



Chapter 1

HOW FIBERGLASS BOATS ARE BUILT

Before you can begin repairing or rebuilding a fiberglass boat, you need to understand how it is put together. Such knowledge will also tell you when a contemplated repair job is worth the time and money, and when it is likely to be so difficult or costly that you'd be better served to give up on the boat.

Consider, for example, a boat with a foam-cored hull that has been holed in a collision. You need to determine how to get to the back of the hole. This usually means cutting away the damaged section of the outer fiberglass skin, or *laminate*, pulling out the core around the hole, repairing or replacing the inner fiberglass skin, filling the area with new core material, and finally replacing the outer laminate. If you are not familiar with fiberglass composite construction, you could spend more time than the boat is worth just trying to get it apart.

This chapter's aim is to avoid such problems by familiarizing you with the materials and methods of fiberglass boat construction. Entire books have been written on this subject. Though this chapter is only an overview, it will provide sufficient background for the repairs a boatowner or small shop is likely to do.

FIBERGLASS HULLS

Just as a cotton sheet drapes over a mattress, a sheet of fiberglass material conforms to the shape of any object into which or over which it is draped. Only when resin is added to the fiberglass and allowed to cure does the fiberglass shape become fixed. But what does fiberglass get draped over or into to create the shape of a hull or any of the other parts that go into the construction of a boat? The answer, of course, is a mold.

A *mold* can be either female or male. The finished part fits inside a female mold or over the outside of a male mold, the choice depending upon whether the inside or outside surface of the part is intended to be the smooth, finished surface. Since the outside surface of a hull is the one we present to the world and want to have mirror-smooth, a fiberglass hull is usually laminated in a female mold. Most boats built today also have a smooth interior *liner*, which fits into the hull somewhat like a garbage bag fits inside a kitchen trash can, and into which the cabin or cockpit furniture is molded. This part, also known as a *pan* (see the Hull Liners section on page 22), is made in a separate fiberglass mold.

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Fiberglass revolutionized boating in the post-war years by enabling multiple copies of a hull to be produced one after the other from a single mold. Since the mold has a highly polished interior surface, the hull comes out of the mold with smooth topsides that are then polished mirror-smooth. While the hull is still in the mold, its interior reinforcements and structures are installed. Its deck and its furniture and fittings are added as the boat moves down the production line. A successful fiberglass boat enjoys a production run of dozens, hundreds, or in a few cases even thousands of copies, depending on the boat's size and popularity.

Building a Mold

Clearly the hull mold is critical to the appearance and integrity of the finished hull. The method of building a hull mold has evolved over the decades of fiberglass boatbuilding, but the fundamentals have remained unchanged. The builder must first create a male *plug* of the same size and shape as the finished hull and then shape the female mold over that plug. The mold is then reinforced on the outside, removed from the plug, and polished on the

inside to prepare it for the production run. Building a plug and a mold and all the other smaller parts for a production run may cost as much as or more than building a single boat. The builder hopes to amortize the cost of the plug and mold over the production run of the model.

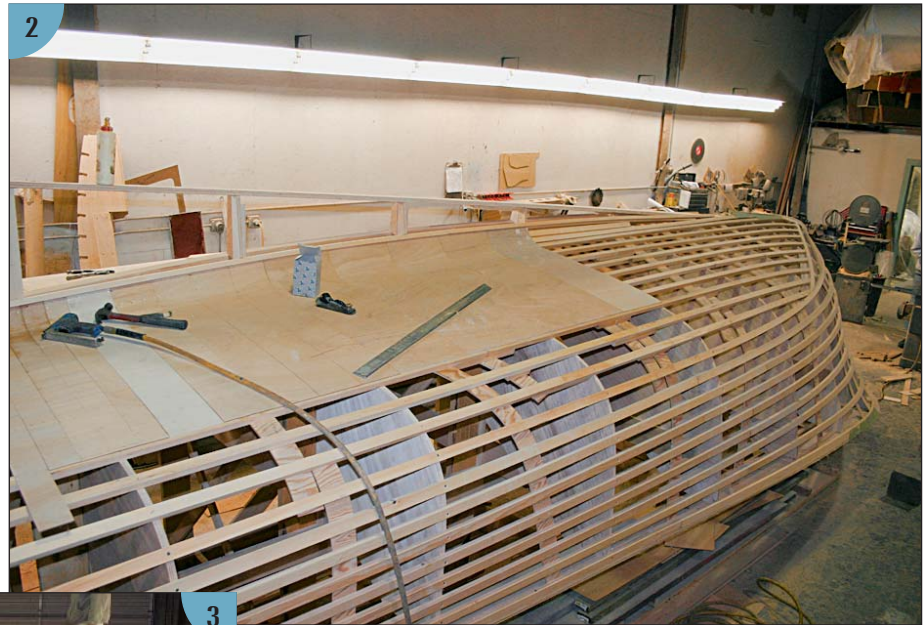
When a fiberglass boat is built on a custom, or *one-off*, basis, the plug and mold represent costly items that are used once only to be thrown away. To avoid the need for a mold, custom fiberglass builders almost always laminate the hull over a male plug or forms. This necessitates laborious fairing and polishing of the hull's exterior surface, however. Alternatively, a one-off large powerboat may be made in a female mold that is built from plywood and does not require building a plug. Fiberglass is laid up inside the mold and polished to a high sheen, and the boat's hull is then laminated in this.

Almost all production runs begin with both a plug and a mold, however. The photos that follow show the building of the plug and mold for one of my designs, the 24-foot Avid powerboat. Construction details vary from one mold to the next, but this one is representative.

(1) *The plug for the 24-foot Avid under construction. The first step in making the plug is to set up the station frames. These frames are cut to the shape of the hull but are smaller than the full-sized boat by the thickness of the plug's longitudinal framing and skin laminate. (The Avid 24 was designed by the author.)*



(2) Once the frames are covered with longitudinals, the shape of the hull is clearly defined. Notice how the framing is altered around the bow area to suit the pronounced changes in curvature there.



(3) Strips of wood laminate are laid down over the longitudinals with irregular gaps between the strips. A router is then used to make each gap a consistent 2 inches (50 mm) wide. Then 2-inch-wide strips (the lighter-colored strips) are laid into each gap to make the surface fair.



(4) The plug is epoxied to stabilize the wood and prepare it for a finish coat of high-build primer. The epoxy brightens the wood, highlighting the striping effect.



(5) A first coat of high-build primer is applied to the plug, turning it gray. This and successive coats will be sanded smooth to get a good finish.

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(6) When the hull plug is completely smooth, the spray rail, quarter rails, and a cove stripe are added. The flange at the bottom of the image (i.e., what will be the hull's sheerline) is for the deck mold to be fitted to the boat. The joint will be covered with a rubrail when the boat is built.



(8) This is a two-part mold because of the boat's tumblehome. The mold has been split apart, and the boat will be craned out ready to be fitted out with the cockpit and interior. A bow-to-stern flange is set up along the plug's fore-and-aft centerline to divide the two halves of what will be a two-part hull mold. This permits the two mold halves to be pulled sideways off the plug (rather than having to be lifted vertically off the plug, as would need to be done with a one-part mold) and then be mated along the flange. This is useful when overhead space is limited, and also when a boat has tumblehome in its topsides (as this boat does in its stern sections), which would prevent the hull from being removed from a single-piece mold.



(7) The hull plug after it has been turned upright and removed from the mold. Here the flange along the top is being worked on to ensure a tight hull/deck joint.



(9) The plug has been sprayed with red tooling gelcoat. This layer will be coated with mold release wax to allow the mold to peel away easily from the plug. The coats of resin and wax are thin enough not to change the shape of the plug. The plug will then be ready for constructing the hull mold.



