·PROFESSIONAL· BOATBUILDER

The magazine for those working in design, construction, and repair

NUMBER 99
FEBRUARY/MARCH
2006
$5.95 U.S.

PRODUCTION BOATBUILDING WITH WET-PREGS
CALCULATIONS FOR SPECIFYING STEERING GEAR
SINGLE-SKIN vs. SANDWICH CONSTRUCTION
SORTING THE PLAYERS IN DISTRIBUTED POWER

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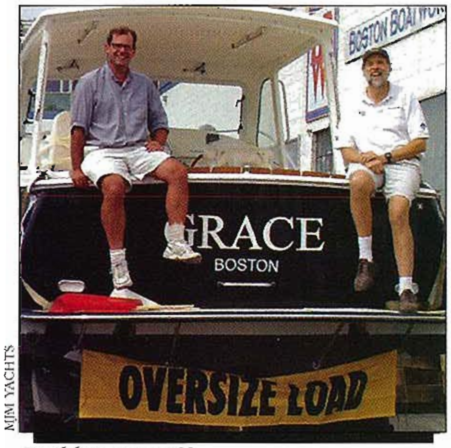

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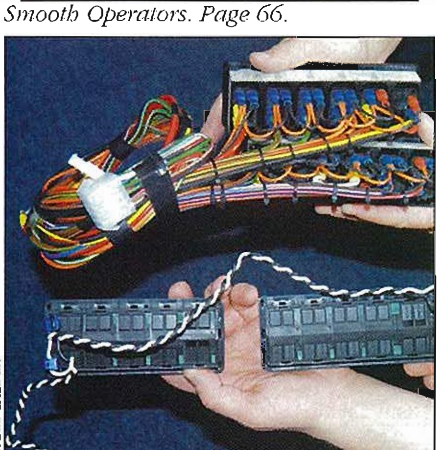

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Photograph by Bruce Pfund.

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Professional BoatBuilder (ISSN 1043–2035) is published bimonthly in February, April, June, August, October, and December in Brooklin, Maine, by WoodenBoat Publications, Inc., Jonathan A. Wilson, Chairman; James E. Miller, President. Editorial, advertising, and subscription offices are at **P.O. Box 78, Brooklin, ME 04616, tel. 207–359–4651.**

The cost of a subscription to **Professional BoatBuilder** for non-qualified subscribers in the U.S. is $35.95 per year. Canadian airmail rate is $52.00 U.S. funds. Overseas airmail rate is $68.00 U.S. funds drawn on a U.S. bank. For credit card orders, please call 207–359–4647. Periodical postage paid at Brooklin, ME, and additional mailing offices. GST #R127081008.

POSTMASTER: Send Change of Address (form 3579) to Professional BoatBuilder, P.O. Box 78, Brooklin, ME 04616.

CONTRIBUTIONS. Address all editorial communications to **Editor, Professional BoatBuilder, P.O. Box 78, Brooklin, ME 04616.** We are happy to consider contributions in the form of manuscripts, drawings, and photographs. All material must be identified with sender's name and address, and when sent with sufficient return postage, submissions will be returned if unsuited to our requirements. Care is taken with contributions, but we are not responsible for damage or loss.

Printed in the United States.

Extreme Textiles

Our cover story (page 66) by technical editor Bruce Pfund details how Boston BoatWorks adapted its wet-preg custom-building process to the series production of a pocket motoryacht. The related story (page 52) by editor-at-large Dan Spurr describes how developer/marketer Bob Johnstone selected Boston BoatWorks to series-build the Zurn-designed product Johnstone had in mind.

BBW was one of two experienced wet-preg shops that Johnstone settled on; the other was Goetz Custom Boats, in Bristol, Rhode Island, which happened to be scheduled solid. I mention this because Goetz's work is featured in a hard-cover book published as an accompanying catalog to a remarkable exhibit recently mounted by Cooper-Hewitt, the United States' National Design Museum, in New York City, part of the Washington, D.C.–based Smithsonian Institution. The exhibit, "Extreme Textiles: Designing for High Performance," just closed in mid-January. But the book lives on.

Both projects were conceived and assembled by Matilda McQuaid, head of Cooper-Hewitt's textiles department, who has been researching advanced composites—with emphasis on the fabric reinforcements that go into them—for more than a decade. McQuaid organized her material around five separate attributes: "stronger, faster, lighter, safer, and smarter." Her interview with owner-operator Eric Goetz, illustrated with shop and product photos, constitutes the chapter on "faster"; she enlisted additional essayists to cover examples of high-performance industrial textiles in service of the other attributes.

Goetz is one of several boatbuilders who, a quarter-century ago, successfully adapted aerospace composites to marine construction. Mark Lindsay of Boston BoatWorks and John Merrifield of Merrifield-Roberts (see the Parting Shot on page 120), to name two, also pioneered this particular technology transfer. All three were involved in *America's* Cup campaigns, where every effort is made—and almost no expense spared—to reduce weight and increase speed.

The beauty of McQuaid's book is manifest not only in the quality of its overall graphic design (hey, it's the nation's design museum), but in showing us—at close range—the intrinsic physical beauty of the industrial textiles themselves, and in putting a number of very different applications into a unified context. Thus it is that we see, in a single volume, the unusual aerodynamic outer helmet of a 140-mph (225.3-kmh) downhill skier; the body of a Formula One racecar; super-strong ropes and cargo nets employed on the modern waterfront; molded racing sails; lightweight skins for innovative architecture in buildings, bridges, and furniture; unmanned spacecraft and life-supporting spacesuits in the advancement of space exploration; sophisticated prosthetics that enable amputee athletes to compete at extraordinary levels of performance; and next-generation battle gear that will assist the foot soldier of tomorrow in sensing the environment to which he or she is exposed. *Professional BoatBuilder* often refers to the composites in these seemingly unconnected pursuits; McQuaid may well be the first to have truly pulled them together. What they have in common, of course, is advanced textiles. And those never looked better: the photographs of otherwise mundane materials, and the engineered objects and structures made from them, are exquisite. Goetz's carbon/aramid boats are in good company. *Extreme Textiles: Designing for High Performance*, by Matilda McQuaid, Princeton Architectural Press, New York, 2005, ISBN 1–56898–507–X, 224 pages, $45.

Enjoy the issue.

Paul Lazarus

LETTERS, ETC.

Networking: The Three-Cable Boat

To the Editor:

I just finished reading Nigel Calder's excellent article "Networking: The Three-Cable Boat" (*Professional BoatBuilder* No. 97, page 148). I was especially interested in distributed power, having understood the control side but not the possibility of eliminating the DC and AC breaker panels and replacing them with local network-controlled switches. I see from the downloaded Octoplex brochure from Moritz that they lay out their system in just this way. That system is far too big for most recreational boats but a sign of things to come.

Do you know of any recreational boatbuilders who are installing NMEA 2000 systems today? I have seen boats such as Boston Whalers with Mercury outboards and SmartCraft engine gauges, but have not so far encountered any electronics that have been networked with "pure" NMEA 2000 (not counting branded versions such as SeaTalk2). What's your feeling on the timeline for manufacturers to begin installing such systems? Or do you see the demand starting as limited system retrofits on existing boats?

I see in the image on page 149 that the author has a Xantrex SCP on his control panel, so I guess he has the MS2000. Xanbus is, of course, NMEA 2000 in disguise; and Xantrex has promised for some time an intelligent battery shunt that would report into the SCP and convert it into a battery monitor, plus a Xanbus/NMEA 2000 gateway.

We'll be creating a new Web site this winter dedicated just to NMEA 2000 products (www.nmea2k.com), and I will follow the rest of this series with great interest.

Peter James
Jack Rabbit Energy Systems
Stamford, Connecticut

Nigel Calder responds:

I am not aware of any relatively low-cost, fully compliant NMEA 2000 distributed power systems that will be available in the near future (the rigorous NMEA 2000 standard pushes up the cost), although Mégatech Électro (now owned by Teleflex) uses the NMEA 2000 protocol with a low-cost physical layer. Outside the NMEA 2000 framework, but still using CAN, the DNA Group has a lower-cost system that is currently being installed on the production line; and Carling/ Moritz is well advanced in developing such a system. In Europe the Swedish company EmpirBus is engaged in a major marketing exercise for a non–NMEA 2000, CAN-based system that began at the METS show in Amsterdam (last November). And then there's ED&D (now owned by Airpax), which has the most fully developed distributed power system of any manufacturer, but it is not CAN-based. An increasing number of manufacturers are jumping into this market (e.g., ETA and Weldon Technologies), so the situation is likely to be remarkably fluid for some time.

You are correct that Xanbus is NMEA 2000 protocol in disguise. In fact, Xantrex has been a major player in developing the message base for NMEA 2000. The Xanbus network uses a much lower-cost cabling system than that required by the National Marine Electronics Association, and as such is not NMEA 2000 compliant in terms of the physical layer. Unfortunately, the Xantrex SCP unit you saw in the photo of our distribution panel is no longer there, because of delays in bringing the other pieces of the system to the market. However, I really like the concept, so have kept it in anticipation of putting it back once the "DC node" (the intelligent battery shunt) and other components are available. The Xanbus cabling is already in the boat.

As you know, the big advantage of the NMEA 2000 protocol is the ability it gives the end user, such as me, to add hardware to and remove it from the bus without having to reprogram the system. This is especially true for all navigational electronics.

Structural Repairs

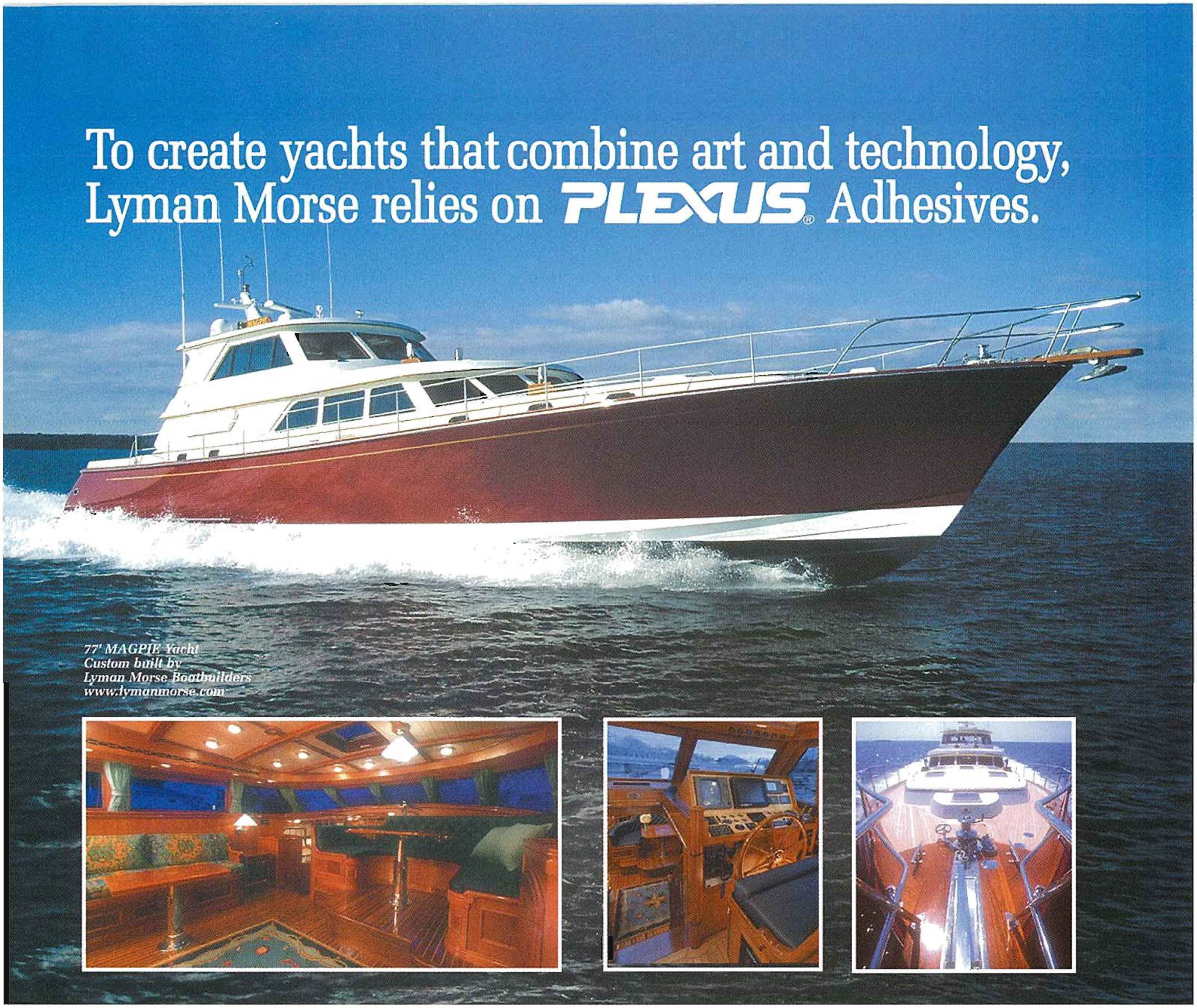
To the Editor:

Thank you for publishing Ken Biddick's "Structural Repairs" (PBB No. 97, page 174). I had to laugh at the "cause of the accident" section. Insurance companies wish owners would be forthcoming. The most frequent explanation I hear is, "My wife/son/brother was driving." I have one longtime customer whom I love because when he did wreck one of his boats, he told me, "I was drunk and shouldn't have been out there. I put her on autopilot, fell asleep, and didn't wake up for the waypoint."

On page 175, "Has the boat been painted?" is too simplistic. The solvent incompatibility issue Ken mentions is found on page 3 of the Awlgrip application manual. The question should be not only paint or gelcoat but what type of paint; how many times has it been refinished; is the current paint job adhered to the substrate? If it is gelcoat, is it too old and oxidized to be matched and blended; has it been treated with Polyglow or some other type of silicon-based polish that must be removed for a decent bond and can take (unestimated) hours to remove? Indeed, we present owners with that information and sometimes suggest a linear polyurethane coating for a finish, always being open with all parties such as the owner, the insurance company, the surveyor, or adjuster. Often the insurance company will pay to paint the damaged side, and the owner can pay to paint the other side. The owner gets a better boat than he had prior to the incident, without any deceit or fraud. We have many instances like this, particularly with hurricane boats.

Obviously, one pass with a hydraulic planer can replace hours of grinding. The first thing I learned about fiberglass repairs is that if there is any alternative to removing damaged laminate besides turning it into dust, use it! Referring to the photograph caption on page 184—"the dark spot in the middle couldn't be peeled because the I-beam interfered"—the cost of re-blocking the boat is easily offset by the savings in labor. We re-block even simple blister repairs at least once, and collision repairs perhaps three or four times.

Page 177—Access, as your technical editor, Bruce Pfund, is fond of saying, is "a no-brainer." We just repaired a 25′ [7.6m] Sea Hawk on which most of the port side was destroyed, and we considered it a walk in the park. The hull is a single-skin laminate, and there are no interior fittings to speak of. For post-repair cleanup, we



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washed the whole cabin out with a hose, drilled a hole in the bottom to drain the water, patched that, and our cleanup was done. Compare this to a 53′ [16m] Carver with about half as much damage, but its beautiful interior had to be disassembled for access, and reassembled. The damage to the Carver laminate was half that of the Sea Hawk, but the bill was twice as much because of access.

HIN and photographic documentation are a must. We are an Allstate-certified marine repair center, a BoatU.S.-preferred vendor, etc. This is required by most insurance companies. As Jim Bronstien of the Rybovich Spencer yard [West Palm Beach, Florida] said, "He with the best documentation wins."

Don't expect too much help from the HIN or the builder. I tried to start a "Boatfax" service similar to Carfax, but was dissuaded due to the incredible number of builders, models, etc. Always look for prior repairs and preexisting damage. A lot of builders are out of business. Even with a builder that is still going strong, records and even parts for vessels over five years old are hard to come by. We ran into a brick wall while repairing a 2004 model from a U.S. production powerboat builder who gave us no support, and some of the year-old parts were no longer available. Contrast that with Mike Thomas at Hunter Marine, who pulled out a six-year-old mold for a Hunter 42′ [12.8m] Passagemaker and laid up a 10′ [3m] bow section for us to scarf onto the damaged vessel. Tiara (S2 Yachts Inc.), Sabre, and KCS International Inc. also stand out as very helpful builders.

I still think Ken wrote a very good article, just a bit elementary. When I read PBB, I expect to learn things I didn't know, not things that should be considered second nature by any good repair shop.

Jim Jacobs
Service Manager
Osprey Marine Composites Inc.
Tracy's Landing, Maryland

Advanced Composites in the Adirondacks

To the Editor:

We wish to comment on several errors and inaccuracies in the article "Advanced Composites in the Adirondacks" by J.T. Hall (PBB No. 97, page 60).

The photo on page 61 identifies Charlie Wilson. The paddler is actually Joe Moore, his much younger and better-looking equal partner. The caption further claims both manufacturers profiled in the article are building canoes based on older hull forms. That is not true either. Our pictured RapidFire started life as a straight line on a 15′ [4.6m] piece of paper in April 2005; SpitFire had similar genesis 13 months earlier. Both are very sophisticated, very modern designs.

A later caption that claims gelcoat "simply adds weight" seems disingenuous. *Professional BoatBuilder* has published several articles on gelcoat application and repair as recently as issue No. 90. Gelcoat is both a cosmetic and an easily repairable sacrificial layer that protects structural laminates. Raceboats are skincoated to minimize weight, with a significant reduction in longevity—fine for competition hulls but not for recreational craft with an expected life span of decades. We always include a white waterline patch to protect the carbon outer laminate, hide scratches, and give an easy, visual trim check.

The article cites vacuum-bagging as offering minimal benefit in small hulls, with Mr. Hall legitimizing that statement through unnamed "industry experts." Strangely, builders Ted Bell, Mike Cichanowski, Gary Dayton, Sandy Martin, Steve Scarborough, and John Winters all utilize vacuum-forming for their canoes or kayaks. Vacuum-formed hulls, particularly infused hulls, are environmentally cleaner, healthier for workers, eliminate styrene voids, have higher fiber/resin ratios, and are stronger and lighter than contact-laminated skittles.

When we started closed-cavity vacuum infusion of our 12′ [3.7m] SpitFire, cloth content went up 24 oz [0.7 kg], resin use down 40 oz [1.1 kg], and total part weight down 16 oz [0.45 kg], and 48 oz [1.4 kg] with skincoat above the bottom gel patch. Our fiber-to-resin ratio improved from 1:1 to 2:1. CCVI parts are of higher and more uniform quality, stiffer, stronger, and lighter than contact laminates. Few designers, builders, or consultants would think that combination only marginally beneficial. We would enjoy Mr. Hall identifying those "experts" who do.

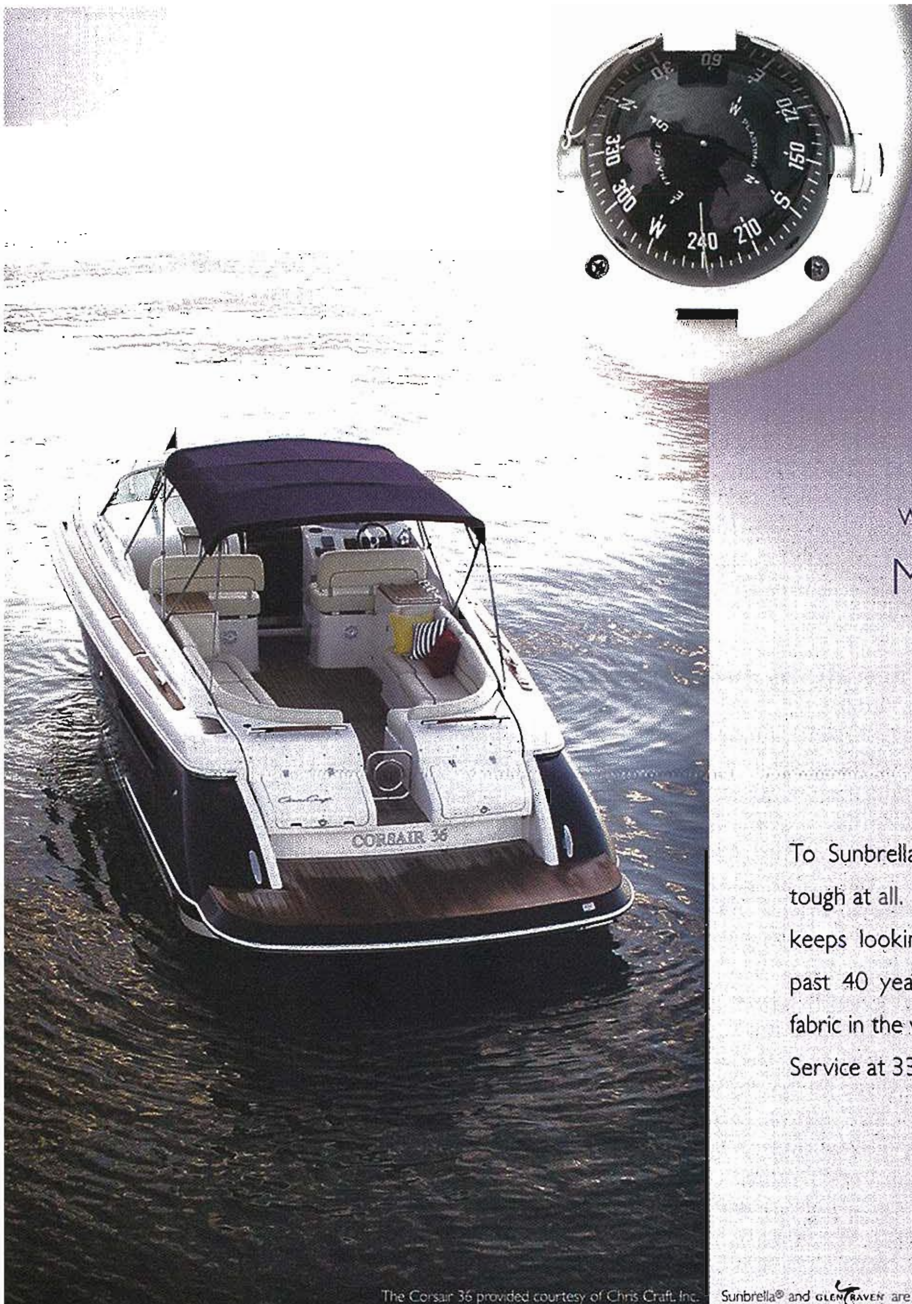
The article then mentions Bell Canoe's Dave Yost. While David, or "DY" but *never* Dave, has designed more than 75 hulls produced by Bell Canoe, Curtis Canoe, Loon Works, Perception, Placid Boatworks, Sawyer Canoe, Swift Canoe, and Tubbs, and has designs in production by Hemlock Canoe, he is definitely an independent designer, and not specific to northern Minnesota.

We cannot imagine how Mr. Hall might think SpitFire, or Bell's BuckTail, has any relationship to the *Wee Lassie* beyond two pointy ends and an open, elliptical top. *Wee Lassie* was a 10′6″ [3.2m] Rushton-designed hull made for Will Durant in 1893 over the original form for Nessmuk's 1884 *BuckTail*. (Note that the 105-lb/48-kg Mr. Sears ordered a 10.6′/3.2m hull in '84 after paddling the 9′/2.7m *Sairy Gamp* in '82.) Symmetrical with scant rocker, all Rushton hulls feature excessive hollow, or cheek, occasioned by bending wood planks from 45° amidships to vertical at the stems. Cheek shortens *Wee Lassie*'s effective waterline to 8.5′ [2.6m]. As forward speed/efficiency is a function of the square root of waterline length, that is a critical shortcoming. Significant cheek also reduces hull volume, which adversely affects stability and seaworthiness.

Biomechanically, the flare of lapstrake hulls requires use of a 250cm [8.2′] paddle, which, in combination with low seating, causes most forward strokes to become inefficient, horizontal, turning sweeps. Those 125-year-old designs are very compromised by the characteristics of their construction materials and methods.

Bell's BuckTail is a symmetrical, more highly rockered, flared pack canoe of efficient, modern design, with slight V aft to counter paddlers' tendency to carry the paddleblade behind their bodies into a turning sweep. Twelve feet overall with an 11′6″ [3.5m] waterline, BuckTail is able to safely float a heavier burden and is much more stable and seakindly. It both outtracks and outturns *Wee Lassie* and is much faster.

SpitFire is another efficient, modern


CORSAIR 36

hull with fine-tuned handling characteristics. Its hullform is asymmetrical, with differential rocker; its bow and stern radii are 11" and 6" [28cm and 15.2cm], lengthening the stern to counteract poor stroke technique without resorting to stern V, which decreases stability. The shouldered tumblehome yields 3.5" [89mm] rail inset from maximum width, encouraging more efficient, vertical paddlestrokes and the use of shorter, lighter 225cm [7.38'] paddles. Maximum beam occurs 3" [76mm] below sheer, not at sheer, as the author states. Solidly constructed and rigged with molded seat, footpegs, and backband, it is not a pack canoe at all but, rather, an open-topped touring kayak.

Lastly, we have never had any plan to develop dealership distribution. We sell a few off-season hulls to a couple of friends in the retail end of paddlesport. Mr. Hall has mistakenly offered unavailable product to a nation of fine, committed paddlesport retailers, occasioning several disappointing communications of late.

It was nice to be included in an article on high-tech canoe building. Strangely, our state-of-the-art design and construction were disparagingly compared to fine hand-lamination of century-old designs using 50-year-old lamination techniques. An article including so much misinformation and such bias calls to question the intent of the author.

Joe Moore, Charlie Wilson
Placid Boatworks LLC
Lake Placid, New York

J.T. Hall responds:

Obviously Placid Boatworks is not producing carbon copies of the *Wee Lassie*, but the enduring core concepts that defined Rushton's solo canoes are readily apparent in the SpitFire. The gelcoat issue is clear; the major producers of high-performance recreational canoes typically offer their composite hulls without gelcoat to save weight. The SpitFire's white bottom patch is an elective cosmetic feature; any impact powerful enough to damage the hull would not be deterred by a thin layer of pigmented resin. It is also clear that it is possible, in small hulls at least, to apply resin and remove the excess manually to achieve a hull weight comparable to that of a resin-infused and/or vacuum-bagged boat. Hull weights don't lie. The information about Placid Boatworks' desire and willingness to distribute surplus inventory to retail dealers (Mountain Man and others) was generated by Mr. Moore during conversations at Placid Boatworks on May 11, 2005. Finally, my article was written to feature two small specialty builders successfully resisting the current of corporatization, not as a gunwale-to-gunwale comparison of their products.

Penetrations and Closeouts

To the Editor:

I have been attempting to make a point to the marine community about generalizations and assertions that are mistakenly accepted as truths. In "Penetrations and Closeouts" (PBB No. 97, page 130), Bruce Pfund states that temperature changes of 70°F (from 70°F to 140°F/21°C to 60°C) and/or volume increases of 10% within a sandwich laminate create significant positive and/or negative pressures, and that these pressures are large enough to draw water into a core's kerf structure through fittings and penetrations as well as through wet laminate facings.

If we apply science to Mr. Pfund's scenario, we quickly see that the scenario creates no significant positive or negative pressures. By applying the universal gas law (general chemistry 1, PV = nRT) to his scenario, we find that a 70°F temperature change in a fully constrained volume (no expansion, restrained system) creates about 3.12-psi internal pressure. That is not significant. If the volume does expand 10% upon heating, only 1.82-psi pressure is generated, because we have now allowed the volume to increase (unrestrained system), thus relieving some of the pressure.

If we consider the opposite effects creating a vacuum, we convert the pressure from psi to inches of mercury (the more commonly used value for measuring vacuum pressure) and get 6.35" Hg and 2.64" Hg, respectively. Neither represents a significant pressure. These pressures are certainly well below the capacity of most sealants and do not approach a threshold that would cause an average, correctly produced through-hull fitting to leak. It certainly is not enough pressure to have even a minor effect on drawing moisture through a properly cured composite facing. In the same statement, Mr. Pfund infers that the vacuum pressure might pull moisture from a wet laminate facing. In more than 1,000 blister core samples I have measured for moisture content, the highest value I recorded was 4.7% by weight. The average is around 2.4%. This does not provide enough moisture to constitute a water supply to wet a core, even over a long term. Also, in a closed system the drawing effects of nighttime cooling would be offset by the reverse effects of daytime heating (state of flux).

If fittings are poorly produced or a breach exists in an unsealed "through facing" penetration, these pressures may introduce moisture to a core network. This is true only if incorrect penetrations exist. A properly produced composite will certainly not suffer any ill effect from these conditions, resulting in "gulping" water. Before we draw conclusions, we need to check the scientific accuracy of our theories.

Additionally, the author seems to state that decomposition of balsa core via decay is a chemical process that is speeded by water sloshing when a hull rocks. Decay decomposition is a biological process, not a reaction, and its rate depends on the conditions present that support the proliferation of fungal decay—temperature, decay type, oxygen supply, and moisture content.

The so-called "abundant" supply of oxygen in the kerf network is not necessarily so abundant in a balsa core. When balsa gets wet, it swells; and unless the kerf network is spread over a pronounced curve, it closes. That is one reason why balsa is so difficult to dry. If water is moving through and accumulating in a kerf network, those locations have their oxygen supply displaced by water. Decay cannot grow in water. We are not sure what exact moisture level makes decay impossible, but we do know that decay will not grow in a saturated core. In most instances, air

within the kerf escapes from the same location of water ingress. In the case of balsa, air does not necessarily need to be displaced for the core to get wet, since water travels through cellulose fiber by diffusion (the result of its kinetic energy and random motion of its molecules).

Rick Strand
Impact Matrix Systems LLC
Hampstead, New Hampshire

Bruce Pfund responds:

I believe that Mr. Strand and I agree that improper penetrations in otherwise high-quality cored panels can produce water intrusion problems, and that water in cores of any type is a bad idea.

I agree with Mr. Strand's math on air expansion and contraction with heating and cooling, and his comments about potential pressure equalization—but not his assessment that 2.64" Hg is an insignificant amount of vacuum. A quick Internet search located a number of 2.5-hp shop vacuums that produce 54" of water column vacuum. If my math is correct, that's about 1.6" Hg vacuum—a bit more than half of the vacuum Mr. Strand calculated might result from the large temperature changes I mentioned. I rate the suction produced by a shop vacuum as significant. Of course, I am not suggesting that the pressure/vacuum cycles I described within cored panels will produce effects similar to a shop vacuum's suction on a cored panel with open kerfs, as illustrated in the photo on page 132; but based upon firsthand observations, I do believe they contribute to water ingress. I maintain that the expansion and contraction of air within a cored panel's kerf system—in the presence of breaches in the skins—can affect the rate of water ingress, and I illustrated the air expansion phenomenon with a photo of bulging caulking on a poorly executed joint, on page 134.

I apologize for my lack of clarity in the paragraph adjacent to the photo that Mr. Strand refers to, where leakage at "any skin penetrations that connect to the kerf system" is mentioned. I did not intend to suggest there, or anywhere else in the article, that normal-quality laminates could pass water under slight vacuum or pressure, but rather that the dozens of cutouts in, and fasteners through, the open-kerfed core in the typical sailboat cabintop (mentioned in the previous paragraph), for handrails, boathooks, dinghy cradles, hatches, and portlights, were potential air and water leak sites. The chances for leaks at these locations only increase as their bedding and caulking deteriorate with age.

Mr. Strand states that outside pressures may introduce moisture to a core network but *"only if incorrect penetrations exist."* The italics in Mr. Strand's quote are mine, because that was the major point of my article. I agree that a properly produced panel will not experience pressures that result in "gulping." *I did not describe the phenomenon occurring on a properly produced cored panel*; rather, it was a panel with very poor construction. There's nothing particularly scientific about my observations of bulging wet caulking, rapidly debonded dried caulking, and a margin of wet core in way of this region. Dismissing my observations as unscientific is silly. These things happened, and the photos are in the article.

More on Whisperprop

To the Editor:

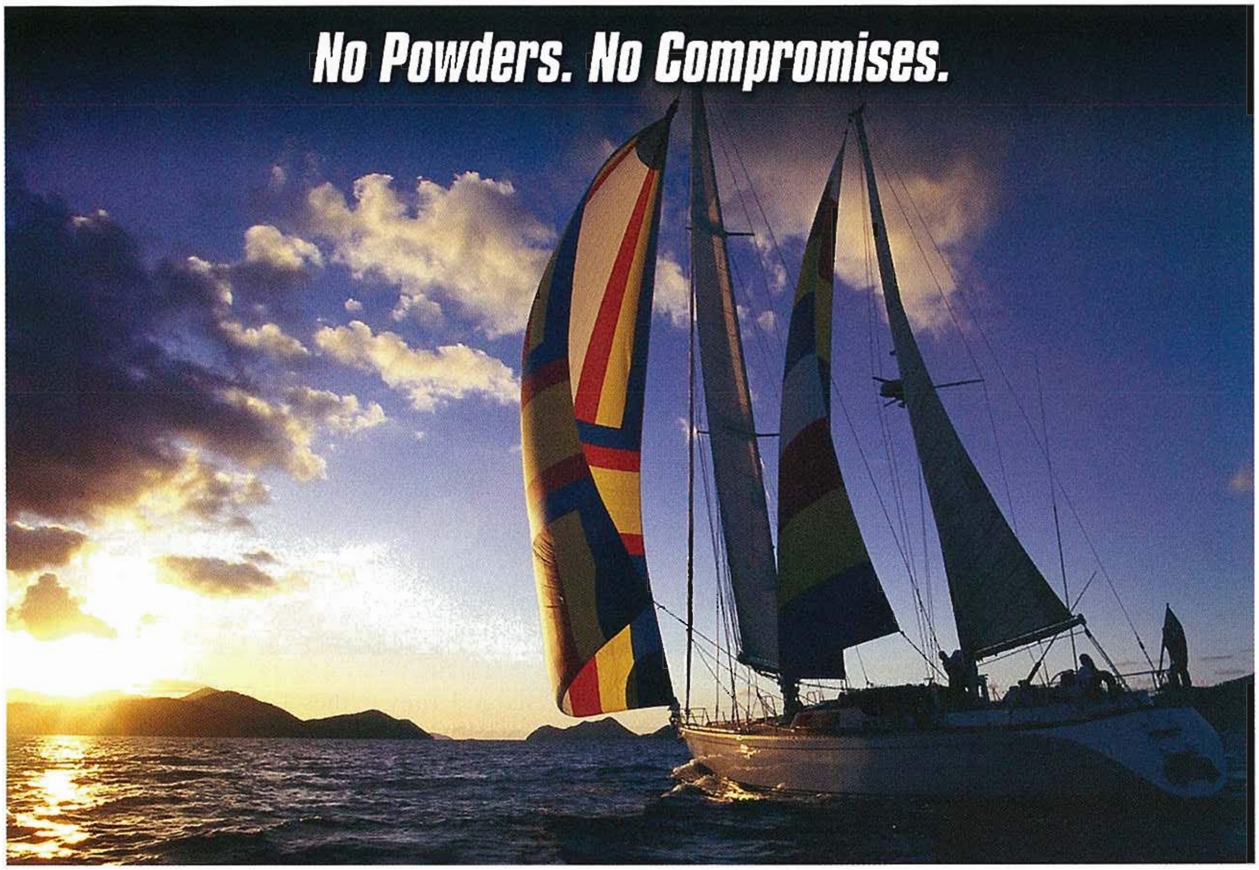
In the October/November 2005 "Rovings" (PBB No. 97, page 16) Jean-Yves Poirier expounded on the Whisperprop electric/diesel hybrid propulsion system offered by Icemaster GmbH (Fischer Panda). It is always good to see articles recognizing the merits and possibilities of this technology. I say that, obviously, from my position at Solomon Technologies, manufacturer of marine electric propulsion and power production systems.

Long before I came to Solomon I had a passion for electric propulsion and hybrid and alternate power production systems, as well as for sailing. It is important that publications such as yours present viable alternatives—not only because dwindling oil supplies and increasing fuel costs are becoming so "front page." My concern is that several of Solomon's fellow electric propulsion companies are missing an important point. If one wants a truly energy efficient and "green" system, simply running an electric motor by constantly running a diesel generator is not the answer. Heck, if I've got to start my diesel generator every time I want to move the boat, why not avoid all the added complexity of an alleged green boat and just use a diesel motor to power it directly?

Sure, there is some efficiency gain with the Whisperprop system. A diesel engine operates best under a load and at constant velocity. This describes a diesel generator. And an electric motor, but not a diesel, is happy running at any velocity and under varying loads. So it certainly makes better sense to use an electric motor for propulsion applications. But an important element is missing in such a simple system.

As a sailor I intend to do a lot of sailing. While I'm sailing along, wouldn't it be grand to convert a bit of that motion through the water into energy, which could be stored for later use? While sailing or sitting in a tropical anchorage with all that sun beating down on my boat, wouldn't it be nice to absorb some of that free energy with solar panels and store it for later use? With the gentle breezes blowing my wind generator, where am I to store that energy? And every time I want to move my boat with my quiet, odorless electric motors, I have to start that diesel generator. No, that's not my idea of an energy efficient, green boat. An electric-powered sailboat without batteries—where's the genius in that logic?

