The Keel Specialists

The Canadian firm Mars Metal Company, a major producer of lead keels for sailboats, has expanded into other markets, including radiation shields and counterweights.

SOUTHERN WIND SHIPYARD

Text by Rob Mazza

Photographs courtesy Mars Metal (except where noted)

Above—*With her keel fitted, the 95' (29m)* Lady G*, built by Southern Wind Shipyard, in Cape Town, South Africa, is ready for launching. With so few foundries interested in casting large lead objects, Mars Metal Company has clients worldwide.*

Every large monohull sailboat depends on ballast to provide stability to counter the heeling forces of its sails. After the introduction of fiberglass boat building and the success of the production-built Cal 40 (12.2m) and custom-built *Red Jacket* in the 1960s, this ballast was most often cast in the form of a separate airfoil-shaped fin keel. The cast fin not only provides the required stability but also the hydrodynamic lift necessary to allow the boat to go to windward without slipping sideways (making leeway). Since the advent of external ballast, 35%–50% of the weight of nearly every large production sailboat has been in the cast ballast keel.

The two popular choices of material for ballast keels are lead and iron. Lead has distinct advantages over iron in its higher density (and thus lower volume for a given weight) and its immunity to corrosion. However, cast iron has two important advantages over lead: higher mechanical properties and substantially lower cost. For production builders, as we shall see, recent fluctuations in metal prices, combined with an exceptionally challenging market for production sailboats, have tilted the advantage toward iron. That shift has left traditional lead-keel manufacturers scrambling to redefine their market.

The Beginning

During the sailing boom of the 1960s and '70s, when lead keels were provided by a number of local foundries throughout the continent, Canada

Preparing a large open mold, fabricated in Ceramicast tooling material, for a continuous lead pour. At 153,500 lbs (69,626 kg), the largest keel the company has cast to date was for the Bruce King–designed and Hodgdon-built 155' (47.2m) Scheherazade*.*

Metal in Toronto supplied most of the cast lead keels to the 40-plus sailboat builders in Ontario and Quebec. Then Mars Metal emerged in the adjacent community of Burlington, Ontario, to challenge, and then supplant, the older foundries. However, the decline in production sailboat construction forced the company to become more versatile. It began supplying a better and more specialized product, and it diversified into other industries. Today, its three divisions of lead products include not only keels (MarsKeel Technology, our focus here) but also counterweights for lift bridges (MarsMetal Specialty Casting), and shielding and containment devices for medical, nuclear, and border-security purposes (MarShield).

The Mars Metal Company began in 1979 when Philip Milne established a small 1,500-sq-ft (140m^2) "one pot" lead foundry in the Burlington area, producing lead solder for the automotive industry, plumbing lead, fishing weights, and small ingots, all cast from melted lead scraps.

It wasn't long before Mars Metal was also casting the occasional lead keel for the burgeoning sailboat industry at the western end of Lake Ontario. Back then, there were more than a dozen sailboat builders within an easy one-hour drive of the plant, noted Kevin Milne, Philip's son and now owner and president. The company's credibility in that market increased with its first "large" customer, Hughes Boatworks near London, Ontario. With all boatbuilders looking for a secondary source of supply, Mars was soon getting small orders from CS Yachts, and even C&C Yachts. Soon it had all the keel business from local builders. In the early and mid-1980s Mars made inroads into the United States, supplying some keel castings to Hinckley Yachts, in Maine, and to the O'Day Corporation, in Rhode Island. Then builder Andy Wiggers of Bowmanville, Ontario, asked Mars Metal to build the cast lead keel for the Canada's Cup defender *Coug I*. When that Doug Peterson design went on to successfully defend the Canada's Cup in 1981 in Hamilton, against the American challenger *Black Magic*, Mars Metal gained standing in the custom one-off market as well.

Ready to Go

By providing production keels to O'Day, Mars Metal took a big step to differentiate itself from other suppliers. Previously, the lead casting sent to the boatbuilder was often very rough, with flashing and grinding marks still visible on the surface. At C&C Yachts, for example, those keels were "faired" by further rough grinding during the night shift, and then primed and painted while awaiting installation over the next few days. Mars Metal set out to change that with a ready-to-install keel—faired, primed, and painted.

