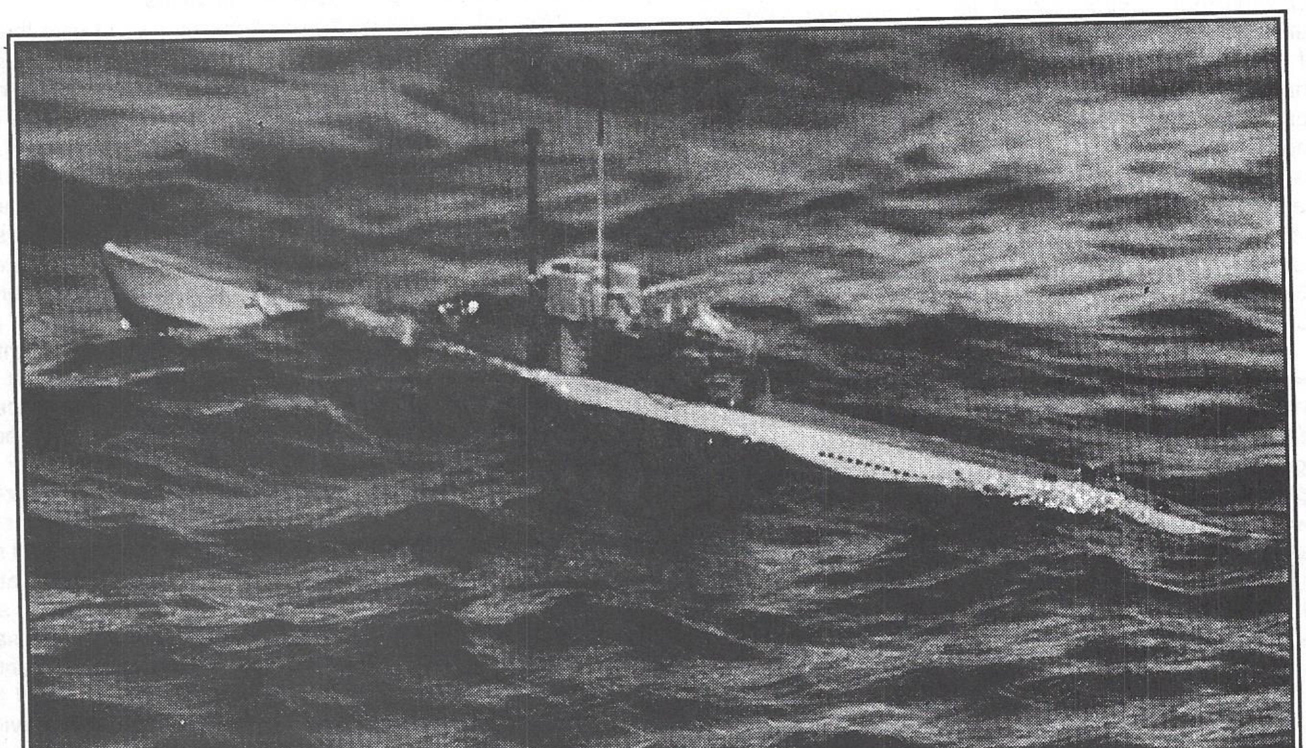
Model Submarines IN DEPTH!

by *Skip Asay*



From the series originally published in Flying Models magazine

The September 1990 issue of Flying Models magazine included the first installment of a series dedicated to making R/C model submarines work. I wrote that series as a means of sharing some of the lessons I had learned in the 13+ years of successful (and sometimes not so successful!) operations I had enjoyed (at that time). The amount of interest in that series has really surprised me, as well as the editors of FM who report that those are among the most wanted back issues. After spending so many years thinking that I was one of a fairly small group, I admit to a good deal of shock. Since then, mostly as a direct result of The Subcommittee, I've seen a tremendous number of fellow "bubbleheads" come out of the woodwork as well as many "crossovers" from the ranks of the flying and "target" end of the model hobby. I sincerely hope that making this series available again will help expand the ranks even more. This should not be confused with "The Book", however. I am trying to have a definitive book on R/C model submarines available by January '95.

It should be understood that this is basically a re-release of what was printed in Flying Models. I have made very few changes to the basic text itself.

