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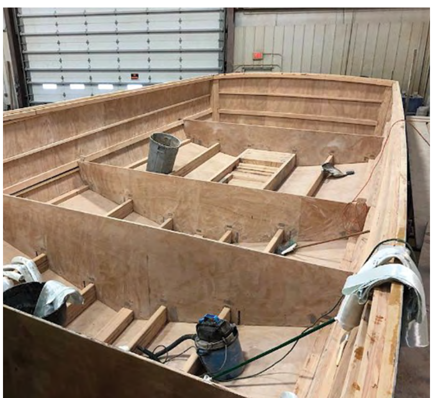
SS Eastland *capsized. Page 16.*



Weaver Boatworks build method. Page 22.

Electric oyster-farm tender. Page 28.

RAD 40 in autonomous mode. Page 34.

FEATURES

DEPARTMENTS

READER SERVICES

On the cover: RAD Propulsion's unique outboard configuration, of a lower leg capable of 180° rotation married to a fixed powerhead, allows for a tight turning radius even on boats with a single unit. Story on page 34.

Photograph Courtesy of RAD Propulsion.

PHOTOS (TOP TO BOTTOM) PATRICK BRAY, COURTESY WEAVER BOATWORKS, JACK SULLIVAN, COURTESY RAD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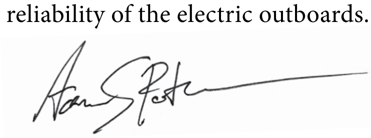
FROM THE EDITOR

Use Profiles Matter More as Propulsion Choices Multiply

In the mid-1990s, I worked on a series of charter boats and replica vessels and inhabited a subculture defined by shared obsession. My fellow fanatics and I talked endlessly about boats—the models we liked, our performance expectations, aesthetics, materials, designers, builders, destinations, etc.—refining our preferences to a list of essential boats we aspired to possess. Journal notes confirm that at one point, with all the certainty and accumulated wisdom of 25 years, I declared that the only boats worth owning were a Jimmy Steele peapod, a Concordia yawl, and a Jonesport lobsterboat with a dry-stack Oldsmobile V-8. With those, I figured I could do it all. But that was before I encountered the impossibility of comfortably navigating my 6'2" frame among the corners, cleats, winches, and slats in a Concordia cockpit; or experienced how much easier it was to cover a few miles in a small outboard rather than a superb rowboat. And while prettier and more graceful than a thoroughbred, it eventually became clear to me that a Jonesport boat with a big gas engine was also loud, low, thirsty, and well-suited for one thing: lobstering. True use profiles, I learned over time, were more essential to boat selection than aesthetic ideals or even theoretical utility.

As I compiled this issue of *Professional BoatBuilder,* I ruminated on the heightened relevance of use profiles in boat selection as alternative propulsion technologies increase their share of the market. Nic Compton's profile of RAD Propulsion (page 34) explores the development of a refined electric outboard option with a lot of promise. But for all its potential, the examples cited required careful matching of intended use to the capacity of the outboards. Indeed, every producer of electric propulsion options I spoke to at IBEX and Metstrade in 2025 warned that you couldn't just replace an internal combustion powerplant with electric and expect consistent performance.

In my research for the article on Fogg's Boatworks (page 28), I spent time looking at which applications would benefit the most from electrification. As we learned from the International Council of Marine Industry Associations' 2023 research, commonly known as the "Ricardo Report," most recreational vessels don't operate enough hours every year for operational savings to overcome the carbon penalty of producing the electric propulsion system in the boat's projected useful life. Commercial boats like *Heron*, the Evoy electric-powered oyster-farm tender built at Fogg's, run for many more hours every year, locating them on the virtuous side of the overall equation. The day-to-day challenge, as I learned from oyster farmer Willy Leathers, is to have the boat's use profile as an aquaculture tender match the capacity of the electric outboards and batteries. While the aluminum, landing-craft style, planing hulled *Heron* works well on the farm for a standard workday, adding a 25-mile round trip to deliver oysters to the seafood dealer in Portland, Maine, exceeds the boat's power capacity. The solution was not to install more large, heavy batteries to extend range and runtime, but rather to help advocate for the installation of a fast charger on the Portland waterfront that would be open to any electric boat. With the help of Maine's Island Institute, the Gulf of Maine Research Institute, and local governments, that charger has been installed, and with just an hour plugged in at the dock, *Heron* now has more than enough power to get back to her home berth and charger in Freeport. The change means that Leathers and his crew must shift their schedule and use patterns to spend an hour at the dock on the Portland waterfront, a small price to pay for the efficiency and quiet reliability of the electric outboards.



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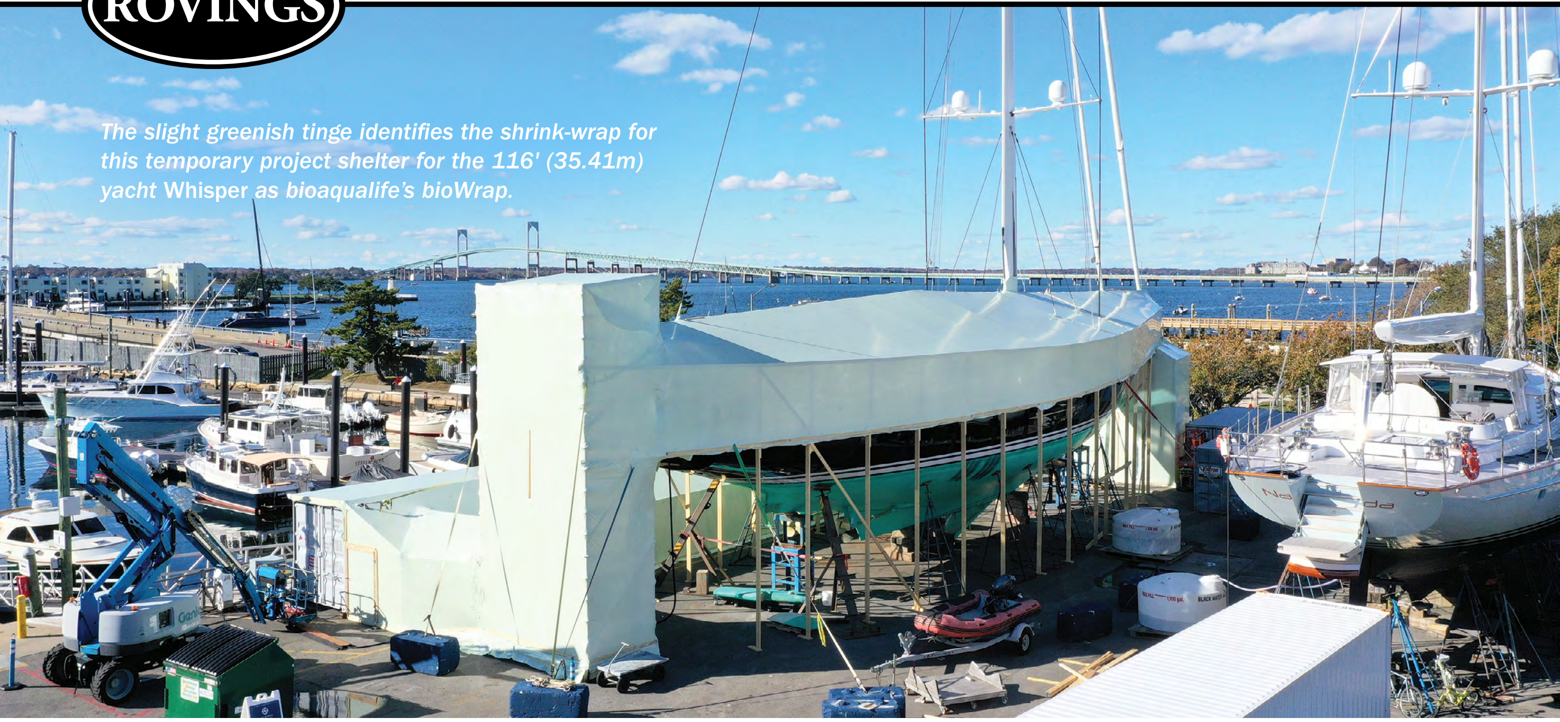

The slight greenish tinge identifies the shrink-wrap for this temporary project shelter for the 116' (35.41m) yacht Whisper *as bioaqualife's bioWrap.*

Betting on Better Wrap to Beat a Bad Rap

When the patent for boat shrink-wrap was filed in 1980, it quickly transformed how boatyards stored and protected vessels, especially through northern winters. As we near the half-century mark of this now ubiquitous material, few technicians even remember the days of costly custom canvas covers or cheap blue polyester tarps lashed down with rope and shredding in the wind and rain. But the convenience came at a cost: 46 years' worth of plastic polymer trash is now breaking down into microplastics that are infiltrating our soil and water supplies. Shrink-wrap waste has become a necessary evil—an unavoidable tradeoff for a convenience most yard workers and boat owners can't imagine living without.

The first meaningful push toward greener practices since the turn of the century has focused not on eliminating shrink-wrap, but on recycling it. What began as small grassroots efforts has grown into established programs diverting hundreds of thousands of pounds of plastic from landfills each year. While we're not eliminating the microplastics problem, we're reframing it.

For boatyards, the grant-supported nonprofits and state-run recycling programs have become so efficient that participation is often easier and cheaper than ordering an extra dumpster. While doors, zippers, and ties must be removed before baling, the processing cost of $12-$14 per boat is low enough to fold into customer invoices without complaint.

Most recycling expenses stem from transporting the material. Shrink-wrap must be clean before it can be reused, which requires a stop at a processing facility. Victor Horton of the **Maine Resource Recovery Association** says the roughly 44,000 pounds (19,958kg) collected annually in Maine move through two processors that bale and load it for transport. In Rhode Island, Jen Huber of the **Rhode Island Marine Trades Association** notes that its members' 197,000 pounds (89,358kg) of shrink-wrap waste are picked up directly from boatyards, then sorted and baled off-site by an independent processing facility. From there, trucks in both states—and beyond—haul bales of plastic to what is optimistically referred to as the "recycling marketplace."

The wrap eventually lands at one of several outlets around the country, which pay about 15 cents per pound. This is where the recycling should happen. Unfortunately, one of the most popular destinations, New Jersey-based TerraCycle, settled a 2021 lawsuit over unlawful and deceptive recycling claims after thousands of tons of plastic sat untouched in its warehouse. Reliable recycling outlets are hard to find in the marketplace, but at least one Virginia plant called NexTrex turns shrink-wrap into "lumber" for Trex Decking composite deck boards and outdoor products. Still, once you factor in the carbon cost of hauling hundreds of truckloads of plastic thousands of miles, it's hard to say the environment comes out ahead.

The reality hasn't changed: landfilling shrink-wrap remains the cheapest and easiest option—just as it has been since the first loads arrived at dumps in 1981. Four years ago, a Rhode Island-based

PHOTO COURTESY BIOAQUALIFE

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The waste from seasonal shrink-wrapping in North American boatyards runs to the hundreds of thousands of pounds of plastic, only a fraction of which is actually recycled.

A standard service yard shrink-wrap application for boat storage includes a zippered door and air vents.

company addressed that inconvenient truth by introducing a new type of shrink-wrap deliberately designed for the landfill: **bioaqualife**® sells bioWrap™, a material for boat winterization, tenting, and other applications. This shrink-wrap is engineered with a proprietary formula that keeps it strong, durable, and easy to handle during installation on boats, yet enables it to break down in a landfill within three and a half to five years after disposal, according to bioaqualife's independent laboratory testing. With this formulation, recycling isn't the best end-of-life option for bioWrap—the dump is.

Manufactured in the U.S. and distributed by Land N Sea, bioWrap is installed, removed, and disposed of exactly like traditional shrink-wrap. Rather than asking yards to change their processes, bioaqualife founder Simon Milne focused on creating a product that fits into existing workflows and performs better overall—not just environmentally. "Even if it weren't biodegradable, it would still be a better product, outperforming existing shrink-wraps," he says.

Priced about 10%-12% higher than other shrink-wraps, bioWrap's extra expense is comparable to the recycling costs of approximately $14 for the average boat. Plus, bioWrap is tear- and puncture-resistant, pliable, and purportedly requires less heat than conventional shrink-wrap during installation. Milne says the company's thickest film at 11 mil matches the strength of competing products offered in 13-mil and 14-mil thicknesses. All bioaqualife products break down in the landfill—including doors, tape, and wrap used in painting or sandblasting that's too contaminated to be recycled. And, no, it won't disintegrate while it's on boats, even over long periods of time outdoors in the sun and elements. bioWrap's proprietary additives remain completely stable until reaching an anaerobic, microbe-rich landfill environment where they draw in the microorganisms that eventually fully consume the material, leaving nothing behind—not even dreaded microplastics.

The bioaqualife film is sometimes met with disbelief by boatyard operators, in part because the product is so new that the first dumpsters of bioWrap waste are only now reaching landfills. Its proprietary technology has also left some waste-management professionals wary. An email sent to ten environmental experts from state agencies, universities, and sustainability-focused nonprofits seeking their impressions was met largely with skepticism. Asked instead for recycling success stories or promising new technologies that boatyards could implement, the group responded with near-total silence. Eventually one researcher replied diplomatically that, "it's still a tough go, to get shrink-wrap material back into some useable form," before extoling the "great opportunity for leadership" available to whoever may invent the product or process we were all silently anticipating.

While many industry leaders also wait quietly for a convenient alternative, Milne is offering one loudly and assuredly. In just two years, his signature pale-green wrap has become an increasingly familiar sight, not only in U.S. boatyards but across the Middle East, Australia, New Zealand, the EU, Turkey, and the United Kingdom. Confident in the technology, Milne isn't stopping at shrink-wrap; a nine-layer technical film now in testing could open the door to vacuum-bagging applications. As the industry looks ahead to more sustainable materials and practices, Milne's hope is simple: that underground microbes are already hard at work turning yesterday's bioWrap into tomorrow's clean slate.

—Nicole Jacques

Not just for storage, bioWrap can serve as a protective layer for vessels in transit.

PHOTOS COURTESY BIOAQUALIFE

Augusto 'Kiko' Villalon receives an Industry Icon award from ABYC President John Adey in 2024.

VANISHINGLY RARE:

Augusto 'Kiko' Villalon, 1931-2025

The best journalistic source is one who knows full, clear details of the story you are reporting. Ideally, they've been around from before the full arc of the narrative commences, they have been attentively and intelligently observant, and the quality of their recall of details is beyond reproach. It helps immensely if they are a patient teacher and engaging raconteur. It's an ideal I learned about early in journalism school and dismissed as an impossible standard as soon as I got to work.

I met Augusto "Kiko" Villalon and his wife Gordie in the early aughts having been invited to visit aboard their Brewer 44, *Alfin* (one of his many boats so named) anchored near the magazine offices in Brooklin, Maine. They were waiting for a repair part to be delivered before continuing their cruise downeast. Then Publisher Carl Cramer and I rowed out through the warm foggy harbor guided by the mellow smoke of Kiko's Cuban cigar. In the broad-ranging and personal dinner conversation that followed we were delivered an unselfconsciously comprehensive history of the evolution of modern boatbuilding in America from a man who had seen much of it firsthand.

We started with sailing, and Kiko's youth in 1930s Cuba with a Bahamian sloop and building a Seabird yawl with his father, Next, his migration to the U.S. in the 1960s where fate led him to work for Jack Riggleman at Arkansas Traveler, building affordable runabouts and small cruisers in aluminum and composites. Then on to engineering at Caravelle and Sea Crest and the evolution that led to his founding of tooling and prototyping company Marine Concepts in 1975. There he was in the catbird's seat, building molds for everyone with fresh ideas and new models in the industry: Regal, Chaparral, Ebbtide, Monark, Glastron, Thunder Craft, Wellcraft, Chris-Craft, Correct Craft, Aquasport, Crestliner, Mako, Hunter, Carver, and some obscure players like Hyundai and Porsche. It's no exaggeration that he did work for nearly every production boatbuilder in North America from the 1970s until he sold the company in the mid-90s.

