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

NUMBER 179
JUNE/JULY
2019
$5.95 U.S.

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DIETER LOIBNER

Modifying outboards at Raider. Page 16.

NIGEL CALDER

Repairing a rudder again. Page 34.

DIETER LOIBNER


HDPE workboat test drive. Page 46.

STEVE D'ANTONIO

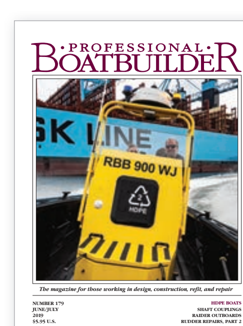
Shaft coupling installation. Page 56.

FEATURES

DEPARTMENTS

READER SERVICES

On the cover: At the helm, Bruno Tideman puts his 8.7m (28.5′) jet-drive workboat through its paces at the 9th High Speed Boat Operations (HSBO) Forum in Gothenburg, Sweden. Tideman has optimized the design and build of his boats for efficient production in high-density polyethylene. Story on page 46. *Photograph by Dieter Loibner.*



PROFESSIONAL BOATBUILDER MAGAZINE

Reading Working Fleets

There's something undeniably appealing in the ruthless utilitarianism of workboats. They do what they're supposed to and they do it well, or they disappear. Unlike yachts, they can't get by on good looks alone. A successful workboat type is the most evolved technology available to provide the mode of buoyancy best suited for the human endeavor it facilitates. Consider the delicate balance of sailing power, seakeeping ability, and efficient cargo-carrying capacity of a Grand Banks fishing schooner of the 1920s (a type that quickly disappeared with the advent of reliable internal-combustion engines and mechanized fishing), or the equally refined shoal-draft, low-freeboard Chesapeake Bay skipjacks that still dredge oysters commercially under sail today. Take a look at either of them, and their commercial purpose is obvious. Indeed, there's very little about individual working boats that one could identify as extraneous to their use, and their level of fit and finish is usually indicative of the current prosperity of the industry and/or the individual boat owner. It's not an oversimplification to say that workboats tell a story of market demands, regulatory landscape, and individual motivation and innovation.

Living in Downeast Maine and Maritime Canada I've watched from up close as fleets of working boats, large and small, evolved with changes in boatbuilding technologies and shifting fortunes in the fisheries since the 1970s. The fine-hulled low-freeboard inshore boats grew in stature as fish stocks thinned and fishermen required greater range to make a living. Concurrently, reliable powerful diesel engines became available, and easily built GRP hulls standard, though building in female molds robbed the regional types of some of the graceful sheer and tumblehome that characterized the wooden originals. In Maine, trap limits, fuel prices, and geographical zones in the lobster fleet continue to determine the size and carrying capacity of new working boats. In Canada, boat-length regulations in some fisheries have led to the practical popularity of incredibly burdensome wide and tall workboats with proportionally short waterlines, lacking the grace and the seakeeping abilities of their antecedents. But in all cases, the workboats evolved quickly to satisfy regional regulations and changes in market needs, and the success or failure of new models was evident in the bottom-line accounting of the fishermen who used them.

Visiting the biennial High Speed Boat Operations (HSBO) Forum in Gothenburg, Sweden, is a window into another highly specialized working fleet—military, government agency, and commercial small craft operators. In the six years *Professional BoatBuilder* editors have been attending the invitation-only conference, we've watched market trends evolve, including growing concern about the exposure of operators to damaging vertical accelerations from slamming, and the development of diesel and multifuel outboards to meet very specific needs for military applications. The latter led to Dieter Loibner's portrait of Raider Outboards (**page 16**), an instructive account of one small company's successful development of highly specialized technology primarily to answer the demands of the U.S. Navy and Air Force but also civilian search-and-rescue operators in the HSBO fleet.

My article about Dutch builder Tideman Boats (**page 46**) tracks the development of an emerging workboat type we first saw at HSBO—the welded-high-density-polyethylene hull that's incredibly durable, requires almost no maintenance, and is easily repairable in the field. On top of its practicality during a boat's service life, HDPE satisfies increasingly common requirements for responsible disposal of boats that are no longer serviceable. The plastic is 100% recyclable.

While the aesthetics of HDPE boats still leave me cold, their undeniable practicality and recyclability lead me to predict that I'll see one soon mixing with the indigenous workboats that service fish farms or harvest seaweed on my own stretch of Downeast coast. And, who knows, it might even be powered by a civilian model outboard from Raider.

Aaron S. Porter

Professional BoatBuilder

Subscription Services

U.S. and Canada: 800–877–5284
International: 937–610–0234
www.proboat.com/subscribe
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Professional BoatBuilder (ISSN 1043–2035) is published bimonthly in February, April, June, August, October, and December in Brooklin, Maine, by WoodenBoat Publications, Inc., Jonathan A. Wilson, Chairman; James E. Miller, President. Editorial, advertising, and subscription offices are at P.O. Box 78, Brooklin, ME 04616, tel. 207–359–4651.

The cost of a subscription to *Professional BoatBuilder* for non-qualified subscribers in the U.S. is $31.95 per year. Canadian rate is $36.95 U.S. funds. Overseas rate is $44.95 U.S. funds drawn on a U.S. bank. For credit card orders, please call 937–610–0234. Periodical postage paid at Brooklin, ME, and additional mailing offices. GST #R127081008.

POSTMASTER: Send Change of Address (form 3579) to Professional BoatBuilder, P.O. Box 292635, Kettering, OH 45429-0635.

CANADA POST: Publications Mail Agreement #40612608. Canada returns to be sent to Pitney Bowes, P.O. Box 25542, London, ON N6C 6B2.

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

Printed in the United States.

Westlawn Students Chime In

To the Editor:

Given recent statements regarding the ABYC/Westlawn transaction ("Westlawn Students Chime In," Rovings, PBB No. 178), I feel compelled to respond on behalf of the American Boat & Yacht Council. While transactions such as the sale of Westlawn are kept confidential, our transfer of the Westlawn assets to Mr. Smyth was transparent and complete, and all financial information was handed over at the time of transfer in 2014. ABYC wishes continued success to Westlawn and wishes the school, its outstanding mission, and the students and faculty well.

John Adey
President, ABYC
Annapolis, Maryland

To the Editor:

I was a Westlawn student at the time Mr. Smyth acquired the school. I was more than halfway through the course and, despite the turmoil, completed the second of four modules that make up the curriculum before suspending my studies. I regret the change because I am captivated by the discipline and dearly wish to continue my studies. I, like others Mr. Smyth bemoans, have little likelihood of ever practicing the trade as a professional yacht designer. Success to me would be to have one of my designs favorably reviewed by someone at a major boating publication. The study, however, strengthened my standing in other related fields such as my profession as a marine surveyor and my skills as an amateur sailor and small boat builder. I really love it.

I don't think the school ever had a large student body at the time of my enrollment; there was an active core of perhaps 10 or 12 students on the e-mail forum, some of whom had been around for many years. Likely there were others who were less comfortable communicating on the forum. We were all nautically obsessed and shared a respect and admiration for Dave Gerr, the director. It became clear that there was friction between Gerr and Smyth within weeks of the takeover, and I don't think any of us welcomed Mr. Smyth's vision and control. From my point of view, the enthusiasm and goodwill we all felt seemed to evaporate at that time.

I think Westlawn, despite its flaws, is a worthy and venerable component of the industry, and ABYC was an appropriate home for it. The nagging problem with ABYC is that it is dominated by major players in the industry it regulates. It is with grudging respect that I admit that the foxes have done a pretty good job of guarding the henhouse so far. But they are still business leaders and perhaps respond to that imperative.

I am sensitive to the tuition question because I could not afford to enroll at Westlawn without the help of the Woods Scholarship program for the modules I completed. I would love to see some sort of endowment or permanent scholarship to benefit the school and future students.

As a student, it was clear to me that some Westlawn lessons were rather historic and "quaint." Dave Gerr had personally revamped part of the curriculum and wrote the voluminous study guide I found so valuable. That kind of contribution is substantial. It looks like ABYC's divestiture and Mr. Smyth's purchase of the school were hasty and ill considered. I hope a solution can be found that will preserve the legacy of Westlawn and its future.

Tony Allport, SAMS, AMS
Anderson Island, Washington

Emergency Rudder Repairs en Español, Part 1

To the Editor:

Nigel Calder's interesting article on his rudder repairs was not up to his usual standard and would have had Archimedes turning in his grave ("Emergency Rudder Repairs en Español, Part 1," PBB No. 177).

On page 52, Calder writes: "Presumably, the epoxy foam used to fill the interior of the rudder was more buoyant than the original foam."

The net buoyancy of the sealed rudder—equal to the volume of water it displaces minus what it weighs—is totally independent of the nature of any foam filling or anything else inside the rudder. The foam may have been a little lighter but would not have been more buoyant.

John McK. Blundell
St. Heliers Bay, Auckland,
New Zealand

CAN Bus at Sea, Part 1

To the Editor:

In "CAN Bus at Sea, Part 1" (PBB No. 177), a good story, I can't believe the designer/builder would put all those expensive control systems in the bilge, even sealed in a composite box. What about the wires, cables, etc. entering and exiting the box—and eventually new cable runs having to be made, and not to builder's specs, by a man bent double to reach them? Looks like the box is also in front of the companionway, exposed to crew entering and exiting. On a 100′ \$2–3 million yacht, could not a dry elevated space have been found near or beside the engineroom, or in the back of a closet with a foldout panel for easy access to those systems? We know what salt water can and will do, and yes, it will get in (see Nigel Calder's "Emergency Rudder Repairs en Español, Part 1" in the same issue).

Arnold Lucas
Deltaville, Virginia

Tough Sledding

To the Editor:

Regarding the article on the Hickman Sea Sled and its further development ("Tough Sledding," PBB No. 178), the elephant in the room with this design and its variants is their bone-crushing ride, especially upsea. Trapping wave impact between the chines is the exact opposite (of the desirable) effect that a deep-V has in dissipating wave energy outboard. You can talk about easy planing, efficiency, and downsea coursekeeping all you like, but a boat with such considerable seakindliness and speed limitations within at least half the compass has extremely limited usefulness, unless the sea state is flat or close to it. A Sea Sled is only useful in calm conditions, when running downsea in a moderate sea, or at slow, nonplaning speeds.

Even when running downsea, however, a boat with a fat bow (too much waterplane forward) can actually be too stable and react to wake and wave excessively in roll, which can and often does lead to yaw and diminished control and even to a broach.

Another problem with the design dynamically is that it turns flat, which compromises passenger safety, absent the centrifugal force-canceling effect of a proper deep V's heel in a turn. Ideally, a planing vessel will heel like a bicycle leans or an airplane banks in a turn to prevent passengers from feeling or being subjected to lateral acceleration. In calm water in a hard turn at 25 or 30 knots with your eyes closed, you shouldn't even know you're in a turn with heel appropriate to hull speed and turn rate.

Lack of heel also encourages hooking (the stern skidding out suddenly), which can ruin a person's day, especially when they're seated aft. It also presents control challenges, especially when running downsea and then turning upsea. Heeling into a turn is crucial in maintaining transverse stability at planing speed, especially in a seaway.

Any article that examines hullforms—especially planing hullforms that are more susceptible to dynamic forces—like this one does should scrutinize their pros and cons more thoroughly for a more balanced and useful picture.

Eric Sorensen
Morrisonville, New York

Jim Kyle responds:

Eric Sorensen is right: there are known difficulties with the Hickman Sea Sled hullform, but its positive qualities have intrigued designers since its inception. Our project aims to reduce the challenging aspects, improve turning, and build on these positive characteristics. If this could be accomplished, it would be worth promoting to the boating public. Improving the turning characteristics rings true for me; I have firsthand experience being ejected from a boat (not my design). Thankfully, I took safety precautions, because the boat tripped while conducting root-cause-analysis tests for anticipated high-speed turning problems.

Using full-sized functional prototypes, we were able to build, test, and modify hullforms through many iterations, resulting in our (unanticipated) patent application. We used the library of known forms and their various configurations (in particular tunnel, catamaran, and cathedral) experimenting with Hickman's idea of trapping and using the bow wave to increase a boat's efficiency. This design process led to our hullform concept that reduces the impact forces experienced by the boat and its occupants when encountering waves at high speeds. We have demonstrated it is possible to alter the vertical acceleration of the boat through experiments including modifications to the boat's radius of gyration and changing its dynamic response to the oncoming waves. This stands on its head the traditionally accepted naval architecture principle of trying to keep the weight out of the ends of the vessel. Why are people not questioning the dynamic response of traditional deep-V hullforms that now have the considerable weight of multiple large outboards hanging off their transoms?

While a detailed description of the hullform covered in our patent application was off-limits to Dan Spurr's article, a closer examination of the 3D model illustrated on page 54 shows a familiar V-bottom hullform fading out as it runs forward. Combine that with the article's opening illustration of a military proposal with folding hull sides, and you can see the prominent deep chines forward and the beginning of the central-V-bottom hullform. This hints at what we have found to work, achieving the integrated goals of our project. Working with full-size proof-of-concept prototype hulls, as opposed to tank-testing scale models or computational fluid dynamic (CFD) simulations, we instantly know the results of our design modifications through real-world testing. Several people with vast boating experience have driven the boat and confirm that we are onto something real and exciting.

Compiled by Dan Spurr

Princely Projects

Last we spoke with Bill Prince of Bill Prince Yacht Design (BPYD) was about a highly engineered hardtop for a 78-mph Schiada Boats express cruiser, destined for Kuwait (*Professional BoatBuilder* No. 156, page 12). Prince, as we noted then, is based in Port Washington, Wisconsin; he holds a degree in mechanical engineering, and has earned his stripes with an enviable list of designers and naval architects: Michael Peters, Timothy Graul, Ted Hood, and Bob Johnson. His current work has migrated to mostly high-end recreational craft, and the portfolio is diverse.

Talking with him recently revealed intriguing projects: among them are construction of a new 132′ (40m) megayacht in South Korea; a refit of the "oldest Huckins" in Maine; a runabout at Van Dam Custom Boats in Michigan; a 77′ (23.5m) motoryacht at Crescent Custom Yachts in Vancouver, British Columbia; a refit in Fort Lauderdale, and another of a 114′ (35m) Burger near his home in Wisconsin. Recent and current project highlights in this update on BPYD are a reimagined rendition of Ernest Hemingway's Wheeler 38 (12m) Playmate, named *Pilar*, and work with Seacraft Design on an 81′ (25m) Lake Geneva Day Yacht with electric propulsion.

The original *Pilar* was built by the Wheeler Yacht Co. in Brooklyn, New York, a very successful business founded by Howard Wheeler in 1910. He built boats and ships

Hemingway customized his Wheeler Playmate 38 (39'5"/12m) with a flybridge and outriggers, said to be firsts for the sport.

COURTESY BILL PRINCE YACHT DESIGN (ALL)

Top—*Calling Ernest Hemingway's* Pilar *the most famous fishing boat of all time, Wes Wheeler restarted his great-grandfather's yacht business and commissioned Bill Prince to design a modern version of it, shown here in a computer rendering.* ***Right***—*Brooklin (Maine) Boat Yard will build the new* Pilar *of cold-molded mahogany. No fish scales or blood below, please.*

MARK PUDLO

The 81' (25m) Henry Knox*, powered by two electric motors, is the latest and largest Lake Geneva Day Yacht to be launched on the Wisconsin lake.*

for the U.S. military for both World Wars, eventually settling into private yachts. At one time he employed 6,000 people. *Pilar* was a custom version of the company's Playmate series, and featured what some have said is the first flybridge. Hemingway also is said to have been, if not the first, at least an early proponent of outriggers to add and separate fishing lines, and a live bait well. He paid $7,455 for his boat in 1934. The great-grandson of Howard Wheeler, Wes Wheeler, believes a modern version of the "world's most famous fishing boat" could sell well, and so commissioned Bill Prince to execute the design, and Maine's Brooklin Boat Yard to construct it, scheduled for spring 2019. Because no drawings survived a fire at the Wheeler Clason Point Shipyard in 1963, Wes Wheeler traveled to Havana, where the original *Pilar* is exhibited, to take photos and measurements for the re-creation. The first, built on spec, will be cold-molded mahogany, and the interior upscale—it's not a fishing machine but a coastal cruiser with galley, berths, and leather seats…if the website photos are indicative of the finished product. In place of Hemingway's 75-hp (56-kW) Chrysler Crown Marine gas engine, the new *Pilar* will have twin Cummins QSB 6.7L diesels and ZF transmissions that deliver 23 knots at 2,600 rpm.

By contrast, the Lake Geneva Day Yacht is a one-of-a-kind genre of elegant lake launches; Lake Geneva, in southeastern Wisconsin, could be a movie set of elegant homes, elegant yachts, and elegant people. Mark Pudlo at Seacraft Design, who took over Tim Graul's practice when he retired, was the lead architect on this unusual project, and collaborated with Prince for the above-deck styling and the computer renderings. There are only seven yachts of this kind on the lake, and this new build, the *Henry Knox*, inspired by steam-powered yachts of the 1890s, is the largest on the lake, and perhaps also one of the largest all-electric yachts in the world. Pudlo says it has long been a tradition that each mansion on Lake Geneva has a boat for leisurely family outings and summer social events. "The project was tastefully executed in every way," Pudlo said. The aluminum hull was fabricated by Anderson Boat Works in Douglas, Michigan, and finished in a temporary yard set up by the yacht owner. Common to these long and narrow launches—picnic boats, or commuters as they are variously described—is a near full-length canopy or hardtop that parallels the lovely, gentle sheerline. The *Henry Knox*, a true day boat without berths, is powered by two Torqeedo electric motors supplied by six 30-kWh BMW i3 lithium-ion batteries that deliver 11.5 knots and more than 8 hours of silent, vibration-free cruising time between charges. And if the lake gets rough, a Seakeeper gyro stabilizer smooths the ride. Finishwork includes a Burma teak deck, and Honduras-mahogany interior.