I have taken some liberties in this rewrite in the form of describing the products I have made available through my company, **SubTech**. These products have resulted from the experience accumulated over many years and are designed to make building and operating a model submarine easy, reliable, and fun!

"There are two types of ships - Submarines and Targets". A well-known submariners' phrase, to be sure. However, as far as R/C is concerned, submarines are actually bigger targets. The shells, depth charges, and torpedoes being fired at them come from all directions (and depths) and yes, even from within. These attacks come in the form of negative thinking and lack of thinking as well as lack of common sense.

When I started construction of my first sub (over 20 years ago), I pored over every article, letter, etc. I could get my hands on. I spoke to every modeler I could locate and every so-called radio "expert". All had the same response - "it won't work". "Radio doesn't penetrate water" was the most common reason offered as well as "too much engineering required". "Water pressure will crush it" was another beauty and let's not forget "what good is it if you can't see it?". It won't take much to see that everyone knew why it wouldn't work but none of these supposedly knowledgeable people had ever put any effort into proving their theories.

This was the catalyst that got me going. Besides being a dedicated student of submarines in general and World War II German U-Boats in particular (which by itself made me want to build one), I love a challenge. I made up my mind to find out why "Submarines won't work". Well, after over 17 years of successful operations with 4 boats of my own and direct involvement with many others, the results are in. Submarines DO work and quite well at that. In this period of time, others have proven the feasibility, too, but between us we have disproved all the so-called experts. There is no "black magic" involved, an engineering degree isn't needed (I have no formal training in engineering) and a tremendous amount of experience isn't necessary (except for some rubber powered airplane kits for the kids, my first model, first sub, first R/C anything, worked). It doesn't even require a large amount of time (my entirely scratch - built Type XXIII U-Boat took 6 months from enlarging drawings to launching). It does require a healthy dose of common sense, a positive attitude ("How can I make it work?" rather than "I don't know but maybe"). And, of course, a plan of action. Another ingredient which is very helpful but not altogether necessary is K.I.S.S. - Keep It Simple ------ (In my own case I use "Stupid", but I'd rather not chance offending any readers). This does not mean to reduce operating functions, but to keep the mechanics of those functions as simple as possible.

Now if any of you are wondering what all of this is leading to, let me explain. I feel that there are many people who would love to build subs of their own but because of all the negative press that's been around for so long (and still is today even though submarines are so popular), they are steering clear and either settling for the comparatively mundane 2 dimensional left-right forward-backward world of surface ships or just not building at all. (Before anyone starts getting the wrong idea, I am not putting down the surface ship community. After all, we need targets, don't we?) I would like to try to change that. There are few things to match the thrill of watching your sub slowly glide beneath the waves and then maneuver ever so slowly into that convoy ahead (ducks) and all the while maintain a crisp, clean periscope depth, followed by a smooth scale-like surfacing to check for "survivors".

What follows will be an effort on my part to give the reader as much information as possible, based on my experiences as well as others, to help avoid some of the pitfalls found in model submarining. I have no intention of spending any time on how to go about building hulls or the scale detailing involved. These are items which are best left to the individual builder him (or her) self, and the modeling press has devoted a tremendous amount of ink to this part of it. Neither will this be a step by step "HOW TO". What I will concentrate on, in detail, are those areas that pertain to the OPERATION of a model submarine. This includes the ballast system, watertight integrity, control functions, general layout, trimming and the all-important "what do I do the first time I put it in the water?". One point I must emphasize, though, is that my own personal preference is for almost totally scale operating which means scale speeds and scale handling characteristics. Except for the nuclear attack boats and "boomers", there really aren't any full-size submarines that leave a rooster tail behind the periscope and I don't think there are any that come up on a plane at full speed, so I don't build my boats to do those things. Moving at scale speeds means that it is somewhat more difficult to, among other things, maintain that periscope depth so necessary for "stalking a convoy". But these are my own requirements and the nice thing about model building is that you build to suit yourself and not somebody else unless you are heavily into scale competitions. What I hope to do is help with some potential problems that I learned the hard way and if it triggers some new ideas along the way, so much the better!

One of my ultimate goals is to attend a show that is strictly for submarines and to be able to do that, there have to be more submarines built. So stay tuned and I'll try to help you get around, over, (and under) some of the obstacles I've encountered. Model submarines are really a heck of a lot of fun and certainly worth the extra effort!