The initial coating was a clear urethane that the company had originally applied to downrigger fishing weights. O'Day then asked that the primer coat for the bottom paint also

Working With Lead

When dealing with lead, the many environmental constraints include remaining within code, restricting and monitoring air emissions, and giving employees regular blood tests. It is primarily for those reasons, as well as quality concerns, that MarsKeel uses only ingot lead, not scrap lead, for its castings.

The mechanical properties of lead can be greatly increased by adding antimony. The company inventories and orders lead ingots varying all the way from pure lead to the required antimony content, which for keels is in the 2%–4% range, depending on the physical properties required. All of this, of course, drives up prices, but creates a much more comfortable and environmentally friendly work environment, and a much more consistent product. The addition of antimony has an incremental effect on density, but a 4% addition will increase strength threefold and hardness by 2.5, with a still-high 22% elongation, down from 80% for pure lead.

—*Rob Mazza*

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Precision and care are required in lowering Lady G's *hull onto its 38,500-lb (17,463-kg) keel.*

be applied over the initial coating. For a while, some keels were even supplied with bottom paint over the primer, so the keel could be the last thing installed as the boat went out the door. Soon the company was fairing the keels with thickened WEST System epoxy or ATC Poly-Fair (now produced by Scott Bader-ATC), under the sealer and primer coats. For C&C Yachts' higher-performance boats, Mars went further by clamping fiberglass molds around the cast ballast keel, into which it poured thickened epoxy to fill the thin space between the lead and the mold, creating perfectly fair and accurate shapes ready for priming and painting.

According to the company website, for production keels today, MarsKeel receives the keel drawing from the designer or builder, fabricates the wooden pattern approximately 1% oversize (to account for shrinkage of the lead as it cools), and then chooses the mold medium that best suits the anticipated production volumes. For tooling, Milne explained that the company employs its Ceramicast molding material for high-volume productions (usually large keels with limited details), while it prefers AccuSand, which incorporates traditional sand-casting technology, for smaller castings with higher levels of detail, making it more expensive.

A crew member removes clamping bolts from a multi-piece permanent steel mold for a large shoal-draft wing keel. Note that the keelbolts are cast in place.

For both methods, size is not a problem. In-house, MarsKeel can transfer up to 200,000 lbs (90,680 kg) of lead in a single pour. Its largest casting to date, and the largest single-pour lead casting in North America, according to the company, was the 153,500-lb (69,626-kg) keel supplied to Hodgdon Yachts in Maine in 2000 for the 155′ (47.2m) Bruce King–designed *Scheherazade*. It was achieved by pouring from two furnaces simultaneously into a single mold. A pour can continue indefinitely, as the furnaces are recharged with lead during the casting, with no loss in temperature and no interruption. In large open molds the cast surface is continually "flamed" with a propane torch to keep the lead liquid to ensure a uniform casting. For closed molds, such as bulbs, pouring gates are kept open and liquid. Even after the pour begins to cool, the casting is continually "topped up," and the open surface is flamed to maintain a liquid top. This can take hours but reduces shrinkage during cooling. For larger keels, complete cooling of the final casting can take several days. Thus the filled mold is often left under the furnace for up to two days until it is cool enough to be safely handled. At that point, the bolt-mounting hardware is removed, and the handling fixtures are installed to support the weight of the casting as the mold is dismantled and removed. The surface is coated with two layers of InterProtect epoxy, then faired, sanded to #320 grit if required, and coated with several more layers of epoxy. For custom-cast lead keels, full-size templates are also produced to assure accuracy.

Through the Lean Years

In some cases, MarsKeel utilizes a customer's own permanent tooling. For a number of prominent sailboat builders—including Catalina, Hunter, Bénéteau, C&C, Tartan, and J Boats—the company has in inventory more than 100 keel molds, either built by MarsKeel or supplied by the builder. In 2009, for instance, when Catalina Yachts closed its longtime California operation to concentrate production in its Florida facility, it shipped all its permanent keel molds to MarsKeel. Prior to that, Catalina cast its own lead keels in California. MarsKeel still has all the Catalina keel molds in storage and often supplies replacement keels to aftermarket boats. This service is of particular value to a boat owner who wants to switch from a standard deep-draft keel to an optional shoal-draft keel; the company may well have the mold for the shoal keel in stock.

