Casting a lead keel for your model yacht isn't too difficult, but does require a certain amount of specialized equipment and certain precautions to guard against personal injury and property damage. This article will show you how to cast a keel using the sand mold method. I will also make a few comments regarding the plaster mold method, and of course much of the process applies to either method.

**TOOLS and EQUIPMENT NEEDED**
- Block of wood for a pattern
- Table saw
- Stationary belt sander
- Accurate scales
- Foundry sand
- Lead metal
- Aluminum sheet or plate
- Propane burner or stove
- Crucible
- Leather welding gloves
- Face mask
- Auto body filler such as Bondo

**DESIGNING the KEEL**

The first step is to design your keel. This consists of determining how heavy the keel will need to be, what shape it will be, and how it is to be fastened to the keel fin or deadwood. The design of the keel will be dictated by one of the following:

1.) You are accurately building a model from detailed plans, and the ballast weight and shape are given on the plans. This assumes that all of your scantlings are as per the plans and the weight of your completed hull minus the ballast conforms to the design.

2.) More commonly, model boat plans consist only of a set of exterior lines, with the design water line and overall displacement given. In this case, you must measure or estimate what the finished hull will weigh complete with rig and fittings, and then subtract this from the design displacement to get the ballast weight. Often, the designer will include a ballast weight and its C.G. location on the plans, but this will only be an estimate since he doesn’t know what materials you will make the hull from. Fortunately, boat designs are generally pretty forgiving of variations in the displacement. You can be over or under by 10% and find that the waterline has hardly moved.
3.) Specific class rules may set limits on your design, such as: A-boats and 10-raters have rating formulas that include the waterline length. Deviating from the design displacement will thus have an effect on your allowed sail area. San Francisco club rules limit the draft of X and M-class boats. Thus a heavier keel may necessitate shortening the keel fin a little. X-boat rules don’t permit prognathous keels (i.e. the keel bulb may not project ahead of the keel fin). The X and M-classes have overall minimum (but not maximum) weights. If you are building a class boat, review the rating rules carefully before making your keel.

4.) If you are building a model boat scaled down from a full sized yacht, your keel design will have to differ from the original or else the model will not perform well. This is because the sail area is scaled down by the square (it is a planar area), whereas, the displacement is scaled down by the cube (it is a volume). Thus a scale boat will have a displacement far too small to support the scale sail area. The slightest breeze will lay it over. For example, a half-scale model yacht will have $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ the sail area, but it will have $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$ the displacement. The solution is to make the keel fin longer, doubling the draft. If you want an authentic-looking display model for your mantle piece, yet want it to sail well too, then you will have to devise a removable display keel which can be replaced by a deeper one to sail with.

5.) The best way to determine the ballast weight and C.G. is to directly measure it by floating the hull in a testing tank with weights added inside to simulate the ballast. (Photo 1). Keep adding weight and position it fore and aft to
bring the hull to the desired waterline. Mark the C.G. of the added weights directly on the inside of the hull with a marking pen.

Remove the weights and measure them on an accurate scale. Subtract from this reading the estimated weight required to finish the boat (deck, rig, fittings, vane). Finally, multiply your answer by 110% and you've got your required ballast weight plus it's location. This final 110% adjustment is necessary because the weights you've been putting into the hull have been in the open air, i.e. total weight. The finished keel, however, will be displacing additional water not measured in the testing tank. Thus you need to convert to buoyant weight. Lead has a specific gravity of 11.37, or 0.4108 pounds/cubic inch. Underwater, however, this becomes 11.37 – 1.00 = 10.37, or 0.3747 pounds/cubic inch.

**MAKING the PATTERN**

6.) Begin by squaring off a piece of wood, then weighing and measuring it to compute the density of the wood. Once you've got the basic density of your pattern material, it's easy to monitor the number of cubic inches you've got at any stage of the shaping process (Photos 2, 3).

7.) You've determined the weight of lead needed by either ballasting the unfinished hull in a testing tank, or by taking the weight off the boat's plans, if given.
8.) Convert the weight of lead to cubic inches: the buoyant density of lead is 0.3747 pounds per cubic inch. Thus, for example, a 10 pound keel needs 26.7 cubic inches. Lead shrinks significantly as it solidifies, so add a bit to this value. Also, it’s easier to take off a little if heavy than to add lead if light, so I err on the heavy side. It’s volume in cubic inches, using the previously computed density of the wooden block. The advantage of this method is that it applies to any irregular keel shape.

9.) Shape your keel pattern from the wood block, initially with a band saw, followed by a stationary belt sander (Photos 4, 5). Weigh it periodically to compute its volume in cubic inches, using the previously computed density of the wooden block. The advantage of this method is that it applies to any irregular keel shape.

