CONSTRUCTION

There are so many choices of materials in both new and used boats that it can be difficult to know where to begin making a choice. For some, there will be an emotional bond to one sort of construction over another.

Linda and I have owned one or more of just about every type; each has its advantages and disadvantages.

And what about all those construction details? Questions of tankage, ballast, and rudder construction?

The issues to be considered and integrated into a cohesive decision-making process can become overwhelming. But if you take them step-by-step, evaluating each of the many questions to be considered, in the end a line of reasoning that is correct for your own needs will emerge.

FIBERGLASS

Fiberglass offers many advantages, not the least of which is low production cost and modest maintenance. We now have a historical database to suggest what works well and where the problems lie.

Modern race boats have taught builders, designers, and owners the ultimate limits of composite structural design. A plethora of real-world data has shown that designers and builders using high-tech materials and the latest analytical data have made craft just a bit too light in construction. They have shown that one can construct an around-the-world boat or a high-tech daysailer for professional sailors of exotic and expensive materials.

These design parameters are used for mass-produced cruising yachts, where many of the same engineering disciplines apply — except that more common (and less costly) composite materials, with a huge practical database, are used.

Building production boats is a very competitive business, and the industry has a sense that it is a price-driven business at the retail level, so builders are always looking for ways to cut corners while delivering a boat that suits its owner's needs. The majority of cruising yachts never leave their moorings, and when they do venture forth, it is usually within protected waters. If the boats rarely leave the slip, they can be built with less structure in order to save money and weight. The owner who uses his boat for local cruising gets a lower-priced product (which makes him happy), and the boat is a hair faster because it is lighter.

Now along comes someone who wants to go cruising. This means the boat is bound to see some stress and strain, whether from the sea, from plain old miles sailed, or from an unforeseen mistake — such as running aground — which would be considered abuse by the average boatbuilder.

Since a boat tied to the dock can't run aground, the odds are greatly diminished that its keel will push the back end of the hull up, breaking floors and furniture in the process.

In addition, if you are trapped on a reef for any length of time your boat will probably have damage to your topsides as well.

We've always felt that the industry was shortchanging itself and its customers by cutting too many corners. For a few percent more in hardware costs, it could deliver relatively bulletproof boats, with fore-and-aft watertight bulkheads, and a heavily reinforced keel structure. When we've offered this, the market has responded favorably.

Okay, I got that off my chest. Let's take a look now at the basic engineering that goes into a fiberglass hull.

The hull of a Sundeer 64 after molding has been completed. You can see the solid area of laminate around the keel. The long rectangular patches in the turn of the bilge are where the water tanks will be bonded in.

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Balancing Components

To begin with, as with any structure, the components should be balanced so that they all work together and so you have a predictable mode of failure.

This means that resins and their physical properties should be tailored to match those of the reinforcements being used. Cores, where they are used, need to be able to transmit the ultimate sheer loads between the skins without failing.

Secondary bonds, used to integrate primary and secondary structures, must be carefully made, with high factors of safety to allow for variables inherent in the manufacturing process.

REINFORCEMENTS

It wasn't long ago that all fiberglass yachts were produced using pretty much the same reinforcements. Today, however, this is not the case. Manufacturers — driven by the need to cut costs, reduce volatile emissions (for the EPA) and trim weight — are building with an array of new types of materials.

Regardless of whether you're buying a new vessel or a used one, you will want to consider the lay-up schedule used in its construction.

Woven Rovings

Traditionally woven fiberglass reinforcements called woven rovings have been used for the bulk of structural laminates. These materials are made up of large bundles of fiberglass rovings. Relatively easy to work with, they conform to curved shapes and are simple to impregnate with resin.

Because each of these roving bundles of fiberglass is rather thick, there is a lot of contouring between the rovings as they weave over one another to create this material. The thickness of the fabric makes it difficult to get any two layers of woven roving to stick together, as there's not a lot of surface area touching and there are many void areas which are filled with resin.

However, woven roving enables one to apply a large mass of reinforcement to a laminate quickly. Since it is relatively efficient to weave, the laminate costs are quite reasonable.

Mat

To solve the interlaminary bonding problem, a layer of chopped strand mat is used to fill the voids between the layers of woven roving. The fibers are typically about 2 inches (50 mm) long and laid down in a random pattern by the manufacturers.

Mat is not really a structural material, per se, but rather a tough filler that also enhances the impact strength of the laminate. In a resin matrix it is reasonably strong and provides the bulk to bridge the gap between the woven undulations of the two layers of woven roving. The mat also adds thickness to the laminate, and by so doing, helps the stiffness of the structure by increasing its moment of inertia.

The big negative with mat is that it holds lots of resin and, for its weight, is relatively weak.Where weight is not a major concern, mat and woven roving combinations can create an extremely strong structure at a moderate cost.

Unidirectionals

Unidirectional (UDR) reinforcements eliminate the weaving process and the need for a mat interface between layers of the laminate.They consist of much smaller bundles of fibers running in one direction in a single plane in the laminate. These bundles are layered together by knitting or are fused together with lightweight fibers to hold them in place until the laminate has cured.

The advantage of this material is that it can be oriented in the most efficient direction to accept the design structural loads. Orientations commonly used are layers at right angles to each other for longitudinal and hoop strength and off-axis 45-degree angle layers to resist torque loads.

The UDRs offer a series of advantages: Because the weave, and its attendant strength reducing crimp has been eliminated, these reinforcements pick up the load much more directly and efficiently than woven roving/mat laminates. (Woven roving has a spring effect from the over-and-under nature of the material.)

As there is no weave thickness, multiple layers can be built up without the use of mats, or if mats are used, they can be much thinner.

The result is a laminate that is stronger for the same weight, or lighter for the same strength. However, because the UDR laminate is much thinner than the mat and woven roving laminate, it does not have as much moment of inertia and panel stiffness in a solid-skin laminate case (as this is primarily a function of laminate thickness). As a result, UDR laminates are typically only found in cored structures.

In a cruising context, an important issue to be addressed is localized impact resistance. Because the layers of UDR are thinner, they can't withstand as much impact load as the solid-skinned mat/woven roving laminate. This means that a laminate, developed to take basic seagoing loads in conjunction with a core, may not have enough strength to adequately resist the impact encountered on an exotic reef.

Strength to Weight Ratios for Various Materials
(Expressed in miles of material required to break of its own weight)

Material	Density (#/Cu.In.)	Tensile Strength (Kilo pounds / Sq. In.)	Distance (Miles)
E-GLASS	.0547	150.00	43.28
GRAPHITE	.0454	132.00	45.89
KEVLAR 49	.0421	157.5	59.05
S-GLASS	.0535	199.50	58.85
316 SS	.2900	88.00	4.79
6161-T6	.0980	42.00	6.76
DOUG FIR	.0173	12.40	11.31
MAHOGANY	.0163	9.30	9.00
SPRUCE	.0134	10.30	12.13
TEAK	.0228	12.80	8.86

Here's an interesting chart from Kozloff Enterprises, comparing various materials on a strength-to-weight basis for tension strength. The key figure is the right-hand column, which indicates the amount of material required to bring a given material to failure.

For cruising, when using a UDR reinforcement system, it is usually advisable to add additional thickness (and weight) to the areas that might hit things.

E-Glass

E-glass, which was developed in WWII for electrical circuit boards (hence, the designation "E") is the standard fiber used in most boats. It has reasonable mechanical properties and is relatively easy to work with.

S-Glass (R-glass)

S-glass and its close cousin R-glass, were developed in the late 1950s for aircraft use to provide a structural (hence the "S") glass material that was 5% lighter but with 25% more elongation, strength, and stiffness than E-glass.

When combined with higher performance resins, it can produce very light, tough structures. You will sometimes find S-glass used in rudder stocks and around the structural floors supporting keels.

Kevlar

Kevlar is another notch up the exotic scale because of its low density. It is much more difficult to work with than E- or S-glass and much more costly. It has better abrasion and tear resistance than carbon, E-glass, or S-glass — but, as can be seen from the attached table, it is not as strong as some of the others.

If this material is used by itself, as a protective layer, it can deliver an extra margin of safety. However, there are a number of commercial hybrids of Kevlar and S-glass that are stitched together, with the Kevlar having only a token presence.

Some builders use these materials and tout the fact that they thus have an exotic Kevlar-reinforcement material for your vessel. However, the small percentage of Kevlar in the hybrid indicates that it will have a small, if any, impact on the structural equation.

Carbon Fiber

Carbon fiber is king of the hill in terms of strength and stiffness-to-weight ratios. Matched with the correct resins and/or sandwich cores, the performance gains that can be achieved are truly remarkable. In some instances, the judicious use of carbon fiber in conjunction with conventional laminates makes economic sense. Two examples are in a mast step, or in the reinforcement at the aft end of the keel — both of which are subjected to high bending loads.

RESINS

Holding all these fibers together are various forms of resins. While there are many chemical and physical properties to evaluate, we're mainly concerned with one — tensile elongation, or brittleness. This fancy engineering term is a measure of how far a resin will stretch before it fails. Ide-

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ally, the resin will stretch to the point where the fiberglass reinforcements can carry the full load. However, this isn't usually the case, leading to the milky-looking fractures typical of damaged fiberglass.

Finally, we get to the really good stuff. Vinylester and Acrylic-Modified Epoxy (AME) resins are stronger than the common polyester and isothalic resins, and also have a tensile elongation more closely matching the fiberglass reinforcements. They're highly resistant to blistering and have excellent secondary bonding characteristics — which means the attachment of bulkheads, chainplates, etc., to the main hull structure.

While they're somewhat more expensive than polyesters, this cost adds up to a small percentage of the total cost.

If I were building a new fiberglass boat today, I would use one of the above resins.

Orthothalic Polyesters

The most common form of polyester resin is orthothalic. These have the lowest structural properties and the least elasticity before failure. Typically they fail at less than 1.5 percent elongation, whereas the fiberglass reinforcements will go to 4 or 5 percent before breaking. Orthothalics are also subjected to chemical attack from base materials which leads to blistering, or the pox.

Isothalic Polyesters

Next up the scale come the isothalic polyesters. These have better than twice the tensile elongation and much better structural and chemical properties. Better-quality yachts are built with these isothalics, typically having fewer problems with osmosis, since the isothalics are more chemically resistant.

Vinylesters

Vinylester (VE) resins have been with us since the 1950s, when they were first used in building fiberglass structures that required chemical resistance. However, along with being expensive, they were difficult to work with due to specialized catilization procedures.

About ten years ago we started to see VE resins with handling properties like the normal boatbuilding resins, so the only issue remaining was the 100% cost premium.

Expensive? Yes, but look what you get:

1. The resin itself is about 12 percent lighter than polyester, yielding an easy 7 or 8 percent laminate weight saving. It is chemically resistant, especially to petroleum products, and is not subject to osmosis.

2. Secondary bonds are easier to accomplish and are of higher strength. More important are the physical properties. Tensile strength is about 15 percent higher than polyesters — 25 percent if you consider strength for weight.

3. Most critical, however, are the tensile-elongation properties. Where orthothalic resins begin to fail at around 1.5 percent tensile elongation (typically before the reinforcement starts to play much role), the VE resins can go to 5 percent elongation before failure. In an impact situation, this will have a huge impact on the survivability of the laminate.

In the last ten years or so, we've specified all our production yachts to be built with VE resins.

Epoxies

Epoxies have the best physical properties of all resins, with strength-to-weight ratios as much as 10 percent better than even the VE resins. However, they tend to be more difficult to work with and are incrementally more costly.

If you are looking for the ultimate structure, epoxies are the way to go. But the weight savings in a cruising context are not significant enough to justify the added expense.

CORES

Because most solid-fiberglass laminates typically have a low modulus of elasticity, it takes a lot of laminate thickness to get a hull panel stiff enough to accept sailing loads. Such a hull laminate must be very thick (and therefore heavy) to develop the proper moment of inertia, which, when multiplied by the modulus of elasticity, results in the panel stiffness required. The alternative is to use much lighter skins, separating them with a core. Because stiffness of a sandwich panel goes up with the square of the distance between the faces, very stiff panels are generated for low weights.

From a structural standpoint, the outside sandwich skins are considered to be loaded in com-

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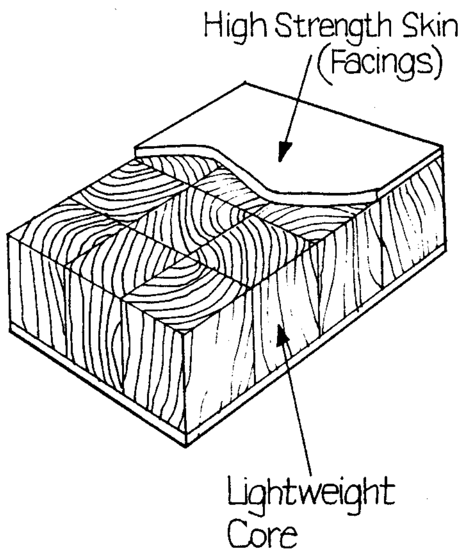
pression, the core transfers the outer skin load to the inner skin in the form of shear, and the inner skin picks up this load in tension. Because FRP laminates are typically stronger in tension than in compression, the outer laminate usually ends up being 1.5 times thicker than the inner laminate.

Cored boats have some other advantages. First, they have a natural insulation value (which varies depending on the core). Second, the panels are almost always stiffer than their solid FRP counterparts, reducing hull-flexing and scantling requirements and improving the performance and longevity of the hull.

However, to be successful, the builder using a cored laminate must maintain higher quality controls than those of solid FRP construction. The materials must be properly sealed and bonded. Obviously, make sure that the FRP skins are well adhered to the core!



The core acts as a "sheer web" transferring load from one skin to the other. The thicker the core, the stiffer the panel.

Physical Characteristics

It is the sheer properties of core materials that are of greatest interest. The better these are, the better the job the core material will do in resisting loads.

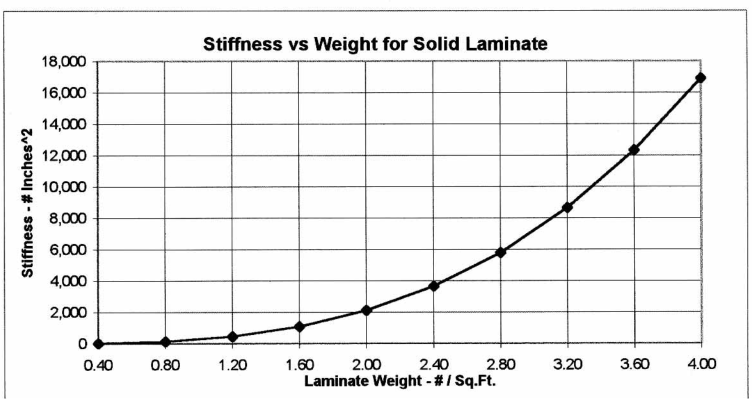
Sheer value varies between core materials with density. The higher the density (heavier) of a given material, the better shear strength it will have.

Compressive strength is interesting. This helps to deflect localized loads, such as bolting of hardware or the tip of an outboard fin. With end-grain balsa cores, except for highly loaded deck fittings, compression is not usually a problem. However, it is something that needs to be watched with plastic foams.

Since cores are available in different thicknesses and densities, there is a considerable amount of "what if" engineering done with each structure.

SOLID LAMINATE

THICK (Inches)	WEIGHT # / Sq.Ft.)	MODULUS (Psi x 10^6)	MOM INERTIA (Inches)^4	STIFFNESS (# Inches^2)	T STRENGTH (Psi)
0.05	0.40	1.63	1.04E-05	17	27,500
0.10	0.80	1.63	8.33E-05	135	27,500
0.15	1.20	1.63	2.81E-04	457	27,500
0.20	1.60	1.63	6.67E-04	1,083	27,500
0.25	2.00	1.63	1.30E-03	2,116	27,500
0.30	2.40	1.63	2.25E-03	3,656	27,500
0.35	2.80	1.63	3.57E-03	5,806	27,500
0.40	3.20	1.63	5.33E-03	8,667	27,500
0.45	3.60	1.63	7.59E-03	12,340	27,500
0.50	4.00	1.63	1.04E-02	16,927	27,500



Stiffness for a solid laminate, using standard E-glass hand-laminate, with orthothalic resin. This is based on a 50 percent by weight volume of glass to resin (29.5 percent by volume).

The chart on the next page shows the same data for a cored panel. The same materials are used, but with substantially less laminate, as you can tell from the weights. The core material in this example could be balsa or PVC.

(Kozloff Enterprise charts)

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If you go with thicker cores, thinner skins can be used. However, these structures are very rigid and thus more damage prone in a collision, especially when their thin skins are taken into account. For cruising, it is usually better to specify an outer laminate that has the local impact capability you are looking for, and then work the core to be efficient with this somewhat thickened outer laminate.

Balsa

End-grain balsa makes a wonderful core material. It has very high sheer properties, is moderate in cost, and easy to work with.

One of the big advantages in the shop is that the end-grain tends to suck in the resin, making a good bond to the fiberglass laminate easier.

This is, however, a two-edged sword. If not handled correctly, it will suck in excess amounts of resin, thereby increasing your weight. To get around this problem, the balsa supplier can pre-coat the surface of the balsa so that only a modest amount of resin will be aborted — or the builder can pre-coat the balsa with resin himself or herself.

Several densities of balsa are available. The least costly and most commonly used is about 10 pounds per cubic foot. The lighter, aircraft-grade is about 7.5 pounds per cubic foot.

We typically specify the lighter density for use in decks, and the heavier for the hull.

There's been a question about the longevity of balsa core. What happens if it gets wet? How does it stand up to aging? Our experience is that long-term viability is not an issue — as long as it is properly installed in the laminate, and any penetrations for deck hardware are done so the edges are sealed.

Moisture migration does not seem to have been a problem for us, or on many of the boats we've looked at that have been built with balsa as a core.

Some builders leave it out of the hull below the waterline. We haven't had problems with using balsa below the waterline. However, we do not put it in the keel sump.

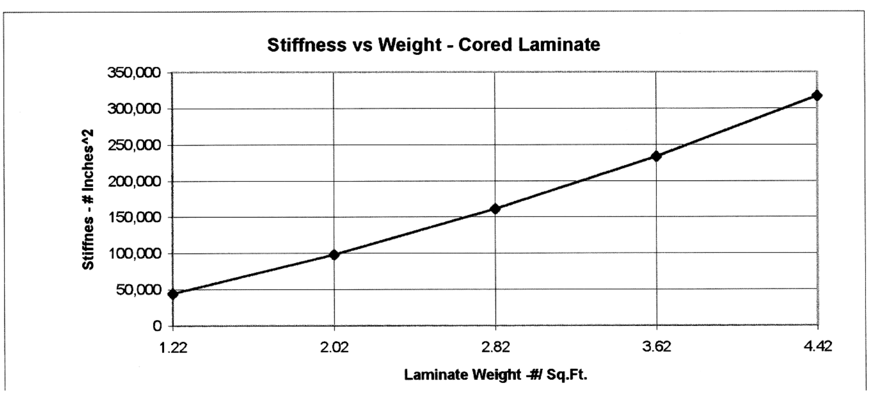
PVC Foam

PVC foams come in two varieties — stiff, cross-linked foams like Divinycell and Klegecell, and non-cross-linked flexible foams such as Airex and core-cell.

The cross-linked foams are often used in racing boats (as well as many cruising boats) because you can develop a stiffer laminate for a given weight. These cores tend to be lighter, although more costly, than balsa.

CORED LAMINATE (With 1" Thick 5 Pound per Cubic Foot Core)

SKIN THICK (Inches)	Total Thick (Inches)	WEIGHT # / Sq.Ft.)	MODULUS (Psi x 10^6)	MOM INERTIA (Inches)^4	STIFFNESS (# Inches^2)	T STRENGTH (Psi)
0.05	1.10	1.22	1.63	2.76E-02	44,789	27,500
0.10	1.20	2.02	1.63	6.05E-02	98,313	27,500
0.15	1.30	2.82	1.63	9.92E-02	161,180	27,500
0.20	1.40	3.62	1.63	1.44E-01	234,000	27,500
0.25	1.50	4.42	1.63	1.95E-01	317,383	27,500



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Airex and core-cell tolerate more abuse. They will allow the outer laminate to deform, while keeping the laminate-to-core bond intact, under conditions in which the same bond would fail with cross-linked foams.

Foam-core materials can be purchased in densities ranging from a couple of pounds per cubic foot up to 18 pounds per cubic foot. Most boatbuilding takes place in the range of 5 pounds per cubic foot density. The higher-density materials are used where loads are high — perhaps around the rudder shaft or chainplates. The highest densities are used where hard spots have to be created for deck hardware.

While foam cores are common in the decks of race boats, for cruising you need to consider the long-term effects of heat load, as well as resistance to impact damage.

Honeycomb

Honeycombs have long been the staple of the aircraft business, both for structure and furniture. They are available made from materials ranging from paper, to aluminum, to Kevlar-based materials such as Nomex.

Using honeycomb takes sophisticated vacuum-bagging techniques. It can produce very light structures, but their longevity in a cruising context is suspect.

Most racing boats with honeycomb-panel interiors do not stand up to abuse and are typically pretty well shot after a few years of working.

Hard Spots

With any structure — whether solid glass or cored — be careful with areas of load concentration such as winch bases, prop shaft and rudder-bearing connections, chainplates, and windlasses. The concentrated loads from these devices and the fasteners that hold them in place should be carefully spread into the surrounding structure.

With cored laminates it is common to substantially increase the core density, substitute some form of timber, or go to solid laminate.

Where bolts are involved, take care to deal with thread loads.

Delamination

When using a core material, be concerned with delamination — where the skins separate from the surface of the core material. While this is not a widespread problem, it does occur.

Delamination is easily found (in new or old hulls) by simply tapping on the laminate. You will hear a distinct change in tone if you find an area free of the core. If this occurs in a moderate-sized area, the offending skin can be removed and reglassed. Nevertheless, it's better to do it right in the first place!