Ballast Systems

There are a variety of methods available to the model builder to enable his pride and joy to surface after being the "Enemy Below". Please note that I said "surface". There is no secret involved in getting your boat to go under. There are many non-submarines that have performed this daring feat. The trick is to bring your boat back to the surface on command.

The most popular methods include pumping water in and out of the tank using a windshield washer pump or similar device, pumping water in and out of a hospital I. V. bag, piston-type variable size tanks (MRC/Engel), or Propel (airbrush propellant)/compressed air. If anyone has noticed I haven't mentioned "dynamic diving", congratulations. You're obviously paying attention. The reason for this omission is not that I don't consider this type of boat to be worth mentioning, but, quite simply, there is no ballast system involved.

Let me highlight some of the good and bad points of the above-mentioned systems. The worst type, as far as the boat's safety is concerned, is the plain pump system. The reason for this is the fact that the boat MUST have the periscope, snorkel or some type of air pickup tube above water to be able to pull air into the tank to surface. Now by itself this is not a major thing, but let's look a little deeper. The radios we have available today are very reliable; however, they are not perfect. In the event of a radio failure there's nothing you can do except go for a swim. The same holds true if the boat should get tangled in weeds, stuck in soft silt, or if the drive battery doesn't have the oomph to drive the boat back to the surface. Now I'm sure that some of you are saying that with positive buoyancy, none of these occurrences are a problem. To a certain extent this may be true, but for true scale-like submerged operations the closer to neutral buoyancy the better. I'll cover this aspect in the installment on balancing and trimming.

The second system (I.V. bag), which still uses a pump, eliminates most of the above problems except one. Since most windshield washer pumps use a fairly heavy amount of current, a weak battery can still force you to go for a swim. Another short-fall is that you have no real indicator to stop you from overfilling the bag which will make the boat too heavy and consequently too difficult to handle when submerged. Something to keep in mind is that one ounce of water displaces a little less than two cubic inches. With a flexible bag, it's next to impossible to fill that accurately every time and since one ounce can make all the difference in the world, I would rather stay away. I have seen the use of a micro-switch which is activated by the swelling of the bag, but this is not as exact as needed. Using windshield washer pumps has another drawback and that is that their flow capacity is pretty small, which means that it takes too long to submerge and surface.

The variable size tanks as used by MRC/Sun Lane (Engel) consist of a cylinder in which one end moves in and out on a threaded rod powered by a separate electric motor for each tank. When the movable end of the tank is all the way down to the fixed end, the tank itself is empty of water and the boat floats on the surface. When the movable end is at the other extreme, the tank is full of water and the boat is now heavy enough to submerge. The good side to this system is that the volume of the tank is fixed and the difference between surfaced and submerged displacement is exactly the same every time. Unfortunately, these tanks are relatively small requiring the use of 2 tanks in a larger-sized boat. The threaded rod sticking out of one end of the tank also forces the need for a considerable amount of free space inside the boat or, at best, a fair amount of juggling of hardware within an already crowded area. Since this system uses 2 motors (1 per tank), each of which needs a substantial amount of battery power, a weak battery can be a problem just as with the previous two methods. These tanks must also be mounted inside the hull, which leaves several more points of potential leakage.

This brings us to the final method, which also happens to be my favorite. Originally, I mentioned Propel and compressed air together. While the result is the same with either one, there is a world of difference between them. To be able to store enough compressed air to allow a sufficient number of surfacings, a very high pressure is required which can be dangerous as far as the boat is concerned (can you imagine a leak inside a sealed pressure hull?) and, of course, can be dangerous to you or anyone around the boat. It also requires a very strong and thus heavy storage tank, piping and valve. One way around this would be to have a small reservoir and an onboard compressor which could replenish the necessary air for the next surfacing. However, several things can happen. One, the compressor is going to need a substantial amount of current to operate, just as the pump-type systems previously described; two, only enough air for one, or at most two, surfacings will be available depending on the size of the tank and the pressure of the air inside it. Finally, it takes time to pump up to the required pressure and, from the shore, how will you know when to turn off the compressor?

