the size of the patch) to ensure good bonding of the new glass laminates that follow.

A crack that travels through the laminate to the other side requires extensive grinding and relamination on both sides. This could be a real challenge where access is restricted. Sometimes it is necessary to remove interior panels which adds to the repair cost.

STEP 2 Glass Cloth Preparation

A patch is created by rebuilding the laminates. This is usually done by applying multiple overlapping layers of mat and roving, or alternatively, a stitchmat (i.e. Fabmat) that combines mat with roving in one easy to handle cloth. Like

FRP FLEXING CHARACTERISTICS

One of the mechanical properties of FRP composites is that they become more flexible as the years go by. Microscopic damage to laminates accumulates with each wave a boat hits. Quality of design and original construction as well as usage, determines how gracefully a boat ages. (Water absorption and osmosis problems are other factors that affect the longevity and rigidity of the hull.)

Bending a fiberglass laminate also stretches the resin and glass. Polyester resin and standard E glass have very different elongation percentages (a measure of brittleness) before breaking. Resin breaks at about 2% elongation, where glass stretches almost 5% before breaking. This is why gelcoat, which is straight resin, develops cracks long before any problems show in the underlying laminate. Micro-cracking begins to occur in typical laminates at about 20% of the ultimate tensile breaking strength; gelcoat crazing (develops a network of fine cracks) at about 50%.

Different resins and gelcoats too have different stretch characteristics. Tough, flexible resins allow the laminate to reach full tensile strength but may actually flex more at lower loads. Resins, which are more stiff and more brittle, actually prevent fibers from carrying their full load. Hard brittle gelcoats are also sometimes preferred by builders because they hold a polish and resist weathering best, but they are much more subject to stress cracking; less brittle gelcoats are softer and don't weather or hold a shine as well.

all glass cloth, stitchmat comes in different weights (i.e. 1810, which combines an 18oz woven roving with a 1oz mat) and either a plus or minus 45° or 0/90° bias which defines the angle the roving is cut on the roll. Either 1810 or 1808 stitchmat is ideal for most repair work.

A 3mm (1/8") repair depth needs about three or four layers of mat and roving or two or three layers of stitchmat; a 6mm (1/4") depth requires twice that and so on. A fair amount of time is devoted to cutting and preparing each layer ahead of time, carefully cut and sized to the repair. Each layer is cut to overlap the previous layer by an inch or two, depending on how far the feathered edge extends.

STEP 3 Lay-up

Glass cloth is usually prewetted with catalyzed polyester (sometimes vinylester or epoxy) resin that's carefully applied to the patch area with a brush and roller with additional layers applied as required. Trapped air bubbles and excess resin are worked out with a special bubble-buster metal roller.

I'm not a fan of using epoxy resins in repairs to polyester laminates, preferring polyester or vinylester. No resin will chemically bond once a resin has finished polymerization (full cure), but rather are mechanical or secondary bonds. Though epoxy is the most adhesive of the commonly used resins, the different flex characteristics of the more rigid epoxy patch may cause delamination problems later. This is a much-debated issue and some repairers may argue otherwise. [Ed: For another opinion, see "Resin Repair Substitues" on page 42.]

STEP 4 Finishing

Quality cosmetic finishing demands a high level of artistry. When the laminate patch has completely cured, use a feathering sander to remove any rough edges and any portions of the patch that sit proud of the surface, and rough up the surface for application of the finish. For above-waterline repairs, fill low spots with a neutral-colored gelcoat (a pigmented polyester resin) thickened with colloidal silica to a consistency somewhere between peanut butter and mayonnaise. This filler is carefully applied with a large putty knife or drywall trowel to fill repair roughness and pinhole voids. When cured, block sand the filler smooth with 80-grit paper. Fill again if needed. A final gelcoat is carefully color-matched and spray painted over the repair area. Sprayed gelcoat naturally has a fairly heavy orange peel finish, so it must be laboriously block sanded with wet paper from 400- to 800-grit (or higher), then machine buffed with a polishing compound to a high gloss. Below the waterline, when recoating with antifouling paint, it's sufficient to simply renew the hull coatings in the repair area.