10.) Note from the pictures: marking the centerline of the pattern to enable bedding it in the sand halfway deep; marking the C.G. of the pattern by balancing it on a triangular file; marking the leading edge of the keel fin insert; and or marking the locations of any bolts to be cast in. Varnish the pattern, and when the casting is done, write the finished weight on it (Photos 6, 7).

MAKING the MOLD

11.) Build a two-part casting box as shown. Casting box halves need to be aligned with overlapping plywood scraps. Mark box halves to avoid accidentally reversing one half. Box halves must be securely held together with clamps, screws thru the plywood scraps, or dead weights on the top half. Failure to do this will result in the top half being lifted by the fluid lead and molten lead running out the sides of the mold onto the floor (Photos 8, 9).
12.) Foundry sand is a special sand. It’s made with a little clay and a special oil, so it can be pressed together and hold a shape as if it were moist while containing almost no water. Talcum powder is used as a release agent on the pattern as well as to separate the lower box sand from the upper box sand. The sand needs to be packed in medium tight. Loose sand will float to the top of the cavity. It’s important that the pattern be set exactly to its midpoint, using the line drawn around it in step 10 above. A rubber mallet is useful here, as the pattern can be firmly tapped into the sand without denting the wood. Sprinkle talcum powder on the top of the sand filling the lower box, then place the upper box and fasten it down. Fill and pack sand around the upper half of the pattern, filling the upper box completely (Photos 10 thru 16).
Transfer the line on the pattern marking the forward edge of the fin knockout to both sides of the lower box, using a trisquare (Photo 14).
13.) Remove the upper half casting box (Photo 18). The pattern will usually remain in the lower half. It can be carefully dislodged using a sharp awl or pointed knife (Photo 19). If a little sand breaks loose at the midline when the pattern is removed, it’s most often best to blow away the loose sand and leave it alone. After the lead is poured, you will just have a bit more cleanup to do along the join line. Trying to repair such breakouts requires that the pattern be reinserted to do so. If the breakout sand isn’t firmly tamped, it will come out during pouring and float to the top of the pour cavity. Drill a pour hole and a vent hole thru the sand of the upper mold half, using a \( \frac{1}{2}'' \) drill held in your fingers. Carve the sand into a funnel shape around the pour hole on top (Photos 20, 21). Blow off any loose sand and set the upper box aside. Remember, these holes need to miss the aluminum knock-outs.
14.) Knock-outs for the keel fin may be shaped from aluminum sheet, or more crudely an unshaped piece of aluminum plate. Lead will not stick to the aluminum, which can be hammered out after the lead has cooled. The knock-out doesn't really have to be a close fit to the fin shape, because the fin will ultimately be set into the slotted lead with Bondo, which is gap-filling. Casting a solid bulb with the intention of drilling/sawing/filing a slot in it later would be a lot more work. I don't recommend it (Photo 22).

Mark the lower casting box with the position of the knock-out using the fin leading-edge mark previously drawn on the wood pattern, then using a straight edge across the lower casting box, insert the knock-out on center by pressing it into the sand. If the keel fin is raked, note that the fin location marked on the top of the pattern will be different than the location at the middle of the pattern. Shaped sheet metal will displace less sand than solid plate and will require less detail clean up. Try to embed the knock-out entirely in the lower box, with the top of the knock-out about at the top of the mold cavity. If the knock-out is set too high, it will embed itself into the upper box sand when the two box halves are joined. This will risk dislodging loose sand into the cavity, or worse, breaking out a big chunk of sand out of the top. Remember, the top isn't backed up by a piece of plywood like the bottom is, so you can't press against it very hard.

Alternatively, The pattern may placed in the box on it's side, and an extended knock-out can be supported horizontally on the two sides of the lower casting box.
This is more accurate, but requires that the casting box halves be recessed to take
the knock-out. When casting in bolts (i.e. stainless steel all-thread), this latter
method must be used, with the extra-long bolts passing all the way thru the keel, to
be cut off flush on the underside after casting (Photo 23). A traditional A-boat keel
is shown.

15.) Assemble and clamp, screw together, or weight down the box halves.
You’re ready to pour.
16.) If you’ve screwed up somewhere, it’s no big deal to re-melt the lead and
start over.
17.) One word of caution: if you're casting in bolts for an already existing boat, requiring exact placement of the bolts to match already existing holes in the deadwood, be aware that when the lead changes state from liquid to solid, it shrinks. I found that the bolts cast into the A-boat keel pictured had moved closer together by about 1/16” or a little more.