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(10) Here the hull mold is being formed over the plug. A layer of gelcoat thick enough to prevent print-through of the fiberglass cloth that will follow is first applied over the plug's mold release wax. The interior surface of the mold must be mirror-smooth, and the gelcoat ensures this. After the gelcoat sets, a thick layer of laminate is gradually built up. The mottled color visible here is a balsa core that is being added to the mold laminate to give it more stiffness.



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(11) Still more stiffness is imparted to the mold by the cradle built over its exterior. Here the finished hull mold is standing upright in its cradle after the two halves of the mold have been joined along the centerline flange. The curved cradle rockers permit access to the mold interior from either side simply by tipping the mold over. This allows a hull to be laid up in the mold without workers having to walk around inside it. (All courtesy JWI)

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A hull mold for a bigger boat, showing how it is reinforced on the outside to stiffen it so that it can be used many times.



Multiple coats of mold release wax are applied to a hull mold and buffed out, creating a highly polished surface for laminating the hull. (Courtesy Ranger Boats)



Molds for decks, cockpit tubs, and smaller parts are made in the same way, although usually most of the inside of a mold is reachable without having to use a ladder or staging as is needed with a hull mold. Complex shapes, such as a steering console, may be constructed in two- or three-part molds designed to allow the piece to be removed easily when formed.

Forming a Hull in a Mold

Having made a plug and a female mold, a boat-builder's next step is to laminate the first hull in the mold—hull #1 of what the builder hopes will be a long and successful production run. We'll discuss solid-fiberglass hulls first, and then look at how the laminate schedule is modified to build a hull cored with balsa, foam, or some other material.

Making a Plug Using a Five-Axis Router

Making a plug as described in the accompanying text can be a laborious job of hand labor. A faster, more recently developed method is to carve the plug from a large foam-covered frame, or **armature**, using a computer-controlled five-axis router. Such plugs are built off-site by specialized facilities, then shipped to the boatbuilder.

The armature is usually a steel grid, since wooden armatures have been known to break into pieces when the finished plug is transported by road. This steel frame is then covered with wood and foam to form a structure that approximates the shape of the finished plug. The outer layer of foam is sprayed in place and allowed to cure.



(1) The steel armature for a portion of a large yacht's upperworks is welded together.



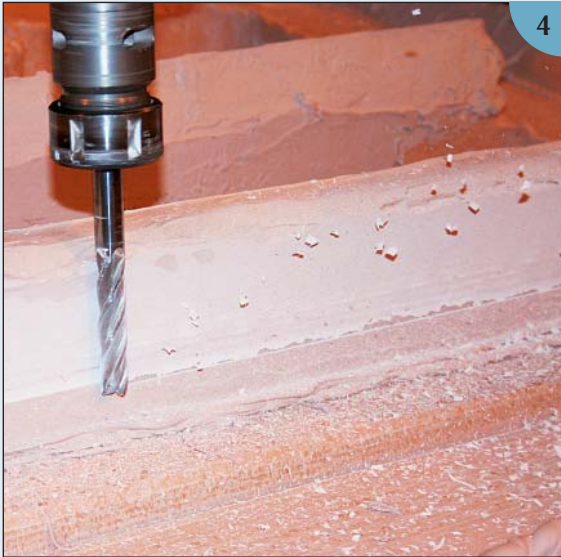
(2) Foam blocks are glued to the armature. Filler foam has been sprayed between the blocks to help glue them together.



(3) Here you can see the parts of the finished plug. The steel armature is in the middle of the yellow foam section made of foam blocks. Pink fairing compound covers the layer of sprayed-on foam, but a little of it shows as a darker yellow than the foam blocks. This sprayed-on foam is cut by the five-axis router, and the fairing compound is applied over the newly cut surface. The router then goes back over the job to make a finish cut, which then receives a final handfairing.

(continued)

Making a Plug Using a Five-Axis Router *(continued)*



(4) Here a router bit is cutting foam. To the right you can see a stream of chips coming off the bit.

While this part of the process is underway, a computer drawing of the finished plug is adapted to program the router. Allowances are made for the thickness of the plug's fiberglass outer layer and its final fairing to ensure that the finished plug is exactly the dimensions shown on the drawings.



(5, 6, 7) The router at the D. L. Blount Associates production facility in Norfolk, Virginia, runs for two shifts a day to keep up with the workload. These parts for a large fiberglass yacht show some of the complex shapes that can be molded with a computer-controlled router. Note how the steps in photo 6 are cut into the bulkhead. (Courtesy D. L. Blount Associates)

Solid, Single-Skin Fiberglass Construction

Solid, single-skin fiberglass construction is the original method of fiberglass boat construction, and it's still in use. First, gelcoat is sprayed to a more-or-less uniform thickness against the mold's mirror-smooth polished interior surface and allowed to set up. The gelcoat might be anywhere from 5 to 20 mils thick (a mil is a thousandth of an inch) but is usually at least 10 mils thick and more often 15 to 20, making it an order of magnitude thicker than a coat of paint. Unlike a coat of paint, it is also chemically cross-linked (not just mechanically adhered) to the fiberglass laminate that follows it into the mold. When the hull is later lifted out of its mold, the gelcoat becomes the laminate's outer coating and serves to protect the hull from UV degradation, scratches, and minor dings. It is not only beautiful but also highly durable.

Through the first three decades of fiberglass boatbuilding, gelcoats were almost universally a pigmented polyester resin. But polyester has the drawback of allowing moisture to penetrate the gelcoat via osmosis and attack the structural laminate beneath it. This can cause blistering (see Chapters 2 and 8), and after blistering began to show up in boat hulls beginning in the late 1980s, most production builders began using a *vinylester* (a vinyl-based polyester) gelcoat in lieu of the traditional polyester gelcoat—or an epoxy barrier coat *over* a traditional polyester gelcoat—thus curtailing moisture penetration. Some builders—generally those building high-performance boats—now use vinylester or epoxy throughout the hull laminate, not just in the gelcoat, but this is rare in production boatbuilding.

The gelcoat is usually followed by one or more commonly two layers of *chopped strand mat* (CSM). *Mat* consists of short strands that are packed together in random orientations to form a flat sheet, then held together with a binder that is resin-soluble. CSM is more easily molded than any other fiberglass material. For this reason—



(1) Spraying gelcoat into a mold to form the polished exterior surface of a hull. (2) Rolling resin over fiberglass. (Courtesy Ranger Boats)

and because it prevents the pattern of the woven fiberglass materials beneath it from *printing through*, or showing on the hull surface—it is the obvious choice to comprise the first one or two layers of laminate behind the gelcoat. The common weights of CSM are $\frac{3}{4}$ ounce and $1\frac{1}{2}$ ounces per square foot.

In production boatbuilding, some manufacturers apply CSM not in sheets but with a *chopper gun*, a tool that chops continuous strands of fiberglass into predetermined lengths and fires them into the mold along with a fine spray of resin. The idea is that the fiberglass is coated with resin on its way into the mold. Chopper guns were commonly used ten years ago because they make the initial laminating go faster, but they are less commonly used now because they emit large quantities of volatile organic carbons (VOCs) and can produce uneven results in the hands of an unskilled operator. You should not need a chopper gun for repair work.

On top of the CSM (i.e., beneath it in the fin-

ished hull), builders usually place the first layer of woven fiberglass reinforcement. The usual choice for this among commercial builders is *woven roving*, which consists of thick bundles, or *rovings*, of parallel strands, with the warp and weft rovings crossing each other at 90 degrees. The result is a heavy, coarse weave that builds up laminate thickness fast, which is why builders favor it. The most common weights are 18 and 24 ounces per square yard. (Note that all fiberglass materials except CSM are weighed by the square yard, not the square foot.)