PRODUCTION PROCESSES

All sorts of crude and sophisticated methods are used today in the production of fiberglass laminates. All have various forms of mystery associated with a successful outcome. Adding the variables of climate (temperature and humidity), time, the working characteristics of the material, and human error, you can see that a successful track record with a given technique is important.

Room-Temperature Laminates

By far the most common form of production takes place at room temperature. Since climate control is costly in terms of capital and operating budget, most builders work in ambient weather conditions. The characteristics of the resins being worked with are adjusted by both the resin supplier and the builder to meet the weather requirements of the time in which the hull is being laid up. Room-temperature-cure resins have a catalyst injected or mixed with them just before application. This starts a chain reaction, leading to cure. There is limited window of workability during the catalyzed stage, during which the laminate must be completed.

Heat-Curing

The use of heat for curing opens up a series of chemical possibilities. One is a much longer working period, allowing larger parts and possibly more layers in one pass. With higher levels of heat, a temperature-sensitive catalyst can be used. This will not start to react until the heat threshold has been reached, allowing the builder to use pre-impregnated materials, unwound from a roll and laid into the mold as required.

Heat also can be used to substantially improve the physical properties of the resins used.

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Vacuum-Bagging

Vacuum-bagging is a relatively inexpensive means of substantially improving a fiberglass laminate, especially if cored materials are involved.

The process is simple enough. Once a part has been laid up in a mold, a plastic sheet (or series of sheets taped together) is laid over the molding surface. The edges of the sheet — or bag, as it is referred to are then taped down to the perimeter of the mold. Finally, a series of hoses are led from different areas under the bag to a manifold, which is in turn connected to a vacuum pump. As air is removed from under the bag, the outside atmospheric pressure begins to push down on the surface. Eventually pressure as high as 7 to 10 pounds per square inch is achieved. This squeezes the laminates closer together, and in the case of cored structure, ensures that the core is forced into the bedding putty/resin matrix. The amount of resin that needs to be used is reduced, yielding a lighter structure — with no sacrifice in structure.

A few years ago vacuum-bagging was considered a technique for racing vessels only. Today, however, it is used quite commonly by production builders just trying to make a high-quality product. Over the years we've insisted that all our cored yachts be bagged during the installation of the core materials.

SCRIMP Process

The SCRIMP process takes this one step further. The entire laminate, all the reinforcement materials and cores are placed in the mold dry. A very high vacuum, typically twice that used in the conventional process, is then pulled on this dry assembly.

When the proper point is reached, suction valves are opened to pails of resin placed around the mold, and the liquid resin is sucked into the laminate.

The technique is a mixture of art and science. The resin has to be specially catalyzed, and the location of the resin injection hoses obviously takes some trial-and-error.

Because this process uses both atmospheric pressure and vacuum while the reinforcements are dry, the final laminate ends up with a minimum amount of resin, saving weight and improving structural performance.

Interlaminary bonds are no longer a problem, as the entire process is done at one time. Also, the cores are really well bonded within the areas between core blocks (if they've been scored) filled with resin.

We used this process to build the Sundeer 56 and 64 and found that we achieved glass-to-resin ratios on the order of 65:35 by weight. We saved considerable weight in resin, most of which was put back in the form of additional reinforcing fibers.

CONSTRUCTION DETAILS

As they say, the devil is in the details, and this is nowhere more accurate than when you are talking about fiberglass construction. Frequently the details that make a difference have a small impact on cost. Getting them right is more a question of understanding the problem of an offshore cruising vessel, and then using your head to come up with the right approach.

Hull-to-Deck Joints

This is probably the most important construction detail in the boat. If done correctly, you will never even have to think about it. However, any problems will quickly manifest themselves in the form of leaks that are difficult to trace and devilish to stop.

There are two types of loads on the hull-to-deck joint. The first is the structural interaction of the hull and deck. The deck acts as a web in a beam, the hull sides being the beam flanges. This helps keep the hull from moving under load.

The difficulty with the hull-flexing loads is that they constantly vary in intensity and direction, with frequent load reversals. All of this makes it tough for the hull-to-deck joint to handle the loads over time.

The second type of load is more transitory, but of much higher magnitude. This occurs when you smack into a piling or have a collision with another vessel. If you do much cruising, your boat will be subjected to this type of abuse. Hopefully your hull-to-deck joint will take the load. There are several key factors in making a good connection between hull and deck. The first is contact area between the two structures — the more, the better. The various scantling rules have recommendations in this regard. We normally like to see 4 inches (100 mm) on a 50-foot (15.4m) vessel.

The second factor is fit between flanges. The better the fit, the better the bond between the two surfaces. Third are the structural fasteners. These should be engineered to carry the full load, regardless of what sort of adhesive is used in the joint itself. The size and spacing of the bolts is a function of the thickness of the toerail or jib track through which they pass. This member spreads the load of the bolt.

Hull-to-deck joints used to be assembled using a mix of fiberglass mat and resin. Today structural adhesives are more effective, providing resilience to maintain the weathertight integrity of the seal in case of any localized movement.

The assembly bolts are frequently a source of leaks over time. Only careful bedding will prevent this.

Another approach is to place a laminate along the hull-to-deck joint on the inside after the bolts have been tightened.

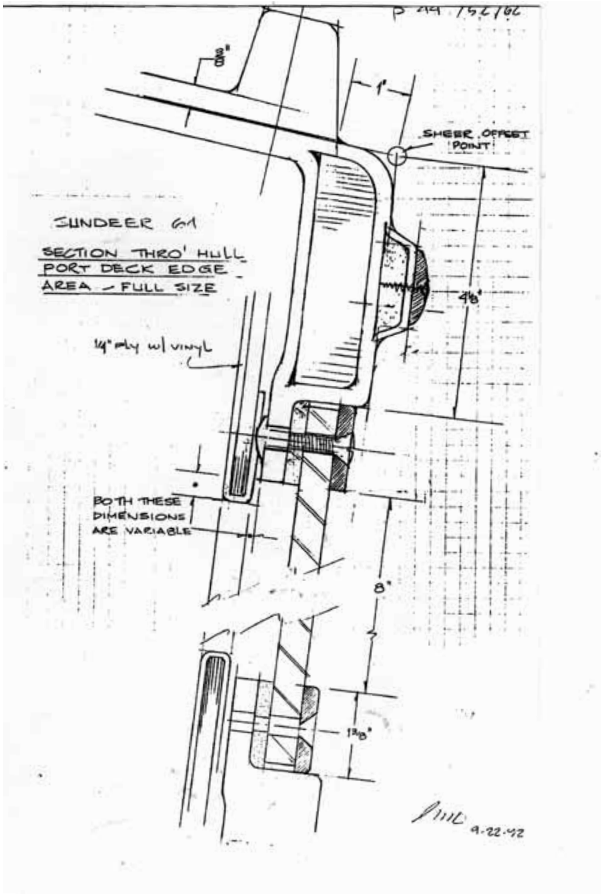
Hull-to-deck joints that are stiffened with an angled gusset are the strongest and most efficient over time at dealing with hull flexing and localized impact.

Furniture as Structure

Furniture is frequently heavily bonded to the hull and used as local stiffening. This makes sense weightwise. However, what you are doing is taking weight from the hull laminate and putting it into the furniture so it will carry loads, then increasing the bonding of the furniture to the hull so it will transmit the load. In an offshore cruising context we prefer to see the hull structure engineered to work without the furniture. The lighter furniture weight is then put into the hull where it will do a better job against abrasion and impact. It does, however, cost money and add weight to the boat.

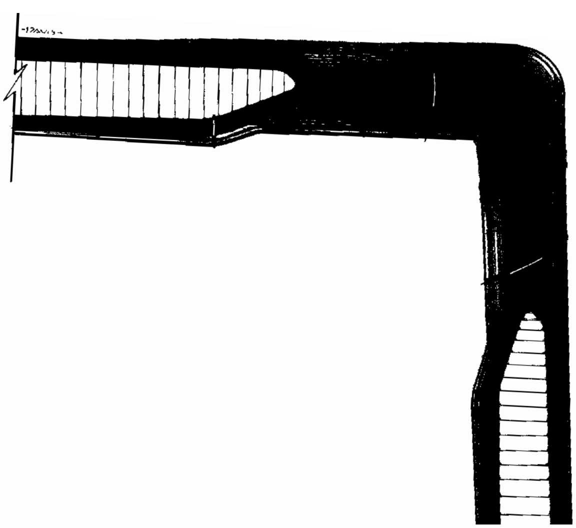
Integral Tanks

Integral water tanks can be built where the hull forms a part of the tank. There will be some taste and odor with glass tanks for several years after manufacture, but this can be dealt with by using a charcoal filter. Having a small stainless steel tank for drinking water also makes sense.



Here's a typical detail (above) from one of the fiberglass hull-to-deck joints on one of our production boats. The deck sits on a wide flange that is formed by an inward projection of the hull. The core necks down to solid laminate in this area, as well as around the window detent.

With one-off projects we usually specify the hull to deck joint be glassed inside and out. This is not only strong, but totally leak proof (lower illustration).



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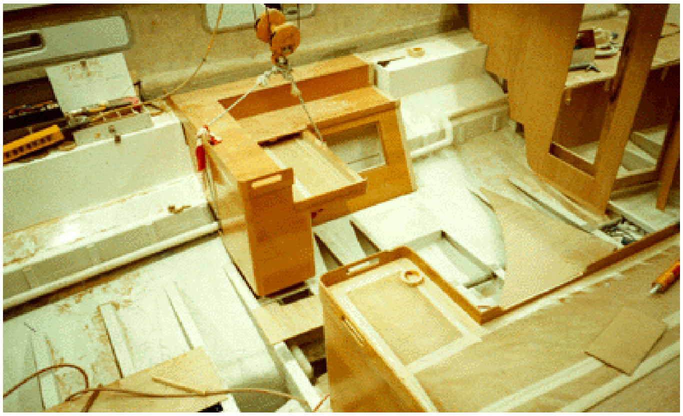


On both of our production yachts we molded in long fiberglass water tanks outboard of the furniture from the saloon bulkhead aft to the engine-room watertight bulkhead. In the saloon these tanks formed the bases for the seating.

It gave us lots of volume in an area in which storage was difficult and had the advantage of being well outboard so that water could be carried to windward on long hauls.

In addition, this tankage, taking place in the turn of the bilge, added an extra layer of protection in case of a severe grounding.

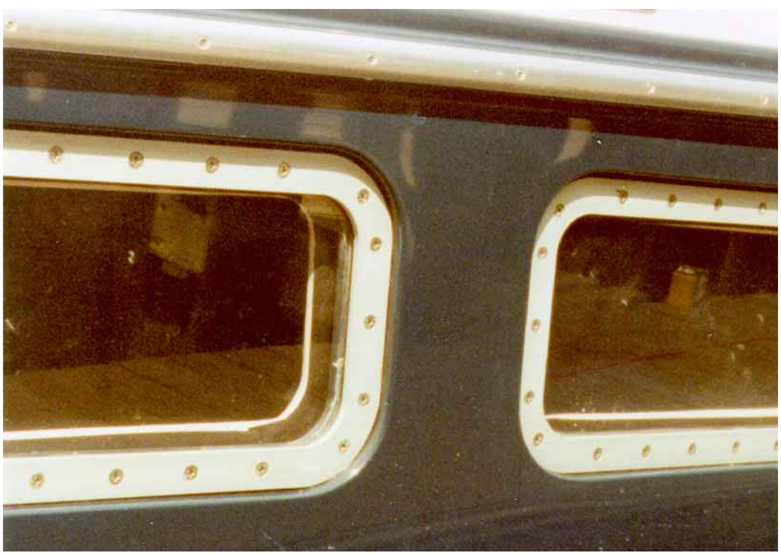
Diesel fuel should never be stored in integral tanks. Diesel has a much lower viscosity than water, and in a tank that appears to hold water you will find diesel leaks everywhere!

Hull Windows

Hull windows in fiberglass hulls should be carefully done so that the stress risers created by the openings do not become the source for cracks in the hull laminate. This means substantially increasing the laminate in the area of the opening, and removing any nearby core.

Hatches

Whenever you cut a hole in the deck, you create a stress riser, concentrated around the corners of the cutout. If the hatch frame is structurally adhered to the fiberglass hatch coaming, it will provide some reinforcement. Typically, however, not much load is taken by the hatch. The best thing to do is to run some extra laminate or unidirectional reinforcement around the hatch corners.



On fiberglass hulls we've found that creating a fiberglass flange onto which the Lexan window is placed works well. These windows sit on a special rubber gasket and are held in place by the aluminum bearing ring.

In the area of the fiberglass flange core is removed and laminate thickness is beefed up, so that there is extra material to deal with the stress riser created by the window opening.

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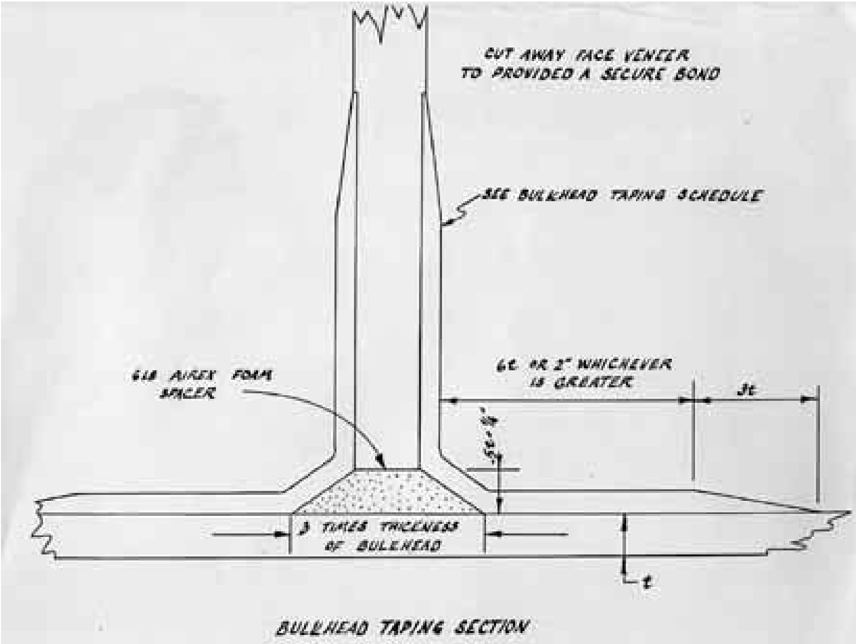

Robb Ladd drew the bulkhead attachment above for a project we were thinking about building in Taiwan (on which we didn't proceed). It shows the basics of how to bond in a bulkhead to reduce the chances of print-through on the topsides.

A section of core material should be placed between the bulkhead edge and the hull laminate. Then, lay up the tabbing between bulkhead and hull in a cool manner, keeping the heat generated in the curing process to a minimum.

Using a high-solids resin with low shrink characteristics will also help to reduce transfer.

Bulkhead Attachment

Bulkhead attachments are not only structural issues but aesthetic ones as well. If done correctly, the bulkhead will stay in place regardless of the load and you will never know from the inside or outside that it is there.

Done incorrectly, the bulkhead will show right through the gelcoat as a vertical crease. To get around this problem of print-through, several things are done. First, the hull laminate needs to be fully cured before the bulkhead is installed. Second, some form of a pad is placed between the edge of the bulkhead and the laminate. This is typically a thin piece of core material to absorb some of the pressure of the bulkhead as the secondary bonds cure and begin to shrink. Third, the secondary bonds are done with resins which have low shrinkage factors, and are done over time so excess heat buildup (which increases shrinkage of the resin) is minimized.

Chainplates

Chainplates, where rig loads are taken into the hull, represent the highest load concentration on the boat. If the chainplates are inboard, for tight sheeting angle to windward, the load needs to be transferred out to the hull. Inboard chainplates are typically bolted to heavy knees or bulkheads, which in turn are heavily glassed to the hull.

The area where the chainplate penetrates the deck should be solid laminate, as chainplates almost always leak at some point in their career. You don't want this water getting into your deck core.

We prefer to use a wide staying base, which reduces rigging loads and allows us to attach our chainplates directly to the hull sides. This is much more efficient structurally and less prone to leakage over time. The laminate in the area of the chainplates should be increased to handle the bolt loads. A common practice is to use long tows of unidirectional reinforcement around the areas where the bolts come through the laminate to spread the load.

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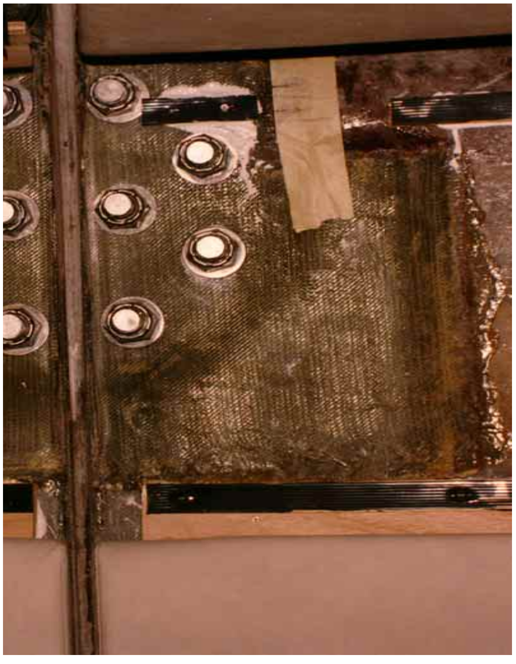
With chainplates attached directly to the hull the connection is quite simple. The laminate is beefed up to absorb and spread the load. With external chainplates they are simply bolted through the topsides. Or a knee is laminated to the hull to which the chainplate is bolted.



Working with Clive Dent at TPI we adopted this stye of chainplate on our production vessels. It is enormously strong and tied, as you can see, to a heavily reinforced section of hull. With ten bolts to spread the load, you can be sure that these chainplates are not going to move.

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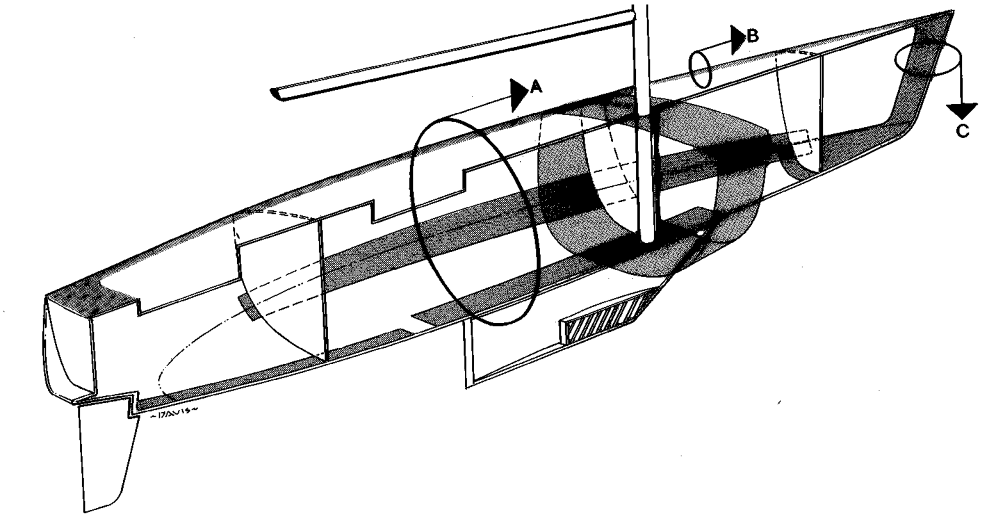


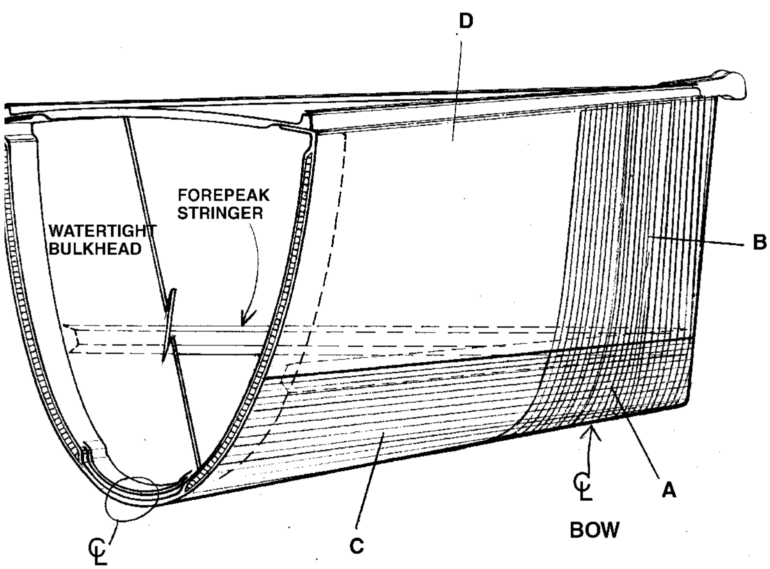
Certain key areas of the hull need to be extra heavily built for cruising:
(A) The turn of the bilge for strandings and the aft end of the keel for taking the ground;
(B) The area around the mast for mast compression and chainplate loads;
(C) The bow for collisions.

CRUISING REINFORCEMENTS

We've already discussed cruising reinforcements, but the subject is so important, we feel a second look is worthwhile.

If you are building new, you should know that for a very small increase in cost and weight you can tremendously increase your factors of safety in the vulnerable areas of the hull. This offers a much better chance to survive an otherwise damaging incident unscathed. It makes so much sense to me, I don't know why all builders don't take this approach from the start and market the fact that they are building bulletproof boats.

Working with TPI on the Sundeer production series gave us a real insight into how to efficiently build a strong, moderate-displacement cruising yacht. We started out using vinylester resin because of its superior structural properties, lighter weight, and, most important, its ability to stretch under load (tensile elongate) in such a way as to match what was happening with the fiberglass reinforcements.



Under normal sailing loads, the bow sees a moderate amount of load. However, in a collision the forces escalate dramatically. In fact, we don't even know how to model collision forces. However, since the total potential surface area of impact is not that great, you can afford to put some real beef into the bow to deal with extra loading.