With Propel, none of the above problems exist. Propel is stored in a liquid state when under pressure and expands tremendously when released, allowing many "blows" from a small-volume storage tank. For example, my Type XXIII U-Boat has a Propel storage tank with a capacity of less than four and a half cubic inches and still allows at least 20 "blows". This is with a ballast tank capacity of 32 ounces of water or approximately 55 cubic inches. Now, while Propel is stored under pressure, this is only in the range of approximately 30 - 60 P.S.I., which is a whole lot safer than the pressure involved with compressed air alone. Half or three-quarter inch copper pipe makes a very nice, easily constructed tank which is quite capable of handling this pressure. An added benefit is that, since the Propel is in liquid form in the storage tank, it has weight. When the tank is empty, the boat will now be lighter. What this means is that you have a built-in indicator of when the tank is empty since the boat will now be too light to submerge. Built-in positive buoyancy!

Another added benefit is that if the boat should become entangled in weeds or stuck in soft silt preventing it from surfacing, you have a locator in the form of a bubble patch to point out exact location. This happened to me on one occasion and when I returned the next morning with a diver, the boat was back on shore within 3 minutes after the diver entered the water. The visibility in this lake was approximately 2 inches and depth about 10 feet. I've gone swimming after my boats before, but when you add large snapping turtles to the depth and visibility problem, discretion was the better part of valor.

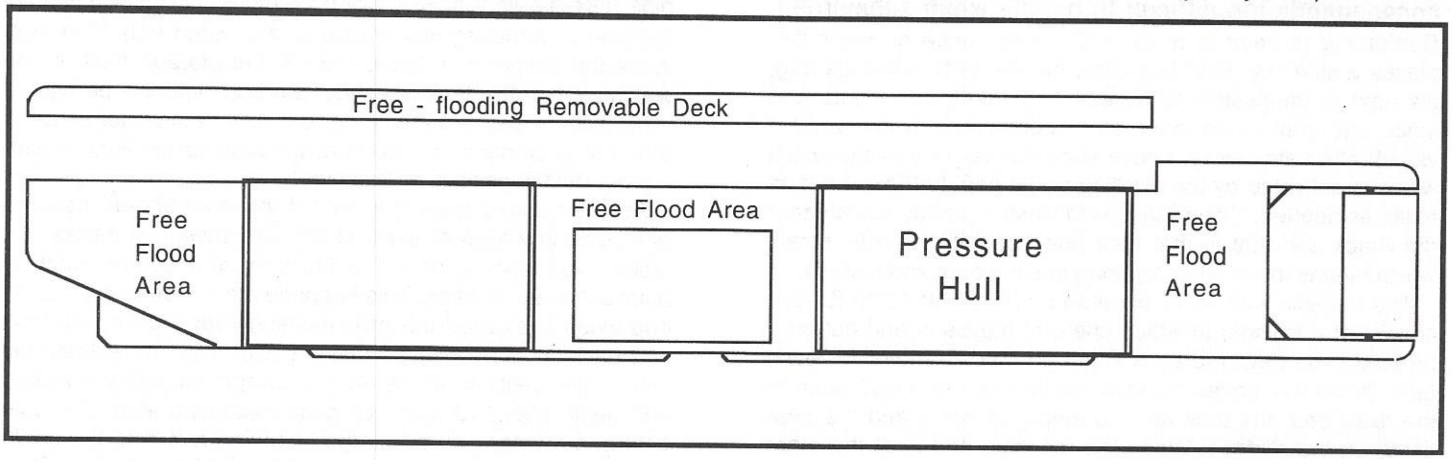
The next important factor in the ballast system is whether to use one tank or two, and where to place it them. Since we are dealing with a miniature version of the real thing, the best and simplest thing to do would be to follow full-size practice and use a single tank mounted midships. Yes, I know, full-size submarines have a multitude of tanks positioned from bow to stern but the MAIN BALLAST tanks are usually MIDSHIPS. The other tanks are trim and compensation tanks and generally not used as diving ballast. In our situation, trim is best done with small pieces of lead judiciously placed. A separate tank and attendant system is not necessary and would just add to the complexity of the model (remember K.I.S.S.?). The main reason for one centrally-mounted tank is simplicity. With two tanks, a lot of time is necessary to ensure that the forward tank fills slightly faster than the aft tank when submerging and empties faster when surfacing. Without this, the boat dives stern first and surfaces the same way. Not too scale-like, is it? Another thing to keep in mind is that with two tanks, the forward tank will almost certainly have to be larger than the aft tank but then the question is, how much? A single tank, properly positioned, prevents this. The need for extra piping, valving, circuitry, etc. just doesn't exist. (Again - K.I.S.S.)