I was also introduced to Kiko's relentless and articulate advocacy for the American Boat and Yacht Council, ABYC, where he'd been an active member since 1962. His recollection of the founding of the council—how builders and designers came together to raise the bar of boating safety despite incentives to ignore shortcomings—and the work with government regulators to vet and create standards for emerging technologies through the decades was invaluable to a young boating journalist who had ample sea time but zero hours in technical advisory meetings.

Sitting in *Alfin*'s cockpit sharing his concerns about higher-powered outboards and recent changes in stability calculations he embodied why standards development is a game for well-informed mature minds doing thoughtful, collaborative, intellectually and morally honest work in the public interest. It's exactly the skill and character set of an ideal journalistic source, a role Kiko would play for me and this magazine until his death Oct. 8, 2025.

What I didn't know yet when I rowed ashore that night, and what they don't tell you in journalism school, is that if you are supremely fortunate, the best sources can also make the best friends. Thank you, Kiko. Abrazos amigo.

(For a profile of Kiko Villalon, see Dan Spurr's "**Out of Cuba**" in *Professional BoatBuilder* No. 114, page 94.)

—*Aaron Porter*

'Kiko' and Gordie Villalon, a familiar sight together at IBEX, were enthusiastic supporters of innovation in boatbuilding.

PHOTOS COURTESY ABYC


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New Skin for the Old Ceremony


Installing Finsulate anti-fouling wrap on a large commercial vessel.

PHOTO COURTESY FINSULATE

It's rare to find a truly new approach to a problem that's plagued seafarers for millennia, but Finsulate film wrap offers such a fix for marine fouling.

Life abounds in the ocean regardless of temperature or geography as nutrients and tiny aquatic plants and animals wash in and out with the constant rhythm of the tide and churn of waves. Because ocean food sources aren't tied to a well-fertilized spot in the soil, many marine organisms have evolved to fix themselves to stable surfaces and feed on the smorgasbord of sustenance that drifts by. Predictably, they grow more successfully and more densely wherever there's more food entrained in the water column, usually in the upper reaches where the smallest organisms float, some of them deriving energy from the sun, and others feeding on floating nutrients and plankton. It also happens to be where boat hulls float in a state of relatively constant immersion regardless of the tide. No surprise then that hull bottoms and other floating structures present ideal residential opportunities for everything from a light algal film to thick matted ecosystems of seaweed, barnacles, tunicates, anemones, mussels, worms, etc.

As long as there have been even the most rudimentary of boats, their users have been challenged by marine growth slowing their progress through the water and destroying their structural integrity. Historically, boatbuilders and yards have applied oils, poisons, spices, and tars to hull bottoms with varying degrees of success. The most effective tend to have negative impacts on ocean health, which has led to regulatory tightening in recent decades as lead-, tin-, and copper-based paint formulations were widely banned or limited in their legal use. Now, in addition to the antifouling toxins in bottom paints, the plastic-based paint material has been found accumulating in marine environments, spurring efforts to develop more permanent coating solutions that don't require annual renewal. Silicone-based coatings offered the promise of multi-year non-toxic antifouling, but difficult removal and replacement, as well as the risk of silicone contamination of other surfaces during application, earned them a mixed reputation among yard crews.

Enter Finsulate, a slightly elastic adhesive-backed polyester membrane with a fuzzy exterior surface of flocked nylon. Developed by Dutch researcher and passionate ocean diver Rik Breur, the surface has more in common with velvet upholstery than hard bottom paint. It's the result of an epiphany Breur had while looking at a crab and an urchin side by side and noting that the smooth crab had barnacles growing on it while the spiney urchin was free of growth. After researching how short and fine the spines or fibers could be and still prevent growth from adhering and then exploring the infeasibility of spraying flocking directly on the hull, he committed to manufacturing a short-nap sheet material in a controlled industrial environment.

The surface has more in common with velvet upholstery than hard bottom paint.

Finsulate USA founder Bernard Hidier explained that the resulting product, which ships in rolls, is cut by trained crews and applied to bottom surfaces that have been prepared with a standard two-part epoxy primer. On large boats, it's almost like hanging wallpaper, he said. On smaller vessels, fitting the film to complex edges and contours can take more time and finesse. But having coordinated numerous training sessions for yard crews, Hidier said, "Painters get it right away." And they appreciate not having to suit up in protective gear to apply or remove toxic bottom paint, in what has become a standard annual ritual of boat maintenance. Indeed, because the Finsulate doesn't shed any paint when a boat is hauled, many yards will be able to dispense with collection of residue and runoff from Finsulate boats.

"When you scrape and repaint, you need to do it in the proper place with

Many of the 900 boats fitted with Finsulate are recreational sailing vessels, for which the material is well suited. Installation is similar to hanging wallpaper.

PHOTO COURTESY FINSULATE

the right gear, and you need to collect the pressure-wash water," Hidier said. With Finsulate, he said, the bottom can be pressure washed or simply allowed to air dry, after which any remaining growth can be brushed off.

During hauling and storage, it's prudent to protect the Finsulate surface from hard chafe on lifting straps and to place scrap cardboard between the hull and the jackstand pad. But come spring, there's zero hull preparation necessary before launching. Hidier noted, it provides a lot more flexibility to yards and owners who want to get on the water as quickly as possible. And at a time when good service-yard workers are hard to get and keep, removing the nasty annual chore of scraping and reapplying antifouling paint is a net gain. For larger commercial vessels, there's also a saving in reducing downtime for maintenance.

Hidier said Finsulate is currently on about 900 boats worldwide; the earliest applications having surpassed the 10-year mark without needing replacement. That's a lot of waste paint, haul-out time, and labor saved. When it must be replaced, old Finsulate is removed by applying moderate heat and pulling the membrane off in sheets. Hidier said, because the membrane is an effective protective coating, they find the epoxy painted surfaces underneath are usually in good condition, requiring only cleaning before new Finsulate is applied.

Fixing damage from impact during service is a lot like repairing carpeting. With the boat hauled, a technician cuts a squared area and heats it to remove the damaged bit. Next, having addressed any issues with the underlying surface, they cut a new piece of Finsulate slightly oversized to fill the bare patch and turn back the edges and trim them flush with the surrounding material to perfectly fill the void.

If you've been thinking a layer of short-nap fabric on the bottom would change a boat's on-water performance, you'd be partly correct. Hidier explained that for displacement boats, there's no speed penalty as the nylon fiber remains fully submerged in water. Only when air is introduced to the running surface does friction increase. He said fast planing boats can expect to lose as much as 25% off their top speed using the shortest nap of the three Finsulate options. At the other end of the spectrum, the longest nap membrane is effective for stationary floats, pilings, offshore platforms, and underwater pipes. Preventing marine fouling on these structures makes them far less vulnerable to damage from storms and high wave action. It's also especially useful for aquaculture barges and floating assets where toxic antifouling is

Visible here is the fuzzy surface of the film that inhibits growth and discourages attachment of marine organisms, but doesn't harm on-water performance of displacement hulls.

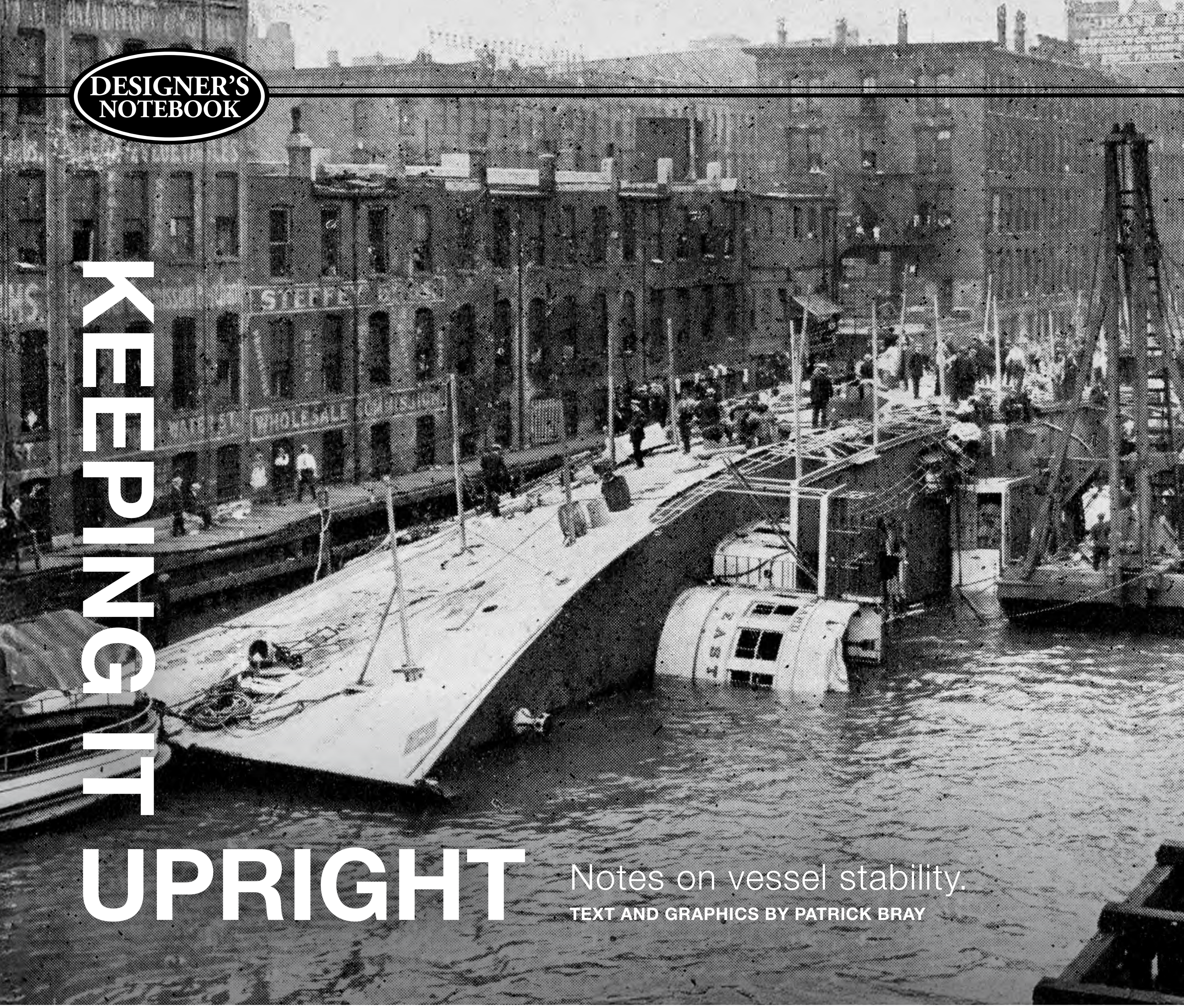
PHOTO COURTESY FINSULATE

detrimental to farming operations.

Applicator training and industry acceptance are the greatest challenges Finsulate faces. Hidier said he's optimistic that boat owners and yards will see the benefits as they use it. In the short term, he holds great hope for the superyacht industry, which comprises large displacement hulls subject to myriad environmental and antifouling regulations as they move among Caribbean, North American, Mediterranean, northern European, and Pacific waters.

"Finsulate," said Hidier, "is the only out-of-the-paint-box solution."

—Aaron Porter



DESIGNER'S NOTEBOOK

KEEPING IT UPRIGHT

Notes on vessel stability.

TEXT AND GRAPHICS BY PATRICK BRAY

Editor's Note: *Stability considerations are at the core of designing and building buoyant seagoing vessels. Yet with centuries of naval architecture and boatbuilding experience behind us, stability failures continue to plague our industry. It's understandable, looking back at the infamous 1628 capsize and sinking of the newly launched Swedish warship* Vasa, *that the state of the boat design art at the time was not advanced enough to predict such a failure. The same can't be said of the 2014 capsize and sinking of the Northern Marine-built 90' (27.4m) expedition yacht* Baaden *at her launching in Washington; the tragic sinking of the 184' (56m) sloop* Bayesian *at anchor during a squall in August 2024; and the September 2025 capsize and sinking of the 24m (79') Turkish-built yacht* Dolce Vento *immediately after her launch. Together, these contemporary failures point to disturbing deficits in understanding of, or attention to, vessel stability. They prompted us to revisit the relevant core design skills.*

For naval architects, stability is the potential of a vessel to return to a previous situation or orientation—usually a balanced upright position. Positive stability is the ability to return to upright, while negative stability results in the vessel overturning. Calculated stability in its most basic form quantifies the relationship between the center of all floatation in the hull—known as the center of buoyancy (CB)—and the center of all weight, commonly referred to as the vertical center of gravity (VCG). In short, it's an accounting of the downward pull of gravity and the uplifting force of buoyancy working against each other to achieve an equilibrium. Beyond these primary factors, all other forces play minor roles in determining vessel stability.

Static Stability

This is stability at rest with no influence from active external forces. The VCG is a relatively fixed point in space at any given loading condition. It reflects the location of major weights within the boat, including the cargo as well as the fixed superstructure and multiple decks.

In spite of a documented history of poor stability, the SS Eastland capsized dockside in Chicago in 1915 killing more than 800 passengers and crew.

Figure 1. Stability Diagram

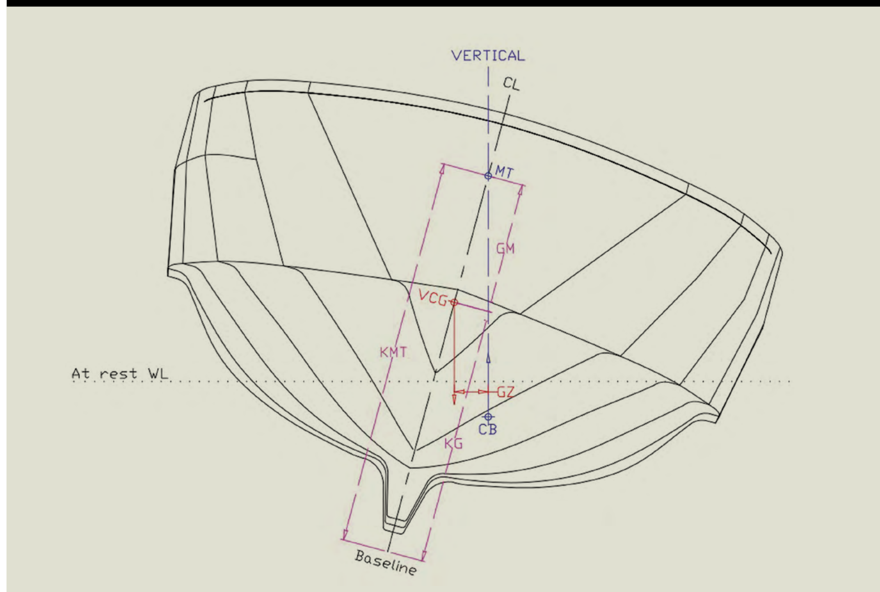
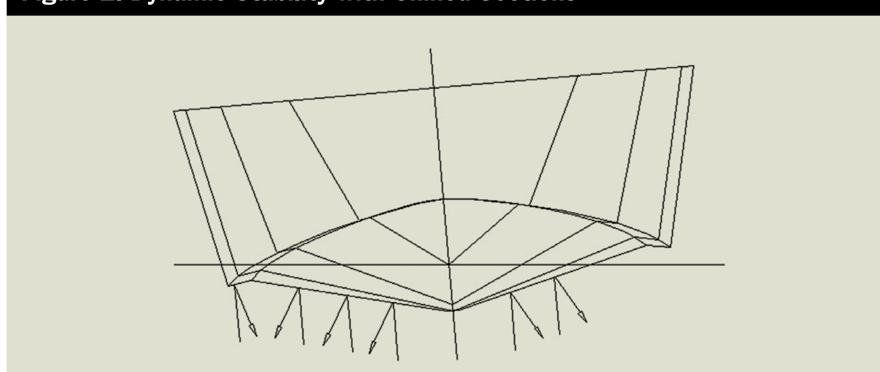


Figure 2. Dynamic Stability with Chined Sections



The shape of the hull determines the CB, which is not fixed. Its location changes with the motion of the vessel to balance the loads and keep the forces in equilibrium. The shape of the hull has a major effect on the path that the CB will take as the vessel heels or trims. At rest, the CB and the VCG align vertically. That doesn't mean a boat will rest even on her waterline, but rather she will list until CB and VCG come into vertical alignment and the vessel achieves equilibrium.