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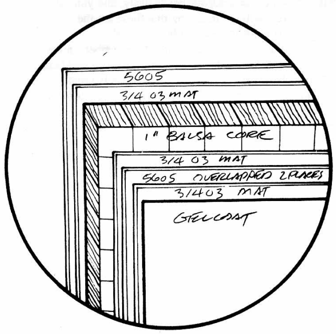
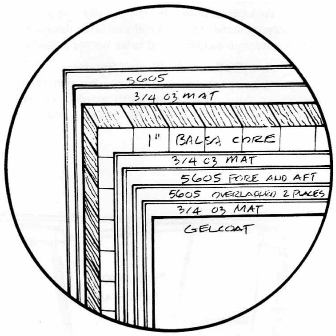
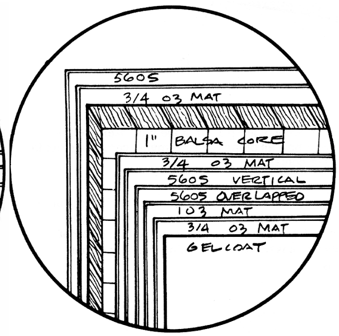




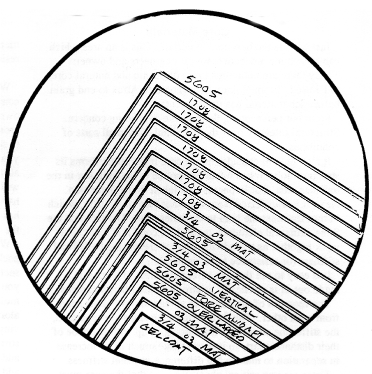


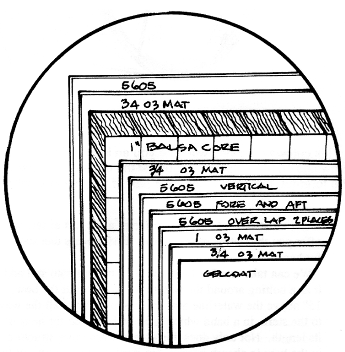
Section (A) is the basic laminate we used on the Sundeer 64 (and in scale on the 56). The basic layer, called 5605, is a 56-ounce quadraxial layer of unidirectional rovings stitched together. These layers by themselves are the equivalent of what ABS requires for a vessel of this size. In addition there is a 3/4-ounce mat between the 5605 and balsa core, as well as between the 5605 and the hull surface gelcoat.

One layer of 5605 is the equivalent of three layers of 24-ounce woven roving.

Section (B) is the same as the basic laminate, but with an additional layer of 5605 that runs below the waterline for the entire hull.

Section (C) is the same as (B) except that an additional layer has been added in the topsides around the waterline to provide puncture resistance. The extra bottom 5605 and the waterline 5605 overlap below the waterline to form a doubled area of extra reinforcements.





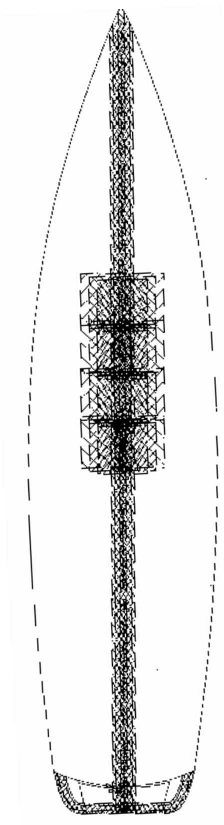
Section (D) is used in the forefoot area.. In addition to the basic laminates in hull and bottom as shown in (B), this adds another layer of 5605 for collision resistance!

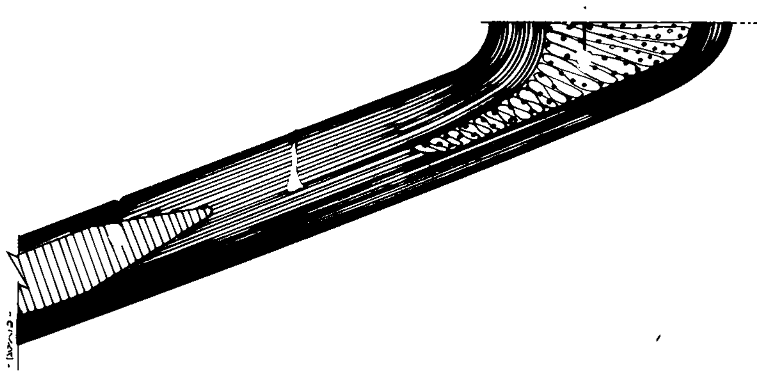
Now we get to the serious bow reinforcements!

Take everything you've seen in section (D) and add seven layers of 1708 biaxial UDR at 17 ounces per yard, and you have a laminate that is the equivalent in impact strength to 3 inches (75 mm) of solid conventional laminate.

These extra layers of biaxial material actually run down the entire centerline of the hull, with additional layers in the area of the keel loading, as you can see in the drawing in the middle.

The right drawing shows the effect of the centerline materials together with the two layers of 5605 in the bottom.





Here is another approach we've used to bow reinforcement. As you get close to the potential impact area of the bow the core material is tapered off and a solid laminate is used. However, about half way up the bow a high-density core is used between heavy inner and outer fiberglass skins to reduce weight.

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When we looked at the types of reinforcing materials to use, it was immediately apparent that unidirectional E-glass was most efficient. Because we had the capabilities of TPI's high-vacuum SCRIMP process, these UDRs could be laid up in a single pass of heavily knitted material for most of the topside and hull areas. Additional material was added, as per our standard practice in the bow for collisions, down the centerline, around the keel, and around the rudder shaft. We used CK-10 balsa for the hull and CK-7.5 for the deck.

While the overall laminate, in conjunction with the vinylester resin, was extremely tough by any normal standards, it was a hair thin for extended stays on a reef in the turn of the bilge. You could argue that the hull-side freshwater tanks gave lots of extra protection in the event of a puncture, but after considering the issue we decided to offer the owners an upgrade in the laminate schedule around the waterline.

This was a second complete layer, narrow at the bow, roughly 4 feet (1.2 m) wide at the turn of the bilge, tapering back towards the transom.

This doubling of the exterior laminate offered an enormous increase in physical and emotional security. The cost was about 0.5 percent of the total cost of the boat, while the increase in weight was about 0.75 percent.

All of the boats were built this way.

EXTERIOR FINISH

The exterior finish on your boat has a big impact on your cost of ownership. Done properly, the finish should look good for years. But once you start to repaint it can get costly very quickly.

Colors

Any color other than white is subject to fading. The darker the color, the faster it will fade, and it will be more difficult to match for repairs. In addition, dark colors absorb heat like crazy, making the interior less comfortable and creating potential problems for foam cores.

Gelcoat

Production fiberglass vessels are always finished with a special resin, called gelcoat, which is sprayed into the mold before the first laminate. Done properly, with good quality gelcoat in white, it will last decades if cared for.

The gloss that gelcoat achieves and then holds over time is moderate, which is an advantage in hiding unfairness in the molds, bulkhead transfer through the laminate, and dings you will incur with time.

LPU

Most custom yachts are painted with linear polyurethane (LPU). This is applied after the hull has been laminated, removed from its plug or mold, and faired. Because the gloss of LPU is so high, it shows every little defect. The surface finish must be to a much higher standard than that of gelcoat.

LPUs typically do better with sun degradation than do gelcoats, and they are a little lighter, as they are not as thick (allowing for fairing).

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Deck Nonskid

Nonskid should be looked at as a safety issue first and in an aesthetics context second. In order to do its job when the boat is heeled and the deck is wet, the nonskid needs to be very rough. It should be rough enough so that if you fall it will scrape your knees and hands, and so that you are worried about it wearing through your foul-weather gear. Anything less than this will be slippery when you least expect it.

The typical method of adding nonskid to a mold surface, or when post-finishing a one-off deck, is to use a sprayed glass or plastic bead held in a resin or LPU matrix.

Anything other than the largest glass beads will be too slippery. And even the large glass beads are marginal.

Course sand gives the best surface (it must be pure, without iron contamination, or the iron will eventually bleed through). The problem with sand is that it is difficult to get an even, good-looking surface and, when used on one-offs, tends to be heavy.

If you are laminating the deck in a female mold, care must be taken that the nonskid surface of the mold does not become filled with mold release. After several cycles of the deck tooling, there will be an accumulation of release agent in the nonskid pores that must be removed.

Molded-In Antifouling

Ferror Corporation has been promoting a molded-in antifouling called Copper Coat. Basically, this is a copper powder that is sprayed into the mold like a gelcoat. The bottom is then sanded before launching to activate the copper.

It does work keeping barnacles at bay. However, the experience of our owners who have used it is that it does not work well with grass and algae and that you must keep after the barnacles and dive periodically.

CHECKING A USED BOAT

Fiberglass is by far the most popular material in today's cruising fleets. It's relatively inexpensive, easy to maintain, and generally makes for good resale value at the end of the voyage.

A majority of boats rarely leave the marina for very long and are seldom subjected to heavy loads at sea. As a result, it's unusual to find a heavily built, modern mass-produced boat. For this reason, it's usually better to look for a fiberglass boat built before 1973. That was the year that resin prices first shot up. Before that, with resin going for under 20 cents a pound, manufacturers could afford to throw in extra laminate here and there.

When I worry about the scantlings of a fiberglass vessel, it's not the sea that concerns me. The loads of heavy weather can be substantial, but hull failures under sea loads are rare even in the skinned-out racing boats of today. It's when the boat meets the ground that problems arise. A lightly built hull, with hard spots at poorly bonded bulkheads, will last a fraction of the time of a heavily built hull when lying on a reef.

When examining a fiberglass hull, look carefully at the bonding of bulkheads and the extra glass at the hull-to-deck joint. If the boat has had some hard sailing, you'll be able to see if she's working. If you can't see all the structural joints because permanent cabinetry is in the way, or if the hull-to-deck joint is hidden, stay away from the boat.

"Old" Boats

It used to be thought that fiberglass boats would live forever. And this is possibly true for some of the earlier, heavily built boats. Because the industry did not understand the physical properties of this new "miracle" material, most builders erred on the conservative side. The first Bounties built by Coleman Boatworks in the late 1950s were over 2 inches (50 mm) thick!

But as the industry learned more and more about what fiberglass would take, they reduced laminate schedules (both to save weight and improve performance).

When you add in the loss of strength created by moisture absorption, easily a 25 percent (or more) hit, some of the more modern vessels do indeed have a finite life-span. That life-span is a function of time (due to moisture) and load cycles (due to sailing in waves).

Just where the limits lie in an offshore cruising context, no one really knows. That's why if you're buying an used vessel, you need to pay close attention to how the sisterships that have seen some sea miles have done.

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ALUMINUM

Advances in aluminum alloys, welding techniques, and paint finishes have dramatically changed the cost of using and maintaining this lightweight hull-construction material. The cost of working with aluminum is similar to any other custom yacht-building material.

Aluminum offers a host of advantages over other custom yacht-building materials — all structural connections welded; low center of gravity for better sail-carrying ability; lighter displacement for a given level of strength; virtually unlimited tankage built right into the hull; easy attachment of brackets, engine beds, and stringers; simple installation of watertight bulkheads; and ease of repair or modification. If used properly, aluminum is a superior yacht-building material.

Now if all you are talking about is keeping out seawater, a medium-tech cored fiberglass hull will be lighter than aluminum. But the minute you start to think about reefs and containers, and add in lots of tankage, our experience is that aluminum will be the lightest structure.

If you find yourself in the unhappy circumstance of being stranded on a reef, aluminum will survive severe, prolonged pounding under the same conditions in which a fiberglass yacht would be destroyed, unless it was built very heavily.

But to me, the ultimate advantage of aluminum is having an *absolutely dry* interior. With an aluminum deck, all fittings can be welded or blind-fastened to prevent any leaks. You will never open a locker to find your gear damp and mildewed after a hard reach or beat.

In addition, aluminum is the only boatbuilding material that affords the option of not painting the exterior. This saves on initial costs, maintenance, and nerves — no need to worry about scratching that fancy paint job!

And now I have a surprise for you. The final advantage of building in aluminum is noise. Done correctly, an aluminum vessel will be quieter than a fiberglass under sail or power. We've seen this numerous times when going from one of our fiberglass to aluminum designs, where the noise generation potential was constant.

Alloys

Aluminum hulls are constructed of a series of different alloys. These are blends of aluminum with traces of manganese, magnesium, and silesium added to improve strength and handling characteristics. For hull and deck plating, 5083 and 5086 alloys are used. They're ductile, easily welded, and extremely corrosion resistant. They have the further advantage of achieving their strength without heat-treating, meaning that when welded they maintain most of their mechanical properties. Of the two, 5083 is the stiffer, favored for decks and topsides, while 5086 conforms more easily to compound curves on the underside of the hull. The 6061 alloy has silesium added and is extruded in the form of structural T's or angles for use as stringers and frames. (It's also used for masts and booms.) The major difference is that it is heat-treated to help its strength. As a result, after welding, the metal loses its temper and becomes weaker, although over a period of time some of the temper returns. It is somewhat less corrosion-resistant than 5000 series metals.

5000 series alloys are more corrosion-resistant than 6000 series alloys. While classifications societies allow the use of 6000 series throughout the boat, practice indicates that only 5000 series should be used below the waterline.

	5005-H34	5050-H34	5052-H34	5083-H321, H116, H117	5086-H34	5086-H116 H32	6061-T6
Principal alloying elements	Mg05-1.1	Mg1.1-1.8	Mg2.2-2.8% 0.15-0.35	Mg4.0-4.9% Mn 0.40-1.0	Mg3.5-4.5% Mn0.20-0.7	Mg3.5-4.5% Mn0.20-0.7	Mg0.8-1.2% Si0.40-0.8
Resistance to seawater corrosion	Good		Excellent		Excellent		Good
PARENT METAL PROPERTIES							
Min. ultimate tensile strength (psi)	20,000	25,000	34,000	44,000	44,000	40,000	42,000
Min yield tensile strength (psi)	15,000	20,000	26,000	31,000	34,000	28,000	35,000
Typical shear strength (psi)			21,000	27,000	27,000	25,000	30,000
Minimum elongation (% in 2")	5	5	7	12	6	8	10
Brinell hardness (500 KG, 10 MM)			68	82	82	75	95

The mechanical properties of aluminum vary with the blend of ingredients; how the material is produced; and the heat-treating (if any) of the material in question. For plating, the most commonly used alloys are 5083 and 5086, in H-32 and H-34 condition. Masts, booms, angles, and tubes are generally made from 6061 in a T-6 condition.

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One of the keys to a proper aluminum hull is the quality of the welding. With modern equipment, a dedicated work force, and the correct environment welding, good quality is not difficult to achieve.

This photo was taken in South Africa. We've gotten good results in Europe and New Zealand too. In fact, the only country where we've ever had a problem was the U.S.A.!

Working with Aluminum

One reason aluminum has enjoyed such a surge in popularity around the world is that it can be cut, ground, and routed with the same basic tools used for wood. The structural systems used for framing hulls are similar, too. As a result, yards with experience in wooden boatbuilding convert readily to aluminum.

For bending frames, stringers, and plate, equipment can run from home-made roll presses and small hydraulic rams to sophisticated computer-controlled multi-headed formers. The main difference is capital investment and production time. High-quality results can be obtained with either approach.

		Property						
		Tension		Compression	Shear		Bearing	
Alloy and temper	Product and thickness range, in.	F_{tuw}[b] ksi	F_{yw}[c] ksi	F_{cyw}[d] ksi	F_{suw}[e] ksi	F_{syw}[f] ksi	F_{buw}[g] ksi	F_{byw}[h] ksi
5052-H32, H34	All	25	13	13	16	7.5	50	19
5083-H111	Extrusions	39	21	20	23	12	78	32
-H321	Sheet & plate, 0.188-1.500	40	24	24	24	14	80	36
-H321	Plate, 1.501-3.000	39	23	23	24	13	78	34
-H323, H343	Sheet	40	24	24	24	14	80	36
5086-H111	Extrusions	35	18	17	21	10	70	28
-H112	Plate, 0.250-0.499	35	17	17	21	9.5	70	28
-H112	Plate, 0.500-1.000	35	16	16	21	9	70	28
-H112	Plate, 1.001-2.000	35	14	14	21	8	70	28
-H116, H32, H34	Sheet & plate	35	19	19	21	11	70	28
5454-H111	Extrusions	31	16	15	19	9.5	62	24
-H112	Extrusions	31	12	12	19	7	62	24
-H32, H34	Sheet & plate	31	16	16	19	9.5	62	24
5456-H116, H321	Sheet & plate, 0.188-1.500	42	26	24	25	15	84	38
-H116, H321	Plate, 1.501-3.000	41	24	23	25	14	82	36
-H323, H343	Sheet	42	26	26	25	15	84	38
6001-T6, T651[i]	All	24	20	20	15	12	50	30
-T6, T651[j]	Over 0.375	24	15	15	15	9	50	30

The mechanical properties of most concern are those left *after* welding. Alloys with a high degree of heat-treating, such as the 6061 alloys, lose a significantly portion of their mechanical capabilities when welded, as the welding draws the heat-treating out. For small parts like spreaders and gooseneck fittings, which are done in 6000 series materials, these properties can be brought back by heat treating the parts after they have been welded.

Welding

Proper welding is obviously a key factor in getting a strong, quality hull. The welding process is pretty straightforward today, as wire-feed "pulse arc" guns do a good job very quickly.

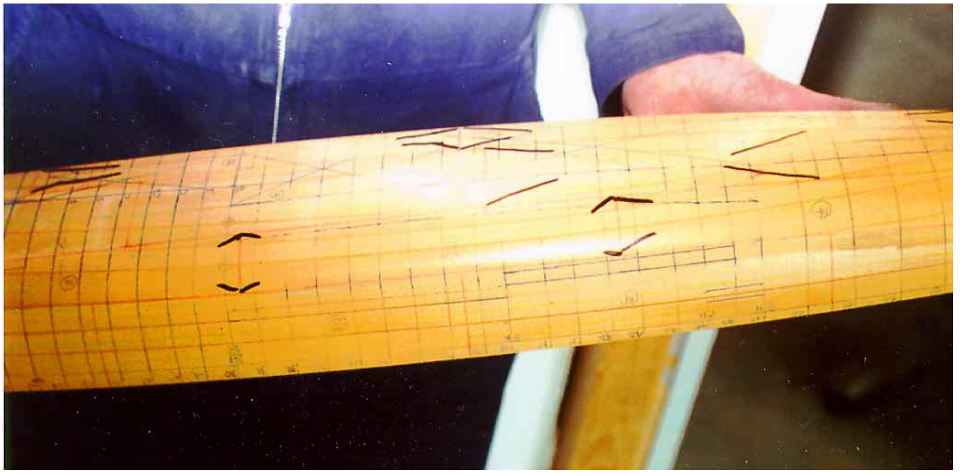
The welds are pretty uniform and, subject to certain caveats, are normally done without difficulty.

When you weld aluminum, the welded areas must be clean and free of any form of outside material. Weld areas are prepared by grinding them. The weld process takes place in an inert atmosphere of argon, or argon and helium gas, which the welding gun sprays over the weld area.

If the gas is disturbed, perhaps by a gust of wind, the weld will be porous and of low quality due to contamination by surrounding atmosphere. This makes welding outside difficult and means that on hot, windy summer days the shop doors must be kept closed.

Weld quality can be checked with visual inspection and X-rays.

When a weld is ground back, if it is porous because of contamination, this will be readily apparent.



In this day of computer design it is rare to see a builder who still uses (or knows how to use) a conventional loft for boat building. Scott Carr, a Kiwi builder, is holding (above) the layout model for an 80-foot (24.6m) design of ours.The model is used to define hull plates and determine quantities of materials.

Scotty and Kelly Archer (Kelly is running this project for us) are working on the full scale loft (above) to determine the exact position of the stern tube through which the propeller shaft runs.This is very difficult to do on the computer with any degree of accuracy.There are literally hundreds of these details, which is why some builders still prefer to loft boats in the traditional manner.

One of Scott's builders is bending a soft piece of aluminum (left) to the shape of the frame, picked up from the lofting.This template will then be used to compare to the frame as it is run through the bending machine.

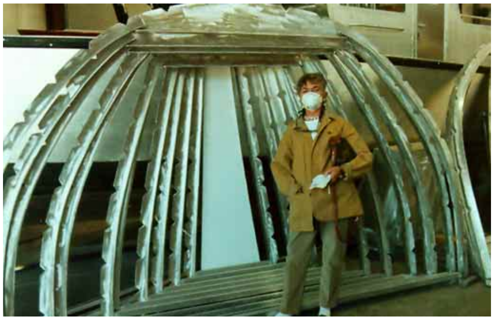
Framing

There are several ways to frame an aluminum hull. The final choice depends upon what the yard and designer are familiar with, and the type of service the yacht is likely to see. One approach is transverse framing. Lightweight frames are placed every 12 to 18 inches (300 to 450 mm). Stringers, usually made of flat bar, are placed longitudinally (fore-and-aft) on about 12-inch (300mm) centers. With this close spacing of both frames and stringers, the hull plating can be very thin: 1/8-inch to 1/4-inch (3 to 6 mm) on topsides and bottom. Overall, a transversely framed yacht will be 5 percent lighter than other systems, so it is favored for racing boats.

Most frame-bending equipment is surprisingly simple, typically put together by the builder himself. It usually consists of a hydraulic ram and some easily adjustable jigs.

T-bars are the most efficient to bend. With a balanced shape, they tend to stay flat as they take on their curve. Angles can also be used, albeit with a bit more care from the workers operating the bending equipment.

As frames are bent, they are compared to templates of the hull shape. This may be computer-produced paper drawings glued to plywood, or a traditional set of lofted lines as shown here.



Linda stands in front of the beginning of one of our boats. These frames will form the bow section, back to about 20 feet (6 m).

Sundeer was framed at roughly 39 inches (1 m) on center.

Note the conduit running under the deck longitudinals. This will later be buried in foam insulation.