At this point, I should explain exactly what the ballast tank actually does and what to look at as far as size is concerned. Yes, it does make the boat heavy enough to submerge, but if the tank is too big and you fill it completely, the boat will be too heavy and, at best, require very high speed to control. At worst, it becomes an ornament on the bottom for the fish to admire. What if I don't fill the tank all the way, you ask? Fine, but how do you know where to stop filling? If the tank is too small, the boat won't be able to submerge all the way, thus again requiring very high speed to control. A compromise with a small tank would be to have the boat float at a lower-than-scale waterline, looking waterlogged. How impressive will your pride and joy look then? Generally speaking, the ballast tank has a volume roughly equivalent to the volume of EVERYTHING above the waterline. What this means is that if you cut your boat lengthwise at the waterline and then put everything you cut off in a tank that is full of water to the very top, the amount of water that runs out is almost exactly how much the tank should hold. For me, the simplest way to figure out how large to make the tank has been - are you ready? Guesstimate! That's it. I've tried to use all the mathematical formulas and still had to change the size. Why not make the tank removable and then through trial and error figure out the optimum size? It sounds crude, I know, but it works and takes less time, too. I'm sure that someone is probably thinking "Why not scale down the difference between surfaced and submerged displacement of the full-sized boat?" The problem here is that unless you've duplicated the prototype exactly right down to the EXACT dimensions of the pressure hull itself, watertight containers beneath the deck, air bottles, etc., etc., then that just won't work. (See note 1)

A note about placing that single tank. The exact center of the boat is not necessarily the best position. Actual location depends on shape of the upper deck, location of the conning tower, etc. Generally speaking, a WWII fleet boat with the tower well ahead of midships and a wide forward deck (compared to the after deck) would have the ballast tank somewhat ahead of the middle of the boat. A WWII U-Boat (Type VII and IX) would have the center of the tank just slightly ahead of the central point. I have given no exact figures here due to the fact that there are no set figures for the size and location of the fore and aft sections of the model's pressure hull. The best solution for this has been to make the mounting pads for the tank adjustable. To check if the tank is properly located just compare (in your test tank) the attitude of the boat both surfaced and submerged. After trimming to make it float level when submerged, blow ballast and notice how it sits when surfaced. If the bow is high, the tank is too far forward. If the stern is too high, the tank is too far aft.

The final point on ballast systems is the construction of the tank itself. I won't spend a lot of time here, though. I've used old peanut cans soldered together (they rusted through even with a heavy coat of Rustoleum paint inside and out), fiberglass cloth molded over a piece of pipe as the plug, and clear plexiglass tubing. To allow room below for an operating periscope mechanism, I have now gone to a two tank system, as you can see in the pictures. While this does not have the pitfalls of the previously - mentioned two tank system, it is a little more involved than a single tank. Each worked well except that the metal tank only lasted 2 years. The important thing to remember is that the top of the tank should be either round or peaked so that when the vent is opened, ALL the air gets out. Any air left in the tank can hurt trim as a result of sloshing; or it may just not let the boat get heavy enough to properly submerge. The same is true to a smaller degree for the bottom of the tank, which should have a row of holes about 1/2 to 3/4 inch diameter along the lowest part of the tank with one of these holes at the farthest point forward and another at the farthest point aft. As far as the vent at the top of the tank is concerned, one hole of about 3/8 to 1/2 inch would be just right but this MUST be at the farthest point aft.

Well, that's about it for the ballast system. Study the pictures and diagrams carefully and use them as a guide but don't be afraid to experiment. Everything can be improved on in some way. I would recommend for all you first timers to keep the experimenting to a minimum until you get your feet wet (?), though. Understand the basics before you try to improve them.



Note 1 - The Universal Ballast System consists of all the components referred to above and is complete except for the ballast tank itself. The instructions describe a very simple method of determining the required size and location of the ballast tank.