About the author: Marine specialist Nick Bailey is service manager of Bristol Marine in Mississauga, Ont., an avid Thunderbird-class racer, and a regular contributor to DIY.

CRACK ANALYSIS

There are many different causes for cracks in gelcoat. So when is a gelcoat crack something to worry about?

1 Classic stress cracks come in all sizes, from minor cosmetic blemishes to grim telltales of imminent structural failure.

- Typically found in tight corners in the cockpit and on deck, around highly loaded fittings like mooring cleats or blocks (on sailboats) but of more concern below waterline on powerboats, especially on running strakes, etc.
- Above the waterline and sometimes below, an individual hairline crack is usually only cosmetic unless it's wide enough to insert something into it.
- A tight group of parallel cracks indicates a previous big flexing event and blunt trauma (i.e. collision), or trailer damage especially near the bow of the boat where the trailer rollers or bunks initially take the weight during retrieval.
- Straight crack on hull at bulkhead line usually indicates oil canning flex of nearby panel. Keep an eye on it — if the crack deepens or can be felt with a light touch, action is required.

2 Isolated spider cracks are cosmetic only.

- Somebody thumped the hull or deck with a rubber mallet to get it to release from the mold. Although present from day one, they get uglier as the years go by, sometimes weathering to the point where the gelcoat spalls off but still an isolated cosmetic problem.

3 Random long wandering cracks

- Below waterline only, they indicate moisture absorption into the laminate and swelling or a too thick gelcoat layer.
- On a powerboat transom it can indicate a wet transom core.

4 Concentric circular cracks.

- If on deck around a fitting, they may indicate wet core and possibly even frost heave.
- On rudder, definitely frost heave from moisture.
- Small isolated spots on hull or deck may indicate a void or bubble in the lay-up.
- At cradle pad areas, indicate improper cradling. If non-cored hull, it may be only cosmetic. If cored, flex indicates delamination so structural repair needed.

5 At keel hull joint and underwater fittings, fairing filler always cracks when applied over metal fittings, so is cosmetic only.

- If a gap shows, retorque keel bolts.
- Small cracks at faired thru-hulls, shaft struts or rudder heel castings are usally cosmetic only.

Fiberglass Clinic THE GOOD, THE BAD, THE UGLY

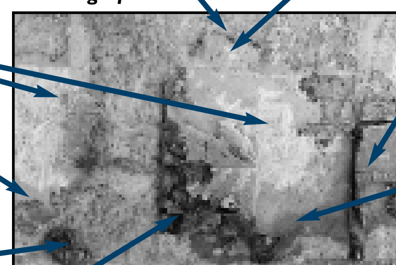
Delamination can occur in a solid fiberglass laminate or cored hull, between the inner or outer glass skins, in bulkhead tabbing fastening interior structures, in deck cores and in rudders. If you own an older fiberglass boat or are looking to buy one, here's how to diagnose the condition and some methods to cure and prevent it.

By Nick Bailey

Fiberglass boats are built from a composite consisting of multiple layers of high strength fibers, usually glass fiber woven into cloth, mat or roving, but sometimes Kevlar or carbon fiber where maximum strength is required. Fibers are then saturated and bonded together with a hardened plastic resin, usually polyester, but sometimes epoxy or vinylester.

The strength and stiffness of the resulting laminate, regardless of the resin and fiber choice, will depend on thickness, the correct ratio of resin to fiber and the effective use of the various cloths. Lightweight core materials (i.e. balsa) are often used, particularly in deck construction, to obtain the stiffness of a much thicker solid laminate without the added weight. Regardless of the construction details, laminates are made up of layers of material that can separate. This is delamination.

Anatomy of a Cored Hull



What is Delamination?