Woven roving provides great strength in the warp and weft directions but is not as strong along the bias. To address this, successive layers of roving in a laminate can be oriented at 45 degrees from one another. Also, adjacent layers of woven roving do not bond well enough for boatbuild-

ing purposes, so a typical laminate schedule alternates layers of roving with layers of CSM, which provides superior interlaminar bonding. Early fiberglass builders aimed for a laminate comprising about 30% fiberglass reinforcement and 70% resin, but builders today can get more than 40% glass in a hand-laid laminate, and even more if using vacuum bagging or resin-infusion techniques. (For more on vacuum bagging and resin infusion, see the sidebar on pages 15–17.)

In *fiberglass cloth*, as in woven roving, the warp and weft fibers cross each other at 90 degrees, but cloth is woven from yarns (each yarn comprising two or more strands of glass twisted together) rather than stout rovings, and the material is therefore neater, easier to work, and more finely woven. Cloth is available in weights from 2 to 20 ounces per square yard, with weights between 6 and 11



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(1) CSM is the most common fiberglass material. To make it, short lengths of fiberglass about 2 to 3 inches (50 to 75 mm) long are lightly glued into a scrim. The glue, or binder, dissolves in the laminating resin, leaving the fibers frozen in the cured resin. CSM is used beneath the gelcoat and also between layers of heavier woven roving to absorb resin and to fill voids within and between the layers of roving. (2) Using a chopper gun to spray a stream of glass fibers and catalyzed resin. Though no longer commonly used to build hulls, the guns are still used to lay up small parts quickly. (Photo 2 reprinted with permission from *The Modern Cruising Sailboat* by Charles J. Doane)



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(1) Because it takes time to lay down a layer of CSM and then a separate and distinct layer of woven roving, glass manufacturers have combined the two as a single composite with woven roving on one side and CSM on the other. The result is named after the weight of the material on each side, such as 1808 for 18-ounce woven roving combined with 7/8-ounce CSM (which weighs 8 ounces per square yard). (2) When rovings are woven, the weft and warp rovings tend to crimp slightly where they cross. Under load these crimps straighten, and this can lead to elongation and fracturing of the laminate. To eliminate crimping and the potential for stretching, builders sometimes substitute unidirectional unwoven roving, in which parallel rovings are lightly glued or stitched together (see the thin lines crossing the material) with no crossings. This gives great strength in the roving direction

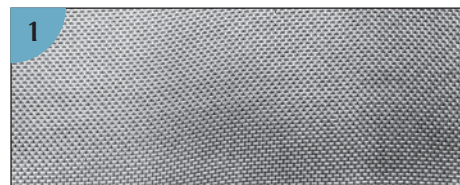


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but not at right angles to it; to rectify this, two layers of unwoven roving can be stitched together at right-angle orientations to form a biaxial roving (not shown here). If additional strength is required along the bias, an additional layer can be added at ±45 degrees, forming a triaxial roving. Adding a fourth layer on the other bias forms a quadraxial roving without the stretch inherent in weaving.

ounces being most common and most versatile. Cloth is stronger for its weight than woven roving and makes a neater repair, so although boatbuilders don't use it much in their laminate schedules, it serves well for repairs. In fact, 1½-ounce mat and some 6- to 10-ounce cloth may be all you'll ever need for fiberglass repairs, though 18- to 24-ounce woven roving is also good to have on hand. (Remember, mat is weighed by the square foot, so 1½-ounce mat weighs the same per given coverage as 13½-ounce cloth.)

The thickness of a 30-foot solid fiberglass hull (i.e., one without a core) might range from 1/8 inch (3 mm) at the toerail to 1/2 inch (12 mm) or more at the keel. Three layers of woven roving separated and sandwiched by five layers of CSM might
(continued on page 14)



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(1) Fiberglass cloth. (Reprinted with permission from The Modern Cruising Sailboat by Charles J. Doane)



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(2) From left, mat, woven roving, and cloth. (Reprinted with permission from Maintain and Improve Your Powerboat by Paul Esterle)

Exotic Skin Materials

E glass is the most basic of the fiberglass family of materials. Developed as electrical insulation (the E stands for electrical-grade), it was first used to build boats in the late 1950s and is still used today by most production boatbuilders. Its strength is lower than that of the latest materials, but so is its cost. It is perfectly adequate for most production boatbuilding purposes, but lighter, stronger reinforcement materials are sometimes substituted for specialized building, and especially for high-performance boats.

S glass. As the use of E glass spread, aircraft builders began demanding more strength and lighter weight in a fiberglass material, and S glass was developed to meet these needs. But S glass may be several times more expensive than E glass, and that's a showstopper for production boatbuilding, a low-volume, low-margin business. So the slightly less expensive but still high-strength S-2 glass was devel-

oped for boat construction. E glass is all you're ever likely to need for repairs on a standard fiberglass boat, however.

Graphite. Graphite fiber, more commonly known as carbon fiber, is probably the best-known high-strength fiber. It has a much higher tensile strength than fiberglass. Developed for high-speed turbine blades, carbon fiber is becoming the material of choice for high-performance hulls and decks. A carbon fiber laminate is twice as strong and five times as stiff as a conventional fiberglass laminate of the same thickness, and as a result, a carbon hull might weigh a third as much as a conventional hull of the same strength. Sometimes carbon fiber is used to reinforce critical areas in boats of otherwise conventional construction.

When a carbon fiber hull is laminated, it is often vacuum bagged and cured in an autoclave to enhance the high-performance characteristics of the material even more



(1) Rolls of unidirectional carbon fiber.



(2) A laminate of fiberglass and polyester resin has a tensile strength of about 27,000 psi (pounds per square inch), whereas a laminate of carbon fiber and epoxy resin has a tensile strength of about 61,500 psi.

(for more on vacuum bagging and autoclaving, see the sidebar on pages 15–17). If you are ever faced with a repair to a carbon fiber hull, you will need to find out how the original laminate was made in order to make a repair of comparable strength. The techniques of carbon fiber repair, however, are nearly identical to the techniques for fiberglass repair as outlined in this book.

Kevlar. Kevlar is an aramid fiber made by DuPont. It is very strong in tension but not as strong as graphite or fiberglass in compression. Kevlar is used in high-performance boat hulls to absorb impacts in the same way that Kevlar bulletproof vests absorb bullet impacts. Repairs to a Kevlar laminate are difficult, as the material is hard to cut and difficult to laminate, but the techniques are, again, pretty much the same as outlined in this book.

Boron fibers. Boron is the very latest in high-strength fibers and has yet to appear in boats, although it is used in aircraft. Boron fibers are made of tungsten and coated with boron vapor to give them strength and stiffness.

The state of the art for racing boat hulls (both power and sail) has become graphite (carbon fiber) with epoxy resin, while cruising sailboats still use fiberglass and vinylester or polyester resin. More esoteric boats might incorporate a laminate of graphite, Kevlar, and S glass laid down as *prepregs* (see page 14) and cooked in an autoclave at elevated temperature and pressure.



(3) A carbon fiber hull under construction. This entire hull and deck weighs under 600 pounds. With a hull this light, you can use smaller engines, carry less fuel, and achieve a much higher performance.



(4) Unidirectional Kevlar combined with S glass makes this high-strength, impact-absorbent material. The Kevlar is light brown, and the S glass is silvery. The thin lines crossing the material are the glue lines that hold the scrim together.