Yes, batteries are the real answer to a truly energy-efficient, green boat—especially when electric propulsion motors can function as generators of free electricity while the vessel is sailing. Perhaps this one point is the reason other electric marine propulsion manufacturers think so little of batteries; their motors can't regenerate. I still don't understand their logic though, when solar panels or wind generators can be installed. Then consider the case where their generator fails. All of a sudden the only source of power on the vessel is gone. You find yourself dead in the water with no hope of going anywhere. Of course you can put up your sails and sail back into the harbor and into



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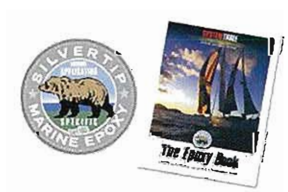

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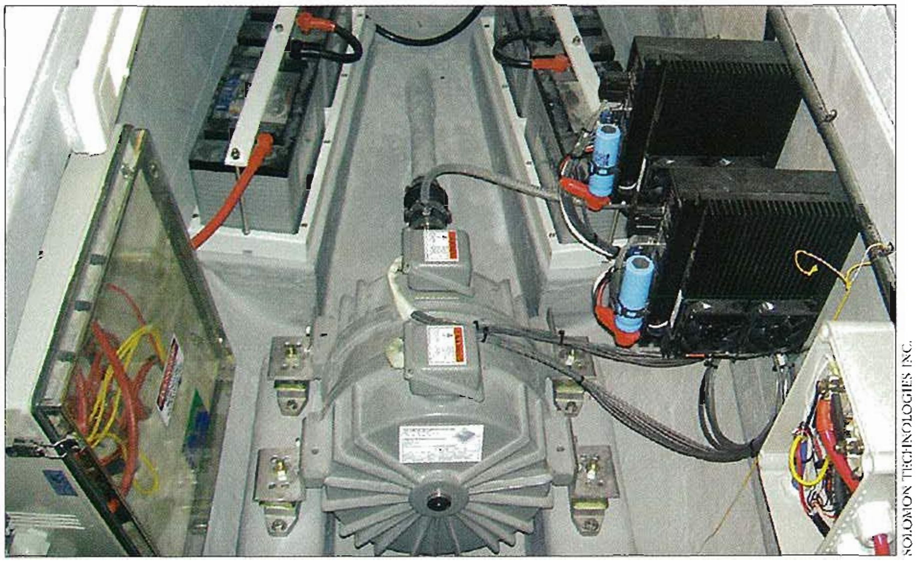


Solomon ST-74 motor in the engine compartment of a Manta 41 (12.5m) catamaran. The 12 batteries are split up, with four in each of the two engine compartments and four under the saloon seats, to allow flexible weight distribution.

your slip, if you're good enough at sailing. Makes you think that maybe a bank of batteries with a few hours of motoring energy stored in them could come in mighty handy at times.

As to questions of cost, weight, and maintenance raised by Icemaster, let's consider these. Take maintenance first. Battery technology has come a long way in recent years. We use absorbed glass mat batteries. They are shock resistant, since the glass mat prevents the lead plates from coming in contact with each other. They are sealed, so never need to be serviced, and can be mounted in nearly any orientation. Basically, as long as you keep them properly charged they require no maintenance. AGM batteries have the most forgiving charging requirements, so they are the easiest to maintain from that point of view as well. And, as far as maintenance on diesel engines compared to maintenance on electric motors, simply put: there is no maintenance on brushless electric motors.

Weight. Well, let's see. A Group-31 battery weighs 69 lbs [31.3 kg], and our system uses 12 batteries; so that's 828 lbs [375.6 kg]. A generic catamaran has two 30-hp [22.4-kW] diesel engines that weigh about 550 lbs [249.5 kg]; so two make 1,100 lbs [499 kg]. A Solomon ST-37 motor weighs 83 pounds [37.6 kg]; so two make 166 lbs [75.3 kg]. If we add the weight of the batteries and the weight of two electric motors, that's 994 lbs [450.9 kg]. Looks like the Solomon system, with batteries, weighs less than the diesel system. Oh, I didn't add in all the ancillary bits required on each of those diesels such as water hoses, strainers, exhaust, muffler, fuel pumps and filters, and the oil and antifreeze, because those weren't included in the dry weight of the engine. And for all that weight, it still doesn't give you any place to store energy. That's what batteries are for.

Now for cost. A set of 12 Group-31 batteries will cost about $3,000 (12 x $250). Those batteries should easily last four or five years—let's say four years of storage for all the free energy you will get from the sun, wind, and regenerative motors. Amortize that $3,000 over the four years, and you have a cost of about $14 per week for those batteries. So, if you spend $14 a week on diesel, you're even. However, if you spend more on fuel, you're money ahead. And if you are a cruiser/voyager and run a diesel generator constantly to power your "other" electric motors for, say, eight hours a day (which isn't really practical, since you'd most likely be running them constantly for several weeks during passages, but what the heck). Let's be forgiving and say you do this only a quarter of the time, so that's 90 days a year. That gives us 720 hours of operation per year (90 x 8) and 2,880 hours for the four years we say the batteries will last (720 x 4). Take that times the cost of diesel these days—what, about $2.75/gal—times a couple gallons per hour for some gensets; that's $15,840, which is more than five times what the batteries cost.

Others make claims that batteries are short-lived and that they pollute. Four to five years for a set of batteries doesn't seem short-lived to me. Especially since in four to five years there will certainly be newer, more efficient batteries available. That will be about the right time to upgrade to the newer technology. As to polluting, well, maybe I'm missing something here, but I don't believe batteries pollute at all unless you dispose of them improperly. If you do what's right and take them back to the shop where you get your next set, they'll simply recycle all the materials, as that's the most economical thing to do.

Since a battery bank doesn't weigh more than the diesel engines being removed, requires no maintenance, costs far less, has a reasonable life span, and doesn't pollute—what's the big problem? Especially when you consider that on a full charge a

Solomon-equipped boat can motor for several hours in nearly complete silence with no offensive odor. Our power-production system also provides for AC and DC house loads in complete silence. Not only can meals be cooked, but on many of our vessels, air-conditioning can be run all night without starting the generator. And if you take off the next morning under sail and have favorable winds, you'll have a fully charged battery bank by the time you anchor for the next night of generator-free air-conditioning.

At Solomon Technologies we aren't antigenerator. Quite the contrary. We feel strongly that nearly every vessel should be equipped with a properly sized generator for those times when sun and wind let you down. We certainly understand that battery power can last only so long. If you will be motoring for extended periods, the generator should definitely be run to provide ample power and to maintain a full charge on the battery pack, in case the generator develops a problem. But to rely on the generator for your sole source of power simply doesn't make sense.

The trouble is, Icemaster and other companies are crying sour grapes because they don't have regenerative motors and therefore feel they have no need for an electrical storage medium; or, because they don't understand regeneration and don't know how to control it. If they really had a green agenda, as Solomon clearly does, they would at least be promoting solar panels and batteries to store that energy; but because their motors use an antiquated technology, not only can't the motors regenerate, they are quite inefficient. Solomon permanent magnet motors are more than 95% efficient. Even after running the motors for many hours under full power, you can comfortably put your hand on the motor case. The large-diameter Solomon motors produce huge amounts of torque. A 40' [12.2m] catamaran, from dead stop, can reach full cruising speed in less than two boat lengths and then can come to a full stop in less than one boat length. Try doing that with a diesel, or with one of those other electric motors.

No, it's quite clear that an electric-powered sailboat needs a set of batteries to store all that free energy and be truly green.

Andy Christian
Director of Engineering
Solomon Technologies Inc.
Tarpon Springs, Florida

More on Wet Balsa Core

To the Editor:

On behalf of the boating industry generally, I want to thank you for publishing Rick Strand's article "Wet Balsa Core" (PBB No. 96, page 16), Bruce Pfund's article "Penetrations and Closeouts" (PBB No. 97, page 130), as well as his sidebar on Baltek

Gold and Greg Group's letter to the editor in that same issue. *Professional BoatBuilder* has always been outspoken in its advocacy of proper core installation. Bruce's maxim regarding core installation, "If you don't do it right, don't do it all," should always be kept in mind.

Wet core can be and has been avoided by many builders who use proper installation techniques, as Bruce illustrated in his recent article and many previous ones. Cored construction is not the issue. Proper cored construction has provided a lifetime of reliable service, as thousands of boats over the last 50 years can attest. However, core installed with an open kerf system and with poor closeouts, as Bruce detailed, can result in water accessing the core and being distributed by the kerf network. Our goal as a core supplier is not to deny that water can enter an improperly installed core, but to determine what the true ramifications are, if and when water does enter the core. Mr. Group's letter clearly illustrates the great concern about this subject among marine surveyors; and, as Rick points out, the purpose of his and our studies is to provide data to surveyors so they can make decisions and recommendations based on knowledge, not speculation. As Greg Group's letter clearly shows, there is a need to answer the many questions that plague marine surveyors.

The data clearly shows that:

Wet core in both balsa and foam can be and has been avoided by filling all the kerfs and by isolating the core from any cutouts or through-fittings. The increased popularity of vacuum infusion will go a long way toward achieving complete filling of all kerfs and voids in a cored laminate, making cored construction literally foolproof.

Wet balsa core in itself does not necessarily represent a structural problem. With only a 20% reduction in shear strength, the safety factor of laminate can be recalculated and in the vast majority of cases will still be within design specifications. Most laminate safety factors are in the 300% to 400% range, so a 20% reduction in shear properties falls well within these bounds.

Decay of wet core will be a potential problem only if oxygen is allowed to access the core. Inevitably, the oxygen enters the core at the same point as the water. Once the point of ingress of the water is determined and sealed, air (oxygen) will also be prevented from accessing the core, and future decay will be prevented.

Concerns about freeze/thaw cycles causing delaminations of wet cored laminates in either balsa or foam have been shown to be false for both a filled kerf system and filled "neverbonds."

As Rick pointed out, all this data has been presented to the annual general meetings of both the Society of Accredited Marine Surveyors and the National Association of Marine Surveyors. Both groups expressed their thanks for finally receiving accurate data that their members can use to guide their clients. They were pleased to replace speculation with facts.

Professional BoatBuilder is by far the best forum to distribute this data to the boating industry. As was pointed out, there are thousands of boats built with cored construction. The vast majority of them are the "good news" that doesn't get published. However, by finding accurate, definitive data on the properties of wet core, we can now better evaluate that 1% of the market that may present a problem. Wet core is invariably a symptom of poor installation practices. By knowing the facts about wet core, these boats can be evaluated and proper action taken. If caught soon enough, these boats, too, will provide a lifetime of service.

Rob Mazza
Structural Core Product Manager
Alcan Baltek Corporation
Northvale, New Jersey

To the Editor:

Rick Strand's article "Wet Balsa Core" offends many of my sensibilities, but as a naval architect and structural engineer I'll address only the author's errors and omissions. The impact of core defects—whether they are delamination, poorer material properties, decay, etc.—was not treated properly. In addition, some of the basic tenets of cored marine structural design were misrepresented or just plain neglected.

Composite marine structures are, in general, deflection limited and not strength limited. This is the main motivation for using a cored structure to begin with—to increase stiffness without a significant weight penalty. Fiberglass has good strength properties but is a relatively flexible (i.e., not stiff) material.

Addressing the author's assertion that stiffness is a function of thickness cubed: While the thickness-cubed function is true for noncored material like aluminum or steel or even the fiberglass skin itself, it is not true for a cored structure. In a cored structure, stiffness is a function of the square of the distance between the neutral axes of the skins—i.e., the square of the sum of core thickness plus half of each skin. The core *must* function to keep the skins separated relative to each other and *must* keep the skins from moving relative to each other. If these conditions are not met, then you only have two thin skins with a large amount of inherent flexibility.

While in a simple sense the statement that shear strength drives the design is true, the author has neglected the deeper and more complicated interactions of a cored structure. Compressive modulus (the amount of squeeze under load) is very important to the contribution of the core to the stiffness of the structure. Also neglected in the simple explanation is the fact that shear modulus too (the amount of shear deflection per load) is important to the stiffness of the panel. Shear modulus is a measure of how fixed the skins are relative to each other. The shear deflection contribution to deflection can be significantly larger than the basic beam deflection. In deflection-critical marine structures, in agreement with David Jones' letter to the editor (PBB No. 98), I would argue that the "distant" second and third factors play a larger part in meeting design requirements than alluded to in the article.

With regard to the nature of the design process, I'll address the author's statement that the factor of safety can be relied upon to "save" a structure. ("Now, a 20% loss in shear strength may not have much of an impact on the performance of a sandwich structure, depending on the safety factors used in the design process.") Factors of safety do not currently include a 20% allowance for loss of shear strength due to moisture in the core. By the author's own statement, these structures are critical in shear strength. Therefore, they are typically designed so that they fail in core shear first. Thus, it would appear that the damaged structure (with its 20% loss in shear strength) no longer has the required factor of safety. Consequently, from a design standpoint, this structure has failed; it no longer meets the requirements of the original design, and must be repaired.

As a final technical note, I do not know the design requirements for trees with 94% moisture content, but I do know the design requirements for boats. Based on the data presented by the author, I doubt that damaged, wet, frozen, or decayed cores will meet the original design requirements for boats.

If we examine the customer's expectations (remember the individual who is paying hundreds of thousands of dollars for this boat), I am sure his expectation is that the boat is designed and constructed to some reasonable level of quality. This level of quality does not include high levels of moisture in the core. There is an expected level of performance (be it speed for a given weight and power or structural integrity or level of safety) that will be unobtainable if water is allowed to collect and stay within the core.

Since the degraded core is unlikely to meet the original design requirements, I expect that once it is discovered, the resale value of the boat in question will be severely affected in a negative way. At this point, as Mr. Group correctly observes in his letter to the editor in PBB No. 97, we are no longer talking about technical merits but public perception. A structure that is left in a flexible and degraded state, which will only worsen with time, will not reflect well on the builder, the broker, the surveyor, or the industry as a whole. The proper course of action is proper installation of core and all associated fittings from the outset, as stated by Mr. Strand in his "Parting Shot" essay in PBB No. 82. Short of this, a proper and effective repair is needed to protect the value of the boat and to maintain a boat in a seaworthy, safe, and survivable structural state for the protection of the people on board.

Dean Schleicher, PE
Technical Director
Donald L. Blount and Associates Inc.
Chesapeake, Virginia

Rick Strand responds:

While I welcome Mr. Schleicher's comments, I would appreciate him reading more carefully and testing some of his academic nitpicks before labeling them "errors and omissions." Yes, both the shear and compressive properties of a core material do factor into its strength and stiffness. But, by how much? If Mr. Schleicher tested his own espousals he would find the following. In a 9-lb [144 kg/m^3] balsa-cored sandwich with average glass skin/core thickness ratios, the total panel deflection that could be attributed to core shear deformation accounts for about 1/20 of the total panel deflection. Any additional deflection that might occur when that core gets wet is miniscule. This is a fact.

If we were discussing wet foam, the shear deformation component would become more important, because of foam's significantly lower shear modulus and its larger loss when wet (in the same density range). That's also true for foam's much lower compressive modulus. The application of compressive modulus is most significant when calculating the critical buckling stress of relatively thin facings. The flatwise tensile properties of the facing-to-core bond are perhaps more important, since they will dictate when the facing (as an unstable column) can free itself from the core, and buckle. Again, if you run the numbers, then you would see there is little threat of either situation contributing to panel failure before a shear-strength-dominated core failure occurs.

To clarify, the conclusions in the article are specific to 9-lb density balsa and relevant to the laminate configurations evaluated for Sea Ray Boats. The company's designs use both moderately thick facings and cores. Sea Ray's construction is conservative. Design factors of safety there were high to begin with, so a 20% loss in shear strength did not reduce the panels to the point where there was any concern over their longevity.

One more time: All wet core situations need proper evaluation before an intelligent judgment of the vessel's state—and a sound repair plan—can be rendered. This requires both computational and laboratory evaluation. Not all wet core needs gross invasive reconstruction; and by the way, design safety factors are not universal. They depend on many variables, including vessel use as well as construction material types, methods, and quality level. Most of all, the proper selection of those safety factors depends on an experienced engineer's knowledge and judgment, along with a professionally executed validation test program.

Rovings: Folkboats—in Glass

To the Editor:

Regarding the "Rovings" item about FRP Folkboats (PBB No. 96, page 8), I'd like to offer a few thoughts.

Erik Andreasen is regarded as the father of the plastic Folkboat, and it is true that he has built most of them. However, there is another aspect that may interest your readers:

In 1975 Svend Svendsen, an avid Folkboat racer in the San Francisco Bay fleet and a boatyard owner, built a mold from a proven fast wooden hull (US 95 *Folksong*, a Boerresen-built boat). That mold was used to build the first-ever FRP Folkboat, *Pokkers Karl*, featuring a white deck and flaming red hull. In 1976 Erik Andreasen in Denmark followed suit and managed to get fiberglass boats approved by the Scandinavian Sailing Association, which still governs the class. What sounds like an anachronism—building a clinker boat in fiberglass—may well have saved the Folkboat's life by helping reverse the trend of dwindling participation in events. An important reason for newfound prosperity was that fiberglass did not sail faster than wood; it just required less elbow grease for maintenance.

Last September the SF Bay fleet hosted the International Cup, the largest Folkboat race outside Europe, with a dozen fiberglass boats built by Svendsen, half a dozen wooden boats, and only four boats built by Folkboat Centralen.

Dieter Loibner
Oakland, California
Author, *The Folkboat Story*
(Sheridan House, 2002)

PBB

Corrections

In the Rovings item "Awlbrite Quik-Fil Clear," PBB No. 98, page 17, an incorrect address was given. The correct address is Awlgrip North America, 1 East Water St., Waukegan, IL 60085 USA, tel. 847–599–6212.

In the same issue, reader Nick Parkyn points out that in "Steering System Fundamentals," on page 87 in the Foil-Thickness Form Dimensions table, the half-breadth at 5.00% chord for the "Intermediate"-section rudder should be 1.338 (not 0.133). Also, the author, Dave Gerr, writes that at the top of page 82, the metric rudder dimension should read $0.442m^2$ (not $44.25m^2$).

We apologize for the errors—*Ed.*

ROVINGS

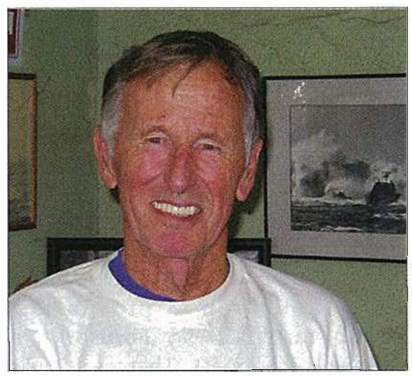
Compiled by Dan Spurr

Bob Stapp's Seaway Boats

"A boat is nothing more than a platform to fish from," says Bob Stapp, a longtime southern California boatbuilder and fly fisherman.

As Seaway Boats' founder and owner, Stapp has been building those and other "platforms" for almost 50 years. Since starting Seaway in 1958, Stapp has put into service more than 160 glass-over-ply custom and semicustom boats, ranging in size from 16′ to 60′ (4.9m to 18.3m).

Stapp built his first boat at the age of 14, in 1945, from a set of plans published in *Popular Science* magazine. It was a 12′ (3.7m) runabout, done entirely by hand (no power tools). At 17 he built a three-plank dory out of Port Orford cedar, and installed a 3-hp (2.2-kW) gas inboard with no gearbox. He kept that for three or four years, and then decided to build himself a 16′ plywood skiff. Before the first one was finished, someone came along and bought it. Stapp built four of those—each of them purchased before he could finish one for himself.



DON ELMS (ALL)

Top and above left—*A recent Seaway build was this 40′ (12.2m) cruising boat, using Stapp's proven construction methods. It's powered by twin 330-hp (246-kW) 5.9 BT Cummins diesels, and tops out at 28 knots.* ***Above right***—*Bob Stapp founded Seaway Boats in Long Beach, California, nearly 50 years ago. Now, after delivering more than 160 durable glass-over-ply vessels, many to municipal agencies along the California coast, he'd like to sell the company and go fly-fishing.*

Stapp did some commercial fishing early on, attended El Camino College, and later worked for Jeffries Boat Co., in Venice, for about six months. At the time, Ted Elliot—himself a glass-over-ply expert—was foreman at Jeffries. Then Stapp set up Seaway and commenced building 16′ lobster skiffs and 26′–30′ (7.m–9.1m) gillnetters, along with other workboats and runabouts up to about 30′.

More recently, Seaway Boats has come to be known for its lifeguard, fire department, rescue, and harbor patrol craft. The first of these was a 30′ lifeguard boat for the Los Angeles City Lifeguards, in 1973, followed by more 30′ and 32′ (9.8m) "Baywatch"-type boats for the Los Angeles County Lifeguards, including one home-ported on Catalina Island off the southern California coast. Thirty-two years later, that boat is still in service.

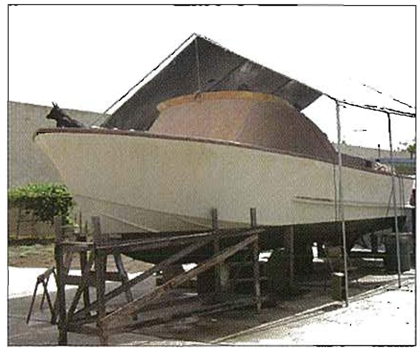
Over the years, Seaway has built boats for coastal California municipalities from San Diego north to Ventura. Most are still in service. In Newport Beach, the Orange County Sheriffs have nine Seaway Boats in harbor patrol and rescue service. The oldest is 35′ (10.7m), built in 1982, and the newest a single-I/O 24′ (7.3m) patrol boat completed just last year. As this is written, Seaway is in the process of building a 31-footer (9.4m) for that department. According to the department's Bob Scott, "Seaway builds a great workboat that is very seakindly. Ours have been through the most extreme sea conditions we get here in southern California. We've been out in 10′–15′ [4m–4.6m] seas making rescues, and every single boat's come back!" Seaway also built a number of party boats: passengers-for-hire fishing boats, ranging from 67′ to 80′ (20.4m to 24.4m). Those continue in commercial service as well.

Early on, Stapp devised a reusable jig for adjusting lengths and beams of his own designs. With no formal education in naval architecture, Stapp has used standard conic projections to develop his designs. He would decide on the size and shape of the hull based on the relationship of the chines and keel. Initially he laminated his stems and keels out of layers of fir and plywood, in a jig. But

Stapp soon learned that the fir would expand faster than the plywood, which stressed the Weldwood plastic-resin glue joints. So he converted to all-plywood laminated keels and stems, and switched to resorcinol glue. That solved the problem, and has continued with much success ever since. Elsewhere in the boat, Stapp employs WEST System epoxy as an adhesive, and for coating all wood surfaces. Sheathing is 7.5-oz (254 g/m²) fiberglass boat cloth: two layers laid simultaneously on bottoms, topsides, and decks, with a single layer on cabins and bridges.

A jig that Stapp devised to bore the shaft hole, involving a length of piano wire to center the hole, has given him spot-on shaft and strut alignments. In 1970 he switched from bronze shaft logs to fiberglass shaft tubes, which are heavily glassed into the hull. He says that was a significant improvement. He also made his own patterns for struts and rudders, which he had sand-cast in bronze.

Right—*In preparation for retirement, Stapp recently bought back one of the West Coast lobsterboats he built for a client years ago.*
Below—*Stapp devised his own setup for scarfing sheets of plywood. Panels are held down on the aluminum plate shown, by suction from a shop vacuum. The head from a joiner is belt-driven by a 3-hp motor, and is fully adjustable. An attached leaf blower clears away shavings.*



DON ELMS (BOTH)

The need to fashion continuous pieces of plywood for bottoms and topsides necessitated a way to scarf individual pieces of panels together. The crew used to stack up four sheets of plywood, one on top of the other, staggered, so that at the ends the stack looked like a set of stairs. Then they'd carefully plane the proper angle with a portable power plane, keeping the plane as close to that angle as possible. But it was time-consuming and less than precise. Boat production was too easily halted, waiting on the planing and gluing process. So, necessity being the mother of invention, Stapp came up with a better, faster, more accurate cutting system—based on a custom-built planer (see photo). With a shop vacuum generating suction through holes in the aluminum plating, the plywood panels are sucked down onto the table and held there. The action end of this rig is the head from a joiner, belt-driven by a 3-hp motor. It is adjustable for the given scarf. A leaf blower has been cleverly clamped in position to blow away shavings as the cut progresses. The whole operation takes just two passes in about five minutes—less than half the time of the freehand method. The angle is accurate, the cut flat, and, it is infinitely repeatable.

Next, Stapp needed to speed up and increase the accuracy of gluing the scarfed panels together. So he welded a steel clamping device to hold the panel joint together while the glue cured. Utilizing heater strips sandwiched in place by aluminum plates, and 20 psi (0.14 Nmm²) of air pressure as a clamping force, the fixture will reach 160°F (71°C) and complete a glue joint in 20–30 minutes. With that, Stapp can complete 12 to 15 scarf joints a day and make continuous sheets of plywood to any length required. Through the grapevine, local plywood distributors learned about Stapp's jig and clamping method for making scarf joints. So when Stapp isn't making scarfed plywood panels for his own use, he makes them up for the distributors and their customers.

For patrol and rescue boats, typically built with an open transom or a transom door, Stapp developed a unique reverse-cambered cockpit deck. Slightly concave, particularly at the outboard edges, it evacuates water through the door much more rapidly than traditional open-style sterns when pulling a swimmer out of the water in rough seas or in a surf rescue.

"There has been a noticeable decline in the quality of domestic marine plywood," Stapp says. He prefers seven-ply ⅝" (16mm) and ¾" (19mm) material; ⅜" (9.5mm) and ½" (12mm) stock is five-ply. And, it's ever harder to find. A typical Seaway will have a 1¼" (32mm) double-diagonal bottom laminated from two layers of ⅝" marine ply, while the topsides will be ¾", made from two layers of double-diagonal ⅜" panels. He also notes that it's getting harder to obtain straight Douglas-fir in long lengths; on the positive side, though, Stapp said he's still able to secure Philippine mahogany in up to 18' (5.5m) lengths. Because Stapp believes in the critical importance of hull strength, he concedes he may be guilty of overbuilding. But that's one reason so many Seaway Boats are still in service.

Although most of Seaway's output has been powerboats, the shop did build one 34′ (10.4m) racing sailboat, and a 24′ (7.3m) pollution-control barge. How does Stapp set a price for a given boat? He favors his own time-tested formula: one-third is the cost of materials, and two-thirds is the cost of labor. That, he says, will be "pretty close."

Despite so many years of boatbuilding, Stapp is still wiry and agile at the age of 74. Even so, he says he'd like to sell the business and go fly-fishing. A few more lifeguard boat orders are being dangled in front of him; he may be hard-pressed to put down his power plane just yet. But the fish are calling and he'd like to retire. Stapp says that, while he's stepping aside, "there are no secrets"; he's willing to share his extensive experience with a new owner.

Stapp recently bought back one of the 16′ (4.9m) lobsterboats he'd delivered in 1984. That boat, like his other fishing boats, was built to be expendable, but has stood the test of time. A little cosmetic touch-up is all that's needed, and Stapp will soon be out presenting flies from one of his iconic Seaway "platforms."

Seaway Boat Co., 1528 W. 14th St., Long Beach, CA 90813 USA, tel. 562–436–3831.

—Don Elms

Eternal Nav Lights

After several months of strenuous testing on board some racing and fishing boats, the French firm Mantagua has decided to market a complete range of replacement LED bulbs for navigation lights. For the same level of efficiency, LED replacement lamps draw one-tenth the amperes of conventional bulbs—between 60 mA and 150 mA—with a life expectancy of more than 50,000 hours. They are also highly resistant to vibrations.

JEAN-YVES POIRIER

Mantagua replacement LED bulbs are compatible with most navigation lights on the international market, such as this red-green nav light.

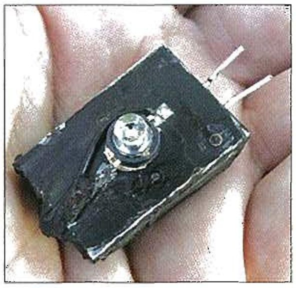
Mantagua's lamps are available in various configurations for navigation, anchoring, and other applications. Depending on the type of light—be it all-round, tricolor, bicolor, stern, or side—the covering angle varies from 112.5° to 360°. Manufacturing quality appears to be quite good, with corrosion-resistant circuit boards and a high level of finish.

A 10-watt replacement lamp compatible with interior halogen light fixtures is now in production. It draws just 150 mA, much less than the 1 amp gulped by a conventional halogen bulb.

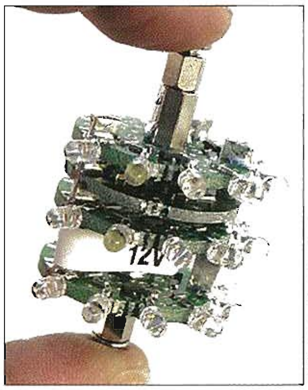
Prices range from €45 to €75, depending on the model.

Mantagua, BP 14, 56660 Saint Jean Brevelay, France, tel. and fax 02 97 60 45 96, on the Web at www.mantagua.fr.

—Jean-Yves Poirier



Above—A prototype 150-mA LED bulb that replaces 1-amp halogen bulbs: the unit is now in production.
Above right—*LED bulbs have extremely low current draw (between 60 and 150 mA), an expected life span of more than 50,000 hours, and excellent resistance to vibrations.*
Right—*Mantagua's LED bulbs are available in various configurations, such as this tricolor.*



JEAN-YVES POIRIER (ALL)

Laser Scanning at US Marine

Here's the problem: As a fiberglass part cures, it shrinks. Steven Boze, concept designer at US Marine (Arlington, Washington), builder of Bayliner, Maxum, and Trophy brands, says shrinkage of 5mm–10mm ($\frac{1}{4}$"–$\frac{13}{32}$") is not uncommon. Boze should know; he's been the company's master plug maker for 14 years.

Like a growing number of boatbuilders, US Marine, a member of the Brunswick Boat Group, employs CAD software—specifically, UG NX—to more accurately model hulls and decks, from concept drawing on the computer to CNC plug cutting. Builders rely on the absolute accuracy of CAD files to assemble the various parts; for example, joining hull and deck, outsourcing modular interior components, and installing equipment such as an engine or steering gear. But, if the hull or deck changes its shape or dimensions between the mold shop and the assembly floor, then of course parts will not fit as anticipated, causing problems and delays. If someone can accurately measure the amount of shrinkage, and modify the tooling to allow for it, then such problems should be eliminated or certainly minimized.

Enter laser scanning, a technology developed to map 3D objects, the data from which can be converted into CAD files. A Massachusetts-based consulting firm called Spar Point Research is documenting the benefits of laser scanning in a number of industries, including marine. According to Spar Point senior analyst Tom Greaves, "Determining exactly how much shrinkage to allow is part of the art of mold design. Laser scanning is bringing engineering discipline to this art. In addition, laser scanning allows the concept design team to reverse-engineer modifications that may be made to early-stage physical prototypes. When the team is satisfied with a layout, they can scan the modified tooling and get the modifications back into the master design model."

Steve Boze: "We're striving to use a digital master model from concept design all the way to customer service." The benefits, he says, go beyond measuring and allowing for shrinkage. If the geometry of subassemblies and equipment is not known, then parts may not fit together or install as required.

Greaves describes how Boze's shop is collecting data: "Boze's crew operates a Trimble GS200 laser scanner purchased from Digital Technologies [Seattle, Washington] to scan plugs, molds, and finished hulls as well as equipment to be installed. Bob Francis, president of Digital Technologies, was part of the group that evaluated reverse-engineering technologies for US Marine.

"The point-cloud data," says Greaves, "is captured with PointScape—the operating software for GS200—then processed with Trimble's RealWorksSurvey application, then exported to UGS's Imageware application, where it is processed in order to be read into UG NX. Once the processed point-cloud data is inside UG NX, then offset analysis against the original design model can be performed on a selective, as-required basis. Typically, data sets range from hundreds of thousands of points to millions of points, which Boze says give him the necessary density."

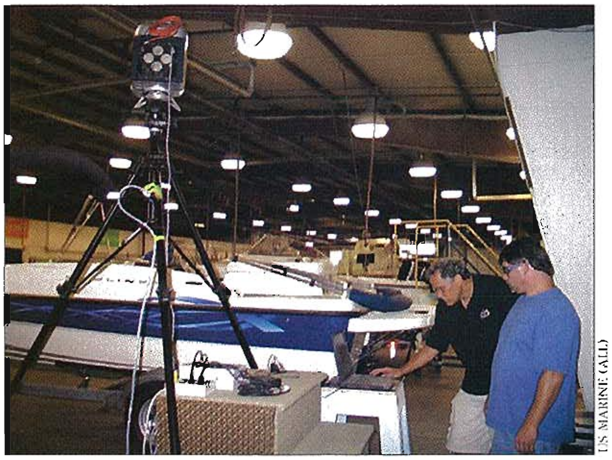
But, as with the adoption of any new technology, there's a learning curve. Plus, Boze sees ways in which laser scanning could be improved, at least for his operation. Greaves elaborates: "He'd like to see scanners improve their ability to capture surfaces that are both black and glossy. The current workaround is to coat or spray the surfaces to be scanned to conform reflectivity to the scanner capabilities."

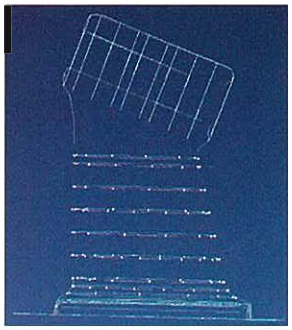
And Boze has another suggestion: "It would be useful to be able to capture data at ranges shorter than 3m [9.8'] in order to set up inside the molds."

Greaves continues: "Registering scan data with the original CAD model is more difficult and less straightforward than Boze believes it should be. He expects this process to get better as his crew becomes more experienced. Part of the solution lies in enhancing UG NX's ability to manipulate point-cloud data directly. Boze says he's a big fan of UG NX—its intuitive user interface makes it his favorite CAD tool; and he expects the point-cloud capabilities to improve in time. He'd like to see Imageware functionality embedded inside UG NX to eliminate one import/export step.

"As part of the procurement process," adds Greaves, "the US Marine team evaluated Rhino from Robert McNeel & Associates [Seattle], as well as Geomagic from Raindrop Geomagic [Research Triangle Park, North Carolina]. The tight integration of Imageware with UG NX gave the nod to Imageware."

Greaves cites another case history, involving a Marathon





***Top**—At one of US Marine's production plants, longtime tool builder Steve Boze, left, and John Nagg begin digitally scanning the hull and deck of a Bayliner 197 (18'7"/5.7m). By measuring shrinkage, the technology guides precise adjustments to the tooling to ensure better-fitting parts. **Above**—At right are construction curves for a Cutless-bearing strut. The "point cloud" was thinned by a factor of 20 in Imageware software to allow it to be imported into a UG NX program. At left, the scanned (orange) model generated from the construction curves has been superimposed over the original green, slightly smaller CAD model of the strut for comparison. Viewed separately, Boze says they would appear visually identical. Of importance, he says, is the difference in centers of the two parts, not apparent in this drawing.*

Petroleum multipurpose shuttle tanker. When the owners decided to reconfigure the 827′ (352m) ship for service as a floating production, storage, and offloading vessel, laser scanning was employed to determine interferences between the existing upper deck structure and piping, and new topsides modules. Though only four years old, the *Alvheim* was not built with 3D CAD, so to collect the necessary data for CAD manipulation, a two-man team from Capnor AS (Stavenger, Norway; Krakow, Poland; Houston, Texas) spent 11 days laser scanning the ship's upper deck. According to Greaves, "The model information helped determine what piping would be demolished and where to put in reserve volumes for the new equipment. All of this had to be completed before sending the ship to a yard in Singapore for the actual modifications. Applying topsides clash-controls methodology to the scanning-based 3D model revealed significant piping conflicts. Since these were found early in the design process, they were easy to fix, saving major late field-modifications, which are costly."

To learn more about laser scanning, one can attend SPAR 2006: Capturing and Documenting Existing-Conditions Data for Design, Construction, and Operations, scheduled for March 27–28 at the Sugar Land Marriott Town Square, Sugar Land (Houston), Texas. Greaves says it's the only conference focused on the business and technology of advanced 3D laser scanning.

Finally, note that *Professional BoatBuilder* has covered laser technology in the large-scale repair of a catastrophically damaged *America's* Cup raceboat (PBB No. 65, page 66); in the measurement system at a tooling shop (PBB No. 66, page 113); and in the digital capture of hulls and small parts at bassboat manufacturer Ranger Boats (PBB No. 78, page 94).

Digital Technologies Inc., 2305 Ashland St., Ashland, OR 97520 USA, tel. and fax 800–350–7810, on the Web at www.dtinc.net. Spar Point Research, 85 Constitution Lane, Suite 2E, Danvers, MA 01923–3630 USA, tel. 978–774–1102, fax 978–774–4841, on the Web at www.sparllc.com.

Good News, Bad News

Last fall there was good news and bad news coming out of Westport Shipyard, builder of 112'/34m and 130'/40m motoryachts (a 164'/50m trideck is in the works). Some background: J. Orin Edson became majority owner after selling Bayliner to Brunswick Corporation in 1986; Westport currently employs nearly 800 people at manufacturing facilities in Westport, Hoquiam, and Port Angeles, Washington.

Touting its "good family wages and a healthy array of benefits and performance bonuses," Westport has partnered with two local colleges to develop courses in marine and finish carpentry, and electronics technology. Those schools are Grays Harbor College, in Aberdeen, and Centralia College, in Centralia. Also involved in that educational partnership is the Pacific Mountain Workforce Development Council, which received funding from the state to help businesses attract and educate the staff necessary for Westport to grow and excel. In addition, PMWDC is working with Westport to develop a composites-training DVD for on-site instruction. Westport says the evening classes "will provide students with the necessary skills to land a job at Westport Shipyard."

As many other builders are finding, there is a growing need for people skilled in the various fields of marine manufacturing. And the skill sets are now sufficiently complex and sophisticated that on-the-job training by a shop supervisor is not always realistic, or even desirable. That's why a cross-section of the nation's marine industry gathered last winter in Fort Lauderdale, at the summit called COMITT (for "conference on marine industry technical training"), to count, review, and assess individual programs such as Westport's. Last year Westport hired 278 employees in production alone, plus more people for other departments.

On a less optimistic note, former vice-president and minority stockholder Larry Nelson filed suit last July seeking to dissolve the company. According to local newspaper reports, Nelson says he was fired for health-related reasons. The company's attorney denies that; rather, Nelson was let go "because he was unable or unwilling to row in the same direction as the rest of the management team." A superior court judge later dismissed the portion of Nelson's lawsuit that sought to dissolve the company, and let stand Nelson's claim that his rights as a shareholder were violated. The newspaper stated further that Nelson's suit is directed primarily at Edson, who owns about 96% of the company. Attorneys hesitated to guess when the case might ultimately come to trial.