Wheeler Yacht Co., 510 Meadowmont Village Circle, Suite 301, Chapel Hill, NC 27517 USA, tel. 919–240–7259, www.wheeleryachts.com.

Bill Prince Yacht Design, 222 E. Main St., Port Washington, WI 53074 USA, tel. 262–822–4000, www.billprinceyachtdesign.com.

Seacraft Design, P.O. Box 234, 957 Green Bay Rd., Sturgeon Bay, WI 54235 USA, tel. 920–746–8613, www.seacraftdesign.com.

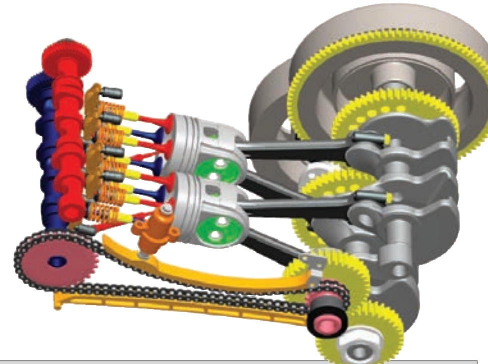
—Dan Spurr

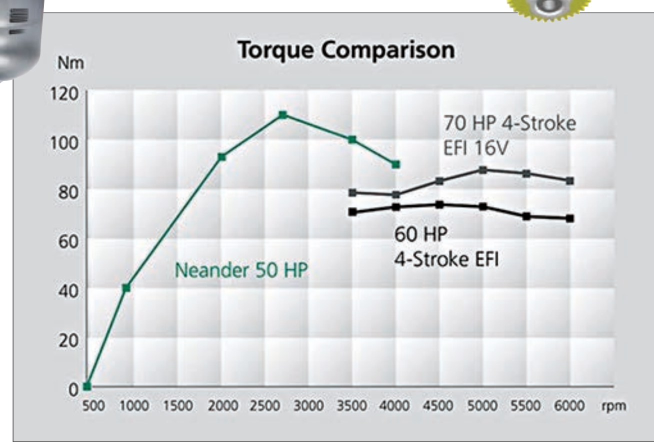
Diesel Outboards

It is well known in the boating industry that the popularity of outboard motors continues to trend upward. I/Os are dead in the water. Inboards now seem relegated to midsize and larger motoryachts. Twin outboards are so passé. Triples and quads are de rigueur. Besides adding another motor to the highly reinforced transom of, say, a 40′ (12.2m) center-console fishing machine, are there any other options? Well, yes, sort of. There is an emerging market for diesel outboard engines (*outboard motors* was always a poor choice of words). All the companies discussed here say they are targeting commercial customers in transportation, oil and gas, fishing, and other marine sectors, because it's perceived that those sectors will pay the higher cost (versus gas outboards) for the convenience of having one fuel aboard the mother ship, and longer engine service life with longer intervals between maintenance. But with more exposure, diesel outboards are now finding a broader market.

Here's a brief overview of several major players in this developing technology.

Interestingly, diesel outboards are not new. A 2015 article in the online publication *Boatmags* cites the Amarc 10, a two-cycle diesel outboard made by American Marc in 1960–61, as an early entrant. As a side note, this is the same company Carl Moesly worked at before eventually acquiring the boat tooling assets (see Rovings, PBB No. 178). Evidently, the company's lofty expectations for boats and diesel outboards foundered.





***Above—**Yanmar partnered with Neander Shark to distribute the latter's 50-hp (38-kW) diesel outboard, the only size currently offered.*
***Above right—**The double counterrotating crankshafts are said to greatly minimize vibrations.*
***Middle right—**Besides less flammable fuel, a main advantage of diesel outboards is low-end torque.*
***Right—**In the early 2000s Neander Shark's founder, Lutz Lester, became intrigued with small diesel engines for nonautomotive applications, and installed a prototype in this hot-looking motorcycle as a proof of concept.*

COURTESY NEANDER SHARK (ALL)

Yanmar developed 27-hp and 35-hp (20-kW and 26-kW) diesel outboards and then ceased their production for a lengthy period, perhaps to reassess its strategy, before partnering with the German company Neander Shark Motors to develop and distribute the **Dtorque 111** in 2015. The 50-hp (38-kW) engine is claimed to have more torque (111 Nm/81.9 ft-lbs at 2,000–3,000 rpm) than a 60-hp (45-kW) gasoline outboard over most of its speed range. The four-stroke turbodiesel has double counterrotating crankshafts that minimize vibration to a level not expected in a two-cylinder engine, and Bosch common rail direct injection. It's touted as a good choice for commercial applications—"pushing heavy vessels, trawling, or idling for hours"—such as a tender working near oil fields, where the lower flammability of its diesel fuel is much safer than gasoline-fueled outboards. Other benefits include higher fuel efficiency (around 12 l per hour/3.2 gph at WOT, said to be half that of a gas engine of similar size), durability, and reliability. Exhaust emissions meet the E.U.'s RCD 2 standards. Weight is 175 kg (385 lbs) compared to 109 kg (240 lbs). A 75 hp (56 kW) is expected soon. The manufacturer of the 10,000-hour engine is Steyr Motors, maker of larger diesel engines for numerous markets. It will be fitted with an outboard leg by Selva.

Neander Shark Motorfahrzeuge GmbH was established in 2003, and an early version of the engine was installed in a motorcycle, a passion of founder Lutz Lester. In 2006 the company incorporated as Neander Motors AG, followed by Neander Shark GmbH in 2009, a subsidiary that develops nautical applications for diesel technology. After its turbodiesel technology won awards in Germany, Yanmar joined as an investor and sales partner in 2015. ▶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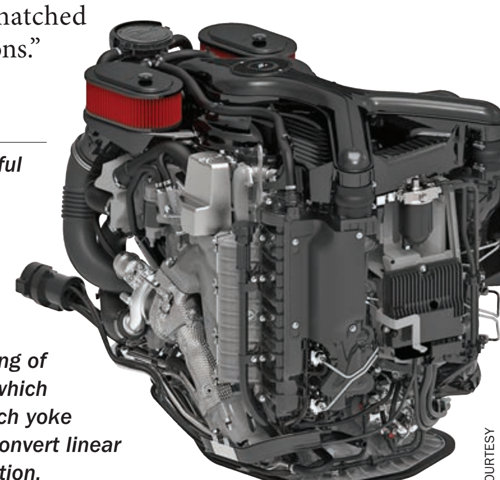
While Lester targeted commercial applications, the engine has been exhibited at the last several recreational boat shows in Düsseldorf to gauge consumer interest. The response has reportedly been positive. However, spokesman Miri Zymny told us: "Our engine is intended for commercial shipping, because it pays off after extensive use every year. Therefore the leisure market is not in our focus."

Cox Powertrain was founded in 2007 by auto engineer David Cox, who believed he could employ F1 racing technology in the development of lightweight diesel engines. The following year $6.53 million (£5 million) was raised to research and create a large diesel outboard engine. The eventual result was a 300-hp (225-kW) turbodiesel that debuted at the Fort Lauderdale International Boat Show last year. The CXO300 is a four-stroke 4.4-liter V8 cast in aluminum to save weight—a primary concern of diesel outboard manufacturers owing to the inherent high compression (16:1) required for ignition of diesel fuel. Reports say the engine has a narrow 60° V angle to reduce footprint. Maximum torque is an impressive 479 ft-lbs (650 Nm) at 1,300–3,000 rpm. The company estimates fuel consumption at 2.6 gph (10 lph) at 2,000 rpm and 13.2 gph (50 lph) at 3,500 rpm. Weight is a hefty 825 lbs (375 kg).

Cox Powertrain utilizes a Scotch yoke, or slotted link, mechanism that converts linear motion to rotational motion, partly because it's more compact. SeaStar Solutions was brought in to supply controls for steering and throttle. Manufacturing takes place at a dedicated facility in Shoreham, West Sussex, U.K., and a worldwide dealer network is in the works. Price will be in excess of $55,250 (£42,000).

About its market focus the company's global sales director, Joel Reid, says: "While we were not initially targeting the recreational market, the high demand from this market has led us to readjust our direction….Our presence at recreational shows such as FLIBS [Fort Lauderdale International Boat Show], Miami International Boat Show, Monaco Yacht Show, or Cannes Yacht Show, where recreational boating and saltwater sports fishing are so popular, has been very strong. The response from this type of user has more than matched our expectations."



The most powerful diesel outboard introduced to date is Cox Powertrain's 300-hp (225-kW) CXO300. This is a rendering of its powerhead, which utilizes the Scotch yoke mechanism to convert linear to rotational motion.

COURTESY COX POWERTRAIN

COURTESY CIMCO MARINE

The largest of several diesel outboards offered by Cimco Marine, this 200-hp (150-kW) engine delivers power to the propeller shaft by means of a carbon fiber belt.

The Swedish company **Cimco Marine** is busy establishing worldwide dealerships for its **OXE** diesel outboard engines. Its 200-hp (150-kW) engine is based on a four-cylinder General Motors automobile engine and meets EPA Tier 3 emission standards. Smaller models are available: 125 hp, 150 hp, and 175 hp (94 kW, 113 kW, 131 kW). OXE's design solution is a horizontal block with a transmission carbon fiber belt taking power down to the propeller shaft. Fuel consumption is 12.4 gph (47 lph) at WOT. Torque is 306 ft-lbs (415 Nm) at 2,500 rpm and weight is 770 lbs (350 kg). The motors feature electronic power steering and CAN bus electrohydraulic shifting.

Cimco's Pim Polesie says, "We do not prevent pleasure craft users from using the OXE Diesel. The benefits of the OXE Diesel are as true for them as for the commercial users, but from a financial perspective it is more difficult to motivate the upfront cost. The break-even period [over gasoline outboards] is approximately 600 hours in Europe and 750 hours in the US."

Cimco also recently announced the Bison Project, converting BMW's 3-liter turbodiesel automobile engine to marine applications. An earlier press release said Semcon (www.semcon.com) was "handling the design work, calculation, and simulation as part of the project." The 300-hp (225-kW) outboard is expected to be released in 2020.

Mercury Racing developed for the U.S. Department of Defense the DSI Outboard, a two-stroke 3-liter V6 diesel that is spark ignited and runs on ultralow-sulfur fuel. The crash of a Navy ship in 1995 that resulted in a gasoline fire motivated the DoD to remove gasoline engines and fuel tanks from ships and develop safer alternatives. The DSI is available only to the military.

R&D is also under way elsewhere in the world, including Italy and New Zealand, so there should be a smattering of new products coming to market in the near future.

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Cox Powertrain, The Cecil Pashley Bldg., Unit 8, Cecil Pashley Way, Brighton City Airport, Shoreham-by-Sea, BN43 5FF, U.K., tel. 44 1273 454 424, www.coxmarine.com.

Cimco Marine, Metallgatan 17 b, SE-262 72, Ängelholm, Sweden, www.oxe-diesel.com.

Mercury Racing, tel. 920–921–5330, www.mercuryracing.com. —D.S.

Sixty Years of BoatLIFE

COURTESY LIFE INDUSTRIES

"Git"-Rot, a high-viscosity resin that penetrates rotten wood and hardens to restore its structure, is one of many products developed and marketed by Edwin Kehrt's Life Industries company.

It's strange and fascinating how some companies are founded. Sometimes the formative event is lightbulb inspiration, other times serendipity or plain dumb luck. For Edwin Kehrt, founder of BoatLIFE marine caulks and sealants, it was an outgrowth of his military service in the Philippines during World War II. As a captain in the U.S. Army Corps of Engineers, he managed a floating power plant in Manila. According to the company's history, the chemical compound polysulfide was used to repair bullet holes in aircraft fuel tanks, and Kehrt became "familiar" with it. After the war he bought his first boat and thought there were no suitable caulks/sealants for marine use—so, remembering those bullet holes and the goo personnel used to fill 'em, he must have thought, "Aha! I know what I can use to bed my leaky portlights!" He started a business and introduced polysulfide to the marine industry, and then to aviation (AeroLIFE) and RVs (RV LIFE). To expand production, in the early '70s he bought a coatings and flooring company and in a few years combined facilities on Long Island, New York, later moving to South Carolina. Today, managed by Kehrt's daughter, Grace L. Schmidt, the product line also includes epoxies, cleaners, waxes and polishes, solvents, and more. This year Life Industries celebrates its 60th anniversary. You can also thank them for the indispensable "Git"-Rot. A job well done.

Life Industries, 4060 Bridgeview Dr., North Charleston, SC 29405 USA, tel. 800–382–9706, www.lifeindustries.com. —*D.S.*

The Undeflatable

COURTESY BULLFROG BOATS

Bullfrog Boats' line of aluminum/foam-hull boats ranges from a 10' (3m) tender to the 22' (6.7m) Offshore Ranger, shown here.

Craig Henderson, whose Bullfrog Boats of Bellingham, Washington, has sold more than 600 RIBs (rigid inflatable boats), calls conventional air-filled technology "deflatable" boats. "Poke a hole in it and gonzo," he told reporters in a local television interview some years ago. The tubes on his aluminum hulls are filled with foam, so technically they cannot be RIBs, though that's certainly what they look like.

Henderson is not the first to retain the advantages of resilient tube perimeters. Neighboring Safe Boats International, Vripack, and Ocean 1 Yachts (reported in PBB No. 169) among others employ foam-filled collars for stability, cushioning impacts, and flotation.

Granted, Henderson's patented solution varies from those to a degree, and he arrived at it in his own fashion. He majored in Industrial Technology Plastics and Manufacturing at Western Washington University in Bellingham, where he developed a strong interest in automobiles. He paid for his schooling by working as a machinist apprentice at the Vehicle Research Institute. On his own time he built a diesel-powered car that won the 1986 Three Flags Econo Rally, averaging 107.7 mph (173.3 kmh) from the Canadian border ▶

COURTESY BULLFROG BOATS

Builder Craig Henderson subcontracts parts cutting and aluminum fabrication and completes assembly and rigging in his own Bellingham, Washington, shop.

to Tijuana, Mexico, a number he bested several years later to 119.1 (191.7 kmh) utilizing a 12.4-gal (50-l) fuel tank.

After a stint working at Honeywell Marine he decided to live aboard a boat. He built a 53′ (16.2m) steel cutter he lived on for seven years before moving ashore to work on the Bullfrog project, inspired by a quest for the perfect dinghy/yacht tender. He spent four years working on a prototype, focused on making it unsinkable, stable, and durable. The result: an aluminum/polymer boat with positive flotation, and a polyethylene flotation collar. He partnered with his friend Andrew Vance, nephew of yacht designer Ron Holland, who from his home in New Zealand develops the computer-generated cut files for Bullfrog.

Freelance writer Bruce Hendrick wrote an (unpublished) piece that Henderson shares to explain how the boat's tubes are rotomolded at Cypress Designs in Bellingham: "He starts by creating an aluminum two-part mold that is then highly polished to facilitate easy release of the part. The next step is to position the metal inserts in the mold to which owner-selected options will be attached. A 'shot' of polyethylene powder is then poured into half of the mold, which is then bolted together. This is where the process gets tricky, as the mold has to be rotated and heated in an oven large enough to hold the mold." The challenge, Hendrick explains, is that the mold must be rotated *and* pitched simultaneously at a controlled rate to ensure that the finished part will be of uniform and constant thickness for maximum strength. This process takes about an hour. Then, while the mold is still being rotated and pitched, it is removed from the oven and set over a bank of fans for even and uniform cooling to guarantee the quality and structural soundness of the final piece. After the mold has cooled, it is unbolted, and the top half is lifted off with a chain hoist, and the piece is extracted. The final step is removing the flashing that's left at the mold joint, which is quick and easy.

The next step is to cut access ports in the finished piece so the parts can be bolted to the inserts in the polyethylene tube, which is then glued and bolted to the aluminum hull structure.

Henderson says, "We use two different fab shops for cutting parts, and then Mike Kearney at Kearnco Specialties welds the hulls. All the FRP parts are made by local boatbuilder BAMF Boats. We then do the final assembly and rigging with foaming the tubes, and complete the boat with everything the customer needs."

Current models include the 10′ (3m) Utility Tender/Dinghy/Yacht Tender; 11.5′ and 13.5′ (3.5m and 4.1m) Yacht Tenders; 15′ and 17′ (4.6m and 5.2m) Super Sport Utility boats; and the 22′ (6.7m) Offshore Ranger.

Bullfrog Boats, P.O. Box 40, Bellingham, WA 98227 USA, tel. 360–714–9532, www.bullfrogboats.com.

—D.S.