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(1) WEST System epoxy resin together with hardener and metering pumps. (Courtesy WEST System) (2) Epiglass epoxy resin and hardener from Interlux. This epoxy is mixed in a ratio of 4 parts resin to 1 part hardener. Other epoxies are mixed in a 3:1 ratio of resin to hardener. In contrast, it takes just a few drops of MEKP (a catalyst) to cure a polyester resin. (Courtesy Interlux)

yield a finished thickness of $\frac{5}{16}$ inch (8 mm). The builder typically lays dry sheets of woven roving into the mold, then wets it with resin in place, working the resin into the weave with squeegees and rollers. (These tools are described in Chapter 3.) This *hand layup* of roving layers may be alternated with chopper-gun layers of CSM.

As an alternative to hand layup, sheets of resin-impregnated roving or mat—chilled to prevent the premature completion of curing—can be laid into the mold without additional resin. After being laid down, these *prepregs* are cured by heating, vacuum bagging, or autoclaving. (For more on vacuum bagging and autoclaving, see the sidebar on pages 15–17.)

The resin used in fiberglass building was invariably polyester until the late 1980s, and polyester remains the predominant choice today. As mentioned, however, since osmotic blisters were found to be a problem on older boats, most builders have switched from polyester to vinylester gelcoat or an epoxy external barrier coat. Some use vinylester throughout the laminate, but vinylester is more expensive than polyester, so others switch to polyester after the gelcoat is in place.

Polyester products are comprised of the resin, a catalyst, and an accelerator. Usually the accelerator comes premixed with the resin (which has the consistency of maple syrup), and a few drops of the catalyst are added as needed. (The catalyst is methyl ethyl ketone peroxide, or MEKP, which is nasty stuff and not something you want in contact with your skin.) Mixing the two components initiates an exothermic reaction, and heat is given off as the catalyzed resin sets up into a solid, never to be liquefied again. Because heat is emitted in curing, polyester resins are known as *thermosetting resins*, and the laminating process must proceed a couple of layers at a time, since the simultaneous curing of more layers than that might produce



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enough heat to damage or warp the mold and, in a worst case, even start a fire.

Like polyester resins, *epoxy laminating resins* come in two parts—the resin and a hardener—that need to be mixed before they will cure. Performance craft are built almost exclusively with epoxy resins because the resulting laminate is stronger and stiffer. Few production boats are built with epoxy resin—which is much more expensive than polyester—but that doesn't mean you can't use epoxy for repairs. I prefer epoxy for many repairs, in fact, as discussed in Chapter 3 and elsewhere in this book.

Laminating Methods Other Than Hand Layup

Hand layup is still the standard laminating method used by many boatbuilders, but emissions controls and the ongoing search for lighter, stronger laminates are inducing more and more builders to adopt closed-mold



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and other high-tech processes. These range from using prepregs (as described in the accompanying text) or vacuum bagging to employing resin-transfer molding as described here, but one objective they all share is reducing hazardous VOC emissions. Unless you're attempting to repair a high-performance boat, however, you're unlikely to encounter the more exotic laminates.

Autoclaving. An autoclave is an industrial machine that delivers elevated temperature (up to 240 ° F) and pressure. After a mast or boat part has been laid up and partially cured, it might be placed in an autoclave, where exposure to pressure and heat forces air and VOCs out of the laminate. A laminate cured this way is stronger for its weight and contains fewer voids, so using autoclaves has become standard for manufacturers of high-tech boat parts.

Closed or resin-transfer molding. Resin-transfer molding (RTM) is a relatively recent laminating technique developed to reduce the quantity of VOCs released into the air. It is becoming mandatory in some places, and the consensus is that this type of boatbuilding will become standard in the future. Several variations exist, the most popular of which is known by its trade name, SCRIMP (Seemann Composites Resin Infusion Molding Process). In all the variations, the fiberglass is laid up "dry" (without resin) in the mold and lightly tacked in place. Structural parts, such as frames and floors, can also be laid up dry along with the hull skin. This means that all parts are infused with resin at the same time, which eliminates secondary bonds and potentially weak joints. When the dry fiberglass is in place, it is covered with a molded plastic bag (rather like a vacuum bag) or by a second part of the mold (like a cap or lid). A

(continued)

(1) After a carbon fiber mast is laminated, it is pressurized and heated in an autoclave such as the one in the background that shows as a black hole. (2) This oven has the capacity to cure an entire yacht hull up to 100 feet long. The door opens to a second area to allow a larger hull to be fitted.



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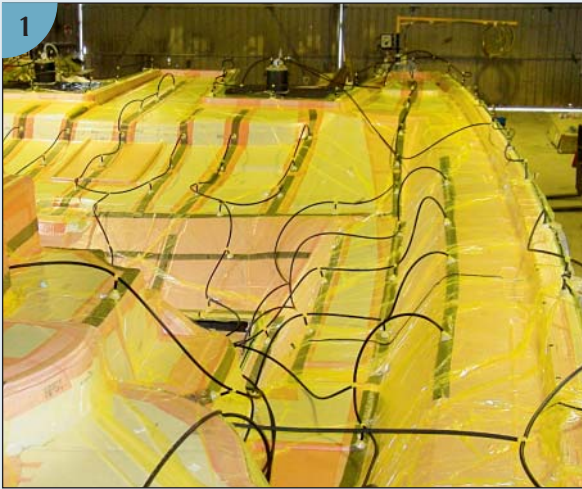
Laminating Methods Other Than Hand Layup *(continued)*

vacuum is generated by a siphon, and the resin valves are opened, sucking resin into the dry laminate. When resin begins to flow out the vacuum tubes, the resin flow is cut off and the entire laminate is cured under pressure, or it might be cured in an autoclave under both heat and pressure.

RTM reduces the need for many layers of precisely aligned cloths. The builder can instead use one or two heavier layers of quadraxial roving precisely cut and aligned on the mold before injecting the resin. Using fewer, heavier layers and injecting the resin cuts

laminating costs while preserving laminate thickness and achieving a higher glass-to-resin ratio for greater strength. VOCs, which are emitted in copious quantities during open-air molding, are contained in the vacuum lines and can be filtered out and captured. RTM is therefore healthier for workers.

Vacuum bagging. After a laminate has been laid up wet in the conventional way, it can be cured under an airtight plastic sheet, or vacuum bag, that is sucked tightly onto the laminate via suction tubes inserted through one or



(1) In resin-transfer molding (RTM), the fiberglass is laid up dry and covered with a plastic sheet. A vacuum then sucks all the air from under the sheet. When the vacuuming is completed, resin valves are opened, and the resin is sucked into the laminate. (2) Another view of this catamaran deck about to be infused with resin.



The infusion lines are in place, and as soon as the vacuuming is completed, the valves will be opened and resin will pass through the larger-diameter lines into the laminate. (Courtesy Perry Catamarans, Queensland Composites, and High Modulus)

Cored Construction

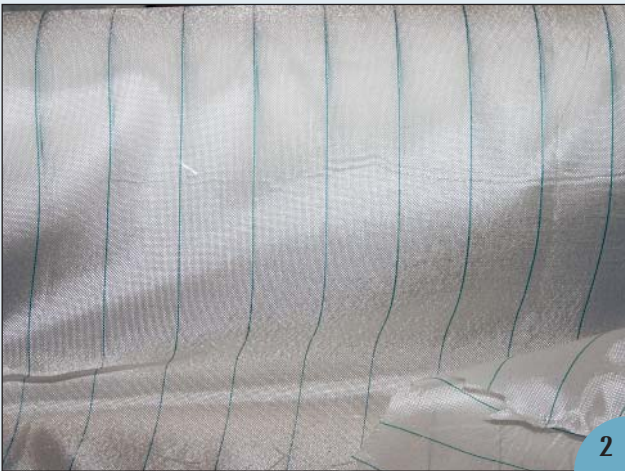
Single-skin, solid fiberglass hulls were universal among early fiberglass boats, but balsa-cored decks and a lesser number of balsa-cored hulls were being built by the 1970s, and other core materials followed. Cored, or sandwich, construction is in most respects the same as single-skin construction, except that the builder inserts a layer of lighter material midway through the layup, sep-

arating the laminate into inner and outer skins. This makes the hull or deck thicker, and therefore much stiffer, without adding much weight. It also insulates against heat and sound and reduces condensation in the boat's interior.