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Longitudinal framing offers some advantages for cruisers. In this system the frames are spaced farther apart, perhaps 3 to 6 feet (0.45 m to 0.9 m) on center. The stringers are made from angles or T's, and both frames and stringers are substantially stiffer than the transverse framing system. As the spacing is wider, the hull plating must be heavier, although the increased weight is offset somewhat by fewer frames. The combination of fewer welds to frames and thicker plates means the hull is smoother. Less fairing compound will be required, and the increased plate thickness counteracts punctures in a collision or severe grounding.

We've used both types of systems. Many of our earlier boats, like *Intermezzo II* and *Deerfoot II,* were done with widely spaced frames and heavy longitudinals. *Sundeer* was somewhere in between, and *Beowulf* was done with closely spaced frames.

There is little if any cost difference between the systems. Any variance is typically the result of what a given yard is used to working with, rather than an inherent advantage one way or the other.

Most builders start framing with the hull upside-down. After plating is completed, the hull is rolled right-side-up. (bottom left).

However, you can start with the frames right-side-up (above) and plate right-side-up. Either system can be efficient, as long as the builder has been trained in that approach.

Corner connections between deck beams and hull frames can be made in a number of ways. Sometimes they are simply butted together.

The next step is to add a triangular gusset to reinforce the corner.

What you see here (right), on one of our 74s built in Denmark, is the ultimate system. What a shame it is to bury this beautiful work behind foam and hull liner panels.

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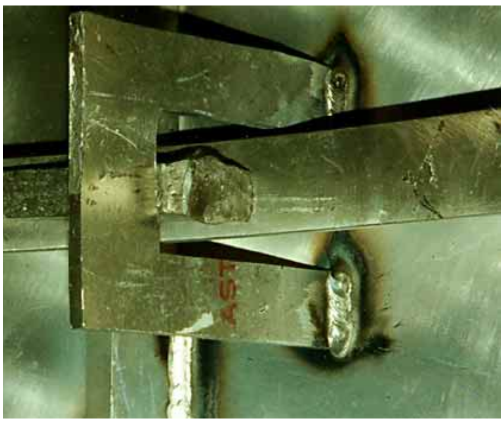
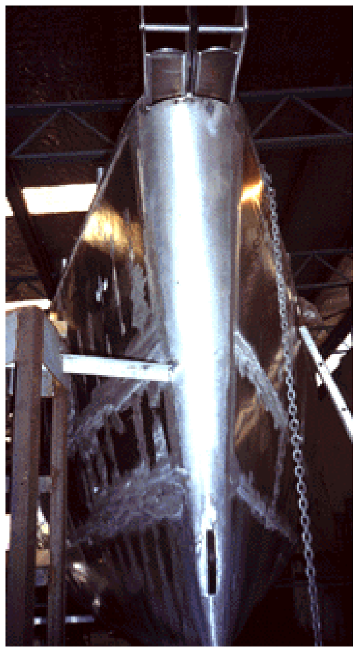
Plates over 1/8 inch (3 mm) in thickness are usually run through a roller of some sort to stretch the metal into the curve of the hull. The more pre-forming of this type that is done, the less stress there will be in the finished hull.

How plates are cut depends on the hull shape, what is available in plate sizes, and the techniques the builder likes to use. These photos of one of our boats being built in Europe shows relatively small plates. In the aft sections, with less radius, the plates will be larger.



There are all sorts of ways of getting plating to conform to the hull shape. Where moderate curves are involved you can use a temporarily welded C shape to the plate, and then drive a wedge between it and a local frame. This pulls the plate in and holds it until it is tacked welded in place, after which the C shape is removed and used elsewhere.



The most difficult area to form is the bow with its very tight radii. The closer the bow is to a cone shape or a constant radius (where a pipe can be used for the leading edge), the easier it will be to form.

We've frequently had our bows formed by outside vendors with large presses.

Plating

Metal-hull plating is a great mystery. Every builder we've worked with has a different approach. Some like to build their frames right-side-up and then plate from the bottom up, while others swear the only way to work is to start with the hull upside down. Some builders prefab large sections of hull and then assemble them, while others prefer to stand all frames up and then begin the plating process.

On long, shallow-bottomed hulls like we tend to design, the plating is a pretty straightforward affair for most of the hull. Plates can frequently be laid down, tacked in place, and then forced to conform with cable winches and wedges. In the turn of the bilge and bow sections, more forming with a hydraulic press of some sort will be required.

Hull shapes with some curve are easier to get fair than those which are quite flat. There is a certain amount of distortion that takes place from the heat of the welding, and this is better held in check and visually hidden with curved surfaces.

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Engineering

Two advantages of working with aluminum are the ease of predicting weight and the ease of engineering for stress.' Since the properties of the material are known and constant, and since welds have predetermined values, the designer doesn't have to rely on intuition or "feel" as much as when working with plastics. In the area of the chainplates, for example, it's easy to insert thicker plating for distributing stress. If you're concerned with noise and vibration in the engine room, the plating can be thickened there, too. Weight calculation is simply a matter of determining surface area and plate thickness. A large collection of engineering data is available to the designer from the Aluminum Association and major suppliers such as Alcoa and Kaiser. The American Bureau of Shipping also issues standards for aluminum-yacht construction.

One of the most difficult things to engineer for is impact load in a collision. Our tendency is to go overboard and make the bow bulletproof. In this case (above) there is a centerline girder of 3/8-inch (9.6mm) plate, backed by a heavy flange which is designed to take the initial impact. Note the very close spacing of the longitudinal stringers in this area.

Quality Control

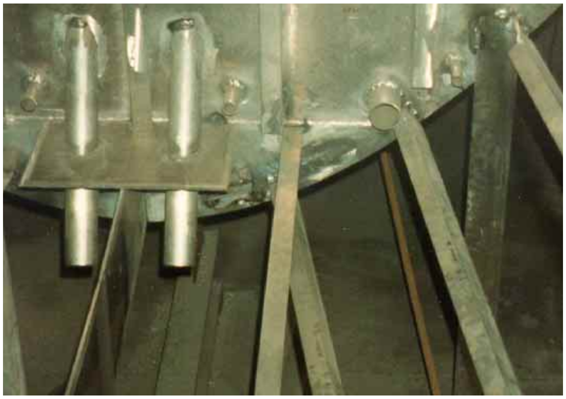
One of the questions that always arises is quality control. The first concern is that you have received the proper material. It's standard for the alloy and batch number to be stamped on each plate or extrusion, but you can go a step further and ask for mill certification of materials. A chemical analysis is then done on each batch to be sure the alloy is correct. Next is the welding. Most classification societies require a series of specimen welds from each person working on the boat, and these are tested for failure.

If you have an aluminum boat, check with your local welding supply house for a portable welder. A number of wirefeed units that will run on battery power are on the market.

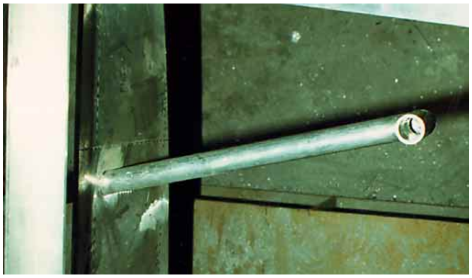
As indicated previously, it's customary to request X-rays of a representative number of welds. I like to have them taken of highly stressed areas such as chainplates, keel-to-hull joint, and prop struts, along with a few hull-plating welds. The X-rays will show internal quality, although with the welding equipment and alloys available today, problems are rare.

This is a critical step, not to be missed. I have only once not insisted on this process — with a builder in whom I had a lot of trust —and that turned out to be a very costly mistake. Midway through the project his interests shifted to other things, and quality went to hell. We didn't find out until we were sea-trialing the boat that many of the welds were porous. In the end, we spent more than a third of the original hull contract repairing the problem!

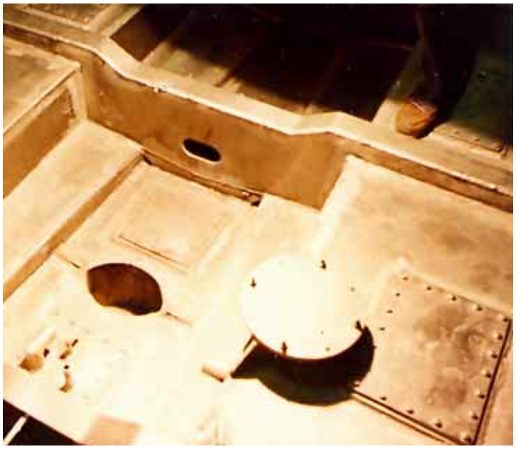
The sequence of welding is critical in maintaining a fair hull shape. One approach is to temporarily tack-weld the plating and, after the entire hull is assembled, weld up the seams. Another method used with longitudinally framed yachts is to weld plates as they are applied. With the correct application and welding pattern, this results in smoother plate intersections.



A key to easy fuel-filling is to have large fill pipes that run to the bottom of the tank (top two photos). We typically specify 2-inch (50mm) fills on our larger boats. These project through the forward watertight bulkhead. Thus all of the visible fuel plumbing is in the forepeak, where it does not interfere with interior furniture.



Sometimes there isn't room to get plumbing from under the shower soles to a pump. In this case (above) you can weld in a drain through the tank top. This process must be started before the tank tops have been welded down.



There are two approaches to integral tanks. One is to have the top plates welded to the structural floor (left). This reduces volume (the tank top is below sole level), and requires a secondary support grid for the cabin soles.

Our preference is to bring the tank tops right up to the top of the structural floors, increasing capacity. The sole is then laid directly on top of the tanks so no support is required.

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Integral Tanks

One of the major advantages of metal boats in general is the ability to weld tanks integral with the hull where the hull forms the outer skin of the tank. This provides tremendous volumes of liquid low in the hull, as well as the security of a double bottom in case of a holing, and a base for the cabin soles.

Many builders leave tank tops down a couple of inches (50 mm) from the finished sole height to allow for a stringer system to support the soles. My preference is to bring the tanks right up to the underside of the soles, then epoxy insulation onto the tanks tops and epoxy the soles to the insulation. This removes an air space that can accumulate dirt or moisture and maximizes tank capacity.

There is sometimes a debate about tank clean-outs or access. Our practice is to have a single clean-out at the low spot for each fuel tank. Our reasoning is that if another access point is ever required, it is easy enough to cut one in when required, and in the interim you don't have to worry about leaks.

Clean-outs should have tapped plates blind-welded for fastening down the clean-outs, so that no fuel ever gets to the threads of a bolt. If for some reason this has not happened then the bolts must be of the type that are designed with an indent under their heads for a diesel-resistant O-ring. If no O-ring is used and diesel gets to the bolt threads, regardless of anything you do, the diesel will leak out along the threads.

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Chainplates

There are many ways to make chainplate attachments. The key issue, design-wise, is to avoid creating a hard spot on the hull, and to be sure of a high enough factor of safety so that in the event of a collision in the chainplate area, there is a good chance some integrity will be left to take rig loads.

If your rig has inboard shrouds, then you will need a way to get the load into the hull. In this photo (above) a heavy piece of plate is welded between three floors. These floors also form the support for the mast step.

Above: Another way to deal with chainplates. In this case a thick plate has been welded to three frames. The frames in turn spread the load to the hull plate.

If you have a wide staying base, with chainplates on the hull, the connection to the skin plating is quite simple.

In the above photo there is a frame onto which the mast is stepped (left side of photo), and then the chainplate is slightly aft allowing for a bit of spreader sweep.

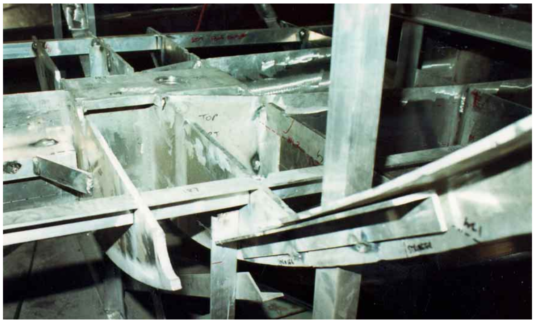
The hull plate has been thickened in this area to spread the chainplate load.

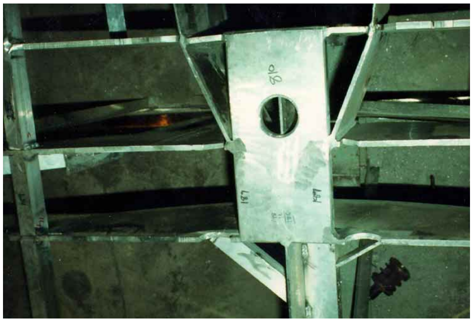
This detail of the mizzen chainplates on *Beowulf* shows attachment T-points for the cap and intermediate shrouds, as well as the lower (the diagonal chainplate to the left) and the main mast runner (above).

This is a headstay tang (above), with allowance for a tack shackle on the aft side of the chainplate.

The Mast Step

Mast steps need to be engineered so that wiring can be brought through the bottom to a suitable location, and so that any water draining down the mast will have a clear path to the bilge.





We typically make our mast steps in the form of a giant beam (upper left), running forward and spreading the compression load of the mast over a number of floors. This beam is usually formed by: a thick top plate onto which the mast step is bolted or welded; a thickened chunk of hull plate below; and a shear web formed by the centerline girder of the hull. One of the things we've learned is to make allowance for the mast to drain into the keel sump, as is shown in the upper right photo. To be sure of a good seal, we usually set the mast heel onto a medium-density rubber into which a drain hole has been cut.

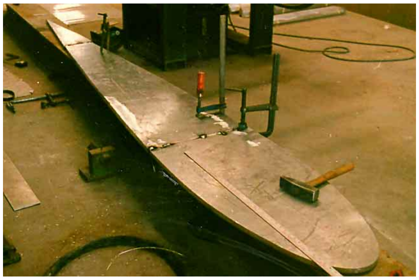
Keel Construction

The big decision with the keel is inside or outside ballast. We normally create a large aluminum tank into which the lead is poured. This has the advantage of eliminating keel bolts and the maintenance associated therewith. It allows you to use pure lead, that is about three percent more dense than lead with has been alloyed with antimony (which you will need if the lead is outside).

The negative is that lead and aluminum, in the presence of water, do not get along. So you need to be sure that the keel is well sealed.

Scantlings obviously vary with keel weight and shape, but our keel sides usually run from 1/4 inch to 3/8 inch (6 mm to 9.6 mm) in thickness, with keel bottoms usually around 1/2-inch (12.6mm) thick.

The other approach is to use a conventionally cast keel and keelbolts. The lead-to-aluminum interface must be isolated in this case. External lead will absorb some impact on a grounding.



Drainage in the keel sump should be enhanced with a sloped bottom (top of the lead) and a pick-up sump as shown above.

The keel structural system is a function of keel shape. With a simple 0000 NACA foil, it can be formed with vertical floors, around which plate is wrapped. The bottom plate (above) for this 67-foot (20.6 m) design is 1/2-inch (12.6mm) thick. The shape shown is a 15-percent NACA foil section.

The next photo (right) shows one keel side tacked onto the floors.

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Sometimes height restrictions make it necessary to weld the keel on in two sections: first, the sump, which is attached to the hull, then, the bottom portion, which contains the lead.

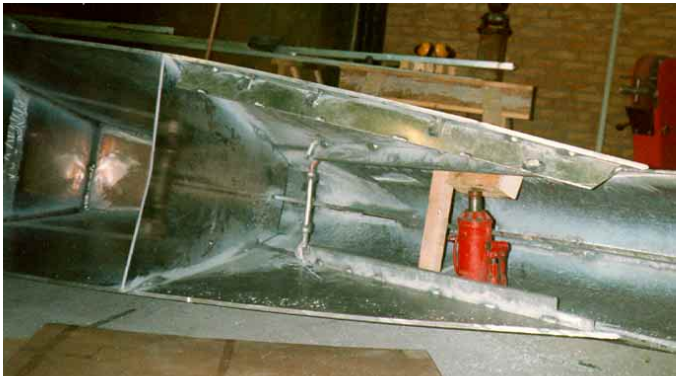
Once the hull has been moved, the two sections are then joined.

Where the keel shape is more critical, ribs can be cut on the bandsaw and welded to notched floors (right). The ribs help to hold the shape in tolerance.

Regardless of the shape and how you achieve it, there is always the issue of welding the closing plate. The first plate is easy, as you have access to the inside. But what about the second plate?

The solution is to carefully mark the plate in each area to be welded. Then, cut out slots where the welds occur. Tack-weld the plate in position, and fully weld the slots to the floors and ribs.

As welding takes place, the plate tends to change shape from the heat and from the gap between the plates tending to close. Sometimes a hydraulic jack is used to wedge things back into the correct shape (right).



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When possible, we like to have the lead poured directly into the keel cavity, as shown here (above and top three right photos). Take care with the height of the liquid lead (head pressure), as excessive height in conjunction with heat can cause the keel side plates to bulge.

Wetting down the outside of the keel cavity (right) helps to reduce heat build-up. After the lead has cooled, a covering plate is welded to the top of the cavity. The keel cavity should then be pressure-tested to make sure it is watertight. It's important to know that no liquid can mix in with the lead and aluminum.

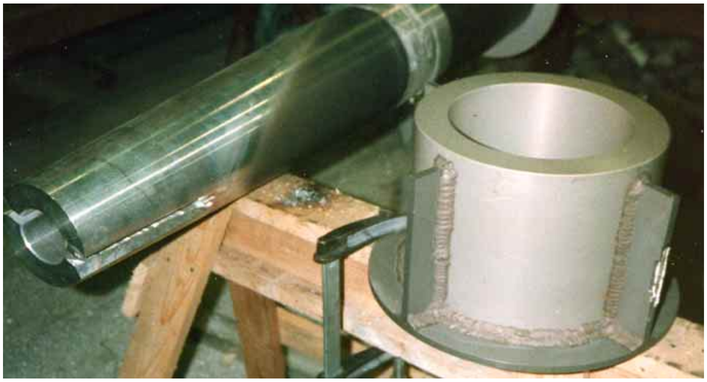
Rudder Construction

We've always used aluminum rudders on solid aluminum shafts for our metal boats. They are somewhat heavier than a glass rudder with a carbon-fiber stock. However, there are no electrolysis worries, and we know that if the rudder starts to work on a coral head, it is going to come out okay. We have lots of real-world experience in this!

We like to have the rudder stock stop about one-third of the way up from the bottom so that in the event of a really severe grounding, the bottom of the rudder can be bent or broken but the stock and the rest of the rudder is left to steer with.

Metal rudders are typically formed like an airplane wing (left photo). A series of ribs are welded to the rudder shaft, which in this case acts as a wing spar.

With modern canoe bodies you can sometimes do away with a rudder packing gland by simply extending the height of the rudder bearing housing, as shown here (lower left). The flat flange will accept a mating flange that clamps around the rudder shaft and prevents the rudder from slipping down.



Top two photos: This rudder shaft and matching collar will later be welded into the hull. The slot in the rudder shaft is at the bottom and will accept flat-plate extension of the shaft, forming a structural spar to which the ribs and plating of the rudder are eventually welded.

Right: We typically stop the rudder shaft about 2 feet (610 mm) up from the bottom. This allows the bottom plate to absorb damage without affecting the integrity of the stock itself. So if damage does occur in a severe grounding, you only damage the bottom plate, and you can still control the boat with what's left of the rudder.

You may want the rudder to have its own zinc. If this is the case, it should be let into a recess, as shown here (above), so that it is flush with the surface. We've built rudders with and without.

The impact from groundings will hit the bottom of the leading edge of the rudder. There are two engineering approaches. One is to make it bulletproof — but then you put the shaft at risk. The other is to make it "frangible." This means that the tip fails before the rest of the rudder. Curved leading edges like this (above left) are frequently formed with pipe or a solid bit of rod.

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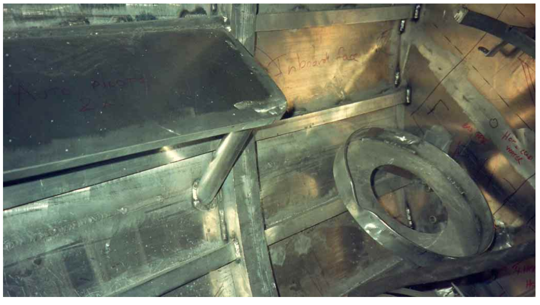
Engine mounts (above) are typically set on flanges that have been welded to girders running fore and aft. These girders frequently block access beneath the engine for repairs and cleanup. If access is restricted, we prefer to keep the girder height low and tie the engine mounts to bases which have been welded to athwartships floors.

The propeller shaft log is welded in place. The prop-shaft stuffing box is clamped to the turned end (above).

Prop-shaft support brackets are best brought up through the bottom some distance, so that the inner leg can be supported off surrounding floors. This reduces vibration and the chances of welds cracking over time (right).



Benches for pumps, bases for machinery, and in this case a water heater (left), are all easily welded in place with metal construction. This saves time over what is required with a fiberglass vessel, and is easily modified if required in the future.

Engine Room Details

One of the joys of a metal boat is the ability to weld in all sorts of brackets, in the engine room and elsewhere. It is fast, efficient weight-wise, and can be quite attractive.

We usually mock up everything in place with light-angle temporarily welded in place. Let all the bits and pieces sit for awhile, and then come back at it a second time. With any engine-room layout, utmost care needs to be given to how plumbing and wiring will run. Access to equipment is also critical — both for building efficiency and later maintenance by the owner.

Through-hull Plumbing

Over the years we've found that welding pipe stubs to the hull (with welds inside and outside of the hull plate) and then threading the inboard ends works well for through-hull fittings. You will want to use a valve which is plastic in most cases. We've had good success with Forespar Marelon valves.

If you are careful with your plumbing plans, you can limit your through-hull fittings and the valves required. We normally use a single incoming pipe for all seawater needs, along with standpipes that have been welded to the hull and that extend above the waterline for all exhausts.

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Deck Hardware

With the exception of where the mast penetrates the deck, there should be no holes anywhere over the living areas. This prevents leaks.