Short Cuts

- Canadian yachtsman **Don Green** died at the age of 86. A member of the Canadian Sailing Hall of Fame and Member of the Order of Canada, Green sailed around the world with Irving Johnson aboard the brigantine *Yankee*, and won the 1978 Canada's Cup with *Evergreen*, a daring C&C design with a jibing daggerboard.
- **SIFCO** Applied Surface Concepts offers portable electroplating that needs no immersion tank and may save time for on-site plating of valves, pumps, propeller shafts, bearing seats, and structural components. www.sifcoasc.com/marine.
- **Evinrude**, partnering with ABYC (American Boat & Yacht Council) and NMDA (National Marine Distributors Association), will donate $2 million worth of its E-TEC G2 3.4L V6 outboard engines to the ABYC Foundation to train marine technicians across the U.S. and Canada.
- **Correct Craft** announced its purchase of 65-year-old Velvet Drive transmissions. Based in Little Mountain, South Carolina, Correct Craft's Pleasurecraft Engine Group also owns PCM, Crusader Offshore, Challenger, and Levitator. *—D.S.*

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COURTESY RAIDER OUTBOARDS/CHRIS WOODRUFF

MILITARY GRADE

A small family firm in Florida builds submersible multifuel outboard engines for tough missions.

by Dieter Loibner

Above—_During a training exercise in Hawaii, United States Marines practice surf launches on an inflatable powered by a Raider 50-hp submersible multifuel outboard._

The High Speed Boat Operators (HSBO) Forum in Gothenburg, Sweden, is a gathering unlike any other. Uniforms are part of the ambience, as 370 delegates including search-and-rescue, police, customs, special forces, and navy converge on this biannual event to exchange information, to learn about new techniques and technologies, and, above all, to sea-trial the boats on display, putting the hammer down on test runs along the skerry-strewn coast. Par for the course is 60 knots and more on these craft with shock-absorbing seats and supersized engines. In this high-octane crowd, a small tiller-steered outboard motor that looks like it had escaped a 1980s time warp certainly stands out as an oddity.

"Well, this might not be the biggest or the fastest motor here," explained Chris Woodruff, 51, "but it can do a few things that nobody else can." That motor was the Raider 50, a two-stroke, multifuel, submersible outboard built exclusively for the U.S. military. Strictly speaking, these motors are government issue, but Woodruff said he's at HSBO because he has permission to shop this product to governments on "friendly terms with the U.S." His company website leaves little doubt about its niche:

"Raider builds and supports reliable outboard motors for the warfighter."

These motors are heavily modified versions of the 40-hp (30-kW) Tohatsu 40C and the 50-hp (37.3-kW) 50D2, with numerous parts swapped out, refined, or added, including a nifty dewatering system patented by the U.S. Navy. Conspicuously, they lack many staples of commercial outboards, like electronic fuel injection or digital shift and throttle controls, features that are either expensive or difficult, if not impossible, to repair in an emergency or in a remote and hostile theater. Raider's motto is KISS: keep it simple, stupid. "We decided to go back to the basics," Woodruff said about those two-stroke carbureted outboards with a pull starter. "Our goal is getting the boys back safely." The downside? These engines don't run as clean as contemporary hi-tech commercial four-strokes or fuel-injected two-strokes. Still, the U.S. Environmental Protection Agency nodded its approval, but more on that later.

COURTESY RAIDER OUTBOARDS/CHRIS WOODRUFF

During training, one of Raider's outboards ended up on the beach, stripped of its cowling, which led to a redesigned closure mechanism. "They break 'em. We make 'em better," said Chris Woodruff, Raider's business development manager.

Built for the mission

Raider outboards are intended for service on small inflatables and are knowingly subjected to admittedly abusive uses—landing facedown in the surf zone on a beach during training, getting tossed out of airplanes at altitude, or being released from the dive-chamber of a submarine for secret operations. Only on rare occasions does the military share details, and if they become available, they most likely concern rescues of civilians (see the **sidebar** on page 30).

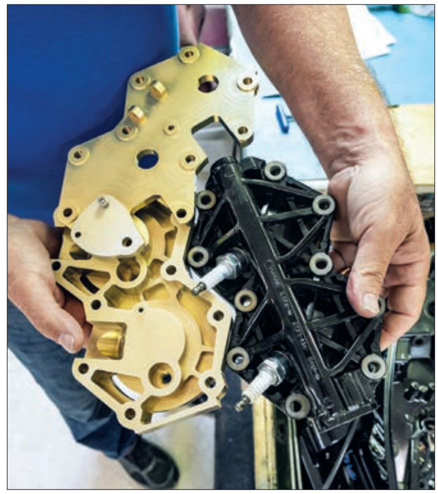
The Raider facility occupies a squat office and manufacturing building a few miles outside Titusville, Florida, a coastal town on the western shore of the Indian River within sight of the Kennedy Space Center. Welcoming visitors from behind the reception desk is a life-size cardboard cutout of a trimmed down Donald Trump, giving a double thumbs-up. It is a family business run by Chris Woodruff, who, in a prior life, sold boats for Donzi Marine, and by his father, George, a twice-retired executive, who'd worked in government sales at IBM and Lockheed Martin. The Raider crew is a cast of colorful characters with diverse backgrounds (most of them military), but all are fiercely dedicated to building these motors.

Formalities are not a priority here, so it takes only a few seconds before I sit in Chris Woodruff's office. Although his official title is business development manager, he is really leading R&D, which is why his desk overflowed with 3D-printed ABS plastic samples of an inflatable boat he has been working on and bits for a jet drive that can be retrofitted to Raider outboards. These are but two examples of models and prototype components the company tries out and modifies with the Raise3D N2 printer in his office, since replaced by a Fusion3 F410 3D printer.

Woodruff took two parts off a shelf, an old and a new head, to show what

DIETER LOIBNER

Woodruff shows off the safety jet drive for a Raider 50-hp motor during the High Speed Boat Operators Forum, in Gothenburg, Sweden.



Woodruff compares the difference between Tohatsu's darker original and the modified 6061 aluminum heads Raider installs. Note the hole at the bottom for dewatering prior to starting after a motor has been submerged. The company says the new heads also improve compression and performance.

kind of value Raider adds when it modifies for the military

"We changed heads, intake, electrical, fuel system, and dewatering components," he said. "We switched out the throttle cams and moved the shifter to the front of the motor. We use new linkages and a special motor mount that makes it easier to put on the engine at sea."

Choosing low tech

The company replaced the Tohatsu motor's original heads with custom ones, to increase compression and improve water flow. They now are made of machined 6061 aluminum and have holes at the bottom of each cylinder. They are equipped with special relief valves to allow water to be removed after submersion. As an added benefit, Raider says these changes yielded about 5 extra hp (3.7 kW) on the 40 and around 7 hp (5.2 kW) on the 50. To burn multiple fuels, including gasoline, diesel, JP-5, and JP-8, Raider selected a different carburetor, which atomizes No. 2 diesel and mil spec JP-5 heavy fuels to a fine vapor, making it suitable for spark-ignition combustion without preatomization or the need to preheat the fuel.

Dewatering an outboard engine that might have sat on the seafloor in up to 66′ (20m) of water is a process that had to be simplified to several steps that could be carried out day or night, in arctic cold or tropical heat, and, if need be, under enemy fire. Just as important is the question of fuel. Testing different additives, Raider found that, in a pinch, the motor runs as well on a 50:50 mix of diesel and gasoline as it does on gasoline only, which is why Woodruff called this "a fuel of opportunity."

Spark plugs in submersible outboards must get very hot to evaporate all moisture left in the cylinders after dewatering. These plugs are hard to find, at least ones made in the U.S., as mandated by the Barry Amendment, which guides procurement for the military. Raider worked with Pulstar in Albuquerque, New Mexico, which made several different types of plugs for Raider to improve heavy-fuel ignition. The chosen model is a stainless-steel plug with a patented internal capacitor that creates plasma during ignition, thus vaporizing residual water and initiating combustion. With diesel and other heavy fuels, the plasma also creates more precise ignition and stable combustion.

Raider orders motors for modification by the container load—60 units of the 40-hp model and 48 of the 50s. The

Left—*An old Johnson IMARS (Improved Military Amphibious Reconnaissance System) outboard with dewatering instructions on the cowling sits next to a 40-hp Generation 1 Raider based on a commercial off-the-shelf Tohatsu motor.* ***Below—****Raider chose a Pulstar stainless-steel plasma spark plug with an internal capacitor.*

DIETER LOIBNER (ALL)

DIETER LOIBNER

Raider's AGM battery, designed for the U.S. military, is heavier and offers less energy density than a lithium-ion one. But it's cheaper and spillproof, and its transport on planes and submarines is not restricted.

goal is to keep about 150 units of the smaller and 100 of the larger motors in stock. Tohatsu likes that volume and helps with favorable payment terms.

"My salvage guy loves me for all the parts we discard," Woodruff laughed. "In the early days we had to make changes, but now we are on Generation 2, and the Navy beats the crap out of it. But out of more than 500 engines we sold thus far, not one was lost due to a manufacturing defect. And we have a one-year unconditional warranty."

Regarding those changes, Raider quickly learned that electronics are not the best choice to manage the electrical system of their engines when they are on critical missions. Alternator output, for instance, is controlled by a custom voltage regulator, George Woodruff explained.

Initially, when the motors ran for an extended period, the lightweight, powerful, and expensive lithium-ion batteries became unstable and required more charging than the old, heavy AGM batteries. The latter have two advantages: they're much cheaper, and they are spillproof. Because their sulfuric acid is absorbed by fiberglass mat, these batteries automatically take care of hazmat restrictions for shipping and storing the engines on planes and submarines.

The user feedback loop

For incremental product improvements, Raider depends on feedback from the troops. "The smartest guy in this scheme is the boathouse mechanic," Chris Woodruff said with a grin. "He can be a crusty Navy guy, an aged hippie. I want to become friends with all of them, and when they talk I just shut up and listen." The man who deals with these technicians most often is Mike Waddell, 48, recently promoted from field technician to production manager. A diesel mechanic by training, he grew up on a farm in Illinois and serviced M1 Abrams tanks for the Army.

"Training users in handling the motor is essential," said Waddell, who was hired straight out of Westland Marina in Titusville, where he worked on boat engines. "If the dewatering procedure is not handled properly, there'll be a flame-over with a mushroom cloud at the backside of the engine where the dewatering valves are. Check the clear carburetor bowl for the separation of water and gas, and check the position of the dewatering lever. Start in gear, then close the dewatering lever."

As a veteran who did a tour in Bosnia in the 1990s, Waddell is familiar with the drill. "Getting dropped in a remote area at 2 a.m. from 12,000′ [3,700m], having to pop the engine and mount it is the same as assembling an M16 rifle blindfolded, or popping the boat out of a submarine's dive chamber and watching it inflate as it floats to the surface. We have trained 200–300 [military] boat operators, mechanics, and technicians. Thus far, we did it all in the same training session, but now we hold separate classes."

Waddell says that problems reported to the company hotline "get addressed within 24 hours." Common issues are with the electrical system, fuel drainage, and the dewatering valves. "The Tohatsu [engine] is a good base—no other engine is still carbureted, so we have to teach ancient techniques," he said. "It's a step back in time." But there are still plenty of new things to learn. He said, for example, from a test near a desalination plant in Abu Dhabi where the water had extremely high salinity, after 24 hours of use, the engine had a level of corrosion equal to that of ones used for two to three weeks in the U.S.

To combat corrosion in general, Raider sprays its motors with Corrosion Zero and seals vulnerable electrical connections such as the starter solenoid with liquid electrical tape. Despite all the precautionary measures, there are still untold ways of roughing up motors. "Every time I

DIETER LOIBNER

Technician Chris Lavallee readies a 50-hp motor for shipment. Before switching careers and attending the Marine Mechanics Institute (MMI) in Orlando, he worked in the restaurant industry.

check an engine and ask, 'How did you do that?' the answer is always: 'We were training,'" Waddell said.

This feedback loop is the reason the original round carrying handle that bends around the back and the side of the motor was replaced with a square version to prevent the motor from tipping over when it is set down on the ground. Similarly, Raider also was asked to replace the metal carburetor bowls with transparent plastic ones, so a visual check for the presence of water in the fuel would be quick and easy.

The crew

Making this transparent plastic part fell to machinist and toolmaker Chet Barker, who operates a clinically clean workshop dominated by a milling machine and a workbench he keeps in meticulous order. Barker said he got started in this line of work at 13 in his grandfather's workshop, and that after 60 years in the trade, he still has his machinist's mojo. "At age 73, I'm retired, but I still put in 25 hours here," he said. "Nobody learns anymore the stuff I'm doing, [which is why] I still make parts for antique motorcycles like Simplex, Mustang, and Cushman."

In 1960 Barker arrived at Patrick AFB, just south of the Cape, and at one point trained to recover Apollo space capsules with a C-130 aircraft dragging a weighted cable. In the 1980s, he got into Jet Skis and dealt with jet drives that sustained damage from rocks and sand when the craft was run up on the beach. "That was an expensive repair, because the impeller and the housing have to fit exactly for the

DIETER LOIBNER (BOTH)

Left—*Veteran machinist Chet Barker works at Raider part-time and also builds parts for antique motorcycles.* ***Above***—*He gets the call when special parts need to be designed and built, like the transparent carburetor bowl he sketched from memory on a piece of quad-ruled paper.*

[jet] drive to work. I thought of a better fix: I removed the impeller, fitted a polyurethane ring into the stator, and corrected the impeller. It cost much less than buying a new impeller."

He showed me the tooling for the dewatering valve, the kill switch, and the transparent carburetor bowl. "The kids who come here as interns don't know where to turn on the milling machine, but they are big on computer drawings," Barker quipped. "When they don't see any in my shop, they ask, 'Where are your drawings?' Right here," he said, tapping his head.

Around the corner from Barker's shop is the workstation of Jim Ness, 62. "By job description I'm a machinist, but you can call me magician," he joked. A lifelong boater and a liveaboard who hails from Michigan, he's been with Raider for eight years. Like Barker, he came to Florida in the '60s. He chose to follow in the footsteps of his dad, an engineer, and an uncle, who both worked at the Kennedy Space Center. Ness said he worked on the Hubble Space Telescope mission and built launchpads. After the Challenger catastrophe he lost his job and went to the Florida Keys to work in land survey, drywall construction, and pool maintenance. Later he got back into making things and ran CNC machines at Seminole Gunworks.

When I visited, he was busy milling the stator of a new Safety Jet drive on a 40-hp engine. Raider is betting big on it, for military *and* civilian markets. In about 10 minutes, Raider says, these jet drives can be retrofitted to the original lower units. The goal is to prevent injury from prop strikes during dangerous surf launchings, and to protect manatees in the shallow Florida waters or flood victims rescued by inflatables in the aftermath of hurricanes.

Machinist Jim Ness checks the fit of an impeller for a safety jet pump. Like some other Raider employees, he worked at the Kennedy Space Center before joining the company.

DIETER LOIBNER

In another area of the shop were two young technicians who graduated from the Marine Mechanics Institute in Orlando before joining Raider Outboards. Army veteran Jon Klein, 31,

__Left—__Jon Klein, replacing a lower unit, worked in automotive prior to graduating from MMI.
__Right—__Inventory manager Geri Deal, who came from the semiconductor industry, holds the emergency kit included with every motor.

DIETER LOIBNER (BOTH)

who worked at Toyota until he hurt his shoulder, was removing a lower unit from one of the 40-hp engines. His colleague, Christopher Lavallee, 33, who switched careers from the restaurant industry to outboard technician, was getting other motors ready for shipment. Both said they like the creative spirit at Raider and the chance to work with their hands to solve problems.

The latest addition to Raider's staff was Geri Deal, 57, to manage inventory. She joined the company just a few weeks prior to my visit. Previously, she'd worked in the semiconductor industry as a procurement manager for circuit boards and other electronic components. "I'm learning. It's a lot of new stuff for me, so I have to ask many questions," she said as she showed me around her domain—the stockroom chockablock with shelves and hundreds of bins.

Among them are a couple of boxes for rejects or defective parts for recycling. Lest they get pinched, Deal keeps a watchful eye on the waterproof emergency toolkits. These little lifesavers contain pins, sockets, spark plugs, a pull rope, and assorted tools and come with every Raider outboard.

Building Raider

To an outsider, it looks like after more than half a dozen years in business, Raider Outboards has come into its own. But it had to navigate some tricky waters, including the specter of bankruptcy at one point. Chris Woodruff's father, George, 75, steered the company through those turbulent times. He had retired to the area from his careers in government sales at IBM and work on programs for the F22 fighter plane at Hughes Aircraft and an advanced-technology-support contract at McClellan Air Force Base in Sacramento, California, for Lockheed Martin. "I went to Titusville to go fishing, to visit Disney, and to play golf," he joked. "But that got old after six months, and I had no clue what I wanted to do next."

But George Woodruff, raised on a farm in upstate New York, always knew hard work and how to figure things out. He said that in 1964 he graduated from a two-year college "on a Friday and started at IBM the following Monday," working his way up to senior positions in government sales, before moving on to defense contractors who were former clients. His Rolodex contained useful highly placed contacts he could call on when starting Raider Outboards Inc., which he named in honor of the Marine Corps Raiders, who went behind enemy lines in rubber boats in World War II.

Woodruff: "I work with state officials and congressional people in D.C. You can say I'm my own lobbyist. If it is for the troops, it is easy to get money."

First "I bought a building with a parking lot in downtown Titusville, and in 2005 I won a research contract for $1 million to build a zipper mast for use with robots in nuclear power plants, and for clandestine [military] applications," Woodruff said. It was a logical step for a man who holds eight patents, for infrared technology and electroluminescent lighting for aircraft. ZipperMast, still in business today, was a kind of dress rehearsal for the outboard business.

In 2010, the Naval Surface Warfare Center (NSWC) in Panama City, Florida, received funding from the Air Force to replace the dated Improved Military Amphibious Reconnaissance System (IMARS) motor, aka Enforcer, built by Johnson. The simple lightweight two-stroke 35-hp outboard was proven and well liked by the troops, but Johnson and Evinrude were acquired by the Canadian company Bombardier Inc. in 2001. It notified the U.S. it was terminating its support for IMARS, offering the more sophisticated and complicated Evinrude E-Tec 30 and the Evinrude 55 MFE as substitutes. It was a fortuitous time for Woodruff to get involved, because he knew how procurement for the military works. "With my experience at IBM, Hughes Aircraft, and Lockheed Martin, it was clear that a government in-house project would never be capable of production," he said.