The builder must ensure a good bond of the core material to the outer and inner skins. This is critical. Delamination of a core-skin bond is difficult for a do-it-yourselfer to repair.



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more holes in the bag. The vacuum isn't total, but the resulting pressure can amount to several pounds per square inch—not as high as in an autoclave, but still substantial. Vacuum bagging reduces the number of voids in a laminate and compacts the laminate (increasing the glass-to-resin ratio) for better strength.

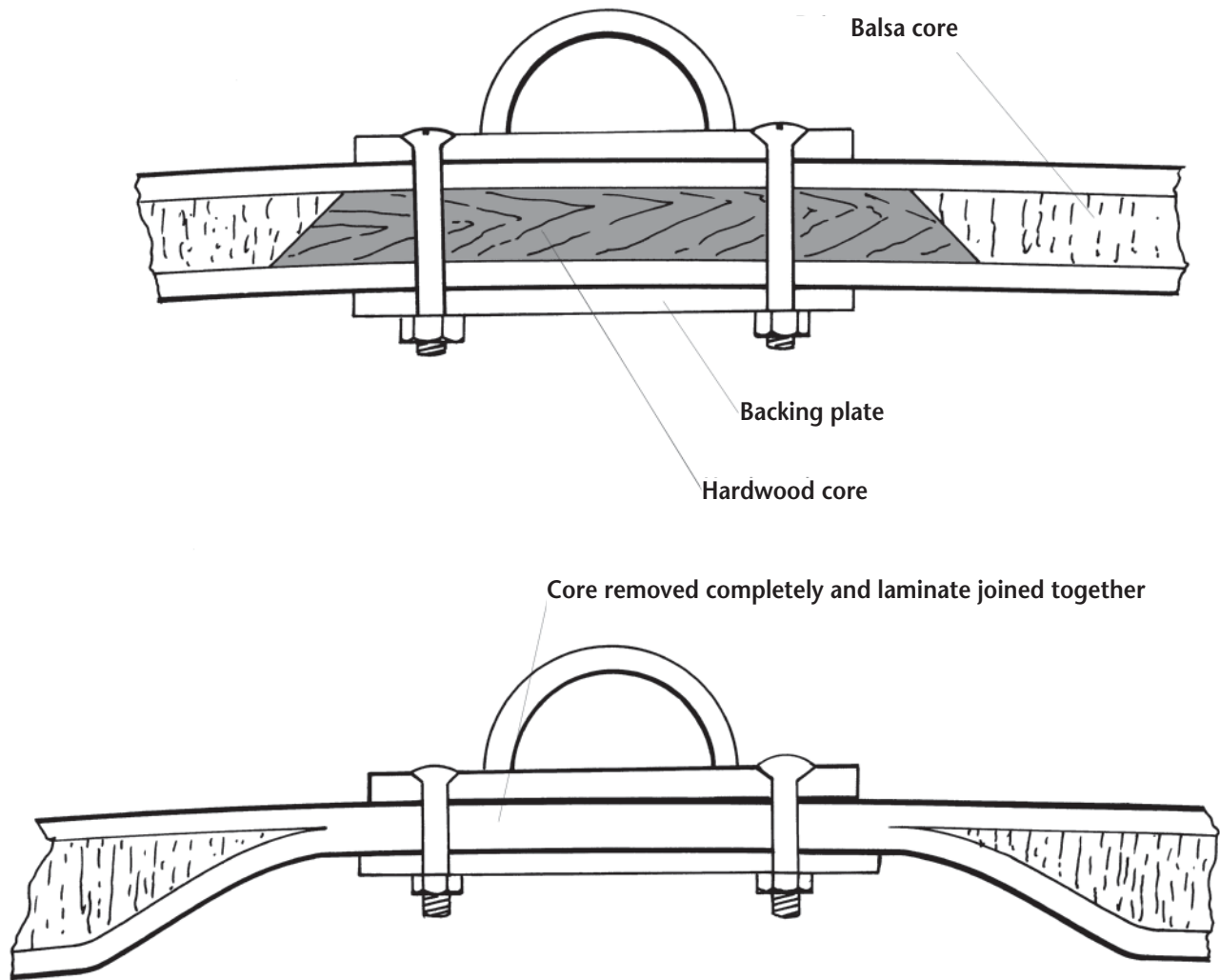
A layer of release fabric (the brand name Peel Ply has become more or less generic) can be placed under the vacuum bag to absorb excess resin and allow it to wick out of the job. A bleeder cloth (usually a polyester blanket) placed on top of the release fabric ensures an even distribution of vacuum and also absorbs excess resin. The Peel Ply is later pulled off the cured laminate.

Unlike autoclaving and RTM, vacuum bagging is feasible for a small shop or for do-it-yourself repairs, as described in the sidebar on page 138.

(1) A vacuum bag in place. Air is sucked from under the green plastic and then the spar is inserted into the autoclave. The whole mast is cured at a higher temperature and pressure than normal to give it additional strength. (2) Peel Ply ready for use.

Through-hulls, deck hardware, and other laminate-penetrating items should not be mounted on or through a cored laminate without proper precautions. To ignore this warning is to invite moisture through the outer skin and into the core along hardware fasteners, and this will sooner or later cause a balsa core to rot and a foam core to become waterlogged and spongy. Further, even when hardware is through-bolted with adequate

backing plates, cinching up on the nuts can crush a balsa or foam core and form an indent in the deck, perhaps cracking the laminate. A good builder will make a transition from a cored deck to a solid laminate for a hardware installation, at a deck edge, or for the tightly radiused curve from deck to cabin side. Most experts now agree that the core taper through the transition to solid laminate should be about 3:1—i.e., if the core is



Installing hardware over a foam or balsa core is asking for trouble. Water might reach and attack the core through the fastener holes, and tightening the fasteners might crush the core, which could damage the outer skin and, again, admit water into the core. A better solution is to replace the balsa or foam with a noncrushable core material (such as plywood or hardwood) beneath the hardware, or to transition from cored to solid-fiberglass construction under the hardware. Both solutions are shown here. When this isn't feasible—

for example, when you retrofit hardware on a balsa- or foam-cored deck—you should at least ream out the fastener holes oversize, plug them with thickened epoxy, and drill the fastener holes through the epoxy plugs. The plugs not only keep moisture away from the core but also serve as compression struts. (This procedure is illustrated in Chapter 5 on page 96.) All hardware installations should be backed by load-distributing backing plates as illustrated here.

1 inch (25 mm) thick, the taper to a single skin should be 3 inches (75 mm) long. This allows the single skin to flex slightly and transition the load to the cored section, whereas an abrupt change in material stiffness might fracture under load.

If you install a through-hull (for a transducer,

a toilet outlet, etc.) in a cored hull, you should cut the hole oversize, remove the core, replace the core with thickened epoxy, and cut a hole of the proper size through the epoxy. Use the same approach for fastener holes in a cored deck. This is covered in detail in Chapter 5 on page 95.

Core Materials

Builders use core materials to increase the thickness of a laminate and thus the distance between its outer and inner skins, which are the laminate's strongest part. A cored laminate acts like an I-beam. The core itself absorbs very little load but greatly increases the structure's stiffness.