Form Stability

As forces such as propulsion, wind, or waves are applied to the vessel, its attitude changes in relation to the water's surface. As the boat heels, sides of the hull previously above water are immersed and bottom sections previously underwater are now exposed. This causes the CB to move, resulting in righting arm forces (GZ) to bring the vessel into equilibrium (see Figure 1). If the CB can't create adequate counterforce to right the vessel, it will capsize.

It's the sort of thing best not left to chance—or to discover at launching. Fortunately, the required counterforce at various angles of heel can be determined mathematically from the designer's drawings and then verified on the finished boat with an inclining experiment. (For more on inclining experiments, see Butch Dalrymple-Smith's **"Best of Inclinations"** in *Professional BoatBuilder* No.162, page 24). The first step is the naval architect completing a weight calculation to establish the VCG. This extensive analysis accounts for every item on the boat, down to the weight of the paint and screws, along with the vertical and fore-and-aft position of each item in the vessel. (Transverse measurements are considered less critical, as most boats are largely symmetrical from side to side.)

With a fixed VCG calculated, the next step is to look at where the CB moves for each angle of heel and loading condition. This is a far more complex calculation best done by an experienced naval architect (and their computer). Hullform and ballast, if any, play major roles. Both will affect overall stability.

Dynamic Stability

Once a vessel is under way, the effects of wave train, bottom pressure, and change of trim can add or detract from the amount of stability. Many planing hulls designed to exceed displacement speed gain stability on plane, due to the change in pressure distribution across the hull bottom (see Figure 2). Because of the V-bottom and the spray rails outboard, unequal pressure builds up on the lower side in a turn, which helps restore the vessel to upright when the heeling forces of the turn abate. At higher speeds, these pressures can become unequal or unstable, potentially leading to porpoising or chine walking.

Stability Requirements

International regulatory organizations set minimum standards of stability for various types of commercial and pleasure craft, depending on their use and area of operation. However, these are minimums, and any additional margin will provide a higher factor of safety. Also, these standards do not address comfort, which is of course subject to personal interpretation.

A vessel designed for offshore passages will often feel tender initially and exhibit a long, easy rolling motion—one that's unlikely to unbalance crew or dislodge gear. For recreational boaters, the period of this roll can seem disconcertingly long and the angle extreme. However, this is frequently a feature of the design, not a flaw, for seagoing vessels.

If a boat is very stable at the dock—great for liveaboards in flat water—it will often have a quick, jerky motion at sea. Consider a 110' (33.5m) powerboat that runs harbor charters and seats 95 passengers for dinner cruises. When taken to sea, it has such a quick motion in a seaway that the crew go around on their hands and knees to avoid being knocked off their feet.

Compare that to a 60' (18.3m) model with a low GM—the distance between the metacenter, where a vertical line through the heeled CB crosses the vessel's centerline, and the vessel's VCG (see Figure 3). The boat may noticeably shift under your weight as you step aboard, which doesn't instill faith initially. Having it heel under the press of a strong breeze may further erode confidence; yet a vessel with low GM can have an excellent sea motion, long range of stability, and be extremely comfortable offshore once you get your sea legs.

A naval architect must strike a compromise between stability for dockside comfort and a suitable motion for safe operation in an average seaway. The specifics of that compromise depend on many details, including the vessel's intended use and the prospective owner's level of experience.

For the Number Crunchers

A monohull motor yacht intended for extended coastal cruising, open-ocean passages, or any vessel expected to be caught out in really bad weather, must meet the international standards requiring a minimum of the following:

- Maximum righting arm (GZ) must be over 25° and preferably over 30°
- Downflooding angle must be in excess of 40°
- Initial GM must be over 6" (152mm)

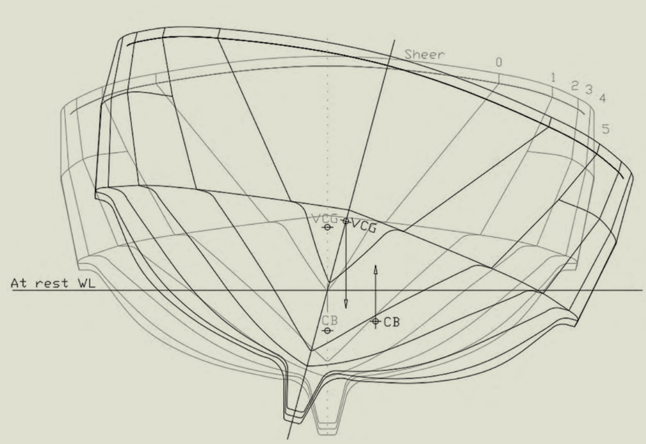
In my opinion, these characteristics are inadequate for offshore safety. A Seaworthy motor vessel should hope to achieve:

- Maximum righting moment (GZ) that occurs after 45° and preferably after 60°
- Minimum range of stability to 60° of heel and over 80° preferred
- GM of at least 1.5' (457mm) and preferably around 3.5' (1,067mm) for comfort

For sailboats expected to cruise open waters, the international standards require a minimum of the following:

- A positive range of stability in excess of 90° (In vessels over 45m/147.6'), a lesser range may be considered.)
- Downflooding angle must be in excess of 40°
- An "angle of steady heel" calculation must exceed 15°

Figure 3. Upright and Heeled Sections



Design Considerations

Let's look at the effects various elements of design have on the stability characteristics of a vessel.

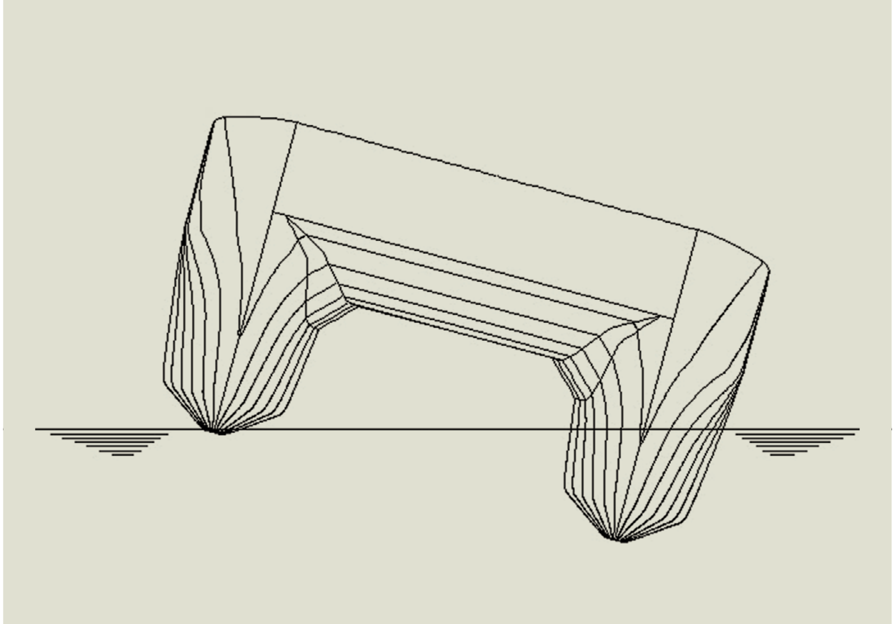
BALLAST: When we look to increase stability, we often think first of adding ballast. This will help, but not in all cases. If ballast reduces the freeboard to the degree that the deck edge will enter the water at a much lower angle of heel, overall stability is drastically reduced. Again, it's the relationship between the hullform and the overall center of weight that tells the story. In this situation, removing top weight from as high up as possible will have a greater effect than adding ballast low down.

Ballast does little to increase initial stability (stability at very low angles of heel). Its useful potential is to improve seakeeping ability at heel angles exceeding 45°.

BEAM: Wide beam yields high initial stability but low ultimate stability at high angles of heel. It's great for liveaboard space and comfort at the dock, but when taken to extremes, it will produce a boat with quick, uncomfortable motion in a seaway as it works to keep itself level with the water surface. The combination of very wide beam and low freeboard in a monohull can be dangerous as the high initial stability peaks at a low angle of heel, and once overturned the vessel becomes very stable in that inverted position.

A catamaran cruiser is a classic example of wide beam and no ballast (see Figure 4). The interior volume and low heel angles make these vessels very comfortable to liveaboard but with low ultimate stability. To compensate for this, specific

Figure 4. Catamaran Stability



ocean-going hullforms have been developed that allow high immersion of one hull before the other hull leaves the water.

INERTIA: One way to improve the motion of an existing vessel is to alter the inertia. If you have a boat with a quick motion and want to slow it down, try moving major weights horizontally outboard from the centerline. This will increase inertia and dampen out the motion. By moving the weight horizontally rather than vertically, you do not affect overall stability. If your vessel has a slow roll you aim to quicken, move heavy weights inboard or down to reduce the inertia and/or increase the stability.

SUPERSTRUCTURE: Once a deck edge is immersed, the shape and size of the superstructure become important factors in determining the CB. For this reason, trunk cabins and deck houses must be well built, with minimal openings that could allow water to enter. If a vessel is fitted with wide side decks, the house will enter the water later, reducing its effect on the stability curve. On a flush-deck vessel, all stability must come from the hullform itself.

Another potential stability influence of a large superstructure is windage, allowing a strong breeze to heel the boat. If a hull's form stability is adequate, this shouldn't be a problem. Indeed, in some seagoing boats, the press of wind on the superstructure can act to dampen rolling motions. Unfortunately, it is not a sail area that can be reduced as the wind pipes up.

Stability is not something that just looks good on the sales sheet; it will prove itself when needed the most in trying conditions on the water.

WAVES: All vessels will suffer some loss of stability on a wave face. If the waves are short and steep, the situation becomes worse. Running with the waves, a vessel spanning between two crests will be supported by the buoyant ends where there is little waterline width (see Figure 5). As the vessel heels, the buoyant midsection can fall into the trough. This can induce deep rolling motions and potential capsize.

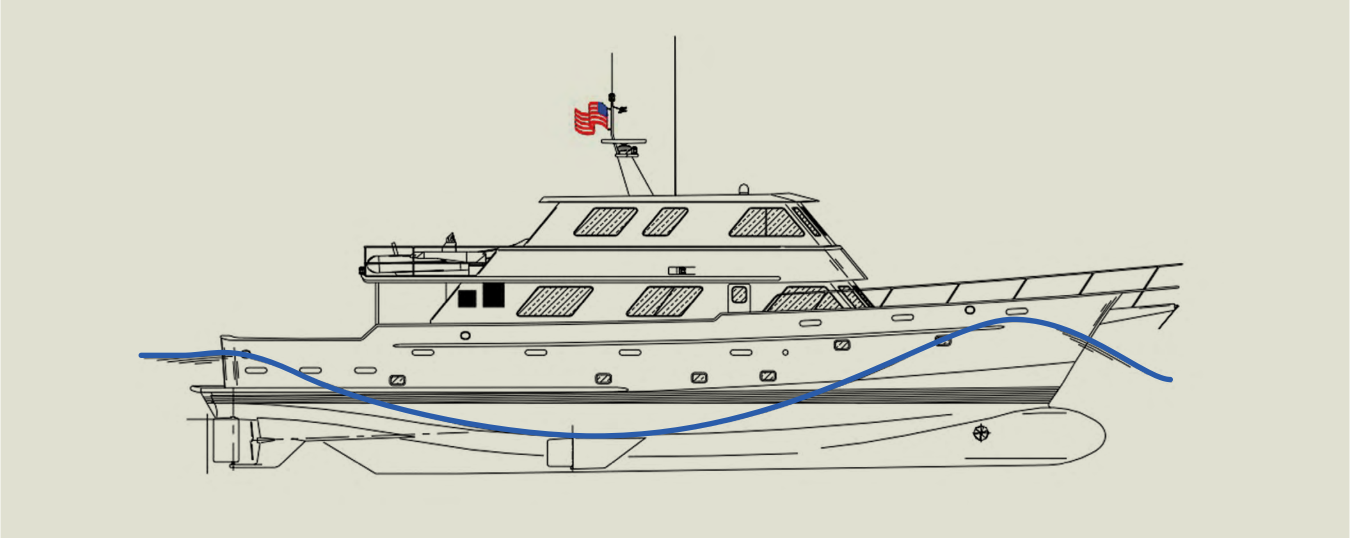
Even a beam sea can create serious problems if the wave train coincides with the vessel's natural rolling motion. While a minor change in direction or speed can avert a progressively worsening stability situation, that depends on operator ability and experience—factors a designer can't count on.

ACTIVE STABILIZERS: These are usually automated hydraulically activated fins installed amidships. Their dynamic forces return the vessel upright when a heeling force is detected. They can dampen rolling motions by more than 80% under way, but don't increase the vessel's actual stability. While fin stabilizers are most effective under way, they can provide limited dampening at anchor when a zero-speed system is installed. Alternatively, gyro stabilizers have no appendages and offer better stabilization at anchor.

PASSIVE STABILIZERS: These passive systems vary from paravanes to fixed bilge keels to anti-rolling ballast tanks. Their primary feature is that they have few to no moving parts and are mechanically simple and, therefore, relatively reliable. While they do nothing to increase actual stability, they can dampen the effects of external forces acting on your vessel, but not as effectively as an active system.

DOWNFLOODING CONSIDERATIONS: All the stability in the world will be of no use if there are low openings in your hull or superstructure that will let water flood your boat. Loading doors and engine-room intakes located low in the hull sides and leading directly below decks

Figure 5. Stability in Waves



are classic design vulnerabilities. Even if a boat has a good range of stability, it won't do much good if water is pouring in through a large opening. Penetrations for interior ventilation need to be placed carefully, and non-watertight hatches to hull compartments should be checked during design to ensure water won't enter at low angles of heel.

The effects of uncontained water inside a boat are dramatic. Water always runs to the low side, making matters worse. As a vessel rolls, the water shifts from side to side, amplifying motion. Even uncontained water on deck has the effect of raising the VCG and reducing stability. Large freeing ports in the bulwarks are necessary to get water off the boat quickly before the next wave adds to the burden on deck.

Once a hull has been damaged and water is pouring in, there is little that can be done if there are no watertight subdivisions in your boat. Commercial vessels are required to have watertight bulkheads and must be designed to remain afloat and stable with one and sometimes even two compartments completely flooded. It's a good standard to meet when designing offshore cruising pleasure craft as well.

Stability Isn't Accidental

Good stability can and should be achieved during the design phase of building or refitting a boat. Careful placement of heavy items down low, and knowledgeable design of hullform, superstructure, and hull penetrations that takes stability characteristics into account will produce a sound vessel with a comfortable motion. Attention to the numbers that determine the vessel's final characteristics will assure a safe boat long before it is launched. Stability is not something that just looks good on the sales sheet; it will prove itself when needed the most in trying conditions on the water. PBB

About the Author: *Patrick Bray is a naval architect with more than 50 years of experience in design and new construction, including three years as on-site naval architect for Crescent Yachts (Surrey, British Columbia) doing shop drawings and ensuring compliance with the classification societies. He filled a similar role at Trites Marine Services, another B.C.-based aluminum commercial vessel builder. Doing business as Bray Yacht Design and Research Ltd., he has worked directly with many other yards as designer and project manager.*

LOOSEN *UP*

Collaborating on a new T-boat for fishing charters on Chesapeake Bay.