Woodruff submitted a proposal for a nongasoline-burning outboard motor to the Special Operations Command (SOCOM) in Tampa, Florida, and was awarded a $2.5 million contract to develop a multifuel submersible outboard motor that could burn heavy fuel like JP-5 and JP-8 but also gasoline. "We surveyed all the available


COURTESY RAIDER OUTBOARDS/CHRIS WOODRUFF

Marines carry an inflatable with a 40-hp Raider to a waiting helicopter. This motor had a round handle in the back, which Raider replaced on later models with a square version for better stability when it rests on the ground.

outboards, looking at reliability, supportability, patent information, rights in data, etc. and selected Tohatsu or Nissan as the outboard motor of choice," George recalled. But the NSWC, which managed the process, was not confident in the Tohatsu/Nissan option and requested a new build.

The company signed a contract with the Detroit office of Ricardo Plc, a global strategic engineering and environmental consultancy specializing in transport, energy, and scarce resources, to build a motor within six months that met the military criteria. But the motor, according to Woodruff Sr., was delivered late and did not pass the military's test. The seven-figure sum spent with nothing to show in return forced him to take out a second mortgage.

George, by now joined by his son Chris, focused on the Tohatsu 50-hp two-stroke low-pressure direct-injection outboard as a base for the multi-fuel outboard the military wanted. "We purchased four Tohatsu 50-hp TLDI outboards and began modification," George noted. "After six months we demonstrated and tested the motors at Nellis AFB [near Las Vegas, Nevada]." On the upside, the motors ran on JP-5 and JP-8, they were submersible, they had an electric starter, and Raider had an excellent catalog of spare parts. However, at more than 200 lbs (91 kg), they were too heavy to be carried and too complicated and difficult to maintain in the field with electronics and periodic software updates. Now the Woodruffs had a compliant product, which they got paid for, but one that the customer did not like. Also, Orbital Corporation Ltd of Australia, which made the TLDI fuel injection, demanded a hefty licensing fee.

The Woodruffs took another look at the old IMARS motor, which was refreshingly simple and still well liked by the troops. It was compact and lightweight, had practical features like the shifter on the front, was submersible without a bag, and was easy to repair. "Let's make something for the soldier to do his mission…get home, and forget high technology," George Woodruff recalled. The next phase was dedicated to resurrecting the IMARS idea but with some modern touches. To get around the EPA's emission rules that effectively outlawed the sale of new carbureted two-stroke motors, "Raider received a security exemption from the government that permits the EPA to approve our outboards for military applications," George Woodruff said. "All Raider engines are new and are only sold to the U.S. government, not to the public."

The Tohatsu 40C was well regarded in the consumer market for reliability and performance. Besides, it is, in some respects, similar to the IMARS


DIETER LOIBNER

Semi-retired machinist Maurizio Croppi shows housing parts of the safety jet drive. Raider says this system, while less efficient than props, helps prevent injuries from prop strikes in training, on rescue missions, and around manatees.

motor. Raider had learned from past mistakes and mishaps and developed a product that hit all the right notes, and included the Navy's patented dewatering system, which they had permission to use. All looked good—until the two demo motors blew up within minutes of each other during testing with the U.S. Air Force. "I wanted to crawl under a rock," Chris Woodruff said. "We took the motors back to Titusville and found the problems: a faulty oil injection and an errant metal shard." A week later they got another chance, and both motors "ran flawlessly and passed the test with flying colors," according to Woodruff. The Air Force did not respond to *Professional BoatBuilder*'s requests for comment but must have been sufficiently impressed to place orders for 132 motors for Special Ops and 150 for the Guardian Angels.

The Navy also got in on the act but wanted the 50-hp version, which Raider continued to develop along the same guidelines for simplicity, but also customized for specific applications: The Air Force wanted a battery disconnect and transparent fuel lines, while the Navy asked for an 18″ (45.7cm) fuel attachment extender that makes it easier for SEALs to plug in the fuel line when wearing gloves. "We are now on the second generation of motors that feature better carburation, a new battery case, new mounting brackets, a new head design, an improved fuel system, and better overall performance, which is a result of honest, sometimes withering feedback from the boathouse technicians," Chris Woodruff said. "During testing [with inflatables] we found it was important to place the motors on center [of the transom]. Also, if the

Long-range rescue with a Raider

On July 7 and 8, 2017, the U.S. Air Force's 920th Rescue Wing set out from Patrick Air Force Base near Cape Canaveral, Florida, to pull off a risky and logistically challenging rescue that went beyond the operative range of the U.S. Coast Guard. Its task? Picking up two injured and exhausted German sailors drifting in their life raft on the open ocean, about 500 miles off Florida's east coast. Their Bénéteau sailing yacht had caught fire and sunk. There were 80 airmen involved, 30 hours of combined flight time between two HC-130P/N King fixed-wing aircraft and two HH-60 Pave Hawk helicopters, and eight aerial refuelings. Six Guardian Angels and their gear were deployed by parachute over the accident site, along with one inflatable and one of Raider's motors. The pararescuemen saved the two shipwrecked sailors, one with severe burns on his legs, and transferred them onto a diverted tanker nearby, where they were airlifted to an Orlando hospital. The bravery of the rescuers earned accolades including the 2017 Jolly Green Association Rescue Mission of the Year and the German Search and Rescue Service's Medal of Honor.

—Dieter Loibner

jackscrews got loose when going into a sharp turn, you might lose your motor. As a result, Raider and the Air Force came up with a new transom plate [that] centers the motor and provides a lip that [secures] the motor when entering a sharp turn."

And sometimes necessity is the mother of invention. "Selling outboards to the Marine Corps proved to be an issue," said George Woodruff, who told the story of the Safety Jet. "The U.S. Marines use a pump jet on their motors to provide safety to the soldiers. They do not run open propellers. We went to

COURTESY NORDEN NIGHTINGALE

A Guardian Angel of the 920th Rescue Wing climbs a Jacob's ladder to the deck of a tanker diverted to the rescue site. The inflatable with a Raider outboard used in the operation was deployed by parachute.

the maker of these pump jets to have them build one for the Tohatsu. They declined, [so we] decided to develop our own. We did not like the existing design, which required modifications to the lower unit. And if damaged, it had to be sent back to the manufacturer."

The more than two years it took the company to ready the Safety Jet for prime time were well spent, as the product filled an important niche. The military acquired 100 Safety Jets for the Raider 40-hp motor, while the one for the 50-hp model, with an improved impeller design, is expected in 2019. Eventually, these drives will fit a wide range of different outboards, and Raider has plans to make them commercially available in 2020.

New products in the pipeline

While basic technology is the heart of its motors, Raider is investing in modern development tools. In addition to a 3D printer for rapid prototyping, during my visit Chris Woodruff was in the final stages of researching 3D scanners for product design, customization, and reverse engineering. "This could have saved me months during the development of our motors," he said after a demonstration by TriMech—a firm specializing in 3D design and

Above—*TriMech technician Keith Taylor demonstrates an Artec Eva 3D scanner on one of Raider's engine cowlings. Woodruff, convinced it was a time saver, procured a more advanced model.* ***Right***—*This is a prototype of the electric submersible outboard with safety jet drive that Raider won a contract to develop. The company also hopes to break into the commercial search-and-rescue market.*

DIETER LOIBNER (BOTH)

prototyping tools—of an Artec Leo 3D Scanner. "I like to [use it to] scan the lower units, which will help with development of the Safety Jet drives."

Raider recently received a $250,000 contract to develop a submersible electric outboard, a sturdy unit that will have to match the fossil-fuel models in performance and reliability and that someday might become available for the commercial market; and a $100,000 contract for a patented hard-deck roll-up inflatable, to be built in Massachusetts by Inflatable Boat Racing, that will have space to safely stow the batteries without having to carry large waterproof Pelican boxes.

Woodruff Sr. seems happy with the underdog status of Raider Outboards Inc., which must compete with much larger outfits when selling motors and accessories either to the military or in the commercial market. "We have a good record, because we don't squander money," he noted. He's a bit more philosophical about his own involvement—including applying for government grants and contracts that have funded much of Raider's business to date—which has kept him busy and vital. "I am 75. I still get excited. I had a knee replaced. I don't fish anymore. I don't hunt anymore, and I'm a lazy golfer. What else am I going to do? If you don't do a job that you like, you probably won't like what you're doing."

Next time the HSBO Forum rolls around in Gothenburg, the Woodruffs might not just crash the high-speed party with a tiller-steered two-stroke outboard that's submersible and thrives on a 50:50-mix of diesel and gasoline if it has to. They might bring their own boat, too. PBB

About the Author: *Dieter Loibner is an editor-at-large of* Professional BoatBuilder.

PBB Resources

Artec Leo 3D Scanner: artec3d.com/portable-3d-scanners/artec-leo

Bombardier Inc.: us.bombardier.com/us/home.htm

Donzi Marine: donzimarine.com

Evinrude: evinrude.com

Fusion3: fusion3design.com

High Speed Boat Operators Forum: hsbo.org

Orbital Corporation: orbitaluav.com/about-us/our-business

Pulstar spark plugs: pulstar.com/

Raider Outboards: raiderout boards.com

Raise3D N2 printers: raise3d.com

Tohatsu outboards: tohatsu.com/outboards/index.html

TriMech 3D design and prototyping: trimech.com/about

ZipperMast: zippermast.com

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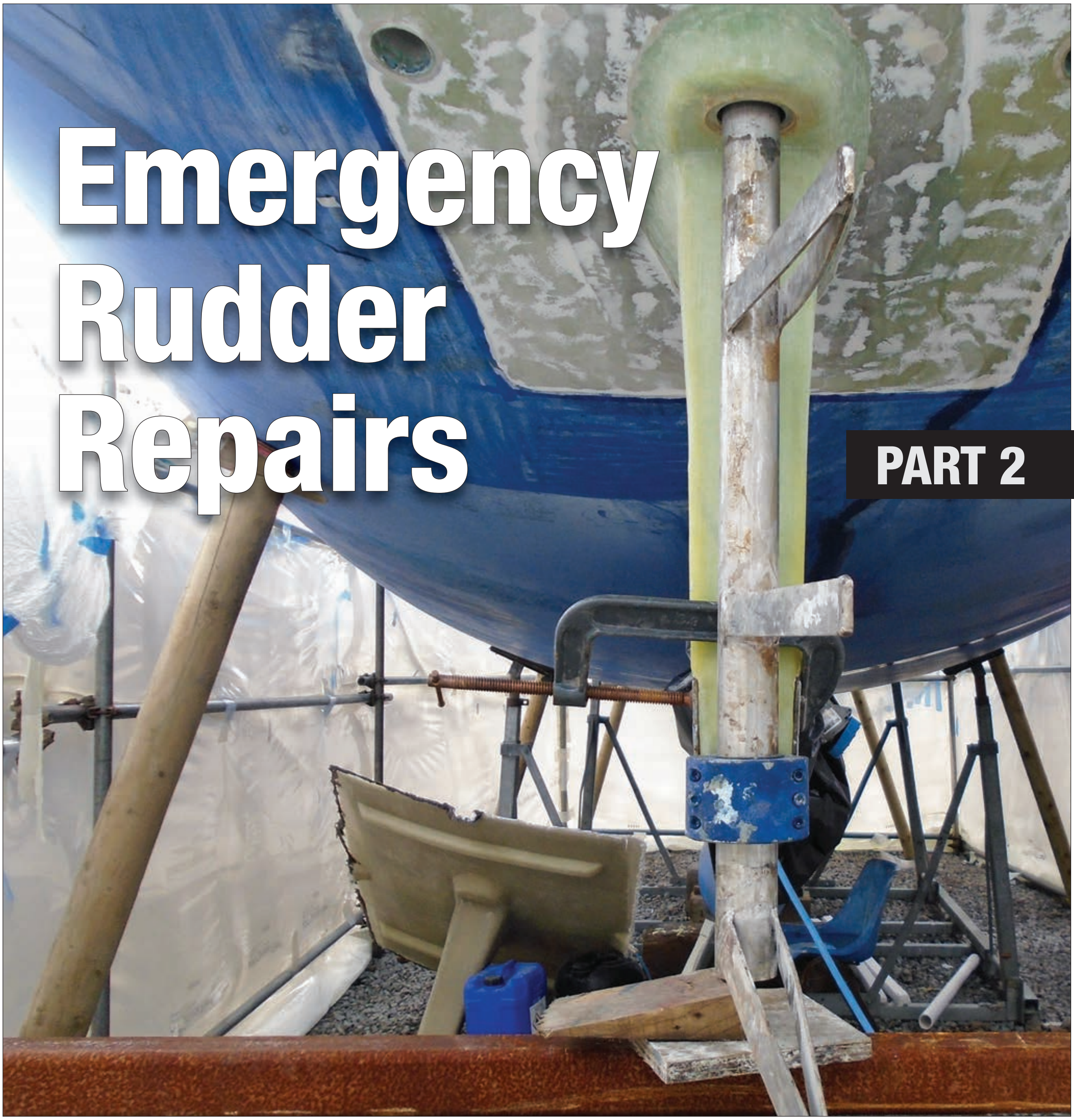


COURTESY FALMOUTH BOAT COMPANY (FBC)

Emergency Rudder Repairs

PART 2

After the initial structural repairs to a damaged hull and rudder failed, a second yard put it right with a more extensive fix.

by Nigel Calder

*In Part 1 (*Professional BoatBuilder *No. 177) the author described how the rudder and skeg on his Malö 46 sailboat,* Nada, *were seriously damaged on a sandbar at the mouth of the Minho, a river on Portugal's northern border with Spain, and the technical details of subsequent repairs carried out at a Spanish boatyard. Sadly, the damage was more extensive than first thought.* —Ed.

A couple of weeks after completing the repairs in Spain and putting *Nada* back in the water, my wife Terrie and I, together with a crew recruited for the passage, sailed *Nada* across the Bay of Biscay to northern France. What started as a quiet motorsail in light winds and calm water ended in 30-knot winds, gusting to 40, with rough seas and considerable rudder loads. *Nada* began taking on water, bubbling up through the base of a limber hole close to the rudder tube repair area. Just as before, the rate of inflow was easily controlled. I thought it was a seal leak around the base of the rudder tube, which would mean we had no serious structural problems. However, I was reluctant to attempt repairs in another country where we could not speak the language.

While the gale blew itself out, we holed up in a marina in France and then motorsailed in light winds and seas toward Falmouth in the United Kingdom. I e-mailed Simon Firth, the claims adjuster with our insurance company, Pantaenius, with the bad news and my detailed thoughts on potential causes.

He replied: "This is a disappointing turn of events, especially after a sea trial. Ordinarily insurers would expect you to go back to the repairer to see how they missed this crack or hole that has caused the ingress—would this be a possibility? If not, you will need to obtain another estimate for repair and forward this to me for insurer's consideration, but the first route of recourse is against the repairer."

We were not in a position to sail back across the Bay of Biscay to Spain, so I let Firth know we were headed to Falmouth. He contacted a local surveyor, David Cox, who showed up as soon as we arrived, and had us hauled out by the Falmouth Boat Company (FBC) before the end of the day. The minute the bottom of the hull emerged from the water, we could see the problem: the antifouling paint, only two weeks old, was missing at the junction of the skeg with the hull. My optimistic theories about the leak were completely wrong, and we could flex the skeg and rudder from side to side by hand, with water dribbling out of cracks that opened up around the skeg.

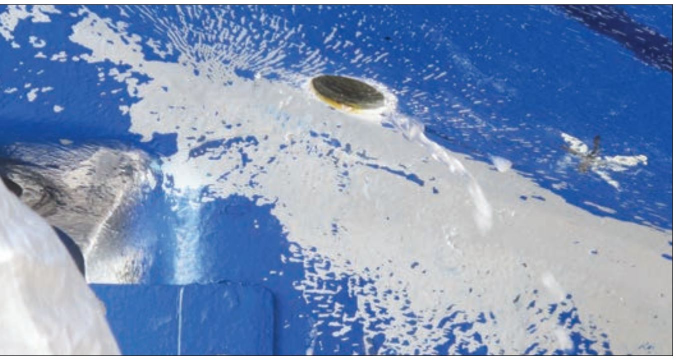
What had gone wrong with the Spanish repair job?

Although he could not detect it by tapping with a hammer, Cox suspected delamination deep within the hull layup. If correct, RoNautica, the Spanish repairers, had not cut back deep enough into the hull, either internally or externally, to reveal the delamination. As a result, the repairs likely failed to reestablish the bond between the hull skin, of which the skeg is an integral part, and the skin inboard of

NIGEL CALDER

Facing page—*In the second attempt at repairing damage from a 2018 grounding, a replacement composite skeg and hull section have been laminated into place on the author's Malö 46 sailboat,* Nada. *The skeleton of the rudder has been temporarily installed to establish alignment of the rudder tube inside the hull.* ***Right***—*On the ladder, David Cox, the surveyor, makes a preliminary assessment of the damage while the author's brother, Chris Calder, flexes the rudder and skeg, visibly relieved to be safely ashore.*

NIGEL CALDER (ALL)



Above left—*The initial core samples indicated substantial delamination deep within the hull structure.* ***Left***—*Several days after the haulout, water was still dribbling out of the hull laminate where a core sample was cut out.* ***Above***—*Cox chiseled some fairing compound out of the hull-to-keel joint. This revealed water penetration.*

the skeg, to which the rudder tube and support structure attached. Under load, the skeg had been flexing independently of the inner rudder tube structure, gaining little or no support from it. This would explain the cracks in RoNautica's new hull laminate.