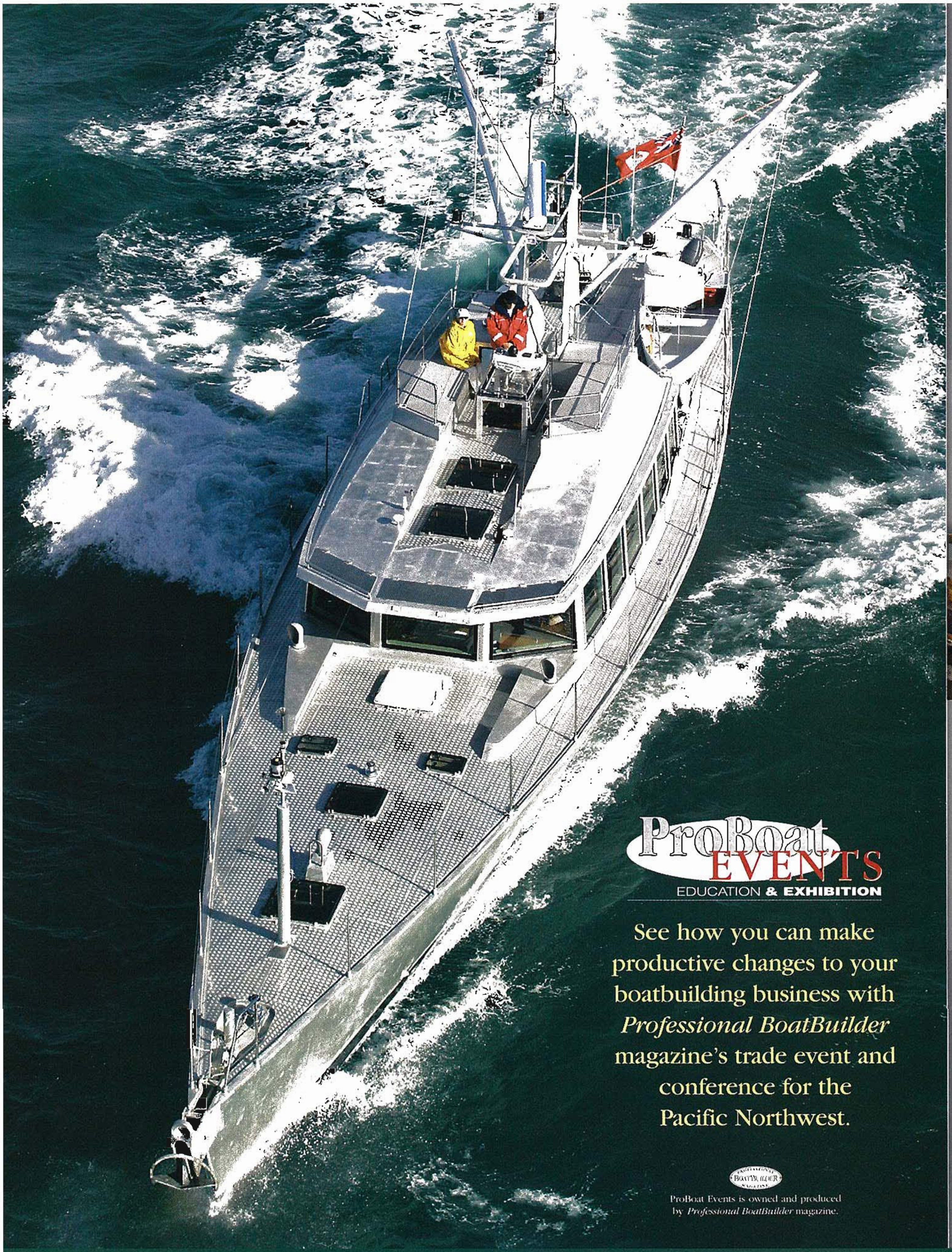
Westport Shipyard builds 10 boats a year, lists $33 million in equity, $14 million in working capital, and minimal debt. Small wonder it can pay "family wages."

Short-Range Boat-Moving Rig

SEA-LIFT

An alternative to operating a Travelift-type marine hoist in dedicated wells, the Sea-Lift is a self-propelled, hydraulic lift trailer that marinas and yards are finding makes easy work of launchings and haulouts at boat ramps. Its 5-mph speed also facilitates efficient ground transport between sites, such as virtually adjacent yards in Anacortes, Washington. The city of Clinton, Iowa, recently purchased a 32-ton capacity Sea-Lift for its 100-slip marina. John Skornia of J&E Marine, the marina operator, says, "Instead of double-handling the boats with our older equipment, we can haul, transport, and block the boat up in one operation with our Sea-Lift. Plus, we can store at least 30 percent more boats now." The trailers support boats on low-pressure air bunks. A larger trailer can handle loads to 60 tons. Both the 32- and 60-ton lifts are powered by Cummins diesels. Sea-Lift, 6059 Guide Meridian Rd., Bellingham, WA 98226 USA, tel. 800-509-3302, on the Web at www.sea-lift.com.

PBB



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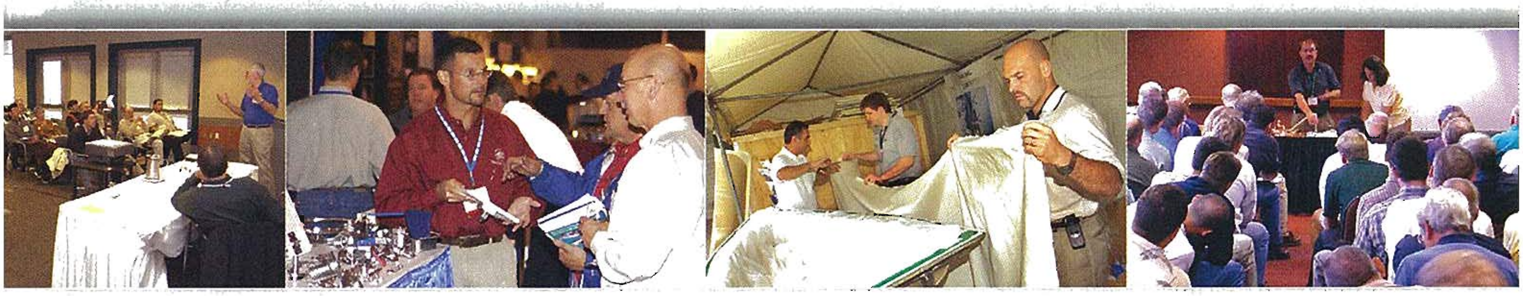

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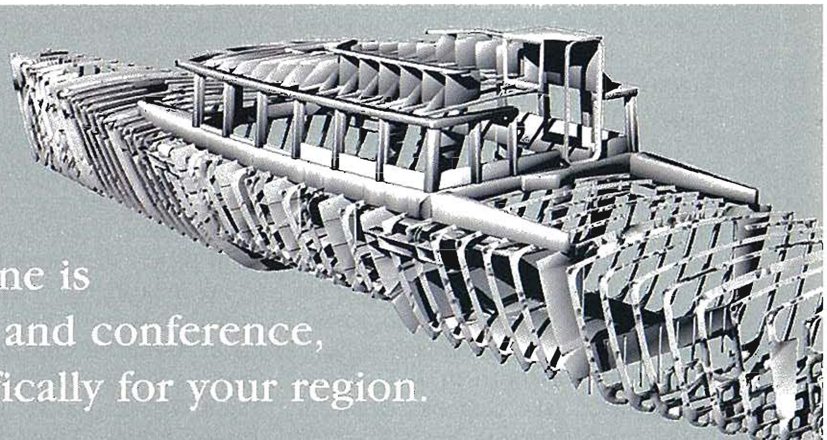


Boat builders, designers, repairers, surveyors, and marina/boatyard operators in the Pacific Northwest:

Professional BoatBuilder magazine is presenting a regional trade event and conference, formerly known as IBEX U, specifically for your region.

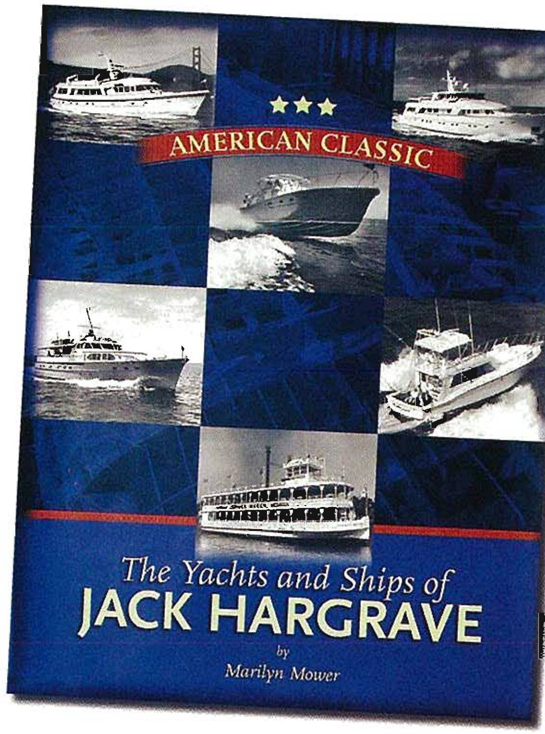
Photos courtesy of Dashew Offshore

www.ProBoatEvents.com

WORTHWHILE READING

Hargrave Gets His Due

by Dan Spurr



Unless you're very young or have zero interest in yacht design, Jack Hargrave's name should ring a bell. His achievements include: 38 years as one of America's preeminent motoryacht designers, 300 designs, more than 7,000 boats and ships built by 65 yards in 21 countries, and design of the Hatteras 41—the first large, series-built fiberglass powerboat. (Are those hall-of-fame numbers, or what?) The first "Hat" was introduced in 1960, and in the years that followed, the shooting star over Hatteras also scribed the arc of Jack Hargrave's career. Though he went on to design many custom yachts, for a lot of people his legacy is most visible through the lens of Hatteras.

A newly published biography will be a rewarding read for anyone interested in yacht design, especially motoryacht design. *American Classic: The Yachts and Ships of Jack Hargrave* was written by Marilyn Mower, former executive editor of *ShowBoats International* magazine, and something of an expert on the design of large yachts. She finished what Michael Joyce started. Joyce, a yacht broker, was a great admirer of Hargrave. He bought the J.B. Hargrave design office in Palm Beach, Florida, after Hargrave's death, in 1996. The book Joyce was working on languished, and, feeling an urgency to have it completed before Hargrave's contemporaries too expired, he turned the project over to Mower and graphic designer Darcey McNiff Thompson, both of whom have done Jack right.

Hargrave was born in 1922 in the settlement of Lake Gogebic, in Michigan's Upper Peninsula. He was skilled as an artist and a musician. As a kid, he sold his paintings for a penny apiece, and as a teen he organized a local orchestra, adapting musical pieces to the instruments available.

Boats were part of the Hargrave family life. While still an adolescent, Jack helped his father deliver boats on Lake Superior and Lake Michigan. When Jack was 16 his father enrolled him in a 10-lesson navigation course offered by *Motor Boating* magazine. Soon after, he obtained a U.S. Coast Guard captain's license, and over the next several years found employment as a professional skipper.

In 1941 he matriculated at St. Olaf College in Northfield, Minnesota, where he met his future wife, Janet Hobbett. During World War II he served in the merchant marine (the U.S. Navy wouldn't take him because he'd lost an eye in a childhood accident), after which, on return to the Great Lakes, he bought his one and only yacht, a 40′ (12.2m) Lawley motor cruiser, which he ran as a charter fishing boat out of Duluth. He also crewed on a number of racing sailboats, one year logging 12,000 miles on the 72′ (22m) staysail schooner *Ben Bow*. Eventually, Jack and Janet's travels took them to Florida, working on a yacht. Their first child, Susan, was born there in 1949. And there, in West Palm Beach, they settled.

Still in search of a career, or at least one that wouldn't require frequent travel, Hargrave enrolled in what was then called the Westlawn School of Yacht Design, run by founder Gerald Taylor White. The correspondence program required a two- to three-year commitment, with one assignment not being sent to the student until the previous one was completed. Anxious to get on with it, Hargrave persuaded White to send him the entire program (paperwork and texts), which Hargrave completed in just seven months—a record at the time, and perhaps evermore. For his final exam, he submitted a boat he'd designed before starting the course. (That's not a knock on Westlawn; rather, recognition of Hargrave's self-determination and keen intelligence.) For a few years he supported his family by selling paintings ($150 each), building a few boats, and organizing charters to the Bahamas. But his life still required focus, and that came to him in 1956 when he went to work for Rybovich and Sons in West Palm Beach, an emerging design/build yard and already an acknowledged pioneer in the development of the modern sportfishing boat.

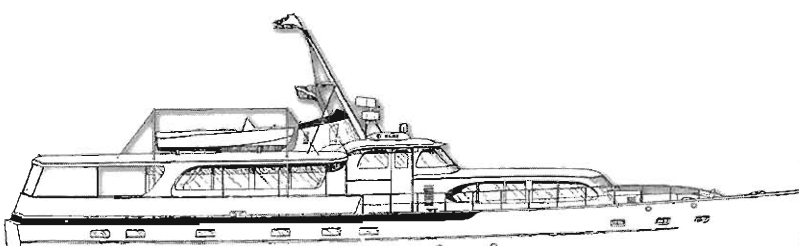
He was assigned to the design office, apprenticing under Tommy Rybovich. Within a year, he'd been noticed by Rybovich customer Charlie Johnson, a wealthy car dealer and avid yachtsman. Recognizing Hargrave's talent, and believing, as Mower points out, that the young man was "underutilized," Johnson commissioned Hargrave to design a large steel motoryacht. Mower writes, "Although he had never designed a steel boat, Hargrave operated on the philosophy of take the job first and then find out how to do it." The result was the 89′ (27m) *Seven Seas*, very much a megayacht at the time, and ably built by the Burger Boat Company in Manitowoc, Wisconsin. Another commission from a second Rybovich customer for a 70-footer (21m) prompted Hargrave to leave his job at Rybovich and open his own office in Palm Beach. The second frontispiece of Mower's book is an impressive black-and-white photograph of *Seven Seas* running powerfully, her widely flared bow looming over the camera lens. The next photo spread shows her awkward sideways launch, and another photo shows builder Henry Burger, owner Charles F. Johnson, and young Hargrave—hands in pockets, bow tie perfectly horizontal, standing ramrod-straight on the dock, his flattop haircut making him look like the no-nonsense guy he certainly was.

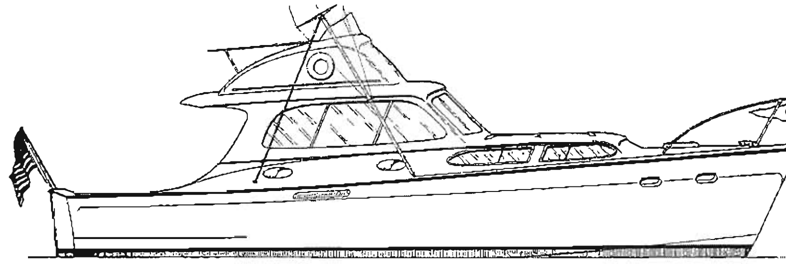
Fame and a modest fortune, however, still awaited. Both arrived at his studio door in the person of argyle-sock maker Willis Slane, of High Point, North Carolina. How Slane came to build the first large fiberglass powerboat is a widely told tale, and probably considerably embellished, but just in case you missed it: Slane and some of his buddies—members of the Hatteras Marlin Club—were sitting around drinking one day when bad weather kept them from fishing. Their skippers were afraid to take the small wooden boats out. Boating journalist Pete Smyth told what happened next. "Slane pounded on the table and said, 'I'm damned tired of these chickenshit captains who won't go out, telling me their boats won't make it.' Slane threw a check for $5,000 on the table and said, 'Let's build some boats that *will* go out!'" This isn't quite the way Mower tells it, discrete as she is (and no doubt more thorough), but the truth is probably somewhere between—or not.

In any event, Slane was introduced to Tony Gibb and George Irvine at Owens-Corning Fiberglas; early fiberglass boat builder Don Mucklow; and eventually to Jack Hargrave. The result (with a consultation from Gibbs & Cox, the naval architecture firm that wrote the first manual for fiberglass construction, at the behest of OCF) was the 41′ (12.5m) sportfisherman *Knit Wits*. Within three years, 93 more of these boats rolled out of the High Point plant, each marketed as a "convertible," a term coined by Slane to emphasize the yacht's versatility (fishing and cruising). In 1962, the same hull was used to build the 41 Double Cabin motoryacht. And the rest, as they say, is history: 158 Hatteras designs by Hargrave's office over 36 years, of which 110 models were built, totaling 6,300 units.

Perhaps the longest and most unusual chapter in the book is titled "The Business of Yacht Design." As any independent designer knows, it isn't easy running a business, much less a profitable one. Hargrave apparently picked up some financial sense from his industrious mother, who ran an inn and studied hotel management. Mower writes, "The office at 205½ Sixth Street was a quiet place, and Hargrave was a man of few words. Hargrave had a private office and then there was a large room with several designers and draftsmen, an area for files and one for making prints. From 1964 to 1967 Hargrave also operated an office in Miami, which was primarily concerned with ships and commercial projects." These included the patented 14,000-hp (1,044-kW) catamaran tug coupled to a 587′ (179m) barge, called a CATUG. His office also did a variety of passenger boats and ferries, including Fort Lauderdale's well-known *Jungle Queen* tour boat. In addition, between 1970 and 1983 Hargrave ran a yacht brokerage downstairs from the Palm Beach office.

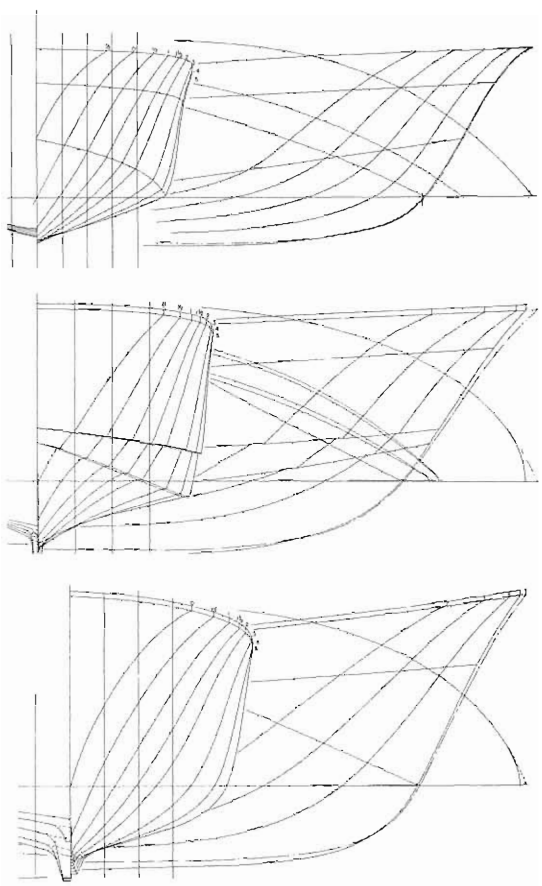
This chapter is sewn with snippets



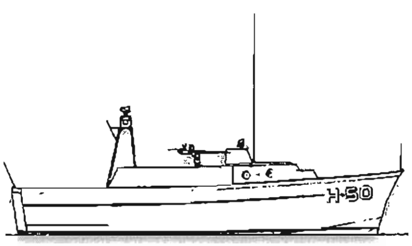


***Facing page**—The dust jacket of Marilyn Mower's recent biography of the late designer J.B. Hargrave.*
***Right, top**—*Seven Seas*, a custom steel motoryacht built by Burger Boat Co. (Manitowoc, Wisconsin) in 1958. At 89′ (27m) she was a very big boat for the era and the design commission that really launched Hargrave's career, since he was then a relatively little-known in-house designer at the Rybovich yard, in Florida. **Right**—The 41′ (12.5m) Hatteras* Knit Wits*, built in 1960, was the world's first large production fiberglass powerboat. Her cruising interior became the basis for calling this robust sportfisherman a "convertible." The Hargrave office designed—and defined—Hatteras Yachts' product line for more than three decades.*

The forebody lines of three seminal Hargrave hulls.
Top—*The express-style sportfisherman TX-41, which set a longstanding speed record for her nonstop 1964 run from Miami to New York. Hargrave's early work with deep-Vs was virtually contemporaneous with Ray Hunt's.*
Middle—*The semi-planing shape of a Hatteras 43 convertible, circa 1977.*
Bottom—*The full-displacement hullform of a Hatteras 48 Long Range Cruiser, circa 1977. Hatteras' Long Range series attracted a large and loyal following.*



of remembrances from the many people who worked for Hargrave over the years. Prominent among them was his vice-president, Dudley Dawson, who is quoted as saying: "Jack was a



Hargrave's 1965 sketch, based on a 50' (15.2m) Hatteras hull, for a proposed coastal patrol boat for the U.S. Navy in Vietnam. After Hargrave downsized the design to 28' (8.5m), Hatteras built a successful jet-powered prototype for riverine warfare—but lost the contract when Hatteras' owner balked at the government paperwork.

good listener. At some point during initial client meetings he'd pull out a sheet of paper and a number-two pencil and start sketching. By the end of the meeting he'd have a profile, and it was so good you could take a one-quarter scale and pull a dimension off it. The first few times I saw him do this, it stunned me. And of course it stunned the client! They would say, 'Can I have a copy?' and Jack would reach for the design and say, 'No, but we can draw you up a contract.'"

The picture of Jack Hargrave that soon emerges from these pages is of a rather stiff, scrupulously honest man, devoted to family, and fair with his staff. He wouldn't accept funny money, and if he thought a builder wasn't doing something right, he said so directly. If not always loved, he seems to have been universally respected.

The back of the book contains profiles and arrangement plans of 75 yachts designed by Hargrave, from the Prairie 29 (8.8m) production cruiser to the 184' (56m) *Katamarino*, which represented a "design departure," Mower says, in the "half-deck separation of the forward and aft portions of the decks." This part of the book is preceded by designs that were never built, including several sailboats. Mower says that one of Hargrave's regrets was never having a sailboat built. Indeed, many family vacations were spent charter-sailing in the West Indies. The sketches of unbuilt motoryachts suggest where Hargrave's thinking might have taken him had he lived longer, and they are anything but stodgy. Mower writes, "Hargrave modernized his motoryacht designs in a style that was the polar opposite of Italian fashion." (You'll have to buy the book to see for yourself.)

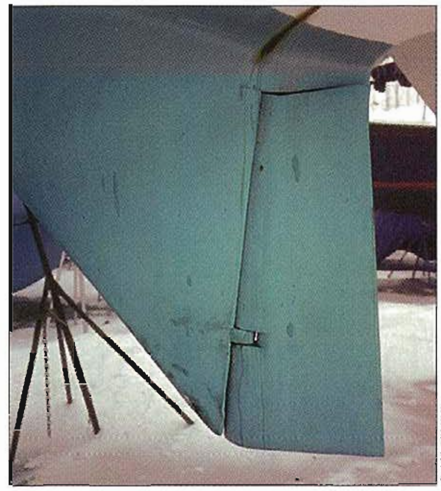
Mower, Thompson, and Joyce have done an excellent and tasteful job telling the story of Hargrave's life, in a manner he would have approved—respectfully and fairly. He might not have welcomed a show of affection, and Mower knows it, but she has given us more than a hint of that, too.

American Classic: The Yachts and Ships of Jack Hargrave, *by Marilyn Mower. 224 pages, 334 photos and illustrations, 75 yacht design profiles. $79.95. Nautical Media Group, 1887 West State Road 84, Fort Lauderdale, FL 33315 USA, tel. 954-463-0555, fax 954-463-8621, on the Web at www.jackhargrave.com.*

For his own retrospective of Jack Hargrave's work, see Dudley Dawson's article in *Professional BoatBuilder* No. 43, page 36. PBB

About the Author: *Dan Spurr is* Professional BoatBuilder*'s editor-at-large.*

More on the Fundamentals of Steering Systems



In this second of three parts, we present formulas for calculating water pressure on the rudder, and then for specifying appropriate rudderstocks and rudder bearings.

Text, photos, and drawings by Dave Gerr
(except where noted)

Note: *In Part 1, which appeared in* Professional BoatBuilder *No. 98, the author covered balance, size, aspect ratio, and shape of powerboat and sailboat rudders—Ed.*

Above—*The rudder on this Sparkman & Stephens–designed 1975 Tartan 44 is hung on a full skeg. Its solid stainless steel rudderstock is secured by a bearing and a bronze gudgeon located near the base of the rudder.*

Rudderstock and Bearing Calculations and Construction

To calculate the required rudderstock diameter:

1. Find the water pressure on the rudder blade at 35° (maximum rudder angle).

$$\text{Pressure, lbs} = C_L \times \left(\frac{1}{2}\rho\right) V^2 \times A$$

Where:
C_L = coefficient of lift for the rudderblade section shape at the angle being investigated
ρ = mass density of water, 1.987 slugs or 1,025 kg/m^3
A = rudder area, sq ft or m^2
V = speed, ft/sec or m/sec

Now, as we've seen in Part 1, the coefficient of lift isn't accurately known for most real-world rudders, and since we're interested in the maximum pressure—which occurs at maximum helm angle (almost always 35°, or at a lower angle, determined by when the rudder stalls)—and since the mass density of water is constant, then the formula above can be simplified to:

Standard Rudder Pressure Formula

Pressure, lbs =
$C_L \times (\text{Pf} \times \text{Speed, ft/sec})^2 \times \text{Area, sq ft}$

Knots x 1.69 = ft/sec

or

Pressure, kg =
$C_L \times (\text{Pf} \times \text{Speed, ft/sec})^2 \times \text{Area, m}^2 \times 52.55$

Knots x 0.514 = m/sec

Where:
C_L = coefficient of lift, use 0.5
Pf = Propeller factor: 1.0 for sailboats or boats where the propeller is more than 2.5 times propeller diameter forward of the rudder; 1.2 for all other boats.

If we had a 28-knot twin-screw planing boat with two 5.28-sq-ft (0.49m^2) rudders, the force on each rudder at 35° would be:

28 knots x 1.69 = 47.32 ft/sec

Pressure = 0.5 x (1.2 x 47.32 ft/sec)^2 x 5.28 sq ft = 8,512 lbs

or

28 knots x 0.514 = 14.39m/sec

Pressure = 0.5 x (1.2 x 14.39m/sec)^2 x 0.49m^2 x 52.55 = 3,839 kg

Note: Because pressure is a force, it is more properly indicated by the symbol "kgf" for kilograms of force; however, the "f" is understood in this application.

2. *Locate the center of water pressure on the rudder.* Refer to the drawing to locate the geometric center of area either by means of your CAD program or by balancing a cardboard or stiff paper cutout of the rudder blade. You can see in **Figure 1** how this is worked out.

A horizontal line, parallel to the datum waterline, is drawn across the rudder through the geometric center point. This line is the effective mean chord. Measure 35% of mean chord length aft of the rudder's leading edge, on this mean chord line, to find the center of pressure. Use 40% aft on wedge-section or parabolic-section rudders. (See Part 1 of this series for help estimating the location of the center of pressure at rudder angles other than 35°.)

3. *Find the twisting arm.* Draw a line at right angles to the rudderstock centerline through the center of pressure on the rudder blade. Measure the distance along this line, from the center of pressure on the rudder blade to the center of the rudderstock—that is, the rudderstock axis.

4. *Find the bending arm.* Refer to Figure 1. The distance from the center of pressure up to the middle of the lower rudder bearing in the hull, measured along the length of the rudderstock, is the bending arm. (If the rudder blade has a bearing at top and bottom, the bending arm is zero; see page 38.)

5. *Find the twisting moment (TM) and the bending moment (BM).*

TM = rudder pressure x twisting arm
BM = rudder pressure x bending arm

If the twisting arm for our example rudder is 3.64" (92mm) and the bending arm is 23.8" (605mm), then:

TM = 8,512 lbs x 3.64" = 30,984 in-lbs
BM = 8,512 lbs x 23.8" = 202,585 in-lbs

or

TM = 3,839 kg x 0.092m = 353 kgm
BM = 3,839 kg x 0.605m = 2,322 kgm

6. *Find the combined twisting and bending moment—combined moment (CM).*

$$CM = BM + \sqrt{BM^2 + TM^2}$$

In our case:

$$CM = 202,585 \text{ in-lbs} + \sqrt{(202,585 \text{ in-lbs})^2 + (30,984 \text{ in-lbs})^2} = 407,525 \text{ in-lbs}$$

or

$$CM = 2,322 \text{ kgm} + \sqrt{(2,322 \text{ kgm})^2 + (353 \text{ kgm})^2} = 4,671 \text{ kgm}$$

Note: Though the calculation for CM should be done as above, the result will be consistently close to twice BM. Use this as a check on your calculation. If the number is significantly different than 2 x BM, then reexamine your work. In this case, 2 x 202,585 in-lbs = 405,170 in-lbs; or 2 x 2,322 kgm = 4,644 kgm, which is nearly identical to our calculated CM.

7. *Find the diameter of a solid rudderstock.*

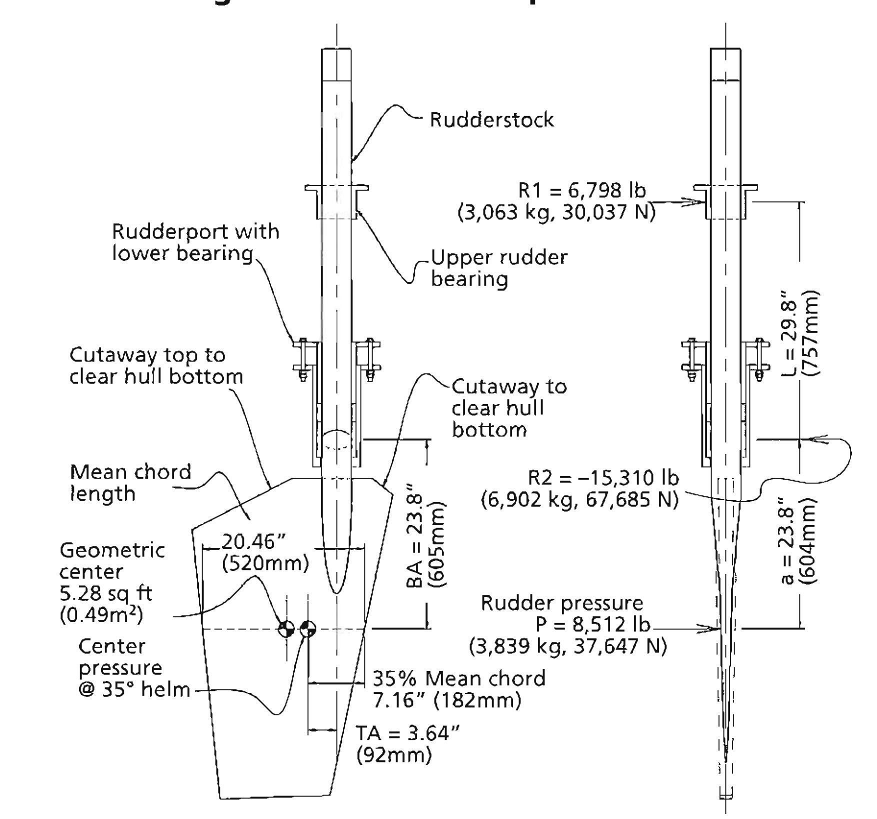
$$\text{Dia, inches} = \sqrt[3]{\frac{16 \times \text{Moment}}{\pi(\text{UTS}/\text{SF})}}$$

Where:
Moment = combined bending and twisting moment, in-lbs, for spade rudders
UTS = ultimate tensile strength of the material, in psi or MPa (N/mm^2).
SF = safety factor; use the boxed table on the next page.

On metal spade rudders, there must be no welds from 1 shaft diameter below the top of the rudder blade up to 1 shaft diameter above the top of the lower rudder bearing. If welds are closer than this, then use the "As Welded" strength from the table on the following page.

In spade-rudder configuration the bending moment will be vastly greater

Figure 1. Powerboat Spade Rudder



Safety Factors	SF
Powerboat spade rudders	3.34
Racing-powerboat and patrol-boat spade rudders	4.00
Power- and sailboat rudders, bearings above and below rudder blade	4.00
Sailboat spade rudders	6.00

Strengths and Densities of Standard Rudderstock Materials

Material	Ultimate Tensile Strength psi	Ultimate Tensile Strength MPa*	As Welded Tensile Strength psi	As Welded Tensile Strength MPa*	Density lbs/cu ft	Density g/cm³
Aluminum 5000 series	34,000	234	16,000	110	168	2.69
Aluminum 6082	46,000	327	20,000	138	168	2.69
Silicon bronze	60,000	413	27,000	186	500	8.00
Stainless steel (316L)[1]	85,000	586	36,000	248	505	8.09
Carbon composite[2]	120,000	827	NA	NA	98	1.57
Aqualoy 22 HS[3]	130,000	986	60,000	414	508	8.14

*MPa = N/mm² (megapascals = newtons per millimeter squared)

Notes:

[1] Use only 316L (L for low carbon) stainless to avoid pitting corrosion and weld decay problems.

[2] Carbon composite requires expensive custom fabrication. Confirm mechanical properties and engineering details with the manufacturer.

[3] Aqualoy 22 HS is a chrome-molly alloy stainless from Western Branch Metals (Portsmouth, Virginia). Aquamet 22 from Marine Machining (Clinton Township, Michigan) is similar. Confirm alloy strength in the diameter specified.

than the twisting moment; therefore, we use the "Ultimate Tensile Strength" of the material from the table.

That's a fairly large rudder for this speed. We want to keep stock diameter down, to reduce drag. Thus, we'll go with a very high-strength, chrome-molly stainless: Aqualoy 22 HS.

$$\text{Dia, inches} = \sqrt[3]{\frac{16 \times 407{,}525 \text{ in-lbs}}{\pi\left(\frac{130{,}000 \text{ psi}}{3.34 \text{ SF}}\right)}}$$

= 3.76", use 3¾" Aqualoy 22 HS

or

Metric structural calculations should be done in newtons, not kilograms. To convert kgm to Nm (kilogram meters to newton meters), multiply kgm by 9.8066.

So,

4,761 kgm x 9.8066 = 46,699 Nm

$$\text{Dia, mm} = \sqrt[3]{\frac{16 \times 46{,}699 \text{ Nm} \times 1{,}000\text{mm/m}}{\pi\left(\frac{986 \text{ N/mm}^2}{3.34 \text{ SF}}\right)}}$$

= 93.05mm, use 100mm Aqualoy 22 HS

Note that Nm has to be multiplied by 1,000 to get Nmm so all the units are the same—in this case, "mm."

8. Find the weight per lineal foot of the selected stock.

$$\text{Section Area, sq ft} = \frac{\pi\left(\text{Dia, in}/2\right)^2}{144}$$

or

$$\text{Section Area, cm}^2 = \frac{\pi\left(\text{Dia, mm}/2\right)^2}{100}$$

Thus:

$$\text{Section Area} = \frac{\pi\left(3.75''/2\right)^2}{144} = 0.076 \text{ sq ft}$$

0.076 sq ft x 508 lbs/cu ft
= 38.6 lb/lineal ft

If this stock were 6'2" (6.16') long, it would weigh 238 lbs—minus a bit for any tapering.

or

$$\text{Section Area, cm}^2 = \frac{\pi\left(100\text{mm}/2\right)^2}{100} = 78.54\text{cm}^2$$

78.54cm² x 8.14 g/cm³ = 639.3 g/lineal cm

If this stock were 1.87m long, it would weigh:
1.87m x 100cm/m x 639.3 g/lineal cm ÷ 1,000 g/kg = 119.5 kg

9. Optional: Find the section modulus of the required solid stock.

$$Z = \frac{\pi\left(\text{Dia}\right)^3}{32}$$

Where:
Z = section modulus, inches³ or cm³
Dia = rudderstock diameter, inches or cm

So:

$$Z = \frac{\pi\left(3.76''\right)^3}{32} = 5.22 \text{ inches}^3$$

or

93.05mm dia = 9.305cm dia

$$Z = \frac{\pi\left(9.305\text{cm}\right)^3}{32} = 79.1\text{cm}^3$$

10. Optional: Select a hollow pipe or tube section with the equivalent section modulus.

The pipe must be a minimum of Schedule 80, or heavier wall.

Referring to a standard U.S. IPS pipe and tube-stock table, a 4.5"-OD tube with a ½" wall has a section modulus of 5.67 inches³. This weighs 22.16 lbs/lineal ft.

or

Referring to a standard heavy-wall DIN-2448 pipe table, a 114.3mm-OD pipe with an 11mm wall has a section modulus of 84.2cm³. This weighs 28 kg/lineal meter (see below).

The section modulus of a hollow, round section can be found from the following:

$$Z = \left(\frac{\pi}{32}\right) \times \left(\frac{OD^4 - ID^4}{OD}\right)$$

For the metric DIN pipe, we get:
114.3mm OD – (2 x 11mm wall) = 92.3mm ID

$$Z = \left(\frac{\pi}{32}\right) \times \left(\frac{(11.43\text{cm OD})^4 - (9.23\text{cm ID})^4}{11.43\text{cm OD}}\right) = 84.2\text{cm}^3$$

The larger diameter would create

more drag. Further, the Aqualoy 22 HS alloy isn't available for this size tube, so we'd have to redo the calculation above for 316L stainless, and find the pipe or tube size for appropriate section modulus for that alloy.

Saving Weight in Sailboat Rudderstocks

If the rudder is fitted to a strong skeg or to the back of a traditional long keel, with bearings above and below the rudder blade, then sailboat rudderstocks aren't too large and heavy. On many modern fin-keel boats, however, balanced spade rudders can be both large and high aspect. A solid stainless, bronze, or even Aqualoy stock might well weigh more than 500 lbs (225 kg) on a larger boat. Such weight in the ends of the vessel is detrimental to performance, because it increases pitching.

In such instances, it makes good sense to go to heavy-wall stainless or bronze pipe or tube. Even though the rudder blade must be thicker to accommodate the greater diameter stock, the weight savings is well worth it. The more expensive alternative is a custom-fabricated carbon/epoxy composite stock. Another excellent option is a solid aluminum rudderstock of 6082 alloy. Certain companies (such as Jefa Marine of Greve, Denmark) specialize in custom fabricating and machining solid aluminum rudderstocks of 6082. These can be machined to any diameter desired, and tapered as well. Weight can be close to that of carbon composite.