BY CHRISTOPHER SWANHART

Designers **DLBA Naval Architects** (Chesapeake, Virginia) and builders at **Weaver Boatworks** (Deale, Maryland) have worked together for more than 20 years. DLBA's diverse portfolio includes high-speed motoryachts, workboats, patrol vessels, production boats, and top-end custom sportfishing yachts. Jim Weaver and his team are known for building sportfishing yachts that regularly extend the limits of performance with superior fit and finish. The two teams have collaborated on designs ranging between 41' (12.49m) and 97' (29.57m). I have been fortunate to work with Weaver and his crew for many years on multiple projects.

In addition to conventional sportfishermen best suited to running offshore for trophy fish, we've collaborated to develop a line of low-profile bay boats that feel right at home in and along the waterways of the Chesapeake Bay. These range from 43' (13.1m) to 51' (15.54m) in length and are a departure from the high-performance offshore models Weaver is best known for, but they are equally refined fishing machines for recreation and commercial charter operations.

The largest of the Weaver Bay Boats is a 51-footer built for Frank Carver, owner of Loosen Up Charters, a fishing service operating out of Deale, Maryland—the same town Weaver Boatworks

Frank Carver's new 51' (15.5m) charter boat Loosen Up *was designed by DLBA and built by Weaver Boatworks (Deale, Maryland).*

PHOTO FRANK CARVER

calls home. They are literally a stone's throw down Rockhold Creek from one another. Like any fisherman, Carver had very specific requirements for the new boat he wanted when he brought the Weaver and DLBA teams on board for what would become a not-so-typical build for Weaver.

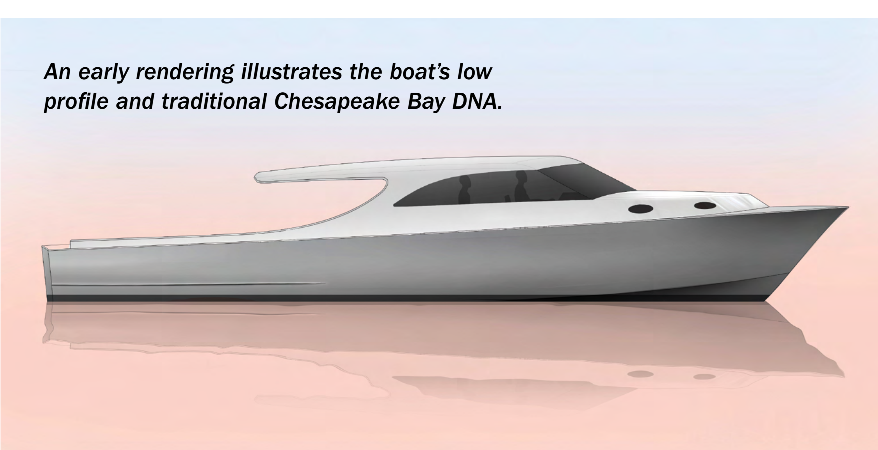
The Brief

When Loosen Up Charters needed a new boat to take parties fishing on Chesapeake Bay, there was no question that Carver's friend Jim Weaver at Weaver Boatworks was the obvious choice to build a custom vessel to meet his requirements. To start, the look was important—a combination of a classic bay-style craft with some added modern features. Performance had to be superior for what was to be a single-screw design. Finally, and perhaps most challenging, this boat had to meet U.S. Coast Guard (USCG) requirements for a Subchapter T vessel carrying up to 49 passengers. Designing and building a boat to USCG standards requires significantly more effort (and money) than creating a non-certified vessel. Myriad features and parameters must be considered, weighed, and adjusted early in the design discussion to meet all necessary criteria.

For this build, the DLBA office provided naval architecture and engineering design including hullform development, structural design and hull jig frames for production, propulsion arrangement and performance estimates, general arrangements and deck styling, mechanical layout, and general consulting to support the Subchapter T requirements.

Knowing the boat needed to accommodate as many as 49 passengers, we settled on 51' LOA and a 15' (4.57m) beam to provide ample interior and exterior deck space. The concept design started with the aesthetic goal of replicating the general look of previous Weaver Bay Boats. That meant a hull with a sweeping sheer and modest tumblehome aft transitioning into a nicely balanced flare in the forward sections—a blend of classic sportfisherman and bay-boat styles. The deckhouse has a long overhang sheltering much of the cockpit and sportfishing-inspired window lines. A raised trunk forward allows for comfortable standing height down below. Those characteristics are clear in an early rendering (*below*).

While she has somewhat traditional lines from the waterline up, the hull bottom is far more modern. Top speed was important to the client. Knowing this, and consulting the projected equipment lists provided by Carver and Weaver, we developed a preliminary weight estimate early in planning. Weight and center of gravity are critical in the design of planing craft. Dialing them in was somewhat more challenging in this case because the boat would be a charter vessel with passenger totals ranging from a few people to 49. That variation in load impacts performance and drives basic design considerations regarding USCG requirements—more on that later.



An early rendering illustrates the boat's low profile and traditional Chesapeake Bay DNA.

RENDER DLBA

Hullform

Performance and efficiency are goals for almost any new hull design, but with this project, they were especially important. The hull had to yield good top speed to reach fishing grounds (like most sportfishing yachts), and as a charter boat, fuel burn would be critical. With high projected operating hours, minimizing fuel consumption at a reasonable cruise speed was a priority.

With initial weight predictions in hand, we made a performance estimate based on Carver's engine of choice, a single 900-hp Scania DI 16 diesel. At a predicted normal operating weight of approximately 32,000 pounds (14,500kg), the projected top-end speed was about 33 knots. We built the boat on a hard-chined planing hullform with a deadrise increasing from a relatively flat 9° near the transom to approximately 20° near midships, transitioning into a fine entry forward. The warp designed into the running surface allows for a controlled running trim and efficient operation across the full speed range. Since the boat is typically operated in the bay, we could get away with a somewhat flatter bottom than sportfishing yachts that operate in open-sea conditions.

The large fluctuations in load due to varying passenger counts and location made it challenging to keep the longitudinal center of gravity (LCG) consistently far enough aft to ensure superior ride quality and predictable handling. On a typical cruiser or sportfisherman, most people tend to collect in the aft areas of the deckhouse or cockpit, but on this charter boat, many could congregate far forward on deck and in the house enclosure, shifting overall LCG forward. Our solution was a direct-mount V-drive gear to keep the engine well aft, helping ensure proper

LCG placement. To the same end, the two 225-gallon (851.7l) fuel tanks are located relatively far aft.

A centerline propeller tunnel helps reduce shaft angle, maximizing propeller efficiency, which is important as the large-diameter prop sees somewhat high loading. Another benefit of the tunnel design is decreased draft.

Weaver's conventional wood/epoxy composite construction method includes Douglas-fir stringers and stiffeners, Okoume plywood planking and bulkheads, and fiberglass sheathing inside and out on hull, deck, and cabin structures.

Structural Design

Structural development of *Loosen Up* followed Weaver's established construction methods—cold-molded with epoxy and Okoume marine plywood planking, and internal stringers and stiffening of Douglas-fir. All hull planking is skinned on the outside and inside with fiberglass, which also encapsulates the stringers. The deck and deckhouse are built with a stiffener grid and Okoume plywood planking skinned with fiberglass. This true composite build comprises bottom structure of 2.5" (63mm) laminated Okoume core sheathed between skins of 1208 and 1808 fiberglass on both sides. Hull topside sheathing is 3/4" (19mm) Okoume sheathed in slightly lighter laminates. And in way of the propeller tunnel and shafts, wood and laminate structures are thicker.

The centerline propeller tunnel reduces shaft angle and reduces draft while accommodating a large-diameter prop.

The result is a very solid boat. With structural wood elements, once the design is made strong enough for service, it is more than stiff enough. Unlike single-skin fiberglass, which can transmit excessive movement and vibration, the wood structure damps noise and softens wave impacts. While this construction method is not new, the materials—especially the fiberglass skins—employ modern technology, and the Weaver team has fine-tuned their process to create a robust structure without excess materials or weight.

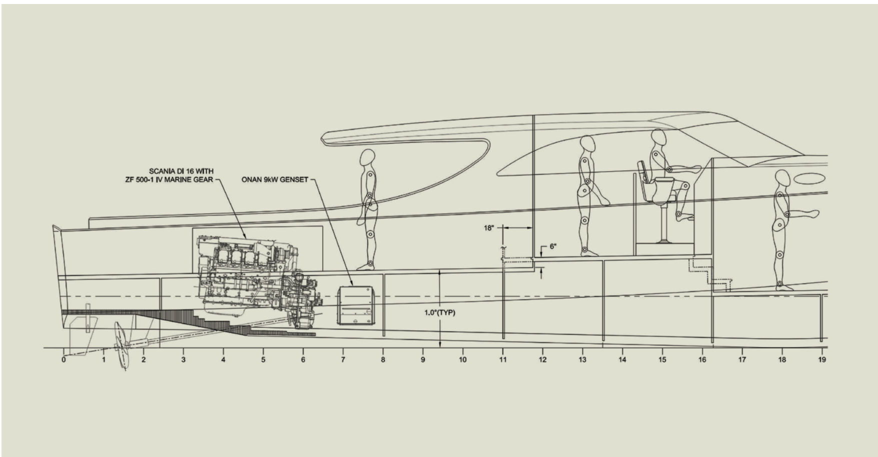
Typically, DLBA uses a first-principles approach to the structural design of a Weaver boat. But this one was different, as it needed to be reviewed and approved by the Coast Guard to meet an accepted guideline. We designed the structure to American Bureau of Shipping (ABS) Yacht Rules, which the Marine Safety Center (MSC) approved up front. While it provides a slightly heavier scantlings plan, it is not excessively heavier than a design using a more traditional approach. In short, it didn't require Weaver's crew to deviate markedly from their standard scantlings or build method.

Interior and Engine

Interior arrangements on this charter fishing boat are relatively simple but set a high standard for the application. As with many sportfishing boats, our design path started with the cockpit, which we wanted to locate at a specific height relative to the expected waterline. For fishing, optimal height may be 6" to 9" (152-229mm), but a USCG requirement sets this dimension at a minimum of 10" (254mm) in the heaviest full-load condition. On the new Weaver, this had to include the maximum passenger count of 49 people, which can add more than 6,000 pounds (2,722kg)—not an insignificant amount on a hull with lightship displacement just over 27,000 pounds (12,247kg). The requirement drove up the cockpit deck height, which had knock-on impacts on other elements of the boat, such as raising the hull and deckhouse profiles.

Another height-related requirement states that there must be a step up or lip between the exterior (cockpit) deck and the salon (deckhouse interior) deck with a minimum height of 6" (152mm). This prevents water in the cockpit from sloshing into the deckhouse. While this detail

PHOTOS COURTESY WEAVER BOATWORKS



The V-drive transmission keeps the engine weight and box aft, allowing charter guests to ride forward under the shelter of the long deckhouse overhang.

is not uncommon, its impact here is worth noting—it, too, drives up the deckhouse deck height. These two requirements combined to create a hull and overall boat height (off the water) somewhat taller than standard for a recreational boat of this style not being chartered.

While the deck-height requirements are not directly consequential to performance, they are critical in achieving certification as a T-boat. If she didn't pass the loading test after construction by meeting stability criteria—including deck height above water—*Loosen Up* would not be certified. Because deck and topside height are not easily modified features, starting our design work with an accurate weight estimate was essential.

We designed the deckhouse interior with good sight lines from the helm and space for passengers to shelter from the elements. Additional seating and a small head are available down below. All interior spaces are climate-controlled. Because this is a fishing vessel, most activity takes place outside in the cockpit, which offers expansive space with seating on the engine and machinery box located on the centerline. The total deck area aft of the deckhouse is approximately 280 square feet (26.01m^2). The long roof overhang covering some aft-facing benches just outside the deckhouse provides ample shade for those wanting relief from the sun. With such a long top, there is plenty of space above to accommodate all electronics, the life raft, and numerous rocket launcher rod holders.

Engine choice was driven by the client's preference and validated by our initial design numbers. The Scania is a proven engine with a superior power-to-weight ratio, providing the necessary horsepower to hit desired speeds. The single diesel is quieter than twins, and resilient mounts and insulation in the engine space and box further limit engine noise.

Propeller noise and vibration can be heightened in a poorly designed propeller tunnel, so we ensured appropriate geometry and tip clearance for the 30" propeller.

At the helm station, the modern engine instrument display is joined by a standard onboard electronics package: a 96-mile (154.5km) radar, FLIR, GPS, depth finders, and communication systems.

More Subchapter T Impacts

There are too many requirements triggered by Subchapter T status to detail here. They include the structural scantlings and general layout of the boat discussed above but also touch almost every onboard system. In some instances, certification requires simple documentation of system components to ensure they meet minimum requirements, but others are more involved and directly impact design and construction. For example, fuel tanks on a certified vessel must be inspectable (an annual requirement), while in a non-certified build, this is not a concern. On *Loosen Up*, we arranged the tanks appropriately, including a fuel shut-off valve within 12" (305mm) of the fuel compartment access point.

Often, an arrangement or detail that makes sense from a pure design or use standpoint doesn't meet the requirements. In those cases, we balance good design with regulatory compliance. For example, on *Loosen Up* much effort was made by the builder and equipment suppliers to provide drawings and documentation illustrating that the electrical system met standards. In that process, many details had to be considered, including the proper grade of conduit and drawings delineating features of the overall system.

The single 900-hp Scania DI 16 diesel rests on its engine beds as systems and structure are built in around it.

The Weaver team navigated system requirements with the help of the Officer in Charge, Marine Inspection (OCMI), who ultimately must be satisfied that all requirements are met for final certification. For this reason, early communication between the design and build teams and the OCMI is important, and it proved to be beneficial as the build reached later stages. (For more on building for Coast Guard Certification see John Marples's "**Satisfying Subchapter T**," *Professional BoatBuilder* No. 211, page 40).

The successful fishing charter boat is certified by the Coast Guard to carry up to 49 passengers. She cruises at 25 knots and provides a soft dry ride.

PHOTOS FRANK CARVER

Conclusion

Whenever a new design first splashes, excitement and stress levels run high. In the case of a T-boat, the load test is a high-stakes milestone—failure can be a showstopper. *Loosen Up* was put in the water and tested at full load, including the weight of 49 passengers. The critical detail was that the cockpit deck maintained or exceeded the minimum required height above the waterline. Because the OCMI had been involved with the project from early on, other arrangement and system requirements were already known to meet criteria.

Sea trials followed, and the new model proved to be a superior performer. While coming in just a bit heavier than the design weight, she runs upward of 34 knots at wide open turning the 30" x 34" (762 x 864mm) four-bladed propeller through the 1.75:1 V-drive gear. At a cruise of 2,000 RPM, she makes 25 knots while burning only 31 GPH (117.3l/h). Carver reports that over the first year of operation, *Loosen Up* ran approximately 30% faster and 40% less fuel than his old boat, which was only 46' (14.02m) long with 2' (610mm) less beam.