Even though this was large-volume business, the margins, as with most builders this size, were “cut throat,” admits Milne. Then it got worse. MarsKeel was also supplying keels to Florida-based Hunter Marine (now Marlow-Hunter), but all business with Hunter, and a number of other production builders, ground to a halt after the 2008 recession, which devastated the boating industry, especially the sailboat segment. The lead-keel business was further hurt by the huge increase in commodity prices at the time. When lead jumped from 80¢ per lb to $1.50 per lb, it raised the price of a delivered keel to over $2.50 per lb. With cast-iron keels being delivered at about 80¢ per lb, a number of sailboat builders were forced to retool their keels and switch to lower-density, greater-volume iron, which could potentially save over $10,000 per boat. Although this was a blow to MarsKeel, it had already taken steps to diversify.

The company had made itself indispensible to the production sailboat market by supplying keels that were ready to install. However, to serve the expanding one-design market, especially companies like J Boats (at the time being built by TPI), Mars developed the ICB, or integral cast bulb, keel. It is formed by attaching an integrated triangular flat-bottom lead bulb to the bottom of a cast or welded structural airfoil-shaped fin. This lowers the center of gravity of the ballast as much as possible, and greatly increases sailing stability.

Initially, the company produced fins from solid nickel-aluminum-bronze (NAB) alloy C95500, chosen for its light weight, strength, and resistance to corrosion. NAB fins were suspended over, and extended into, the split mold for the lead bulb. The lead was poured into the mold, locking the bulb onto the fin without requiring fasteners (see the Rovings item “Thin Is Beautiful,” PBB No. 54, page 22; and “Keels and Rudders: Engineering and Construction,” PBB No. 96). Recessing at the intersection of the cast bulb and the fin allowed the addition of epoxy-laminated Kevlar tabbing to prevent thermal cracks at the joint. This process was originally used on the J/90 (32′/9.2m), and then the larger J/125 (41′/12.5m), and J/145 (48′/14.7m). It is still used on the J/111 (32′/9.2m), but with a welded stainless steel fin instead of the NAB cast alloy.

Its success with J Boats led MarsKeel to cast keels for a number of other TPI models, such as the Alerion line, and to employ ICB keels on some of Morris Yachts’ higher-performance boats.

Scaling Up

As the production-boat market was faltering, the custom-superyacht market was not, especially in Europe. Realizing this, Milne hired Willem Vraets, based in Amsterdam, The Netherlands, to promote the company’s interests in Europe. While MarsKeel had displayed at the gigantic Marine Equipment Trade Show (METS), in Amsterdam, for several years, in 2013 Milne decided to display instead at the Monte Carlo Yacht Show. He felt that this was much closer to MarsKeel’s desired market, and the show produced a number of good contacts and brought the company increased visibility in European markets.

Cast-lead production sailboat keels await shipping. With a combination of low center of gravity—achieved with the use of a triangular bulb—and elliptical planforms for reduced drag, the modern sailboat keel has become a complex and sculptured appendage.

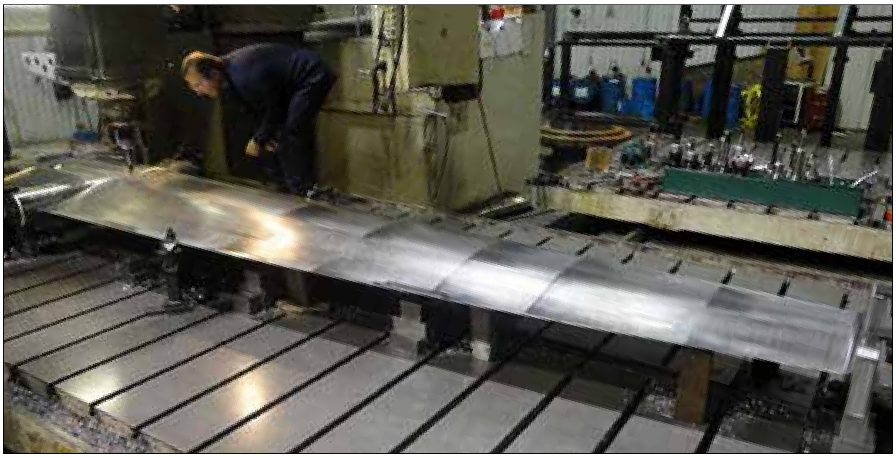
About eight years ago, the company started casting keels for Southern Winds Shipyard in Cape Town, South Africa, beginning with a 50,000-lb (22,670-kg) bulb and fin for the Farr-designed SW 100 RS (99′/30.2m). Projects for Southern Winds Shipyard now range from 82′ to 120′ (25m to 37m), with boat designs by Farr and Reichel/ Pugh. Their keels are cast-lead torpedo-shaped bulbs on welded-steel fins. In this way, the bulk of the weight is kept as low as possible to provide sailing stability in the form of a streamlined bulb, and the fin becomes a structural cantilevered beam in bending to support the lead as the boat heels. At the same time, the air-foil-shaped fin generates the required hydrodynamic lift on the high-aspect-ratio fin, the bulb providing an end-plate effect to increase the lift/drag ratio and foil efficiency. The loading at the root of this fin as it attaches to the hull, and the concentrated bending load of the fin and ballast on the hull itself, are considerable. Both must be well understood and well engineered.