It is also worth considering whether such a high aspect rudder really pays. The difference in performance between a rudder with an aspect ratio of 3 and 5 (of roughly equal area) isn't all that great. Lower aspect ratio will reduce the bending arm, thus the bending moment, and also reduce the required stock diameter as well as stock length—and thus reduce weight.

Checking Rudderstock Strength Going Astern

Because forward speed is so much higher than astern speed—for most conventional boats—simply checking the rudderstock strength in the ahead condition is generally adequate. Some craft, however, may have rudder configurations that create greater loads when going astern. The reason for that is, when making sternway, the center of pressure is about 20% of mean chord *forward of the trailing edge* (which, going backward, becomes the leading edge). This, in turn, significantly increases the length of the twisting arm, and so the twisting moment.

For displacement boats, use 70% of maximum ahead speed as speed for sternway calculations.

For planing hulls:
Sternway, kts =
(max fwd speed, kts +20) ÷ 3

If you're in doubt about the rudderstock strength going astern, repeat all the above rudderstock calculations, using the sternway speed, and locate the center of pressure 20% of the mean chord forward of the trailing edge.

Rudderstocks With Bearings Above and Below the Rudder Blade

A rudder that is supported with bearings above and below the rudder is in nearly pure torsion with minimal bending. What bending exists is the result of the side force of the water, which is assumed to be distributed roughly evenly along the height of the rudder. This could be calculated as a "combined twisting and bending" condition similar to the above, but because the bending moment is such a small portion of the total load, it can be taken care of simply by employing a slightly larger safety factor of 4, rather than 3.34. You could then apply the formula above for combined twisting and bending, with a zero entered for bending arm, though it's more straightforward to define torque alone as simply:

TM = rudder pressure x twisting arm
Along with a safety factor of 4 as in the table on the previous page.

In the combined twisting and bending of the spade rudder, bending dominated, so we used ultimate tensile strength. In the current case, however, torsion dominates. Accordingly, you need to use ultimate *shear* strength (USS), which can be taken as 60% of UTS.

If we assume for a moment that the rudder above was supported by a lower rudder bearing on a strong skeg, then we would find the required stock diameter as follows:

TM = 8,512 lbs x 3.64" = 30,984 in-lbs
or
TM = 3,839 kg x 0.092m = 353 kgm

Since the resulting stock will be considerably smaller in this configuration, we'll go with the more standard 316L SS, which has a UTS of 85,000 psi (586 MPa). Shear strength would then be:

85,000 psi UTS x 0.60 = 51,000 psi USS
or
586 MPa UTS x 0.60 = 352 MPa USS

$$\text{Dia, inches} = \sqrt[3]{\frac{16 \times 30{,}984 \text{ in-lbs}}{\pi\left(\frac{51{,}000 \text{ psi}}{4 \text{ SF}}\right)}}$$

= 2.31", use 2⅜" or 2½" 316L stainless steel

or

353 kgm x 9.8066 = 3,462 Nm

$$\text{Dia, mm} = \sqrt[3]{\frac{16 \times 3{,}462 \text{ Nm} \times 1{,}000\text{mm/m}}{\pi\left(\frac{352 \text{ N/mm}^2}{4 \text{ SF}}\right)}}$$

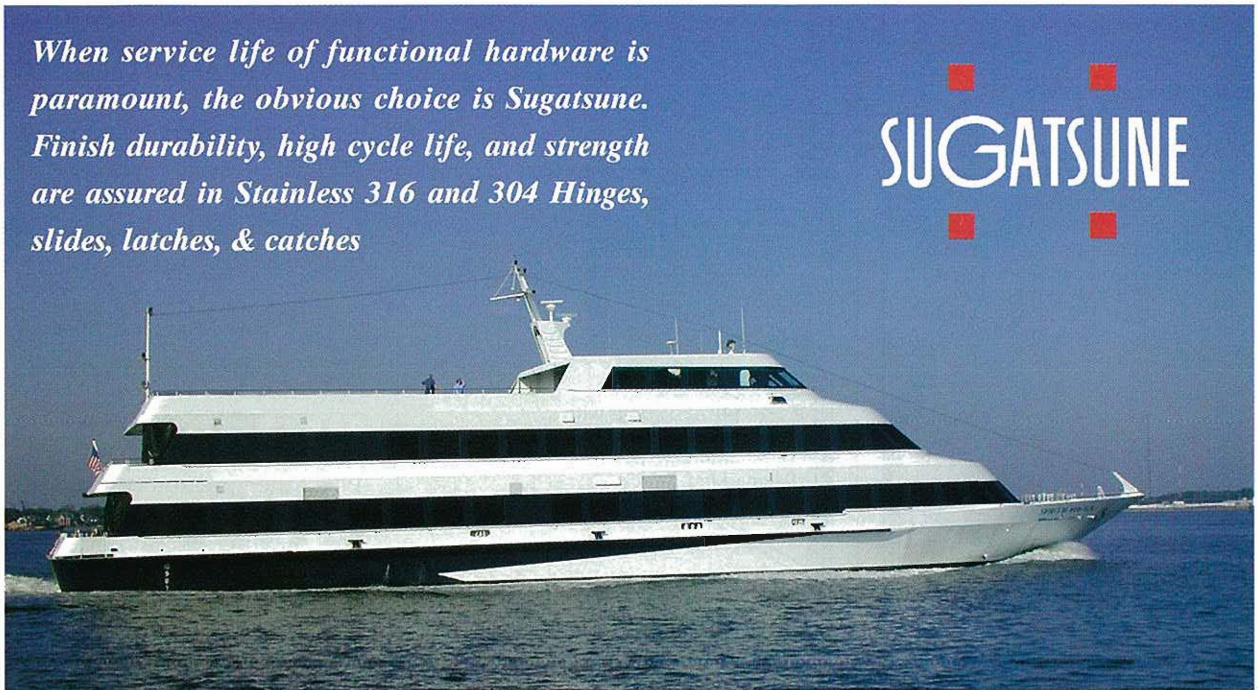
= 58.5mm, use 60mm 316L stainless steel

(Nm has to be multiplied by 1,000 to get Nmm.)

Silicon bronze would be superior for any boat that isn't aluminum or steel. The silicon bronze would not have stainless steel's susceptibility to pitting corrosion. Applying 60,000 psi (413 MPa) UTS for bronze, the USS is 36,000 psi (248 MPa). Entering this in the formula above would give a required diameter of 2.59" (65.7mm); use 2¾" (70mm) silicon bronze.

Rudder-Bearing Loads for Spade Rudders

All rudders must have at least two bearings—an upper and a lower bearing (**Figure 2**). We'll next take a look at bearings for rudders that have bearings below the bottom of the rudder blade. Here, we'll examine the loads on the upper and lower bearings of a spade rudder. For such rudders, the lower bearing is just inside the hull bottom, while the upper bearing is well above this, in the hull. Within



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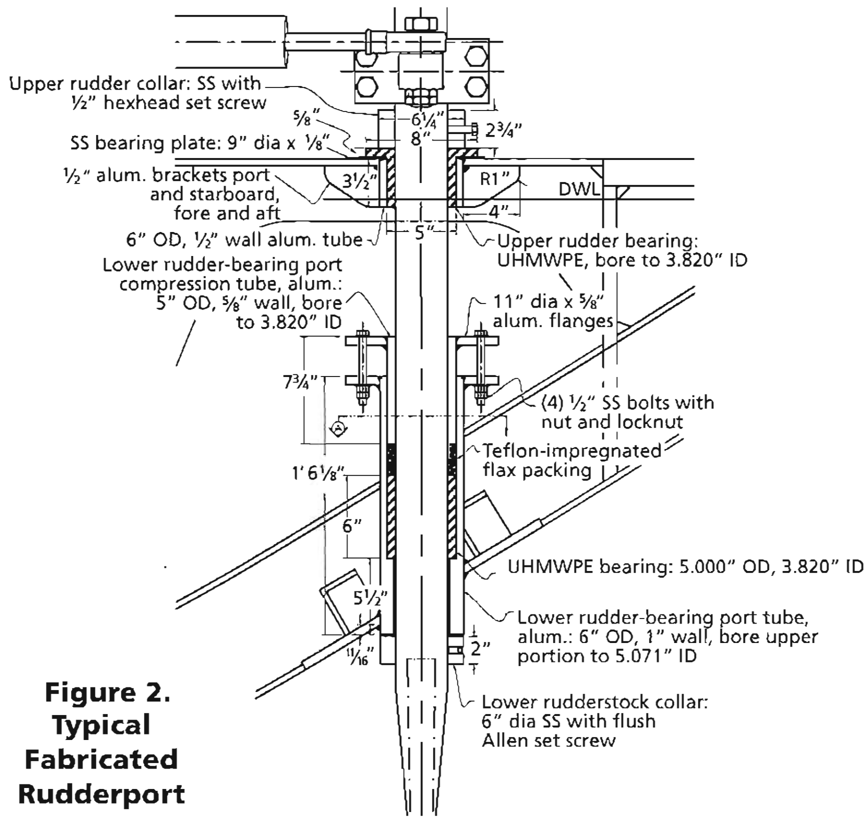


Figure 2. Typical Fabricated Rudderport

practical limits, the higher the upper bearing can be in the hull the better, as this reduces the loads.

Find loads (reaction forces) on rudder bearings:

Upper rudder bearing: $R1 = \frac{Pa}{L}$

Lower rudder bearing:
$$R2 = -\frac{Pa}{L}(L + a)$$

Where:
P = water pressure on rudder blade, in pounds or kilograms
L = distance from upper to lower bearing, in inches or meters
a = distance from center of water pressure to lower bearing, inches or meters
R1 = reaction force on upper rudder bearing, lbs or kg
R2 = reaction force on lower rudder bearing, lbs or kg
Note: R2 is negative because it operates in the opposite direction of R1.

R1 plus R2 must cancel out to equal –P.

For our example spade rudder (Figure 1), we've already found that rudder pressure is 8,512 lbs (3,839 kg). Referring to the drawing, we see that a = 23.8" (604mm), and L = 29.8" (757mm). Then:

$$R1 = \frac{8{,}512 \text{ lbs} \times 23.8''}{29.8''} = 6{,}798 \text{ lbs}$$

$$R2 = -\frac{8{,}512 \text{ lbs}}{29.8''}(29.8'' + 23.8'') = -15{,}310 \text{ lbs}$$

Note: –15,310 lbs + 6,789 lbs = –8,521 lbs. The net reaction in the bearings equals the load (rudder pressure) applied in the opposite direction.

or

$$R1 = \frac{3{,}839 \text{ kg} \times 0.604\text{m}}{0.757\text{m}} = 3{,}063 \text{ kg}$$

$$R1 = 3{,}063 \text{ kg} \times 9.8066 = 30{,}037 \text{ N}$$

$$R2 = -\frac{3{,}839 \text{ kg}}{0.757\text{m}}(0.757\text{m} + 0.604\text{m})$$

$$= -6{,}902 \text{ kg}$$

$$R2 = -6{,}902 \text{ kg} \times 9.8066 = 67{,}685 \text{ N}$$

Note: –6,902 kg + 3,063 kg = –3,839 kg. The net reaction in the bearings equals the load (the rudder pressure) applied in the opposite direction.

Find bearings that have enough area to fall below the allowable stress:

Material	Allowable psi	Bearing Stress MPa*
Lignum vitae	360	2.48
Babbitt bearing metal (oil lubricated)	650	4.48
Plastic bearing (UHMWPE)	800	5.51
Roller bearings (alum. or stainless)	800	5.51
Roller bearings (plastic)	350	2.41

*MPa = N/mm^2 (megapascals = newtons per millimeter squared)

Lignum vitae is a very hard, dense, oily wood, traditionally used for bearings in marine applications (including propeller-shaft bearings). Though practical, lignum vitae is largely obsolete today. Babbitt bearing metal (or white bearing metal) should be oil lubricated and has been largely abandoned for rudder-bearing applications. Of the hard, tough, slippery (low coefficient of friction) plastics, ultrahigh-molecular-weight polyethylene, or UHMWPE, is probably best for nonroller rudder bearings. Not only is it very strong and resistant to attack by chemicals, it has virtually zero water absorption, and so doesn't expand after immersion, which would squeeze or bind the shaft.

Bearing area is shaft diameter times bearing height.

Maximum bearing height (length) is 1.75 times shaft diameter.

Minimum bearing height (length) is 1.0 times shaft diameter.

For the lower bearing (of UHMWPE) we find:

15,310 lbs ÷ 800 psi = 19.14 sq in required.
19.14 sq in ÷ 3.75" shaft dia = 5.1" high
Max. bearing height is 1.75 x 3.75" dia = 6.562"
Min. bearing height is 1.0 x 3.75" dia = 3.75"

Accordingly, a 5.1" high bearing will do, but a bit more will reduce bearing stress; go with 6" high.

For the upper bearing (of UHMWPE) we find:

6,789 lbs ÷ 800 psi = 8.50 sq in required.
8.50 sq in ÷ 3.75" shaft dia = 2.27" high
Max. bearing height is 1.75 x 3.75" dia = 6.562"
Min. bearing height is 1.0 x 3.75" dia = 3.75"

Accordingly, a 3.75" high bearing will do.

or

For the lower bearing (of UHMWPE) we find:

67,685 N ÷ 5.51 N/mm^2 = 12,284mm^2 required.
12,284mm^2 ÷ 100mm shaft dia = 122.8mm high
Max. bearing height is 1.75 x 100mm dia = 175mm
Min. bearing height is 1.0 x 100mm dia = 100mm

Accordingly, a 122.8mm high bearing will do, but a bit more will reduce bearing stress; specify 150mm high.

For the upper bearing (of UHMWPE) we find:

30,037 N ÷ N/mm^2 = 5,451mm^2 required.
5,451mm^2 ÷ 100mm shaft dia = 54.5mm high
Max. bearing height is 1.75 x 100mm dia = 175mm
Min. bearing height is 1.0 x 100mm dia = 100mm

Accordingly, a 100mm-high bearing will do.

If the rudderstock has been tapered down at the upper bearing, then the upper rudder bearing will have to be calculated, using the smaller (tapered down) diameter.

The structure supporting the upper rudder bearing must be able to withstand the 6,798 lbs (3,063 kg) side load, with a safety factor of 4. Similarly, the lower rudder bearing structure must withstand 15,310 lbs (6,902 kg), with a safety factor of 4. Built into the keel structure, for the lower rudder bearing, this isn't usually difficult to achieve, but keep the large loads in mind.

Rudder-Bearing Clearance

Because the rudderstock must be free to turn in the bearings, the bore (inside diameter, or ID) of the bearing must be slightly larger than the OD of the shaft. The stock is almost always of standard, off-the-shelf diameter rod or pipe. Normally, you can't specify its diameter tolerances beyond what's commercially supplied. The bearing ID is thus specified to give proper clearance.

The difference between the shaft

OD and the bearing ID is called *allowance*. The amount that the machinist can deviate from the specified ID with the allowance is the *tolerance*.

For low-speed (low-RPM) heavy equipment (such as rudder bearings):

Allowance = 0.0025 x (dia, inches)$^{0.67}$
Tolerance = 0.0025 x (dia, inches)$^{0.34}$

or

Allowance = 0.0073 x (dia, mm)$^{0.67}$
Tolerance = 0.0211 x (dia, mm)$^{0.34}$

Where:
dia = shaft diameter

Thus, for our 3.75″ shaft, we'd call for a bearing ID of:

Allowance = 0.0025 x (3.75″ dia)$^{0.67}$ = 0.006″
Tolerance = 0.0025 x (3.75″ dia)$^{0.34}$ = 0.003″

or

Allowance = 0.0073 x (100mm dia)$^{0.67}$ = 0.159mm
Tolerance = 0.0211 x (100mm dia)$^{0.34}$ = 0.101mm

So:
Bearing ID = 3.756″, +0.003″, –0.000″ (meaning the ID can't be smaller than 3.756″ or larger than 3.759″)

or

Bearing ID = 100.159mm, +0.101mm, –0.00mm (meaning the ID can't be smaller than 100.159mm or larger than 100.26mm)

UHMWPE-Bearing Wall Thickness

Minimum bearing wall thickness (for UHMWPE) should be 0.15 times nominal shaft diameter. Somewhat greater thickness is fine, to fit properly inside the bearing housing wall.

For our 3.75″ (100mm) shaft, the minimum wall would thus be 0.5625″ (15mm). Or the minimum bearing OD would be:

2 x 0.5625″ + 3.75″ = 4.875″ OD
or
2 x 15mm + 100mm = 130mm OD

The inside wall of the lower portion of the rudderport (which houses the bearing) should be machined to 4.875″ (130mm) ID, or somewhat larger inside diameter, as convenient.

The UHMWPE bearing is slid down into the rudderport. So it needs to be a close sliding fit. Use:

Allowance = 0.0014 x (dia, inches)$^{0.67}$
Tolerance = 0.0013 x (dia, inches)$^{0.34}$

or

Allowance = 0.0041 x (dia, mm)$^{0.67}$
Tolerance = 0.0101 x (dia, mm)$^{0.34}$

Where:
dia = bearing outside diameter

If we'd selected 5″ (130mm) ID for the lower rudderport tube, then the bearing ID would be:

Allowance = 0.0014 x (5.00″ dia)$^{0.67}$ = 0.004″
Tolerance = 0.0013 x (5.00″ dia)$^{0.34}$ = 0.002″

or

Allowance = 0.0041 x (130mm dia)$^{0.67}$ = 0.107mm

Tolerance = $0.0101 \times (130\text{mm dia})^{0.34}$ = 0.053mm

So:

Bearing OD = 5.000″, +0.000″, –0.002″
Rudderport Tube ID = 5.004″, +0.002″, –0.000″

or

Bearing OD = 130.000mm, +0.000mm, –0.053mm
Rudderport Tube ID = 130.107mm, +0.053mm, –0.000mm

The opening at the bottom of the rudderport should never make contact with the shaft, so this opening needs to be larger than the bearing diameter. Use twice the shaft allowance for the bearing ID, or a bit more. Thus—again, for our 3.75″/100mm shaft—the ID of the opening in the rudderport (below the bearing) should be:

0.006″ x 2 = 0.012″, and 0.012″ + 3.75″ = 3.762″

or

0.159mm x 2 = 0.318mm, and 0.318mm + 100mm = 100.318mm

Rudderport Tube Wall Thickness

Aluminum = 0.13 x shaft dia, min.
Not less than ¼″(6.5mm)
Steel, Stainless, Bronze = 0.08 x shaft dia, min.
Not less than 3/16″(4.7mm)

If we were building this rudderport into an aluminum boat, the rudderport would be of aluminum pipe or tube. Minimum diameter would be:

Wall min. = 0.13″ x 3.75″ dia shaft = 0.4875″

or

Wall min. = 0.13 x 100mm dia shaft = 13mm

We selected a 5″(130mm) OD rudder bearing, so the OD of the rudderport tube would be:

0.4875″ wall x 2 = 0.975″ + 5.00″ bearing = 5.975″ OD; use 6.00″ OD, or slightly greater as convenient for the lower rudderport tube

or

13mm wall x 2 = 26mm + 130mm bearing = 156mm OD; use 160mm OD, or slightly greater as convenient for the lower rudderport tube

Rudderport Packing Gland

The lower rudderport tube is fastened to the hull and houses the rudder bearing, the packing gland that makes the rudderport watertight, and the upper rudderport compression tube, which squeezes down on the packing to make it watertight.

Traditional packing for the gland is made of standard flax packing. A better choice is Teflon-impregnated flax packing, which has lower friction and longer life. (Never use graphite-impregnated packing; the graphite will cause corrosion.)

The packing diameter should be approximately equal to the bearing wall thickness. The height of the uncompressed packing should be approximately 60% of shaft/stock diameter.

The rudderport compression tube should be machined to have the same OD as the bearing below, and an ID with 50% greater allowance than the bearing. Our bearing allowance is 0.006″ (0.159mm).

0.006″ x 1.5 = 0.009″, so:
Compression tube ID = 3.75″ + 0.009″ = 3.759″ ID, +0.003″, –0.000″

or

0.159mm x 1.5 = 0.318mm, so:
Compression tube ID = 100mm + 0.318mm = 100.318mm ID, +0.101mm, –0.000mm

Compressing the Rudderport Compression Tube

On off-the-shelf machined bronze and stainless rudderports, the compression to squeeze the compression tube down on the packing is usually generated by a screw-down nut, threaded onto the top of the lower rudderport tube.

On metal hulls, the entire rudderport is usually built into the hull, and the rudderport compression tube is tightened down with four bolts through flanges on the compression tube and lower rudder-bearing port tube. The bolts should be of 316 stainless. Diameter should be 0.13 times rudderstock diameter, or larger, but never less than 3/16″ (4.7mm).

The flange thickness is:
Aluminum: 0.18 x shaft diameter, or more
Not less than 1/4″ (6.3mm)
Steel: 10.12 x shaft diameter, or more
Not less than 3/16″ (4.7mm)

Figure 3.

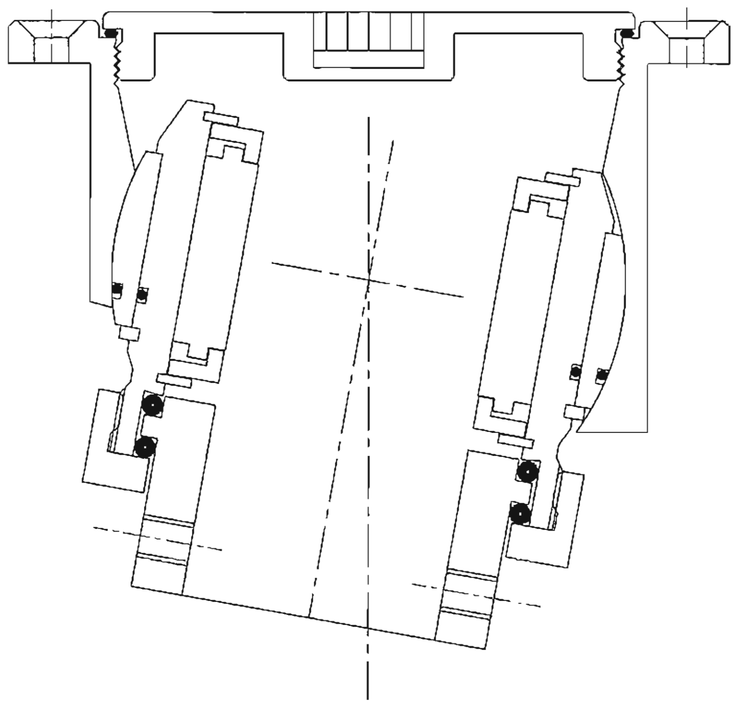
COURTESY EDSON INTERNATIONAL

Roller Bearings

Not long ago, Delrin and other hydroscopic plastics that expand and degrade when immersed in water were routinely specified for rudder bearings. But, since its advent, I've found UHMWPE has few problems and gives good service if installed as described above. The ultimate in rudder bearings, though, would be stainless or aluminum roller bearings. Such rudder bearings have closer clearances for less "chatter" in the bearing and less "backlash." They also have the lowest friction for even better helm feel (**Figure 3**).

Initial dimensions for the bearing height can be estimated by applying the allowable bearing loads for roller bearings, above. Note, however, that manufacturers provide tables giving

Figure 4. Section Through Self-Aligning Rudder Bearing



JEFA RUDDER SYSTEMS

the design loads for their specific bearings in different sizes and constructions.

Another advantage of manufactured roller bearings is that they are available in self-aligning configurations. This means the bearing is free to rotate slightly to align with any bend in the rudderstock, and thereby prevent binding, uneven wear, and excess friction. For performance sailboats with high-aspect spade rudders, self-aligning roller bearings (**Figure 4**) are strongly recommended.

Premanufactured roller bearings are available with or without built-in bearing seals, and in configurations suitable for installations in wood, fiberglass, aluminum, or steel hulls.

Rudder Bearing Loads—Rudder Bearings Top and Bottom of Rudder

All of the preceding applies to spade rudders, with no bearing at the bottom of the rudder blade. On many single-screw boats (and some twin-screw vessels), the rudder is supported with a bearing in the hull just above the rudder blade, and with a lower bearing at the bottom of the rudder fastened to the keel or rudder skeg. In this case, the rudderstock experiences only modest bending loads; however, the stock and the bearing must resist the total side pressure of the water.

If we assume that our 5.28-sq-ft (0.49m^2) rudder is on a single-screw 28-knot boat, then the force on the one rudder would be the same as we've already found: 8,512 lbs (3,839 kg, 37,647 N). Each bearing takes half this load, or 4,256 lbs (18,823 N).

You'd find the required bearing size (for allowable bearing stress) as above. But, it makes sense to turn down the lower end of the rudderstock to fit into a smaller, more streamlined bearing/skeg below, as that portion of the stock is taking only the shear resulting from the side load; it's not also transmitting the torque from the steering gear.

You are then forming a pintle for the lower rudder bearing. Generally, this should be approximately 44% of overall shaft diameter, though you need to check that it has adequate shear area to take the side load. Employ a large safety factor of 5 to allow for the stress concentrations of abrupt changes in shape between the main rudderstock and the lower pintle.

Now, for this rudder, with bearings top and bottom, the stock diameter will be considerably smaller, with no bending load. Working through the formulas above (and using 316L stainless instead of Aqualoy 22 HS), we find the stock diameter required is 2⅜" or 2½" (60mm or 64mm) 316L SS. We'll go with 2½", since it's more readily available and has a larger safety factor. For the metric shaft, we find 60mm.

2.5" dia x 0.44 = 1.1", try 1" dia

or

60mm dia x 0.44 = 26.4mm, try 25mm

Check shear stress (single shear):

Area = π (1.0" ÷ 2)^2 = 0.78 sq in
4,256 lbs ÷ 0.78 sq in = 5,456 psi
51,000 psi ÷ 5,456 psi = SF 9.3, which is well over 5 SF, and thus acceptable

Ultimate Shear Strength (USS)

Material	psi	MPa*
Aluminum 5000 series	20,400	140
Aluminum 6082	27,600	190
Silicon bronze	36,000	248
Stainless steel (316L)	51,000	352
Carbon composite	Not recommended in this application	
Aqualoy 22 HS	78,000	538

*MPa = N/mm^2 (megapascals = newtons per millimeter squared) or

Area = π (25mm ÷ 2)^2 = 491mm^2
18,823 N ÷ 491mm^2 = 38.3 N/mm^2
352 N/mm^2 ÷ 38.3 N/mm^2 = SF 9.2, which is well over 5 SF, and thus acceptable

Gudgeon and Pintle Proportions

If this were a traditional rudder hung on gudgeons and pintles instead of bound to a stock, then the load would be divided by the number of gudgeons and pintles. The pintle diameter can be as small as practical—so long as the safety factor, SF, in shear is greater than 5. Divide the side load by the number of pintles and gudgeons to get the load on each.

Pintle length in the gudgeon or bearing should be at least 1.2 times pintle diameter.

The pintle can be tapered at a ratio of approximately 1 to 6 from maximum diameter at the top, to minimum diameter at the bottom.

The height of the gudgeon housing the pintle must be at least 1.2 times pintle diameter.

The gudgeon wall thickness is to be 0.5 times the pintle diameter, or more.

Fastening of the gudgeons into the hull or transom must take the side load from the pintles with a safety factor of 5. Check:

- fasteners in shear
- fasteners in tension
- fasteners in bearing in the hull/transom

Axial Bearing Loads and Shaft Collars

Rudders have weight that pulls them down out of the boat. This axial load must be resisted with a shaft collar inside the boat at one of the bearings, or by an axial bearing at the lower rudder bearing (**Figure 5**).

Where the lower rudder bearing is necked down to form a pintle, as described above, the shoulder that is formed works well as an axial-load bearing. A UHMWPE disk bushing/bearing can be placed under the main rudderstock here to take the axial load.

A spade rudder can also be struck from below and knocked upwards, damaging the steering gear. To prevent this, another shaft collar below one of the bearings should be installed.

On performance sailboats, roller-bearing shaft collars can be built into the upper or lower rudder bearing. These are sometimes termed "thrust bearings." Such roller-bearing shaft collars give the smoothest helm feel and fingertip control.

Fore-and-Aft Rudderstock Angle and Boat Trim

An often overlooked aspect of rudder installation is the rudderstock angle. The stock can be dead vertical or angled either forward or aft, as viewed from the side. Keep the following in mind:

- A rudderstock raked aft depresses the bow when the rudder is put over.
- A rudderstock raked forward depresses the stern when the rudder is put over.

On contemporary sailboats, it's not unusual to have moderate aft rake to make the spade rudder more nearly perpendicular to the swept-up hull bottom aft. A moderate amount of aft rake is acceptable, but you should avoid raking rudders aft more than 9° to vertical, or forward more than 12°. In fact, there's usually no reason for forward rake, except for transom-hung rudders. Traditional long-keeled sailboats often have forward rake well over 12°, but this is not best practice; and there's no reason for such rake on a modern boat.

For powerboats, rudders should always be vertical or nearly so.

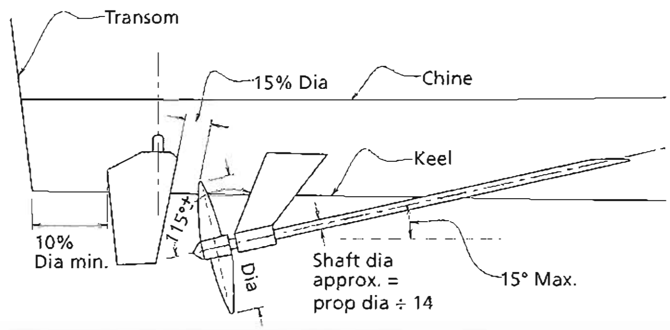
Figure 5.

Transverse Rudderstock Angle

On sailboats with twin rudders aft (such as the Open 60 class), it's normal to have the stocks at roughly right angles to the hull underbody. This splays the rudders out at an angle to the centerline (i.e., to vertical). On a wide-sterned sailboat when heeled, this is a good thing. The lee rudder will be deeply immersed and closer to vertical when heeled, thus more effective on the wide underbody aft. Such hullforms roll a single centerline rudder out of the water to a large degree when well heeled.

On planing powerboats, twin rudders must always be dead vertical athwartships, though it can look right on the drawing to have the two rudders project out from the hull underbody (behind the propellers) at right angles to the hull shell. On a deep-V boat this would mean an athwartship rudder angle of 21° or so

Figure 6. Planing-Boat Rudder and Propeller Configuration

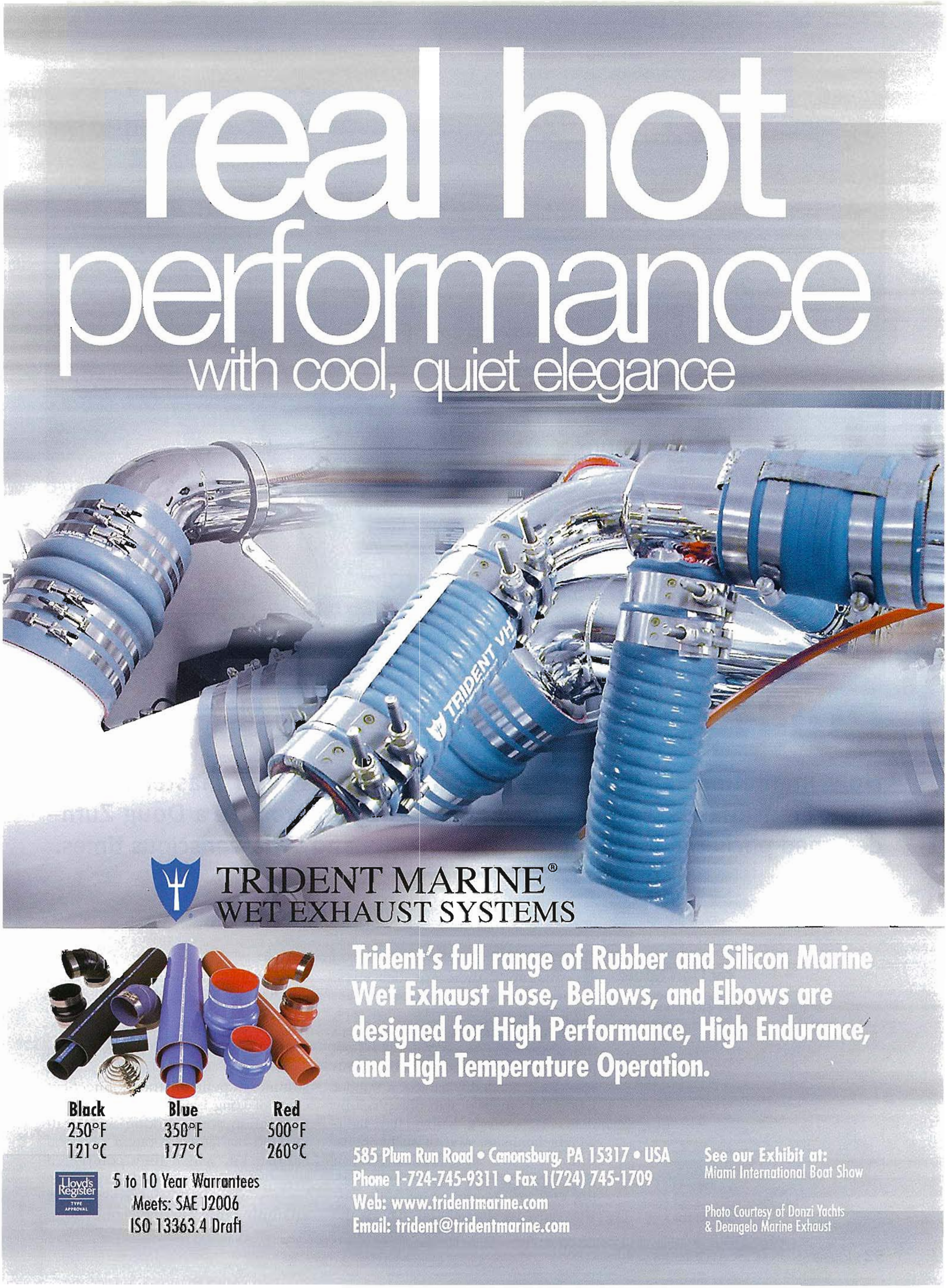


to the vertical. Though it may look right—it's wrong. The angled rudders, instead of acting like rudders, will also act as diving planes or trim tabs, an effect that is aggravated further (and unpredictably) when the boat rolls.

Rudder Configuration for Planing Hulls

Figure 6 shows the best proportions for rudders in relation to the hull, propeller, and shaft on twin-screw planing hulls. The leading edge of the rudder should be about 15% of propeller diameter aft of the propeller blades. Less is too close and can cause vibration or difficulty pulling the prop. A bit more is acceptable, but much more than that and the rudder becomes less effective, since it is farther aft in the slipstream. The aft edge of the rudder should ideally be 10% of propeller diameter forward of the transom's bottom edge. A bit farther forward is okay, provided you meet all other criteria. Having the prop farther aft allows a shallower shaft angle, but as the rudder blade nears the transom edge there's an increased chance of ventilation at the rudder, now no longer shielded from surface air by the hull above. There are many successful planing boats, however, that do have their rudders much closer to the transom. PBB

About the Author: *In addition to serving as director of Westlawn Institute of Marine Technology, Dave Gerr maintains his longstanding design practice (Gerr Marine, based in New York City), whose projects include sail and power, monohulls and multihulls, yachts and commercial vessels. He is the author of* Propeller Handbook, The Elements of Boat Strength, *and* The Nature of Boats.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SCOTT SMITH

Build It and They Will Come

How marketing legend Bob Johnstone (J Boats) and master builder Mark Lindsay (Boston BoatWorks) teamed up to produce a Doug Zurn–designed pocket motoryacht for these energy- and style-conscious times.

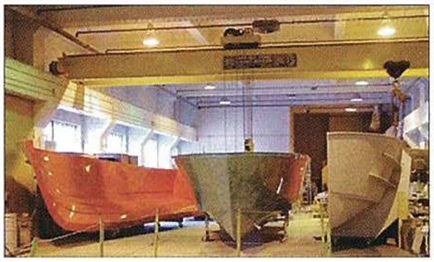
by Dan Spurr

In this world there are idea guys, and there are get-it-done guys. They need each other because each has something the other one lacks. In the case of the Doug Zurn–designed MJM 34z, developer/marketer Bob Johnstone needed a hands-on builder who could meet design objectives by delivering a strong, high-quality, lightweight laminate. And, it so happens, builder Mark Lindsay of Boston BoatWorks, after a long career building custom one-off racing sailboats, was eager for a steady gig. This is the story of how they found one another, and why.

Master Builder

Mark Lindsay, 61, grew up in Lexington, Massachusetts, with summers spent on the Connecticut coast of Long Island Sound. His early fascination with working watercraft inspired his father to buy a plywood Sailfish kit, which they completed together. Two years later, when Lindsay was just 16, he won his first championship in that same boat,

SCOTT SMITH (3)



MJM YACHTS

Opposite page—*The plywood frames for MJM Yachts' 34z plug, set up at the Boston BoatWorks shop in East Boston, Massachusetts, during the winter of 2002–03.*
Clockwise from top left*: Sheathing the plug; finished plug showing its strakes and chine flats; first hull, freshly popped from the two-part mold in May 2003; and Boston BoatWorks co-owner Scott Smith test-driving a mock-up of the hardtop structure for the Down East model of a 34z.*

thereby embarking, he says, on a lifelong quest to learn "what makes boats go faster." That quest was more interrupted than aided by several stints in college, first at the University of Pennsylvania, and then at Massachusetts Institute of Technology. Upon graduation he spent two years building Olympic-class Star boats in Winthrop, Massachusetts, with Joe Duplin, a world champion. In 1971, they built their first epoxy boat, of which Lindsay says, "The exceptional strength and weight characteristics were immediately obvious."