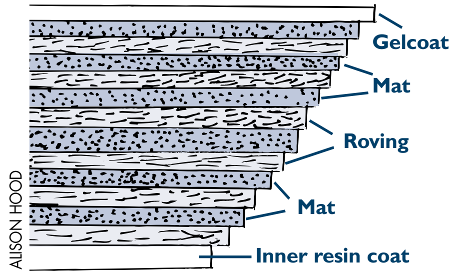
Delamination is one of the two common stress failure modes that can occur in a fiberglass laminate; the other being cracking as discussed beginning on page 40. Cracks result from a laminate flexing and bending and may or may not be any deeper than the cosmetic gelcoat layer. [Ed: Refer to DIY 1998-#1 for complete step-by-step fiberglass cosmetic repair procedures.] A deep crack in the laminate cuts through the bundles of fibers which make up the laminate layers. Delamination is a break in the bond between the layers. This can occur within a solid fiberglass laminate or between a core material and the inner or outer glass skins. It's also a common problem at secondary bonds attaching interior structures to the hull and deck.

Delamination results from either shear stresses where opposing horizontal forces cause the layers to separate and move horizontally in relation to one another or peel stresses where one layer is torn away from the others by forces acting vertically on the laminate.

A delaminated hull may not be in immediate danger of sinking but the first effect of a delaminated condition is a drastic reduction in stiffness. The stiffness or resistance to bending of a solid laminate varies with the cube of its thickness: a laminate twice as thick will be eight times as stiff. When a glass lay-up delaminates, you suddenly have a situation where one or more layers is no longer attached to its neighbor and can move independently in shear as the panel flexes. If the internal break is in the middle of the laminate stack this would half the effective thickness and cause a drop in stiffness to 1/8 of the previous value. If two or more layers are delaminated things will get very soft and spongy. Glass layers now may have much of their original tensile strength but no longer support each other to give stiffness. Once excessive flex is allowed the other failure mode, cracking and breaking of the glass layers, will surely follow. Whether or not a glass laminate delaminates depends on two conditions: the strength and quality of the original construction; and what sort of wear, tear and abuse it has been subjected to since that time.

Pitfalls of Solid Laminates

Many details affect the quality of the bond between different layers in a laminate. Laminates least prone to trouble are the primary laminates applied in the mold wet on wet: the next layer is applied before the one below has fully cured allowing the new resin layer to fully cross-link molecules with the previous layer. Traditional iso or ortho polyester resins are relatively forgiving as they are air inhibited from a full cure at the surface exposed to the air and will remain ready to receive a new layer of cloth and resin for a long



Typical fiber-reinforced plastic lay-up for a 25-footer.

time after the layers underneath have fully cured. The final layer will usually include some air-dry wax to isolate the resin from the air and bring it to a full cure. Once any resin is fully cured, it will be necessary to prep grind the surface to promote a primarily mechanical secondary bond if any additional laminates are applied. Wet-on-dry secondary bonds are relied upon to tab bulkheads, stringers, floor grids, etc. in place, and often to bond core materials into the lay-up.

A good wet-on-dry secondary bond should be nearly the same strength as a primary wet-on-wet bond but relies heavily on workmanship. Inadequate prep grinding or contamination of the bond surface with wax, moisture or solvents can cause premature failure. So too can lay-up faults that reduce contact between layers such as inadequate wet out with resin, too many trapped bubbles or "bridging" where the next layer of cloth or core rises above a bump below.

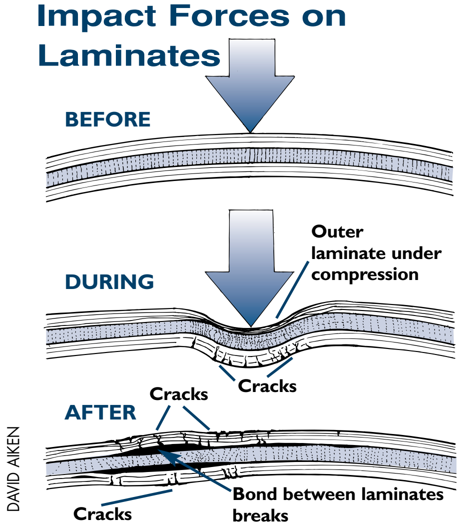
Use and Abuse Failures

The most obvious causes of delamination problems are from impacts or collisions. When a laminate is struck and bends, the outer layers come under compression and the inner laminates stretch under tension (**Figure 1**). Opposing forces create shear forces between the laminate layers and break them apart. If severe, the laminate will also crack or tear at the point of impact. Delamination around the impact can be quite extensive, involving the area of the hull which bent but did not obviously break. Stress cracks are also usually in evidence in the delaminated area. A planing powerboat hull can delaminate over wide areas on the bottom without any obvious signs of distress until cracks appear. The delamination in this case is due to the constant stress and flex from slamming waves.