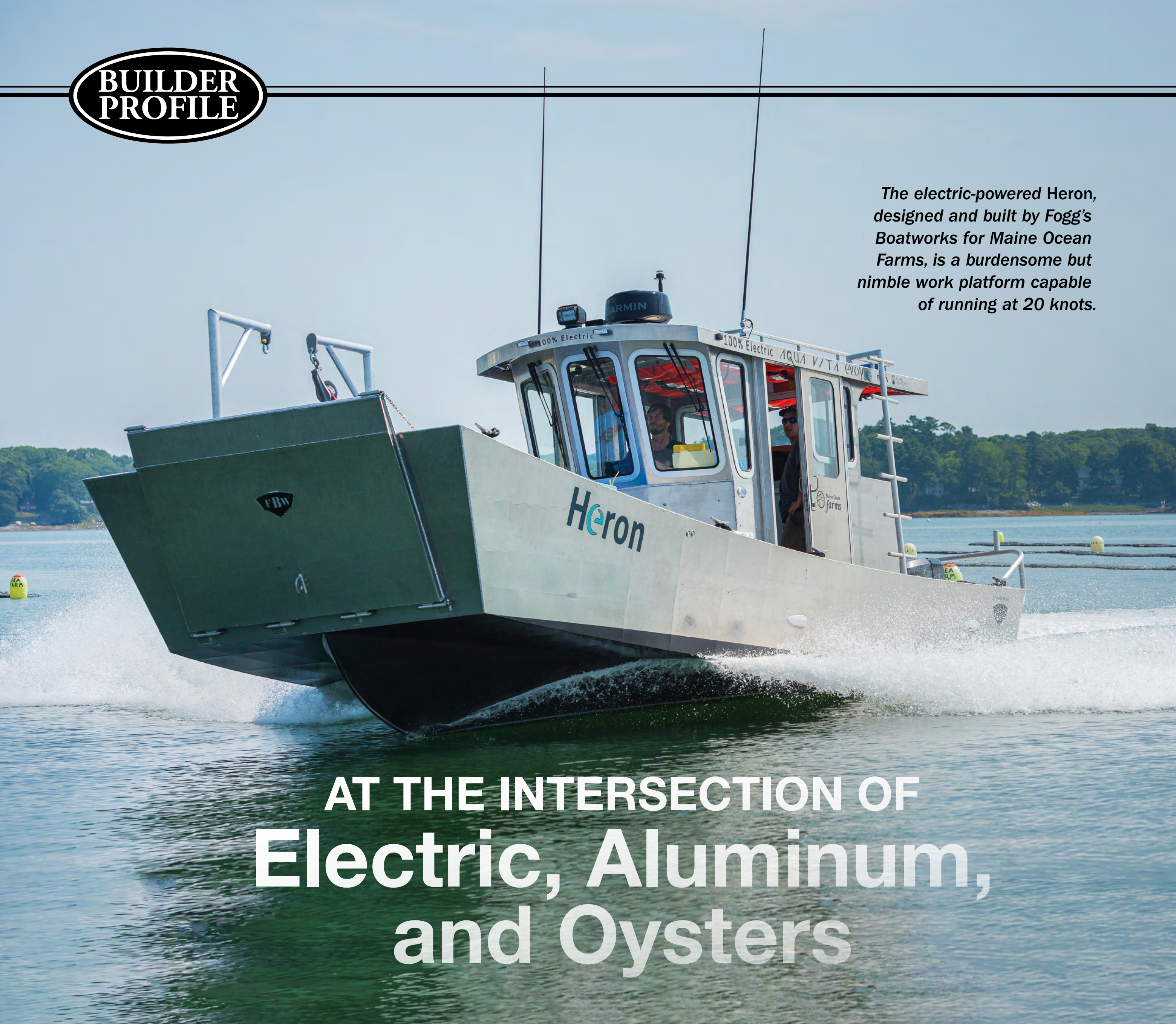
Whenever a new design first splashes, excitement and stress levels run high.

The hull bottom design incorporating the single propeller and tunnel, results in a dry ride and extremely clean wake—a sign of an efficient running surface and a benefit for fishing. Carver said the efficient hull design knocks the water down, for a dry, soft ride, even when running in head, beam, and following seas. He also appreciates that the shallow draft afforded by the propeller tunnel opens up skinny-water areas on the bay for fishing.

From the paying customer's perspective, a charter boat should provide comfort, fun, and safety on the bay—something Carver reports *Loosen Up* does with ease and grace. That's music to a designer's ears. Word is she also raises fish with the best of them, though I would have to give credit for that to her captain. PBB

About the Author: *Christopher Swanhart is Director of Recreational Boats at DLBA Naval Architects.*

BUILDER PROFILE



The electric-powered Heron*, designed and built by Fogg's Boatworks for Maine Ocean Farms, is a burdensome but nimble work platform capable of running at 20 knots.*

AT THE INTERSECTION OF Electric, Aluminum, and Oysters

Fogg's Boatworks embraces the latest in electric propulsion as it delivers practical metal hulls for work and pleasure.

BY AARON PORTER

Anyone who has ever used a backing-out plane or an oyster knife knows the pragmatic beauty of a tool perfectly suited to its purpose—a tool with a specific intended use that does exactly what it's supposed to, with as little fuss and wasted capacity as possible. I find a similar practical aesthetic appeal in the no-nonsense, welded aluminum workboats common in government agency and demanding commercial services like search-and-rescue, windfarm tenders, and fishing.

Perversely, despite their ubiquity in the Pacific Northwest and popularity along the Gulf Coast, these admirable aluminum vessels have never been numerous on the foggy coast of Maine. It caught my attention when a trickle of new aluminum workboats started showing up over the last few years, some from the West Coast, but many of them built in-state by Maine boatbuilders Lyman Morse and Fogg's Boatworks.

My interest ratcheted up when I noticed how many of these vessels are ultra-stable landing-craft models, equipped with bow ramps for beach loading and designed to serve as tenders for aquaculture operations like oyster and kelp farms. When a series of anomalous winter storms and seasonal high tides damaged or destroyed hundreds of Maine wharves in 2023, the utility of landing

PHOTO BRENDAN BULLOCK, COURTESY MOF

craft capable of serving coastal communities directly from beaches became even more apparent. The price of a nimble new 28' (8.5m) utility boat that can be moved out of harm's way as threatening weather approaches pales in comparison to the expense of permitting and rebuilding a fixed pier that remains vulnerable to rising sea levels and volatile weather patterns.

The Fogg's Shop

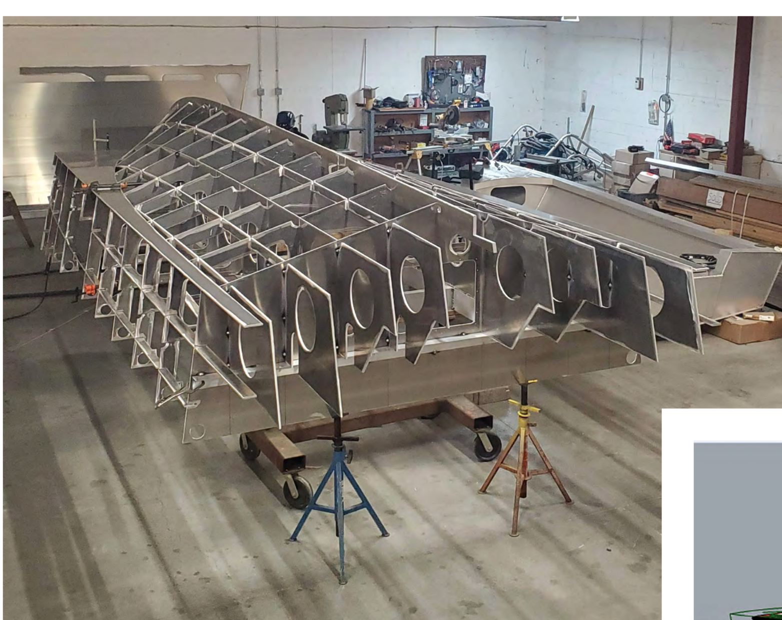
That rough calculation prompted a visit to Fogg's Boatworks in North Yarmouth, Maine, where Dennis Fogg—now joined by his son, Patrick—have been building welded aluminum boats since 2000. Dennis grew up navigating the fine line between work and play on Casco Bay, taking up lobstering at 15 in a 28' wooden boat and later training as a boatbuilder at the now-defunct Boat School in Eastport, Maine, in the late 1970s. Upon graduating, he spent five years in San Diego building mostly cold-molded wood boats at Kettenburg Marine before returning to southern Maine in the mid-1980s to work for local boatbuilders and service yards.

A decade later—firm in the knowledge that he didn't want to work with a boss or fiberglass any more than he had to—Fogg was running his own shop. He had serviced several aluminum boats that impressed him and completed a brief apprenticeship at the naval contractor Bath Iron Works, where he worked with a weld-quality inspector. While he knew what good fabrication looked like, it wasn't until 2000 that he built an aluminum boat to his own design.

"Two things bothered me about a boat—you couldn't see over the bow at half speed and accessibility of fuel tanks (for maintenance)," he said. To combat the first, he opted for a long, narrow hullform that's easily driven and doesn't dig a hole before popping onto a plane but simply rises as speed increases. For the second, he placed accessible tanks along the boat's centerline—a design hallmark that remains central to Fogg boats even as operation of the company has passed to Patrick, also a Boat School alumnus.

The first Fogg boats were built on spec and became part of a water taxi service serving Casco Bay. "One of the reasons we started up the water taxi was to show off our boats," Dennis said. Their fleet now includes six Fogg-designed and built boats, including a Coast Guard-certified 46' (14m) catamaran. Before long, clients looking for custom aluminum boats came knocking.

In the modest room that passes for a design office in Fogg's build shop in North Yarmouth, Patrick walked me through a recent design for a 27' (8.2m) outboard cruiser he was finalizing. Using Rhino 3D design software, he was nesting cut files for custom parts on standard aluminum plate stock to be sent to the CNC laser-cutting contractor. Blue lines indicated full cuts, while red marked shallow etched marks that would remain on the plate to guide assembly. Patrick learned boat design at a drafting table with splines and weights, but like most of his contemporaries, he has shifted entirely to Rhino for almost all design development. That doesn't mean there's no art left in the process.



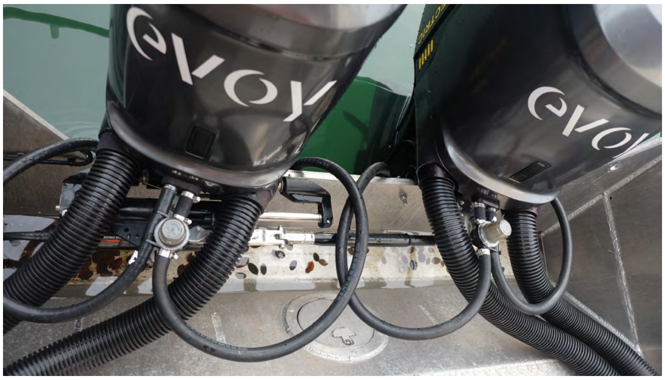
PHOTOS (CLOCKWISE FROM FAR RIGHT) AARON PORTER, FOGG'S BOATWORKS (2)

Clockwise from above—Heron's *CNC-cut aluminum structural grid takes shape. Patrick Fogg on the shop floor. Refining the bow sections of a new Fogg design in Rhino.*

Heron Particulars

Length:	28' (8.5m)
Beam:	11' (3.4m)
Draft:	1' 10" (.5m)
Weight:	9,500 lbs. (4,309.1 kg)
Propulsion:	Evoy Vita twin outboard electric motor (2x 120+ HP)
Battery:	126kWh Lithium-ion
Use Case:	Heavy-duty aquaculture—gear transport, harvesting, crew ops
Builder:	Fogg's Boatworks (Maine, USA)
Build:	Aluminum

"This is the first time I've done sort of a curved plate," Patrick confessed as we looked at the fine bow sections of the boat on his screen. "I tried to sweep up the front to give it a nice curve, but the program doesn't like it. It tells you what it thinks is a little inaccurate." But Patrick's experience tells him that he can torture the flat plate into a curve that challenges the theoretical bounds of a developable surface the computer adheres to. Building on a jig upside-down on the shop floor, he knows he can coax the aluminum to do a little more than the computer calculates. "It's stuff you can do with the push of a hand," he explained.



Under their cowling, each Evoy 120+ outboard houses an electric powerhead as well as water pumps, filters, and heat exchangers to cool the motor and batteries.

Finalizing the files is a complex high-stakes part of the process when Patrick wants to include as much of the cutting as possible, thereby minimizing the need for adjustments on the shop floor. That means, in addition to the essential structural elements and plate curves, he has spent a lot of time planning where all hatch openings will be, as well as cutouts for fuel lines, vent lines, and electrical chases. If he gets it right, the pallet of cut aluminum that arrives from the CNC shop is a virtual kit that requires only assembly and welding.

One of the great advantages of working in Rhino software to refine every new boat is the ability to make changes to accommodate a client's needs right up until the cut files are sent. "You're not stuck with a mold," Patrick said. "This method of building is really good for that. It's easy to make a change. They're not just building a standard

PHOTOS (TOP TO BOTTOM) FOGG'S BOATWORKS, AARON PORTER boat. If they say, 'In my perfect world, I want my boat to do this,' we can try to hit all those parts."

Heron

In September 2024, a new client came through the door with a request that changed the trajectory of Fogg's for at least the next couple of years. Maine Ocean Farms, a Brunswick, Maine-based aquaculture company, was looking for a new work platform to tend its nearly 10-acre (4-hectare) oyster farm, and it had to be powered electrically.

Willy Leathers, co-founder and director of farm operations, explained that the boat was part of a federally funded pilot project aimed at introducing dockside fast charging to Maine, deploying electric propulsion to a commercial fish farm, and developing a working farm tender compatible with electric propulsion. The demonstrator project, coordinated by the Island Institute (Rockland, Maine), was to use Aqua superPower's fast charger, which requires 480V, 3-phase, 300-amp shoreside service. (The charger was installed at the Gulf of Maine Research Center's Portland waterfront wharf in early November.) Propulsion for the boat was to come from twin Evoy electric outboards rated for 120 continuous horsepower and higher short bursts.

While some partners suggested a production-built RIB would be adequate, Leathers insisted that the boat be customized for its intended service. "We were going to design the boat we wanted, then start making concessions to its electrification," he said. That meant starting with an enclosed pilothouse for winter operation; a stable open work deck for harvesting, cleaning, and sorting oysters; the ability for carry a payload of 4,000 pounds (1,814.4kg) of ice and oysters; cruise speed of 16-plus knots; the capacity to be Coast Guard certified; and a 30- to 40-year working life. "I came to Patrick with a Word document and said, 'This is what I'm looking for.' And he came back with a preliminary hull shape. I went back with house shape and then layout—he synthesized all of that," Leathers said. The basic form of the final boat is a 28' x 11' x 1' 1" (8.5m x 3.4m x .5m) bluff-bowed landing craft.

"I always thought that would be a really great platform for these oyster guys, and just a good workboat in general," Patrick said. Consequently, he had one roughly designed that he was able to refine into the boat that would become *Heron*. Leathers said one of the greatest challenges for the designer was trimming the hull appropriately with a permanent installation of two 4' x 3' x 14" (1.2m x .9m x .4m) 800-lb (362.9-kg) lithium-ion batteries and a movable working payload of oysters and aquaculture gear. The boat would have to run well loaded or light, which meant the batteries would have to be centrally located but preferably not directly under the wet work deck. Patrick's solution was to install them under the 8' (2.4m) pilothouse, which has a small service hatch in the sole providing access to electrical and cooling-system connections on the working ends of both batteries. To load them, each battery was lowered through the large hatch in the work deck and slid aft into place on a rack system under the pilothouse. Removal would require pulling a soft patch in the bulkhead aft of the large hatch, Leathers said.

In the space under the 12' x 10' (3.7m x 3m) work deck is storage area and two 20-gallon (75.7-liter) tanks—one for fresh water and one for wastewater—serving a marine head housed in a tiny cabin at the aft end of the pilothouse. Leathers wanted the head for workers who would be on the boat all day at the oyster farm and potentially for passengers touring the farm.