18.) If you don’t have or can’t get foundry sand, a mold can be made from plaster of paris. I’ve never done this, so cannot say much about it except this: the mold must be baked in the oven long enough to drive out every trace of free moisture from the plaster. If the plaster is at all damp, even just a little, the mold may crack or even explode.

**CASTING the LEAD**

19.) Lead can be melted over a propane burner, using a proper crucible, or even a coffee can and vise-grips. Heavy gauntlet style leather welding gloves and a face shield are a must. The work must be done in a well-ventilated area over a surface that won’t be damaged by spillage. The kitchen stove is not recommended. Note that the crucible pictured has a sliding grip, so it can be kept cool while the lead is melting, then slid up close to the pot when ready to pour. In planning the operation, bear in mind that in a worst-case scenario, you may have to drop it, so don’t get too complacent, and do maintain a wide area of clear floor all around (Photos 24, 25).
20.) An adequate amount of lead should be put into the crucible before heating. That way, any moisture adhering to the raw lead will be driven off as it warms. Adding more lead to an already melted quantity can be dangerous in case it contains any moisture. Even a single drop of water will cause the molten lead to explode in your face. Use a large metal spoon to stir the molten lead and skim off any slag.

21.) Metallic lead (as opposed to lead compounds) is not much of a health hazard, but lead vapor can be. Don’t heat it more than or longer than necessary. Pour it promptly when ready. As lead inside the mold cools and solidifies, it will shrink. You may find that your pour hole will need to be topped off once or twice (Photo 26).
FINISHING the KEEL

22.) Remove the cast keel from the mold boxes after it has cooled. Most of the foundry sand can be recovered and reused except for the scorched bit in direct contact with the lead. Wash off all traces of sand and cut off the sprues resulting from the pour hole and vent hole. Cut off any lead that may have protruded along the centerline between the mold halves. Knock out the aluminum insert (Photo 27).
23.) Check the weight. It’s quite difficult to alter the weight as cast. If it’s way off from expectations, you may as well start over. If it’s fairly close it won’t have much effect on the waterline length, draft, or sailing qualities. If you absolutely have to take some weight off, say to meet a class rule, there’s really only one way to do it: with a hand-held electric planer, or with a joiner. Using a file or sanding it off will get you nowhere. Now using an electric hand planer or joiner might strike you as nuts, but it really works! Two difficulties are a.) with a joiner, take particular care not to lose any fingertips, and b.) unlike wood shavings which settle to the floor behind the machine, lead shavings fly all the way across the shop. The blades actually cut the lead so effortlessly that you won’t even feel any resistance as you make each pass.

24.) Lead can be difficult to drill, as it tends to grab the drill and bind it tight. If you must drill it, use plenty of thin oil or kerosene and don’t force it.

25.) For final smoothing, rather that trying to sand the lead surface smooth, it’s better to coat the entire keel with a layer of Bondo and sand the Bondo surface smooth. This will require more than one coat and some patience. A plaster mold will make a smoother bulb than a sand one, but note my warning in 18.) above (Photos 28, 29).
26.) For a traditional keel, you will have cast in mounting bolts. But for a fin-and-bulb type keel, you will have cast in a slot using an aluminum knock-out. To fasten this type of keel to the fin, I’ve had success using Bondo. Simply rough up the inside of the slot by scoring the lead with a pointed tool, and use rough sandpaper on the (fiberglass-coated wood or metal) fin. As an adhesive, Bondo is not particularly strong, but in this application there are more than enough square inches of contact area and it’s particularly formulated to adhere well to metal. It’s also gap-filling and easy to use. I’ve never had a keel bulb come loose. No fasteners are necessary (Photo 30). The fin shown has been fiberglassed, although this may not be apparent in the photo. I wouldn’t Bondo in bare wood.

27.) For a traditional keel, bolted thru deadwood, you can be sure that a crack will develop between the lead and the wood. Thermal expansion/contraction of the lead, and moisture-caused swelling/shrinkage of the wood, not to mention the physical stresses in operation will all combine to work this joint open. Therefore, the bottom of the deadwood must be thoroughly painted or varnished before bolting up the lead, including the insides of the bolt holes. The bolt holes themselves need to be sealed with o-rings or a sealant. If you don’t anticipate ever having to remove the ballast, you can slather the join with 3-M 5200 polyurethane adhesive sealant, or surround both keel and deadwood with fiberglass.

Well, that’s all there is to it. As I said at the beginning, it doesn’t take any special skills, but it does require some special equipment and materials. Most everything can be reused when making more castings, as little but the lead itself is consumed.