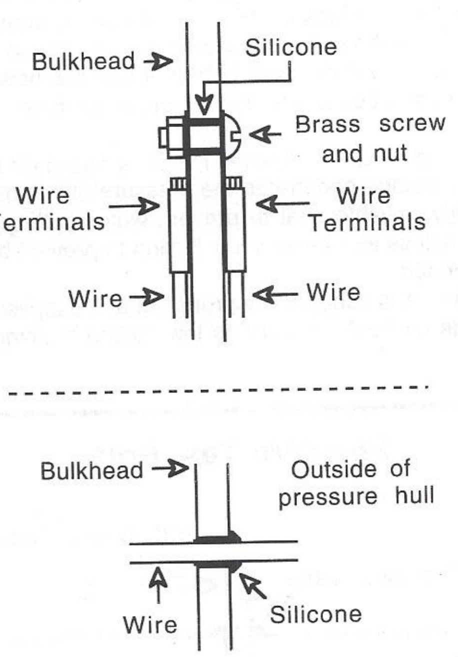
Watertight Integrity

If you think that keeping all that precious radio equipment, batteries, etc. dry in a model boat that only runs on the surface can be a real chore, then you probably think that accomplishing the same thing in a boat that is designed to go under the water is impossible. Wrong! Keeping your "powder" dry is not difficult at all. In fact, with just a little effort a model submarine can be made to withstand surprising water pressure and stay dry inside too. Please note that I said "a little effort". This means, among other things, common sense and attention to detail. A chain is only as strong as its weakest link and the best prepared submarine is going to get wet, or worse yet, sink, if a minor detail such as an unsealed propshaft/stuffing box is overlooked. With this in mind, let's see what it takes to make your pride and joy capable of diving below the surface and coming back up dry.

The average operating depth of most model submarines is 5 feet or less so this is where we'll concentrate our efforts. I know that many modelers don't want their boats to go any deeper than periscope depth which would allow for a somewhat simpler method of sealing; however, don't forget Murphy's law. Just a little extra time is the best insurance. After all, isn't your boat worth it?

To begin with, the items that need to be sealed, besides the pressure hull itself, are the main hatches for access to the inside of the pressure hull, propshaft/stuffing box, linkage push rods, on/off switch (if it's external), and any wires used for externally-mounted solenoids, wires, etc. In short, anything

Wires through Bulkhead

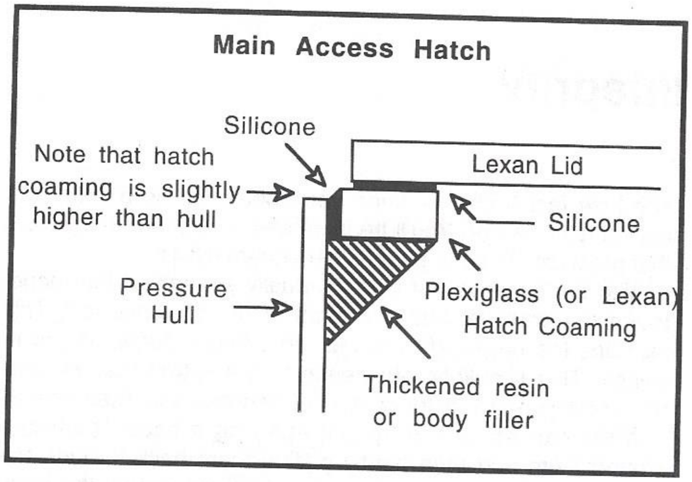


that penetrates the pressure hull MUST be capable of withstanding outside pressure. This also includes any solenoids or other electrical apparatus that's mounted outside the pressure hull. By the way, that pressure is over 4 pounds at 10 feet and if you don't think 4 pounds is that much, punch a hole in a small plastic Tupperware-type container with a straight pin and see how fast it fills up when you hold it on the bottom of a bucket full of water. You'll be surprised. One more thing about that pressure. That's 4 pounds per square INCH!