Balsa. End-grain balsa is one of the most popular core materials, especially for decks and cabintops. It is light and will not rot as long as it is totally encapsulated in the laminate. The styrene present in polyester resin inhibits rot. Wet or even damp balsa should be dried thoroughly before it is laid up, however. Also, if water gets into the core through laminate cracks or fastener holes, balsa

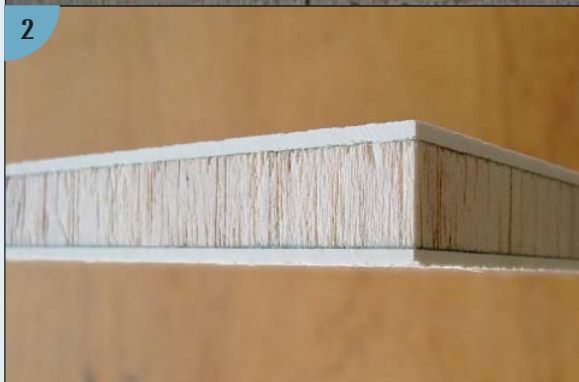
may rot, although the rot does not often spread across the grain unless the leakage is severe.

Foam. There are a number of foam cores on the market, exhibiting varying degrees of density and flexibility. Most builders use Divinycell or Klegecell from Diab Group (www.diabgroup.com). Diab Group also produces ProBalsa core, and Corecell is available from SP, the marine business of Gurit (www.gurit.com). Builders also use Penske board (now called Airex PXC), a urethane foam board with fiberglass laminate on either side, where a high-density foam is needed, such as in a transom repair. Airex PXC is made by Baltek (www.baltek.com) and is available from Jamestown Distributors (www.jamestowndistributors.com).

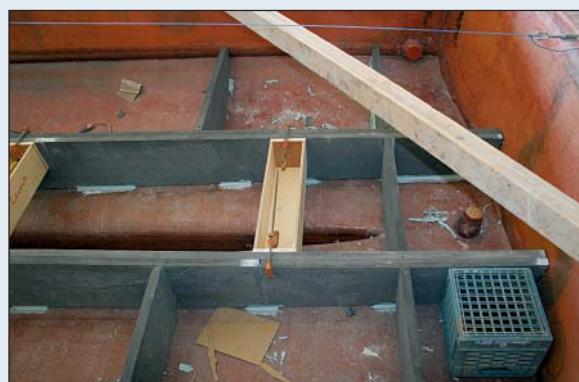
Sharply curved laminates may use a scored foam core to allow the material to bend. Curved cored laminates tend to be heavy, however, because resin fills the voids between the core materials unless a special light-weight filler is used for this purpose.

When a builder must fill a larger void, such as the space between an interior pan and the hull, he may use a special cavity-filling foam such as Kwik Foam from DAP (www.dap.com), a single-part, spray-in, closed-cell polyurethane foam that expands to fill any void. Evercoat Marine (www.evercoat.com) supplies an equivalent two-part foam that can be used to fill buoyancy

(continued)

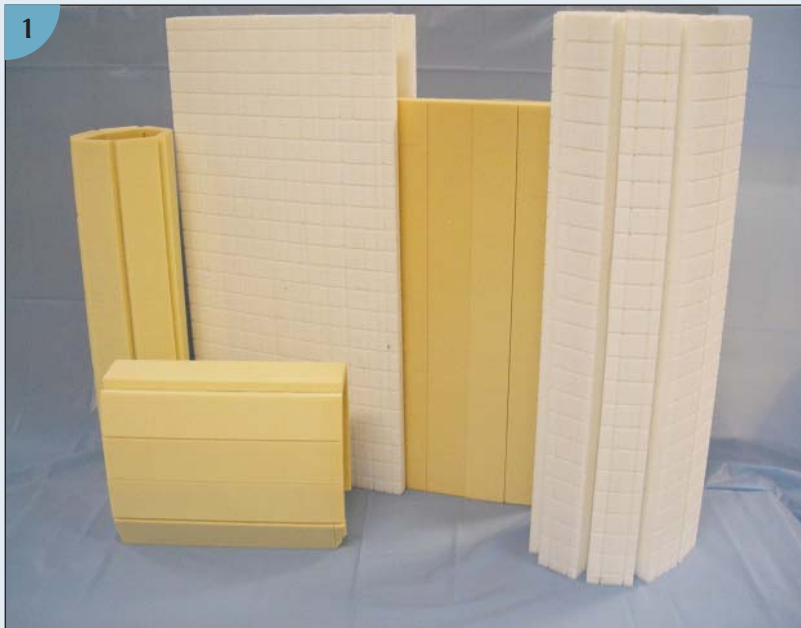


(1) Balsa core material shown close up so that the grain is visible. (2) A balsa core laminated into a panel with upper and lower skins. This is what a cored deck or hull looks like in cross section. (Courtesy Nida-Core)



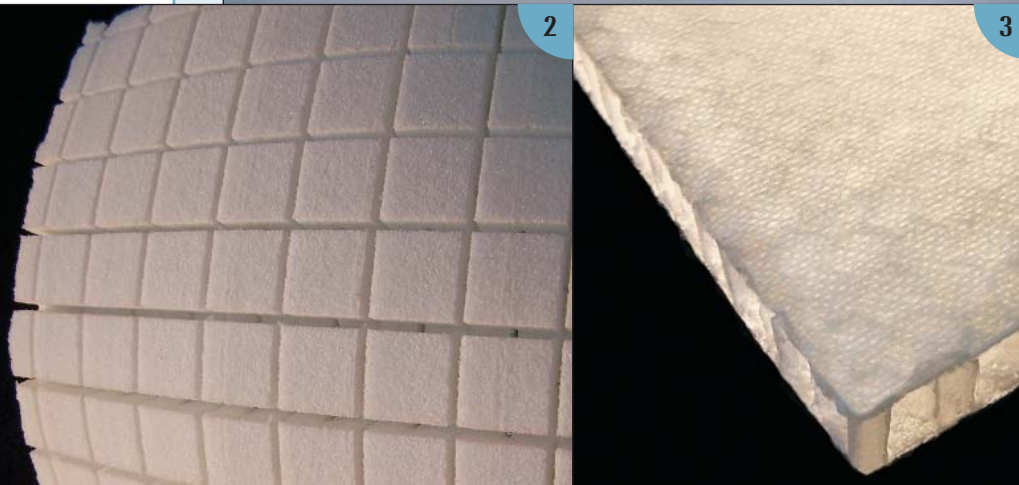
The interior of a hand-laid boat I designed. The Penske board structure has been bonded in place before the installation of the interior pan.

Core Materials *(continued)*



chambers and any other voids that need to be watertight. Both types of foam can be fiberglassed, but it is more usual to put the fiberglass shell together first, then spray the foam into the void.

Hexcel core. Hexcel (often known as HexWeb honeycomb) is an aramid honeycomb core material that is mostly air. It is very light but requires special laminating techniques. A repair to a hexcell-cored laminate in a high-performance boat is a highly specialized job requiring the use of prepregs and a good understanding of how to get a strong laminate.