During the early to mid-1970s, Dick Carter ran a booming design business north of Boston, in Nahant. His forte was sailboats designed to the International Offshore Rule, which then dominated the racing scene. Doug Petersen was on the staff; when he left to start his own design office, Lindsay applied for the job and got it. There he joined Chuck Paine, Bob Perry (see *Professional BoatBuilder* No. 97, page 28), and Yves-Marie Tanton. Carter's designs were very successful, but the brain wave that his staff was generating pretty much flatlined during the winter of 1975. All four staffers were laid off when the

MJM YACHTS

Astride the transom, Scott Smith, left, and BBW co-owner Mark Lindsay are all smiles as 34z hull #1, bought by MJM developer Bob Johnstone and his wife, Mary, is readied to leave the yard. At the time, the Johnstones spent winters in Charleston, South Carolina, and were interested in a boat that could be reasonably trucked between there and their summer home in Northeast Harbor, Maine.

bottom fell out of the domestic production sailboat market (at the time, Carter was building boats overseas, in Greece, and at the time of the closure, he had other facilities ready to go on line in Poland, and Fort Worth, Texas); each member of the crew went his separate way. Lindsay started an eponymous shop—Mark Lindsay Boatbuilder, Ltd.—in an old barn on Boston's North Shore. His first build, which used aircraft-grade plywood, was an International Fireball-class sailboat that placed first in the double-handed Worlds. Lindsay: "With its unique structural design, the boat was able to carry much higher rig tension, giving better sail-shape control."

Next, he turned his attention to the International 505 class, which he built with vacuum-bagged epoxy, Nomex honeycomb core, and carbon fiber and Kevlar reinforcements, resulting in what Lindsay says were dramatically lighter, stronger, and stiffer hulls.

By the early 1980s Lindsay was applying his knowledge of advanced materials and processes to larger keelboats. As his reputation grew, Lindsay was called on to direct off-site projects, such as the *America's* Cup–class *Jayhawk*, built at Hercules Aerospace, in Utah. He also became expert at fabricating carbon fiber masts, rudders, and other components.

Lindsay met his business partner and Boston BoatWorks cofounder Scott Smith in 1990. Smith, 47, is another get-it-done guy. He grew up sailing in Old Greenwich, Connecticut, on his family's 1924 Fishers Island One-Design sloop. "Keeping that 40-year-old boat afloat was my first introduction to boatbuilding," Smith says. "We refastened the entire hull, steam-bending a number of replacement ribs, and re-covered the deck." After studying biomedical engineering at Boston University, Smith had stints in a medical laboratory, financial services, and banking; in the latter, he was a vice-president managing more than 100 people in a three-shift, six-day-a-week operation that processed more than 60,000 investment purchase transactions daily. Smith describes himself as "a lifelong sailor, sailing competitor, technophile, and entrepreneurial spirit." It was those characteristics, plus a racing campaign aboard one of Lindsay's boats, a Taylor 40, that attracted Smith to Lindsay. "I felt there was an opportunity," Smith explains, "to create a company whose purpose was to further the work Mark had done in advanced-composite construction, and make that expertise available to a wider audience." So he asked the noted builder if he was interested in doing some sort of joint venture on East Boston's waterfront—the historic neighborhood where, in the 1850s, Donald MacKay once built clipper ships. If there's one thing Lindsay responds to, it's enthusiasm, and Scott Smith had it coming out his ears.

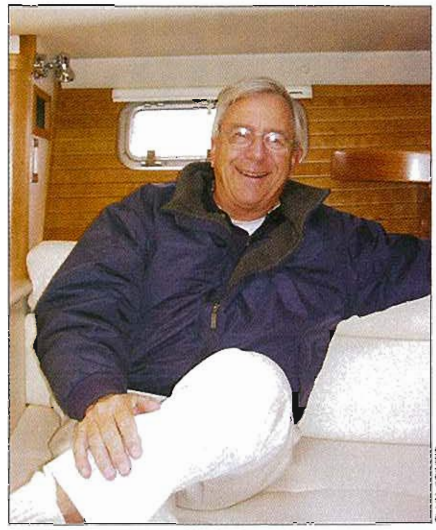
In addition to Boston BoatWorks' building, repair, and refit work, Smith has involved himself in the community, chairing various groups such as the East Boston Economic Development Council, serving as trustee of the Boston Harbor Association, and as director of the East Boston Chamber of Commerce. Any visitor to this area will attest that there's a lot to be done here; it could use a hundred more Scott Smiths.

(For a closer look at an early, major Boston BoatWorks project, see PBB No. 57, page 110. It describes how Lindsay directed the hull and deck construction of *Reindeer V*, a custom performance yacht built for Morris Yachts of Southwest Harbor, Maine.)

The Marketing Whiz

Bob Johnstone, 71, is a longtime sailor and marketing executive. His introduction to boatbuilding was similar to Lindsay's: in 1947, in the family garage in Glen Ridge, New Jersey, Johnstone and his father kit-built a 19′ (5.6m) Lightning. After an international corporate career with two large conglomerates (Quaker Oats and AMF), he and brother Rod founded in 1977—and still own—J Boats, based in Newport, Rhode Island. Beginning with the J/24 one-design keelboat, their company has sold more than 12,000 boats, ranging up to its latest, the mostly carbon J/65, built by Pearson Composites in Warren, Rhode Island. (For the full story of J Boats, see PBB No. 98, page 28.)

On a rainy spring morning in East Boston, I'm down below in Bob Johnstone's current project, a pocket motoryacht designated the MJM 34z. As if to demonstrate the simplicity and livability of the boat, Johnstone serves freshly perc'd coffee and a high-carb chocolate croissant. Life is good.


DAN SPURR

Bob Johnstone is a demanding customer; just ask builder Mark Lindsay and designer Doug Zurn. A marketing director with two major conglomerates (Quaker Oats and AMF) before founding J Boats with brother Rod in 1977, Johnstone has shown he can identify an emerging market niche—and then fill it.

For finding the next market niche to exploit, the Johnstones, as a family, have been reliably guided by their own preferences in boats. And those preferences run to family-oriented activities: racing and cruising. Bob Johnstone and his wife, Mary, have always sailed together, even qualifying for two world championships in the 470 class, with Bob as skipper and Mary on the trapeze. It's as if to say, "If *I* like it, others probably will, too." This assumes, of course, that Bob and Mary Johnstone are representative of some identifiable consumer group. And experience shows that to be true. Johnstone says he's benefited from being a decade ahead of the most influential consumer group of our time: 77 million American baby-boomers. "First," he says, "it takes a while to realize that a production-boat idea is worth pursuing. Then a while longer to persuade myself and others to get it built. By then the timing to fill the needs of boomers is just about perfect." In this case, it's a now-familiar tale of aging sailors and powerboaters seeking comfort, simplicity, and safety in a powerboat that will allow them to extend their boating years.

Johnstone explains the train of thought that led to the MJM 34z:

Interior Solutions (Part 1)

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- **Awlbrite Clear Gloss** - An acrylic urethane finish that provides a high gloss, long lasting finish.
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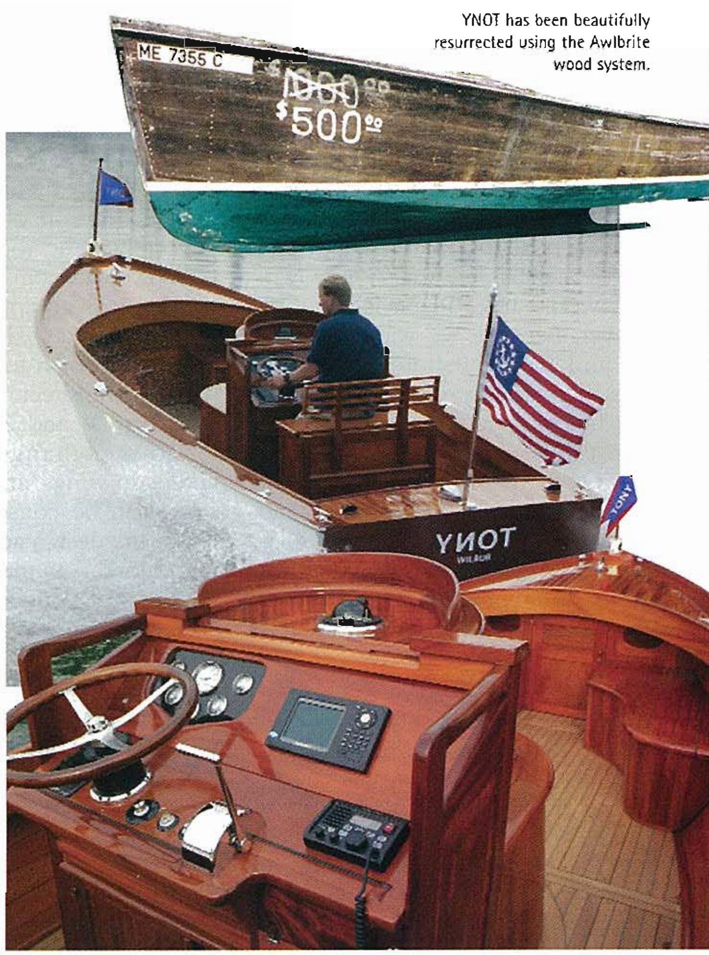

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"Mary and I had done our big-boat cruising on J/44s and J/42s, and I'd done my campaigns with J/105s and J/120s. As we got older, sailing became mostly me racing with the guys. Understandably, Mary doesn't find much joy anymore in getting cold and grinding winches; we were spending more time on a powerboat, our Dyer 29 [8.8m], taking short cruises up and down the Intracoastal Waterway or among the islands off Maine. And we could do that anytime. It could be a lousy day like this, rainy and cold, or no wind, and we could still go out." (The Dyer 29, built by The Anchorage in Warren, Rhode Island, and delivered in a variety of configurations, has been in continuous production since 1955. See PBB No. 28, page 72.)

So Johnstone began focusing his practiced eye on the powerboat market. He tried to envision a boat that, as he says, "might do a better job than the Dyer 29 in fulfilling our needs. We didn't want a large boat. I wanted a boat that Mary would still drive by herself if I wasn't in town. Yet, it would have to be larger than the Dyer, because we wanted sociability and more offshore seaworthiness, a boat that could sit six people down below. You certainly can't do that in the Pearson True North 38 or Hinckley Picnic Boat or any other boat this size that I know. It also had to sit three couples who could converse under way in any kind of weather. That meant a pilothouse. Seems you'd have to buy a 44-footer [13.4m]."

Or would you?

Johnstone drew a rough layout of what he wanted and then posed the following question to himself and to son Peter (now running Gunboat Multihulls): "What's the prettiest powerboat under 40 feet [12.2m] on the market?" He and Peter agreed it was the Zurn-designed Shelter Island 38, commissioned by singer/songwriter/boat aficionado Billy Joel. "Doug Zurn has the eye," Bob says, "plus he has experience designing higher-speed, offshore boats. The problem with the conventional Down East boats is that they aren't especially good over 20 knots in a seaway. As keelboats, they bow-steer down waves, and they roll around unless designed with excessive beam. And they're not shoal draft. [The MJM 34z draws 2′4″/0.7m.] I wanted more of an offshore performance boat than an inshore lobsterboat."

In the design brief to Zurn, Johnstone made clear his concerns about Down East styling as well as performance. He told Zurn that the boat had to bowl him over with its beauty, while still fulfilling performance and functional objectives; otherwise, it was no go. "I didn't want to own another boat company just to introduce another motorboat to the market," Johnstone says. "Down East–style cruisers have too much superstructure. They have nice sheer, but too much spring to the sheer emphasizes the cabin sides. So my thought was to cut away the superstructure, giving it more of a workboat-looking configuration...and just have roll-up Strataglass panels. It made a big difference in the look of our boat, even though the hardtop is fairly high. Designing a good-looking 34-footer [10.4m] is a real challenge if you want to stand on top of the engine. Once you elevate the roof to get 6′6″ [2m] piloting headroom with just a line of windows, it can appear a bit ungainly. We took that side window and brought it down to a line that sort of parallels the sheer."

Johnstone and Zurn engaged in a lengthy exchange of e-mails and faxed drawings and sketches. Johnstone can be considered an exacting client; the design adjustments went on for a month—to the sheer, cornerpost, pilothouse layout, the bow, and more. Some changes, to Lindsay's chagrin, were made at the plug stage, where it's costly. "Despite all the experience of this team," Johnstone says, "when you see the prototype *live*, it doesn't always come out the way you imagine it should, even after looking at 3D CAD drawings. Painful as it may be, you have to bite the bullet and make things right."

The net result of that process is a 34′ hull with a pleasing tumblehome aft, reverse sheer, and a generously flared bow for better visibility from the helm, better seakeeping in waves, a drier ride, and more space below. Three superstructure variations are offered: Express, Express Hardtop, and Downeast (see PBB No. 84, page 18). The hullform is a modified deep-V with 18° transom deadrise. Dry-weight displacement is 10,000 lbs (4,545 kg) and beam is 11′(3.4m).

Having seen the agonies that Hinckley went through with a raft of look-alikes to its popular Picnic Boat, and wanting to establish a signature look for this and future MJM models with some degree of legal leverage, Johnstone and Zurn took the unusual step of applying for and securing a U.S. Design Patent on the "ornamental look" of the boat and its line variations and extensions.

A driving design principle for Johnstone is combining functional simplicity with beauty, on the premise that a simple boat is likely to be a more usable, fun boat. Johnstone: "Part of this theory I've got, what's happened to Mary and me, is unloading the baggage of boating. Make it easy, make it really fun...coming full circle to what got you involved in the sport, whether it's motorboating or sailing. The joy of just going out on a nice day in a beautiful boat and not having a care in the world."

And this is where, in a roundabout sort of way, Boston BoatWorks comes in.

Mary Drives the Design and Construction

Mary Johnstone liked their old Dyer 29, and the size seemed about right for her to manage alone. The question, back in the summer of 2002 when they were contemplating the potential for a new boat, was how to achieve that in a boat that is more livable, sociable, and seaworthy. The new design would probably have to be in the 32′ to 35′ (9.8m to 10.7m) range. Bob Johnstone concluded, "The only way is high-tech, strong, narrow, and light, so one can still push it off the fuel dock. Doug [Zurn] and I went back and forth on that. It couldn't weigh 15,000 pounds [6,795 kg]. Furthermore, if we could get the weight down, then the performance from a single engine could match most twins, not to mention using half the fuel." (Escalating fuel prices in the wake of Hurricane Katrina now make development of a fuel-miserly cruiser look like a stroke of genius. Okay, sometimes it's better to be lucky than good, but as director of market strategy for Quaker Oats, Johnstone was, after all, the consummate "futurist.")

Johnstone next consulted his sons Stuart and Peter, both active in the marine industry. Among other enterprises, Stuart had started the Internet business www.boats.com; and Peter,

before launching his own Gunboat Multihulls company, had contact with former Boston Whaler engineer and longtime fiberglass boat pro Bob Dougherty (who had also set up and sold Edgewater, then started Everglades Boats). Peter suggested his dad consult Dougherty, which he did. According to Bob Johnstone, Dougherty said, "Bob, even the Carolina guys can't build that boat. Nobody in the powerboat market has experience building a boat like what you're looking for." Johnstone concluded that he'd have to go back to his sailboat buddies, ultimately narrowing his decision to two hands-on builders who'd turned out *America*'s Cup boats: Eric Goetz (Goetz Custom Boats, Bristol, Rhode Island) and Mark Lindsay.

Johnstone: "I didn't want to go with an operation that said they can do impregnated epoxy layup but hadn't been doing it for 25 years, as these two guys have. I know the SCRIMP process gives a very high-quality laminate, but the problem is you can't control it in the corners and in joints between balsa panels, so you don't really lose weight when you build with SCRIMP; you just improve the quality of the laminate, often gaining weight compared to hand layup. I wanted to match the laminate properties of the SCRIMP-type layup, so it had to be a vacuum-bagged layup to remove trapped air—every 1% trapped means a loss of 10% of laminate properties—without the weight of high resin content. To control resin content implied pre-impregnating it somehow. Both Goetz and Lindsay had been doing that."

Goetz, though, was a year out building TP 52s, the new transpacific class, but Lindsay was available and willing to make Johnstone and his Zurn-designed project the number one priority.

And that's how Boston BoatWorks and Bob Johnstone got together—because Johnstone wanted a fast, strong, lightweight boat his wife could push off the fuel dock. While the trademark MJM doesn't officially stand for anything other than a decorative trademark with a "J" that a guy with a name like Johnstone thinks looks nice at the end of a covestripe, the unofficial meaning of the letters is Mary Johnstone's Motorboat. And in case you hadn't guessed, the "z" in 34z stands for Zurn.

Construction

As a precautionary step, moving into the powerboat market for the first time, and concerned about product liability and meeting European standards for marketing purposes, Johnstone wanted to engineer the boat to the highest international standards. To accomplish this, he brought in Steve Burke, a University of Michigan–trained naval architect and marine engineer with CE Mark certification experience. Prior to opening his own office—Burke Design, in Bristol, Rhode Island—Burke was the marine engineer responsible for structural and composite engineering at TPI Composites in nearby Warren; among other boats he'd spec'd for TPI were two technically advanced models in the J Boat product line, the J/125 and J/145.

BOSTON BOATWORKS

The 34z's FRP pan is outsourced to Meikle Marine & Machine in Tiverton, Rhode Island, and trucked to Boston BoatWorks.

MJM YACHTS

MJM's interior modules, including the honeycomb-cored component here, are fabricated by East Coast Interiors in North Dartmouth, Massachusetts.

Surprisingly, Johnstone says, the ISO and CE Mark standards existed only in the 2003 draft form. But, to err on the overbuilt side, he asked his design-and-engineering team of Burke, Zurn, and Lindsay to engineer and build the 34z to exceed those ISO draft structural requirements for a Category A 50-knot oceangoing boat. (The initial plan was to offer the 34z with both single- and twin-screw installations, but buyer preference for single screw, and rising fuel prices, made Johnstone rethink that strategy.) Burke specified a Kevlar/E-glass laminate with epoxy resin, noting the latter's superior mechanical properties, improved fatigue characteristics, resistance to water degradation, and good adhesion. Burke says Boston BoatWorks is achieving a 60%–62% glass-to-resin ratio. The company uses a

Marketing the MJM 34z

Just as he did targeting markets for the various sailboat models of J Boats, Bob Johnstone is taking aim at a specific segment of the Down East–style cruiser market. Fast, modern, stylish, economical. Those might be the watchwords. Five years ago, when he was planning the MJM 34z, he and his wife lived winters in Charleston, South Carolina; summers were spent in Northeast Harbor, Maine. Always willing to use himself as a test case, he wanted a boat that could be trucked between the two addresses. "It's hard," he says, "to justify putting $300,000 to $400,000 in a boat you leave half the year."

Those logistics were altered when the Johnstones themselves relocated their winter home to Boston, albeit partly to be closer to Boston BoatWorks. But, like a lot of smaller, good-quality boats, the MJM 34z has a certain appeal, says Johnstone, for people moving down from larger, more complicated yachts. "By now," he reasons, "they probably have a nice piece of shorefront property somewhere. They don't need to live on the boat as a second home. And it doesn't make sense to park a big sailboat or trawler in front of their award-winning architectural shoreside gem. It's not easy to go sailing or use that kind of boat. Give them something they can jump on, on a whim."

MJM YACHTS

But what about that market in a slow economy?

"People with the money *are* the market," he avers. "If they find something they like, they'll buy it."

Available in three models—they differ primarily in superstructure—the MJM 34z features a cherry wood interior and some elegant options, such as Stidd seats in the pilothouse and a gloss-varnished teak Adirondack seat across the transom. The first nine hulls sold for just under $400,000 all-up, the later units more.

—*Dan Spurr*


MJM YACHTS

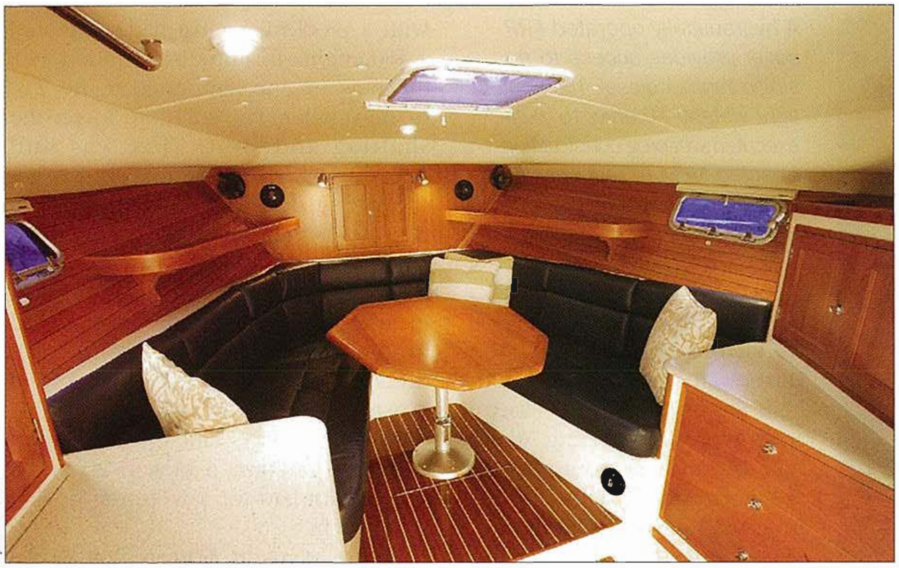
Johnstone and Zurn tried to minimize the mass of the Down East–style superstructure by using roll-up Strataglass instead of solid panels. An important design requirement was to be able to comfortably accommodate six in the pilothouse area—easily done with the two Stidd seats, opposing settees, and an Adirondack-type bench along the transom.

fabric impregnator designed and built by *Professional BoatBuilder* technical editor Bruce Pfund 15 years ago. Pfund describes the machine and its operation at Boston BoatWorks in the companion article, "Smooth Operators," on page 66 of this issue.

Fabric reinforcements are delivered to BBW precut, with clean edges, from Composites One (Arlington Heights, Illinois). Resin is supplied by Pro-Set Inc. (Bay City, Michigan). For post-curing, a tent of double-walled plastic sheeting is erected over the structure, and heat from a 60,000-watt electric oven in the basement gets ducted through the floor of the shop. Temperature inside the tent is ramped up to 145°F (70°C) for 12–18 hours. BBW's Scott Smith says one of many reasons they use epoxy instead of vinyl ester is that the latter would have shorter gel times due to the thickness of the chines, which would require doing the layup in two shots instead of one.

Why not pre-pregs? you might ask. Lindsay and Smith say there are several good reasons, namely: lighter weight with wet-pregs; exclusion of air and better control of adhesion; and the inability of pre-pregs to fill core kerfs.

Contour-cut Core-Cell SAN foam of varying densities, made by SP Systems (Magog, Quebec), is employed in the



MJM YACHTS

Most, but not all, of the fiberglass pan is covered by a teak-and-holly sole overlay, wood ceiling, cherry cabinetry, and bolstered Ultraleather upholstery. Countertops are Corian. The cooktop is electric, powered by an inverter off a 505-AH battery bank.

hull and bulkheads—higher density in the hull bottom, lower density in the topsides and bulkheads. Core panels are pre-bent on shop-made jigs to open up the kerfs, and then filled with epoxy and fumed silica. For the deck, the core material is SuperLite end-grain balsa, shipped in precut kits by the manufacturer (Alcan Baltek, Northvale, New Jersey).

The fabrication of a CNC-machined structural grid, using low-cost foam from the Elliot Company (Indianapolis, Indiana), is outsourced to Meikle Marine & Machine Inc. (Tiverton, Rhode Island). Boston BoatWorks installs it with wet-preg tapes and co-cures it with the hull laminate. Meikle also fabricates the 300-lb (136-kg) liner that incorporates the cabin sole, forward berths, and backrests, as well as the lower lockers in the head, galley, and entertainment center. Keel and chines are solid fiberglass. Engine beds have Penske board for forms.

Cook Composites & Polymers (Kansas City, Missouri) gelcoat and a Generation 2 (non-water-soluble) tie coat, plus 6-oz surfacing veil, make up the skincoat. Contact layers are deblushed before beginning the structural laminate. Interior surfaces receive gelcoat that is rolled on without a tie coat, and finished with Awlguard. Finished, gelcoated hulls are trucked to Metan Marine in Rockland, Massachusetts, where they are painted with Awlgrip linear

MJM YACHTS

A hydraulically operated FRP cover provides access to a single Yanmar diesel. The boat's light weight—thanks to well-executed wet-preg construction—enabled MJM to dispense with a second diesel and its significant associated costs.

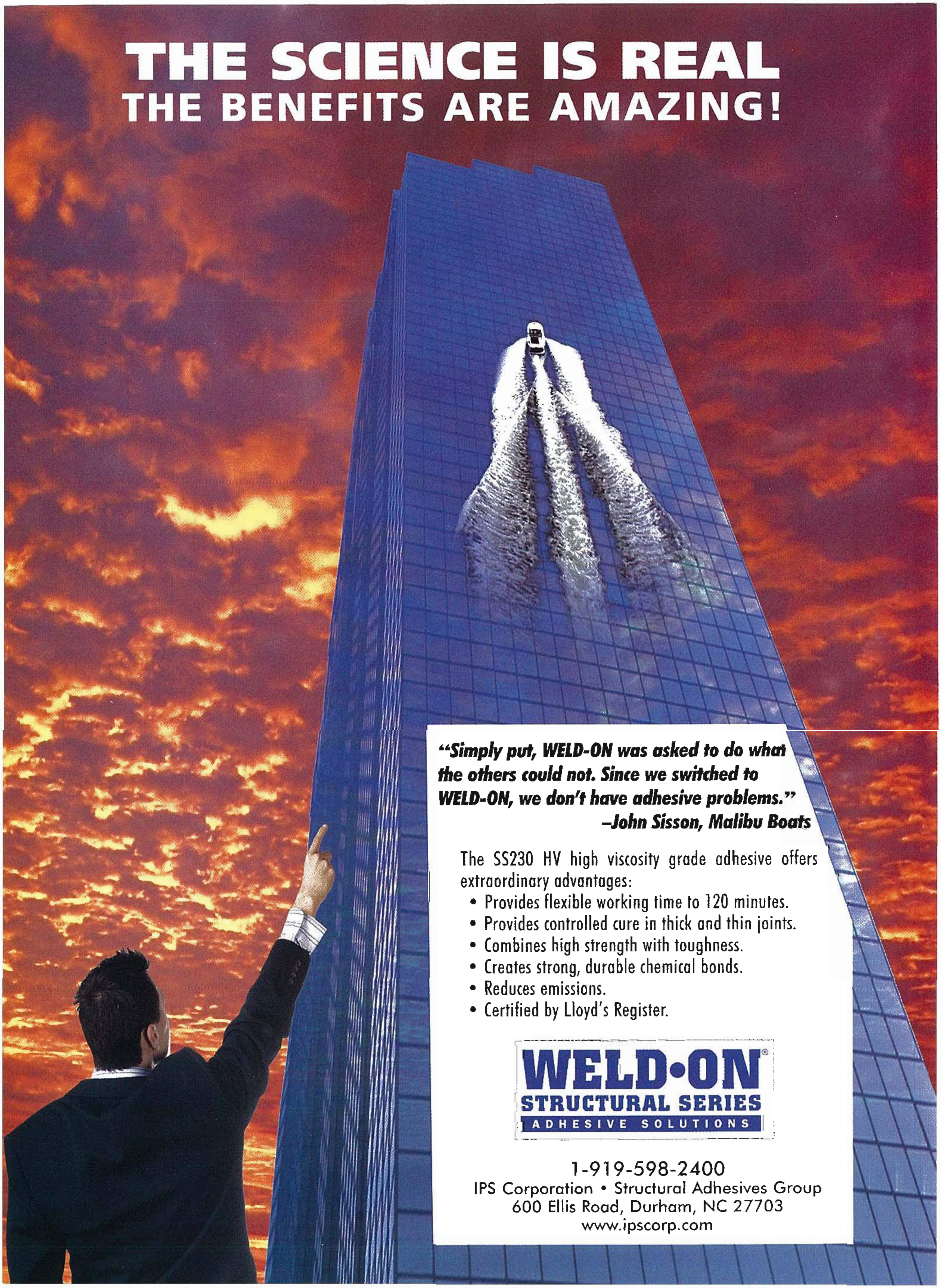
polyurethane and then returned to BBW. Decks are given a removable protective coating of Alecseal (Mankiewicz Coatings, Hamburg, Germany).

Hull layup and final assembly takes place at Boston BoatWorks' waterfront facility on Boston Harbor. It's a former Bethlehem Steel plant where Liberty ships were built during World War II. Interior components are outsourced to East Coast Interiors, a North Dartmouth, Massachusetts, cabinet shop serving yacht and business-jet builders (see PBB No. 97, page 20). Hull and deck are prewired with harnesses from American Marine (East Patchogue, New York). Several Yanmar diesel-engine packages are available.

On the day that Bruce Pfund and I visited BBW, Lindsay was buzzing around the assembly area wrestling with a problem: Yanmar had substituted a 480 engine for the discontinued 440; the new engine happened to be 2⅝" (67mm) taller. The solution: lower the shaftlog and strut. That was hull #21...just when you think you've got everything down. Hull #1 took 6,700 man-hours; #22 just 1,800 man-hours. Lindsay says the target is 1,750 man-hours, though he comments, only half in jest, "We'll find some way to add hours." More than likely—as the unexpected engine problem above illustrates—through no fault of his own. Either way, Lindsay and Smith will keep building a boat every three weeks. Not bad for a wet-preg pocket motoryacht.

Future plans at Boston BoatWorks call for the construction of additional MJM models (larger and smaller than the 34z), and continuing the shop's repair-and-refit business. And, naturally, taking on new projects that fit the partners' way of building boats. PBB

About the Author: *Dan Spurr is* Professional BoatBuilder's *editor-at-large.*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Smooth Operators

Boston BoatWorks has deftly moved from custom one-offs to series production without changing its basic menu of materials: vacuum-bagged epoxy wet-pregs.

Text and photos by Bruce Pfund
(except where noted)

Professional BoatBuilder editor-at-large Dan Spurr and I visited Boston BoatWorks, on Boston Harbor, last spring. His article, on page 52, covers BBW's origins and products; mine will look at BBW's advanced-composite construction practices—specifically, its reliance on a large fabric impregnator to produce just-in-time wet-preg laminates that are then vacuum-bagged, cured at room temperature, and finally, post-cured at elevated temperatures.

The impregnating machine at the heart of the BBW production process lives in a dimly lit alcove off the main shop, out of the way of molds, materials, and part movements, yet close enough for easy transport of wet-out reinforcements. The impregnated fabric is rewound onto cardboard- or PVC-tube carriers, and walked to the tooling. Having designed and built this particular fabric impregnator, in 1991, I was delighted to see it again in operation, albeit with a few more miles of fabric run between the rolls and more resin stuck to its metal surfaces than when it left my shop. Boston BoatWorks cofounder Scott Smith said, "When Mark Lindsay [Smith's partner in BBW] had that impregnator at his boatshop in Gloucester [Massachusetts], he used it to build a number of sailboats and a couple of

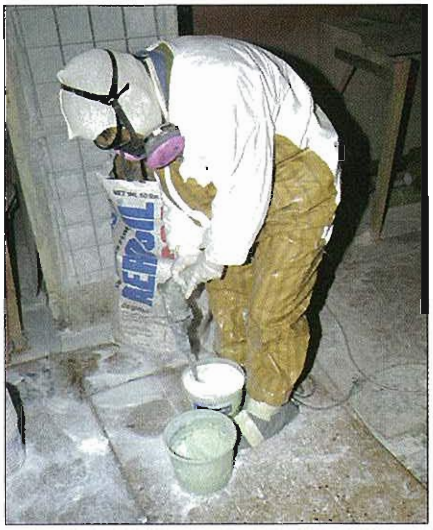
MJM YACHTS

Opposite page—*Boston BoatWorks personnel add four plies of epoxy wet-preg to the engine beds of one of MJM Yachts' 34z hulls after all the other laminating and process materials have been applied. The waiting vacuum bag rolled against the side of the mold is ready to be deployed when it's time for the wet-preg hull to cure under moderate vacuum levels.*
Top left—*The BBW fabric impregnator is bucket-batch fed, and operates with a crew of two, plus a resin mixer, when processing material of moderate width. For wide material, the impregnator crew increases to four: two to prepare resin for feeding the machine, and two to serve as machine operators and to deliver wet-preg to the mold.*
Below left—*The new MJM 34z* Grace *is a study in light-displacement performance, thanks, in part, to the care taken in BBW's wet-preg construction of her hull.*

powercats. Here at our Boston facility we're now [as of June 21, 2005] working on hull number 27 of the Zurn-designed MJM 34z, so we've made quite a few large parts with that machine, not to mention plenty of smaller parts and some architectural projects, too."

A critical difference between wet-preg production and in-situ wet layup is that the impregnating machine can reliably produce enough material to keep up with the placement crew's demands. Once the impregnator is fired up, the crew in the mold can basically forget about wet-out concerns, including how the impregnator is running. Fabric wetout is now someone else's job. The placement and tailoring personnel should be able to rest assured that the reinforcements they receive have the correct resin content, and at BBW, are also cut very close to their final lengths because the impregnator operator is carefully monitoring the machine's footage counter.

Is there a downside to the impregnator's high-output capability? Maybe one: the machine's output must be coordinated so the placement crew does not get overwhelmed with more wet-preg than can be applied within the working-time window *before* process materials and vacuum bag have to be secured in place.



A crew member prepping a bucket batch. He first combines the resin and hardener using a low-shear power mixer, and then thickens the batch slightly with fumed silica.

Why Wet-preg?

I asked Lindsay and Smith why they elected to build a good-sized production powerboat with vacuum-bagged epoxy wet-preg reinforcements rather than, say, frozen B-staged pre-pregs, or some type of infusion process. Since all of these systems require vacuum-bagging and an oven cure, why go with wet-pregs?

Lindsay replied: "We were plenty familiar with the impregnator from previous one-off projects, and were confident we could achieve better economies when building multiples of the same boat. We'd never done that before. This is not a raceboat.

"Also, we're not aiming for an extremely low resin content in our laminates. The goal is a well-consolidated, void-free laminate that can be produced in a reasonable amount of time. We want the resin exactly where we want it."

Lindsay continued, "When I worked at Hercules [an early producer of carbon fiber reinforcements

Above left—*The machine operator, while manually rewinding wet-preg onto a cardboard core, looks up frequently at the footage counter on the unwind roll. Most rewound materials the author saw handed into the mold were precisely cut to length, with no end-trim required by the in-mold placement crew. Note that the wet-out material is being manually rewound onto the cardboard core, and that the roll of dry fiberglass above the nip is sitting off-center on the unwind arbor, with no side-stops or cone collars to align or center it. This setup works for low-to-moderate speeds—around 10–12 lineal feet (3m–3.7m) per minute. At faster speeds, not only will the rewind operator be unable to keep up, the unwound roll of dry fiberglass will start to wander from side to side. At that point, it's time to engage the air-operated rewinder, and fit the cone collars to align and center the unwound roll on its arbor.*
Above right—*The BBW impregnator has an arborless rewinder, where the rewind core is driven directly by an air motor on one end and aligned by a free-rotating cone collar on the other. This end's cone-collar axle can be slid in and out approximately 4" (10cm), and then locked in position to accommodate different rewind-core lengths. The cone collar is also spring-loaded to accommodate rewind cores with ends that are not cut off perfectly square. BBW co-owner Scott Smith said, "We only use it for running full-width materials while laminating the hull sections and the deck." Rewound rolls of wet-preg for those parts can weigh well over 100 lbs (45 kg).*
Right—*The drive side of the arborless rewinder, showing the air motor and, attached to the cone collar, the drive lugs; the latter register in corresponding cutouts in the ends of the PVC rewind cores. The rewinder system is driven by an eight-vane, ⅜-hp Gast Manufacturing Company (Benton Harbor, Michigan) air motor. An eight-vane configuration stutters less than a four-vane motor when stalled or at low rotation speeds. It also offers smoother start-up and more sensitive tension-control adjustments.*
Far right—*Three-inch (7.6cm) Schedule 40 PVC tubes serve as rewind cores for the impregnator's rewinder. BBW uses the rewinder only when working with 50"- and 60"-wide (127cm and 152cm) reinforcements. Note the fiberglass reinforcements on the tube ends, meant to handle the high drive loads developed during the rewinding of long runs of heavy fabric.*

and finished parts] on *Jayhawk* [an *America*'s Cup boat], some areas in the boat had 90 to 100 *layers* of prepreg laminate only six-thousandths of an inch thick, with a debulk cycle after every two plies.

"By contrast, with our wet-pregs we can run much thicker reinforcements, apply multiple layers in a single gel cycle, and assemble hull and deck skins in only one bag cycle—because the resin is still liquid, not B-staged and 'locked-up,' except for a brief period when the resin liquefies during the cure cycle. The bag works on our laminates for quite a while before the resin gels. With our resin's low viscosity, it's easier to move bubbles around—out of the core kerfs and the wet-preg laminate stack."

Smith and Lindsay pointed out that selecting the correct perforated release film is critical to producing well-consolidated laminates that have not bled too much resin and become aerated. "Wet-pregs also have advantages when working with cores," Lindsay added, "especially contour-cut cores. We devote a lot of time and effort to filling all the core kerfs on a special curved fixture, using epoxy putty. The putty is completely compatible with the laminating resin. Again, contrast that with pre-preg construction, where a film adhesive would typically be applied to bond core-block faces; but then filling the kerf system can be difficult, even if you use a special kerf or butt-splice filler adhesive that expands when heated."

Top—*Approximately 40 lineal feet (12m) of 18"-wide (46cm) wet-preg biaxial tape—wet out and rewound in about three minutes' elapsed time—is ready to go over the sheer flange and into the tooling to the placement and tailoring crew.*
Above—*One layer of wet-preg has already been applied to the starboard stringer and has darts cut at the corners of the cross-member intersections.*

The Impregnator

BBW has developed highly choreographed laminating procedures. The impregnator operator matches the machine's output rate to the human crew's application rate. Two, and sometimes three, placement crews work inside the hull mold during framing lamination. More people would simply not fit, and the ones who do have all the wet-out and rewound fabric they can handle. The application sequencing is methodical and efficient, set up so the crews work without ever having to walk or stand on any of the wet-preg materials.

On the day of our site visit to BBW, the impregnator was producing laminate tapes ranging in width from 18" to 30" (46cm to 76cm). The person mixing resin at the machine—his primary task was to feed the impregnator's dip bath—also delivered rewound rolls of wet-preg to the placement crews. Fabric reinforcements, made by Johnston Industries (Phenix City, Alabama), had been slit to width by BBW's local fabric supplier in Bristol, Rhode Island (Composites One, Arlington Heights, Illinois). Lindsay agreed with me that vendor-slit material, with its true edges and uniform rewind tension, tracks straighter and runs better through the impregnator than does shop-cut fabric. During an afternoon of observing, I saw no significant fraying of the cut edges, and no windup snags on the impregnator rolls or when materials were unwound in the mold.