Although sailboat hulls can also be damaged over time by wave pounding, other than the

Figure 1

Impact Forces on Laminates

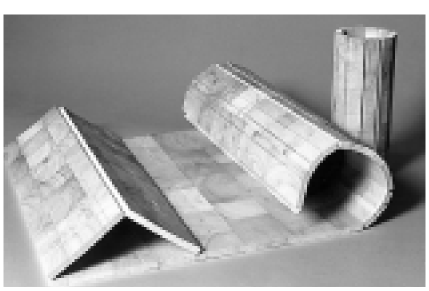


obvious damage from accidental grounding, improper cradling is the most common cause of sailboat hull delamination. Most sailboat manufacturers specify that at least 60% of the boat's weight rests on the keel with the cradle pads taking the remaining load. If the cradle base frame is not rigid enough and sags under the keel when transported, this can grossly overload the cradle pads, dimpling the hull at the pad locations. A solid glass lay-up hull may be flexible enough to tolerate dimpling without permanent damage; if the hull is cored, then maybe not (see below).

A dubious yard practice, which also contributes to sailboat hull problems, is storage with the mast up. Ever notice how a boat will heel 15° or more under bare poles in a storm when tied to the dock? A 50-knot gale shuddering and shaking a dry-stored boat with mast in will slam load the leeward cradle pads with many extra pounds per square foot. I'm not going to attempt to calculate the loads, but judging from the damage I have seen, the typical four- or six-pad storage cradle was never designed to safely distribute such overloads, nor was the hull designed with this sort of abuse in mind.

Wet Delamination

In extreme cases of water absorption into a solid laminate very large osmosis blisters can form between the laminate layers. These can be pie-plate size and bigger, and the osmotic pressure forces apart the laminates. Such delamination problem is rare where boats haul and dry during the off-season, but is more common where boats remain in the water year-round, particularly the tropics.



BALTEK CORP.

Used in decks and other curved surfaces, Baltek's Contourkore is end-grain balsa core panels cut into small squares and glued to a fiberglass scrim.

Core Problems: Manufacturing

Cored laminates employ either balsa or PVC foam cores in a sandwich construction to maximize stiffness without adding weight. When laying up a hull or deck it's often difficult to get a perfect bond between the core and the inner and outer laminates. New techniques such as vacuum bagging, the application of core bonding putties, improvements in the core materials themselves, and the use of various resin-infusion processes all contribute to better bonds between the core and inner and outer skins than was possible using the traditional hand lay-up technique. Despite the fact that a perfect bond between core and skins was difficult to achieve in the past, thousands of production-line boats with cored hulls exist and nearly all have cored decks.

Core lay-ups are traditionally applied by prewetting the core with catalyzed resin and bedding it down to a resin-rich layer of mat. When the core is layered after resin has gelled, this causes bonding problems and future delamination.