Pantaenius notified us that they would pay for the new repair but would deduct from it the cost of the failed repair, and it would be up to us to chase RoNautica for damages. The failure, from my perspective, was *not* due to RoNautica, which had faithfully executed the repair that had been deemed necessary by Pantaenius's surveyor. The problem was the surveyor's failure to determine the extent of the damage and to identify the necessary repairs. The surveyor had made his second visit after the rudder and debris around the rudder tube had been removed, and at no time specified further action to investigate the bond between the inner skin and the hull skin/skeg.

Cox and FBC took core samples at four different points around the skeg. Even though *Nada* had been out of the water for several days, water dribbled out of the laminate when the holes were cut. All four samples revealed substantial delamination within and between the hull and inner skins. They decided this was not repairable—the skeg and the hull area around it would have to be cut out and rebuilt.

Jonathan Fielding, owner of FBC, and Cox now also took a close look at the hull-to-keel joint. Fielding was convinced there were signs of keel movement. Cox chiseled out the fairing material between the keel and hull in several places, revealing some water. Fielding believed the keel needed to come off and be rebedded. Cox was not so sure. I was of two minds: wanting to be absolutely sure that all problems would be fixed, and *not* wanting the keel to be removed unless it was absolutely necessary.

Back in 2008, when *Nada* was first launched, we enjoyed a summer of sailing among the hundreds of small islands off the west coast of Sweden and then laid her up ashore for the winter. Immediately after we launched the following year, we had a substantial leak. The yard determined that when the boat was built, the keel had not been properly bedded, and expansion from the freeze-thaw cycles over the winter had opened up a water path into the boat. The keel had to come off to be rebedded, but to do this the rig had to come down; the saloon had to be partially disassembled; fiberglass beams supporting the cabin sole had to be cut out; and a water tank had to be removed to provide access to the keelbolts. Some of the bolts were under a second aft water tank under the galley. Malö had succeeded in getting the nuts off the bolts by reaching under the tank. The keel was removed and rebedded, which fixed the leak.

After additional discussions between Cox, Firth, Fielding, and me, Cox recommended we take out the forward water tank to look for signs of damage to the hull laminate in the area of the keelbolts, or damage to the seal around the bolts. If this looked okay, he proposed Falmouth Boat Company could repair the exterior fairing around the hull-to-keel joint. Assuming the hull and joint were okay, this would minimize the repair cost, though the estimate was already several times higher than the cost of

NIGEL CALDER

COURTESY FBC

Above—*A mold was laid up over the original hull and skeg before these were cut out. Note the registering lugs on the hull (left and right sides of the photo) so the new part can be accurately relocated later.* ***Right—****The mold has been pulled off the hull. Next, the new skeg will be vacuum-bagged inside it, and the old skeg and surrounding hull cut away.*

the failed Spanish repair. We chose this course of action.

Pantaenius seemed to have accepted that the Spanish repair failure was the responsibility of the first surveyor; there was no more discussion of deducting the cost of that repair from what the insurer would pay for the new repair, and Firth immediately offered to pay 50% of the new repair estimate.

Fielding put together an extremely detailed estimate, with each task itemized and given a budget. He set up an Internet-based tracking system with regular photographic updates so I could follow progress from home in the United States.

The Falmouth Boat Company got to work, and in contrast to RoNautica's job in Spain, erected scaffolding and staging, built a work platform at toerail height, removed our equipment and supplies and placed them in storage, and sealed off the work areas.

I obtained the specifications for the original hull laminate from Malö. FBC coated the exterior of the hull and skeg with mold-release agent and laminated a mold over it with locating lugs on the hull so the mold could be accurately registered in place later on. The mold was popped off and a new skeg laid up and vacuum-bagged inside it, using Malö's laminate schedule and specified epoxy resins. Meantime, the boat's interior around the rudder tube and skeg area was disassembled. This required removing hoses, the steering system, the hot-water tank, and numerous cables and other fittings. The bonded-in cockpit drains were cut out and a couple of major bulkheads and some interior structures cut back.

My optimistic theories about the leak were completely wrong, and we could flex the skeg and rudder from side to side by hand, with water dribbling out of cracks that opened up around the skeg.

The weakened skeg and the surrounding hull area were also removed, revealing additional delamination where an 8″ (203mm) plastic cable tie could be fully inserted between the layers. Consequently, the aft starboard cabin had to be disassembled in order to remove the fuel tank and provide access to the damaged hull. *Nada* has a cored hull above the waterline, with a single skin below. The additional delamination, which now had to be cut away to fair in the new hull and skeg section, took the repair job into the cored topsides and way over the projected budget.

Meantime the saloon was partially disassembled, the cabin sole support beams cut out, and the forward water tank extracted to expose most of the keelbolts. To inspect the few bolts under the aft water tank below the galley, FBC cut away the lower half of a structural fiberglass beam between the forward and aft tanks. Cox e-mailed me:

"The keel trough has been opened. This was done by cutting out the floor midway down it, which was evidently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A significant amount of cabinetry was disassembled so the fuel tank could be removed from the aft starboard cabin for access to repair the enlarged area of hull delamination that was detected.

done when you had the initial leak problem when *Nada* was new. What I find very hard to understand, however, is how it would have been possible to undo and reaffix the nuts on the aft studs in the very limited space that is available at the aft end of the keel without dismantling the tankage further aft. From what I can see, it looks as if the studs further forward, which could be reached, have had their nuts undone and lagged in sealant only, and I wonder whether this was the way that they solved the leak rather than totally remove the keel.

"All looks as it should be at the aft end of the keel trough.… I cannot categorically say that there will not be a leak, but if one looks at probabilities, I would be 99% sure that all will be OK.… To remove the keel…would in my opinion add an enormous amount to the cost of this claim, and also the yacht would be out of action for a significant period while the fit-out was removed and reinstated. One has to ask the question: Is this worth doing for such a small chance of there being a leak?"

I contacted Ulf Mattsson, the former general manager at Malö, and confirmed that the keel had been removed and rebedded in 2009. He wrote: "I remember they managed to free all the keelbolts without removing the water tank, don't ask me how, but there might be enough space to work on them." I forwarded Mattsson's phone number to Cox in case he wanted to follow up with more detail.

I then e-mailed Firth at Pantaenius: "Unless it is absolutely necessary, I am not at all keen to see the keel come off, as I know how disruptive this would be. Cox's current assessment is that he is almost 100% certain we will not experience leaks. I am happy to go with his judgment on this so long as there is some understanding that if it turns out this is incorrect (e.g., we have a keel leak when we relaunch), insurers will accept the responsibility for fixing the problem."

Firth responded: "The further costs have come as something of a surprise, but following a conversation with Cox, I understand why they have escalated. I am pleased to hear that the extent of the delamination has been found. Insurers agree to the keel proposal." The keel stayed on.

COURTESY FBC (BOTH)

A view aft under the aft water tank shows the keelbolts, which are extremely difficult to reach. Had it been decided to remove the keel, it might have been necessary to remove the water tank, requiring disassembly of much of the galley.

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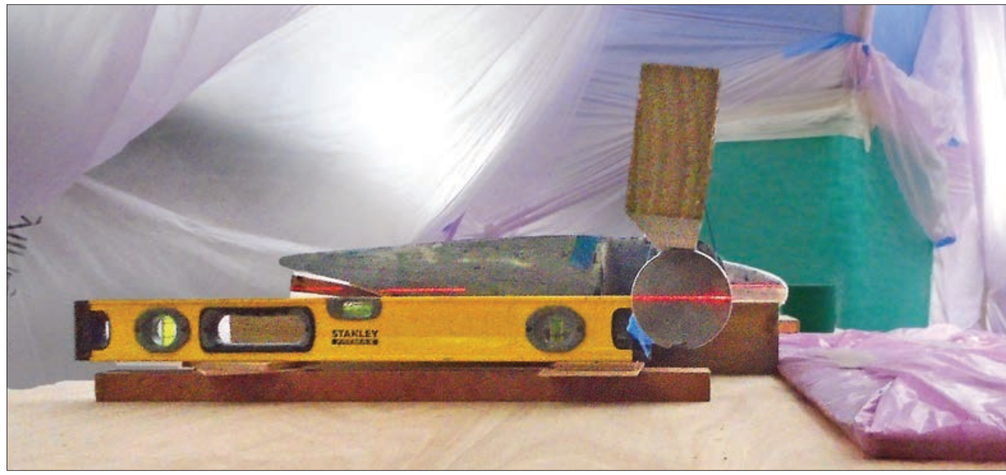
The Falmouth Boat Company turned their attention to the rudder. It had been extensively rebuilt during the Spanish repair but without correcting a significant bend, which resulted in substantial steering loads when under power. Fielding wrote: “Having now been able to fully assess and measure the rudder, it is in an awful state regarding the profile.… Can we discuss this when you have a moment to call, as I am thinking we ought to simply make another blade and solve the problem once and for all.”

To Cox he wrote: “In regard to the way forward, we have expended 31 hrs to date removing, stripping, investigating, mapping and planing the blade all round, and I propose to spend a further four hours now opening up the blade to find out its content’s condition and construction. Our original estimate was for 48 hrs to straighten the rudder to best advantage with the use of laminate and fillers; however, having now established the actual profile and discussed this with the owner, this is not acceptable. Therefore, subject to what we find today, we have two options:

“**1.** Cut the remnants of the rudder back to as square a section as it will allow, and apply a foam foil section to either side, laminated, vacuum consolidated and then filled back to profile, incorporating the additional weight we had imagined we would install.



A laser beam was one of various tools used to assess the extent of rudder warping. It was decided that the warp could not be corrected through fairing, and the rudder was rebuilt.

“**2.** Make up a new rudder blade on the current stock and tang arrangement

a. fully in ply

b. fully in ply with a break joint at ⅔ from the top

c. ⅔ in ply with a break joint at the bottom and then a foam sacrificial section

“Option 1 would be quicker than option 2 but entirely reliant upon the condition and construction of what we find today. In the event this is not feasible, I believe option 2c would be the best for a new unit. I will confirm a final estimate and cost on completion of our findings.”

Fielding sent estimates for all the options, which I forwarded to Firth. After significant back and forth, we decided to proceed with refairing the rudder. Fielding e-mailed: “Unless I misinterpreted your email, we are heading for option 1.… All seems good inside, just the wrong shape!”

At this point, there was a glitch with posting photos to the repair website, and I was tied up for almost a month and not tracking progress. The next time I logged in I discovered the rudder had been completely disassembled down to the stainless-steel rudderstock, even to the point of replacing the internal webs, and then entirely rebuilt. I contacted Fielding and was

Left—*The rudder was stripped down to its stock and internal webs.*
Below—*After other repair strategies were considered, a new rudder was constructed on the original stock.*

COURTESY FBC (ALL)

COURTESY FBC (ALL)

Left—*All damaged areas of the hull have been removed and the hull extensively faired back inside* Nada. *The mold, with the new skeg inside it, has been lifted into place and accurately aligned using the locating lugs. The new skeg is being laminated into the hull, and the hull rebuilt with multiple layers of vacuum-bagged material.*
Above—*Carbon is added inside* Nada *to strengthen the attachment of the new skeg.*

informed: "We started with option 1 and when commencing, found that the blade would not have enough 'meat' to it to make it a viable repair. In conjunction with David [Cox], we agreed on option 2c, and this is now close to completion."

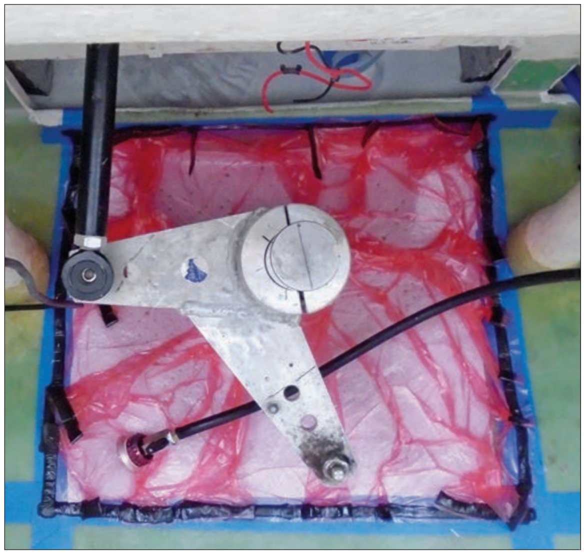
By now, FBC crews had cut out and feathered back the hull around the skeg to the limit of the delamination. The new skeg inside its mold was lifted and accurately registered in place with the lugs previously added to the hull. They vacuum-bagged the skeg in place with multiple layers of laminate based on Malö's original hull specifications, adding some carbon reinforcement down into the skeg and around the curvature at the top and onto the hull laminate. The skeg was filled and laminated over. The areas of core that had been cut away were restored and the inner skin vacuum-bagged into place.

A hole was cut for the rudder shaft and the rudder lifted into place and supported with the bearing at the lower end of the skeg. The rudder tube and bearing were slid onto the shaft from above and bonded into place with substantial rudder tube reinforcement. This time the rudder could be turned with the tip of a finger.

Removal of the mold revealed the new skeg laminated in place.

Next, the crew reassembled the interior, restoring the cutaway sections of bulkhead, replacing the fuel tank under the aft starboard cabin and the water tank in the saloon, repairing the cabin-sole-support structures that had to be cut away for access, reinstalling the various pieces of cabinetry, and replacing the cabin sole itself.

The quadrant, drag link, and autopilot were bolted back in place. James Taylor, the electrician, reconnected the multiple cables running through the aft end of the boat that had been disconnected to clear the area for the repairs. The engine exhaust and other hoses went back in.



The steering system's tiller arm and drag link have been temporarily replaced to check rudder alignment. Beneath them a vacuum bag covers the final layers of rudder tube reinforcement.

COURTESY FBC

Two months later than anticipated and 100% over budget because of the considerably greater area of delaminated hull than had been detected, the repair was complete. Terrie and I flew into the U.K. to inspect the work and do sea trials, which went perfectly. We had our *Nada* back.

It had been a long haul, but in retrospect we had been extremely lucky. Sooner or later, the Spanish repair job would have failed. Had the near gale in the Bay of Biscay not cracked the hull-to-skeg joint when it did, the failure might have occurred in worse conditions farther offshore, resulting in the loss of *Nada* and even loss of our lives. David Cox, the U.K. surveyor hired by Pantaenius, was extremely thorough; Simon Firth and Pantaenius, the insurers, very fair; and above all, Jonathan Fielding's Falmouth Boat Company turned out to be an excellent yard with a wide range of talented workers able to assess the extent of damages and fashion appropriate repairs. Thanks to them, *Nada* is once again good to go.

Not so easily repaired will be Terrie's confidence in my navigational abilities.

***About the Author:** A contributing editor of* Professional BoatBuilder, *Nigel Calder is the author of* Boatowner's Mechanical and Electrical Manual *and other marine titles (including, earlier in his career,* Marine Diesel Engines*), and is a member of the American Boat & Yacht Council's Electrical Project Committee.*

Black Plastic Boats

Dutch builder Tideman Boats had to define material-appropriate scantlings and build protocols before starting production of high-density-polyethylene workboats.

Text and photographs by Aaron Porter
(except where noted)

High-density polyethylene (HDPE) has been a staple of modern boatbuilding since the 1980s, largely for original components and aftermarket parts, especially on small recreational boats. The replacement of increasingly expensive and hard-to-source teak with solid, durable plastic for cabinetry, consoles, grabrails, and trim has driven the success of companies like HDPE-sheet-supplier King Plastic Corp. (see Rovings, *Professional BoatBuilder* No. 175) and innovative marine component manufacturer Teak Isle Manufacturing Inc. The chemically inert material has also become a favorite for custom and production fuel, water, and wastewater tanks. But its low modulus, high weight, and thermal expansion coefficient made building hulls and decks from HDPE a challenge. Successful small boats were created in rotomolded polyethylene (see "Tri and Tri Again," in PBB No. 135), and for models designed to accommodate the inherent lack of stiffness in both the high- and low-density formulations of the material, it offered efficient mass production. But the boats always flexed and softened perceptibly in high temperatures. Owners of some early lower-density polyethylene kayaks played the properties to their advantage, folding the boats in half through the section to fit them in small bush planes for delivery to remote waters. Keeping them from folding up again while afloat became the challenge.

In the 1990s there were a few attempts to build slightly larger boats in welded HDPE. I encountered one such custom-built center-console being used as a harbormaster's utility boat in 2000. The boat's slick white-plastic topsides were scarred and cracked, and every transverse frame was clearly visible, as the firm ribs supporting the otherwise wobbly topsides had the hungry-horse look of an old and hard-used metal hull. The plastic welds joining the developable surfaces of the hull were uneven and had cracked in places at the vulnerable deck edge. On the strength of that experience, I categorically dismissed the idea of using HDPE sheet goods to build boats.

Enter Bruno Tideman. I first learned about the Dutch entrepreneur in June, 2018 when PBB editor-at-large Dieter Loibner reported back from the 9th High Speed Boat Operations (HSBO) Forum in Gothenburg, Sweden. Among the many small craft specially tailored for military, agency, and commercial tasks available for testing at the conference, Tideman Boats snagged Loibner's attention with its practical model of workboat built in the unlikely HDPE. It helped that when Tideman performed his standard demonstration of durability—slamming a long-handled 5-lb (2.3-kg) maul into the narrow side deck with all his strength—neither dents nor cracks appeared, only a scuff mark on the black HDPE. He had my attention even from the other side of the North Atlantic.