How do you fasten all your deck hardware? With tapped plates fitting the bottom of the gear in question, and then welded to the deck. For example, think about an inboard genoa track. We'll take a piece of 3/8-inch (9.6mm) plate the same width as the underside of the track, tap it to match the track's bolt pattern, and then weld it in place.

Lifeline stanchions are most often aluminum sockets welded to the deck surface for pushpits and pulpits, or let through the deck and welded to a frame or gusset for stanchions. The aluminum socket then has a nylon or PVC sleeve between it and the stainless-steel stanchion.

If you take this approach, list all your hardware and tie-down points in advance. Then they can be laid out and welded when the coamings are finished.

This includes allowance for dinghies, docking cleats, life rafts, staysails, jackstays, helm foot racks, spray deflectors for hatches, awning tie-down points, anchor storage, windlass drip strips, handrail sockets, handrail bases, storm-cover tie-down points for hatches, stowage for spinnaker and jockey poles, special sports gear like outboards, windsurfers, and jet skis.

Here are a couple of views of a turning-block base (upper left and right). The side plate has been lightened with cutouts.

These jib-track bases (left) are 3/8-inch (9.6mm) plate that have been drilled and tapped to match the mounting holes in the jib track. These plates have been welded to the top of the deck in order to prevent leakage between the fasteners and the interior.

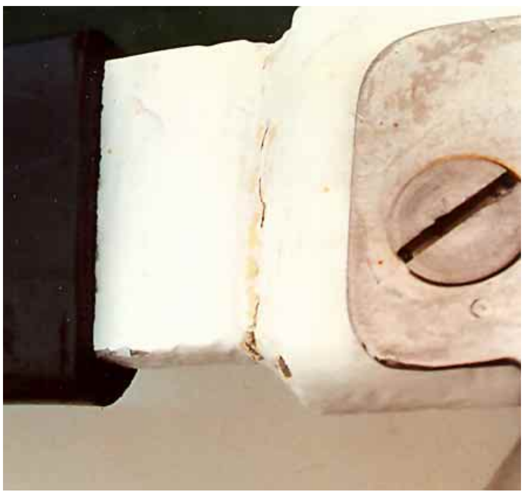
The jib tracks are set onto neoprene rubber gaskets to keep the fasteners sealed where they enter the threads of the tapped plate.

The mast area before the deck collar (which matches the spar shape) has been welded in place. The bales on each side and aft are for attachment of blocks that will be used to direct halyards and reefing lines to winches (far left photo).

Hardware Isolation

Hardware with bases made from materials other than aluminum need to be isolated. This typically applies to winches that have bronze bases. A layer of plastic will do the job. However, our preference is to use a moderately hard rubber, typically with a Shore hardness of around 40, as it tends to dampen sound transmission.

Two views of a lifeline-stanchion socket (above and left) — welded to the deck and to a frame below the deck. A nylon insert isolates the stainless stanchion from the aluminum socket.



The aluminum toerail (above) is welded onto a high toerail. It projects beyond the topsides a little and has a hard rubber extrusion placed over the edge to protect it and neighbors from the aluminum.

An interesting detail for attachment of turning block to the deck (above). Note the shape of the U-bolt. The aft leg is angled to help restrain the entire structure against forward pull.

Deck Hatches

There are two ways to go with deck hatches. One is to use extruded hatch frames and bolt them down to the deck. This means you have a potential source of leaks and will need to form up a flat base on which the hatch can be bedded.

The second approach, is to go with cast hatches, such as those made by Atakins & Hoyle or BOMAR. With cast hatches you can weld the bases directly to the coamings.

These hatches normally come with painted bases into which holes have been drilled. We order ours with unpainted bases without holes so they are ready to weld down when we get them.

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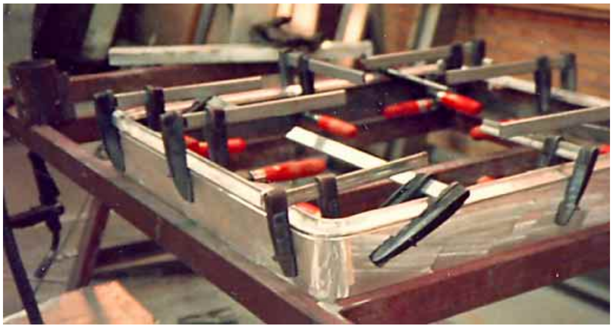
The tricky part in this equation is pre-welding the hatch base to the coaming. This is usually best done in a jig, in advance of welding it to the deck (right). Lots of clamps are necessary, and a series of tack welds are used to get everything aligned.

The heat buildup needs to be watched. Excessive heat (or excessive weld bead) will lead to warping.

The hatch and gasket will tolerate a certain amount of misalignment, but it is best to keep the surfaces fair.



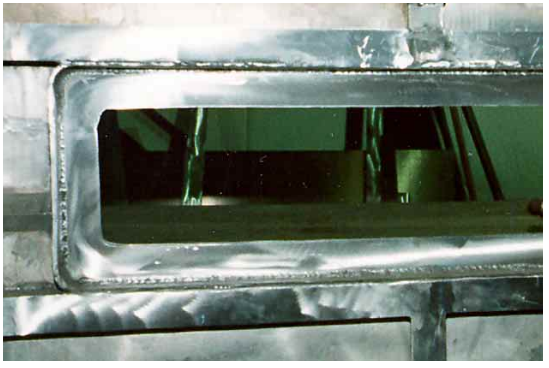
The ideal solution is to weld hatch bases to coamings (left). The hatch base helps reinforce the deck opening by forming a beam with the coaming as the web and deck and hatch bases as the flanges.

This is also a waterproof base that never needs maintenance.

Windows

With widely spaced framing, windows are typically placed between every other frame. A larger-than-normal angle is run longitudinally above and below the cutout to spread the load between frames.

With closely spaced frames, it is sometimes necessary to cut a frame to get a proper-size window. In this case the longitudinal angle will have to carry the load from the cut frame out to those frames on each side.



Left: Paul Oeland, one of Denmark's master craftsmen, prepares to weld in a window frame. Since this window does not break any frames, the structural loads are easily dealt with. The Lexan glazing will lie against the flat formed by the flat plate, which he is about to weld into place. A detail shot of this landing can be seen in the right photo.

When you break a beam (right photo), the top and especially bottom longitudinal must carry the load from the cut frame to those on each side. Because the load comes in at the end of the sister frames, it is easily dealt with by the structure.

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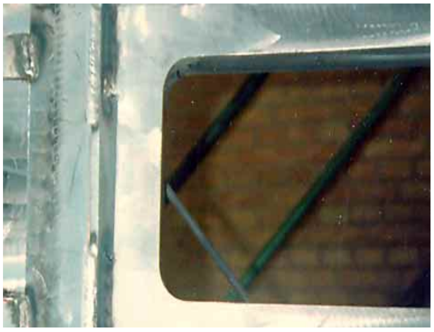
There are two ways to mount windows, both of which have their advantages. If the windows are mounted on the inside (as they are in these three photos), they are then inset from the topsides several inches (50 mm) so that they are protected from pilings and vessels rafting alongside. Being on the inside, they can be maintained at sea — for example, you can adjust the bolts, or even replace a window from the interior.

On the other hand, this is inefficient structurally, as the water load is trying to separate the window from the hull. When the window is mounted on the outside, water pressure tries to push the window against its gasket. Another negative comes with heel, if your windows are close to sea level at normal heeled angles. Waves running in and out of the windows can be quite noisy, and drag is high.

We've used both systems. Where window drag is not a problem we prefer to mount them on the interior.

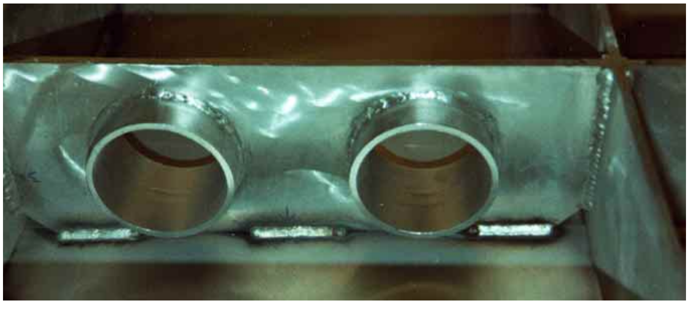


Miscellaneous Details

One of the pleasures of building a metal boat, especially when working with a real craftsman, is the ingenuity that can be found to solve various design problems. Following are a series of interesting details which we've used over the years.

Getting ventilation into the pilothouse is always difficult. We frequently specify a conical shaped fairing to be welded to the coaming, onto which a vent cowl is attached.

When anchored head-to-wind, these work quite well, as do those on the windward side when sailing.



Sometimes it is necessary to cut a hole through structure for plumbing or wiring. A simple way to keep the structure intact is to weld into the hole a piece of heavy walled pipe. Another (not shown) is to weld a doubler plate.

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A metal boat provides all sorts of opportunities to get creative with bow roller assemblies. In both of these, the center divider also provides an attachment point for the headstay (or bottom of the roller-furler drum). If roller-furler drums are close to the anchor, look at the pivoting action of the anchor to see if it will clear the drum when winched home.

Not all our ideas work out so well. These two shots show a well welded into the transom (lower left corner) which was to be used for life-raft stowage — low, out of the way, and easy to launch. The problem came in the occasional wetting the transom would get in sloppy conditions. Life rafts are not designed for immersion when stored. We had ours serviced after 18 months, and it was a mess inside from water damage. We welded the door shut and used the space for engine-room storage. Thereafter the raft was stored on deck.

Another mistake was the oblong exhaust through the transom. This looks good and works well in smooth water. But when motoring in a chop, it dips into and out of the waves, making annoying changes in exhaust noise. We eventually welded this shut and raised the exhaust pipe so that it was always clear of the sea.

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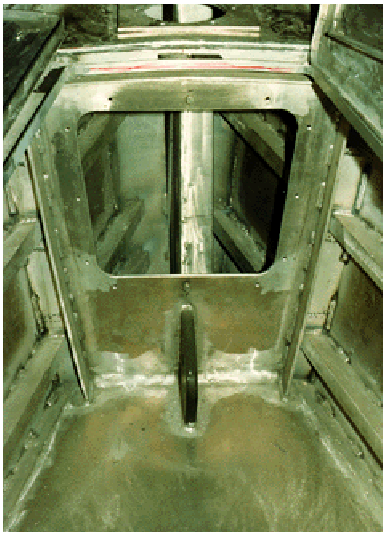

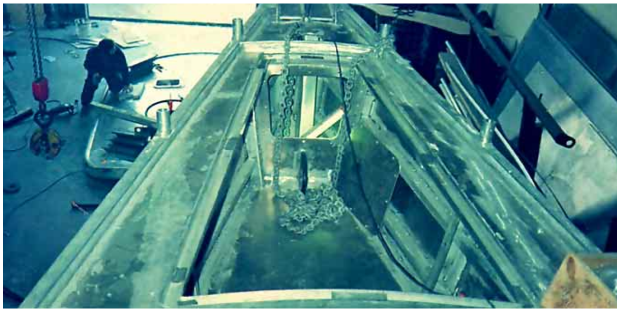

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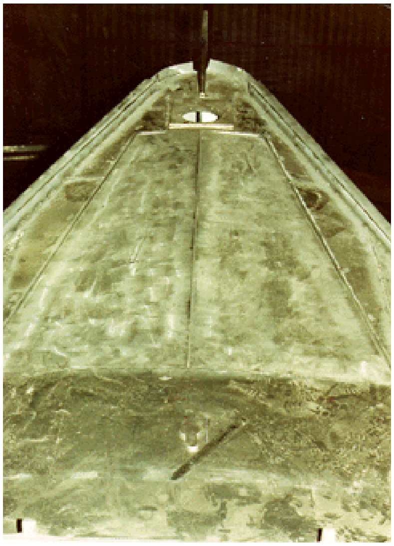
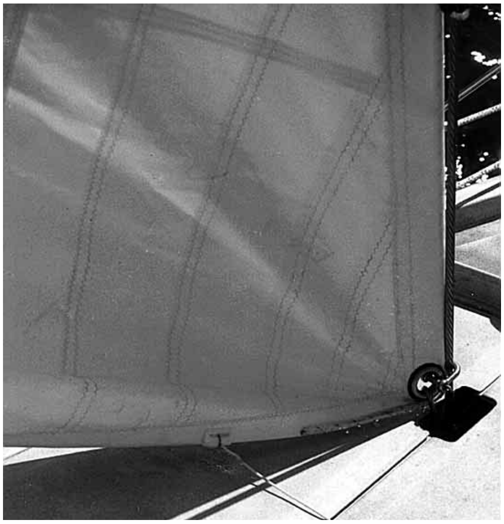
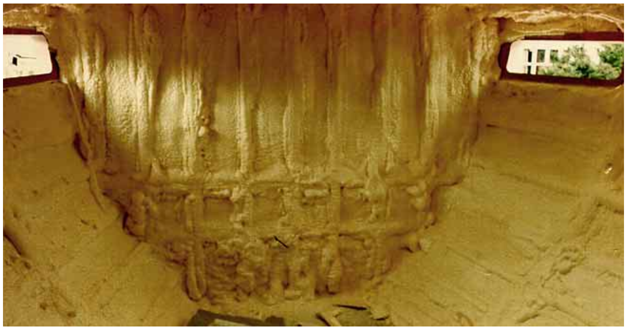


Here's an idea that worked really well! Rather than use roller furling on *Sundeer,* we developed a system in which our hanked-on jib could be stowed in a self-draining locker below deck. Bottom and aft bulkheads were welded into place. A removable forward bulkhead bolted against a gasket, and hinged doors closed to protect the jib from sun and sea.

When the time came to hoist, we simply opened the deck doors, attached the halyard, and hoisted away. Putting the sail away, we did a rough flake against the headstay, then rolled it down the deck until it dropped into the storage area.

This was not as fast as roller furling, but consider the advantages: No extra weight aloft when sailing or when the sail is stowed, easy changing of headsails due to jib hanks — whenever we changed down in size, the big jib remained stowed, and the smaller jib was simply hanked on deck. Finally, the sail could be cut low on the foot; with a batten in the head, it was much more efficient.





Spraying polyeurethane foam is the most efficient way to insulate a metal hull. Usually you spray an inch (25 mm) or so. For the most part, it requires little clean up.

On this project, the foam was sprayed to a thickness of 3 inches (75 mm), which is just about even with the depth of the frames.

The guys in the yard then had to trim off the excess, so that furniture, hull, and headliner panels would fit well.

Once the skin of the foam has been broken by cutting or sanding, it must be sealed to prevent moisture absorption.

In this case, the entire foam surface was sealed with a water-based, fire-retardant paint.

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Hull Insulation

There are various theories about insulating aluminum hulls. Although we've tried a variety of systems, we usually come back to sprayed poleurethane foams. These are easy to apply, modest in cost, and do a good job as both thermal and sound insulation.

There's a debate about whether or not the hull should be primed before foaming. I've listened to argument on both ends of this, and it seems to come down to the kind of chemical blowing-agent that is used in the foam. If it reacts with aluminum, you'll need a barrier coating, typically a strontium chromate-type of paint. If the blowing agent is inert, a barrier coating is not required.

Foam quality varies. Be sure to get the best-quality, most-stable material possible. All foams absorb moisture with time, and this adds considerably to their weight. You can reduce this tendency by making sure the foam is sealed — either with the natural skin that forms during the spraying process, or with a paint film applied wherever the foam has been cut or abraded. Foams should be self-extinguishing once a source of flame has been removed.

Anodizing

It often makes sense to hard-anodize any aluminum structure subject to corrosion, such as plumbing fittings and chainplates. If you take this approach, be sure this is a hard-anodizing of at least 15 microns in thickness. The anodizing is ground off where these bits have to be welded.

Electrolysis

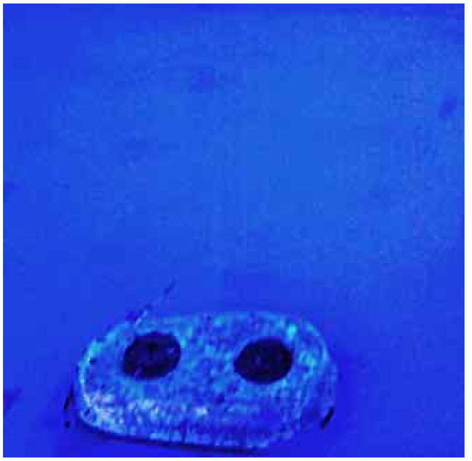
The one negative to owning an aluminum yacht is the potential problem of galvanic corrosion. The best way around this is to build, paint, and wire your yacht properly. This will be discussed in more detail in the electrical chapters.

Most serious corrosion problems originate in the DC electrical system. To minimize this risk, the DC electrical system is kept isolated from the hull. Each piece of DC gear is also isolated in case leakage occurs between it and the hull. This is known as a "floating ground." As an example, pumps are often bolted to fiberglass bases, which are in turn fastened to the hull.

All wiring should be protected from abrasion with the hull.

Last, the hull should be protected with sacrificial anodes. These are made from zinc and, in the presence of galvanic corrosion, will break down before the hull is attacked. On most cruising yachts these are attached on the hull, keel, and rudder, as well as inside sumps.

The hull zincs can be welded to the hull or attached at various points around the hull perimeter with wires to the toerail. In the latter case, they are pulled up when you are under way.



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If the electrical system is dealt with correctly, and if you have sacrificial zincs, electrolysis will not be a problem. But you do need to take care. The aluminum mast (upper left) was sitting on a steel base in a damp bilge. The aluminum was gradually eaten away, as you can plainly see. Had the two materials been isolated from each other, this would not have happened.

There are three approaches to hull zincs. The first two involve welding zincs to the hull, either proud (above right) or flush (lower right). Periodically brush the zincs to keep their active surface clean, and *never* paint them. Of the two approaches, the totally exposed is the best, as it has more surface area in contact with the water and is easily cleaned on the exposed sides. However, a series of these will increase drag.

On some of our boats we hang the zincs over the side when at anchor or in port. This way they are easy to change, clean, and generally keep an eye on. However, this does not provide protection at sea. We keep a zinc in each wet sump to help out when the on-deck zincs are stowed.

Noise

You've probably heard stories about noisy aluminum yachts. This is true for stripped-out racers, but once you add an interior, insulation, hull and headliner panels, and bulkheads, aluminum is definitely quieter than fiberglass, with its hard surfaces bouncing noise around.

Fasteners

Fasteners are always a problem with aluminum. They are typically made of stainless steel — and stainless and aluminum don't get along well. Fasteners should be avoided whenever possible. It is possible to make attachments based on welding, which eliminates the need for the stainless bolt in the first place.

While this won't work for winches or jammers, it can often work with cleats where you can use aluminum cleats and weld them down, with pad eyes, and other tie-down spots.

When the time comes to use a stainless-steel fastener, if the aluminum is unpainted, a simple barrier coat like Alumalastic or NeverSeize works quite well at avoiding corrosion. However, on a painted finish, corrosion will eventually start at the bolt threads and spread under the paint, regardless of what coats the bolt!

There are two ways around this. The first, which is partially effective, is to have the stainless-steel bolts coated with a very hard finish called Sermatech. There are licensees of the Sermatech company around the U.S. The coating keeps most of the stainless isolated from the aluminum. However, this method is not foolproof and will eventually break down.

The better approach is to use an oversized hole for the fastener, then sleeve the hole so that a plastic sleeve is placed around the bolt, between it and the aluminum paint finish.

Note that the paint finish must go all the way into the hole so there are no edges to the paint system. This means deck hardware should be positioned and fastening holes should be drilled *before* painting starts.

Sometimes there is lightly loaded gear which needs attachment and that you forget about or is impossible to position before the boat is launched. If loads are low enough, you can purchase nylon bolts that work well for eyestraps and related hardware. For slightly higher loads, high-tech aircraft bolts made from epoxy laminates are also available.

Painting

For finishing the hull, there are several highly successful, low-maintenance systems on the market. As with any paint job, the key is preparation. Exterior surfaces of the hull are ground or sandblasted to remove any impurities and to provide a mechanical "tooth" for the undercoats. Then the hull is washed with Alumiprep 33, a chemical that removes oxidation. The Alumaprep is hosed off with fresh water before drying, and immediately a second chemical, Alodine 1200, is applied. This is an acid which temporarily protects the aluminum skin and makes it receptive to undercoats. A high-solids epoxy undercoat is subsequently applied. This forms the base for holding the rest of the paint system to the aluminum skin. From here on, the finishing process is the same as with any other custom yacht. Microballoon-filled epoxy resin is used for fairing the hull, followed by high-solids epoxy primer. When the hull is smoothed to the desired quality, a linear poleurethane top coat is applied.

Painting aluminum is covered more thoroughly in succeeding chapters on paint systems.

Paint Protection

Properly applied paint films protect the surface to which they are applied from the electrolytic corrosion process as long as they are impermeable (i.e., moisture proof). However, if the surface becomes porous and allows moisture to enter between it and the metal underneath, the situation is much worse. There is an electrolytic potential while the paint film keeps the healing oxygen-rich atmosphere at bay. This can lead to consequences far more serious than if no paint film had been applied.

Paint companies frequently use zinc or other less noble metals in their undercoats so that if there is failure of the paint film, the zinc is what is eaten away rather than the structural metal underneath.

Going Bare

Bare aluminum (above the waterline) is an alternative that has been popular among workboats for some time and that is now starting to gather favor with yachtsmen. With paint accents for waterlines and cove striping, it can be quite attractive, while saving cost and maintenance. Marine alloys turn a flat gray after prolonged exposure to salt. They form a small amount of oxidation, then maintain this appearance. Of course, they can be periodically buffed or polished to restore luster.

When we put *Sundeer* into the water we thought we'd try her bare for a year or two. The reasoning was we could always come back and paint later on. At first we had a difficult time adjusting to the "workboat" look. But within a few weeks the subtle, non-flashy appearance began to grow on us. After we'd cruised for a few weeks, and docked in some very tight spots without worrying about a fancy paint job, we were absolutely ecstatic!