BBW's impregnator is fed by the bucket-batch method, even when running full-width heavyweight reinforcements. Any resin that leaks around the dams containing the nip bath is occasionally scraped off the rotating rolls. This resin drops down onto polyethylene film that lines the impregnator's inclined drip tray,

which drains into a large waste bucket. Escaped resin is *never returned to the wet-out bath*, because its remaining working time is unknown.

Smith commented that adding meter/mix/dispense equipment to the impregnator is on the BBW wish list. "Our guys spend a lot of time mixing resin and hardener, and then adding fumed silica to it," he said. "An equipment setup that would put out prethickened and premixed resin to the dip bath with the push of a button would be really nice. A while ago we looked at high-output equipment with gear pumps and static mixers, but didn't buy it. Now that we're running the impregnator so much, I wish we had."

The build cycle at BBW—during which the crew applies outer-skin wet-pregs, followed by structural core and inner-skin wet-pregs, and then bags it all together—requires rapid output and rewinding of wide material. BBW's impregnator has a 2-hp air-motor roll drive, and is geared to generate up to about 24

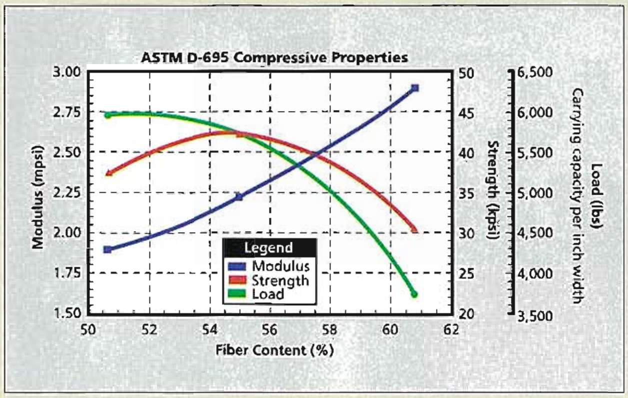
Continues on page 77

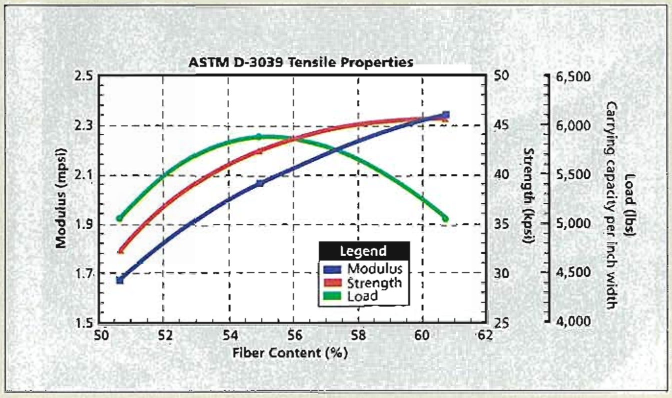
Fine-tuning the Fiber-to-Resin Ratio

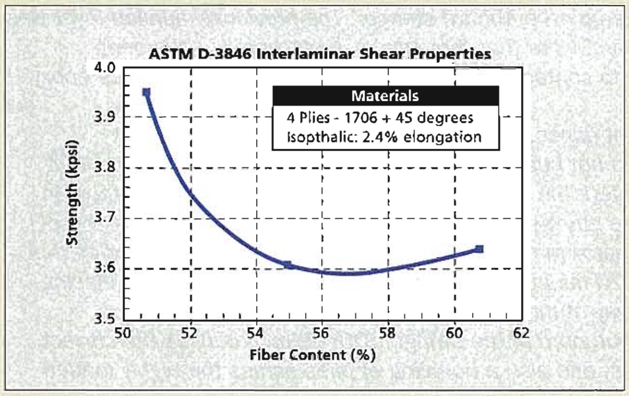
Fabric impregnators offer two big advantages over wetout by either manual layup or sprayup methods. The first is uniform fiber-to-resin ratios, whether high or low, in the impregnated material. Resin content from a good machine that's been set up correctly should not vary more than plus or minus 1%, whereas resin content in hand layup in a reputable shop typically varies plus or minus 5%. The second advantage is a brisk production rate. An impregnator can output up to 25 lineal feet (7.6m) per minute of 24-oz knit or woven reinforcement with 1.5-oz mat stitched to it. At 60″ (1.5m) wide, that figure translates to roughly 32 lbs (14.5 kg) of reinforcement and approximately 3.6 gal (13.6 l) of resin per minute, at 50% resin content by weight.

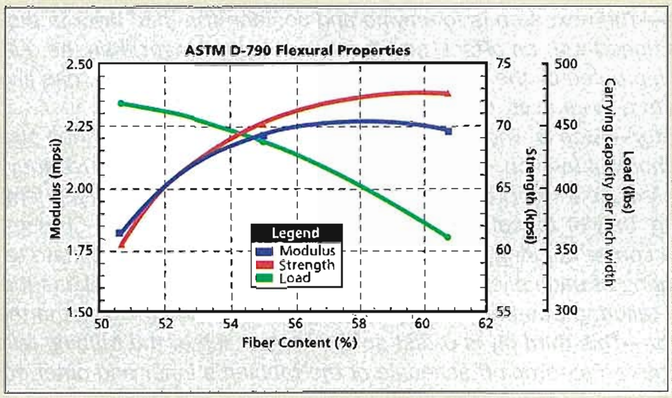
During an IBEX '05 seminar in Miami Beach last October, structural engineers David Jones (D.E. Jones & Associates, St. Petersburg, Florida) and Richard Downs-Honey (High

The mechanical properties illustrated in these graphs are for hand-laid laminates with no vacuum consolidation. Low-resin/high-fiber laminates are commonly associated with better mechanical properties when well compacted, but show weaknesses here because manual layup also allows high air content in the laminate. Note the better flexural properties of the laminates with very high resin content—another apparent contradiction that occurs because the laminates become thicker, and therefore stiffer, with more resin.



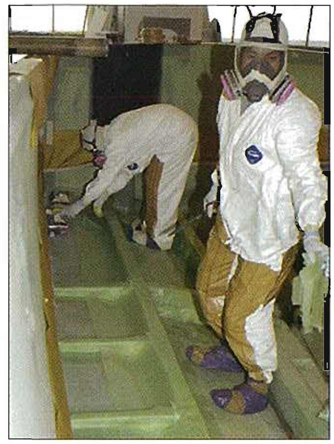






D.E. JONES & ASSOCIATES (ALL)





Left—*The next step is to unwind and position the third layer in the starboard outboard stringer. The previously applied layer was positioned with an offset, so the inboard leg is longer than the outboard. Note that the crew's Tyvek overalls have been resin-proofed by the application of Mylar shipping tape in areas likely to contact the wet-pregs. Everyone in contact with epoxy wears a Tyvek suit, respirator, and gloves.*

Center—*Step 3. The wet-preg tape applied to this stringer has straight edges, and is thus easy to tailor in a neat and methodical fashion. Darts and pleats stay organized because they are not bubblebusted, just gently squeegeed into contact with adjacent wet-preg layers. While frame members are being laminated, the few buckets inside the tooling have no resin in them; they're for collecting scraps from laminate tailoring. Cutouts are saved; these fill in the "windows" that develop at outside corner tailoring. Total time to apply three layers of laminate to approximately 20 lineal feet (6m) of stringer, including the tailoring of each ply to the seven structural intersections? Less than 20 minutes. Concurrently, another taping crew—placing and tailoring wet-pregs in forward sections of the hull—is not in the way of the three-man team laminating the stringer.*

Right—*This third ply is offset so the longest leg of the tabbing falls outboard of the stringer. Offsetting produces the correct staggered ply-drop-off schedule at the tabbing's inner and outer edges, and also a doubling of plies across the highly loaded stringer-cap surface. The first ply goes down symmetrically.*

To determine whether laminates to be vacuum-bagged have sufficient resin, a simple but effective test is to select one or more sample areas and then apply gloved thumb or hand pressure. A slight resin puddle should form there, but then disappear back into the laminate rather quickly. Note that the palm print at the top aft end of the engine-bed laminates is void free—a sign there is sufficient resin content. For more on this shop level procedure, see Professional BoatBuilder *No. 95, page 26.*

Modulus, Auckland, New Zealand) and I discussed the merits of wet-preg construction. Jones presented graphs—four of which appear here—that clearly illustrate the improved mechanical properties of laminates made with an impregnator. Such laminates contain less resin than would normally be in the reinforcements after sprayup or manual layup. In addition, an impregnator offers *consistent* resin content, permitting accurate predictions of a part's final weight and its mechanical properties.

The same fiber and resin variables that affect sprayup and hand layup processes play a role in wet-preg production. Resin viscosity and temperature are significant factors, as are fabric type and weight. Densely packed unidirectionals or heavyweight knitted materials will take longer to wet out than lighter, more open fabric. Accordingly, their dwell time in the machine's nip must be increased by slowing down the impregnator speed.

Other strategies to increase fabric wet-out rate include specifying a lower-viscosity resin, or reducing resin viscosity by heating. To determine correct settings, you'll have to test the device's output at various speeds. Check fiber-to-resin ratios in increments of 5 lineal feet (1.5m) per minute output speed until you hit the target proportions. Tip: *change only one variable at a time.*

You can heat resin in several ways. For small projects where the impregnator bath is hand fed, the resin can be dispensed from drums warmed with electric band heaters. For larger projects and higher speeds, you can use in-line electric block heaters between the resin pumping system and the dispense head, but you'll have to make provisions for constant resin recirculation when the impregnator is *not* running, to prevent resin from "cooking" in the heater. Heated nip rolls are yet another

The thick four-ply laminate in the engine-bed region is consolidated by squeegeeing—but no liquid resin runs out ahead of the squeegee, as it would in conventional wet layup. Squeegee pressure only releases entrapped air from between the wet-preg plies. Small amounts of epoxy resin, thickened with fumed silica and glass microballoons, get applied as fillets on inside corners, and to taper out regions having many ply drop-offs, such as the engine-bed area.

Continues from page 72

lineal feet (7.3m) per minute, full speed, at a nominal 60" (1.5m) nip width.

But, Smith then said that BBW had difficulty getting the impregnator and rewinder to run at high speeds. Running both the impregnator and the rewinder at full throttle requires an air supply of approximately 22 cfm at 100 psi; I suspected that inadequate airflow was causing the problem. I noted that the impregnator was fed air though a ¾"-ID (19mm) flexible hose, and that the original ¾" pipe-thread size filter/regulator and lockout/tagout valve assembly had been replaced with a ½" (13mm) pipe-sized filter/regulator setup. Smith told me, "The shop's compressed-air plumbing is inch-and-a-quarter [32mm] black iron; the compressor has plenty of output." I replied that increasing the bore of the machine's flexible supply hose to 1" (25.4mm), and reverting to ¾" NPT air-handling hardware, should allow the impregnator to achieve full speed again.

option for some processes, although you'll then have to avoid cooking resin in the nip.

Downs-Honey pointed out another factor when considering fiber-to-resin ratios in reinforcements: pressure on the wet-out reinforcements caused by rewinding. Rewind the fabric too tightly, and resin will be squeezed out; too loosely, and the rewound roll will become a sloppy, disorganized mess. Interleaving an impermeable carrier film (peel ply is a possibility, too) on one or both sides of the wet-preg usually solves the problem, as does careful adjustment of the drive tension on the rewinder system. Generally speaking, the best results are achieved with just a little more than the minimum amount of drive effort required to rotate the rewind roll.

Although automatic tension-control systems for rewinders are not too complicated, they can add at least $1,200 to the cost of the equipment. A sharp impregnator operator is usually more cost effective—someone who knows how to adjust the rewinder's slip clutch, or the rewinder drive's air-motor pressure regulator as the rewind roll grows in weight and diameter. Note that it's also good practice to check the wet-preg's fiber-to-resin ratios twice: once directly out of the nip and again after rewinding.

Remember, producing low-resin-content wet-pregs is a bad idea if the overall construction process will not create a void-free laminate. If, however, you wish to have skins with 45% resin content and that will be vacuum-bagged at medium pressure, then an impregnator will certainly deliver. By contrast, a hand-layup skin with that same resin content will be of poor quality, at best. I've been in impregnator-equipped shops that produce very dry wet-pregs; the workers place and squeegee

Left—*Preassembled, precut lengths of three-ply stacked-and-sequenced process materials are located on a bench near the impregnator.* ***Right***—*Moderate vacuum levels, combined with the controlled bleed of perforated release film, prevent absorption of excess resin into the bleeder. The soaked-through section in this image is over the thick engine-bed laminate region, and is normal.*

I asked Smith about any modifications he might propose to BBW's (or any) impregnator, and he had some good suggestions. "We always have one of our skilled guys set up and run the machine. We'd love to have vernier gauges or dial-indicator readouts for setting the gap between the rolls, or perhaps a dial with a needle that would point to settings for specific styles of reinforcements, such as 1208, 1808, or 2408."

As a matter of fact, in the late 1980s I built two high-accuracy impregnators fitted with dial-indicator nip readouts. They looked and worked great—except the dial indicators did not survive more than a few weeks on the shop floor of a laminating operation.

Smith continued, "I also wish that all the resin on the impregnator would just 'peel-ply' off. Or, that our rig had an automated 'rinse cycle.'

We spend quite a bit of time on cleanup."

Cleanup has always been a chore with impregnating machines. It's a design problem I investigated thoroughly when building these devices. Teflon-coating the complete machine is possible but very expensive and, according to the industrial coaters I spoke to, not practical. They basically told me that once the machine's operator attacks the Teflon-coated surfaces with a scraper, the coating will start to fail. All exposed surfaces and components on BBW's impregnator were made from unpainted 304 stainless steel or anodized aluminum. Operators can scrape away, use a sander or grinder, or even get out a propane torch or air-powered muffler chisel, if necessary. A more practical solution, though, would entail a liberal application of polymeric release agent on all exposed surfaces. That'll make future cleanup easier.

The net result of BBW's impregnator operators' hard work is that the personnel in the mold—which in more traditional composite boatbuilding shops would likely be called the laminating crew—is actually the placement and tailoring crew. That's because all the reinforcement wetout now takes place *outside the tooling.* There are no buckets of resin, or disposable brushes, or wire-frame rollers, or bubblebusters in the mold. Only rolls of neatly cut wet-preg.

Tailoring the Tapes

Taping and tabbing is typically a messy, time-consuming task during

the wet-out reinforcements, and then add more resin (by roller or saturator gun) until they think it "looks right." Such procedures simply short-circuit the benefits of wet-preg boatbuilding.

Finally, here are a few thoughts on evaluating new or used impregnating equipment. Machines with thin-wall rolls that are spring-loaded together will not be able to produce low-resin-content wet-pregs without extensive modifications to increase the squeeze in the nip. Be sure to check carefully for roll roundness, with an accurate dial indicator. Similarly, machines with thick-walled rolls and high-pressure nip mechanisms may not be able to produce high-resin-content wet-pregs, because the nip will have to be opened too much to "bite" the reinforcement and pull dry fabric off the supply roll. Machines that effectively produce high-resin-content wet-pregs (in excess of about 55% resin by weight)—perhaps for bedding structural core, or to generate a resin-rich surfacing layer—will probably have rubber-faced brake and unwind rolls synchronized to the nip rolls' speed. This feature feeds fabric into a wider, "softer" nip, and prevents the weight of the "tail" of material hanging below a soft nip from pulling additional fabric through. *—Bruce Pfund*

BBW's vacuum-bagged wet-preg is well finished, with little if any grinding required. Peel ply is left in place over any areas scheduled for secondary bonds, such as bulkhead and partition locations, and the hull-to-deck joint. BBW co-owner Mark Lindsay says, "We do whatever we can to minimize grinding, and we use suck-sanders. When we do have to grind something, we ask ourselves why, and try to figure out a way to prevent it."

the assembly of most open wet-layup projects. It's also a hard-to-predict source of weight gain, especially on big jobs. The BBW mold crew's skills in placing, tailoring, and consolidating the wet-preg tapes make taping-in the 34z hull's structural grid of urethane foam stiffeners and frames a remarkably tidy and efficient process. By carefully sequencing the application of wet-pregs and the follow-on process materials, the BBW crew avoids walking on any of the complex arrangement of wet laminates. Also, they avoid dripping resin on the panels between tabbed sections.

The speed and accuracy of the BBW crew were impressive as they applied two laminates of biax-and-mat tabbing to a stringer section approximately 20′ (6m) in length, along with seven cross-member intersections. You can see the neat straight edges on the tabbing, courtesy of the impregnator and pre-slit tapes; the three photos on page 74 capture that production sequence.

Process Materials

Ply-by-ply application of wet-preg laminates is but one part of the operation of placing, tailoring, and consolidating material; *process* materials must be added, too. At BBW, that stack consists of white peel-ply, a clear nylon perforated release film, bleeder-breather fabric, and the vacuum bag.

An important element of successful vacuum-bagging is planning, which involves pre-fitting as many of the layers as possible prior to layup. Note in the photos on pages 66 and 76 that the vacuum bag is already sealed to one side of the hull's inner skin, about halfway up the port topside panel. Tacky tape for the other hull side and transom is also in place, protected from resin contamination by brown-colored plastic-film tape.

Instead of laying down each material ply by ply, BBW sprays a mist of contact cement to bond the peel-ply to the release film and the release film to the bleeder cloth—outside the tooling. In the mold, the three preassembled layers are put down and tailored in one step. The crew's current practice is to assemble the materials stack by hand on a flat layout table. Smith was interested when I mentioned that the BBW impregnator, with a few tweaks (such as additional unwind stations), could also be enlisted to laminate the three layers of process materials together in a full 60″ width at a rate of 10 to 15 lineal feet (3 to 4.6m) or more per minute.

As the amount of framing inside the 34z hull increased, there was less and less space for the placement crew to work, and so the number of people within the mold gradually reduced. But, there was always a place to stand on laminate surfaces that had already cured. The four laminate layers for the engine bed—applied with offset edges to produce the correct ply dropoffs and ply doubling at the cap—went down in less than five minutes, but only after all nearby laminates and process materials were in place. Each length of fabric for the bed section was cut to length from a roll of wet-preg tape.

BBW's impregnator operator was paying attention to the machine's footage counter when the roll of wet-preg dedicated to the starboard engine-bed region was wet out and cut to length. At the end of the roll, after four lengths were cut, less than one foot of unused material remained on the cardboard core.

After years of one-off and custom boatbuilding, Lindsay and Smith are enjoying Boston BoatWorks' new role as a production shop. "We have the chance to fine-tune every aspect of building these boats," Lindsay said, "and to increase the efficiency of our laminating and bagging techniques. On one-off projects, those considerations were much less critical." To which Smith added, "Most of our good ideas come from the guys out in the shop and in the tooling. We're constantly innovating. I'm confident that in six months' time, we won't be building the way we are now. *That's* what keeps it interesting." PBB

***About the Author:** As "Bruce Pfund/ Special Projects LLC," Bruce consults on composite processes and inspects marine composite structures. He is the technical editor of* Professional BoatBuilder.

Shakeout

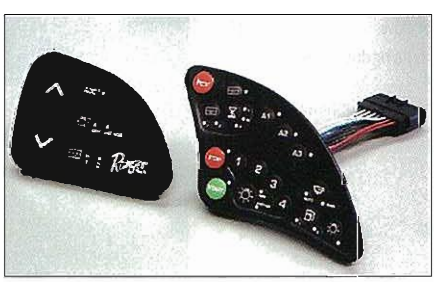
Our third and final installment on networking marine systems takes a closer look at the various players vying for position in the emerging—and important—technology of distributed power.

Text and photos by Nigel Calder
(except where noted)

In Parts 1 and 2 of this series—see *Professional BoatBuilder* No. 97, page 148; and PBB No. 98, page 50—I discussed the potential of contemporary networking systems to greatly simplify wiring harnesses on boats while also increasing the functionality and reliability of marine electrical, navigational, and propulsion systems. I also reviewed some of the competing protocols presently available. Now I'll examine in detail how this relates to the remote switching of loads (a.k.a. "distributed power system"), which is critical to wiring-harness reduction.

The principal players in the marine marketplace that I have identified to date can be grouped into those using the Controller Area Network, or CAN, protocols (see Part 2 of this series), and those using non-CAN protocols.

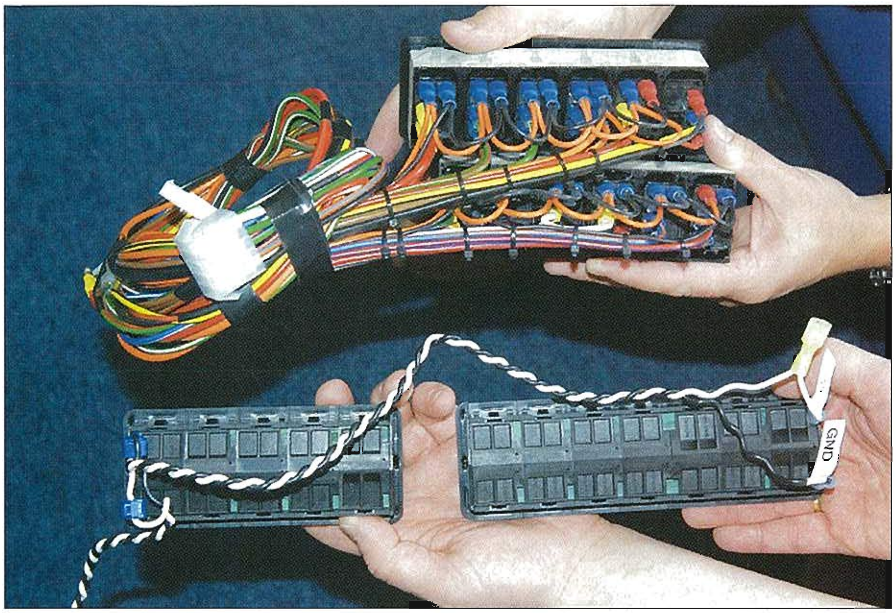
Within the CAN family the two systems having the highest visibility are SmartCraft, which has been developed by Mototron, a Brunswick Corporation company; and NMEA 2000, developed by the National Marine Electronics Association. However, distributed power is not the primary focus of either of those systems: SmartCraft has come out of the engine control field and NMEA 2000 out of navigational electronics. SmartCraft is still in the beginning stages of getting a distributed power system up and running. The principal work is being done by Digital Switching Systems, a subsidiary of the DNA Group, and by BEP, a New Zealand company. The NMEA is much further along, with a so-called message base for NMEA 2000 that is being applied by Moritz Aerospace, a subsidiary of Carling Technologies; and by Megatech Electro, a subsidiary of Teleflex. (Megatech Electro's system—Megalink—is now installed in Ranger bassboats.)



Teleflex Megalink rubberized keypads. The unit on the left has a single data cable to devices on the network. On the right is a combination keypad and power distribution module, with six power outputs coming directly from the keypad, hence the substantial wiring harness. The latter includes load cables from the six-channel power distribution module, along with a data cable that operates another 16 circuits remotely.

A Swedish company, EmpirBus, has another CAN-based distributed power system that is well developed and has, in fact, been installed on a number of boats, including Swedish rescue craft—a particularly demanding application. Aside from its work with SmartCraft, Digital Switching Systems also has its own proprietary, relatively low-cost CAN-based system, which it has been installing since 1999; it is the most widely deployed distributed power system in the marine industry. Carling Technologies has a similar system that has been put into Skeeter bassboats for the past five years. And, in 2006 ETA will release a proprietary, CAN-based "Powerbus," equipped with a "gateway" to NMEA 2000.

Outside the CAN world, ED&D (a subsidiary of Airpax) has what is almost certainly the most fully developed distributed power system now available for boats. It is installed on the production line by British powerboat builder Sealine (see the sidebar on page 84), and in prototypes by



New and "old" wiring technologies at Sealine, a U.K.-based, Brunswick Corporation–owned production powerboat builder. (See the sidebar on page 84.) The lower unit, a two-cable block of switches, considerably improves functionality over the upper unit—conventional switches fitted with a large wiring harness.

other prominent builders; chief among them is Sea Ray. In December 2005 Sea Ray Boats (a Brunswick company based in Knoxville, Tennesee) launched a new 36′ (11m) "sport yacht" model with a fully developed ED&D distributed power system for both DC and AC circuits.

Victron, a Dutch firm, is debuting another non-CAN system, as is Weldon Technologies, that has come out of the automotive sector. And, there is Cole Hersee, a company that has had a low-cost, non-CAN digital switching system for some time.

The Overcurrent Challenge

In the system envisaged here, a primary "two-wire bus" is run through a boat, with direct connection of devices at the closest point to that bus. This arrangement is quite different from conventional setups, in which a technician would run the load cables for the devices back to a circuit breaker or switch in a panel some distance away. At the point of connection to the two-wire bus, there will be a remotely operated switch, with a data (control) cable running back to the control panel. For a detailed description, see Part 1 of the series.

In such an installation, the remotely operated switches are commonly called upon to provide branch circuit protection as defined by Underwriters Laboratories, the American Boat & Yacht Council, and other industry standards organizations. (For the record, the principal relevant standards are UL 1077, UL 489, UL 1133, and ABYC E-11; the ISO 10133 and 13297 standards also apply, but are less rigorous, so meeting the UL and ABYC standards is sufficient to ensure compliance.)

Granted, it's possible to take a conventional circuit breaker or switch that complies with UL and ABYC standards and add components and circuitry to make it remotely operable. There's a name for it: Remotely Operated Circuit Breaker, or ROCB, and remote operation is now done in a number of applications, mainly in battery switches with overcurrent protection. Moritz has recently introduced a line of AC breakers that operate this way. However, there are concerns related to response time and cycle life; and in any case such devices have less functionality than do electronic devices (see below). As a result, the focus for remote switching has been almost entirely on solid state devices, notably what are known as Metal Oxide Field Effect Transistors (**MOSFETs**), because these can be economically configured to make and break just about any current (amperage) level, while being relatively easy to control via remotely operated circuits. It is not at all clear, though, what standards-compliance means in the context of such devices.

For DC systems, the ABYC requires that branch circuit protection devices have an Ampere Interrupting Capacity of between 750 and 2,500 amps (depending on the size of the boat's battery banks), which is to say that given a short-circuit amperage equal to the AIC rating, the device will safely break the circuit without arcing over, and without the points on a circuit breaker fusing together. On AC circuits the AIC rating is 3,000 amps. MOSFETs react so quickly to rising amperages that they never allow those types of short-circuit currents. On a recent site visit to ED&D, I got lead designer Dave Bateman to repeatedly put a dead short across an ED&D device that was hard-wired via short, heavy cables to a Group 31 battery (with a potential short-circuit current of thousands of amps) so I could photograph the resulting spark. That's like trying to photograph lightning; it took me many attempts to get the picture. The unit successfully broke the circuit every time; indeed, it wasn't fazed one bit by the abuse.

There are additional requirements for branch circuit breakers. First, they must be "trip free"—meaning they cannot be reset until a fault has been cleared, no matter how hard you try to hold them "on." And second, once tripped, they must be manually reset—as opposed to automatically resetting themselves. With solid state devices, these characteristics almost always become a function of the controlling software rather than something physically inherent in the device, which is clearly not what anyone had in mind when the standards were written.

The standards for circuits above 50 volts (typically, AC circuits) also contain certain dielectric requirements; in particular, a device must withstand twice its rated voltage plus 1,000 volts, applied across the switching elements without passing more than 5 mA. So far as I know, none of the current crop of MOSFET-based devices can pass this test.

And there are things that are *not* in the present standards but probably should be for solid-state circuit breakers. The most obvious are rigorous Electromagnetic Interference or Radio

Frequency Interference tests for the devices themselves *and* their control circuits. Urban legends are already starting to spread about boats whose circuit breakers turn themselves on and off every time the mike on the Single Sideband Radio is keyed! A couple of boatbuilders I've spoken with that have been using low-end distributed power systems for several years report numerous instances of this type of problem, with one reporting that the relevant RFI signals can even be generated by failing motors on electric pumps.

Less obvious, but also probably needed, are software standards: Once you transfer to software such key control features as the trip setting on a circuit breaker, it becomes critical from a safety perspective that the software continues to operate under the most adverse conditions.

It seems the presently available MOSFET-based solid-state electronic circuit breakers, or **ECBs**, probably meet ABYC requirements for branch circuit protection in circuits under 50 volts, but do not in circuits over 50 volts. *They do not pass the dielectric tests.* Another concern (for circuits both below and above 50 volts) is that when MOSFETs fail, they tend to fail shorted, at which point there is no overcurrent protection.

To ensure compliance with existing branch circuit-breaker requirements, some solid-state circuit breaker manufacturers are presently moving down a similar path, which is to cluster ECBs in what I will call a *Power Distribution Module* (**PDM**). It goes by other names, depending on the manufacturer. For instance, DSS calls its module a Power Management Enclosure, while Moritz terms its a Power Distribution Unit. In these modules, the power input is protected by a conventional circuit breaker and/or a fuse that meets AIC, dielectric, and other requirements;

The Sealine Experience

Sealine is a United Kingdom–based, Brunswick Corporation–owned powerboat builder with 15 models of sport boats, flybridge cruisers, and "small" motoryachts, ranging in length from 25' to 60' (7.6m to 18.3m). The company's work force of 700 produces more than 400 boats a year. Sealine runs an entirely in-house operation, including all aspects of design and construction. In 2002 Sealine began installing the E-Plex power distribution system on its S38 model (11.5m), designating the system "Seaplex." To date, approximately 100 of those boats have been built; and two other models in the product line are now equipped with the Seaplex system.

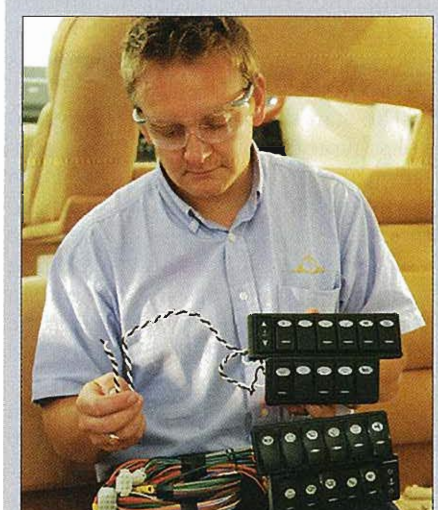
On the DC side, the Seaplex system remotely operates all interior lighting, bilge pumps, macerators, navigation lights, engine fans, and windshield wipers. Sealine is just beginning implementation on the AC side.

The impetus to get into distributed power systems came from the head of the company. Julian Potter, Sealine's supervisor of manufacturing and engineering, recently commented, "There was a gut feeling that there's a better way to wire boats. Both the automotive and housing industries have moved beyond traditional wiring, and we felt it was time to do the same." Sealine shopped the marketplace and selected E-Plex on the basis of its advanced state of development and broad range of applications, and, according to Potter, "because ED&D is very responsive, and very nimble on its feet." The process from design initiation to implementation on the first Sealine model took just over two months.

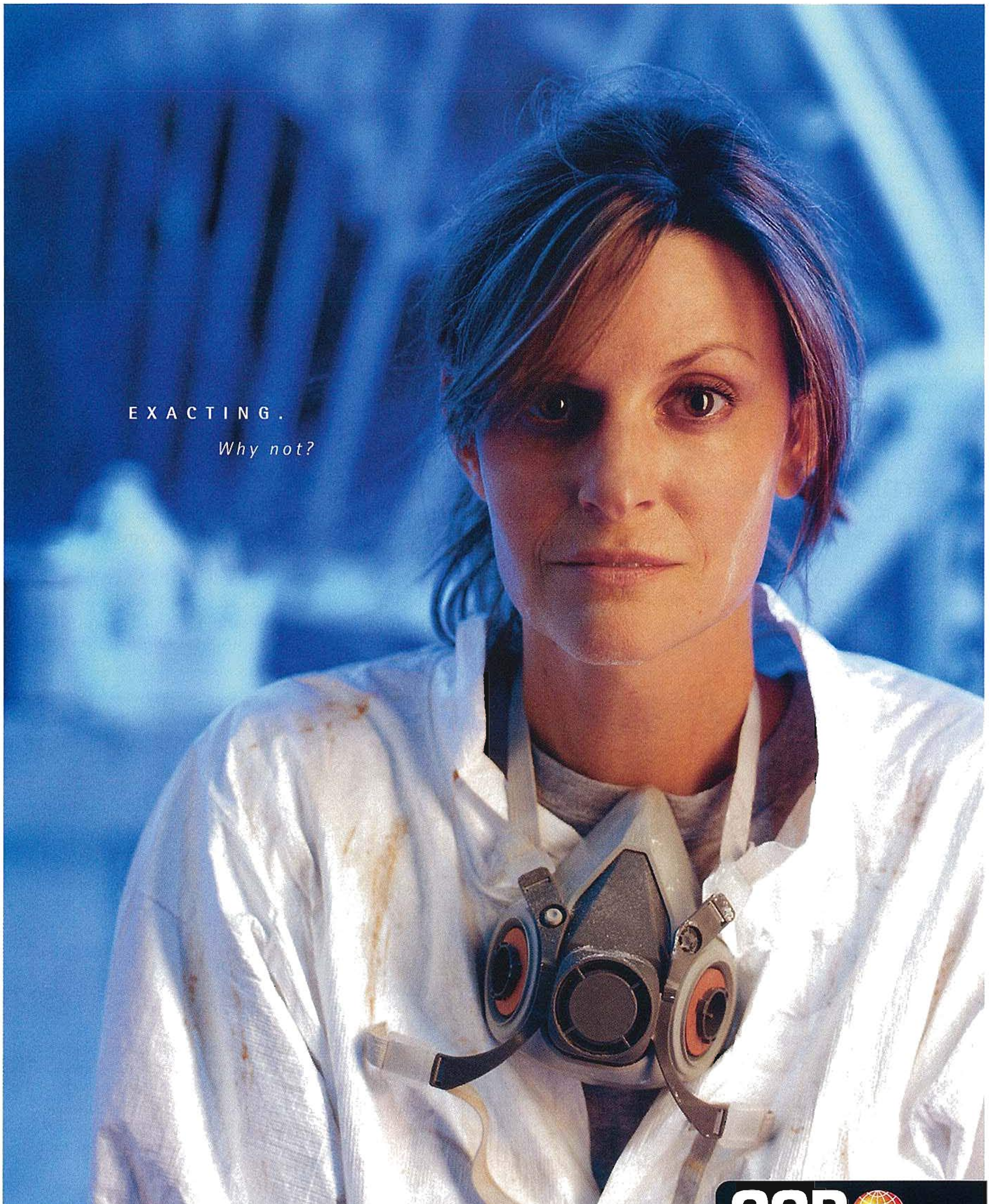
Sealine runs three data buses from the E-Plex clock—the name E-Plex has given its central control unit. One bus is forward, one aft, and one is in the flybridge area. Sealine chose *not* to integrate the Volvo engine networking system with the Seaplex system. "We feel this provides more security for the propulsion system," remarked Potter, "and we believe our customers share that feeling."

By way of illustrating the benefits of Seaplex, Potter noted that, at the helm, the Seaplex twisted-pair data/power cable has replaced two banks of seven switches and "an awful lot of wires." Overall, installation of the Seaplex system has cut 40% of the cabling out of the boat, with concomitant time savings in wiring-harness creation and installation. In terms of hardware costs, he said that "it's very difficult to compete against the cost of wire—which is cheap, although rising copper prices have recently driven it up—but when you look at the labor costs, it's a wash, and Seaplex may even be a little cheaper. And then there are all the additional benefits of Seaplex...."

At that point Potter described an intricate windshield-wiper system Sealine developed, using E-Plex's "E-Logic" software, to synchronize the blades—even with one at full speed and the other intermittent. "It just makes it look so much better." It took the Sealine crew only 30 minutes to do the programming. Potter: "E-Logic is essentially a blank sheet of paper that you can do anything with. You can make



Julian Potter, manufacturing and engineering supervisor at Sealine, is outfitting selected models with an E-Plex power distribution system made by ED&D. Moving to networked marine systems constitutes a transformation, not just a changeover. At the helm alone, says Potter, one twisted-pair data/power cable (in his hand) has replaced two banks of seven switches and "an awful lot of wires."


EXACTING.
Why not?

the ECB, in effect, serves as a switching relay and overload protector. For circuits below 50 volts, other manufacturers have chosen to omit the fuse or circuit breaker. As of this writing, PDMs are manufactured with up to 32 ECBs.

To protect against shorted MOSFETs—with or without a fuse or circuit breaker on the "front" end—almost all manufacturers include a fusible link designed into the circuit board on which the MOSFETs are mounted. In essence, a fusible link is a narrowed-down section of the circuit on the printed board, which will overheat and melt in an overcurrent situation just the same as a fuse—except now you have to replace the entire circuit board.

Power Distribution Modules

Although PDMs as presently manufactured are similar to a conventional subpanel on a boat, there are some important differences. Because the individual ECBs in such a box can be remotely operated from any appropriate device wired into the data circuit, these boxes—unlike a subpanel—do not need to be readily accessible; they can be placed at any convenient location close to the loads they are controlling, with significant potential savings in cabling and installation time.

As for the electronic circuit breakers within the boxes, typically a manufacturer employs a single design of ECB that has a maximum amperage rating (determined by the ampacity of the MOSFETs within it) high enough to handle the highest load it is intended to protect and/or switch. In other words, it is designed for the worst-case amp load. The MOSFET includes a device that measures current flow through it; and the breaker control circuit is such that the MOSFET can be programmed to "trip" at any amperage up to its maximum amp rating. This enables the exact same ECB to be used for multiple amp ratings, with the rating determined *through the software program*, not through the ECB's physical construction. (Weldon Technologies is apparently the only manufacturer right now with fixed amperage ratings for its MOSFETs, as distinct from setting the ratings via software).