HDPE Afloat

I met Bruno Tideman and his boats in November 2018 when he picked me up from the pier behind Central Station in Amsterdam in an 8.7m (28.5′) T-top model powered by a single OXE diesel outboard (see page 11 of this issue). My skepticism was waning even as I watched Tideman approach. While the straight-sheered monochrome black hull wasn't about to win the Concours d'Élégance at a superyacht show, it suffered from none of the aesthetic failings of the welded-HDPE boat I'd seen before. He nosed the small flat-fendered section of the prow into the pier, I stepped easily on board, and we were off.

DIETER LOIBNER

Facing page—*A bulky extrusion welder and a steady hand are essential for assembling Tideman Boats' high-density-polyethylene (HDPE) hulls in Opmeer, The Netherlands.* ***Above***—*Bruno Tideman demonstrates the durability of his boats with a long-handled maul that, when swung against the narrow side deck with all his strength, leaves only a scuff.*

Straight sided and available only in black, Tideman boats are aimed at the workboat market and make no pretense of yacht finish. They are recyclable at end of life.

The boat was nimble but stable in the confusion of wakes, chop, and brisk wind on the river IJ. Tideman showed me what the boat was capable of as he explained the characteristics of the material. With ample warning, he demonstrated his flair for the dramatic and the boat's durability and low coefficient of friction by running the bow on a rocky shore at a slow-but-deliberate speed, holding it there as though we were unloading crew on the island, and then backing off smartly. The boat accomplished this without complaint—none of the loud bangs, scrapes, or cracking sounds you'd expect from a stiffer metal or composite hull. It reminded me that a layer of HDPE is often added to the hulls of other boats that make frequent rough landings or run in particularly shoal waters.

I had been concerned that a strong, serviceable boat in HDPE would be unworkably heavy, but at 2,200 kg (4,850 lbs), our test boat was amply powered by the single 150-hp OXE, responding promptly to throttle and helm. With generous chine flats, her moderate-deadrise V-bottom hull planes easily, and thanks to the dampening properties of the HDPE, runs quietly compared to boats of higher-modulus hull materials.

After we tied up at Tideman's dock in North Amsterdam, I had a chance to go over the boat carefully with the builder on hand to explain some of the peculiarities of HDPE construction I was seeing. One primary limitation of HDPE is largely aesthetic. Because of its low coefficient of friction, the material won't hold paint, Tideman said, so to resist degradation from the sun's ultraviolet rays, it must contain carbon black (other colors are available but aren't UV resistant). That's why Tideman boats, like the early Model T Fords, come in black or black. This could be a problem in the yacht market, but Tideman insisted, "We don't sell to leisure customers. It's only professional use." That statement is mostly true.

High-density polyethylene's incompatibility with paint also means it is resistant to the marine growth that makes antifouling paint a necessity on conventional hull materials. Tideman explained that HDPE is simply too difficult for marine organisms to effectively adhere to, especially if a boat is driven at speed with any regularity. He confirmed my worry that the same material would be challenging to walk on, especially in wet conditions. His solution, which I got to test thanks to some cooperative rain, is to cover the deck surfaces with strips of adhesive nonskid material, easily replaced when it gets old or damaged.

It's tempting to consider building the upper surfaces of the boat from a

Among the complex, sturdy HDPE structures skilled welders assemble is this transom transition detail that includes an attachment point for lifting the boat. The slippery HDPE deck surface is fitted with nonskid strips for safety.

__Left—__This HDPE boat in build reveals the welded grid of longitudinal and transverse frames that fill the space between the cockpit sole and the moderate deadrise V-bottom.
__Below—__Hardware is attached to the HDPE deck with ample fasteners.

skid-resistant material, but another peculiarity of HDPE makes that solution impractical. Tideman explained that the plastic's thermal expansion of as much as 1% makes joining it to other materials challenging. For these boats, homogeneity is a virtue. Tideman said many are sold as service fleets for oil companies in the tropics. When they make the change from Dutch winter to African summer, they grow by as much as 9cm (3.5″) in length, but because the HDPE sheet and weld material are exactly the same, they expand and contract at the same rate—nothing to worry about unless you've tightly bolted on something that expands and contracts at a different rate, stressing the component or the HDPE. Tideman explained that the variation in thermal expansion makes shaft-driven propulsion impractical, because the full drivetrain and shaft bearing would have to be mounted to a rigid metal structure bolted into the hull.

Our test boat had no through-hull fittings, and the aluminum cleats, center-console, and outboard were attached to the HDPE structure with large-headed bolts and generously wide washers to accommodate the plastic's expansion and contraction. It's no surprise that the mounting hardware and support structure of inboard engines and hull penetrations for the jet drives in the larger models were the only proprietary details Tideman asked that we not photograph or discuss.

The HDPE Fabrication Shop

Tideman Boats isn't housed in a stand-alone facility. To see how the boats are made, I drove first with Tideman to the town of Opmeer, where a tidy industrial manufacturing facility specializes in welding HDPE water tanks and pipes, and now boats.

In build, you can see the grid of welded transverse and longitudinal structural frames essential to support a running surface built in this pliable low-modulus material. While structurally familiar, the scantlings are obviously different than those of metal or FRP boats. The floor frames are tall, the full height of the bilge from the bottom panels to the cockpit sole or work deck, which is welded to them. The result is a closed, rigid-bilge structure that simultaneously supports the V-bottom and the sole. Tideman showed me how before the sole is welded in place, the bilge voids are filled with polyethylene balls, which provide 700 kg of buoyancy per m^3 (43.7 lb/cu ft) and will not retain water like some flotation foams. "Even when the whole hull is filled with

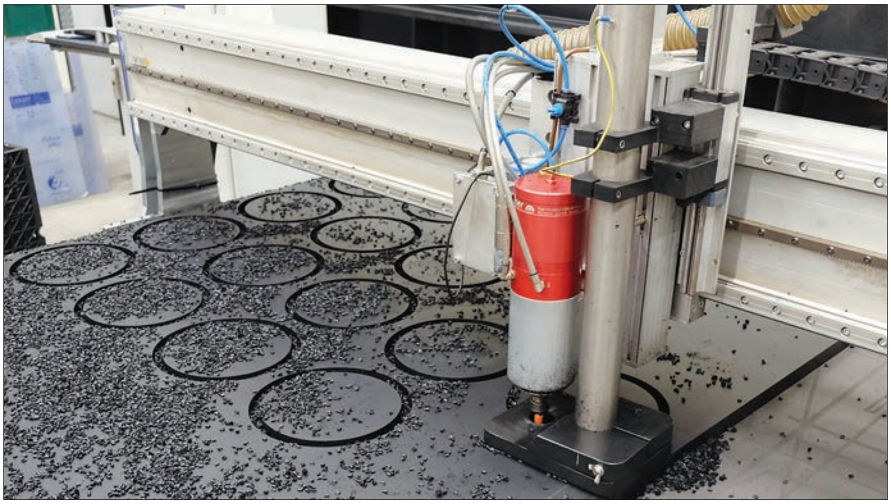
The electric-powered extrusion welder delivers heat and a bead of melted HDPE to join two pieces cut from stock plastic sheet.

water, she will stay afloat," Tideman said. It helps that the HDPE itself is buoyant.

To fuse HPDE parts, extrusion welders heat the surfaces with cumbersome-yet-sophisticated heat guns and deliver a thin bead of melted HDPE into the gap. To join the 1.5cm and 2cm (0.59″/0.79″) stock material, two-sided welds ensure that they are sound. Unlike metal welding, the only check possible for weld quality in HDPE is visual, so process controls and welder certification are important in this shop.

Tideman: "All the welds below the waterline need to be continuous welds—no start-stop—so these guns sometimes go one hour or more." Not surprisingly the welding crew, all tested and re-certified annually, are steady-handed, focused, and patient—the quality assurance for these boats.

Another complication of assembling the boats is the size of the welding guns, which are fine for fabricating large round tanks but can be difficult to work into tight spaces like the many corners of the bilge grid. For some of the CNC-cut elements that would be inaccessible from below, the solution is to strategically join them before dropping the grid into the hull. Order



Above—*All HDPE parts are precision cut on a CNC router.* ***Right—****Tideman demonstrates the cutouts for handholds and lashing points in the narrow side decks fresh from the CNC cutter.*

of operations is important, and the fabricators' experience and skill are essential in creating and then following procedures for building each boat.

The shop is very clean, in large part because contamination of the HDPE with dust, humidity, or other foreign material can compromise weld quality. Tideman explained that welds can also be influenced by the quality/purity of the HDPE used. While he's testing the strength and durability of stock with

Class 5 Boatworks

Jerry Fleishman stopped at the ProBoat booth at last year's IBEX to make the case for welded high-density-polyethylene (HDPE) boats—robustness, low maintenance, and flexibility.

Fleishman heads Class 5 Boatworks (Fairbanks, Alaska), in the market since 2014 and backed by the experience of the Lifewater Engineering Company, which manufactures thermoplastic tanks for industrial applications in arctic and subarctic climates. In 2005, Fleishman and company founder Bob Tsigonis started out by designing and fabricating aboveground wastewater-treatment systems and custom tanks for diverse customers in research and commerce, including the Large Animal Research Station at the University of Alaska Fairbanks, and the Alyeska Pipeline Service Company. In 2014, they decided to apply their expertise not only to "systems that hold water in but also to boats that have to keep water out," Fleishman said.

They started their line of Rough Duty Boats for research, fishing, hunting, and river-running. It's a well-chosen name, too, because these vessels must withstand real-world use on rivers and lakes in and around Alaska, often in subfreezing temperatures. Like Tideman in The Netherlands, Class 5 Boatworks bets on its expertise in welding thermoplastic sheets to withstand extreme impacts and extreme temperatures, albeit on the cold end of the spectrum.

The 14' (4.27m) DragonFly jet boat from Class 5 Boatworks in Alaska is powered by a Rotax jet engine.

COURTESY CLASS 5 BOATWORKS

Thus far, the Alaskans offer the 14′ (4.27m) DragonFly mini jet boat, with a 5.75′ (1.75m) beam, 10° of hull deadrise, and a 150-hp to 250-hp four-stroke Rotax jet engine. That punch is the point of this craft, since "it's all about the hole shot," Fleishman explained. A bit larger and more docile is their Kobuk utility/workboat, whose 8′ (2.4m) beam provides good stability. The hull is built in lengths from 18′ to 24′ (5.5m to 7.32m), depending on purpose, with an open or closed bow, center or side console, various cabin options, and either a 250-hp to 400-hp inboard engine or 250-hp outboard. Class 5 is working to expand its utility line with two new models featuring hulls with reverse chines—the versatile 16′ to 24′ Anvik for outboard engines, and the 18′ (5.5m) Stikine for inboard jet drives and shallow-water operation.

Quality, Fleishman stated, starts with the design, which includes finite element analysis and 3D modeling of scantlings in Solidworks. "We do our own calculations of forces and work with structural engineers to design the boat around them," he explained. Class 5 Boatworks also retained the services of the naval architects at Ocean5, based in Stuart, Florida, to review hullforms and hydrostatics. The company's future plans include emphasizing custom products such as a 38′ (11.6m) landing craft for a children's camp in Alaska, and introducing its boats to markets in the lower 48 by attending West Coast trade shows in 2020.

—Dieter Loibner

some recycled content, for now he uses only virgin HDPE from a single German supplier who delivers consistent quality and material properties. At the end of their useful service lives, Tideman Boats can be completely recycled.

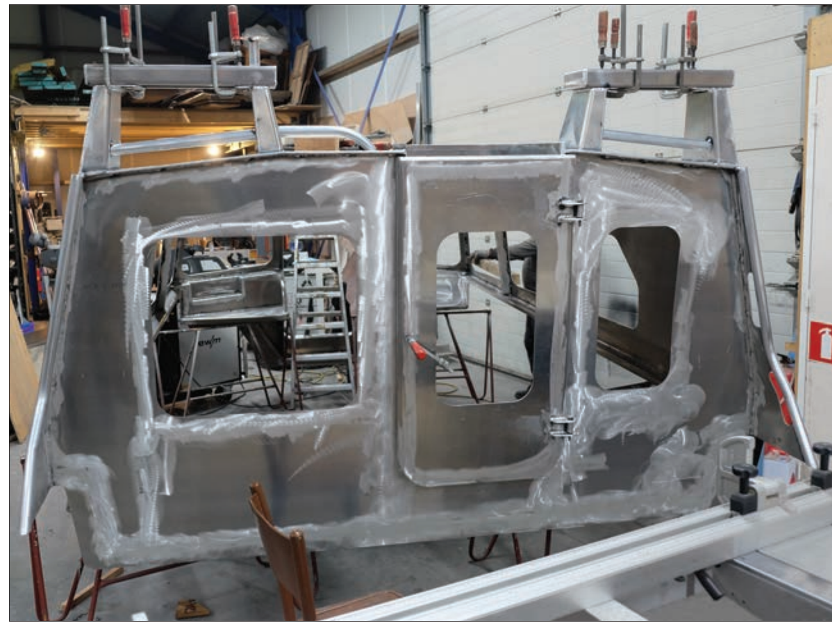
Dick Gilles Jachtbouw

The "dirty" work of fitting the boats with engines, aluminum structures like consoles and cabins, and other onboard systems is done at Dick Gilles Jachtbouw in nearby Middenmeer. "When Dick and I are happy about a hull, it comes here," Tideman said as we pulled into the yard. Gilles and his crew of four had devoted more than half their shop to Tideman projects on the day we visited, but that varies depending on orders in the pipeline.

According to Tideman, his company can deliver about 30 boats a year—with a construction time of eight weeks for the smaller ones and 16 weeks for the larger, more complex models with enclosed cabins. He offers 26 standard designs as large as 12m (39.4′) and, to meet client needs, can accommodate variations in layout but not in overall hullform. Gilles said he orders the components he'll need to finish a boat when Tideman and the client have agreed to the details and the crew in Opmeer starts on the hull. By the time the hull arrives in Middenmeer, so have the engines, other off-the-shelf components, and raw aluminum for a console or cabin.

As simple as Tideman tries to keep his boats, some of the non-HDPE structures Gilles must build are complicated. In the shop during our visit, the RB 1100 jet-drive-powered pilot boat for Antwerp occupied all Gilles's crew, who were installing nearly 700 hp of Yanmar diesels wedded to Finnish-built Alamarin jet drives and building the aluminum pilothouse. Essentially, Gilles's skilled crew of boatbuilders are turning a bare HDPE hull into a functional boat.

An accomplished metal builder himself, Gilles has come to see how similar construction in HDPE is to



Left—*Rigging and fitting of all onboard systems and custom superstructures are performed by Dick Gilles Jachtbouw, in Middenmeer. Here, technicians ready one of two Yanmar diesels for installation in a 10.7m (35.1') jet-drive pilot boat for a client in Antwerp.*
Above—*The enclosed cabin for the same boat is fabricated in aluminum.*

aluminum. "I never thought this material would be so promising as it is," Gilles said. He started working with Tideman in 2015 on some of the smaller low-powered versions. He recalled his early skepticism about HDPE, which was allayed by the practical testing Tideman subjected the boats to during development, including giving one to the Dutch Marines for two weeks of abuse.

"Mainly it's the tensile strength and elongation that differs [from aluminum]," Tideman said. "There is flexibility in the material, so the welds can take a little bit of distortion." For a workboat, that's a real virtue. For military or law enforcement uses where stealth is a priority, there's the additional benefit of HDPE's low radar signature. Plus, the material, while not bulletproof, is self-sealing around bullet penetrations, which could keep the boat from swamping on the way home.

Especially for workboats in remote areas, the capacity to complete hull repairs outside of a service yard or composites shop is a draw. "Plastic welding is something you can do yourself," Tideman said. With that in mind, he includes an extrusion welding kit with every boat and advises that any scratch or ding more than 5mm (0.2″) deep should be repaired using the gun and some fresh HDPE.

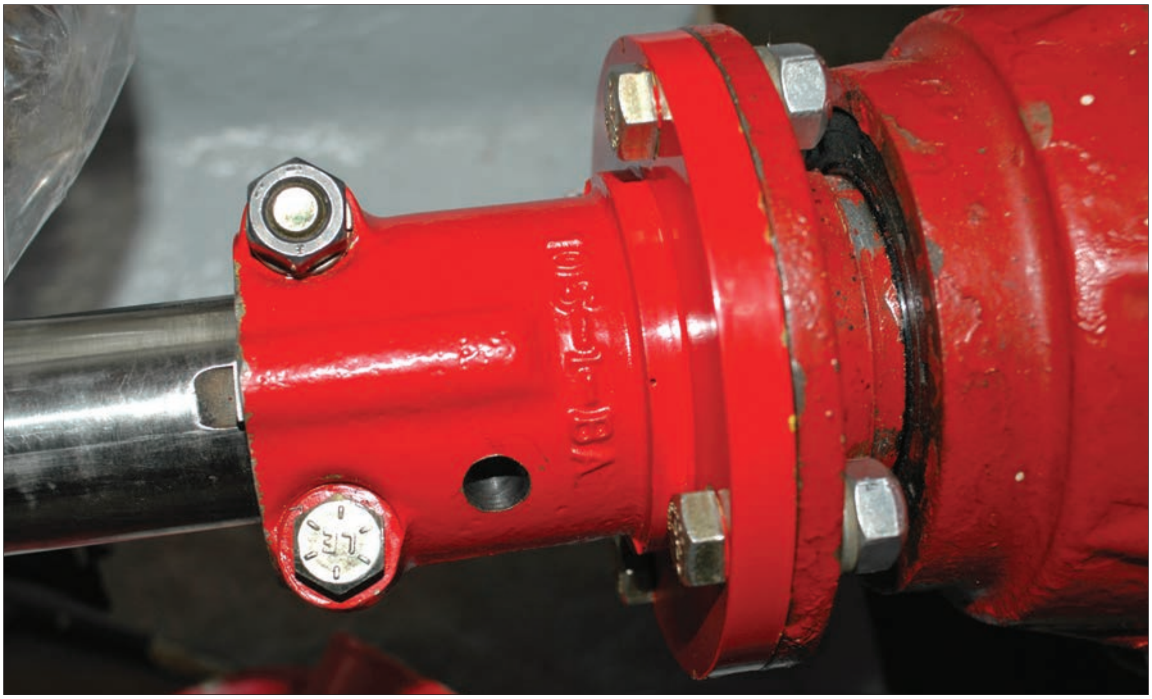
While Tideman insists that these boats are only for commercial purposes and fit and finish of HDPE surfaces admittedly fall shy of yacht standards, there have been exceptions and likely will be more. He somewhat grudgingly admits that he has sold three jet-drive versions as superyacht tenders. While they may not yet be a common sight around tidy yacht club floats, I can imagine these boats' appeal to crew who must run to rough industrial piers and remote and rocky beaches, where vulnerable high-gloss tenders are out of their league. The HDPE launch is immune to fuss and resistant to damage, looking and handling the same in whatever conditions the fates throw at it. PBB

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

PBB Resources

Alamarin-Jet: alamarinjet.com
Class 5 Boatworks: class5boatworks.com
Dick Gilles Jachtbouw: 123waterwonen.nl
King StarBoard: kingplastic.com
Teak Isle Mfg Inc.: boatoutfitters.com
Tideman Boats: tidemanboats.com

Shaft Couplings



The marriage of engine to propeller shaft is the most essential link in the drivetrain. Get it wrong at your peril.