With the exception of wires, virtually everything that penetrates the pressure hull is a shaft or rod of some sort. This includes the propshaft, linkage rods, and a push/pull power switch. This simplifies our needs to the extent that we only need one type of seal for everything except wires. (See note 2)

Wires can be sealed by just applying a bead of silicone around them and then gently pulling them back through the hole so that the silicone starts to bunch up around the hole. This gets silicone inside the hole as well as around it. Be careful not to move the wires at all until the silicone sets for at least an hour. A little extra time spent here is well worth it. Then another bead can be built up around the wire for further strength. With this method, make sure that the hole is not too much larger than the wire itself. In other words, if the wire is 1/16 inch diameter, don't put it through a 1/4 inch hole! If two or more wires are going through the same hole, make sure you separate the wires at the point of penetration and put some silicone between them. Then they can be twisted back together and put through the hole. A safer and stronger method would be to use wire terminals both inside and outside with a brass screw and nut passing through the bulkhead. Put a little silicone on the threads where the screw goes through the bulkhead and it will never leak. Again, check the diagram. One more thing about wires - where they attach to whatever component outside the pressure hull (solenoids, pumps, etc.), make sure the end of the wire itself is well tinned with solder to a point past the end of the insulation. Then put a sleeve of heat-shrink tubing over the end of the insulation and the exposed tinned wire. This prevents water from working its way back into the boat between the individual strands of wire. It's amazing where water under pressure can go!

The largest opening to seal and probably the simplest is the main hatch/hatches for access to the inside of the pressure hull itself. My personal preference here is Lexan which is a stronger, more flexible version of plexiglass. This material is easy to cut, quite strong and has the added benefit of being clear, which allows you to see what's happening inside. Now this is where I stray quite a bit from the norm. I don't screw these lids down but instead, I glue them down using silicone. Sounds too permanent, you say? Not at all. While it's true that it involves a little more time, in the long run it is far more efficient. For one thing, with plastics of this type, warpage around the screws can render the lids unusable because they just won't seal any more. The most obvious problem is that you now have a very large area for possible leaks. Gluing the lids on eliminates all of this. Access is still possible by using an Exacto knife and cutting through the silicone and then using a single edge razor blade to clean up the surfaces so that the lids can be re-installed. Notice on the diagram that the hatch coaming is slightly higher than the hull. This is to allow the knife blade to get in between. Immediate entry (to charge batteries, etc.) can be had by using plastic bottle necks and tops. (The tops themselves don't have to be plastic.) This allows you to get in and out quickly at dockside with a minimum of fuss and with very little chance for leaks. If the on/off switch is mounted just under this bottle top, that's one less seal to be made and one less potential leak. Any major work that must

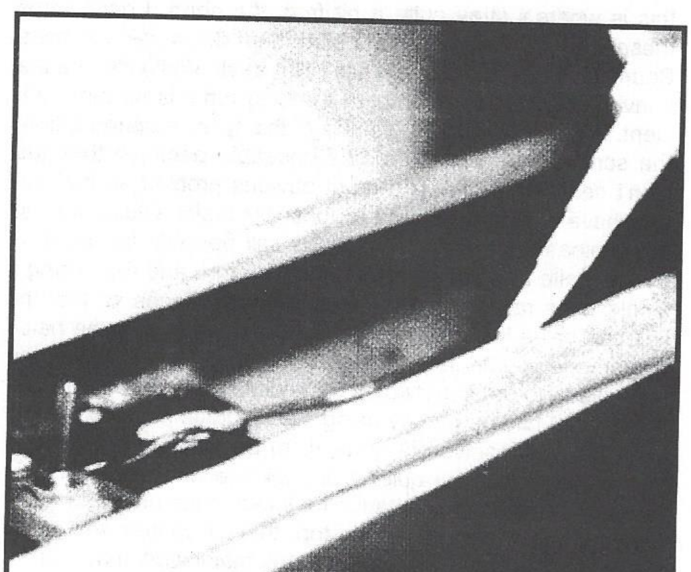


Main Access Hatch

be done inside the hull can be done more comfortably in the shop (where it should be done, anyway) by removing the entire lid. When using plastic bottle necks, beware! Not all plastics can be glued. The thickness of these lids should be in the 1/8-1/4 inch range depending on the size of the opening itself. Be careful here! A large opening (3 or more inches) should use 1/4 inch minimum although I've never seen one requiring thicker.