Top—*Heron's ample and protected pilothouse provides good sight lines over the forward work deck.* ***Above***—*A hatch in the pilothouse sole grants access to electrical connections and cooling inputs for the boat's two 800V batteries.*

PHOTOS (TOP TO BOTTOM) BRENDAN BULLOCK, AARON PORTER

Heron can accommodate 4,000 pounds (1,814.4kg) of ice and oysters on her work deck and still run at 16 knots.

PHOTO JACK SULLIVAN

With passenger carrying in mind, the boat—including its 12V house electrical system—was designed and built to inspectable standards. But Leathers said he hasn't applied for Coast Guard certification knowing the fire-suppression requirements for the lithium-ion batteries are still being hammered out, and some components in the European-built outboards would likely need to be altered to meet U.S. standards.

Patrick said scantlings on *Heron* reflect T-boat standards with transverse frames coming through the deck and supporting the bulwarks and side decks. The standard hull plating is ¼" aluminum on 3/8" frames and a 3/4" x 5" center vertical keel. They used 5086 and 5083 alloy throughout. Fogg's relies on TIG welding to minimize the need to clean up seams afterward. Patrick explained that he also sends some cut plates out to a bending shop to set clean right angles in structural frames and other components wherever he can eliminate welds.

Leathers praised Patrick's attention to custom details such as a minimalist ladder to the pilothouse roof, a towing bit, davits, a hinged door section in the starboard topsides, and the break in the deck between the work deck and pilothouse level—an element Leathers insisted upon.

With electric outboards, there are no fuel tanks, filters, and pumps, but there are still cooling requirements for the electric motors and batteries. Under the cowling of each Evoy outboard are two heat exchangers, water strainers, a water pump, and an electric motor, all bolted to an aluminum substructure. Below that are a standard mid-leg shaft and a lower unit from a gasoline outboard manufacturer. I was on board one of the first mornings there was snow on the ground and Leathers was concerned about what maintenance protocol and judicious application of nontoxic antifreeze would be necessary to keep the seawater intake and filters for the heat exchangers from freezing through winter service.

Under Way

"This boat is expected to shift gear at scale and speed," Leathers said. But his definition of speed is specific to the boat's refined use profile. "Most of our operations are going to be at low speed. All I care is that I get the right amount of power when I need it and get something that performs the way we want it to."

With 126 kWh of battery power to draw on, he must be mindful of how he uses it. The 9,500-pound (4,309.1-kg) boat with a moderate 15° deadrise aft will get up on plane quickly and run at 20-plus knots in a chop, but not for long. While low energy density of even the best lithium chemistry batteries limits high-speed operation, at six knots, *Heron* has a theoretical range of 90 miles. Standard operation, according to Leathers, is a 3-mile (4.8-km) roundtrip with ice, crew, and gear from a slip on the Harraseeket River in Freeport to the oyster farm, running at 7 knots. While working on site, energy draw for the motors is minimal, as most harvesting and shifting oyster gear are low-speed operations. They unload the

4,000 lbs. of harvested oysters and ice at the dock and drive them by truck to the shellfish dealer in Portland.

On the day I joined Leathers, we were exploring a new option: the new level-3, 75 kWh charger in Portland. It would allow him to avoid the seasonal bottleneck at the dock in Freeport and deliver oysters directly to the Portland waterfront after harvesting them. He estimated the 12-mile (19.3-km) run fully loaded at 16 knots, on top of the energy consumed in harvesting, would bring his charge down to 20%—too little to make the trip back to the Harraseeket. But about an hour on the fast charger would bring the batteries back to between 50% and 75%—plenty to get home. All he needs to make it work is some task or distraction on the Portland waterfront to consume an hour of his time on every harvest day while the batteries charge. It's a reminder that as well as you design and build with the technology at hand, sometimes you have to adjust the job slightly to optimize the refined tool you've created. PBB

***About the Author:** Aaron Porter is editor of* Professional BoatBuilder *magazine.*

PHOTO AARON PORTER

Willy Leathers pulls Heron *up to the new level -3, 75 kWh dockside charger at the Gulf of Maine Research Institute's Wright's Wharf facility in Portland, Maine.*

In designing their electric outboards, the principals at RAD Propulsion started by identifying the most efficient propellers for a given thrust and speed.

PHOTO NIC COMPTON

Start With the Propeller

A U.K. tech team builds a unique electric outboard and new company from scratch.

BY NIC COMPTON

It seems inevitable in 2026 that any company with an innovative approach to electric transport will be compared to Tesla. And if that company is involved in marine transport, there's almost an inevitability it will be referred to as "the Tesla of the seas." It's a lazy comparison, yet as I talk to some of the players behind **RAD Propulsion** at their offices near Southampton on the south coast of England, it repeatedly comes to mind. These are smart, tech-savvy people taking a bold approach in a fast-moving world with massive potential but also huge risk for failure. Sound familiar?

"When we first started this," says RAD Director and co-founder Rich Daltry, "we looked at the electric outboard market and thought everyone's taken an internal-combustion format and just whacked an electric motor on top, which is near enough what most people are still doing. And we just didn't understand why. When you look at a Tesla, apart from where the four wheels are placed, its architecture is almost entirely changed from a combustion-engine car. Why would you just do the same thing again?”

Daltry continues, “We weren’t being devil’s advocates, deliberately doing it a different way. We felt, well, OK, what can you do? What new features can you bring to the market? So, we started with the prop. What’s the most efficient prop we can give for a given thrust and speed? And then we worked our way back up the drivetrain, from the propeller up.”

The conclusion Daltry and co-founder Dan Hook reached was that there was definite room for improvement—starting with the propeller. Because electric motors produce incredible torque—the capacity to go from zero to maximum power almost instantly—they can swing bigger propellers than a gasoline engine. The 40 kW outboard they were designing could easily cope turn a 13" (33mm) propeller (and larger) rather than the standard issue 11¼" (286mm) model fitted to an equivalent gas outboard. If correctly pitched, those bigger propellers could increase efficiency.

Another holdover from conventional gas outboards was the cooling system, with water intakes on the leg and an exhaust exiting through the propeller, creating more drag. An electric engine doesn’t heat up as much, so it can be cooled internally by a closed-circuit system fitted with a heat exchanger. Job done. No need for raw-water intakes and the associated complications of blocked filters and corrosion—and you get a more streamlined propeller into the bargain.

Blue-sky thinking was also needed for the steering system. Daltry and Hook wanted to incorporate 180° rotation, which they achieved by fixing the top part of the outboard (the powerhead) and only rotating the lower leg. After all, why swivel the whole unit when only the lower leg needs to turn? When fitted to the back of a boat, this has the added benefit of freeing up space normally needed to accommodate the arc of the outboard powerhead. In practical terms, that means appendages such as a bathing platform can come right up to or even over the engine.

The next step was to hinge the outboard from the top of its front edge rather than from under the powerhead, so when it was raised it didn’t impinge on the internal space. This effectively frees up almost a cubic meter of internal volume, a significant factor on a 6m (19.7') RIB, for instance.

For the motor, they opted for an axial-flux geometry rather than the more common radial-flux technology found on most electric outboards. We won’t go deep into the relative merits of axial versus radial here, but suffice to say axial is lighter, more compact, and more energy-efficient—with a claimed efficiency of 96% compared to 80% for a standard brushed motor (or just 35% for an internal-combustion engine). Axial-flux motors are often described as “pancake” designs because they are low, wide, and round.

Left—*RAD co-founders Dan Hook and Rich Daltry.* ***Below***—*The RAD electric motor has a distinctive low profile which depends on its ability to be submerged in service. Installation is simplified by the fact that the fixed powerhead doesn't need room to rotate in steering the boat.*

PHOTOS COURTESY RAD

In place of a central inboard engine in this classically styled 26' (7.9m) commuter launch from Stephens Waring and Belmont Boatworks in Maine, is the massive 400V battery powering the RAD 40 motor discreetly installed under a shapely curved transom.

The system was designed to be powered by 400V batteries, which deliver greater power and can be rapidly recharged at a suitable fast-charging station. For their first creation, they chose 40 kW (rated at 55-60hp) as a popular mid-range size that could power most RIBs and other small motor vessels.

When the RAD 40 launched in 2022, it looked strikingly different than anything else on the market. The pancake motor configuration means the outboard sits extremely low, with almost none of it protruding above the transom of an average RIB. At first sight, it looks more like a sterndrive than an outboard. Indeed, the whole low-profile engine is submersible and has been tested underwater to a depth of 1m (3.3')—although it's not recommended as common operating practice.

The steering and throttle are digitally operated, making installation remarkably simple. There's no need for elaborate push-pull cables or hydraulic systems. All you have to do is attach the outboard to the transom, connect the power cables into the appropriate batteries, and plug the electronic control cables to the appropriate controls at the helm. And you're away.

In short, the RAD 40 is efficient, unobtrusive, and aesthetically current and cool. It's the sort of product you'd be proud to own—like a Tesla in the early years.

Use Profiles

The RAD 40 has proven popular for working boats and defense vessels, increasing numbers of which are unmanned. The work patterns of these vessels are often ideally suited to electric propulsion, as they typically spend all day working—occasionally going fast but mostly at slow speeds—before being docked overnight, when the batteries can be recharged. Daltry estimates the RAD 40 fitted with a 120-kWh battery will run for three hours flat out and much longer at lower speeds, with a range of about 100 miles—ample for many workboat applications. For long-range autonomous craft, the engines are used as part of a hybrid system powered by gas generators and solar panels.

The RAD 40 has also found favor among expedition cruise ships and ecotourism operators. Unlike many electric outboards, the motor on the RAD 40 is located out of the water rather than in an underwater pod, making it much quieter underwater—an advantage for wildlife watching.

"Our customers are commercial operators who work in an environment where you don't want petrol and diesel noise or the association with pollution," says Daltry. "It's primarily noise, if we're honest. It's less about CO2 emissions, albeit that's a factor, too. But it's actually much more about the experience in nature and wildlife. Their customers are paying to go on very expensive cruises and holidays. And if you're going nature-watching, you don't want the sound of a diesel or petrol outboard while you're trying to watch whatever it is you've found out there. So, that's a big market right now."

There were other, more surprising applications, such as the floating hotel used for wildlife safaris on the Chobe River in Botswana. Four RAD 40 outboards have been fitted to the large trimaran platform, one on each corner, allowing it to move in almost complete silence and get significantly closer to wildlife. Combined with solar panels and a pair of 61-kWh batteries, the propulsion system is completely self-sufficient,

Four RAD 40 outboards charged by solar panels power this floating hotel on the Chobe River in Botswana.

PHOTOS (TOP TO BOTTOM) ALISON LANGLEY, COURTESY RAD

***Left**—RAD's background in unmanned systems make the outboards well suited to remote and autonomous operation.*
***Above**—Components like throttles are modular and can be switched out by plugging the cables into the preferred module.*

PHOTOS COURTESY RAD

delivering a 100% fuel-cost savings.

So far, so good. But Daltry and Hook have bigger ambitions than just making electric outboards. The two former naval architects have a background in maritime robotics, having previously founded a company that built unmanned surface vehicles (USVs)—a company they eventually sold before starting RAD in 2018. The new company's first major project was developing a rim-drive for **RS Electric**'s new range of electric RIBs. Better known for their range of high-performance sailing dinghies, RS had decided to expand into the emerging electric motorboat market with its own 20' RIB. The Pulse 63 featured an innovative cathedral hull, with a deep central section and sponsons (or outriggers) on either side, partly made from recycled water bottles. Although the rim-drive—essentially a propeller mounted inside a spinning cylinder—turned out to be a blind alley, the eventual outcome of that project was the RAD 40, launched in 2022 and fitted to the revamped Pulse 63 the following year.

Other partnerships followed, including the Hyrex 28, a zero-emissions day cruiser powered by hydrogen cells; and the Valkama, a 17' 4" (5.3m) aluminum speedboat capable of 25 knots. When I visited, RAD 40 outboards were being fitted to 13 workboats in 10 locations as part of the £5.4 million ($7.13 million) **ZENOW** project spearheaded by RS Electric, which aims to promote the use of electric propulsion in harbors and marinas throughout the U.K. The company has also been active in the United States, with a RAD 40 powering the new, classically styled 26' (7.9m) commuter launch designed by **Stephens Waring** and built by **Belmont Boatworks** in Maine.

It's notable that in 2024 RAD secured £4.27 million ($5.7 million) in funding to help carry them into the mainstream—almost double their original target of £2.5 million ($3.4 million).

The Building Blocks

An outboard was just the starting point. The founders' vision was to produce all the mechanical elements of an electric-powered vessel to the highest standard possible.

"The idea behind RAD was to make things very reliable and robust, highly digital, software-driven, and very autonomous," says Daltry. "In almost all cases, our unmanned systems were very connected. Everything was connected back to one computer infrastructure where all the software could manage it. That was then connected to humans onshore. And so RAD was born of that same mindset but trying to build it in a productized set of building blocks, starting with our electric propulsion business."

This modular approach means the various elements can easily be replaced. Take the throttles: You can have a single throttle or dual throttle, top- or side-mounted, simply by plugging two cables into whichever configuration you want. And RAD is currently developing a joystick control to replace the throttle and the steering wheel for those who want to dispense with them.

Because it's digitally controlled, the system can all be linked to a computer and operated remotely. As Harry Beadle, RAD's head of embedded systems, puts it: "It's very easy to swap out a throttle and a steering wheel and put in an autonomy system because the outboard isn't expecting a steering wheel, it's just expecting a steering input. So, if a customer wants a robotic boat, they can put our drives on there, put a battery on it,

The combined drop-in battery box and steering console simplifies construction and systems installation for builders looking for an accessible electric propulsion option for smaller boats.

The tidy battery box and console installations are possible in part because all connections for steering and throttle control are electrical, not mechanical.

PHOTOS (TOP TO BOTTOM) COURTESY RAD, AARON PORTER

and we have one cable that they talk to, and that's it. It literally takes 20 minutes."

A case in point is the Oceanus12 produced by **Zero USV** (Plymouth, Devon). The 40' (12.2m) boat has been developed as "a fully autonomous, low-carbon unmanned surface vessel designed for over-the-horizon missions." It has been fitted with a hybrid propulsion system made up of two RAD 40s, two batteries, a generator powered by hydrotreated vegetable oil, and some solar panels. The boat is capable of going to sea for several weeks with complete autonomy while being monitored from a computer at company headquarters. Try that with conventional outboard controls.

Even manned vessels can benefit from this connectivity. RAD is currently working with the University of Plymouth developing a fleet management system to help in the transition from internal combustion to electric propulsion. The system measures a boat's speed, position, engine RPM, fuel-injection rate, and other data while using a conventional engine and then analyses the information to calculate the potential savings by switching to electric. The information can also be used to calculate the optimum propeller for a boat.

"Lots of people think they spend 70% of their time at full speed," says Beadle, "but actually most people spend much more time at lower speeds. Having that evidence allows you to design more appropriate propellers. People often over-specify batteries, too, and you might find you need smaller batteries than you think, which will increase your savings. You can even spot if a driver is driving a bit heavy-handed and, with that real-world evidence, put them on a training course and save some carbon that way."

Drop-in Electrification

Another clever idea to come out of the RAD offices is their all-in-one console unit comprising a battery box/seat with a steering wheel, throttle, their so-called RAD tag (i.e., a remote key/kill cord), and either a 21-kWh or a 42-kWh battery. The whole contraption, along with the outboard, can be shipped to where it's needed and fitted to almost any appropriately sized boat to give instant clean, silent propulsion. No need for deep technical expertise—just fit the outboard to the transom, attach the console to four secure points, plug it all together, and you're good to go. To make it even easier, RAD has teamed up with RIB manufacturer Zodiac, which has incorporated cleats on the floors of certain boats to accommodate RAD console attachment.