(1) Foam core materials of various densities. (2) This foam core sheet is scored to allow it to conform to the curvature of a boat's hull. Scored balsa core is also available. (3) Nida-Core honeycomb is an ultralight honeycomb material similar to HexWeb honeycomb. It usually comes with a laminate prebonded to either side, as shown here, because bonding laminate to the core is difficult. (Courtesy Nida-Core)

HULL REINFORCEMENTS

Once a hull is laminated, the builder customarily adds interior reinforcements—floors, longitudinals, and bulkheads—to stiffen the hull before removing it from the mold. The common practice prior to the early 1970s was to bond wooden floors, stringers (i.e., longitudinals), and bulkheads to the hull using fiberglass tabbing, fillet joints of thickened resin, or both. *Tabbing* consists

of laying strips of fiberglass cloth over the joint between the hull and covering the reinforcing member with polyester resin. *Fillet joints* dispense with the fiberglass cloth and instead use thickened resin to accomplish the same thing. (Fillet joints today use thickened epoxy rather than thickened polyester, as covered in Chapter 5 on page 97.) These wooden parts were prone to rot after a few years, and their removal and replace-



(1) Setting interior framing into a hull and levelling (with light blue shims) before lifting the hull out of the mold. This wood framing helps stiffen the hull, but the modern practice is to use fiberglass rather than wood floors and stringers. (2) Fitting and tabbing bulkheads (see green tabbing on left) into a hull before removing the hull from the mold. (3) These plywood floors in an older J/24 sailboat have delaminated and need to be replaced. The replacement project is described in Project #2 in Chapter 7.

ment with foam-cored fiberglass floors is Project #2 in Chapter 7.

Today a boat's floors (transverse reinforcing members) and stringers (longitudinal reinforcing members) are more likely to be constructed of foam-cored fiberglass than of wood. The foam core gives a member the hat-shaped cross section it needs for stiffness, while the necessary strength comes from the fiberglass laid over the foam. The floors and stringers may be laminated as a single-piece waffle-like grid and then glued into place in the waiting hull, or they may be formed individually in place. Such modern methods have



decreased the time required to build a fiberglass boat from thousands of hours to hundreds, if not fewer.

Once the hull is sufficiently stiffened with interior reinforcements, it can be removed from the mold, which is then rewaxed and prepared for the next hull layup.

The stringer system of a modern small powerboat shows a completely encapsulated wood or foam structure. The rearmost portion of this hull (in the foreground) is visible when the hatches are opened and has therefore been painted white. This boat has a two-piece hull liner, the forward section of which is already in place. A transverse bulkhead will be installed next and will separate this forward section of the hull liner from the main piece.



HULL LINERS

In contemporary boatbuilding practice, an *interior pan*, also called a *hull liner* or *hull pan*, is customarily set in place over the reinforcing grid, or the grid may be part of the liner. This liner, which is formed over a male mold in one, two, or even ten or more pieces, depending on the boat's size, provides the polished gelcoat surface of the cabin sides and floor (or of the inner hull sides and cockpit sole in an open powerboat), hiding the raw fiberglass of the hull laminate and reinforcing members. It also provides a foundation



(1) The first 24-foot Avid emerging from its mold. Because this boat has tumblehome in its topsides aft, a split mold is necessary to enable the finished hull to be removed from

the mold. (2) Having been pulled from the mold, the Avid is suspended from a chain hoist waiting for a cradle to be wheeled under it.



(1) A partial hull pan ready to be fitted with equipment. This is part of the forward head unit and will be fitted with drains and other parts before it is installed.

(2) A craftsman making a mock-up of the forward part of a cabin before tooling is made. Building a mold of this complexity is difficult and requires a thorough knowledge of the parts that will be fitted in order to allow sufficient space behind the unit for wiring, piping, and even bolt heads. (3) An interior pan before it is installed in the hull. On this pan the locker liners (pale blue) have been installed. Other parts are in the process of being installed.



for furniture and for the engine and generator (if fitted), while at the same time serving as the shower pan in the head (if a shower is fitted).

The use of hull liners dates back to the early 1970s. On some smaller craft the bunk flats and countertops may in fact be molded into the hull pan. The tooling to create an elaborate hull pan can be incredibly complex.

A hull pan frequently poses the most difficult challenge in a fiberglass boat repair. When a pan is installed, it is often bonded to the hull structure with a nonremovable glue. If you can't get behind a hull pan to reach a damaged area, you will need to cut into or through it in order to access the problem. Often this means also cutting away wiring, plumbing, and other parts that were fitted before the pan was bonded to the hull. Sometimes

access to the back of the pan is virtually impossible, and even if access can be obtained, the whole structure will have to be rebuilt after the repair is made.

INTERIOR FURNITURE

The furniture in older fiberglass boats was often “stick-built”—that is, carried into the boat's interior piece by piece and built in place. Alternatively, it was built in small sections outside the hull and taken into the boat to be assembled and fitted. In production factories today, however, the furniture is simply dropped into place before the deck is installed. On smaller boats, the furniture might be part of a module that is fitted into the pan be-



(1) The interior of this boat is being fitted out before installing the deck. This procedure cuts down on the time needed

to build the boat, but it also makes some components hard to reach for later repairs or rebuilding.



(2) On larger boats the interior may be made in a furniture shop and fitted to the boat while the deck is still being made. Here the components of the cabin spaces can be easily seen.

fore the pan is installed on the yacht. On some boats the entire lighting harness—including the lights—is installed before the deck and hull are mated. On larger yachts, the furniture might be built in a cabinet shop and then installed aboard the yacht before the deck is placed.

These contemporary building practices may make it difficult or even impossible to remove parts of a hull pan in order to change an interior layout. To tell how an interior has been constructed and how difficult making changes to it will be, simply look at a bulkhead-to-hull joint. If the wooden bulkhead is carefully fiberglassed to the hull with a fillet, tabbing, or both, it is likely that the furniture is simply glued and screwed to bulkheads and glassed in a few places. This makes the renovator's job much simpler. Parts can be removed in small enough sections that they can be taken out through the companionway hatch. In contrast, restoring a boat whose furniture is built into the pan may be extremely difficult, because



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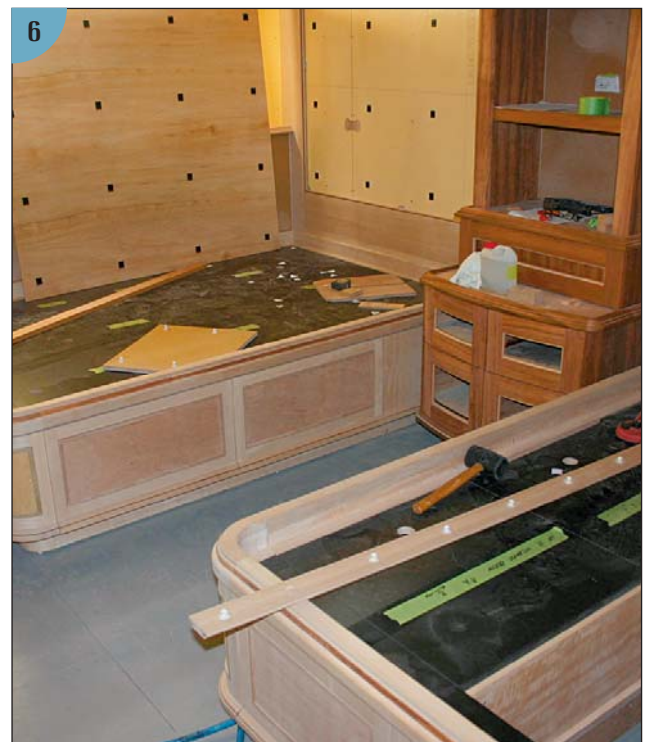
(3, 4) Furniture for a yacht being built off-site. These joinery pieces will be carried to the vessel and installed after the boat is built. (5) The SMI plant in New Zealand

many of the connections were likely made before the pan was installed in the hull, and these connections may be inaccessible.

DECK CONSTRUCTION

Like the hull, the deck of a production fiberglass boat is usually built in a mold. Typically the gelcoat is sprayed on, the outer laminate is installed, and then a core is set in place. For most yachts this core is lightweight balsa, which can lead to problems of waterlogging and rot later in the boat's life. After the core is in place, the inner skin of fiberglass laminate is laid down. If the job is done in one shot, it might be vacuum bagged to reduce weight.