To provide such advanced design and engineering services, the company worked with two other firms to create the MarsKeel Group. MarsKeel's Bill Souter, who is in charge of technical keel sales and design, consults with experts Dave Fornaro, of Ariston Technologies, and Steve Burke, of Burke Design. (Keel shape, weights, and center of gravity locations are designated by the specific design office involved). Fornaro provides structural and design services on complex keels, and he will produce the working drawings with all the weld details required to build the keel, especially the welded-steel fin. He often accompanies MarsKeel personnel on trips to Europe to meet with potential superyacht customers and builders. Burke is brought into projects for composites engineering.

As boats continue to increase in size, they require reduced draft to allow their access to common cruising grounds and harbors. A shoal-draft fixed keel, like the 153,500-lb specimen cast for *Scheherazade*, reduces draft, but can also compromise sailing performance. That's because it's necessarily heavier, and it has less hydrodynamic efficiency. To fix this, powerful hydraulic mechanisms with solid material bearings can lift the keel into the hull, but that introduces some challenging design requirements, as the ballast keel transitions from a static element to a dynamic element. In addition to the commonly accepted hydraulic systems, MarsKeel has evaluated ball screw jack systems. While they have more than enough power to lift the weights involved, achieving the speed required to lift these massive keels is challenging.

To simplify the installation of the many components involved in a lifting keel, MarsKeel has developed a cassette system in which the entire assembly is housed in its own structural box and is attached to a mating structure in the boat. This again is a logical extension of the ready-to-install philosophy established when the company was founded.

Final keel assembly of ballast, trim tab, and wings for the New Zealand 12-Meter NZ-7 Kiwi Magic*, designed by Bruce Farr. The first 12-Meter built of fiberglass, she lost to* Stars & Stripes 87 *in the Louis Vuitton Cup for the right to challenge defending champion* Kookaburra III *for the America's Cup.*



MarsKeel has access to this CNC router with a 60' x 20' (18.3m x 6.1m) table. Shown here, a welded steel fin for a retractable keel is machined.

For projects this complex, MarsKeel is usually involved early in the design phase, although, in reality, the fabrication and final keel design are often later areas of design; that's because the final ballast weight may well be influenced by the recorded weight of the boat as it is being built. This engineering work, if supplied by the MarsKeel Group, usually appears as a line item on the final invoice, with the final cost of the keel itself representing, on average, approximately 5% of the cost of the total project.

MarsKeel finds that its North American location is not an impediment to being competitive in the European market. Indeed, if the keel and bulb, properly supported, can be loaded into an open-top container, shipping costs and logistics are seldom a problem. Shipping considerations may well determine if the bulb is integrally cast to the fin or bolted in place. If the finished assembly cannot fit in a container, provisions must be made to ship it by whatever means suits the project.

Keels are designed as precise airfoils to achieve the optimum lift/drag ratios, so they must be accurately machined to the final shape from IGES files supplied by the design engineer. In addition to its own CNC router, the company has access to a large CNC mill, which has a maximum horizontal boring mill with a 60′ x 20′ (18.3m x 6.1m) table and a lifting capacity of 60 tons. The machined finished surface usually offered has scallop depths of 0.005″ (0.13mm). Although more time in the mill will produce a mirrorlike finish, a minimum amount of surface "roughness" is required to achieve proper primer and paint adhesion.