This off-the-shelf approach has obvious benefits for medium- to small-scale boatbuilders, who may not have the skills in-house to fit an electric motor—particularly those with a 400V architecture.

Competitive Comparables

While far from mature, the marine electric-propulsion market has outgrown niche status. New players come and go with invigorating regularity as technologies are developed or adopted from other sectors. It's exciting to keep up, but pity the poor boat designers, builders, and service technicians challenged to keep current. With that in mind, below are a few existing competitive companies with broadly comparable offerings to RAD's—at least for now.

EPROPULSION X40

The X40 is the biggest in ePropulsion's line of electric outboards, which includes the X12 (rated at 15.6hp) and the X20 (rated at 26hp). Like the RAD 40, the X40 has electric steering and throttle that can be integrated into a digital management system. The manufacturer claims the engine is 60% smaller and 65% lighter than the equivalent gas outboard, with 88.2% efficiency. An interesting feature is the integrated hydro generator, which allows you to recharge the battery while sailing or being towed. Visually, the X40 is very different from the RAD 40, being tall and upright, with the motor located underwater in the propeller pod.

X40 SPECIFICATIONS
Power 40 kW
Rated horsepower 52hp
Voltage 96V
Propeller speed 1500-2100 rpm
Weight 99kg (218lb)
Steering angle ±45°

ELCO EP50

Elco (aka the Electric Launch Co.) has been making electric boats since 1893, including building the U.S. Navy's first commissioned submarine in 1900, so they know a thing or two about the subject. They took a break from electric power for most of the 20th century but returned to the market in 1987 and, with renewed vigor, in 2007. They now offer a range of six electric outboards from 5hp to 50hp (they prefer horsepower to kilowatts). The EP50 is available with a tiller or remote (electric) throttle but not electric steering.

EP50 SPECIFICATIONS
Power 26.4 kW
Rated horsepower 50hp
Voltage 96V
Weight 87kg (190lb)

EXPLOMAR WAVE 70+

According to its YouTube channel, ExploMar is "a visionary ecological company leading the charge in electrifying water mobility". The company is based in Shanghai, China. The Wave 70+ is the smallest in their range of electric outboards, which goes up to 300hp (225 kW). Like the RAD 40, the Wave 70+ is fitted with an axial-flux (aka "pancake") motor, with steer-by-wire and a closed-circuit cooling system.

WAVE 70+ SPECIFICATIONS
Power 60 kW
Rated horsepower 70hp
Voltage 350V
Propeller speed 3,500rpm rpm
Weight 80kg (176lb)
Steering angle ±30°

TORQEEDO DEEP BLUE 50 R

Since the company was created in 2005, Torqeedo has been at the forefront of the electric outboard revolution—and usually several miles ahead of most of the competition. They led the way again with their high-voltage Deep Blue range of outboards, launched in 2014. Since 2024, the company has been owned by Yamaha. Torqeedo now offers three high-voltage outboards (alongside their 10 smaller outboards), rated at 25 kW, 50 kW and 100 kW. Like the RAD 40, the Deep Blue 50 R has modular elements and a "fully integrated propulsion and energy-management system." Unlike the RAD 40, it has an axial-flux motor located in the propeller pod. The company claims 89% efficiency.

DEEP BLUE 50 R SPECIFICATIONS
Power 50 kW
Rated horsepower 80hp
Voltage 350V
Propeller speed 2400rpm
Weight 139kg (306lb)

—Nic Compton

"We know the future of higher-power electric boats is high voltage," says Daltry. "It's physics; it's obvious. There's been a little bit of reticence in the market about it, principally because lots of boatbuilders are not comfortable with high voltage. We can deliver complete solutions to boatbuilders. We can provide the expertise, train their people in assembling and commissioning so that it's all completely safe, provide all the necessary paperwork and risk assessments, and even help write manuals to make sure their customers understand how it all works. We see this as a mission. Our goal is to make it possible for every boatbuilder to be able to offer electric products in their lineup."

Under Way

Having heard so much about their technology and hardware, I was keen to try it out for myself, and RAD duly obliged with a test drive. So, one bright September day, I headed down to the scenic River Hamble, a stone's throw from the RAD office, with Beadle and Sam Pickering, head of products. Moored up at the

***Above**—RAD's Harry Beadle and Sam Pickering put the twin outboard Willelectro workboat through its paces on the River Hamble. **Right**—The workboat's simple helm station.*

dock was a high-density polyethylene (HDPE) Willelectro workboat complete with landing-craft-style bow ramp and powered by twin RAD 40s connected to that ingenious all-in-one console.

For anyone accustomed to the roar of an outboard or the putt-putt of a diesel, it's disconcerting to climb aboard an electric-powered boat and set off without any of the usual preliminaries and startup rituals. Pickering spared no time in getting us out of a tight corner—even without a bow thruster, the twin engines with 180° rotation make maneuvering in tight quarters a doddle. When I persuaded him to open up the throttle, I experienced an on-water equivalent to the famous G-force snap you get while driving an electric car as the boat leapt forward without any preamble or hesitation.

Once well clear of potential obstacles, I took the helm. After a lifetime of driving boats with dodgy old push-pull throttles, the sensitivity of the bespoke RAD controls took a bit of getting used to. This, it turns out, was the slightly desensitized version; the more sensitive version had proven too "nervy" for inexperienced folks like me. It didn't take long to get comfortable and confident running the boat in open water, though I declined to moor the boat on our return, just in case. That gave Pickering a chance to show me the RAD 40's party trick. That 180° rotation means the boat can spin practically in its own length, and we were soon pirouetting around in the middle of the river in merry circles. It was an impressive performance, even if it did put me off my lunch. From a practical point of view, the enhanced maneuverability showed that the outboard's turning angles are much more than just a gimmick.

As we headed back to shore, Beadle returned to the car theme. And it turns out the comparison with Tesla isn't so far-fetched.

"A lot of what we do uses automotive technology," he said. "There's so much investment into electric cars, and we get to piggyback that. So, if a new battery chemistry comes in or if a new motor architecture comes out, that's something we can fold in—and that helps to bring the price down as well. Typically, the marine

PHOTOS NIC COMPTON

The 180° articulation of the outboard's lower unit makes for amazing maneuverability, such that even single-engine boats can turn easily in their own length.

RAD 40 SPECIFICATIONS:
Power 40 kW
Rated horsepower 55-60hp
Voltage 400V
Propeller speed 2250 rpm
Weight 98kg (216lb)
Steering angle ±90°

industry lags the automotive industry by many years, and there's good reason for that—obviously a lot of work goes into marinizing an entire combustion engine and you want something reliable. But we're managing to be right on the edge of the electric vehicle technology. There's no time lag. What's in our drive is what's in the current state-of-the-art electric car."

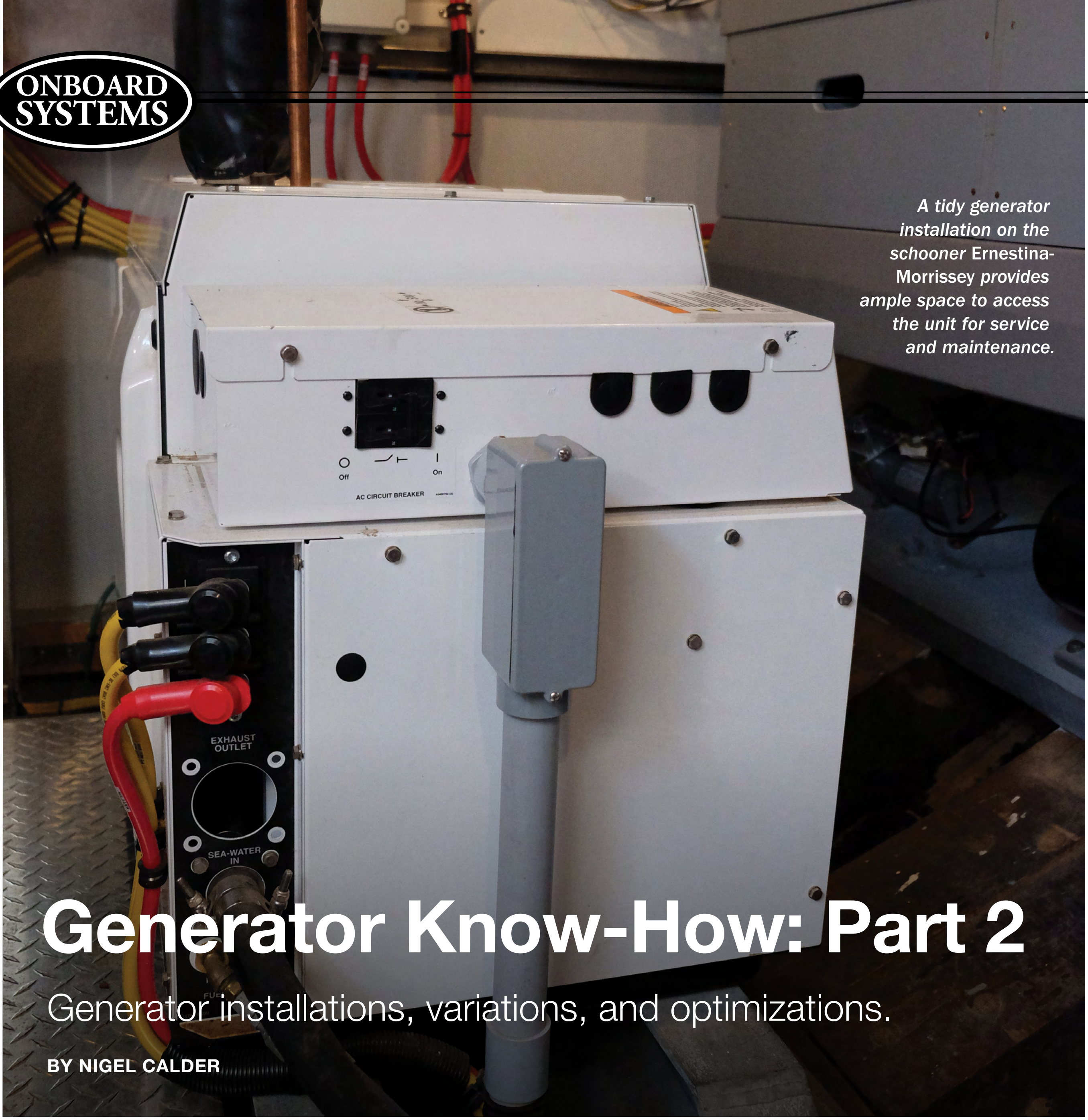
With the RAD 40 fully launched and most of the supporting infrastructure now in place, the team are now turning their attention to broadening the company's range of products. A 120-kW model (rated at 160hp) is currently in development for larger craft, as well as a smaller model currently known as the RAD X because its size hasn't yet been finalized—though it's likely to be in the 5-10 kW range, tiller-steered, and powered by a 48V battery.

Meanwhile, the company continues to go from strength to strength, with a new office opening in Charlestown, South Carolina, from which their collaboration with Zodiac and other American companies will no doubt continue to grow.

The future looks bright and, well, pancake-shaped. PBB

About the Author: *Nic Compton is a freelance writer/photographer based in Devon, U.K. He lived on boats in the Mediterranean until the age of 15 and worked as a boatbuilder for many years before swapping his chisel for a pen and his router for a computer. He sails a Rhode Island–built Freedom 33, currently based in Greece.*

PHOTO COURTESY RAD



A tidy generator installation on the schooner Ernestina-Morrissey *provides ample space to access the unit for service and maintenance.*

Generator Know-How: Part 2

Generator installations, variations, and optimizations.

BY NIGEL CALDER

We continue our series on selecting and installing appropriate onboard generators from Part 1 in *Professional BoatBuilder* No. 213.

Installation

The mechanical installation of a generator is similar to that of a propulsion engine. You need a solid engine bed, and there are similar cooling-water, exhaust, and fuel-system requirements, though on a smaller scale. The generator will also require comparable levels of maintenance at the engine end. Note that engine oil change intervals may be shorter than those of a propulsion engine. And if the generator comprises a V-belt driving an alternator, the belt may need more frequent replacement because of the high ambient temperatures inside many insulated sound shields. Fischer-Panda, for example, recommends belt replacement every 100 hours on some model

While the engine driving the generator is water-cooled, in most generators the electrical end is air-cooled, which leads to some unique vulnerabilities. Inside a generator are multiple insulated copper windings (see Part 1). Inevitably, the insulation has small defects and voids. In the humid marine atmosphere, moisture from cooling air can collect in these flaws. Fresh water is an insulator, while salt water is a conductor. But add a few impurities to fresh water, and it, too, becomes a conductor. In short, the combination of moisture and dirt degrades the insulation.

Compounding these technological vulnerabilities is the practical reality that generators are often installed in restricted compartments with high ambient temperatures. Heat lowers the ampacity of the insulation on the various windings and conductors and stresses control-circuit electronics. Generators are also often undersized for the inrush currents they encounter. Those peak currents further tax insulation already

PHOTO AARON PORTER

suffering from reduced capacity. When localized short circuits develop in the windings, this degrades the insulation even more. Meantime, the engine itself is also stressed more than it should be from a combination of the high ambient inlet air temperature and often restricted air supply for combustion.

This all points to the single most important installation consideration in terms of heading off unnecessary trouble: locating the generator where it will receive the coolest, driest, and cleanest cooling and combustion air possible. A close second, on the engine side, is preventing saltwater intrusion from the wet exhaust, which can be difficult, especially when a generator is installed off the centerline of a boat.

A critical safety issue of the installation is minimizing the potential for carbon monoxide poisoning, especially with gasoline-powered generators (*see sidebar, page 24*).

True Cost of a Kilowatt

There is a common presumption that the principal cost of generating electricity on a boat is the fuel. In this case, the lower the efficiency of the engine driving the generator, the more expensive the electricity generated. Because fuel efficiency on all engines is reduced at light loads as compared to higher loads, light-load operation drives up the fuel cost per kWh delivered to the boat. This is especially true for carburetor-fed gasoline generators and diesel engines with traditional fuel injection systems, but not so much with fuel-injected gasoline engines and diesel engines with a high-pressure common rail injection system.

But fuel is only part of the equation. A major hidden cost lurks in amortization of the generator itself. Let's say by way of example, the installed cost of a generator is $25,000 and its life expectancy is 5,000 hours. It costs $5 an hour to run it, whether or not it is doing any useful work. If it is generating 10 kW of electricity, the amortization cost is 50¢/kWh; if it is generating 2 kW, that jumps to $2.50/kWh. Then there are maintenance and other operating costs to be factored in, all of which bump up the kWh cost of electricity. Most times, these costs end up being substantially greater than the fuel cost per kWh of electricity generated, even at European prices for gasoline and diesel.

The total cost per kWh for the electricity generated is the sum of all these costs. Because of poor generator optimization, it is not unusual for it to be $3 to $10 per kWh for generators installed on recreational boats. It's typically much lower in commercial applications.

—Nigel Calder

Electrical Integration

On the electrical side, if you have a North American-style 120/240V split-phase system, it is important to balance as much as possible the 120V loads between the two 120V buses. High unbalanced loads unnecessarily stress stator windings.

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All too often a generator is stuffed into too small a space with very poor access for maintenance. This generator also inhibits access to the propulsion engine located below it.

Note that some generators are supplied by the manufacturer without the neutral-to-ground connection required by the ABYC and ISO at the "source of power." When installing a generator, you must ensure this connection is made at the generator, with the sole exception of installations with a polarization or isolation transformer on the shore-power inlet—those allow the connection at the AC grounding bus.

Many AC generators are installed to power the onboard AC system from either shore power or the generator. If no other AC sources are present, a generator must be able to handle the peak AC load, including peak inrush loads from electric motors, and it must run whenever AC power is needed, even if it's just for a low-power device. Without load management, the generator must be rated close to the sum of all possible AC loads.