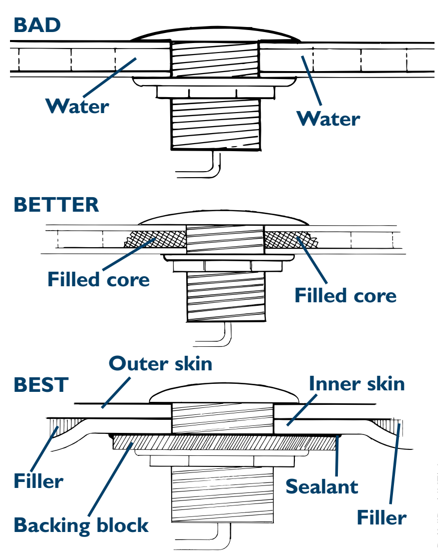
Core designed to lay into a curved surface, such as a deck, is contour cut into small blocks and held together with a light scrim of backing material. When not enough resin soaks into the gaps between the core blocks, the bond is too dry and weak and delaminates. When too much resin soaks in, particularly when thinned with more styrene monomer than ideal, styrene vapor lingers in the core, the resin never fully cures and it delaminates. The problem of excess styrene vapor is surprisingly common. It can register as a wet area on a moisture meter, albeit it's usually nowhere near any hardware that could provide ingress for water. A core sample reveals dry core, tacky resin and the characteristically pungent odor of styrene — it smells like maraschino cherries and vinegar.

Core Problems: Maintenance

Even when a cored laminate is well constructed, it's subject to water penetration from leaking thru-hulls and deck hardware. In theory, well-bonded core should not allow water to migrate from a leaking fitting. In practice, the partly open slots of the contour cut core blocks provide passageways for water to infiltrate. This occurs more rapidly below the waterline in the curved hull panels and more slowly in the flat deck areas. For example, the quickest way I know to condemn a cored hull to a premature death is to install a knotmeter or depthsounder thru-hull into a cored area without removing the core at the thru-hull location (**Figure 2**). Because of this risk most manufacturers of boats with cored hulls will provide a special location where the core has been deleted suitable for thru-hull installation. The affect is further exag-

Figure 2

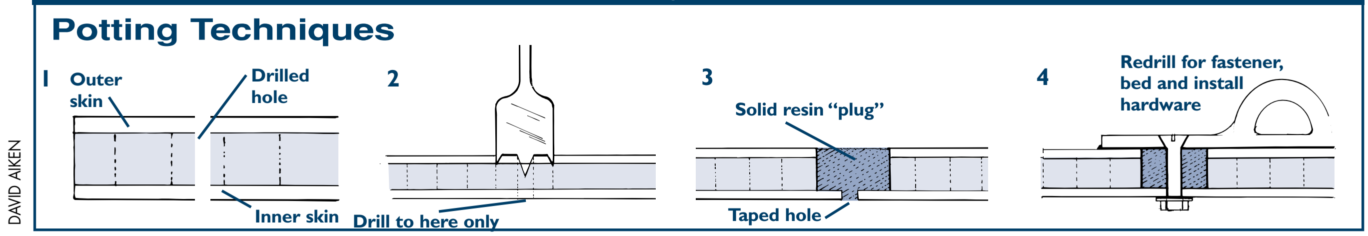
Proper Installation of Thru-hulls in Cored hulls



DAVID AIKEN

(top) Bad: Even when well bedded, water will inevitably leak into the core; (middle) Better: Core removed adjacent to thru-hull and filled with thickened epoxy resin; (bottom) Best: Surrounding core completely removed and area filled with thickened resin mixture.

Figure 3



(1) Core is drilled with small pilot bit; (2) ream everything out with speedbore drill or small holesaw to remove all material to the depth of the the inner skin; (3) hole plugged with thickened resin mixture; (4) hole redrilled for fastener, hardware properly bedded and installed.

gerated in northern climates, where the soggy core is subject to freezing and the resulting frost heave further delaminates the lay-up. The same leak-freeze-delaminate cycle is also responsible for many cored decks on older boats facing radical surgery. [Ed: Refer to DIY 1998-#2 for a first-hand account of a do-it-yourself reconstruction of a fully delaminated deck.]

Cradling Cored Hulls

The same cradling concerns mentioned above hold true for cored hulls. Although a cored laminate is more rigid and will resist cradle dimpling, it has structural limits. Any significant depression or dimple at the cradle pad usually indicates that the delamination damage is already done. Sometimes the delamination at a cradle pad results from an internal fracture of the core itself as opposed to a loss of bond to the inner or outer skins.