While the bulb is always a lead casting, the fin can be produced in a variety of materials and by different methods. Perhaps the simplest is traditional cast iron with a lead shoe bolted in place for standard shoal- to moderate-draft boats. For higher-performance vessels with deeper draft and lighter displacement, the choices include a fin cast in NAB; a fin welded from mild steel plate and sheet; a fin from 316L or Duplex 2205 stainless steel; or one that is produced with A514 or CHT-100 high-strength steel plate. MarsKeel has produced fin-keel combinations from a 400-lb (181-kg) stainless steel fin supporting a 1,100-lb (499-kg) bulb, up to a 7,650-lb (3,470-kg) welded mild-steel fin supporting a 61,200-lb (27,760-kg) lead bulb. The internal structure of these welded fins can get complicated, especially if designed for hydraulic lifting. Like the NAB-cast fins, the welded fins, too, can be CNC-faired, as long as additional skin-plate thickness is specified to account for the removal of some material.

Like cast fins, the welded fins are bead-blasted, primed, and coated with two layers of InterProtect 2000 epoxy before sanding, final fairing, and the application of several more layers of epoxy. They are then either dry- or wet-sanded to a final 320-grit surface.

The keelbolts for fastening the fin to the hull—or the bulb to the fin—are also made in a wide range of materials. The choices include basic 304 and 316 stainless steel, Duplex 2205 stainless steel, C95500 NAB, and Aqualoy 22.

Draft Reduction

The decline in production sailboat building means that many sailboats designed with deep draft for race performance are now almost exclusively used for cruising or club racing. Most of these past racers had drafts in the 6′–8′ (1.8m–2.4m) range, which makes

At MarsKeel, a technician examines a machined, faired, and epoxy-coated steel fin to ensure that it's ready for the bolt-on bulb.

it difficult for the boats to access a lot of cruising grounds, especially on the Great Lakes, where water levels have dropped dramatically in recent years. MarsKeel offers a fix to this problem with its draft-reduction service. For about $6,000 the company supplies a bolt-on two-piece bulb that attaches to the sides of a shortened keel; the retrofit achieves sailing stability comparable to that of the original deep-draft keel. MarsKeel works with the boat owner and the yard doing the work to determine how much keel should be cut off and the weight of the required bulb, chosen from a number of existing split-bulb molds. In the 20 years since this service has been offered, Milne figures the company has provided over $1 million worth of bolt-on bulbs.

Left—*The company offers a draft-reduction service that advises how much this deep-draft iron keel is to be shortened to allow the boat's access to shallower water.* ***Right***—*Sailing stability is restored with a MarsKeel bolt-on split lead bulb, installed by the yard doing the retrofit.*

Bulbs can also be added to iron keels, but while lead can be cut with a chainsaw, shortening iron requires more advanced technology. In some cases, the bulb can be designed to extend aft of the trailing edge of the keel, which not only allows for a larger bulb but also results in a cleaner-looking installation. In all cases, the yard or owner supplies a horizontal template of the keel in way of the bulb, so Mars can incorporate the appropriate curvature into the mating surfaces of the split bulb for a tighter fit to the fin. The bulbs come pre-drilled and countersunk for the 316 stainless steel threaded rods and nuts, and washers, for quick installation by the yard.

Mars also does a lot of insurance work on bent and damaged keels sent to the company by repair yards. These repairs often involve keelbolt removal and replacement. In some cases, a new keel can be cast using existing inventoried tooling.

Out of the Water

Because lead is one of the densest materials on the planet, it offers excellent protection and containment for radiation and X-rays. As part of its diversification, Mars Metal has turned to lead shielding for radiation in medical and nuclear applications. Growth in these markets now accounts for almost 70% of its annual sales. The MarShield line of containment products includes a wide range of lead-lined stainless steel storage cabinets for radioactive materials, while shielding products include lead screens, walls, bricks, and barriers. With the rising number of X-ray inspections of trucks and containers by customs and immigration agencies at national borders, the company has seen increased sales of its lead brick and lead sheet products. Because this is a distinctly different market, the MarShield division has its own specialized sales and marketing arm for these products.

In addition to MarsKeel Technology and MarShield, the Specialty Casting division produces lift-bridge counterweights and mine shaft elevator weights. This division also distributes lead shot and sheet lead, and produces lead ingots.

In addition to the large CNC mill shown on page **xx**, *MarsKeel employs this in-house CNC router for machining versatility in its casting operations.*

Mars Metal has updated its lead-manufacturing capabilities with the recent addition of an in-house CNC router for precision machining lead components (which most companies are reluctant to handle) and producing patterns in wood and high-density foam.

While it remains committed to the marine industry, Mars Metal, like many other companies, has found other markets that have allowed it to prosper during the cyclic ups and downs of the sailboat industry. PBB

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