The electrical installation in this system is simple and uncomplicated: You need an appropriate two-pole selector switch—Shore/Ship/Off.

This conventional setup results in long hours of generator operation at light loads, which, aside from the noise and exhaust fumes, is extremely inefficient. It's especially so if the generator is powered by a diesel engine with a traditional fuel injection system (i.e., not a high-pressure common rail system). With all generators, if you factor in amortization, there is an extraordinarily high cast for the energy generated (*see sidebar above*). Light loads intensify maintenance and shorten the service life of diesel engines with traditional fuel injection and for gasoline engines with carburetors. Despite drawbacks, this combination remains the most common generator setup.

Let's look closely at a hypothetical example: A well-equipped, medium-size sailing yacht has a core daily energy requirement of around 4 kWh for navigation systems, refrigeration, lighting, water pumps, radios, etc. You can generate and supply this level of energy with a powerful alternator, a suitably sized battery bank, and possibly solar and wind energy. However, if you add AC consumers—air-conditioning, a watermaker, or a dive compressor—energy consumption rapidly increases to exceed the alternator

High-draw appliances like this air conditioner commonly exceed the capacity of alternators and require a generator.

PHOTO AARON PORTER

capacity. With a generator, appliances such as a microwave or electric kettle become practical. As a result, it's easy to conclude that a generator output of 8 or more kilowatts is necessary on such a boat. But that's not necessarily true.

On this vessel, the only AC device running for long periods is the air conditioner, averaging 700 watts for roughly 12 hours (assuming it's not used overnight). The microwave and kettle together run for maybe 40 minutes, and the watermaker for 2 hours. To power the air conditioner without other sources of AC power, the generator must be run for the entire 12 hours. If fully loaded, the generator could theoretically deliver 96 kWh during this time. Instead, we have the 4 kWh DC load that's now supplied via a battery charger, the 8.4 kWh aggregate air-conditioning load, and maybe a combined 5 kWh load for the other devices. That's a total load of 17.4 kWh (ignoring AC-to-DC conversion losses). During the 12 hours, the average load is 1.45 kW, which is less than 20% of the generator's rated output.

In practice, the load swings between roughly 50% when the air conditioner cycles on to nearly zero when it cycles off and only small DC loads remain. This is an expensive and, for many engines, unhealthy duty cycle.

Improving Duty Cycles

There are several ways to improve this dramatically. The simplest is load management. If the boatowner can ensure no more than half the peak loads are running simultaneously, the required generator capacity drops to 4 kW. The generator will still run 12 hours a day, but it now has an average load

Perils of Portable Gasoline-Powered Generators

Portable gasoline-powered generators are by far the most cost-effective way to add modest AC capability to a boat. They are widely available and relatively inexpensive, which is the reason that many cruising sailors keep one on board. However, these generators are not marinized, and they are almost never installed with proper grounding practices. The combination of corrosion over time and inadequate grounding can make them electrically unsafe.

Then consider the following American Boat and Yacht Council (ABYC) requirements, with which few portable gasoline generators comply:

- "All (gasoline powered) generator sets shall be ignition protected…"
- "If any electrical component is required to be ignition protected, the generator set, and the sound shield or enclosure, shall be visibly marked with a safety label…"
- "Generator sets installed with a sound shield shall have a firefighting port installed for discharging a suitably sized, gaseous fire extinguisher directly into the space immediately surrounding the generator set, without opening the sound shield."
- "All exposed noncurrent carrying metal parts that could become energized due to a fault shall have metal-to-metal contact, or otherwise be electrically connected or bonded together, to provide a common ground connection."
- "The generator set shall be provided with a designated bonding terminal. This terminal shall not be on a part of the machine disassembled during operation or routine maintenance. The bonding terminal shall be of adequate size for a flexible grounding conductor, and the terminal shall accommodate at least 8 AWG wire or its equivalent."
- Carburetors must meet various requirements, including a flame arrestor.
- Fuel lines must pass stringent Coast Guard permeation and fire resistance tests and cannot be fastened with common clamps that are dependent on spring tension.

Portable generators are frequently connected to a boat's electrical system via extension cords with plug-in connections not suitable for water and corrosion resistance in a marine environment, and do not comply with ABYC and International Organization for Standardization (ISO) requirements, including the need to have a locking arrangement at both ends.

Finally, and critically, there's carbon monoxide. All fossil-fuel engines generate some carbon monoxide. This is compounded with free-standing engines such as portable generators, in comparison to an engine that's installed in compliance with ABYC and ISO standards. Many portable gasoline generators are fitted with carburetors, resulting in especially high levels of carbon monoxide. Almost none can pass EPA emissions certification standards for marine generators.

When a portable generator is run onboard, the exhaust has the potential to form pockets of carbon monoxide on deck; from there, it may find its way below decks. Let's say, for example, a boat is at above 50%, substantially improving efficiency and reducing energy cost.

A better approach is to view the AC and DC systems as a combined entity with battery chargers and inverters as the interface. If you properly design and manage such a system, all the light AC loads can be run from batteries via the inverter. (This includes modest air-conditioning needs in many applications.) Such a setup greatly reduces generator runtime. In an optimized system, whenever the generator is running, battery charging loads are added to the AC loads such that the former will be appropriately adjusted as the latter fluctuates, maintaining a near optimum load on the generator. The generator must still be powerful enough to handle at least the peak AC load when it is running, plus any additional battery charging load.

Another considerable step-up in sophistication and energy systems optimization is possible with a synchronizing inverter. These have the capability of paralleling their AC output with a shore-power connection or a generator's output. When the generator is running and the peak AC load exceed the generator's rated output, the inverter kicks in to supply the necessary extra energy from the batteries. If the AC loads go down, the inverter switches into battery-charging mode to add load to the generator. Sophisticated inverter/chargers have software in which you can set the desired generator load to always run it at peak efficiency. Depending on the shifting AC loads, the inverter/charger will cycle back and forth between inverter and charger modes to maintain this load.

This technology shifts the calculation linking peak AC load and an onboard generator's maximum rated output, which has traditionally determined generator size. The net result can be a dramatic improvement in generator efficiency, with an equally dramatic reduction in the cost of energy produced. You can either optimize for a substantial reduction in generator size, in which case the generator will still have to run relatively long hours, or for a substantial reduction in the generator runtime, in which case the generator will not be greatly downsized. In either case, the generator will be optimally loaded when running.

With such a system, a sizable battery bank is required to support inverter loads and absorb battery-charging energy when the generator is running. In modern systems, you can fully automate the functionality if the generator has an autostart function triggered by AC load or battery state of charge.

Years ago, I participated in extensive tests by Victron Energy demonstrating these advantages. The test results are still available on the Victron website.

Conclusions

To optimize efficiency and reduce the cost of power from a generator, it is best to load the unit to at least 50% of its rated output. On the other hand, generators in recreational boats are rarely built to run continuously at their full rated output. As a rule, generators should not be run for extended periods above 80% of rated output. A load target of about 70% is ideal.

anchor facing into the wind. The generator is running on the aft deck with the idea the wind will blow away the exhaust. To ventilate the boat, there is an open aft-facing hatch in a forward cabin. The wind over the hatch in the forward cabin will create a vacuum. In the U.S., this phenomenon is known as the "station wagon effect." It will pull potentially contaminated air into the boat from the aft deck. There are numerous other scenarios in which carbon monoxide can migrate into spaces occupied by people.

Carbon monoxide is odorless, colorless, tasteless, and only a little lighter than air, so it tends to hang around. If there is any carbon monoxide in the air you breathe, your body will preferentially absorb it over oxygen. Even if there is an available supply of fresh air and oxygen, the carbon monoxide replaces critical oxygen molecules in your blood hemoglobin, which leads to poisoning.

Once attached to hemoglobin, carbon monoxide is relatively stable. It blocks the attachment point for oxygen molecules and slowly robs your body of its vital oxygen supply. Consequently, low levels of carbon monoxide over time can cause progressive poisoning. Initial symptoms are similar to seasickness, flu, or food poisoning, escalating to an inability to think coherently, headaches, drowsiness, nausea, dizziness, fatigue, vomiting, collapse, coma, and finally death. If carbon monoxide is present while you are sleeping, you may not wake up. This is not academic. Carbon monoxide poisoning claims multiple lives in the boating community every year.

The best antidote is an inboard generator that's properly installed according to ABYC and ISO standards with its exhaust plumbed to the exterior of the hull. The generic ABYC standard for AC generators is **A-27, Alternating Current Generator Sets**. Aside from installation requirements, this standard contains numerous detailed criteria for the construction and manufacturer-testing of marine AC generators. Any generator installed in a boat should be labeled as complying with ABYC A-27.

The ABYC has strict requirements around ventilation and sealed bulkheads between any gasoline engine and accommodation spaces. These requirements are in the ABYC **H-2 standard**, ***Ventilation of Boats Using Gasoline***. There is a separate standard with respect to the exhaust system for any onboard engine: ABYC **P-1**, ***Installation of Exhaust Systems for Propulsion and Auxiliary Engines***.

If despite these warnings, a noncompliant portable gasoline generator is used, it should at the least be certified as complying with the second edition of the UL 2201 Standard for Carbon Monoxide Emission Rates of Portable Generators. This standard contains detailed carbon monoxide test procedures with a low limit for emissions. In the event these limits are exceeded in the immediate vicinity of the generator, the generator is required to shut itself down.

A carbon monoxide detector should be installed in all sleeping cabins.

—N.C.

Until recently, generators were sized to handle the greatest anticipated short-term AC load on a boat, and most still are. However, since the average output is well below the rated output, most generators operate extensively at low loads, which drives up fuel, amortization, and maintenance costs, and—on carbureted gasoline engines and diesel engines with traditional injection—reduces service life.

With load management, the peak power demands and the corresponding generator rating can be substantially lowered. Adding a conventional inverter to the system can eliminate long hours of generator run time at low loads. A synchronizing inverter can break the link between peak demand and a generator's rated output, with a dramatic reduction in generator sizing or runtimes. Reduction in generator run hours results in a disproportionate reduction in the cost of energy produced through a drop in the kWh amortization cost.

The key installation considerations are: a dry location with a supply of clean, cool, dry air; an exhaust system for the engine that isn't vulnerable to saltwater flooding at any conceivable heel angle or sea state; and good access for maintenance. Electrically, the installation must comply with American Boat and Yacht Council (ABYC) and International Organization for Standardization (ISO) standards, including the neutral-to-ground bonding.

While I remain skeptical that generators are necessary for many marine applications where they are common, we now have mechanisms to ensure they run far more efficiently, with a greatly reduced cost for the electrical energy created, and with less maintenance and a longer service life, than was standard on the previous generations of recreational boats. As an industry, we do not take advantage of these mechanisms nearly as much as we should. PBB

About the Author: *Nigel Calder is the author of* Boatowner's Mechanical and Electrical Manual *and other marine titles. He is a member of the American Boat & Yacht Council's Electrical Project Technical Committee. He recently teamed with OceanPlanet Energy to continue pursuing his passion for improving the efficiency of boat energy systems, and became one of the co-founders of* **BoatHowTo**, *a platform for accurate online marine electrical education.*

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Wishes and Warnings for the Electric Propulsion Surge

BY STEVE D'ANTONIO

While visiting Metstrade 2025 in Amsterdam—a must-attend annual show one perceptive marine consulting client aptly described as my "Superbowl"—I noted continued steep growth in the marine electric propulsion sector. The trending popularity of electric vehicles (EV) in general, makes this predictable. But watercraft differ from popular terrestrial EVs in many essential ways that make comparison difficult. For instance, while electric boats offer none of the regenerative braking opportunity that boosts efficiency of electric automobiles, the larger ones can offer ample space for solar panels that car designers have never dreamt of.

Fueled by compounded direct investments and subsidies, EV technology has advanced rapidly in the past decade—batteries are more energy dense, and propulsion systems have become more compact and efficient. But still, there's no free lunch. The CO2 reduction afforded by electric propulsion is valid so long as the charge source—typically a utility company—derives its power from an equally carbon-free source such as solar, hydro-electric, or wind power, which still constitute a small fraction of overall energy production. In short, actual carbon emission calculations are complex and frequently identify decades of standard recreational boat use necessary to reach the break-even threshold for electrical propulsion.

My intent is not to debate carbon reduction, green energy, or climate change; I'm more concerned for the health and viability of the recreational marine sector. For almost as long as I've been in this industry, equipment manufacturers, and in some cases boatbuilders, have introduced new, complex, and often costly products to the market without considering the capital required for service and support. Regardless of how good a product may be, or the strength of market demand for it, if it isn't well supported, failure is almost assured.

It seemed every aisle at Metstrade 2025 included electric propulsion system manufacturers or major diesel-engine manufacturers that also offer electric, or electric hybrid products, all touting the virtues of their "clean," "efficient," "green," "blue," "net-zero" systems. Many enumerated benefits and advantages are based in technical fact. The average internal combustion engine (ICE) comprises hundreds of individual parts, while an electric propulsion system is far simpler (a Tesla powertrain has about 20 moving parts) and thus more reliable, in theory at least.

I noticed something disturbing as I prowled the show floor—while electric motors themselves may be simple, the propulsion *systems* built around them were anything but. Production numbers of these expensive new systems are low, which means they remain relatively untried compared to terrestrial EVs where high use has revealed many common flaws for correction.

I saw one hybrid electric propulsion system coupled to a conventional diesel engine in a way that made access to the transmission dipstick impossible. When I inquired, the representative looked at it and said, "You don't need to check that very often, but when you do, you'd need to remove our component." That mentality will spawn dissatisfaction among owners and ultimately slow adoption.

Out in the real world, the electric and hybrid propulsion systems I encounter are impressive in their performance and quiet fume-free operation, but they are complicated and costly. I can't help but wonder how well they will be supported, and for how long.

I worry that this headlong rush to electrification could harm us in several ways:

- Higher cost of acquisition
- Lower reliability because of small production volume and system complexity
- Increased service challenges
- Limited service, parts, and expertise availability as the system ages, reducing resale value
- Fewer entry-level boat buyers

When internal combustion was new to the marine sector, the primary market was commercial with early adopters looking to reduce cost and boost efficiency. If it didn't meet those goals, it failed. The recreational marine industry is entirely different. None of what we offer is essential, and all spending is discretionary. Electric propulsion adopters do so for many reasons—perceived environmental benefits, quieter operation, simplicity, etc. Some clients seeking affirmation have asked me, "Since it has so few parts, it doesn't need oil changes, valve adjustments, and fuel filter changes. It must be less expensive to operate and more reliable, right?"

I work primarily with large, long-range, bluewater passage-making vessels that are already extremely complex. For the moment, electric propulsion isn't going to power long-range cruising yachts; not on its own. But for other types of craft such as tenders for larger vessels, it's worth considering for my clients.

For years I've been looking to get rid of gasoline on larger vessels. Electric propulsion is one way to do it, but will it be cost effective and practical over the life of the tender? Right now, conventional outboards for these applications last 10 to 15 years, thousands of them are made every year, they are largely reliable if properly maintained, and service and parts are readily available from multiple sources. Can the same be said of a new electric propulsion system?

Above all else, long-term support is essential to this equation. I implore manufacturers of these systems to consider that there is no faster way to lose the confidence of the boat-buying public than to sell a product for which assistance is fleeting.

I love the idea of new technology, especially if it is well supported, more reliable, more efficient, and less expensive to own and operate. Heck, I'd accept three out of four of those, but as plentiful as the options appear to be, I'm not sure electric propulsion has attained even that goal just yet. If it does meet these standards, the recreational boat-buying public won't have to be convinced of its value—they will beat a path to manufacturers' doors. PBB

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