Text and photographs by Steve D'Antonio

Above—*In this split shaft coupling, grade 8 machine screws fasten the pinch and the flange. The flange cap screws are too short; they should protrude slightly beyond the nut. Note the coupling is designed to be pinned.*

While relatively simple in design and construction, propeller shaft couplings are the sole mechanical tie in the drivetrain between the propeller shaft and the transmission and engine. To fulfill their essential role in a boat's propulsion system, they must be properly selected and installed.

The design of a coupling is simple. It's a wide, flat flange mounted on the end of a driveshaft that interfaces with a mating face on the transmission's output coupling. To keep the two faces centered on each other, the shaft coupling incorporates a male pilot bushing, which stands proud of the face and registers with a corresponding female recess in the transmission coupling. (Note: The bushing is vulnerable to damage when not mated to the transmission.) The two round flanges are secured to each other with multiple common fasteners running through them. While these are the basics, there are variations.

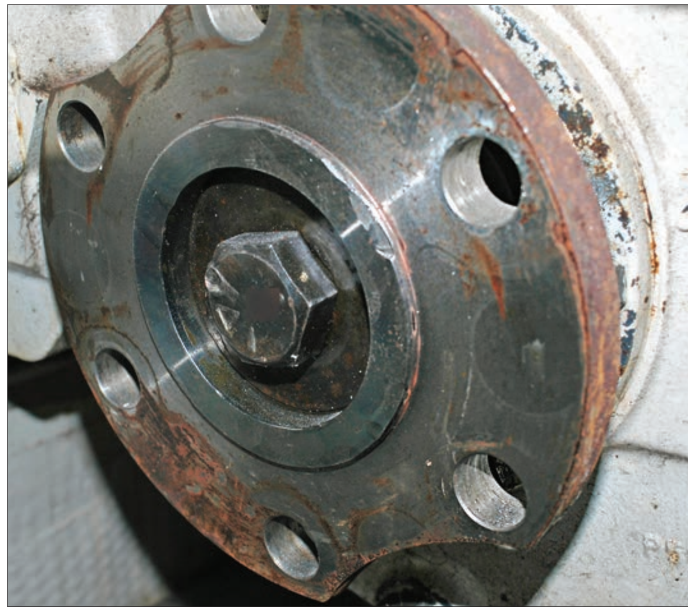
Coupling Types

For vessels up to about 75′ (22.9m), there are three common styles. The ***solid, or straight-bore, coupling*** relies on a bore the same diameter from end to end, and engages the propeller shaft with a light interference fit. It is typically pushed onto the propeller shaft using a mallet, or a maul and block of wood. A coupling should *never* be struck directly with a metallic hammer or maul, because doing so could damage the finely machined coupling face and pilot bushing. A small hammer mark can create 0.01″–0.02″ (0.25mm–0.51mm) of raised material on the face, causing the shaft to have run-out (deviation from the transmission's center of rotation), which will probably lead to vibration.

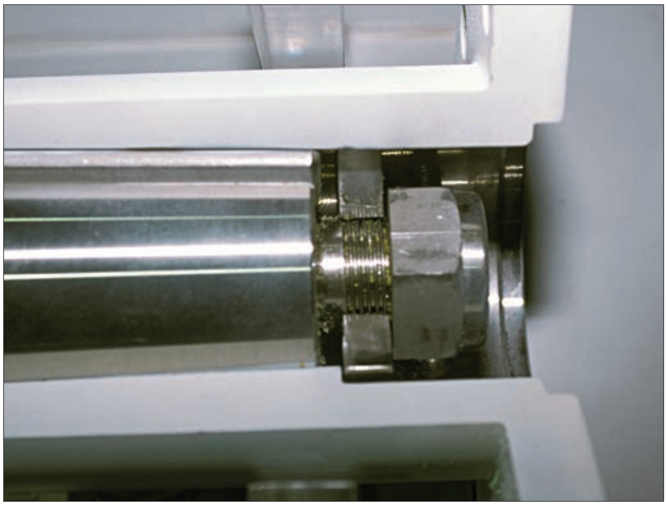
Straight-bore couplings are common in low-horsepower applications, including sail auxiliaries. While they work, they lack the shaft holding power required for larger engines and props, which can place significant strain on the shaft-to-coupling interface. Getting the interference fit between shaft and coupling bore just right is a challenge. If it's too tight, driving the coupling onto the shaft may be difficult if not impossible, especially in confined enginerooms with no space to swing a mallet. If it's too loose, the shaft may begin to work in the coupling with each shift evolution, which in turn will gall the shaft key, allowing for more and more movement with continued wear. It often ends when the key and set screws or roll pins shear off, allowing the shaft and prop to slide out of the shaftlog to strike, and possibly jam, the rudder. The worst-case outcome is that it doesn't jam, and the shaft and prop slide out of the stuffing box altogether, leaving a shaft-sized hole with a geyser of seawater into the bilge, likely overwhelming the pumps.

Split couplings are easily identified by their bifurcated design. While this coupling is made up of one part, the aft plate is divided into two sections, which are clamped against the shaft by two or more machine screws (these should be SAE/Society of Automotive Engineers grade 8). With this arrangement the coupling can actually apply clamping action to the shaft. Its main advantage over other coupling types is that it enables easy removal from the shaft (and thus easy shaft removal from the boat) by driving a pair of steel wedges or cold chisels into the gap between the two split halves. Beyond this, I see no other benefit to using a split coupling, and would argue that rather than make it easy to remove, the primary mission of a coupling is to reliably secure the shaft. And, because it is split, it moves or distorts each time the shaft is inserted or removed. When that happens, the coupling face may not remain truly perpendicular to the shaft. That's because it is easy to make an installation mistake—not torqueing pinch bolts in proper sequence, or pinching against a set screw, which leads to the coupler being off perpendicular, resulting in a nasty vibration. So, unless you know you'll want to remove your shaft regularly, there's little to recommend this type.

The third common option is a ***taper coupling***. Its bore is cone-shaped in precisely the same manner as a propeller hub bore, and it engages an identical male cone machined in the forward end of the prop shaft. I prefer to install propellers on a taper engagement because it's extremely reliable: it can never be too tight or too loose;



Above—*Pilot bushings are critical to centering the shaft on the transmission output coupling. This coupling's pilot bushing has been damaged by impacts in two locations.* ***Below***—*The primary benefits of a split coupling are its easy removal and, when compared to tapered couplings, the reduced cost of the shaft machining required.*



Left—*Tapered couplings offer several advantages over straight and split models. The interface between the taper shaft and the bore makes for an exceptionally tight fit. In some cases where locking nuts have loosened, the shaft and coupling must still be separated with a hydraulic puller.* ***Right***—*This tapered coupling has the added security of set screws to retain the locking nut.*

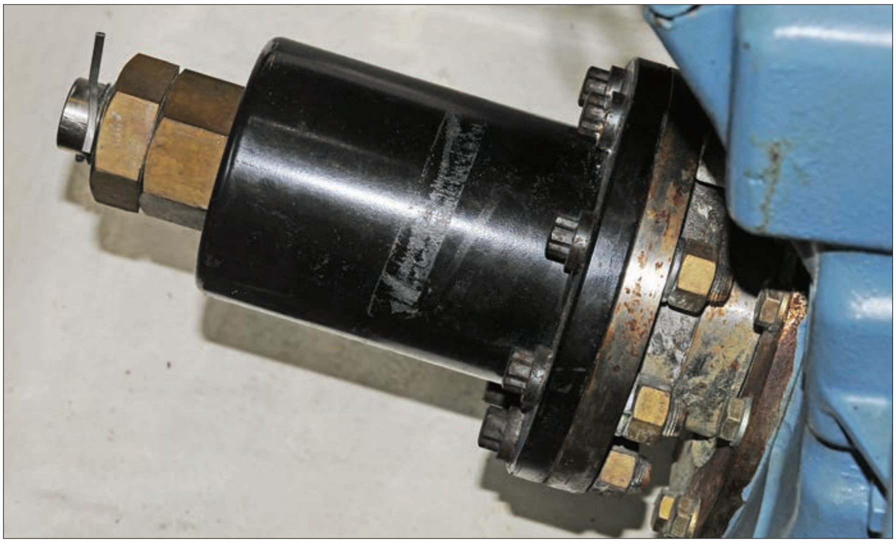
it never compromises the perpendicularity of the shaft and propeller when installed correctly; and once engaged it is highly unlikely to shift or separate. Its primary weakness is the potential for key binding during installation. In short, this is an excellent means of securing the shaft to the coupling, so let's look at some details.

The shaft end fitted to the taper coupling is threaded and retained by a large nut housed in a recess in the coupling face. As on a propeller, the nut is commonly augmented by a cotter pin (sometimes heavy seizing wire) or is replaced with a nylon locking nut. In some cases, set screws installed in the coupling, perpendicular to the shaft and close to the flange end, are tightened against the shaft nut flats, thereby locking it in place.

Much like tapered propeller installations, tapered couplings benefit from lapping, wherein the coupling and shaft tapers are custom fit to fine tolerances with the help of valve-grinding compound. The goal is to maximize contact between the surfaces by grinding away small elevations or ridges in the interface. It should be carried out the first time a tapered shaft and coupling are mated, or when it's unknown whether they've ever been lapped. Thereafter it's unnecessary.

Another tapered-shaft-retention method applies what's referred to as a "three-bolt keeper plate" in place of the large single locking nut. This alternative hardware relies on three recessed Allen-head machine screws threaded into holes parallel to the shaft centerline, located in the coupling end of the shaft. A metal plate located under the heads of the fasteners acts as a retainer. The advantage to this approach, typically found on shafts 4″ (102mm) and larger in diameter, is ease of access. The nut requires a large 1″ (25mm) breaker bar and a 3″ or 4″ (76mm or 102mm) socket for removal and installation, room for which sometimes doesn't exist. The keeper-plate bolts, on the other hand, can use a standard ½″ or ¾″ (13mm or 19mm) ratchet drive, a small Allen socket, and far less torque.

Other than the set screws, none of these retention components are visible after the coupling is bolted to the transmission. I have separated many taper shaft couplings from their transmission flanges, only to find the retaining nut

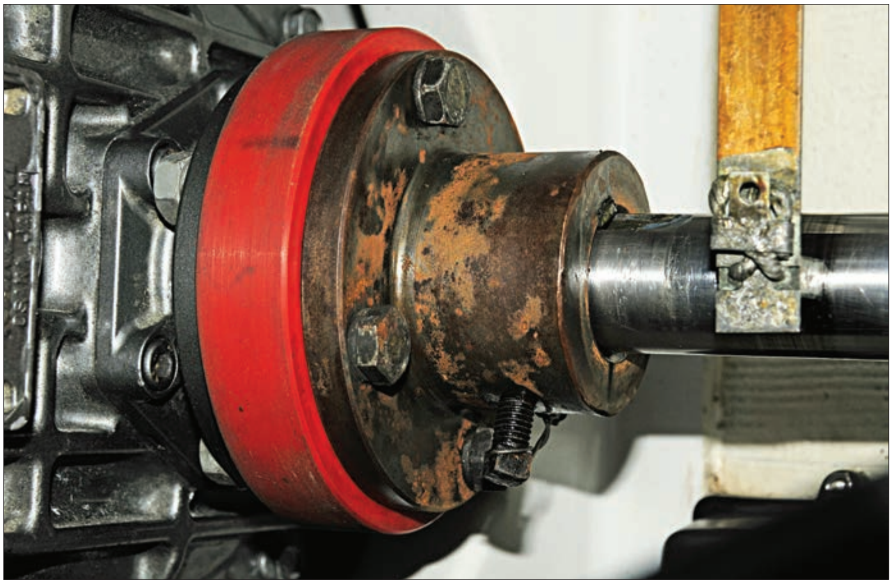


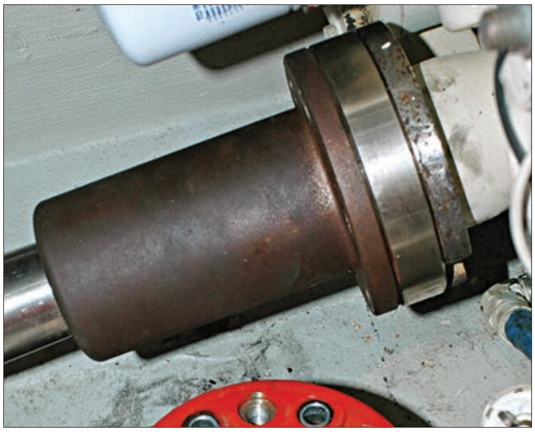
Reverse-taper couplings like this one are often used with V-drive transmissions wherein the shaft passes through a "port" in the transmission case.

loose but the shaft still firmly engaged in the coupling bore—evidence of the taper design's effectiveness.

Another variation on this coupling is the reverse taper. In a conventional taper the large end of the bore is farthest from the coupling flange. The shaft is inserted onto this end. In a reverse taper, the large end of the bore is at the flange end. Reverse tapers are most often used in V-drive applications, where the shaft passes through the transmission. In practice it works the same as a conventional taper; however, the retaining nut and cotter pin are exposed after assembly is complete.

On occasion I've recommended that clients specify a tapered coupling for a new or replacement shaft, only to have them report back that the boatbuilder or shaft shop doesn't recommend this approach. When quizzed, they often have no explanation, other than being told, "A split coupling is better." Invariably, when I explore the issue by speaking directly with the shaft shop, I learn that they do not possess the machinery necessary to make a tapered shaft and coupling. In practice, many smaller shaft shops purchase shafts with the prop-shaft-end taper already cut, and then they simply cut the shaft to length and machine the keyway into the coupling end. This is a convenience and cost-saving measure for the shop, but it offers no benefit to the end-user. For all but the smallest shafts, it pays to insist on tapered couplings.





Above—*This red nonmetallic coupling insert is designed to shatter if the prop strikes a large object. Insert surfaces lack the precision required for accurate alignment measurements. Before an alignment, the insert must be removed and the coupling faces brought together. If shaft length or the insertion of line cutters won't permit that, a precision spacer like the one shown at* ***left*** *can be installed to perform the alignment.*

Flexible Couplings and Inserts

Discussions of the marriage of shafts to transmissions would be incomplete without mentioning flexible couplings. These come in two primary varieties: those that are an integral part of the coupling itself, and those that are inserted between the two coupling halves. True flexible couplings are designed to absorb some limited degree of misalignment between the shaft and engine/transmission. They do so by including a flexible component in the driveline, usually rubber or polyurethane, which converts movement into heat. Consequently, in all cases they eventually wear out. The moment when this occurs can be either insidious, when they simply stop absorbing movement, giving the user no obvious indication, or catastrophic, when they fail completely.

Some flexible-coupling manufacturers *claim* their products reduce vibration in addition to absorbing misalignment, while other manufacturers *claim* theirs shear or shatter in the event the prop strikes a log, rock, etc., thereby preventing or minimizing damage to the transmission. (The only times I've seen them shear is as a result of stresses induced by misalignment, not from striking an object.)

In my experience, there's no substitute for proper alignment, and I have never known a flexible coupling or insert to make a noticeable difference in vibration. I have seen cases where inserts, as a result of their imprecise plastic faces, exacerbate misalignment in otherwise well-installed and -aligned drivelines. Also, they complicate alignment procedures, which, added to their tolerance of misalignment, can lead to acceptance of lower standards for the final installation. Among the most effective means of reducing drivetrain noise and vibrations are combination thrust bearings and universal or CV joints. (For more on thrust bearings, see PBB No. 120, page 42.)

For a coupling alignment, the nonmetallic inserts must be removed and the coupling faces either engaged directly, or, if that's not possible, a precision-machined metal insert installed (these are available from Spurs, the manufacturer of line and net cutters), the alignment checked and corrected,

Left—Set screw tips should be either cupped or pointed, and hardened. Ordinary stainless steel fasteners, shown here, should not take the place of purpose-built screws. On the plus side, these set screws are secured with locking nuts and seizing wire. ***Above***—Scallops cut into this shaft indicate that it's designed for use with a split coupling. Pinch bolts interface with the machined dimples to improve shaft-to-coupling engagement.

and only then should the nonmetallic coupling insert be reinstalled.