As time went on, we grew to love the bare appearance more and more. If people anchored too close, we didn't care. If a friendly local came by in an outrigger canoe, we sat and talked rather than running for fenders. The bare aluminum finish gave rise to a more laid-back, not to mention inexpensive cruising lifestyle.

We now feel that the ability to go bare is one of the major advantages to aluminum!

Cost Comparisons

There is generally very little difference in the cost of a custom fiberglass or aluminum hull. Aluminum is more expensive to paint, but it is less costly to install engine room gear and tankage and to make structural connections like chainplates.

The final cost differential depends more on the skills and efficiency of the fiberglass and aluminum builders themselves than on the material.

Welding after Completion

It is invariably necessary to do some welding after the boat is partially (or sometimes totally) completed. If a self-extinguishing insulating foam has been used, you can weld over it, as long as a careful fire watch is kept below. However, weld areas should be moderate, and weld heat should be as low as possible. Rather than welding large areas at once, it is best to do a small area, let it cool, then return to do another small area.

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One thing you can say about steel — it lasts a long time. This is the skeleton of a sailing ship that went up on the reef of Takaroa, in the Tuamotus in 1906. Seventy years later it was still there!

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One practical problem with steel is the fact that it is magnetic, and therefore affects the compass.

Compasses are thus mounted as high as possible and should be heavily compensated, as shown here with two large iron balls. The problem is deviation changes when you heel. One way around this problem is to use a gyrocompass which is not affected by local magnetic influences.

STEEL

Steel is another good material for cruising boats — strong, easy to work with, and virtually indestructible on a reef. If you collide with a log or another small boat, there's no question who will come out second best. A steel boat over 40 feet (12.3 m) can be moderate displacement. The negatives come in maintenance and resale. For some reason, steel boats are not popular in the U.S. It's possible to pick up a good steel boat for half the price of its fiberglass counterpart.

Weight

Small steel boats typically weigh about 30 percent more in the hull and deck than comparable designs built in aluminum or fiberglass. Since much of this weight is in the topsides and deck, the basic metal work has a higher vertical center of gravity than with aluminum.

To maintain an acceptable range of positive stability, therefore, you must either add lead in the keel, increase draft, or some combination thereof.

With displacement up for the same range under power, you need a larger engine, prop and prop shaft — as well as more tankage and diesel fuel — for the same amount of range.

Finally, if you desire a certain level of performance under sail, you must increase rig height and sail area. But this raises the center of gravity, which calls for more keel...

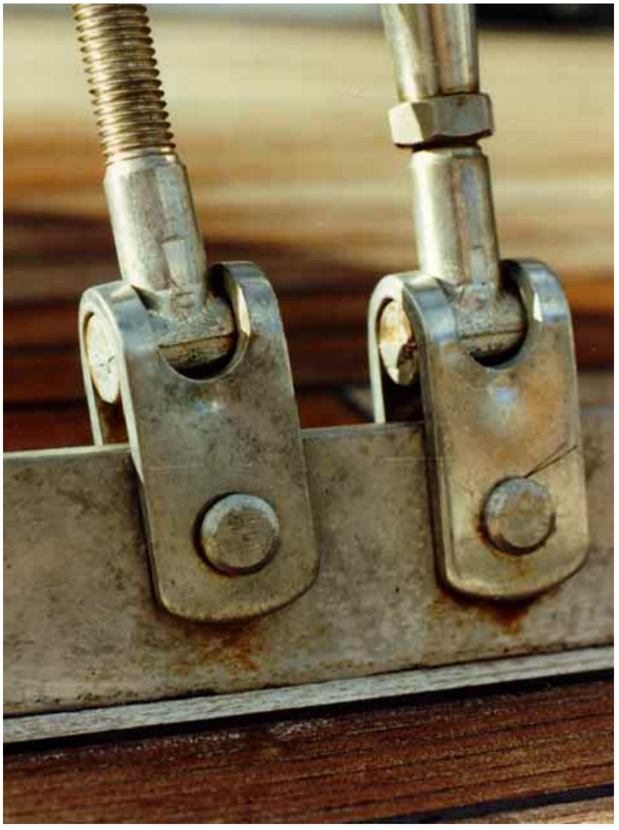
You probably get the idea that I don't care for steel. This is not the case at all. I think properly built steel cruising yachts have a lot to commend them. However, they typically end up costing the same as aluminum, draw more water, and are more costly to maintain, especially if you consider leaving an aluminum boat bare.

Maintenance

Without question, steel presents maintenance problems, especially from a cosmetic standpoint. But with modern paint systems, properly applied, these are not insurmountable. The only way to ensure a good finish is to take the hull down to bare metal, sandblast well, and build back up with a quality epoxy-paint system. The hull should be well painted inside, too.

Flame Spray Coatings

Many commercial boats have areas of deck or bilges which see hard work flame-sprayed with either aluminum or zinc (the same as galvanizing). In this process the metal is sandblasted. Then, a rig that looks like a spray gun with a torch and wire feed mechanism, creates a fine stream of molten metal, which is sprayed onto the steel. The coating is usually thicker than normal galvanizing. Commercial fisherman swear by it — as opposed to swearing at it, which they frequently do with paint.



Construction details for steel are similar to aluminum except that care should be taken to make sure no moisture can accumulate that would eventually lead to hidden rust pockets.

Also, specify extra metal thickness to allow for loss of strength over time, as some metal is lost to rust.

For deck hardware, stainless is frequently welded to underlying steel to prevent chafe on deck hardware from eating through the protective paint scheme.

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This process is not as abrasion-resistant as hot-dip galvanizing, since surface preparation is not as good. (Hot dip parts are taken through an acid bath before galvanizing.)

As you can imagine, the process is slow and expensive. When large surfaces are involved, sandblasting must start and stop periodically so that a nominal amount of time elapses between clean metal and when the hot coating is sprayed.

It is, however, the ultimate finish for steel.

Insulation

Most steel boats are foamed on the inside to help protect the skin, prevent condensation, and reduce noise.

Long-term Considerations

If you buy a used steel vessel, call upon a qualified marine surveyor. Make sure he or she uses electronic gauging equipment to verify plate integrity.

The advantages of steel include built-in tankage, watertight bulkheads, and the ability to have fittings welded to the decks (thus eliminating possible leaks).

From a construction standpoint, the same details that work well with aluminum also work with steel — except that you don't have the galvanic corrosion problems with stainless. This makes it practical to weld stainless-steel handrails and deck fittings right to the mild steel hull — very helpful with maintenance.

TIMBER

Until *Intermezzo*, we owned wooden boats exclusively. We loved the feel of the wood, the smell of it, and the sense of communion with nature that it gave. But cruising is different from keeping a boat stored in a marina and using it occasionally. It entails running aground and going for months without hauling. With wood, there are lots of maintenance chores to perform beyond problems with the hull.

Older wooden boats are cheap to buy because they are maintenance headaches. If you want to get a lot of boat for the money, buy a woody. But it will be difficult to recover any funds you may invest in rigging her for cruising. Once underway, a disproportionate amount of time will be spent on hull maintenance. If you're good with your hands and enjoy working with wood, okay. But if you need others to help out, the initial cost advantage of an older wooden boat will rapidly evaporate in shipyard bills. Wood also has problems in the tropics, between opening up from the heat and being attacked from within by dry rot. When it comes to a reef, there is little chance of rescue. Whereas fiberglass and metal slide reasonably well over coral, wood is too soft to resist the abrasion.

Saturated Epoxy Technique

If you're still entranced with the concept of a woody, there's one form of construction that is, in our opinion, superior to others — double diagonal planking, with an epoxy-saturation system, such as Meade and Jan Gougeon's WEST System. Hulls built in this manner are light, strong, and resistant to rot. As a result they're easier on the maintenance bills.

DuraCore

DuraCore is a composite timber material made of balsa core with a thin veneer of timber on each side — in effect, a wood sandwich structure. The system was developed by Kiwi boatbuilder Arnie Duckworth back in the 1980s and proved so successful that it was picked up by the Baltek folks.

There are several advantages. For one, you can form the hull with a lightweight series of ribs, then "plank" over this using DuraCore. The DuraCore strips come in a variety of widths and are locked together with a mating edge detail. Epoxy adhesives keep the strips permanently bonded.

Once the hull is assembled, interior fiberglass reinforcements are added as necessary. The exterior of the hull is then faired — a big job — and fiberglassed.

The end structure can be quite strong, and is quick to build.

FERROCEMENT

Lest you think I have finished listing my prejudices, let's go on to stone boats (ferrocement). Of all the materials we've seen, it's the most unsuitable. Chosen by neophytes because of its supposed ease of construction, it was at one time considered the "people's" material. A little experience has convinced most insurance underwriters not to touch concrete. That should tell you something.

There are two major problems with this material. The first is resale. You might save 10 percent on the overall cost of a cement vessel compared to that of metal or fiberglass. But when it comes to selling the boat, your materials and labor have been invested in something that doesn't have a ready market. Even if she's beautifully fair, a comparable boat in another material will bring a much higher price. Second is those old reefs. Concrete does not have the impact resistance of other materials, and when the reefs get at ferroconcrete hulls, the hulls go so quickly it's unbelievable.

John Nichols and his beautiful *Heart of Edna* provide a good example. *Heart of Edna* was meticulously crafted to extremely heavy scantlings. One late afternoon in the Louisidad Archipelago in southern New Guinea, John was faced with a no-win situation. With a low sun angle, he was forced to try to find his way into the lagoon. To stand offshore until the next day would have been equally dangerous in those treacherous waters. He missed the pass, and *Heart of Edna* went fast aground on the fringing reef. Unable to free her right away, they left her for the evening and joined two other yachts inside the lagoon. They returned at first light to try to pull her off on the rising tide. They found three gaping holes in her bow section, and there hadn't been much of a sea running during the evening. John's new boat is aluminum.

Near Kieta, on Bougainville Island, also in New Guinea, lies what's left of a beautiful, heavily built ferrocement junk. Caught on a lee shore in a northwesterly blow with a very short fetch, she was driven ashore. The beach was mainly sand with an occasional rock. The short fetch prevented much of a sea buildup. Yet within hours the boat had started to disintegrate.

Everywhere one cruises, stories abound of ferro boats not standing up to groundings that even a wooden boat would have survived. What do you do if you already have a ferro boat? Be damned careful!

TEAK DECKS

For a composite-framed timber vessel, teak decks make a lot of sense. They're resistant to rot, hard enough to last years, and more dimensionally stable than decks made with other timbers. But on a metal or fiberglass yacht, teak is an aesthetic detail with no real practical function and a lot of negatives.

How can a beautiful teak deck have anything wrong with it? Easy. To start with, we take a nice, watertight deck, and drill it full of hundreds of holes, each one of which is a potential leak. Next, we add a layer of dark timber to an otherwise light-colored deck, which means in the sun it will be very hot. Of course, this heat transfers itself below. In the tropics, shoes have to be worn at midday because the decks are so hot.

Then there are the maintenance aspects. Newly bleached and oiled teak is lovely to gaze upon. But within a week, two weeks at the most, it will be grungy again.

But the worst aspect of teak is its weight. A 1/2-inch-thick (12.6mm) teak deck on a 40-footer (12.3m) can easily weigh over 700 pounds (317 kg) by the time bedding, seam compound, and fasteners are added in. That weight, 5 or 6 feet (1.8 m) above the vertical center of gravity, has a substantial negative impact on sailing stability. Either you must add a ton of lead to the keel, increasing draft in the process, or suffer additional heel and slower, less comfortable progress to windward.

Still, for some, the aesthetic considerations will outweigh the practical. Goodness knows, I've been guilty of making that trade-off myself in other areas. If that's the case, here are a few factors to consider.

First and foremost is the thickness of the deck. Three-eighths of an inch (9.6 mm) is an absolute minimum, and will probably cause lots of problems after a few years. A better bet is 1/2-inch (12.6 mm). Next, teak plugs over fasteners should be at least 3/16-inch (4.5 mm) thick.

Use the very best adhesives, with the teak properly degreased before laying.

Stay away from teak-faced plywood. Ply under teak in a deck is just asking for rot problems.

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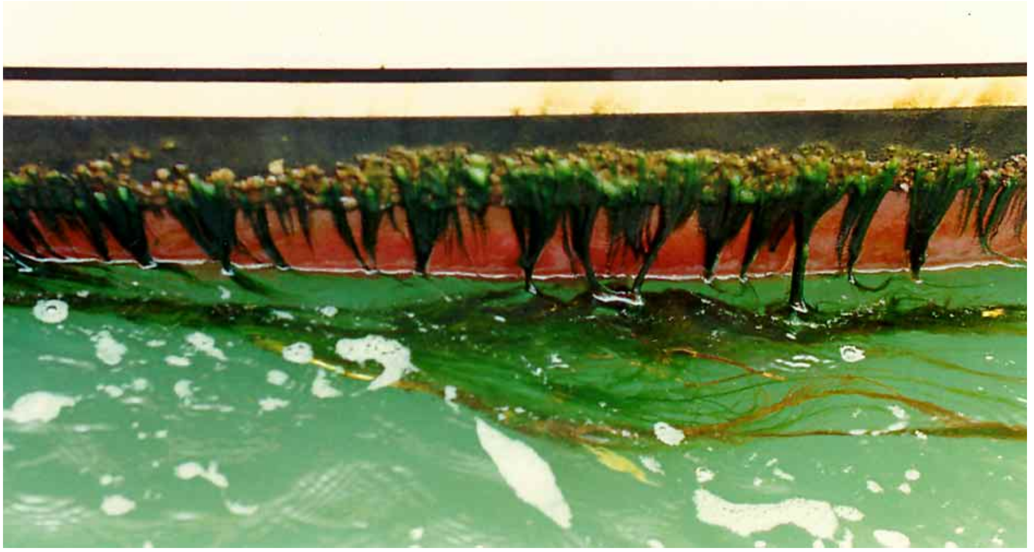

It's surprising how fast grass will accumulate on a bootstripe that is too low. All it takes is a little wave action, or gentle rocking to-and-fro, to keep the area above the antifouling wet and let grass start growing. If you don't clean the grass off right away, it becomes progressively more difficult to remove. When you're sailing, the drag from this grass is substantial.

PAINT

For most cruisers, the paint and varnish brush represent more maintenance time than any other aspect of life aboard — and a considerable investment as well. However, there are a few things we've learned to reduce the efforts and make life aboard more efficient.

Bottom Paint

Most bottom paints are formulated for the marine organisms found in a specific area. A paint system that works well in colder waters may not be quite as efficient in the tropics, and vice versa. Since most of us try to stretch the time between haul-outs, this means that from the middle toward the end of a bottom paint's life we'll be spending time in the water cleaning the bottom. As a result, the harder finishes are more desirable, as they can be cleaned with the least removal of paint. With soft bottom paints, every time the bottom is scrubbed, you take off a large percentage of what's left of the paint film.

The best systems we've seen for cruising are the "self-polishing" paints. Originally developed for commercial ships with tin-based biocides, these are now available in a variety of copper-based paints. The surface is continuously leeched away as the boat moves through the water, exposing fresh biocide at the surface.

Most of these paints are efficient with barnacles, but leave something to be desired with grass and algae, especially in colder waters. That's where diving comes in!

Some years ago I read a story in *Yachting World* magazine about a fellow who had used tetracycline-treated bottom paint on his boat in the Med. It worked for him, so when we hauled *Sundeer* the next time I decided to give this stuff a try. The formula called for using 2.5 grams of tetracycline powder per quart of bottom paint.

You mix the tetracycline in a small amount of paint or thinner first, then start into the entire batch.

We have found that this substantially cuts down on grass growth. My dad tried the same thing on his boat with similar results.

The best place to buy tetracycline is at a farm-supply store, where it is sold for inclusion in animal feed. I'm told that it is possible in some areas to buy pure TBTF to add to your bottom paint. This would be the ultimate biocide.

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Boot Stripes

In calm marina waters, barely anything above the floating waterline is wet. But at anchor there's always some wave action, which tends to keep 3 to 6 inches (75 to 150 mm) above the waterline damp. If this area isn't coated with antifouling paint, there will be a grass line all the way around the waterline, requiring a monthly scrubbing.

To avoid this problem, we always bring our bottom paint 4 inches (100 mm) above the waterline amidships at full cruising load, curving to 6 inches (150 mm) above at the bow and stern.

Boot stripes, if you have them, should be above this point.

Working with paint can be tricky. It requires good preparation, cooperative weather, and quality materials. If any of a number of things goes wrong, you end up with a costly, unappealing mess.

The blue boat (above) obviously has an adhesion problem between undercoat and top coat. This could be due to surface contamination or to a bad batch of paint. When a problem like this arises, make sure you know what went wrong before starting the repair job. You don't want to have the same problem twice.

The paint problem below was caused by a combination of an aggressive dinghy (over time) and a damp day when the undercoating was applied.

External Paint Systems

The most important thing with outside paint is using something you *know* works. Stay away from new "miracle" products. In addition, stick to companies with good reputations amongst commercial yards. This doesn't necessarily mean those that advertise most heavily. If a given product has been on the market four or five years, showing good results over that time period, one can assume it is probably okay — as long as the formulations don't change.

Linear polyurethane (LPU) has proven remarkably durable, as long as the pre-LPU preparation is right.

AVOIDING PAINT PROBLEMS

Over the years we've seen all sorts of paint problems, mostly on other boats. We've had a couple of minor problems on our boats, as well as one major problem — but more on this later.

We've learned that having a clear chain of responsibility, in writing, is the only way to ensure that a job is done right. That way, if something does go wrong, you have a chance of getting it fixed.

The painting process is full of variables and traps for the unwary. As we've already mentioned, there can be weather-related problems, surface contamination, difficulties with compressed air (oil- or moisture-entrained), and variations in paint formulations.

Something as minor as using the wrong type of rag can ruin a paint job. Tack rags, masking tape, spraying equipment, thinners, not to mention the paint system itself must be right for the job.

Choosing a Paint System

The first step in your paint job is to choose the paint supplier. This should be based on local experience and representation. Talk to a number of painters and yards to see whom they recom-

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When the first coat of a paint system is bad, everything that happens afterwards is wasted. This photo shows a well-prepared surface with good tooth marks from the pre-paint grinding. The problem seems to be with the undercoat, an Interlux (International Paint) wash primer. This paint job is currently the subject of litigation.

The products and symptoms appear to be similar to the problems we had with International Paint, for which they paid a $175,000 settlement after a couple of days of trial. However, several years of time and frustration went into getting to that point of recovery, not to mention horrendous legal costs.

mend, and whom they say to stay away from. On a major job, be sure that whomever is chosen to supply the paint has local technical representatives.

And never use a new system. Use only systems with a proven track record.

The First Step

The first step in a paint job is to get a written paint specification from the company. This specification will detail surface preparation, types of paints for each coat, thickness of paint, drying time (and probably temperature range), and special instructions such as types of thinners to be used.

Make sure you and your painter understand the specs. Don't allow anyone to take shortcuts.

Inspection

We like to have a clause in our paint contracts calling for the paint company to inspect and approve the system at various critical stages. This acts as a quality control check for you and the painter, and helps define a line of responsibility should a later failure occur.

Inspections normally take place before the first undercoat is applied, during the applications of several subsequent coats, and usually prior to the final coat.

Paint companies usually will not do this for small jobs. But if you have a choice between a company that will and one that won't, go with the guys that will inspect the system.

Warranties

The written warranty you get with your paint system from the paint supplier should be carefully evaluated. If there is a quality problem, do they repaint the boat for you, or do they simply supply materials and expect you or the yard to pick up the labor bill? As labor is typically 80 percent or more of the total cost, this is a significant issue!

The most important factor in the warranty, however, is the company behind it. All paint companies have problems from time to time. Some stand behind their product and will take care of repainting. Others try to hide behind the fine print or simply take the approach of "sue us and see what you get," knowing that the costs of the lawsuit outweigh any possible recovery.

Preparation

Preparation is the single most important factor in a good paint job. Everything else you do depends on this foundation. Each step must be executed correctly — starting with the surface of the bare hull, whether metal, raw fiberglass, or old gelcoat. The surface has to be dry, at the correct temperature, 100-percent free of surface contaminants and/or corrosion, and must have a mechanical tooth from sanding, grinding or sandblasting.

The very first coat is the most critical in the entire paint system. This is what bonds everything which comes later to the hull. The most examples of paint failure occur between the first coating and the bare hull.

If painting over an existing job, be certain that what lies under the new paint is well adhered. There are a variety of easy-to-run tests to determine adhesion.

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Fairing

The final visual quality of your paint job is determined by those fairing and intermediate undercoats that occur before the top coat. The higher the gloss and/or darker the color, the more imperfections that will show up in your fairing job.

Where a gelcoat surface with moderate gloss may look good, put a high-gloss LPU finish on top and it will suddenly look terrible. All sorts of waves, nicks, and pits you could not see before will now be embarrassingly visible.

Final Coats

The top coat or coats seal whatever is underneath and provide the final finish. As indicated before, the material of choice today is LPU. Formulations for brushing and rolling are available that are relatively easy to use and give a wonderful final finish.

However, the brushable LPUs have a long “tack time” to allow you to work them with brush and roller. This means they also have time to accumulate dust and bugs once you’ve finished. Thus, a calm day with minimal participation by winged critters is a must.

Spray finishes go on faster and have a very short tack period, typically less than a minute, so dust and bugs are not such a big issue. Overspray is an issue, so cover everything you don’t want painted — including all your neighbors.

Handling Hazardous Materials

Most materials in modern paint systems are hazardous to your health. When sanding, and especially when brushing or spraying, use good breathing protection. Charcoal filters with new, active charcoal are a must when fumes are about. If working in a closed area, you may need a fresh air–supply mask.

A Job that Went Bad

Now I want to tell you a horror story — a situation where we did everything according to the book, had a problem, and had a paint company tell us to go fly a kite when a problem occurred.

This started in the early 1980s, when we were building a large yacht in Denmark. We had used U.S. Chemical’s Awlgrip with success on previous aluminum yachts, but the folks at International Paint did a sales job on us and we decided to give their system a try.

I spoke with their head technical chap in the main office in New Jersey. He said that yes, as their distributor had told us, they had an excellent system for painting aluminum yachts.