Detection

Detecting delamination is surprisingly straightforward. A surveyor will refer to the technique as "percussive sounding," which simply involves light tapping usually with a hammer. Healthy laminate gives off a nice sharp rap or knock; spongy or delaminated areas a softer thud or muffled thump. The technique is not infallible: areas of fairing filler can sound cheesy but may not be of any real concern and thick laminates with a deep internal delamination may sound quite solid. A dry delaminated deck when walked on may crack underfoot. Should delamination be suspect, a moisture meter reading and possibly a core sample analysis will determine how best to proceed.

Repairing Solid Lay-up

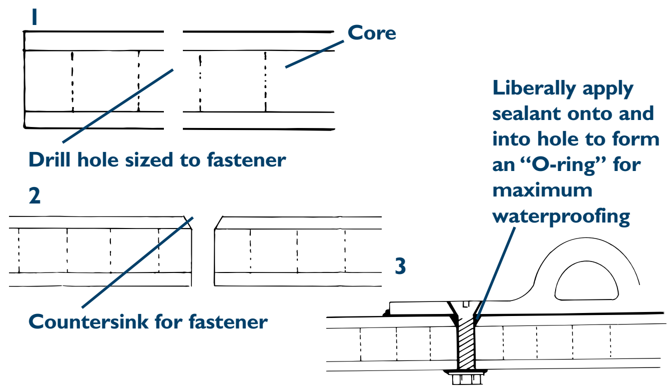
Repairing delaminated solid lay-ups requires addressing the bad area aggressively with a grinder and 36-grit paper to remove the damaged laminates. It's usually possible to leave the very last laminate in place to provide a backing for the new layers of glass. The repair proceeds like any other glass repair, except that you may have to reinforce and stiffen the hull if excessive flex led to the problem. If the solid laminate is also very wet and delamination is the result of very large interlaminate blisters, the boat will need extensive drying, peeling and other work associated with a major osmosis repair.

Core Repairs

Deteriorated cores are the most common delamination repair. If the core is dry, it may be possible to rebond the skin to the core by resin injection and infusion. This is usually done by drilling a variety of holes in the outer skin and persuading unthickened catalyzed epoxy resin by gravity or vac-

Figure 4

Bedding 101 in Cored Laminates



uum into the holes to diffuse throughout the damaged area. [Ed: Refer to DIY 1995-#1 for step-by-step procedures.] After the resin cures, the area should be rebonded. If the core is wet, you have no option but to cut away the outer skin to expose and dry out or replace the wet core.

Wide soggy areas require major surgery and reconstruction but localized areas near a leaky fitting or thru-hull can sometimes be addressed without large-scale removal of the outer skin. A good example is wet deck core around a deck fill plate or ventilator mount. These fittings already require a large hole in the deck that allows access to the damaged core. A variety of improvised tools can be used to dig out the hole perimeter [Ed: See DIY 1998-#2], wet balsa core which is soft, rotten and easy to remove. Leave the hole exposed in a dry or covered location long enough to dry the adjacent core that may be merely damp as opposed to wet. When dry, the cavity is filled with resin and chopped glass fiber mix or thickened epoxy resin and the fitting reinstalled. To gain access to a localized bad area, cut an opening, then later install (after the repair is done) a new deck prism, hatch, ventilator or whatever. This approach neatly sidesteps the issue of how to refinish the repair area, particularly if it's patterned nonskid and more difficult to duplicate. Tip: It's often easier to sand off the nonskid in the repair area and finish the gelcoat as a smooth glossy finish. Do this to the matching area on the other side and your deck appears factory-original despite a localized repair.

Prevention and Maintenance

The single most important maintenance item for all cored hulls or decks is to seal all fittings fastened into or through the core (**Figure 3**). This is rarely done; most cored decks suffer years of neglect simply because core leaks initially do not drip water inside the boat. By the time you see the brown-colored ooze on the headliner, it's too late — a sure sign of terminally rotted balsa core.