Most of these ECBs can be reprogrammed in situ to a different trip value or to a different set of trip characteristics (time delay, for example), either by way of the data bus control panel or by plugging the appropriate tool into the data circuit. Manufacturers are putting a lot of effort into developing user-friendly, intuitive software such as ED&D's "E-Logic" and EmpirBus' "Config." A boatbuilder can build a boat with all the same ECBs, and then program them individually to appropriate trip characteristics once the boat is finished, *and* change the trip characteristics if equipment on the circuit gets modified. The nature of the control circuits is such that more-precise trip characteristics are possible than with conventional magnetic or thermal circuit breakers.

Typically, a PDM will have from four to 32 ECBs, each rated for a maximum ranging from 7.5 amps (Weldon Technologies) to 30 amps (Moritz).

Some manufacturers allow paralleling of outputs for higher loads. Weldon Technologies, for instance, allows up to four to be paralleled for a 30-amp load. The total ampacity of the unit is almost always less than the sum of the maximum rated ampacities of the ECBs. As an example, if there are six ECBs rated at 30 amps each, for a maximum of 180 amps, the total amp rating of the PDM may be only 100 amps. The limiting factor is usually the heat created by the MOSFETS in the ECBs when they are conducting; at 100 amps, that might be as high as 30 watts, depending on the quality of the MOSFETs. The PDM must be designed to dissipate this heat; otherwise, if it builds up, the electronics will be damaged. In general, the more efficient MOSFETs, which generate less heat, cost more. That's why low-cost PDMs tend to have more heat-dissipation problems than higher-cost units. For the PDM designer, there is a trade-off: low MOSFET cost versus greater heat-sinking costs.

things as simple or complex as you want."

Sealine has programmed its newest clocks with a comprehensive test cycle that checks the operation of numerous pieces of equipment on the boat, such as bilge pumps and the freshwater pump, at start-up. The E-Logic software is supplied in a number of languages. If a boat goes overseas, then, with the click of a mouse a foreign technician can change the language to troubleshoot the boat, and switch back to the owner's language when he's done.

The builder believes its boat buyers would like to retain traditional-looking rocker switches, even though the switches are sending a very low-power digital signal down a common data cable. As I've indicated in the main text, using conventional switch technology to make and break the miniscule currents in a digital circuit commonly results in problems: the lack of an arc when the switch is opened leads to oxidation of the switch points, and high resistance. ED&D came up with an innovative design (a patent is being applied for) in which an arm on the back side of the switch breaks a light signal when the switch is operated. That triggers the electronic circuit without the intervention of any switch points.

In summing up Sealine's overall experience with ED&D, Potter said: "One of the things we know from doing this for as long as we have is that it's not just a question of changing boxes on the boat and substituting ED&D products for conventional distribution products. It's a matter of changing the entire culture on electrical systems' design and installation. In return, we see major benefits in functionality, diagnostics, and troubleshooting."

—*Nigel Calder*

The current (amperage) measuring device and small microprocessor found in ECBs provide the opportunity for some really interesting and creative uses for these devices. For example, if the current sensor detects no current when a light circuit is turned on, it can signal that the lamp is out or the wire is broken. Similarly, if it "sees" a higher-than-normal current draw on a motor, but not high enough to trip the breaker, then it can warn of the problem.

Or, consider a bilge pump. The ECB might be programmed to turn the pump on at set intervals. If the current draw goes above a certain level, it signifies there is water in the bilge. (The water creates resistance that drives up the current draw of the pump.) The pump can be kept running until the current falls, indicating a dry bilge, and the pump can then be kept running for a few seconds longer to "sponge out" the bilge before being shut down. This seemingly insignificant process eliminates the need for a float switch—the most failure-prone part of bilge pump circuits.

Similarly, if the bilge pump current goes above normal pumping levels, it indicates a fouled or locked rotor (probably caused by a jammed impeller), in which case the pump can be turned off—to prevent it from burning up—and an alarm triggered. Again, that basic move eliminates one of the more common causes of pump failure. The microprocessor operating the ECB (the "chip") can keep a record of how often, and for how long, the bilge has been pumped, triggering an alarm should the pump run more than usual. It can even "learn" how the operating characteristics of the pump change over time (as, say, the impeller wears) and adjust the control parameters accordingly. At any time, the boat operator can pull up the operating history of the pump. All of these functions are presently programmed into "active intelligence" devices manufactured by Rule Industries (Gloucester, Massachusetts), and can be programmed into systems such as those from Moritz and ED&D.

Unlike traditional circuit breakers, therefore, ECBs have the potential to operate as "smart" devices, with powerful circuit-control and diagnostic features. The more sensing devices that are wired into the data bus shared by the circuit breaker, and the more information there is on the bus, the greater the potential is to engineer creative programming of remotely operated solid-state circuit breakers and switches. There is a whole new world opening up here, and its surface has barely been scratched.

Sophisticated diagnostic software can be developed, and tools built, such that anyone can plug the tool into the network and download information (perhaps over the Internet) to a technician anywhere in the world. This is no different than what happens when you take your car to the shop, where it is plugged into a computer to view its operating history and to diagnose its problems. ED&D cites a case of a superyacht in Europe fitted with its E-Plex system. The boat developed a lighting fault in the dining room, just prior to an important dinner aboard. From Florida, the yacht's chef was talked through identifying the failed unit, swapping it out, and reprogramming the software.

Such capabilities are likely to cost more than traditional circuit switching and protection; but once the full benefits are realized—reduced wiring, reduced installation time, and reduced post-installation problems—there are likely to be major savings for boatbuilders. And, the bigger the boat, the greater the potential savings. Paul Shore at bassboat manufacturer Skeeter Boats (Kilgore, Texas), whose largest model is 22′ (6.7m), reports that there really is not enough cable and installation savings in Skeeter's boats to justify the cost of a digital switching system. But the company is doing it anyway for the "Oh, wow!" factor. In any event, the buyer of a boat so equipped will get a simpler yet more powerful and reliable electrical system with greatly enhanced functionality, and powerful diagnostic and error-warning capabilities.

Lock Out and Limp Home

Concerns have been expressed about the ability to safely troubleshoot and work on electronically operated circuits tied to a two-wire bus. With a conventional switch or circuit breaker, you can very often lock it out so no one can accidentally turn it on while you're working on the circuit. You can always hang a tag on it or put a piece of tape over the switch.

But what does it mean to "lock out" or "tag" an electronic circuit breaker? This requires a modification to the operating software that will thwart any attempt to trigger the device; it produces a warning message or something similar. For example, a password-protected disable feature could have the password set when the circuit is disabled. That way, only the person who disabled it would have the password to reset it. Moritz, among others, takes this approach—along with an override mechanism, in case the technician forgets the password or gets run over by a truck! EmpirBus has a mechanism for manually locking out ECBs directly on the units, which then disables the data circuit to that particular ECB.

There is another concern. Given that ECB ratings are set in the software, what's to stop children from trying to use the touchscreen as a computer game and accidentally resetting all the ECBs to levels that exceed the ampacity of the cables attached to them and creating a fire risk for the boat? Well, at the time the system is commissioned, the boatbuilder will need to program upper limits for all ECBs—based on the ampacity of the cables connected to each ECB—and then lock those settings in the software so they cannot be reset except through a secure procedure controlled by the builder.

Here's another one: What happens if the boat gets hit by lightning and the electronics fry? True, the same thing could happen with a traditionally wired boat, but the potential for a whole-boat shutdown is greater when everything is operating off the same data bus. This concern is being addressed in a combination of ways: tougher "environmental" standards (meaning tougher requirements regarding the kinds of extreme conditions a system must be able to withstand); "hardening" of equipment against the massive voltage and current spikes that occur in a lightning strike; and devising mechanisms to jury-rig failed ECBs. (For more on the latter, see below.) Ultimately, though, the only way to create security against electronics failure on mission-critical circuits is to wire in a parallel redundant circuit with a mechanical protection device, or make it possible to physically remove the electronic circuit breaker and replace it with a mechanical one.

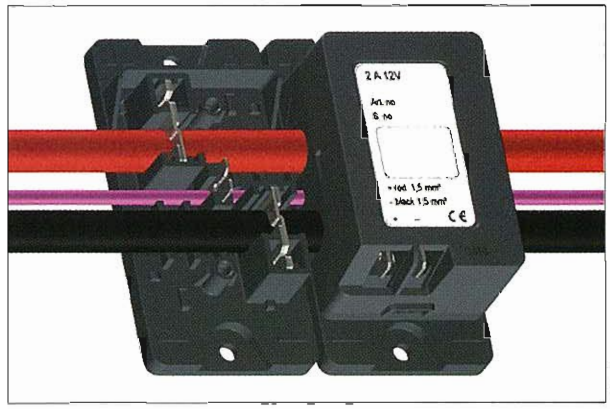
Still, *no system* can be made completely invulnerable to failure. The goal must be to achieve at least as high a level of operational safety as is found with conventional systems, and preferably higher.

Moving Toward Individual ECBs

Because a power distribution module clusters ECBs in one device, the load circuits coming off it still run in parallel for some of their length. To realize the full potential of remotely controlled circuit switching, it will be necessary to move beyond the PDM approach to develop devices for individual circuits that:

- can be rapidly, easily, and economically tapped into large-gauge cables (on many boats, the two-wire bus will consist of 2/0 cables, and on some, these may be as large as 4/0);
- provide switching and overcurrent protection for anything from a single load to multiple loads;
- are easily wired into the boat's data cable via an appropriate drop cable;
- contain the appropriate chip and software to be self-configuring on the system, or easily configured by the installer;
- provide a means for positive lock-out/tag-out;
- conform to the requirements for manual reset; and
- meet all other applicable international standards for branch circuit protection.

To the best of my knowledge, no such device presently exists. (Note: just before going to press, I was


CAPI2

A Capi2 device that is new to the market, for remotely controlled circuit switching. The Netherlands–based manufacturer claims its unit meets the author's demanding criteria for individual circuits, as itemized by bullet points in the text above.

contacted by a European company, Capi2, that is launching such a product—go to www.capi2.com.) The state of the art in this domain is best demonstrated by looking at: ED&D's non-CAN-based approach (E-Plex); three CAN-based systems (Moritz's NMEA 2000 approach, Digital Switching Systems' SmartCraft approach, and Sweden's EmpirBus system); and a couple of the low-cost non-CAN approaches (Cole Hersee and Weldon Technologies).

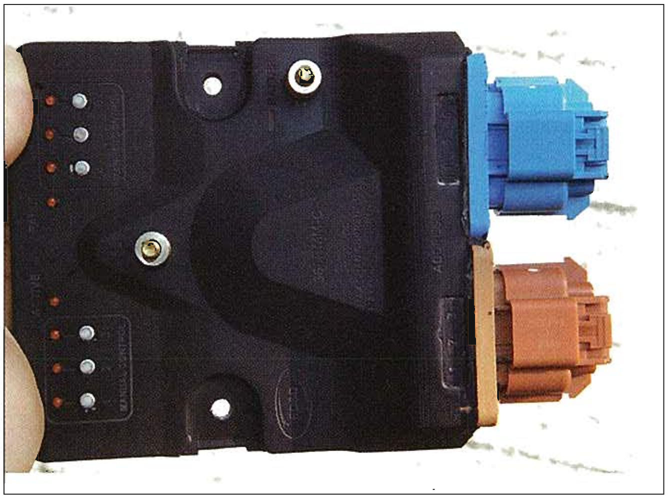
E-Plex

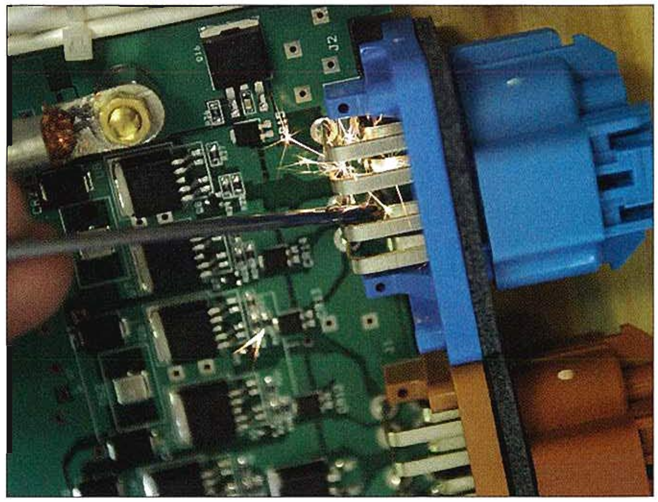
As of this writing, in the finite universe of marine distributed-power systems, ED&D's E-Plex is arguably the furthest along in terms of product development and the broad range of its applications. ED&D has several superyacht systems as well as a production-line powerboat under its belt. Vice-president Jim Habuda says, "There are other companies entering the multiplex [distributed power] field with bits of the puzzle, whereas we already have most of the pieces and are now working on things the others are not even thinking about!"

ED&D clusters anywhere from six to 16 ECBs on a PDM board, with a single "core" (transceiver) providing the interface to the E-Plex bus. Each ECB becomes an address on the bus—or multiple addresses, depending on the complexity of its functions. The circuitry for each ECB includes: a manual override of the remote-switching function; an innovative thermal disconnect device (for which ED&D is seeking a patent); a MOSFET (the device that makes and breaks the circuit); and a fusible link built into the circuit board. There may or may not be another MOSFET associated with pulse-width modulated light dimming. The entire assembly is potted in epoxy. There are no user-serviceable parts; if one circuit goes down, that circuit will have to be taken permanently out of service, or the whole PDM unit will need to be swapped out.

E-Plex is a master/slave system (for a detailed explanation, see Part 2). ED&D calls its master a "clock." The various logic functions for all ECBs in a given system are retained in the clock's memory, so if any module on the bus is replaced with a new unit, the clock automatically reprograms it. This limits the number of parts a boatbuilder has to keep in inventory, or that a boatowner needs as spares.

A feature that, to my mind, sets E-Plex apart at this time is its amazingly powerful E-Logic software package, which can customize a power distribution system. To get a sense of its capabilities, I challenged ED&D's Dave Bateman and Matt Bush, ED&D's lead programmer, to take a bench system in which the company's ECBs operate simulated loads, and to configure it for a bilge pump with the functions described earlier—namely, to cycle the bilge pump on at timed intervals, keep it running if the current draw is above a certain level, shut it down and give an alarm if the current draw goes above a higher level, and shut it down after a timed delay when the current draw drops below a lower level. From a cold start (Bateman and Bush had no idea I would ask this), the two men delivered this functionality in 10 minutes; and they did it without





Above left—*An E-Plex circuit board for a six-"channel" power distribution module that manufacturer ED&D calls a "HexaModule." It is fully potted in epoxy; there are no serviceable parts. The six white buttons on the left are overrides for each electronic circuit breaker, or ECB, that permit the individual ECBs to be operated manually in case the network circuit goes down. The LEDs to the left of the override buttons indicate whether a circuit is "on" or "off."* ***Above right***—*Cover removed, the HexaModule is wired to a battery for short-circuit testing. The screwdriver, shown, repeatedly caused a deliberate dead short across one of the output circuits. Each time, the ECB shut down the circuit—virtually instantaneously—without suffering any damage.* ***Left***—*An E-Plex power distribution module with eight ECBs, or channels.*

adding any cost to the system other than the programming time!

In common with a number of other manufacturers, ED&D and Moritz (see below) provide touchscreen display and control monitors. Typically, the boat's functions are broken out into logical groupings—lights, pumps, navigation systems, DC systems monitoring, AC systems monitoring, heating and air conditioning, entertainment systems, tanks, etc. Touching any "button" pulls up a display of the switches and/or information associated with that system, with additional sub-menus where appropriate (stored data, diagnostics, and the like). Given a fault condition on any breaker or system on the boat, a clear warning is displayed. Trust me, this stuff is all very intuitive. It's not necessary to read a manual to work your way through the options. It's easy to operate, no matter how complex the underlying hardware and software may be.

Moritz

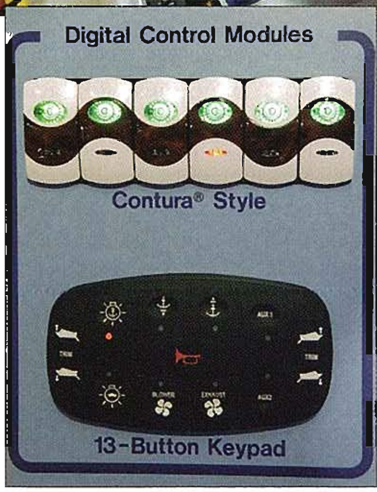
Moritz wet its feet with a Viking powerboat, and is also outfitting a fast-ferry and a 130′ (40m) catamaran.

The company clusters up to 16 ECBs in a PDM, each with a maximum rating of 30 amps. But instead of potting the ECBs in epoxy, Moritz puts them in a metal box (for RFI suppression), where they can be individually removed and replaced in the event of failure. Two ECBs can be paralleled for outputs up to 60 amps. A chip provides the interface to the NMEA 2000 backbone.

With its background in aerospace, Moritz is especially concerned with redundancy, and thus provides two parallel, fully redundant chips (microprocessors), plus two backbones, connected to two parallel and fully redundant display and control panels (also interconnected, so both can show the same information, or different information). If both these networks go down, the PDM has two (redundant) internal power supplies that keep the internal microprocessors running, maintaining the ECB trip settings; all that would be lost is the remote monitoring and control. So, even if the NMEA 2000 bus is severed, the ECBs will still function. Should the backup power supplies go out, or the microprocessors fail, then, unlike the E-Plex system, Moritz's individual ECBs can be removed, replaced with a mechanical circuit breaker, and operated manually.

After installation, the various ECBs are programmed (using NMEA 2000 protocols) via a PC (personal computer) running Moritz software. Some programming can also be done through touchscreens. Once programmed, the various logic functions for each ECB are retained in the two processors' memories. Replacement ECBs do not need reprogramming; that's done from the processors' memories, which thereby enables a stock ECB to replace any ECB on the boat. This limits the number of spares a boatbuilder or boatowner must carry. However, if the PDM itself needs replacing, then it must be reprogrammed by a PC or the display panel (as distinct from the E-Plex system, where it's done automatically by the "clock").

Moritz is presently focusing on



Above left—*Pulling an electronic circuit breaker from a Moritz power distribution module installed on a Viking motoryacht. This PDM has 16 ECBs.*
Above right—*Touchpad control for a lower-cost networked system from Carling Technologies, Moritz's parent company. The device includes the necessary chip to put signals from the touchpad on the network bus via a single network cable with a four-pin connector (two network power cables and two data cables).*
Left—*Carling Technologies rocker-type switches, and touchpad switching, with built-in chip and a single-cable connection to the bus.*

expanding the data acquisition side of its system. Why? In order to increase the range of applications that Moritz can put on the NMEA 2000 bus. In addition to its ECBs and display panels, Moritz now has a marine systems monitor, which will accept analog inputs from sensors monitoring numerous onboard systems: a battery monitoring unit, a fuel system monitoring unit, and various engine transducers (oil and water temperatures, for example). According to Rick Sorenson, chairman of parent company Carling Technologies, Moritz is also "devoting a lot of resources to software development" in order to simplify the process of programming ECBs, and to extend the range of their functions.

The Moritz approach is expensive because of PDM construction and also the redundant display panels and NMEA 2000 physical layer. Those factors limit it to high-end boats. The company is developing a more economical version of its devices in which the individual ECBs will not be replaceable, and control will be via rubberized keypads rather than touchscreens.

Finally, Moritz is exploring the possibility of making its devices also compatible with SmartCraft.

Digital Switching Systems

A subsidiary of the DNA Group, DSS manufactures two types of circuit breakers: remotely operated electromechanical breakers, meaning a data signal triggers a relay that operates the breaker; and fully electronic circuit breakers, or ECBs. Either type can be clustered in what DSS calls a Power Management Enclosure, or PME. At present, the DSS system runs on a proprietary version of CAN (DSS has been selling versions of this system for several years), but for the future, DSS has chosen to work toward SmartCraft certification for two key reasons. The first is that DSS's two largest customers are Sea Ray Boats and Mercury Marine, two of the biggest companies within the Brunswick Corporation. And the second reason is that it would require some hardware changes, and thus expense, to make DSS's devices compatible

Right—*Digital Switching Systems' touchpad with built-in chip. The only connection is the network cable.* ***Below***—*DSS's power distribution module has four built-in manual bypass circuits for "mission critical" circuits. At right is the four-pin connector for the network cable—two network power cables and two data cables.*

with the specific isolated ground requirements of NMEA 2000. (For more on that detail, see Part 2; note, however, that NMEA 2000 compatibility will soon be offered at a small additional cost.)

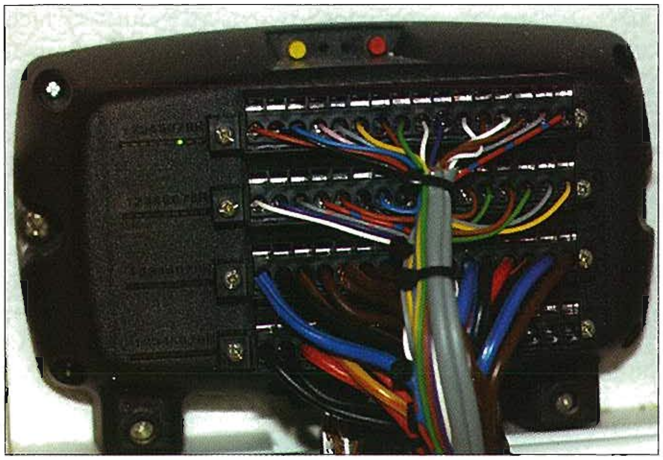
To connect to the SmartCraft bus, electromechanical PMEs will need an adapter, whereas ECB-based PMEs will have the necessary chip and data cable connection built into them. These devices will be operating on SmartCraft's CAN V bus (see Part 2), and will have a four-wire interface on the data side, consisting of two network power cables (positive and negative) and a set of twisted-pair data cables. As with ED&D's power distribution modules, these ECBs are potted in epoxy; if one fails, the entire PDM needs to be replaced. DSS uses a rubberized keypad rather than a touchscreen, to send signals to the PMEs. This arrangement keeps down the cost and the power consumption; there are plans to also introduce a touchscreen. The keypad contains the chip necessary to put data on the DSS bus, resulting in the standard four-wire interface with the rest of the system, regardless of how many switches are on the keypad. The net result is a low-cost system that is competitive with traditional installations at the volume end of the boatbuilding market (entry-level systems can be acquired for less than $100), but which delivers the sophisticated functionality of a microprocessor-based power distribution system together with reduced wiring-harness and installation costs.

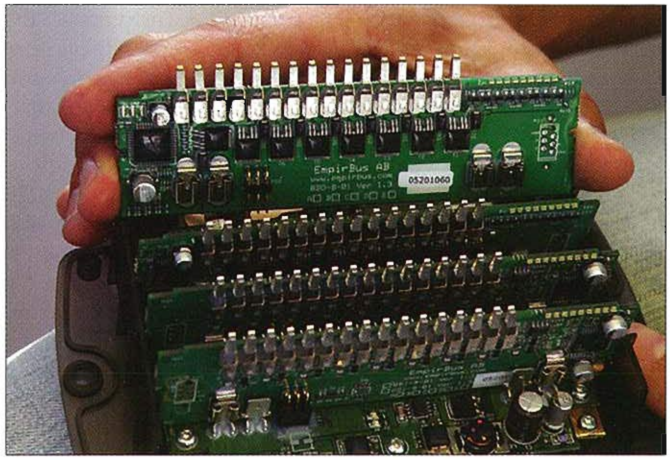
Individual ECBs are rated for a maximum of 20 amps and, as with competing approaches, are then programmed within the software for whatever amp rating is needed for a given circuit. The maximum amp capacity of a PME, regardless of how many ECBs are in it, is presently 75 amps. This is a function of the heat that must be dissipated when the MOSFETs in the ECBs are conducting. At 75 amps, they generate around 20 to 25 watts of heat. The latest generation of PMEs provides a manual bypass option for up to four ECBs so that critical circuits can be kept functioning if the PME is damaged.

Ken Wood, vice-president and general manager of DSS, reports that the company is at the beginning stages of SmartCraft certification. Wood and his colleagues at DSS had originally intended to develop the necessary messages (protocols) for the CAN V bus themselves, but then MotoTron discovered that BEP, a panel manufacturer based in New Zealand, is working on a protocol that could be employed. So, DSS is weighing its options. Wood reports, "We know the language we will speak [SmartCraft's version of CAN], but have not yet developed the precise messages."

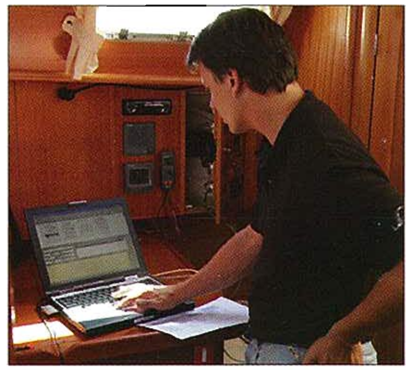
EmpirBus

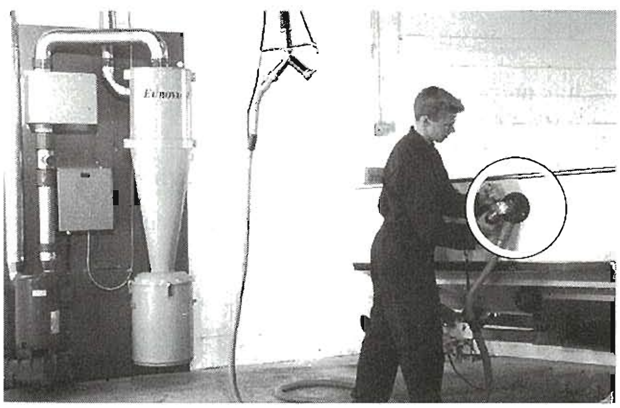
EmpirBus is another proprietary CAN-based system that employs a master/slave approach (like SmartCraft) as opposed to the masterless system of NMEA 2000 (see Part 2). EmpirBus' PDMs contain up to four removable circuit boards with eight inputs (see below), or eight ECBs on each board, for a total of up to 32 ECBs, set in a plastic housing. This is an approach halfway between fully





Above left—*Rear view of an EmpirBus power distribution module. The top two rows are point-to-point cables from traditional rocker switches to the input side of the PDM, where signals are converted to the bus language and put on the bus. Consequently, we see a similar number of cables at the switch panel, as in a traditional installation—but these are signal cables and not load cables, and thus can be sized much smaller. Newer installations contain a chip that converts switch signals into the bus language at the switch, so there is only a single network cable from a bank of switches. The lower two rows of cables coming out of the PDM are load cables to individual devices.*
Above right—*EmpirBus' PDM, showing removable circuit boards. Each converts eight input signals to the bus language, or contains eight output electronic circuit breakers.*
Right—*Hooking a laptop into an EmpirBus network in order to move the boat's VHF from the navigation ECB to its own ECB. This job took a mere 10 minutes of software adjustments (as opposed to having to rewire the boat).*





potted units (ED&D and DSS) and individually replaceable ECBs (Moritz). It permits the boards containing eight inputs or ECBs to be changed out.

Early EmpirBus installations had individual switches wired on a point-to-point basis (that is, each switch has its own wiring) to an input board in a PDM, where the signals were converted to the bus language and put on the single bus cable. The result? Same number of wires coming out the back of a distribution panel as in a traditional installation, but these wires are much smaller, since they carry only a signal and not the load current for the device. A PDM set up close to the panel consolidates all the signals from the switches onto the single bus cable. In 2005 EmpirBus introduced waterproof membrane switch units (rubberized keypads) that include the necessary chip to put the individual switch signals on the network bus (as with DSS and others). Each bank of eight switches has a single cable connection containing positive and negative network power cables and twisted-pair data cables.

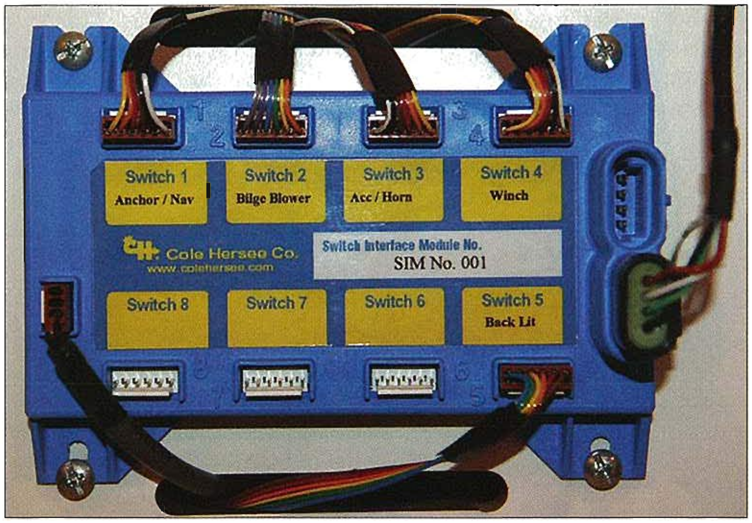
Individual ECBs are rated for 8 amps. Up to three can be paralleled for 24-amp output, although the total output from any one board is limited to 40 amps, with a limit of 100 amps per PDM. Each output is protected by a fusible link built into the circuit board. The fusible link is designed to blow more slowly than the software-fuse function of the ECBs, in order to protect the boards from blowing. The EmpirBus system is explicitly sold as a replacement for traditional fuses and circuit breakers. On each board, two of the outputs have dimming capabilities.

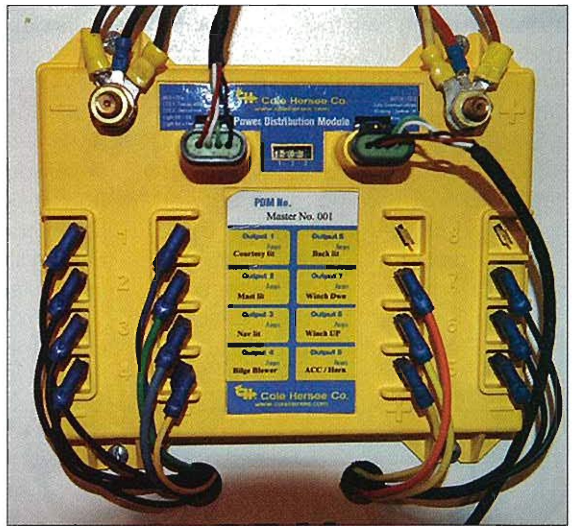
EmpirBus, in common with several other manufacturers, has put a lot of effort into developing easy-to-use software for designing and programming a system. The designer selects functions: an "on/off" switch, say, or "momentary on," or "on/off/on"; the rating for a fuse or ECB; the trip characteristics for ECBs; and the like. The designer selects these functions from a menu-based Windows application, and then applies them to the load at the end of the circuit. The software generates a circuit diagram to which cable numbers and connections can be added (but not cable sizes). Quite complex functions are easily programmed (creative lighting combinations, say, or dimming levels, for different moods, each of which is activated by a single "switch"). And, ECB values are easily reassigned. Circuits can be programmed to give an undercurrent alarm (for example, if a bulb blows or a circuit gets broken).

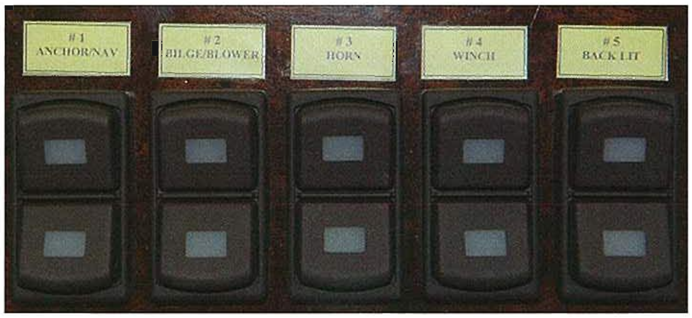
Cole Hersee and Weldon Technologies

As stated, both companies feature low-cost distributed power systems based on proprietary non-CAN protocols. The Cole Hersee system has been sold into the marine industry for several years. Weldon Technologies has come out of the automotive, trucking, and related industries (fire engines, ambulances, etc.) and as yet has no marine installations. Its marine products made their debut at IBEX 2005, in Miami Beach last October.

Cole Hersee relies on switches with







Cole Hersee switches, ***left****. These send point-to-point signals to a switch interface module,* ***above left****, which converts the signals to bus language and puts them on the network cable. That, in turn, is connected to power distribution modules,* ***above right****, where the negative and positive power feeds for the loads are at top left and right of the panel. Network cables, in and out, are center top left and right; and the load cables to various devices are the rows of cables beneath.*

point-to-point wiring to a Switch Interface Module, which serves the same function as an input board in an EmpirBus PDM. From there, individual signals are converted to Cole Hersee's proprietary language and put on its four-wire bus (two network power wires and two signal wires) and connected to the PDMs. Historically, there have been problems in relying on conventional switches with the low voltages (5.0 volts) and currents (milliamps) used for signaling in these systems. The lack of an arc when the circuit is broken causes the switch points to oxidize over time. Cole Hersee has developed a patented "Digital Signal Rocker Switch" that looks, and feels, like a traditional rocker switch but is rated for *more than a million* switching cycles.

Up to 16 PDMs with eight channels each (for a total of 128 channels) can be built into the system. This is a master/slave system wherein one PDM is designated as the master; should it go down, though, another will take over. Individual ECB amp

A Four-Stage View of Digital Switching

The various options for digital switching can be thought of in four platforms. In ascending order of technical sophistication and cost, they are:

1. Electromechanical circuit breakers wherein a low power signal triggers a relay that operates a conventional circuit breaker. There is a separate signal cable from each switch to each circuit breaker. The system has no more functionality than a traditional circuit-breaker installation. It benefits the boatbuilder because the signal cables carry almost no current and can therefore be very small. This, in turn, reduces a distribution panel's wiring harness to one or more multiconductor signal cables that are easy to handle and install. The disadvantage is the added layer of complexity (the relays) at the circuit breakers; there have been reports of relay contacts burning out from inductive spikes.

2. Electromechanical circuit breakers wherein a proprietary digital signal triggers a relay that operates a conventional circuit breaker. The signals use a communications protocol that allows all the signals to be sent down a single twisted-pair data cable, which eliminates the mass of signal cables found in option #1 above. The communications protocol, in turn, will require processing capability at all breakers, enabling the software to add functionality to the system, although this is limited by the presence of conventional circuit breakers. The chief benefit to the boatbuilder is a further reduction in cabling with an increase in functionality. The disadvantage is, once again, the added complexity at the

ratings are programmed by means of Cole Hersee software. Each is given a default setting in case the bus goes down. Compared to other approaches, the software functions are quite limited (there is no data logging and little in the way of diagnostics), but the cost is low.

Weldon Technologies has a proprietary non-CAN system featuring rubberized keypads with an embedded chip. These are connected to PDMs that contain up to 16 input channels (for switches with point-to-point wiring, or signals from other sources) and 24 output channels. Unlike all the other systems looked at in this article, these ECBs all have a fixed output of 7.5 amps. If a higher output is needed, then ECBs can be paralleled.

A Revolution in Boat Systems

Granted, we are still in the pioneer days of distributed power systems on boats, but already the potential is apparent. First-generation systems have shown that distributed power technology can dramatically reduce

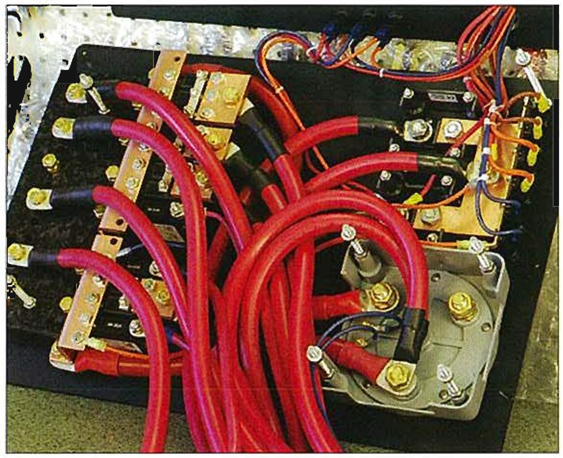
breakers over that of a conventional installation.

3. Electronic (solid state) circuit breakers, or ECBs, replace the conventional circuit breakers and relays in option #2 above. This requires a current measuring capability at each ECB. Now the system is opened up to the full benefits available from the software package, limited only by the processing power in the system, the power of the software, and the ingenuity of the programmer. Typically, low-end systems employ rubberized touch-pad switches to send signals, and have limited processing power, which together limit system functionality. Older systems have proprietary languages; several newer ones use NMEA 2000 or plan to adopt SmartCraft. The industry has accumulated quite a bit of experience with these systems, with mixed results: there are numerous reports of unpredictable operation that, in many cases, requires the main battery switch to be turned off in order to reboot the system.

4. Electronic circuit breakers are coupled to microprocessors with greater power; control is exercised via touchscreens sending signals down a single data cable that can be networked with other systems on the boat. These are the latest systems. As noted in the text, they vary enormously in price and in such factors as levels of redundancy, replaceability of individual parts, the extent of EMI/RFI suppression, and so on. There are significant differences in functionality and ease of use and programming from one system to the next, but since this is largely a software issue it changes month to month as the various companies look at what their competitors are doing, and rapidly integrate the same capabilities into their own software.

—*N.C.*

We'll close our series where we came in: with a view of conventional, if late-model, technology. It's the back of the control panel on the author's recently delivered semicustom cruiser. All the high-current load circuits are fused/switched/breakered at the panel. With the remote switching described in his three articles on networked marine systems, none—repeat, none—of these cables need to be run to the panel.



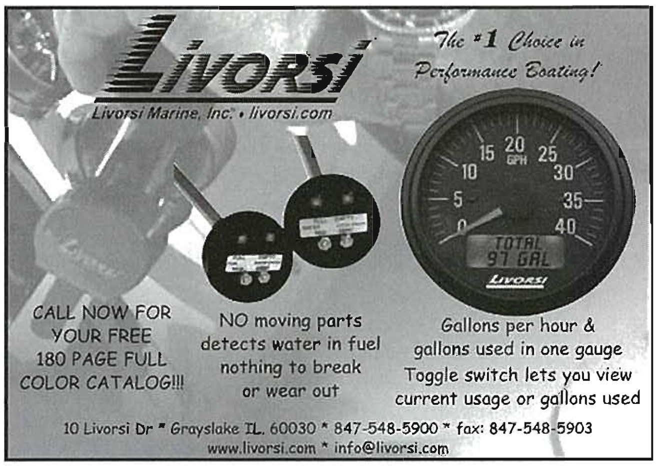
the amount of cabling in a boat and the size of wiring harnesses, which greatly simplifies electrical and electronics installations, and reduces installation costs. Beyond this, distributed power technology substantially increases the functionality of power distribution systems, taking them from the world of simple switching to "smart" switching, with sophisticated integration of different systems on board, and considerable data collection, analysis, and troubleshooting capabilities.