I asked him for a specification to be sure we got the correct material from the U.S. distributor. He in turn suggested we contact International Paint in Denmark where the yacht was to be built, to buy the material directly from them. He indicated that we would save money doing this, and that the formulations were the same in Denmark as in the U.S.

So we instructed our builder in Denmark, Paul Oeland, to get a detailed spec from the local International Paint people.

In due course, on one of my visits I met with the IP Denmark manager and discussed the job, emphasizing that we wanted to use only a tried-and-true system. He followed up with a written specification via telex.

I then sent this telex on to my contact at IP in New Jersey — the head technical man — to make sure the Danes were specifying the correct materials.

The U.S. folks said they could not understand the paint system numbers and asked for us to have the Danes provide the U.S.-equivalent numbers. After a flurry of telexes back and forth, the Danes replied with U.S. equivalents and IP in the United States said, yes, those were okay.

As part of our agreement, IP Denmark agreed to inspect the paint job at critical intervals and to give us a written report that the job was satisfactory. We asked them for an approved subcontractor; they supplied us with the name of a company they said was the best in their area, and familiar with their products.

The job progressed uneventfully until one day I got a call from the yard. They had been cutting out a section in the coaming to install a ventilation grill, and a large section of undercoat had popped off.

They sent me a sample and called in International Paint. The sample that I received showed that the paint system had failed at the wash primer (the first coat) — at least, that's what it looked like under my magnifying glass.

I was very concerned and told the yard to have IP come out to check. They came out, looked at the broken paint area, and said it was caused by the vibration of the sabre saw that had been used to do the cutting.

That did not make sense to me, and I expressed my concerns. The yard told us that the IP representatives had given them a letter stating that the paint was okay and they could proceed.

I was very uneasy about this whole state of affairs, but assumed that International Paint knew what they were doing, so we proceeded with the final coats and fitting out the yacht.

Several months later we launched the boat and commenced with sea trials.

Prior to this vessel leaving Denmark for her voyage back to the U.S., a large section of paint lifted off at the swim platform.

The word we got was that it was a small contaminated area and should not be a further problem once it was fixed.

This was to be the first of many such incidents. By the time the vessel reached California a few months later the paint had failed in numerous areas.

We notified International Paint in New Jersey, who referred us to their office in San Francisco. The local reps came down to look at the boat, took samples, and promised to get back to us.

At this point everything was very friendly, and I assumed that they would take care of what looked like a major problem.

Since we had their written approvals at each stage of the work by their approved subcontractor, we couldn't see where we had any exposure.

A few weeks later we received a telex from the International Paint in Denmark. They said they had analyzed the paint specimens that had been sent to them by IP in San Francisco. Their laboratory reports stated that the surface preparation was okay, the paint film thickness was okay, and that in effect the paint job was fine. In other words, the Danish subcontractor who they had recommended and supervised (in writing) had done his job correctly.

The problem, they stated in the telex, was that the paint system was no good. However, they declined to make good on the paint job because, they said, they had advised us *not* to use this system. They went on to state that there had been problems with this material in the past, but that we had insisted on it, so the problem was not theirs, but ours.

Now, I grew up in the construction business, before turning to the more gentlemanly pursuits of yachting and writing. The first thing you learn in that business, if you want to survive, is to keep a paper trail of responsibility with vendors and subcontractors. We went back into the files and found the original specifications from IP in Denmark, our telex back asking for the U.S. equivalent numbers, and their reply with that data, which we had forwarded to IP in New Jersey.

Armed with this data, I assumed that International Paint somewhere — it seems the home office was in the United Kingdom — would make good on a paint job that we now knew had gone bad due to a poor material choice, which had been made by International Paint personnel in writing.

Nothing could be further from reality. The U.S. office referred us back to the Danes who offered only to replace materials, leaving us with several hundred thousand dollars in labor costs.

In the litigation that followed, we found International Paint (now called Cortaulds Coatings) trying to hide behind Danish law, as this did not provide for our recovery of labor costs even after they had admitted to the problems with their materials in writing.

We sued them in the United States, and after a long preliminary process finally got into a court room with a judge.

It appeared to us that the main defense offered by the company was that we had dealt with a Danish company and so should be governed by Danish law. If they prevailed on this it meant starting over with the hope of recovering only a fraction of what the legal costs would be, since Danish law apparently only allowed for material recovery, not labor.

When the judge ruled that the trial could go forward, we began to hope that our long fight might end in victory. A day or two of preliminary proceedings took place. When we were about to get into the serious part of the trial, the International Paint attorneys approached us and asked to talk settlement. In the end, they paid U.S.$175,000 — not our total damages, but about ten times the value of what had originally been offered. This was after a huge expenditure of effort and legal fees on both our parts.

The moral of this story? Check out your paint supplier carefully, and make sure they stand behind their products. Beware!

SPECIFICATIONS

As we said at the start of this paint section, having the correct paint specification is the first key to a good paint job. The question is, on whom do you rely? For many years now Doug Templeton at Coatings Consulting Group (CCG) in Newport Beach, California, has been our paint guru. Doug acts both as a consultant and supplier and has seen just about every type of problem you can imagine. He often consults on solving problems.

We asked Doug to share a sample specification with us for the three typical marine situations: aluminum, steel, and fiberglass. Each requires a totally different approach to surface preparation and undercoat.

The specifications are quite detailed and you will find them in the appendix at the end of this book.

The hull surrounding this doorway has been properly prepared. However, the doorway itself, where the rust is showing through, was not sandblasted before application of the undercoat. (Doug Templeton photo)

AESTHETIC ISSUES

With so many design issue affecting aesthetics, you could write a book on this subject alone. It's best to start off with a design goal, a certain look you are after. Remember, what you see on paper is not what you will see on the water. As the design is blown up to full size, the relationship between the viewer and the yacht becomes very different from that which exists looking at a drawing pinned up on a wall.

Boot-Stripe Design

Designers use a series of visual tricks to enhance the appearance of their yachts. However, as we've already mentioned, what looks good on paper rarely works in full scale on the water. Take boot stripes, for example. A dead-straight boot stripe, parallel to the water, will appear at some viewing angles to be hogged (i.e., humped) in the middle and low at the ends. For this reason, boot stripes are typically raised a bit on each end in order to look straight.

In addition, as we've mentioned before, lifting the ends of the bottom paint helps to keep grass off the bow and stern. The thickness of the boot stripe, and the question of using a series of thin lines or one thicker line, is quite involved. The further up you bring your bottom paint and boot-stripe — assuming both are dark in color — the more sleek your topsides will appear. In effect, raising a dark line on the bottom reduces the visual bulk of light-colored topsides. As long as there is no pilot house or high coamings to deal with, this usually pays aesthetic benefits. On the other hand, if there is a lot of structure sitting on top of the deck, you should emphasize the height of the topsides so as to have a balancing effect low for what is riding on top.

Complex striping schemes in the bootstripe may look great in the marina, but unfortunately, they are difficult and costly to duplicate when cruising. Generally, cruising boot stripes are better left as a single stripe.

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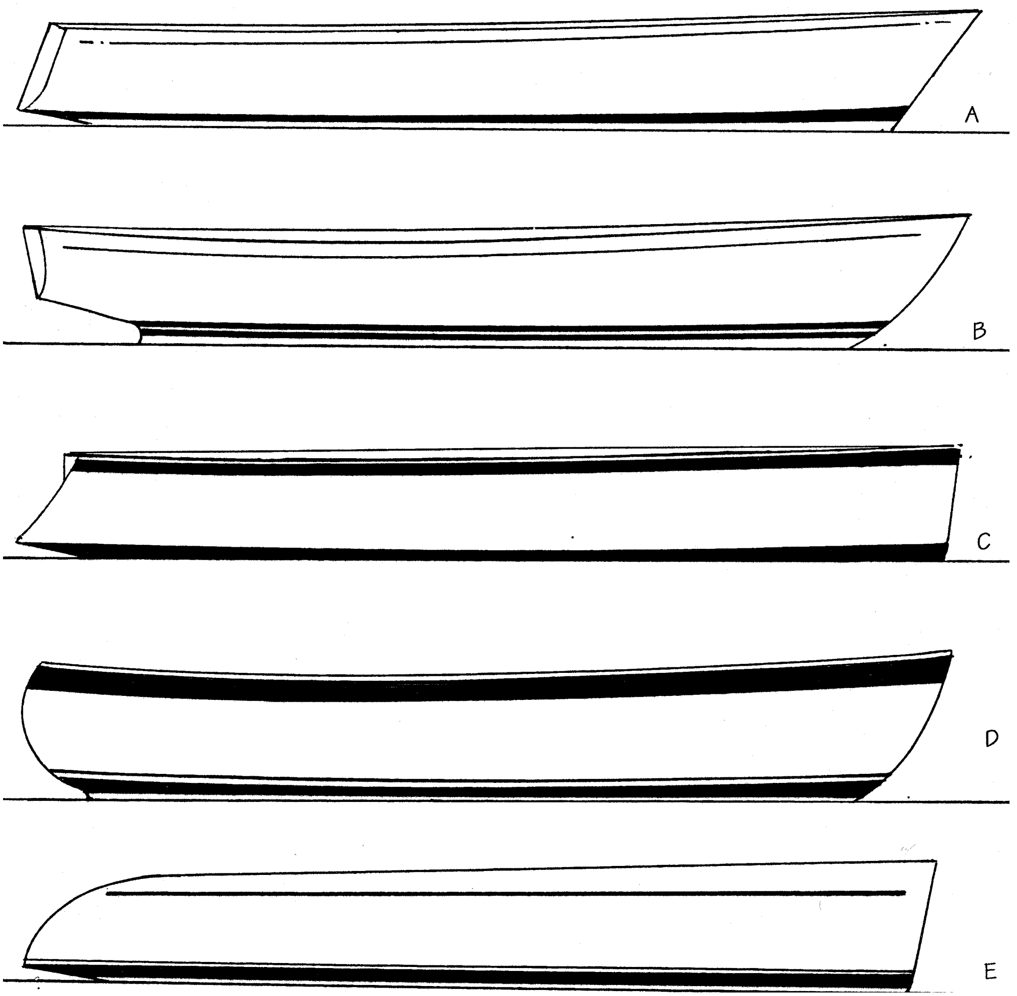
Boot stripes are commonly made thicker at the ends than the middle. Fifty to 75 percent increase is quite normal. At the stern, little of this will be noticeable, as the boot stripe runs under the counter.

Finally, you might consider not having a bootstripe at all. If you bring the top of the bottom paint to the topsides' paint line, there will be no bootstripe to worry about cleaning. This is the approach we take on our own yachts.



There are as many paint schemes as there are hull types. The first question to address is what exactly you are trying to accomplish. Once there is a clear aesthetic objective, you can then work out the approach to be taken.

In general, most yachts benefit more from a simple, strongly stated set of stripes than from a fancy set of graphics.

These five examples are each a little different. "A" is a classic modern design, with moderately sprung sheer and reverse transom. A medium-width cove stripe will accentuate the shear line, which is an advantage. "B" is a classic shape, with lots of spring in the shear and long overhangs. Fancy cove or boot stripes would detract from the simple, elegant lines. A thin cove stripe to lightly accentuate the shear line is all that is called for. "C" and "D" are hulls with more visual height than might otherwise be desired from an aesthetic standpoint. You can reduce the visual topside height by using a thick cove stripe from the shear down a ways, as well as a thick boot stripe. In "E" (at the bottom) you have a cove stripe that diverges from a flat shear to try to give it some visual shape. This is very tricky to get right. The best approach is to experiment with paper and tape before picking up a paint brush.

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Cove Stripes

Cove stripes, typically a thin line just below the sheer line, are an efficient way of enhancing the appearance of the sheer, especially if your deck edge is not capped with some form of rail (usually teak) of a different color than the topsides.

Hull Stripes

Hull stripes are an efficient method of reducing topsides bulk. The same rules apply as with big boot stripes — it makes sense if you have little deck structure to balance.

With very little structure on top, *Deerfoot* (above) could easily get away with a large hull stripe.
The stripe is parallel to the sheer until midships; from there forward it diverges slightly to emphasize the spring in the sheer, which in reality is very flat.

Here is an example of what not to do on one of our own designs (above). This motorsailer has lots of structure above the shear line. To offset that bulk she needs plenty of topsides height.
The complex striping scheme on its own looks great, but it also makes the pilot house look larger, which in my opinion is a big hit.

An interesting graphic (right) on the topsides of another one of our boats. This owner developed the design on his Apple Macintosh computer.
It was very, very difficult to transpose from the small screen to the real world.

Topside stripes are generally quite thick and typically look better if made up from a series of smaller stripes, generally close in color.

Deck Structure

Pilothouses are wonderful to live in, but usually ugly in the extreme when viewed from a dinghy. In fact, any sort of structure above the shear line is generally ugly. The real design question is how to mitigate the effect.

There are several rules that work just about all the time. First, reduce the bulk of the deck structure and enhance the base onto which it sits (i.e., make the hull look bigger). The easiest way to do this is with color. The deck structure and/or pilot house should be darker than the topsides.

When we paint our motor-sailors, we typically specify the house to be several shades darker than the coamings, which are in turn somewhat darker than the topsides.

There is a limit imposed by climate. Dark colors get hot in the sun, so we are usually talking in terms of subtle shadings as opposed to extremely dark colors (unless you don't plan to be cruising in the tropics).

Graphics

Graphics are very difficult to design, as it is hard to predict what they will look like when painted full-scale. Computer designs, models covered with tape, or large scale drawings will not convey what a given design will look like on the water.

Whenever possible, use vinyl tape of correct thickness on the boat itself, and then move back a ways and have a look. Once you come up with the logic of the scheme, the details can then be worked up in detail on paper.

Two views of *Intermezzo*. She had a very high freeboard and not much shear. We started out with just the rubbing strake painted, but soon enlarged this to an 8-inch-thick (200mm) window stripe. This stripe was painted in three shades of blue, significantly reducing the topsides bulk, as you can see in these photos.

The stripe was first done full width in the basic blue color. The shading (lighter in color) was then added to the bottom afterwards. The difference between the single thick line and that broken up by a couple of lighter shades of blue was dramatic.

In the lower photo you can see how much the bottom paint and bootstripe are raised at the ends.

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Aluminum bearing rings help to distribute the clamping load of the bolts. We've found that 2-inch-wide (50mm) rings, about 1/4-inch-thick (6.3mm), with bolts at 3-inch (75mm) centers work well for moderate to large-sized pilothouse windows (with 1/2-inch/ 12.6mm thick Lexan).

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WINDOWS

Before we leave the topic of structure, we should spend a few more minutes talking about windows. Cabin and hull windows provide more enjoyment, light, and ambiance while cruising than just about anything you can think of.

Not only does light make life aboard more pleasant, but the very act of being able to see outside is a real psychological lift. If you're prone to a queasy tummy, windows are about the best preventative of which we're aware.

The problem comes with the structure of the hull. Hull and cabin windows can be subject to huge stresses when the hull falls off a wave. The hull may be reinforced to take this load, but what about the window itself?

And if the window starts to crack, or needs maintenance mid-passage, how do you handle this?

Glazing Materials

There are two basic approaches to glazing. The first is to use a laminated, structural glass. This can be extremely strong, but is also quite heavy, not to mention expensive. Glass has the best optical characteristics and is not prone to scratching. In short, once installed, if the gasket system holds up, there will be no further maintenance.

We tend to use plastics because they are so much lighter, but you have to watch carefully that they don't get scratched.

Of the various materials available, polycarbonates (such as Lexan) work best. The problem with polycarbs is that they are very soft and can be scratched quite easily with a paper towel or a slightly dirty rag. Nevertheless, two major manufacturers, General Electric and Rohm and Haas, sell a polycarb with scratch-resistant plastic.

If you plan to use plastic windows, there are several issues of which you need to be aware.

Thermal Expansion

Plastics have a high coefficient of expansion. This means they expand and contract a significant amount with temperature changes. The size of the window, the area onto or into which it fits, and the fastener holes all should allow for this movement.

Without enough allowance, stress cracks will start to form within the window, usually around the fastener holes or under the clamping ring.

If you use fasteners, the holes need to be substantially oversized. For example, with 1/2-inch-thick (12.6mm) Lexan, on hull windows which are approximately 3 feet (0.9 m) long and 8 inches (200 mm) high, we use 7/16-inch-diameter (11 mm) holes for 1/4-inch (6.3mm) bolts.

Note that fastener holes should have smooth edges, on the inside of the hole and on the surface of the window. It helps to use a sharp, stepped drill. If you don't have a stepped drill, use several

Type	Manufacturer	Product Name
Silicone	General Electric Company Waterford, NY (800) 255-8886	LEXSIL® SPS2900 Sealant
Silicone	General Electric Company Waterford, NY (800) 255-8886	Silpruf® Sealant
Silicone	General Electric Company Waterford, NY (800) 255-8886	CONSTRUCTION 1200® Sealant
Silicone	General Electric Company Waterford, NY (800) 255-8886	CONTRACTORS 1000® Sealant
Gasket/Tape	Norton Company Granville, NY (800) 724-0883	• NORRENE* Foam • V-2100 Urethane Series
Gasket	Tremco Columbus, OH (800) 321-6357	• Silicone (70 Durometer) • EPDM (60, 70 Durometer)
Tape	Tremco Cleveland, OH (800) 321-7906	440 Tape
Butyl Tape	PTI Dayton, OH (800) 543-7570	303, 606
Butyl Tape	Schnee-Morehead Irving, TX (214) 438-9111	Isocryl 5600 Series
Aluminum/ Mesh Tape	DRG Sellotape Utrecht, Holland 030-44 33 44	Sellotape BV Vent Tape
Vent Tape	3M Minneapolis, MN (612) 733-1110	Tape 394

General Electric, the manufacturer of Lexan, suggests these suppliers for gasket materials.

smaller sizes as starters before finishing off with the final size. Remove any burrs around the edges of the holes.

The actual relationship you will need varies with the type of plastic, shape of the window, thickness, and heat range for which you want to allow.

For polycarbonate sheet, here is the expansion formula: multiply the dimension in inches times the temperature differential in degrees Fahrenheit times the constant 0.0000375.

An example would be as follows: 96 inches (length of a given window) times 50 degrees Fahrenheit (the difference between a 70-degree day and a 120-degree day) times 0.000037 = 0.18 inches in dimensional change. When looking at the high temperature, bear in mind that the surface of shaded plastic absorbs heat and so gets much hotter than the surrounding air temperature. This is not a problem with clear.

Gaskets

If your window is to be bedded on gaskets, there are several issues with which you have to be concerned. The first is the type of material being used. Many gaskets have PVC plasticizers used to keep them soft. These eventually migrate to the surface of the gasket and interact with the window, causing loss of strength, cracking, and crazing. The answer is to use a gasket material like an EPDM or pure neoprene.

You'll get the best results if you use a large sheet of gasket rather than a tape. The large sheet means no joints can leak. If you do use a tape, be sure the joint is carefully fit together. If a bonding adhesive is available for the gasket you are using, bond the tape edges together where they meet.

We typically use 1/4-inch-thick (6.3mm) gaskets, usually of EPDM rubber, with a Shore durometer of 25 to 45 and a density of 8 to 12 pounds per cubic foot.

Adhesives versus Fasteners

Lots and lots of windows are held in place with adhesives. We've used them with success on our pilothouses, but only where the cockpit area inside of the pilothouse was watertight.

If loss of a window in a knockdown could flood the interior, use mechanical fasteners. Although these are more costly, heavier, and less sleek, you can be absolutely sure of your structure.

Holes should be at least one diameter in from the edge of the window. This means for a 1-inch (24.6mm) hole there should be 1/2-inch (12.3mm) clearance between the extreme edge of the hole and the edge of the plastic.

Bearing rings

If bolts hold the windows in place, they should go through a bearing ring to distribute the clamping pressure of the bolt to the surround plastic. Our rings are typically about 2 inches (50 mm) wide and of 3/16-inch to 1/4-inch (4.5mm to 6.3mm) thick aluminum.

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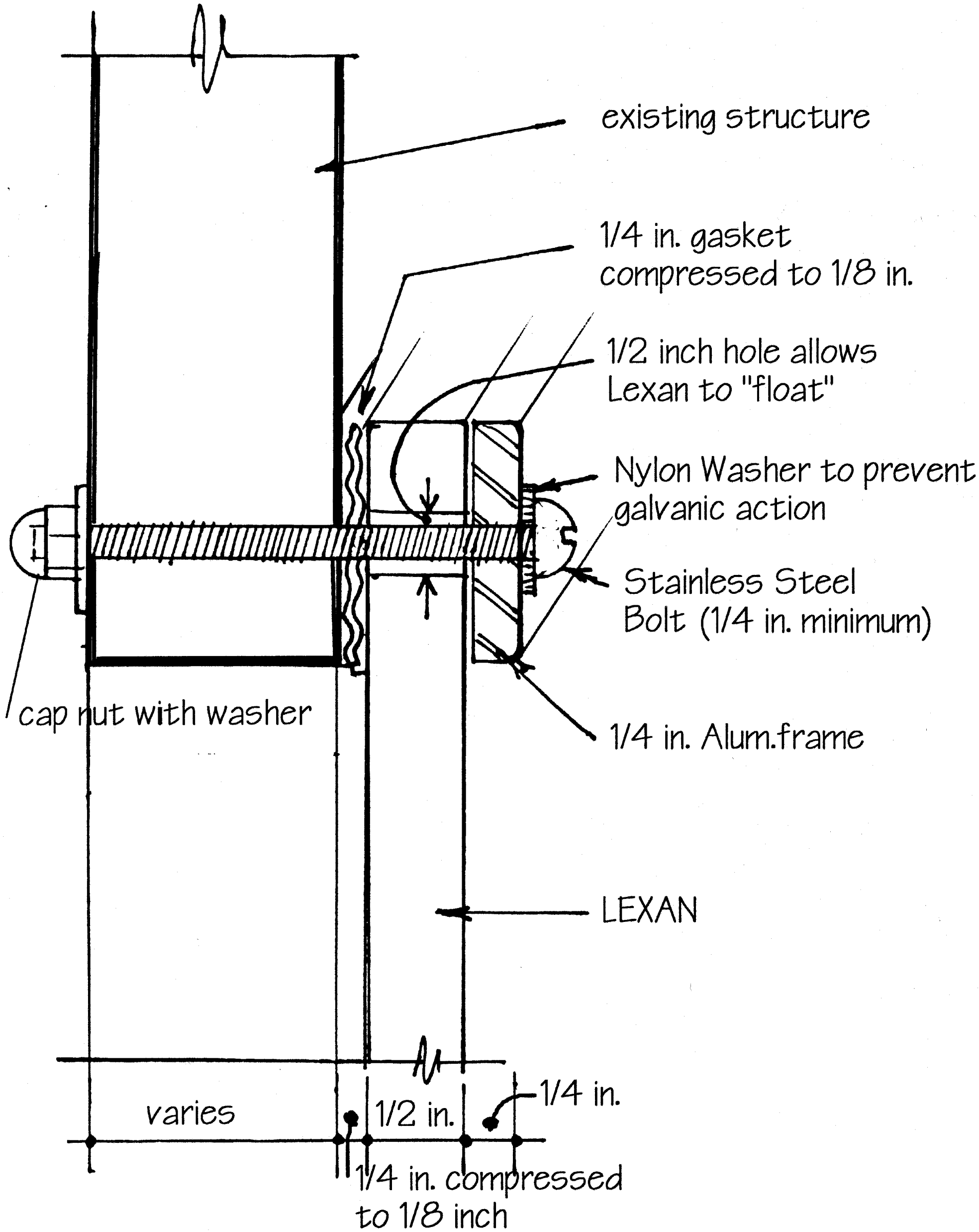

One of the toughest details to get right with plastic structural windows is how they are held in place. We have had good success over the years with wide bearing rings (usually about 2 inches / 50 mm in width) made from 1/4-inch (6.3 mm) aluminum.