The solution to the problem of fasteners allowing leaks into the core is to remove the core adjacent to the fastener and replace it with solid, impermeable material (thickened epoxy resin or polyester and chopped fibers), a process known as potting (**Figure 4**). If manufacturers had done this beforehand, boats may have been more expensive but delamination failures would be less of a concern today. To lessen core problems, I recommend a moisture survey at least every five years and a complete rebed of deck hardware every 10 years or as needed, whichever comes first. ⚓

A CASE OF DRY DELAMINATION

By Ken Hendry

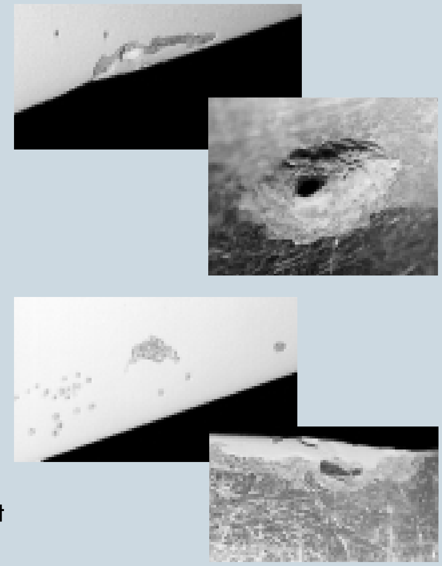
A 1990 Regal 32 Commodore was slated for a routine blister repair job so the hull was sandblasted below the waterline to open voids and create texture for subsequent coats of epoxy resin and Interlux Interprotect barrier coating. Blasting exposed the typical small osmotic voids extending to the laminate, but also many nickel-sized areas with a shallow, flat bottom and obvious dry laminate. Such condition prompted a call to a surveyor to examine the results and devise a repair strategy.

Close inspection found a resin-starved outer laminate under the gelcoat. Rope-like fiber laid along the chine and strake edges from bow to stern to provide a sharper edge was also badly resin starved. Complete removal of the gelcoat was recommended by the surveyor.

I didn't relish doing what must be one of the least pleasant jobs on a boat, namely sanding and grinding, especially grinding gelcoat off the multi strakes of a large cruiser that results in many hours refilling gouges. Instead, I opted to have the hull peeled; a removal technique that involves using a hand-held power "razor" to strip coatings on flat or curved surfaces to a specified measured depth. [Ed: For a synopsis on peeling, refer to "Removing Coatings" in DIY 2000-#2].

Peeling a 32-footer took three hours, removed about 90% of the gelcoat and required minimal sanding to ready the hull for recoating.

In three hours the peeler machine had removed all gelcoat, including on the chines and strakes, leaving a smooth outer laminate that was sanded to obtain good "tooth" before recoating. Peeling had exposed deep voids, probably from air bubbles in the resin, in several areas. It also chipped the fiber reinforcing on chines and strakes, mostly due to the lack of resin bonding the fibers. Another call to the surveyor resulted in an increased repair requirement of laying a thin mat (veil mat) reinforcement with epoxy resin over the existing outer laminate to provide extra resin thickness and surface strengthening. Pieces of mat, about 2m (6'6") long and the width between the strakes were laid on dry then wetted out with epoxy resin, first brushed on, then rolled out and squeegeed. Mat is easier to apply than fiberglass cloth as the weave doesn't skew (twist) when rolled out. About 40 hours were spent laying down the mat, applying another coat of epoxy resin and reconstructing the chine and strake edges. After the surface was sanded and faired with thickened epoxy, I applied Interprotect barrier coat followed by antifouling. It took 73 hours to complete the job and repair costs not including taxes totalled $6,631 in Canadian funds: $500 for sandblasting; $900 for peeling; $150 for the survey; $1,416 for parts and materials; and $3,665 for labor.



Examples of Dry Delamination: (top) Sandblasting of hull reveals resin-starved pockets in outer laminate; (bottom) Peeling of outer laminateexposes "dry" areas on chine and deeper air hole on hull side.