If a production builder is constructing a number of boats, the deck might be given its own interior liner to ensure that the overhead (the ceiling) in the cabin is smooth and shiny. This provides



(6) A cabin interior of a large luxury yacht under construction. This furniture was assembled in the SMI Group plant in New Zealand and trial-fitted in a mock-up cabin before being shipped to Italy for fitting into the yacht.

a nice finish for the boat's interior, but it can be a nightmare for later repairs. In many cases, wiring for cabin lighting is installed on the underside of the deck, and an interior liner covers that wiring. To facilitate future repairs, the wiring should be installed in conduits so that it can be removed or replaced easily. In fact, all wiring should be installed in conduits to protect it from damage and make it easier to work on.

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(1) A deck is almost ready to be bonded to its hull. (2) This view of the bottom surface of a deck shows wiring already in place. A headliner (i.e., an interior liner) may be fitted to this bottom surface before the deck is lowered onto the hull and bolted in place. This construction restricts access for later repairs. (3) The deck of the boat shown in photo 2 with a molded-in cockpit and pilothouse, ready for installation.



As mentioned, deck hardware and fittings should not be installed over a cored deck surface. In original construction, the builder will (hopefully) taper the deck core to solid fiberglass wherever hardware is fastened. When hardware is later relocated to cored deck sections, the core under the hardware fasteners should be removed and replaced with thickened epoxy as described in Chapter 5 on page 96.

Similarly, when hardware and fittings are removed from a cored deck—whether to reconfigure the deck layout or to repair or refinish the deck—the holes left in the deck must be filled so that water can't permeate the core. This is true even if the gear removal is only temporary, especially if you're work-

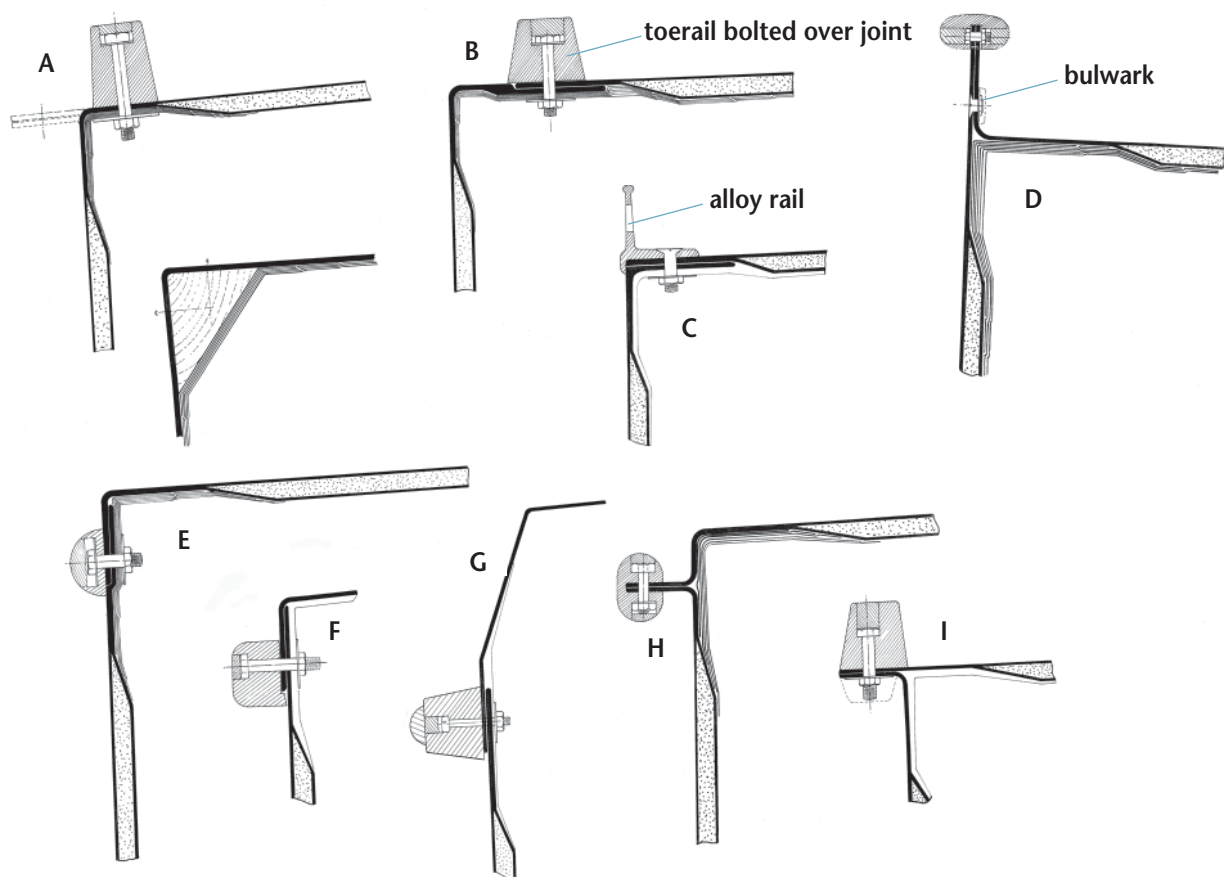
ing outdoors. If you find filled holes in the deck of an older boat, try to determine what material was used as a filler. Silicone sealer is popular for this job but also ineffective.

Hatch and window replacement is another common abovedeck renovation task. Although it can take many hours to replace these fittings (see, for example, Project #6, Replacing a Foredeck Hatch, in Chapter 7), the cost of a new hatch or window and the caulking to seal it is relatively

low. Again, when stripping out an old hatch or window, you must take care not to let water into the core.

HULL-TO-DECK JOINTS

On rare occasions a repair will require tearing apart the hull-to-deck joint to get at parts of the boat under the deck. Should you be so unlucky, it



Several hull-to-deck joints and how they are made. **A** shows a deck that is lowered onto an outward-turning hull flange. The deck is glassed to the flange on the inside, and the flange can then either be cut off (shown dashed) or capped by a rubrail. This method is not in common use today. **B** shows a much more common joint in which the deck is lowered onto an inward-turning hull flange and bolted down. To hide the joint, a toerail is often bolted over it. **C** shows a similar method, but with an alloy rail mounted over the joint. **D** shows a seam that turns upward to form

a bulwark. If this joint is not properly made and scuppered, water may leak into the joint and down into the hull. **E**, **F**, and **G** show the most common hull-to-deck joint variation, in which the deck overlaps the top of the hull. **E** is a coffee-can joint, whereas **F** and **G** are shoe-box joints. In either type the hull and deck are bolted or screwed together horizontally, and often a rubrail is mounted on the outside of the joint. **H** and **I** show outward-turning flanges—a solid joint but one that sticks out from the side of the hull and is prone to damage from pilings and other boats.



will help to understand how hull-to-deck joints are made. While most builders use what is known as a coffee-can joint, there are others, and identifying them can be crucial in making the right decision on how to go about a repair.

This overview of fiberglass boatbuilding should provide the understanding you need to approach almost any fiberglass repair or restoration project. Bear in mind, however, that even a thorough knowledge of fiberglass boat construction can't prevent some changes to the interior layout of a newer fiberglass boat from being extremely difficult. This difficulty can't be helped—it's inherent to a method of construction incorporating hull pans, interior liners, and modular furniture installation. Changing an interior layout is a lot easier on an older boat with glassed-in bulkheads and stick-built furniture. And since that is precisely the sort of boat whose interior layout most likely needs updating, that's a good thing.

This deck was lowered onto an inward-turning flange and screwed into place. The toerail covers most of the joint, but a self-tapping screw is used at the stern quarter aft of the toerail termination.