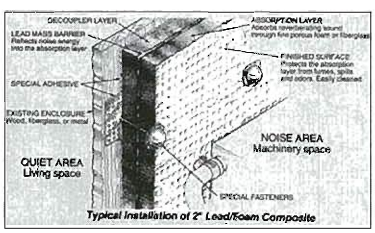
All of this strongly suggests that we are in fact witnessing a revolution in wiring boats that will force the entire boatbuilding industry to rethink electrical installations. There's been little change overall since the first cables were run in boats.

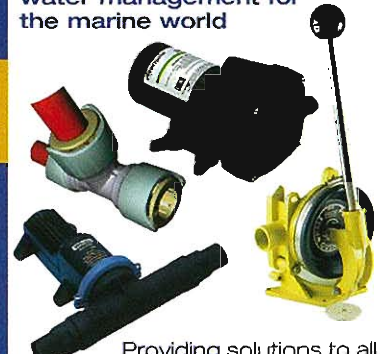
I, for one, am impressed. Enough so to have told the owner of the company that built my new cruiser—a Malo 45, made in Sweden—that if he can find a buyer, he should sell it so we can build a replacement. *That* new boat will become a platform for testing networked navigational electronics (NMEA 2000 and Ethernet) along with a fully developed distributed power system (probably E-Plex or Moritz). If this new-build opportunity comes to pass, the boat will also be equipped with diesel-electric propulsion (from Glacier Bay, Fischer Panda, or Siemens—but that's another story; see *Professional BoatBuilder* No. 92, page 12).

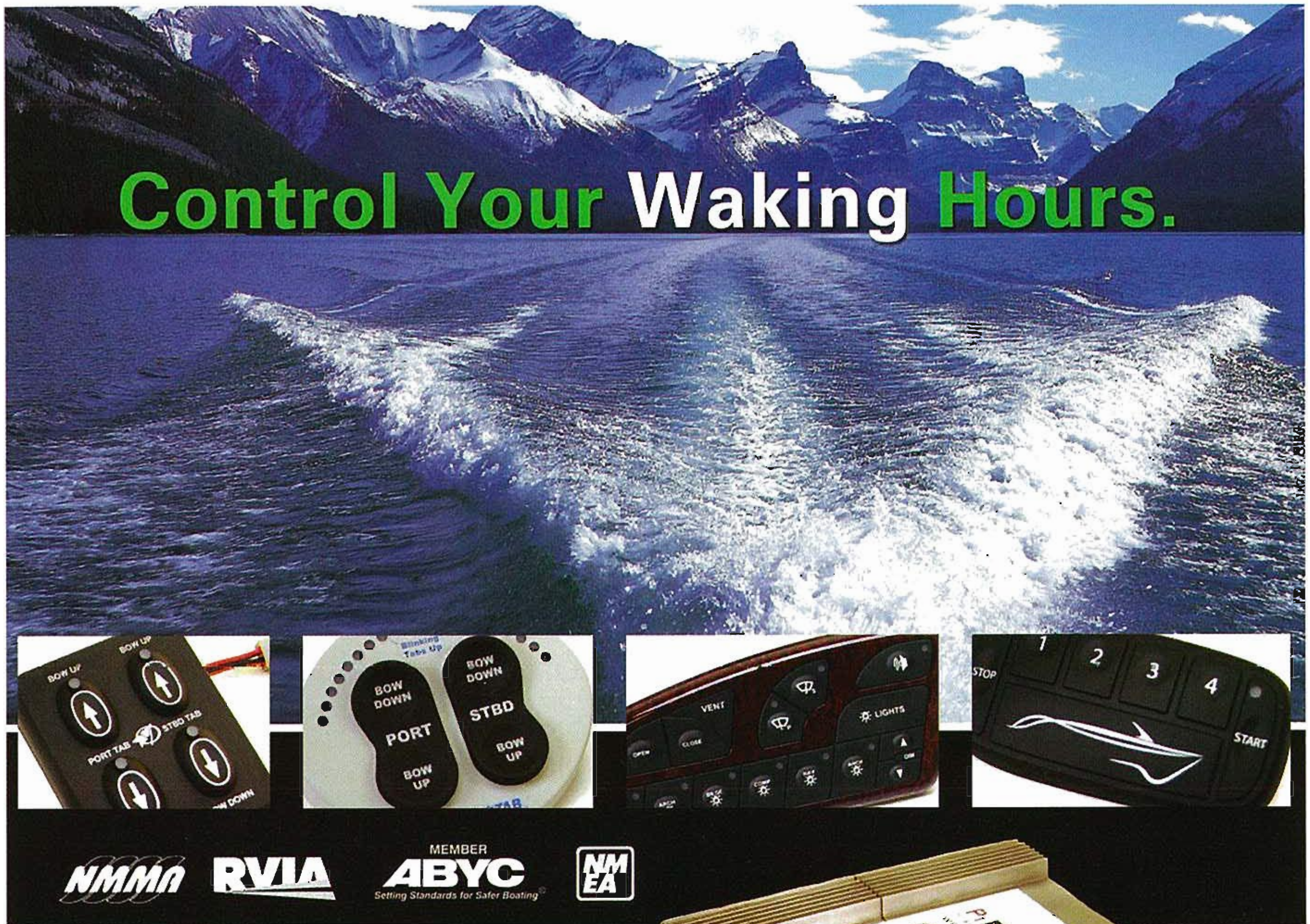
Finally, comprehensive source lists for the manufacturers mentioned in this series can be found at the end of Parts 1 and 2. PBB

About the Author: *Nigel Calder, author of* Boatowner's Mechanical and Electrical Manual *and other marine titles, is a contributing editor of* Professional BoatBuilder *and a member of the ABYC's Electrical Project Technical Committee.*









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Single Skin or Sandwich?

Some boatbuilders still struggle with the question above, because the decision affects not just the price of the finished product but shop-floor processes as well. Here, a veteran structural designer discusses the many factors to consider to make that an *informed* decision.

Text and illustrations by David E. Jones

Many builders and designers think of single-skin construction as heavy, tough, and economical to build. Also known as "solid-laminate construction," single skin is a time-honored process in the marine industry. For the better part of five decades now, builders have produced numerous generations of single-skin hulls.

Sandwich construction, compared to single skin, yields a thick but light laminate, in which core material is bonded between two thin, high-strength, laminate skins. The core can be foam; paper, plastic, or metal honeycomb; plywood; or balsa. By itself, each element in the sandwich is rather weak and flexible. Combined in sandwich form, though, these components create a structure that is stiff, strong, and fairly lightweight.

In selecting either solid laminate or sandwich construction for your composite parts, you will need to blend your choice of materials with your own shop's production efficiencies. You will also need to make many decisions about weight vs. speed, structure vs. cost, ride quality, and even mold-cycle time.

What concerns me is that too many designers and builders do not consider all the necessary factors. Instead, they choose their construction method—whether sandwich or single skin—solely in terms of production economies. In short, they're asking, "What is the quickest and cheapest way to build this part?"

That's certainly a good question, but it's not the only one. In this article, I'll address some additional concerns, and talk about selecting a fabrication method for your project that will result in a structure having optimal strength, stiffness, or weight reduction. In other words, I'm asking, "What is the *best* way to build this part?"

Transferring the Load

Before we discuss materials options, we need to review some basics of composite boatbuilding.

For any vessel, the designer must provide an efficient structure, one that meets the needs of the prime mover—either one engine or two—and distributes the hull-bottom and side loading through a logical framework. When this engineering has been properly executed, the load will transfer cleanly from one structural element to the next; that is, from a hull-bottom panel to the longitudinal stringers, or from the stringers to a frame or bulkhead.

The boat's hull panels must be

strong enough to resist anticipated design pressures, and *stiff* enough to minimize localized panel deflections. When the design includes liners that must fit to close tolerances, then this minimization is essential to avoid any conflict with local panels. If a liner is set too close to the hull shell and the hull shell is not stiff enough for the design tolerances, then damage will definitely occur to the liner and to interior cabinetry, or even to the hull shell itself. Any loss of structure from any member will cause collateral damage to the overall structure of the vessel over time. This situation can be catastrophic if left uncorrected.

It's important to keep in mind that the load will not transfer properly unless the hull panels are supported by longitudinal girders or stringers, which themselves must be supported by deep webs or bulkheads. And the connections don't end there. To complete the structure, the bulkheads must also be bonded to the hull and deck.

The Importance of Attachment

The means of attachment—whether tabbed, encapsulated, or adhesively bonded—must be strong enough to carry the load of any one member and pass that load along to its supporting member. In this respect, it doesn't matter whether you are working with single-skin or sandwich construction.

You cannot simply set a bulkhead in place and tab it at the sole level or screw it to a piece of joinery. That won't do the job. Again, you must ensure that each and every member is adequately attached to its adjacent supporting member; otherwise, the structure will not be able to shed the loads and stresses of even typical operation. The structure will develop high-stress concentrations and will eventually fail.

As we discuss the merits of single-skin and sandwich constructions, remember that the distance between stiffeners, as well as the number of stiffeners and connections required to adequately absorb and shed the load, will influence weight, cost, and cycle time.

Strength and Stiffness

Stiffness is the ability of a panel to resist bending, whereas *strength* is the ability to carry load. If one panel is stiffer than the next one, the stiffer panel may ultimately fail at a lower load capacity, because it does not have the same strength. For example, a piece of ½″ (13mm) drywall and a piece of ⅜″ (9mm) plywood have about the same initial stiffness over a 24″ (60.9cm) span; but I would rather jump up and down on a plywood deck than even dare step out on a deck made of drywall.

The Stiffness Factor

Stiffness is a primary concept to consider when you are choosing between single-skin and sandwich construction. Either way, you'll be dealing with fiber-reinforced plastic—a "stiffness limited" material. FRP has a tensile strength similar to that of aluminum (35,000 psi/2,461 kgcm), but it has only 12% to 13% of aluminum's stiffness.

In boatbuilding, the level of stiffness needed in a structure is governed by deflection criteria. So, what do we mean by deflection criteria? The generally accepted rule-of-thumb tells us that a hull panel should have an allowable Length/Deflection ratio, or constant, of between 75 and 100.

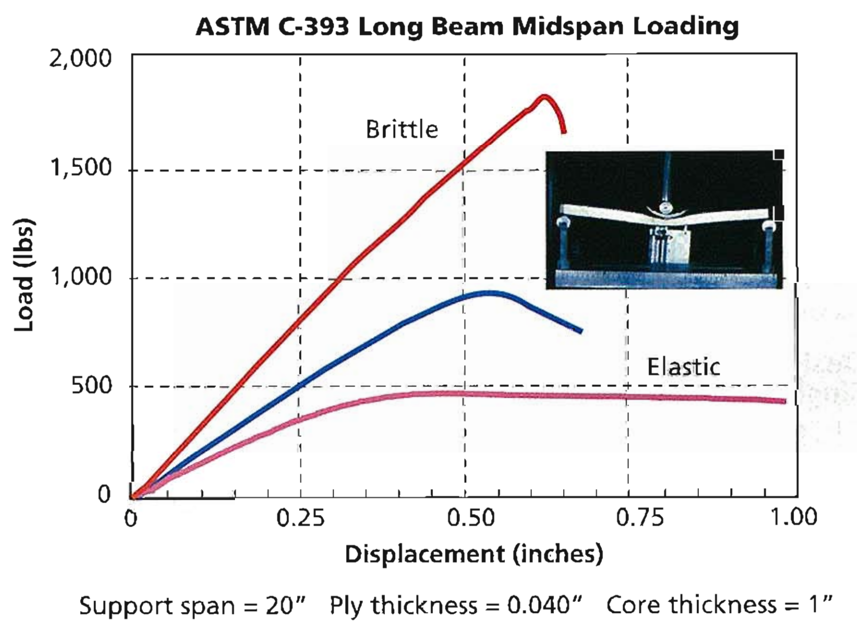
The length is the short span of the panel, which equals the distance between longitudinal stringers in a hull bottom. Using the formula L/D = constant, C, and some basic algebra, the deflection is equal to L/C. The higher the L/D constant, the stiffer the design element will be.

Designers normally specify stiffeners—such as girders, stringers, and frames—to be somewhat stiffer than the adjacent panels. If the panel's L/D is between 75 and 100, the stiffeners' L/D should be 150 to 200, or even greater.

Take engine stringers as an example. Whether your construction choice is single skin or sandwich, the entire driveline from the engine to the propeller must be stiff enough to maintain close alignment in all operating conditions, and the engine girders and support framing for the driveline must have an L/D constant of 200 or more.

Stiffness Comparison

The stiffness of a hull panel is a combination of the inherent stiffness of the laminate itself and the stiffness of the cross-section of the panel. The stiffness of the cross-section of a single-skin laminate is proportional to



Load-vs.-deflection bending curves of composite panels made with different core materials of the same thickness and with identical skins. The slope of the curve is a measure of how stiff the panel is. Balsa core (top line) has high stiffness characteristics but is more brittle at failure. Cross-linked PVC cores (middle line) are more elastic and tend to be less stiff. Linear foam cores (bottom line) have the highest elongation at failure and are thus the least stiff of all the foam-core materials of similar density.

the thickness cubed. For example, a ½"-thick panel will be eight times stiffer than a ¼"-thick (6mm) panel made with the same laminate schedule. If we compare a ½"-thick all-chopped-strand laminate with a laminate that has 2.5-oz (70.8-g) of chopped strand (0.075"/1.9mm thick) on either side of a ½" foam core, the two samples have the same stiffness.

But, where the solid laminate weighs approximately 4 lbs/sq ft (19.5 kg/m^2), the sandwich panel weighs about 1.3 lbs (0.58 kg). Also, as in the plywood/drywall example above, the thin-skin sandwich panel would not be able to carry the same load as the single-skin laminate, and it would certainly fail long before the solid laminate ever begins to develop significant stress.

The Strength Factor

The next consideration is strength—the ability of any material to carry a load for a given thickness, stated as pounds per square inch. When a designer performs engineering calculations of hull-bottom strength and bending stiffness, it doesn't matter whether he is discussing single-skin or sandwich construction. Why? Because the maximum stress in the skin is always at the extreme fiber of the laminate stack, or the greatest distance from the neutral axis. It is the strength of *that* skin that resists the tensile and compressive stresses developed during bending. When you select a stronger reinforcement, you can use less of it for a given application, provided you meet the design requirements for stiffness, minimum skin thickness, and shear strength.

Designing a Structure for Single-Skin Construction

In establishing the structure for a powerboat, most designers start with the engine foundation, and then proceed from there to organize the general arrangement and tankage.

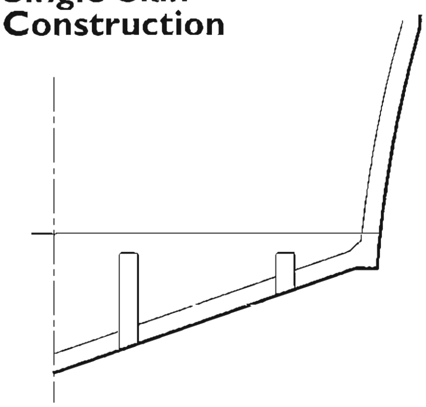
If the laminate is to be single skin, then the longitudinal engine beds or girders will be set on appropriate engine centers, and the frames and bulkheads spaced at normal intervals of 3'/0.9m to 4'/1.2m. (Or sometimes more, depending on factors beyond the scope of this article.) The resulting hull-bottom thickness for such an arrangement can be quite thick for the strength and stiffness required. If we take the example of a 40' (12.2m) sportfisherman—see the accompanying sidebar on page 108—the engines can be set on longitudinal stringers 31" (78.7cm) center to center, which in turn would require a single-skin E-glass laminate of more than ⅝" (16mm) thickness to be just stiff enough to meet deflection criteria. While that ⅝" solid-laminate skin might meet the L/D criteria, it would in fact be far stronger than it really needs to be.

So, to reduce the thickness of that skin, you can add intermediate stringers or frames to narrow the panel span. Need to go even thinner? Then you can opt for some of the more "exotic" fibers—say, S-glass, or Kevlar, or carbon fiber—all of which are not only stiffer but also stronger than conventional E-glass laminates.

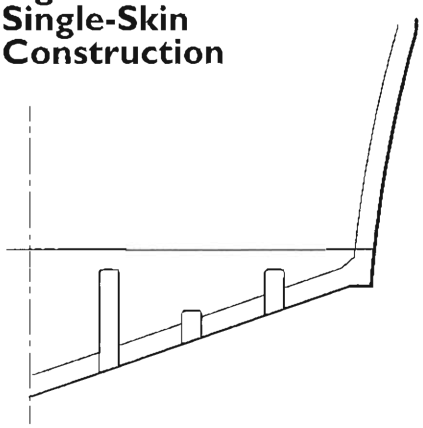
There's the trade-off, though. If you want a *thin* single skin, you need more intermediate stiffeners. And every additional stiffener means more time in the mold—*and* thus more labor to install the framing.

The real engineering advantage to single-skin construction comes when you design the hull shell and secondary structure to be just stiff enough to meet the bending criteria and, at the same time, to provide the minimum safety factor required for

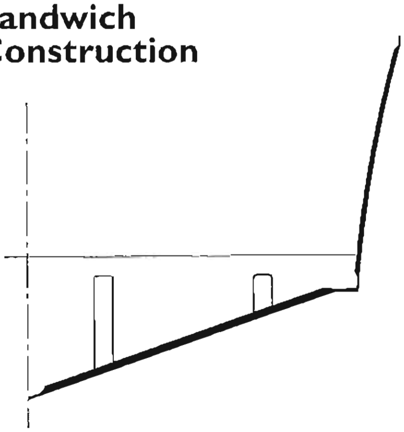
Single-Skin Construction



Lightened Single-Skin Construction



Sandwich Construction



Top—*Generalized structural design sets the spacing of the main stringers to match the spacing of the engine mounts; transverse frames are set at intervals that coincide with major bulkheads and interior accommodations. The result: a fairly thick laminate to meet basic stiffness criteria, but one stronger and heavier than desired.* ***Middle***—*The quickest and easiest way to reduce skin thickness and weight is to reduce the span between supporting members. Here we see the same general structural arrangement as above, with the addition of a midspan stringer to reduce the span.* ***Bottom***—*Since the stiffness of a sandwich laminate can be readily increased with small increases in core thickness and even smaller changes in skin thickness, larger spans can be employed and the structural design simplified (fewer stringers, frames, bulkheads). The result: lighter panel weight, and lighter weight overall of the secondary structure.*

strength. The result is an optimized structure that benefits from the minimum overall weight to meet its expected service duty.

Designing a Structure for Sandwich Construction

The basic theory behind sandwich design is frequently described as being similar to the structural concept of an I-beam. In sandwich construction, the skins, or facings, which are similar to I-beam flanges, carry the tension and compression stresses developed during bending, while the lightweight core material, which is comparable to an I-beam web, carries the shear loads. (In single-skin construction under normal bending loads the top ply on one side will carry the maximum tensile stress while the outermost ply on the opposite face will carry the maximum compressive stress. The developed shear stress is then carried through the interface between adjacent plies—the resin.)

In the construction of any structural element, the most effective way to reduce the number of stiffeners is to incorporate a sandwich panel into the equation. For example, you might specify a sandwich laminate for a coach roof or foredeck since you must cover a large span with little or no framing, and you want it to be lightweight. Do you need to minimize the number of required stiffeners? Do you want to reduce weight in your structure? That's when sandwich construction makes the most sense.

You'll also want to consider other design factors such as high compression forces, static- and/or dynamic-loading conditions, elevated-temperature operating conditions, and interior or exterior applications. High compression loads are easily absorbed with thickened single-skin construction but may require higher-density sandwich core materials to carry equivalent loads. Static loading might require cores with less elongation at failure, while a dynamic loading scenario might require a tougher core with higher elongation. In single-skin construction, you simply adjust the thickness of the laminate to suit the loading conditions.

Operating temperature is another factor. Foam cores have an operating

Comparing Single-Skin and Sandwich Construction

To give you an example of hull-bottom panel weight vs. construction style, I've optimized the laminate schedule and stiffener spacing of a 40′ (12.2m) offshore sportfishing boat. My figures comply with the classification society Det Norske Veritas' published rules for "high-speed light craft and naval surface craft."

I've performed five separate iterations of the DNV rules with five separate laminate schedules. The design options are: solid laminate construction with a maximum span of 31″ (78.7cm); lightened single-skin construction with panel spans of 15.5″ (39.4cm); and then three iterations of core materials with a span length of 31″.

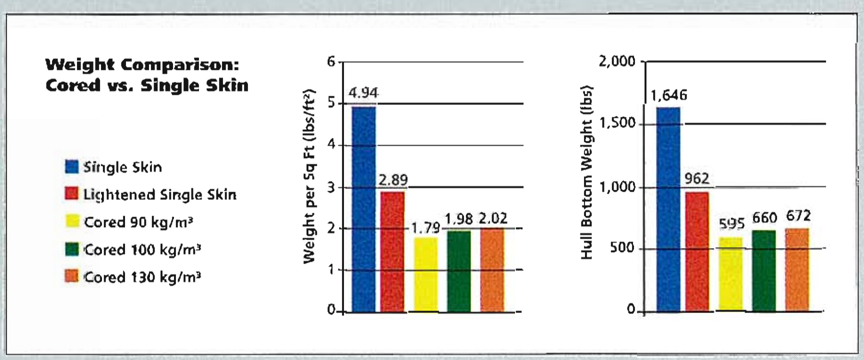
In this notional example, note that the resulting weight of the secondary structure for the hull bottom would be the same for all configurations *except* the lightened single-skin construction. In that case, the added intermediate stiffeners required to reduce panel spans have actually increased the weight of the structure by nearly 25%.

Now, taking the same 40′ fishing boat as an example, and DNV's high-speed rules as a basis for the design, I've explored five laminate schedules with optimized panel spans for each configuration. For each example, the DNV rules dictate a minimum skin thickness for a given design and for laminate properties—regardless of whether it is single skin or sandwich. Taking the minimum thickness as a starting point, I've maximized the spans to a point where the developed stress and deflection are all within the allowable design criteria.

The laminate schedules include: hand-layup single-skin construction using chopped-strand mat, woven roving, and polyester resin; hand-layup single-skin construction using knitted E-glass reinforcement with vinyl ester resin; hand layup and

Weight Comparison

Construction	Panel Weight lbs/sq ft (kg/m²)	Weight of Hull Shell and Structure lbs (kg)
Single Skin	4.944 (24.139)	1,946 (883)
Lightened single-skin	2.890 (14.110)	1,097 (498)
Sandwich 90 kg/m³	1.787 (8.725)	895 (406)
Sandwich 100 kg/m³	1.983 (9.682)	960 (435)
Sandwich 130 kg/m³	2.020 (9.863)	972 (441)



The data and values in the charts and bar graphs on this and page 111 apply to a notional 40′ (12.2m) offshore sportfisherman. Five separate scenarios for composite construction are presented, all based on classification society (DNV) rules.

temperature at which they will soften or may outgas, so the color of the exterior surface could be a problem. Remember, a white surface can develop a temperature of 120°F (48.8°C) in the Florida sun, while a dark color such as black, dark blue, green, or red can readily reach 180°F (82.2°C). Single-skin construction is limited only by the heat distortion temperature of the resin, and that is often much higher than the softening point of most foam core materials.

For interior applications, cores do not need the weather-and-moisture resistance or dynamic impact resistance or compressive strength that a hull or deck core would require. For example, paper or aluminum honeycomb is a wonderful material for lightweight interior applications such as bulkheads and cabinetry, but I would be hard pressed to recommend it for an exterior or high-moisture application, where dynamic impacts and weathering might quickly damage or erode the core. By contrast, most single-skin construction is just too heavy to consider for most interior applications, with the possible exception of headliners and hull liners.

Pros and Cons of Single-Skin and Sandwich Construction

Beyond their engineering differences, both of these methods of boatbuilding have factors in their favor *and* against them. Here is a brief roundup of topics that you will want to consider while making your decision about which process is best for your shop.

Training

Since single-skin construction is an open contact-mold process, whether sprayup or hand applied, workers do not need a high level of training before they can produce a vessel suitable for the general market.

Compared to single-skin lamination techniques, sandwich construction requires more labor and more training. Laminators working in sandwich construction must have the basic skills for single skin to construct the outer and inner skins, and they must also have additional expertise for core-bedding procedures and placement, fillet strips and core returns, core inserts, and closeouts. *[For an in-depth discussion of core-bonding techniques and details, see* Professional BoatBuilder *No. 94, page 48; and for core penetrations and closeouts, see PBB No. 97, page 130—Ed.]*

To install sandwich cores properly, you will need to hire or train more highly skilled technicians, whether you are vacuum-bagging or doing hand layup, and that labor expense is going to drive up your overall cost. Add to that the complication of applying a vacuum bag with bleeders and breathers and tacky tape, and you will drive up the cost even more, both for materials and the additional expertise.

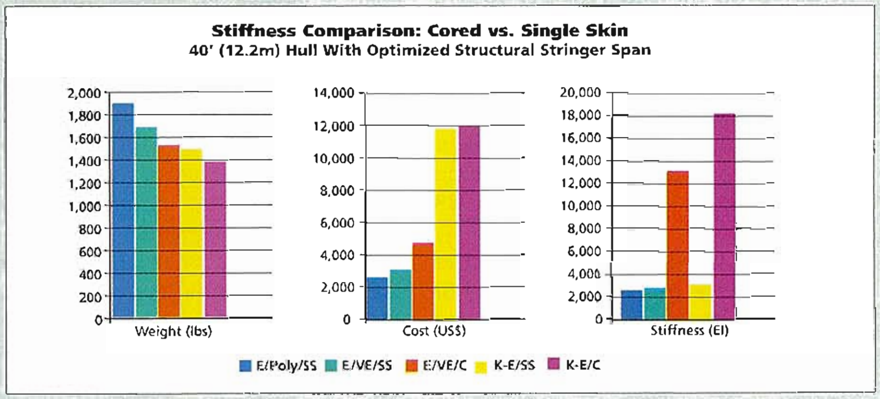
Production Cycle Time

Since solid-laminate construction is usually faster to build, with fewer steps in the lamination sequence, it offers higher production rates and a shorter amount of time in the mold. Solid

Optimized Panel: Material Cost, Weight, and Stiffness Comparison

Description	Cost *	$%	Weight lbs (kg)	#%	Stiffness (EI)	EI%
Single-skin E-glass WR polyester	$2,629	0	1,893 (859)	0	2,514	0
Single-skin E-glass knitted VE	$3,144	+19.5	1,685 (764)	−11	2,726	+8.4
Cored E-glass knitted VE **	$4,819	+83.3	1,522 (690)	−19.5	13,200	+425
Single-skin Kevlar/E-glass epoxy ***	$11,918	+353.3	1,506 (683)	−20.5	3,174	+26.5
Cored Kevlar/E-glass epoxy ***	$12,003	+356.5	1,363 (618)	−28	18,026	+617

Material cost only, labor not included
* Cost includes vacuum bag, if required ** Core vacuum bag (cost = $193) *** Two vacuum bags required (cost = $517.60)



knitted E-glass skins with a vacuum-bagged sandwich core; knitted Kevlar/E-glass hybrid single-skin construction with epoxy resin and full vacuum-bagged construction; and finally, knitted Kevlar/E-glass hybrid skins on a sandwich core, with epoxy resin and fully vacuum-bagged. The results of the calculations are provided in the accompanying table and in graphical form for clarity.

—David Jones

laminate typically has: a gelcoat layer; a skincoat layer, possibly with some pre-laid reinforcement in high-stress areas; and then one or more bulk layers to build up the required thickness.

Sandwich construction in a standard female mold starts with the gel- and skincoat layers, followed by the outer skin. Next, the laminators must dry-fit and install the core. You should also quality-control the core for bond quality and then repair as necessary, making sure to properly fill any voids between core-panel seams or fillet strips. Only after all that can you safely cover up the core material with the inner laminate skin.

For most single-skin production boat hulls with one or two bulk-laminate layers, sandwich construction will require more time in the mold and a slower resultant production-cycle time. Still, sandwich laminates start to make cycle-time sense when the number of bulk ply-sets required exceeds three or four, and you can reduce your cycle time with thin sandwich skins.

The Cost of Reducing Weight

To fabricate a boat with single-skin construction, all a builder needs is basic wet-out equipment, a few bubble rollers, and some cleanup materials. Still, when weight reduction is a factor, it comes with a price: the more weight you want to save, the greater the cost you will incur. It may not be expensive to save 10% in weight, but a savings of 20% or 25% will increase costs significantly.

For example, E-glass fabrics can be $1.50 to $3 per pound, while a Kevlar hybrid is on the order of $11 to $12 per pound. Epoxy resins are more expensive than polyesters and vinyl esters. A ⅛"-thick (3mm) E-glass/polyester laminate has a materials cost of approximately $2 per sq ft, while a Kevlar/epoxy laminate of the same thickness might run approximately $8 per sq ft.

Sandwich construction, on the other hand, is inherently lighter, but again there are costs to be considered by builders that vacuum-bag. The process requires more equipment, in addition to specialized supplies such as vacuum pumps, bag film and tape, bleeder and breathers, and hoses and fittings. This all results in higher overall material costs than you would pay for single skin.

Damage Tolerance

One of the most significant benefits to sandwich construction is damage tolerance, especially compared to single-skin construction. This is due to the resilient nature of most of the cores available for boatbuilding today.

If a worker drops a hammer on a solid laminate, the surface may show only limited damage, but beneath the surface, the damage often extends out into a broader and deeper pyramid pattern of matrix cracking. Drop the same hammer on a sandwich panel, though, and the core would absorb the load from the hammer, limiting damage to the one skin.

Now consider what happens under the dynamic conditions of a planing-hull bottom experiencing slamming loads. Here, core dampens the response of the panel by absorbing the loads and dissipating them throughout the structure.

Another advantage to sandwich construction is that the core also reduces structure-borne vibration and noise. Most of the core materials in the boatbuilding industry today have certain viscoelastic characteristics that tend to absorb typical cyclic vibrations from structure-borne noise, propeller and machinery vibrations, and other noise. With single-skin construction, vibration and noise are readily transmitted throughout the vessel, owing to the high density of the solid laminate and its lack of viscoelastic behavior.

Environmental Concerns

On the downside, single-skin construction produces more volatile organic compounds—emissions—than does sandwich construction. With more regulations taking effect, directed toward clean air and worker exposure limits, the prudent builder has good reason to reduce VOC emissions to acceptable limits. This is primarily because the total acreage of exposed laminate surface goes up with the number of plies in the reinforcement and amount of resin applied.

The number of plies and the amount of resin have gone up steadily in recent years as the "need-for-speed" has increased to a point where laminate schedules now routinely call for stronger, stiffer materials.

While single-skin construction was once a fairly simple matter of saturating reinforcement fabric with polyester resin, the same term now also describes combining engineered fabric reinforcements such as knitted directional materials—unis, triaxials, biaxials, and quads—with higher-performance resins such as vinyl esters and epoxies. Single-skin construction also extends to combination, or hybrid, fabrics such as E-glass and Kevlar, or carbon and Kevlar, plus so-called lamination syntactic pattern blockers. Boatbuilders today are blessed with a wealth of materials far more extensive than the basic building blocks of mat and woven roving. Still, with each significant reduction in laminate weight, the level of training required increases, and the cost of raw materials goes up.

Good, Better, Best?

Both solid laminate and sandwich construction have their places in composite boatbuilding. The key is to learn which method best suits your own shop and your own project by taking into account *all* the factors I've indicated here, including weight, speed, structure, cost, ride quality, mold-cycle time, and the skill level of your crew. If you can balance these sometimes conflicting concerns, then you're no longer looking for the fastest and cheapest way to build a boat. You're finding the *best* way to build it. PBB

About the Author: *A frequent presenter at IBEX and a technical resource for this magazine, David Jones is the principal of D.E. Jones & Associates, a naval architecture and structural engineering firm based in St. Petersburg, Florida, specializing in marine composite structures.*

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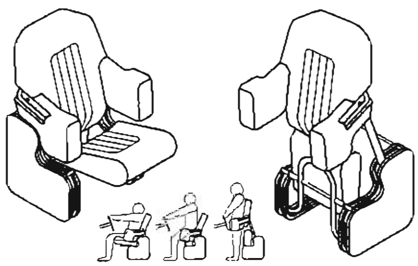

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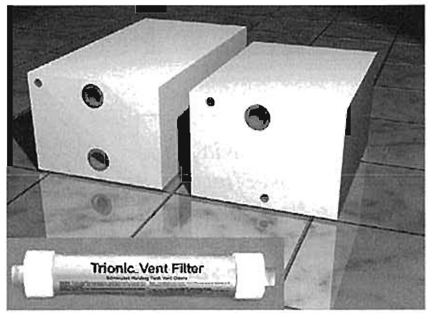

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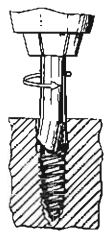

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John Merrifield, 1940–2005

by Kim Roberts

John Merrifield died August 10 at the age of 65 from a brain tumor. He was a sailor and boatbuilder, a professional, a craftsman, a leader of men. He finished what he started, and exactly when he said he would. That's why projects came to him, and why the rest of us had trouble keeping up.

Early in his career he worked alongside builder Bob Derecktor in Mamaroneck, New York, on the wooden 12-Meter *Valiant*. John quoted Bob the rest of his life, always reciting how Bob would handle a situation. John said that Bob worked his men six days a week so that they didn't have time to find another job. When John formed his own company years later, he established a four-day work week—so he could have a life. *[For a profile of Derecktor, see* Professional BoatBuilder *No. 75, page 126—Ed.]*


COURTESY KIM ROBERTS

John Merrifield, right, and partner Kim Roberts together developed some unusual products, including the Flarecraft, a carbon-fiber flying boat, one of the few successful ground-effect craft in the world.

At Minneford Yacht Yard, City Island, New York, John worked with Chuck Sadler building, among other raceboats of note, the first aluminum 12-Meter, *Courageous*. John was instrumental in figuring out how to do it, especially to the satisfaction of Lloyd's.

John had many Chuck Sadler stories. In one, they had to pour the ballast keel for a 12-Meter. The mold broke open at the end of the pour, covering the floor with 60,000 lbs (27,180 kg) of lead, 3″ (76 mm) thick. John built carbon fiber rudders—the first time that material had ever been used in offshore racing sailboats.

In 1979 John was brought to Newport Offshore, in Rhode Island, to build the 12-Meter *Clipper*, and that's where we first met. Again, John built a number of well-known raceboats, all with high-temperature-cure pre-preg decks. We were the first in the industry to employ titanium. John built the 12-Meter *Defender*, along with her pre-preg carbon boom and poles; those were the first composites in *America*'s Cup yachts. For racer Dennis Conner, John built *Spirit of America* and *Liberty*, the boat that lost the *America*'s Cup, but through no fault of his.

All things come to an end, including the IOR, SORC, *America*'s Cup racing in Newport, and even Newport Offshore. In 1985 John and I founded Merrifield-Roberts in nearby Bristol. Our first project was a raceboat for Buddy Melges, the last aluminum 12-Meter. We also built the last IOR aluminum maxi, as well as IMI ProSail 40 racing catamarans, and our largest boat ever, a 90′ (27.4m) luxury yacht.

John was a master craftsman from the old school, multitalented and skilled in every phase of boatbuilding. He was the first to bring aerospace technology to the marine field. He was the first to employ resin transfer molding, for making windmill blades. John was a welder and a painter, and every once in a while he went out to the shop to show the boys how to do it, or just to push.

The last boat he built was a 65′ (19.8m) high-speed catamaran ferry that now runs between Providence and Newport. He built her in five months. On her maiden voyage the vessel smashed into a hurricane barrier while entering Providence. At the time, it had been just two weeks since John had had a kidney removed, but he was up all night grinding and welding alongside the rest of us. He was a hard-working sonuvabitch.

With New Zealand's cheaper economy, custom boatbuilding of the sort we specialized in all but died in America. You could get a boat built there for 40% off. This forced us to metamorphose into building large-scale works of art. We presently serve some of the most famous artists of our day, among them Claes Oldenburg, Coosje van Bruggen, Roy Lichtenstein, Frank Stella, Philip Johnson, and Martin Puryear.

John worked to his last day. Visit www.merrifield-roberts.com to see the great stuff he made. I spent 25 years with him building the most beautiful things. He was as honest as the day is long, and knew how to meet deadlines. He'd pick up the pieces of a mistake that would make most other men cry, then correct it and move forward without regret. PBB

About the Author: *Kim Roberts continues to manage Merrifield-Roberts Inc. in Bristol, Rhode Island.*

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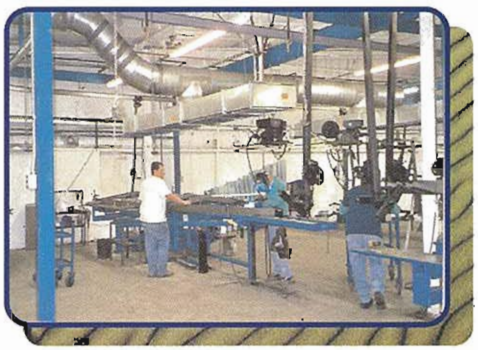

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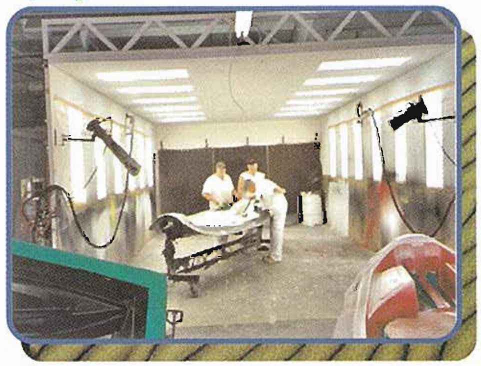

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