Though this was my first occurrence with dry delamination, it's apparently becoming more prevalent, especially with older boats. [Ed: Paul and Sheryl Shard recorded the dry delamination of their sailboat's entire outer laminate and step-by-step repair in DIY 1996-#2.] No manufacturer is infallible — lemons are well documented in the automotive market — and I suspect this cruiser was just the bad one in a lot and not representative of the builder. (The boatbuilder did compensate the owner, who was not the original owner, for a portion of the repair costs.)

About the author: Ken Hendry operates Hendry's Trent Talbot Marina in Beaverton, Ont., and is an experienced fiberglass and osmosis repairer.

Good Boatkeeping

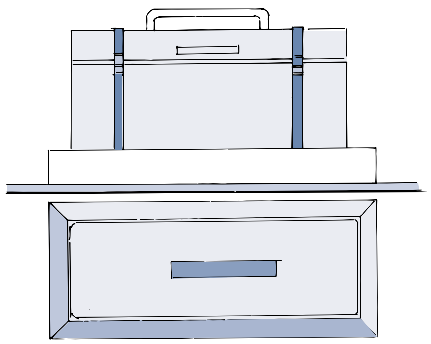
HOLDING TOOLS

Is finding good storage places for tools driving you crazy? Here are three ways to separate, stow and conquer the tool box blues.

By David and Zora Aiken

ONE BIG TOOL BOX

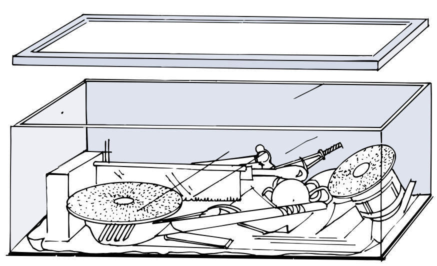
This is most convenient because everything is in one place, but the loaded box does get heavy and keeping it organized is difficult. To help prevent a lot of the shifting and sliding that contributes to a typical lost-tool mess, build a tray to hold the box neatly in its storage area. The sides, or fids, should be about 5cm (2") high all around. Attach some heavy-duty strapping material to the bottom of the tray so you can



Secure bulky containers with hold-down straps.

secure the tool box in place. As with all tool storage boxes, keep an oil-absorbent cloth in the bottom of the box.

STASH AND STACK BOXES



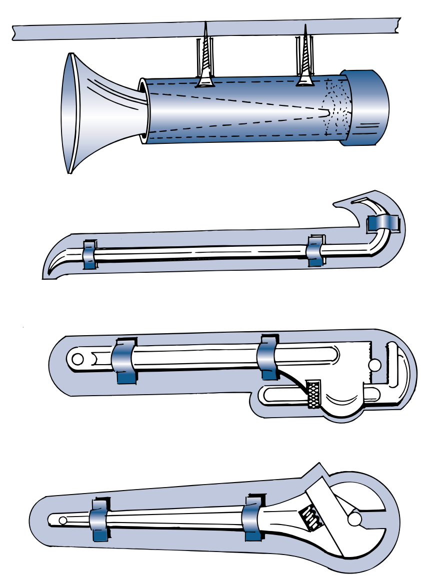
Clear tubs make tool finding easier.

Keep tools in smaller plastic boxes, separated according to the types of tools commonly used for certain types of jobs (i.e. chisels and files in one box, screwdrivers and wrenches in another). See-through plastic lets you find what you need quickly. Line the bottom with oil-absorbent cloth. Add silica gel packs to reduce condensation and rusting of tools.

HANDY HOLDERS

Items that are used regularly need to be immediately accessible. If there is room on the engine room bulkhead, hang these items. Paint the background (either bulkhead itself, or a separate backing panel) leaving silhouettes of the shapes of the tools. Use wooden pegs at appropriate places to hang the tools. Then secure them to the backing with Velcro or snaps, or use 3M Dual Lock fasteners for heavier items. Heat from the engine will help to keep the tools dry and rust-free.

About the authors: David and Zora Aiken are the authors of "Good Boatkeeping" and "Good Cruising" published by International Marine. and live aboard "Atelier," berthed in Grasonville, Maryland.



Tools fastened to engine room bulkhead with hook and loop tape or 3M Dual Lock fasteners are within easy reach.