In the end, I question whether all this time, trouble, expense, and potential sacrifice in reliability are worthwhile. Other than the precision metallic insert, I'm leery of installing any component into the drivetrain that isn't absolutely necessary, as it simply presents another potential point of failure.

Fasteners, Set Screws, and Clevis, Taper, and Roll Pins

The grade of fasteners connecting the two couplings should be a minimum of SAE grade 5, identified by three hash marks on the head in a Y pattern (for metric fasteners the head includes the numbers 8.8) and ideally SAE grade 8, with six evenly spaced hash marks on the head (and the numbers 10.9 for the metric equivalent), all mild steel, fine thread. While stainless steel is desirable elsewhere aboard, in this location corrosion resistance takes a backseat to tensile strength, and for like dimensions, mild steel is simply stronger than stainless steel, and SAE grade 8 is stronger than the more common SAE grade 5. Many lower horsepower applications require nothing more than SAE grade 5, but if you are purchasing the fasteners for this application, it's worth paying a little more for the added strength. (For more on fastener selections and grades, see "Nuts. Bolts. Screws." in *Professional BoatBuilder* No. 118.)

These fasteners should be mated to split lock washers, or nylon-insert lock nuts when installed, and neither should be reused in a reassembly. For especially hard-working applications, where frequent shifting and throttle work is anticipated (passenger and yacht club launches, for example), consider using cam-style Nord-Lock washers, which are significantly more effective than conventional lock washers or nuts and virtually fracture-proof. Wherever clearance permits, use a torque wrench for installation of *all* coupling fasteners.

When the couplings are permanently connected, they and the securing hardware should be coated with a rust preventative such as CRC's Heavy-Duty Marine Corrosion Inhibitor, or painted. Fasteners available in a plated finish are desirable as it will further inhibit corrosion.

In all the above coupling arrangements, save the taper variety, one or more of several retaining methods are used to further secure the shaft to the coupling, including: one or two set screws (usually installed 90° apart); a clevis pin (a straight, solid, round pin retained by friction alone); a roll pin (a straight, round, hollow pin split and sprung—the spring tension holds it in place); or a taper pin (a cone-shaped pin threaded at the small end, inserted into a cone-shaped bore drilled through the shaft and coupling, and secured with a nut). For split couplings, another retention method may be used, one where scallops or half rounds are cut into the shaft perpendicular to its centerline, which are then engaged by the coupling's clamp bolts.

Unless clevis and taper pins and their matching bores are precisely machined and the pins properly installed, they can cause problems. I've removed clevis and taper pin-equipped couplings only to have the pins fall out in two or three pieces, or to have them seize in the coupling and shaft, requiring tedious drilling, driving out with a drift, or cutting the shaft. Note that ordinary hex-head machine screws should never be used in this through-shaft application, as they lack the necessary precision in sizing and the overall strength required.

Especially after wrestling to disassemble a corroded shaft coupling, it's tempting to apply anti-seizing compounds or grease to facilitate removal, but these should *never* be used on taper fittings, including the shaft taper itself and taper pins. The interference of viscous material can prevent proper

***Far left*—*Grease on this coupling and key was applied to ease installation but will actually prevent full engagement between the shaft and coupling, as it cannot be compressed in the confined coupling bores. Shafts, keys, and couplings may be lightly oiled to prevent binding and ease installation.* ***Left*—*This brass taper coupling relies on set screws to secure the shaft end nut. Note that the seizing wire is correctly tensioned to rotate the screws clockwise.*

engagement of the tapered shaft and the coupling surfaces. The same prohibition on anti-seize is true for other coupling fasteners. A coating of light oil may be applied to prevent binding and inhibit corrosion on all coupling components including the coupling bore, shaft surface that's inserted into the bore, key, keyway, and coupling faces. Do not use it on threaded components where you intend to apply thread-locking compounds. Remember, the torque rating of a fastener whose threads have been oiled is lower than one whose threads are dry. Charts for this are readily available online.

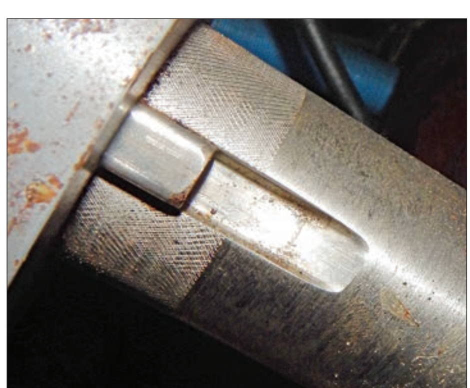
Set screws come in two varieties: square head and recessed Allen-socket-drive heads. (The latter is sometimes referred to as a grub screw.) Ideally, square-head set screws should include a hole through the squared section, which accommodates the added security of stainless or Monel seizing wire to keep the screw from backing out. There is an art to installing seizing wire for this purpose—it must be neat and tight. And always tension the fastener in the clockwise direction. Wire diameter should be selected for the largest size that will fit through the available hole, and because square-head set screws are hardened, those without holes cannot be easily drilled after the fact. If you wish to seize your set screws, order them with holes predrilled. Those that cannot accommodate seizing should be installed with a thread-locking compound. Take the belt-and-suspenders approach and use a locking compound in tandem with seizing wire; in addition to preventing loosening, the compound can also serve as a corrosion inhibitor by preventing water migration into the threads.

For through-shaft applications, ordinary machine screws should *never* be used in place of a hardened set screw, as they lack the necessary tensile strength and proper tip design.

The style of set screw tip plays an important role in securing the shaft. If the tip is pointed, as some set screws are, then the shaft must be drilled with a matching pointed dimple of the same angle, into which the screw point fits snugly. If, on the other hand, the set screw is cupped, then a dimple is not necessary and should not be used.

Like propellers, all couplings are typically interfaced or "keyed" to the shaft using a rectangular section of precision-machined stainless steel stock known as a key set in a corresponding keyway milled longitudinally into the shaft and coupling. The keyway should be radiused, meaning the interface between its vertical "walls" and "floor" should be slightly rounded, and the aft termination of the shaft keyway should be ramped. These features minimize the formation of stress risers and cracking.

The key-to-keyway fit is critically important for proper engagement between shaft and coupling: too loose and movement may occur; too tight and binding may occur between key, shaft, and coupling. If lightly oiled and installed, the key should move in the keyway with fingertip effort; however, it should not be possible to rock the key or produce any clicking sound. When



***Left*—*A ramped and radiused keyway is more resistant to stress-induced fractures, while the knurling improves the interference fit on this small sail auxiliary straight-bore coupling.* ***Right*—*Keys should fit snugly into a keyway and, when lightly oiled, should slide and be easily removed. Unlike this one, they should not rock or clack when moved from side to side.*

If left uncoated in a damp bilge, mild steel couplings will rust. Couplings and fasteners should be painted or coated with a corrosion inhibitor that will not be flung off a spinning shaft

the three components—shaft, coupling, and key—are engaged, all independent movement between them should be entirely eliminated, and all but the smallest fore-and-aft movement of the key would be too much.

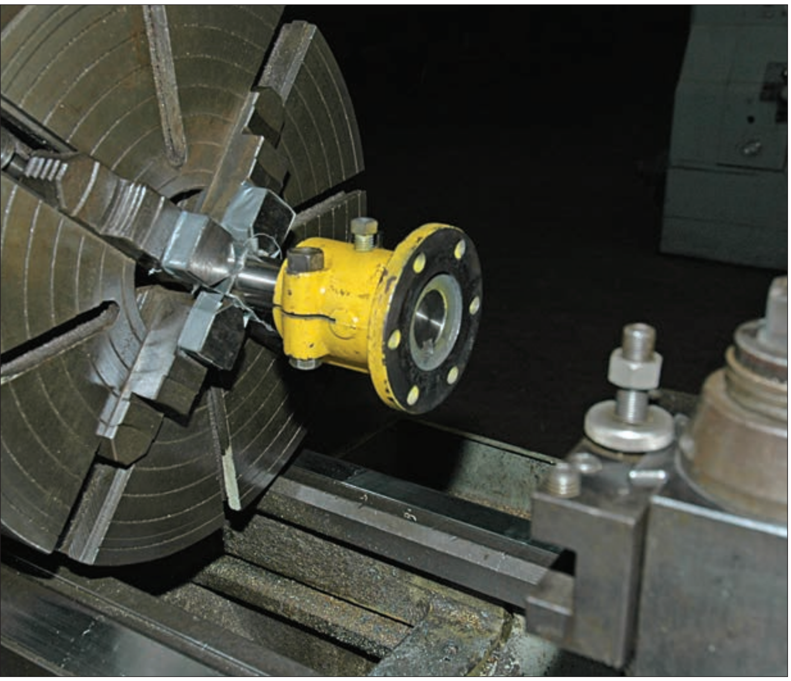
Shafts are notorious for seizing in their couplings. No surprise, as most couplings are made of ordinary ductile iron (though some are brass), which is prone to rust. When the shaft is seized in a rusty coupling, the labor to remove it sometimes makes cutting, and thereby destroying, the shaft a less expensive alternative. This is especially true for smaller diameter (less than 2″/51mm), and short shafts. Keep this in mind if you are removing a shaft from a heavily corroded coupling, and discuss it with crews before the work begins and before they generate an invoice that exceeds the cost of a new shaft.

Fitting and Facing

While shafts and couplings are precision-made and interchangeable, once mated they represent a custom assembly. That's why some element of custom matching is required for shafts and couplings mated for the first time (if either or both parts are new). It's a process known as fitting and facing, which should be carried out by a machine shop that specializes in prop shaft work.

The coupling face and pilot bushing should be carefully inspected to ensure that they are free of dents, gouges, rust, or other irregularities. (Even new couplings should be inspected, as they can be damaged while in storage or during shipment.) Minor blemishes can often be repaired, but severe damage often warrants replacing the coupling.

Next, the shaft is secured in a lathe, and the coupling is installed on the shaft, just as it would be in the vessel.



Left—*Fitting and facing involves installing the coupling on its shaft and checking the coupling face's run-out. For correct alignment, the coupling face must be near perfectly perpendicular to the shaft centerline. If it's not, the face is milled on a lathe.* ***Right***—*This coupling has been marked with its after-machining run-out, which does not exceed 0.001" (0.025mm).*

Loose fasteners, movement between coupling faces, or both frequently lead to fretting, which generates iron dust. That, in turn, rusts very quickly, leaving behind a telltale brown halo. Such clues should be investigated promptly.

Then you measure the coupling face irregularity, or run-out, with a dial indicator, while turning the coupling and shaft slowly by hand. Ideally, the run-out or lack of perpendicularity between the shaft and coupling face should be as little as possible—no more than 0.001″ or 0.002″ (0.025mm or 0.051mm). The larger this irregularity, the greater the imprecision will be when it comes time to carry out an engine/shaft alignment. (For more on engine and shaft alignment procedure, see "The Necessity of Straight," in PBB No. 159.) If the run-out is found to be too great, the lathe is switched on, and the coupling face is fly-cut, or shaved, to make it truly perpendicular to the shaft.

Because coupling bolts are not designed to hold the coupling in the center, it's essential that during fitting and facing, the coupling pilot bushing should also be checked to make certain it is true, centered relative to the shaft, and free of damage, and to ensure that it meets the proper dimensional requirements for engagement with the female recess in the transmission flange. A heavily rusted pilot bushing, for instance, may make it impossible to properly engage the coupling.

Also beware of undersized pilot bushings. Ideally you want the female pilot to be 0.003″ (0.076mm) larger than the male pilot. This allows a perfect fit during coupling to the engine. If it is tighter, there is a chance of binding during installation. If it is too loose, the coupling will not be centered on the transmission flange, which in turn can lead to run-out and vibration.

More often than not, vibration is caused by eccentric or cam motion, which is the result of an off-center pilot bushing, or coupling bore that is not centered, rather than flange-face misalignment, which induces a constant bow in the shaft. The former is easily identified using a dial indicator, while the latter will show no abnormal run-out, again because it is constant.

Finally, couplings should be periodically inspected. With the engine off (not just in neutral), run your fingers over every fastener and set screw, pin, etc. to make sure none is loose. Any signs of fretting or galling should be investigated, along with obvious flaws such as cracks. Industry professionals should get into the habit of checking couplings for the aforementioned flaws, as well as loose or improper fasteners, or improperly installed seizing wire whenever they are in the vicinity of this component, the engine, transmission, or stuffing box.

***About the Author:** A former full-service yard manager, Steve works with boat builders and owners and others in the industry as Steve D'Antonio Marine Consulting. An ABYC-certified Master Technician, he sits on that organization's Hull and Piping and Engine and Powertrain Project Technical Committees, and is also* Professional BoatBuilder*'s technical editor. He acknowledges assistance from Chris Brown of High Seas Yacht Service, www.highseasyachtservice.com, in Fort Lauderdale, Florida, for reading this article for technical accuracy.*

Resources

Buck Algonquin: hydrasearchrecreational.com

CRC: crcindustries.com/products/heavy-duty-corrosion-inhibitor-10-wt-oz-06026.html

Marine Hardware: marinehardware.com

Nord-Lock: nord-lock.com

Spurs: spursmarine.com

Walter Machine Company: waltergear.com/psc.htm

New Products and Processes

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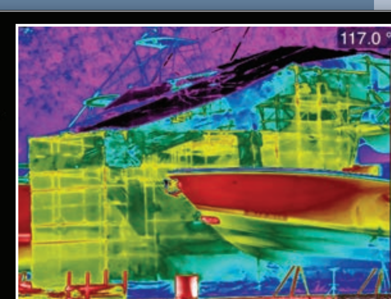

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—John Rousmaniere

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One Practical Boat, Three Generations of Fun and Efficiency

by Michael Morabito

While I was out on the water today with my kids I noticed that I burned about 2 gallons (7.6 l) in just over one hour of enjoyable boating, and I thought about *Professional BoatBuilder*'s 2009 design competition, "The Pursuit of Pleasure at 2 Gallons Per Hour." I had entered a joint design with my mother, influenced in no small part by the 14′ (4.3m) family runabout I'm still driving today. (For details of the design challenge, see PBB No. 122, page 26.)

My parents bought the boat in 1982, the year I was born, but it was built in 1958 by a neighbor of my mother's (Mr. Taylor, a carpenter), who followed plans in *Science and Mechanics* magazine for a design by a naval architect named William "Dade" Jackson. My mother remembers sitting on the dock as a child and watching the boat go around the lake, and, of course, it was ever-present in my own childhood.

Downsizing their possessions in recent years, my parents passed the boat on to my family, and my wife and I brought it from New Hampshire to the Chesapeake in the summer of 2018.

The original 1958, 35-hp Johnson Super-SeaHorse outboard threw a rod around 2000—not a bad working life span for an outboard motor. Its replacement, a vintage Mercury outboard, never ran right, and the boat mainly sat in the garage for too many years. But after we brought it down to Annapolis, I clamped on an old Seagull outboard I had lying around. You know the kind—no reverse, no neutral, leaking fuel everywhere, starting rope you had to wind around the flywheel, maximum speed 4 knots, and so loud that I wore earplugs. Despite the less-than-ideal motor, my family began using the boat. We had an absolute blast.

We could easily trailer the boat from the house to a boat ramp, motor out, anchor, and then swim. We had an old-fashioned swim ladder over the side, which the kids (ages 4, 7, and 9) loved jumping off and clambering back up. And it kept them away from the engine, which was always off but still burning hot.

Under way with just 1.5 hp, we took the kids tubing at such a moderate pace they could stand up on the inflated tube at full throttle. And because there wasn't enough room in the boat for the tube and the family, we towed it like a yacht tender. We could let the kids steer at a top speed slower than the idle speed of most sailboats motoring in and out of their slips. The kids loved it, and people approached us each time we went out to say how much they liked the boat. Here in Annapolis, surrounded by $500,000 boats, this little 60-year-old homemade boat with a Seagull outboard really stood out.

U.S. Naval Academy midshipmen take lines off the author's runabout at the start of their naval architecture curriculum. The author's children show how much fun it can still be aboard the 60-year-old boat.

MICHAEL MORABITO (BOTH)

After the fuel tank fell off the motor (I temporarily affixed it with a coat hanger), I decided to buy a 2003 Johnson 15-hp outboard for $700 at a local place that sells inflatables. Now our 300-lb (136-kg) boat made of ¼″-plywood (6.4mm) sides and ⅜″ (9.5mm) bottom gets on plane easily, and at the top speed of 21 knots feels like it's flying across the water. The kids, whose only experience with engines had been the Seagull outboard, are amazed at how quiet the new motor is (we can hear each other when we yell), and they are happy no longer having to duck to avoid being hit by the flailing starting rope. The speed is thrilling and sometimes terrifying in such a small boat. Neutral and reverse are welcome novelties.

We've been out maybe 10 or 15 times in the boat, using a total of 8 gal (30.3 l) of fuel, including what the Seagull leaked when the tank fell off. We're certainly getting better than the 2-gph goal of the design challenge, and the boat serves a secondary practical purpose as a teaching tool. It was simple enough to trailer it to the Naval Academy to have my students measure the hull and deck and draw their first lines plans based on their measurements.

It seems like the perfect boat if you are content with simple and fun. I'm very happy. PBB

About the Author: *Michael Morabito is an associate professor and the director of the Naval Architecture and Marine Engineering program at the United States Naval Academy, in Annapolis, Maryland.*