The window sits on a high-quality 1/4-inch-thick (6.3 mm) gasket, which compresses by about 50 percent when the window is snugged down.

The most critical factor is providing enough room around the bolts for the window to expand and contract without ever touching the bolt. If you mis-drill the hole, or use one that is too small, a crack will result in a short period of time. This crack does not necessarily indicate that the window is structurally unsound, but it is unsightly, and over time will probably leak (although cracks in thick plastic seem quite resistant to leakage).

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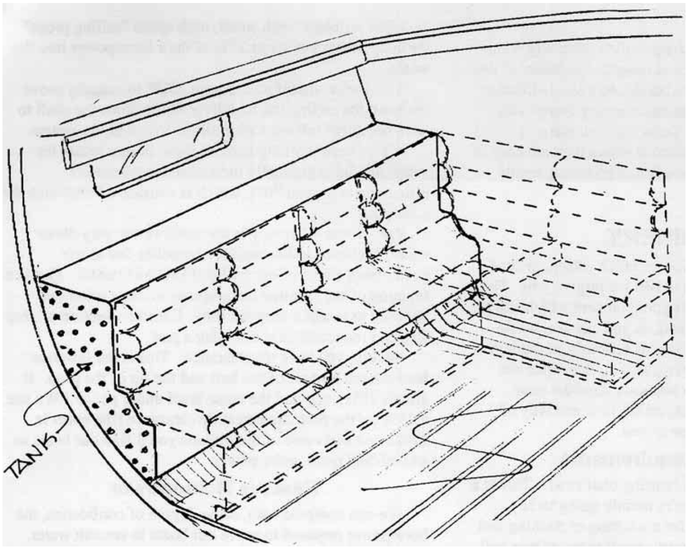
WATER BALLAST

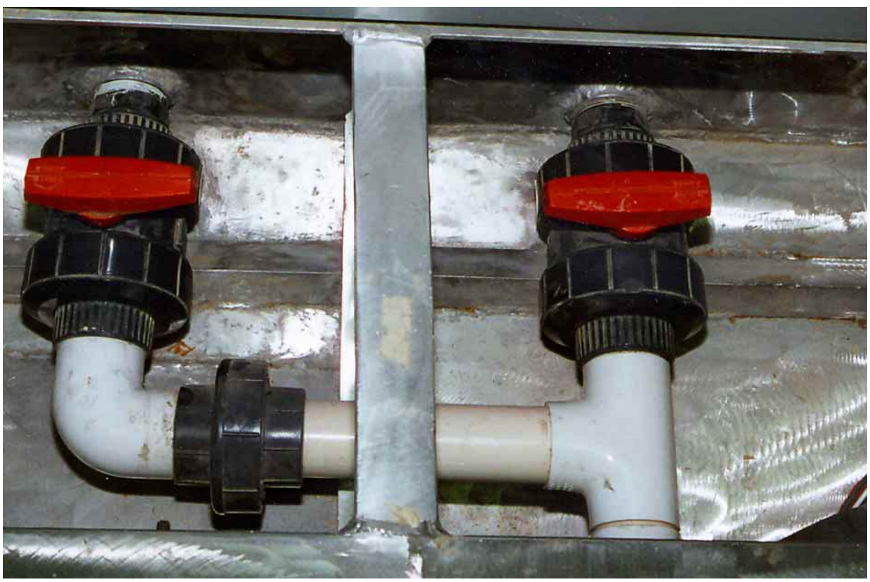
Years ago — I think it was in the early 70s — Eric Tabarly did a singlehanded race across the Pacific in a 35-foot (10.8 m) sloop that used seawater in side tanks for additional stability. “What a clever idea,” I thought at the time. You could reduce your total displacement, but add substantially to stability. The result would be faster and stiffer performance upwind and reaching. Tabarly won the race (he almost always did back then), and I heard nothing more of this concept for many years.

Then, a decade ago, monohulls in the singlehanded OSTAR started using water ballast to try to compete with the big multihulls. Warren Luhrs’ *Thursday’s Child*, which I saw at the Annapolis



Where to put water ballast is always an issue. If the boat is large enough, you can bury it inside of furniture, keeping tank tops below counter level. If this works out, you lose some storage space, but without visual impact.

On the Sundeer production boats we used fiberglass tanks from the main saloon bulkhead aft for freshwater tanks (left). The theory was that on passages you would carry just the weather tanks filled, then top off once you reached your cruising grounds. The reality seemed to be that most of our owners preferred to passage with both tanks filled, negating the advantage of carrying the water to windward.



On race boats, water-ballast plumbing tends to be large and bulky for rapid transfer rates. However, for cruising, where water ballast is more of a strategic long-range issue, smaller plumbing can be used. We’ve found that a single 2-inch (50mm) line will allow us to transfer 4,400 pounds (2,000 kg) in about ten minutes.

The photo below shows selector valves for *Beowulf*’s forward and after tanks. The aft tank is normally used. The forward section is only used when the boat is light and we are looking for maximum performance.

Boat Show, startled the sailing world with her performance, almost beating the first multihulls and massacring the monohulls in the fleet. By the time the second BOC racers hit the starting line in Newport, Rhode Island, most of the serious competitors were using thousands of pounds of water ballast.

We've found this Scott self-priming 3/4-horsepower pump to do a reasonable job of filling ballast tanks. At 60 gallons (230 liters) per minute, it fills our aft ballast tank in under ten minutes.

The selector valve on top of the discharge sends the salt water to either side. By taking this to the top of the tank, we need not worry about check valves for back-feeding. When we need more ballast, we simply turn on the pump and wait until heel has flattened out, or until we see the vents overflowing.

Always thinking about a more comfortable, faster way to go cruising, I started looking into adapting this concept to a serious cruising yacht. The advantages were obvious: speed, as much as a 15-percent increase in beating and close reaching performance, and/or a lot less heel. If we heeled 24 degrees going to weather at 9 knots, we could reduce heel to 16 degrees and maintain the same speed, or carry much more sail and go faster at the old angle of heel. From my perspective, the reduction in heel angle was the most intriguing.

Athwartships, rolling would be substantially reduced and softened when at anchor, when powering in a sloppy sea, and when sailing downwind in the trades. Why? Because putting all that weight into the hull sides would increase sideways polar moments tremendously, and that would help soften or reduce the motion. Water ballast can also be used to trim the boat to leeward in light air to help sail shape and reduce wetted surface.

Intriguing concept, isn't it? But water ballast isn't a complete plus. There are a few negatives. What do you do with the tanks? How much space is lost? What about the noise of that liquid sloshing around if the tanks aren't full and you're pounding uphill? Then there's the complexity of additional through-hull fittings, pumps, plumbing, and maybe a leak or two along the way.

Intrigued with the concept, I started to do some research. Who better to check with than the racers with experience? The first person I reached was Tony Lush, a singlehander with many offshore miles to his credit.

Tony had fitted a J/35 with hull side tanks for an OSTAR race across the Atlantic. He figured a net 15-percent gain upwind with his modest 1,800 pounds of water ballast. (Against the 11,000-pound displacement of his boat, this was like having nine crew sitting on the rail.) Even more important was his ability to drive upwind in heavy air with his lightish displacement. Tony said he could make 6 to 7 knots with storm jib and double-reefed main in 45 to 50 knots of wind (moderate seas running at the time). That's phenomenal in an 11,000-pound (4,988kg), 35-foot (10.7m) vessel. I asked Tony how he had gone about installing the tanks. He said they had been built right into the boat, using the deck and hullside as part of the tankage. He started at the forward bulkhead, near the mast, and worked aft to the start of the cockpit area, about the same as where a crew would sit.

One of the key issues Tony stressed was proper baffling. Allowing any sort of liquid movement in the tanks would not only slow the boat, but would be annoying as hell to the occupants. He used vertical baffles every foot in his tanks. Even with these he still had to keep the tanks full to avoid sloshing.

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I also checked with Steve Pettingel, a professional sailor who has designed a number of water-ballasting systems for race boats, and who recently came second in the BOC. Steve echoed Tony's comments. Saltwater ballasting is relatively simple to install, very efficient at generating boatspeed, and is an excellent candidate for cruising.

Since these conversations many years ago, we've spent a lot of hours studying the concept, talking to people that have used it, and looking at boats equipped with water ballasting.

When Linda and I went through the design evaluations on *Sundeer*, in the end we decided against using water ballast. We did not want to give up the storage space and didn't care for the complexity of the system we thought would be required.

But some more thought and observation led us to the conclusion with *Beowulf* that we'd give seawater ballast a try. And after just a bit of real-world experience we've come to love it! I can assure you that any future vessels we do will use this concept.

Stability and Performance

Let's go back to the beginning and look at the rationale for this whole concept. In a monohull sailboat, the single biggest issue in performance is stability. The more stability you have, the faster you sail. Period.

You can also sail at a more upright angle, which is more comfortable for the crew. Keel and rudder are more efficient, too, at an upright angle. Everything benefits.

As we've discussed before, there are several ways to generate stability. One is with hull form (inertia). However, of course beamy hulls have steering, drag, and motion negatives. You can do it with deep draft or by adding lead to the keel. Both are negatives in a cruising context. Or you can do it by adding weight at the end of a lever arm — like 15 of your best friends on the weather rail.

That's where water ballast comes in. A weight at the end of a lever arm, it works to keep you upright like the crew on the rail. But you can pump it overboard when it's light — and you don't have to share your life with it.

How Much Water Ballast?

This is a trade-off between interior space, stability, the costs of that stability in terms of sail weight, spar size, rigging and hardware impacts, and range of positive stability. In our own work we've found that a 6-degree heel reduction works out about right.

Tank Geometry

The effectiveness of the water ballast depends on several factors. First is the distance off-center. The further to windward, the more effective it will be. Second is height. The lower the water ballast, the more effective, and the less of a problem it will be in a rollover. Of course height and beam are linked, so picking the right combination of tank shape for most efficient use of weight requires some design work. Another issue is longitudinal distribution. The longer the tanks, the more weight they will hold. Longer tanks can be further outboard but have more surface to construct, which is heavy and expensive. We've found that it works well to have the water ballast weight well aft of the center of buoyancy in the hull. This depresses the stern, as the tanks are filled, which improves the high-speed hull shape and helps keep the rudder covered when the boat heels.

All of this theory is fine for race boats, but what happens in a cruising yacht? With cruisers the big trade-off comes in the interior. With a raised saloon design, or one with a mid-engine room, the tanks can be easily hidden and will show little or no impact on the interior. Or, they can be fitted underneath and below the furniture, as we did on *Beowulf*.

Hull Shape

If you've decided to go for water ballast, and if you are building new, then hull shape should be looked at from a unique perspective.

With water ballast in the equation, it sometimes pays to increase beam a bit so that the resulting hull shape aft is more efficient at getting water ballast weight low and outboard. Of course, this creates potential steering problems — but these are mitigated by the more upright sailing angle and ability to depress the stern.

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Range of Stability

Water ballast is a big negative on range of stability because of the higher center of gravity that is typically the result. In our studies we've found losses of 4 to 8 degrees in LPS as a result of water ballast (these were in non-aggressive situations). Be aware of this early in the design equation, and make allowance to get the required range back either by lowering the overall vertical center of gravity and/or increasing freeboard (or deck structure).

Whitbread 60 designers have raised an interesting concept about water ballast and capsize resistance. If you end up in a capsize situation when fully-ballasted, the boat will have a heel induced by the asymmetric ballast loading. This additional heel is going to reduce the wave energy required to get the capsized vessel back on her feet. The theory makes sense to me. But short of testing it, with and without water ballast, I'd prefer to maintain the appropriate LPS. Of course, you could empty the tanks in heavy weather when capsize was a risk. This would get you back to the better LPS, but then you'd have less stability and inertia with which to resist wave impact.

Ballast Tank Construction

Ballast tanks carry substantial loading and need to be carefully engineered. Lots of baffles reduce water movement and sloshing noises, while reducing panel spans inside the tank.

Beowulf had baffles every 24 inches (610 mm) on center, and noise was never an issue, even when beating into steep seas.

You should test the tanks with a static head pressure of at least twice the maximum head they will see when filled.

Plumbing

We look at the plumbing system in the context that the water ballast is a tactical element, typically used for long periods of time on a given tack (as opposed to a strategic element where ballast would need to be rapidly filled, dumped, or transferred from side to side).

In a cruising context this means that smaller, less complex plumbing systems can be used. Plumbing size becomes important if the plumbing is exposed in the interior. Where a 2-inch (50mm) pipe might fit under the cabin sole, a 3-inch (75mm) pipe might create an ugly bump.

Our own experience is that ballast is rarely adjusted except when tacking or jibing. Where we might want half-filled tanks at 11 knots of true-wind speed, and filled tanks at 13 knots (beating), the performance hit for being overballasted is so small that we typically fill the tanks and forget them (unless it gets really light).

There are three approaches to filling the tanks: opening a valve and letting gravity do the job of filling a leeside tank (and then tacking once it is filled); using a forward-facing scoop to make boatspeed force water into the windward tanks; and using an electric pump. The problem with using gravity is that while this is going on, your heel increases substantially. In addition, with a good head of speed, it may be difficult to get water to fill without some form of a hull scoop. It's fastest to use a large forward-facing scoop, as on the BOC race boats. However, this involves a fair amount of structural and plumbing complexity and introduces another potential area for leaks.

My favorite method is to say from the beginning that you are going to pump it in, which allows you to pump the water to windward. We've found success using self-priming Scott centrifugal pumps. The 3/4-horsepower model we've used gives us around 60 gallons (240 liters) per minute.

Dumping water ballast is quite simple. Gravity will do the job as long as the water is to windward. In fact, in many cases the water will be quickly sucked out by the venturi effect created by the sea passing by the through-hull fitting.

Transferring liquid from one side to the other is most easily done with gravity. We used 2-inch (50mm) PVC pipe, with the equivalent of six 90-degree bends between the two sides. Transferring 4,000 pounds (1,800 kg) from windward to leeward side takes about six minutes.

Be sure your air vents are of sufficient size to eliminate the possibility of any restriction when the tanks are filled at the fastest rate. This helps with filling speed and ensures that no pressure (aside from that associated with the "head" of water) is allowed to build up. If air vents are undersized or blocked (perhaps by a dip filled with water), pressure from the pump can build rapidly. This can lead to leaks and/or structural problems with the tanks.

The air vents should be at the highest point of the tanks *when the boat is heeled* (typically an outboard corner). If positioned where easily visible on deck, the overflow will indicate when filling is complete. If you have long tanks, with lots of flat area on top, you may want to consider two sets of breathers.

Also, be sure the baffles have breathing notches cut into the top inboard and outboard corners.

There are all sorts of ways to plumb up the ballast system to make it easier to use on a remote basis. When we started with *Beowulf* we did everything with a series of manual valves in the center of the boat, behind the fridge box. After living with the system, we came up with a simpler approach, which made for easy remote control as well.

First, the output of the electric filling pump is directed by a Y-valve to either port or starboard tanks. The fill is at the top of the tank. Once the valve is directed to port or starboard, any time the pump is turned on, it will pump water into the tank. The water cannot run back out through the pump because the fill is at the top of the tank. Hence, when the filling operation is over, no valves need to be adjusted. The only time it will be necessary to adjust this valve is if you want to fill the opposite tank.

In the center of the boat, at the low spot of the tanks, there is a crossover pipe that serves both to empty the tanks and to transfer liquid from windward to leeward side.

On each tank is a valve (inside a locker). In the middle of the crossover pipe is a Y-valve. This central valve directs the flow to the leeward side in one direction or to the exhaust through-hull fitting when in the other direction.

Normally it is turned in the exhaust direction. On the through-hull fitting is a conventional seacock as a safety device. Just after this we used an electrically operated valve made by Asahi (12-volt and 24-volt models are available). To let water out, simply open this valve and away it goes — assuming the Y-valve and tank valves are open.

Since controls for the pump and electric valve are in the pilothouse, the system is easily regulated without going below to mess with the manual valves.

When we tack or jibe, the Y-valves on the pump and crossover between the tanks are adjusted, and the leeward tank valve is closed while the new weather tank valve is opened.

Using Fuel and Water as Ballast

When we started to work on the Sundeer production series, we talked to our builder about the feasibility of putting fresh water into hull side tanks. This turned out to make economic and structural sense. The tanks acted as local stiffening and longitudinal girders, plus they formed the insides of lockers and saloon seat-backs.

We were able to design in about twice the capacity we'd normally specify in fresh water. We assumed that when passaging, the tanks would be left half-full (with all of that carried to windward), and that at cruising grounds, both sides would be filled.

The nice thing about this approach was that we were left with plenty of space under bunks and seats for normal storage.

Fuel tanks were also done in this fashion, but they were built out of welded aluminum and placed against the hull sides in the aft engine room. Again, capacity was doubled over what we'd normally be able to fit.

Plumbing between the fuel and water tanks can be done in a number of ways. The simplest with fresh water is to use a single crossover pipe for transfer (by gravity) with a T-fitting in the middle from which the pressure pump draws.

Fuel is a little more complex. Various rule-making bodies are unhappy about placing a fuel tank pickup where it exits the bottom of the tank (in case of a leak, they don't want the diesel under a head pressure on the plumbing system). If you adhere to this stricture, use a pump to transfer from one side to the other.

Diesel fuel pumps are typically pretty slow, around 4 gallons (16 liters) per minute. So a single normal-sized pump will take some time to move the fuel. The answer is to fit several pumps, go to a large (and expensive) pump, or be patient.

When you look at using fuel and water to help with righting moment, consider the effect of various levels of liquid on fore-and-aft trim.

POSITIVE BUOYANCY

Surprisingly, there's no reason a boat with a displacement-length ratio under 225 can't be built with positive buoyancy. If you're willing to go to the expense and effort of filling the bilges and some of the lower storage areas with foam and to build in watertight bulkheads, this goal is within reach.

Consider the advantages for a moment. At sea there's the obvious security and mental comfort that comes from knowing your vessel is its own best liferaft. If you happen to be caught on a reef, and the reef chews through the side of the bilge, the rush of water and debris will be met by a barrier of foam, allowing additional time to try to float free.

It isn't feasible to work toward positive buoyancy unless you're building new. If you are, figure the weight that must be supported by buoyancy. This depends first on the building materials. Wood is self-supporting in the water. Fiberglass will support 70 percent of its weight, so only 30 percent is left for buoyancy; steel is a surprising 15 percent buoyant. At the bottom end of the scale is lead, which needs a 95 percent crutch. Once the different weights are analyzed, take what's left in weight that needs support, and divide that figure by 64 pounds (or the weight of one cubic foot of salt water). This gives the answer in cubic feet of foam required to do the job.

The next question is where the buoyancy can be installed versus where the weight is that needs to be supported. The moments of relative balances have to even out, or you may end up floating with one end of the boat pointing up.

DOCKING

It's not uncommon in many parts of the world to lay against pilings, or to have to tie up to extremely rough docks. It makes sense to allow for this before you leave home, especially if you are building new.

Rubbing Strake

The best bet is to build in a proper rubbing strake or belting. This can be as simple as a 3/16-inch (4.5mm) stainless-steel strap, 1 inch (25 mm) high, fastened to your toerail. If the toerail is well secured to the deck, this is ideal, because it will project out from the topsides all the way around the boat.

Or a belting can be added to the hull side. This will usually be a heavy piece of timber, perhaps 2 inches (50 mm) thick and 3 inches (75 mm) wide at the hull, tapering to 1 inch (25 mm) or so, with a metal cap. Belting is only useful as long as it sticks out beyond the deck edge. For most boats this means that the bow and stern sections won't be protected.

One of the problems with belting is that it introduces a series of holes into the topsides, which may at some point leak.

Hulls are easiest to protect if they have some flare from the waterline to the shear, from forward all the way aft. Yachts with tumblehome, where there's more beam just above the waterline than at the deck, are very difficult to protect. In the early periods of the IOR, this was a favorite design trick.

If you don't have rubbing-strake base molded into the hull, the easiest approach is to start with a teak backing block and then cap it with a stainless or bronze rail (above).

However, with a little forethought, the rubbing strake base can be molded right into the hull mold (left and below).This adds a bit to the tooling cost, but in the end you get a much better product.

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