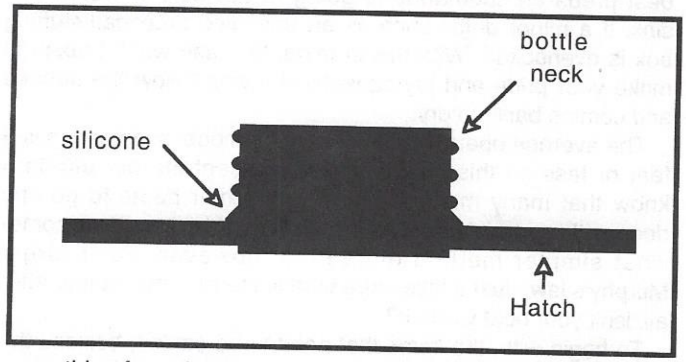
Another thing to watch for is that some Plexiglass/Lexan is marked and sold as 1/8 inch (.125) but actually measures .090-.100. My Type XXIII U-Boat had these thinner lids and at a depth of 8 feet the lids bowed in a measured 1/2 inch! While Lexan is quite strong and forgiving, there is a limit. For added strength here, fill in the area just below the coaming with thickened resin or body filler (see diagram). This can be done very easily by siliconing the coaming in first and then add the filler after the silicone sets. If done properly, it'll never leak.

This bow in the lid has a very detrimental effect on the underwater handling characteristics of a model sub. Since the pressure hull is, for the most part, the part of the boat which is buoyant, any reduction in volume will make it less buoyant (heavier). Therefore as the boat goes deeper, the lid bows in more, and the boat gets heavier and thus harder to control. If you trim so that the boat is just right for periscope depth, any deeper and it becomes too heavy, requiring more speed and more up angle on the forward planes to compensate. I've had it get to the point where I had to blow ballast because it just wanted to keep going down. If you trim for the deeper depth, then running at periscope depth becomes a problem because



the boat is now too light requiring, again, more speed and more down angle on the forward planes. It's far simpler to just use a thicker lid to begin with.

Finally, now that we've made the Lexan lids, and used a lot of silicone, how do we check to make sure there are no leaks? Simple. Cut a small length of brass tubing and glue it in a hole you've drilled in one of the lids. This will allow you to slip a length of small diameter hose such as model airplane fuel line or fish tank hose over the tube and then, holding the boat just under the surface, apply air pressure (lung pressure) and look for air bubbles. From there, any leaks can be immediately spotted and remedied. Use some amount of self-control when pressurizing this way, though, it is possible to overdo it. Oh, yes, don't forget to make a plug for this "test port". A piece of your test hose with a screw, etc. in the end works well. I don't think it would go over too well if, after all your effort to seal



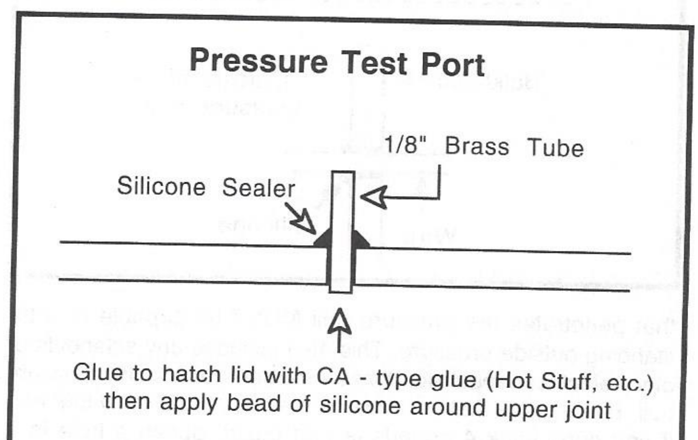
everything from the elements, you forgot to plug this up. I know I didn't like it when I did it.

To this point, all that has been said has more or less taken for granted that the hull is either plastic or fiberglass. While wood is certainly an option, it's one material I would stay away from.

By now you should have a good idea of how to protect your boat from the "ravages of the sea". All of the above methods have been proven to be successful but are by no means the only way to go. As I've said before, if you are new to all this, learn the basics before you try to improve on them.

Note 2 - The BHS - 1 Bulkhead Seal is designed to be used wherever linkage penetrates the pressure hull and provides a high-quality, reliable seal to prevent water getting inside the pressure hull as well as very low friction to prevent binding and servo overload.

The SBS - 1 is used for the propshaft and supplies the same high points as BHS - 1 but has low friction bushings at each end.



Pressure Test Port

Control Systems

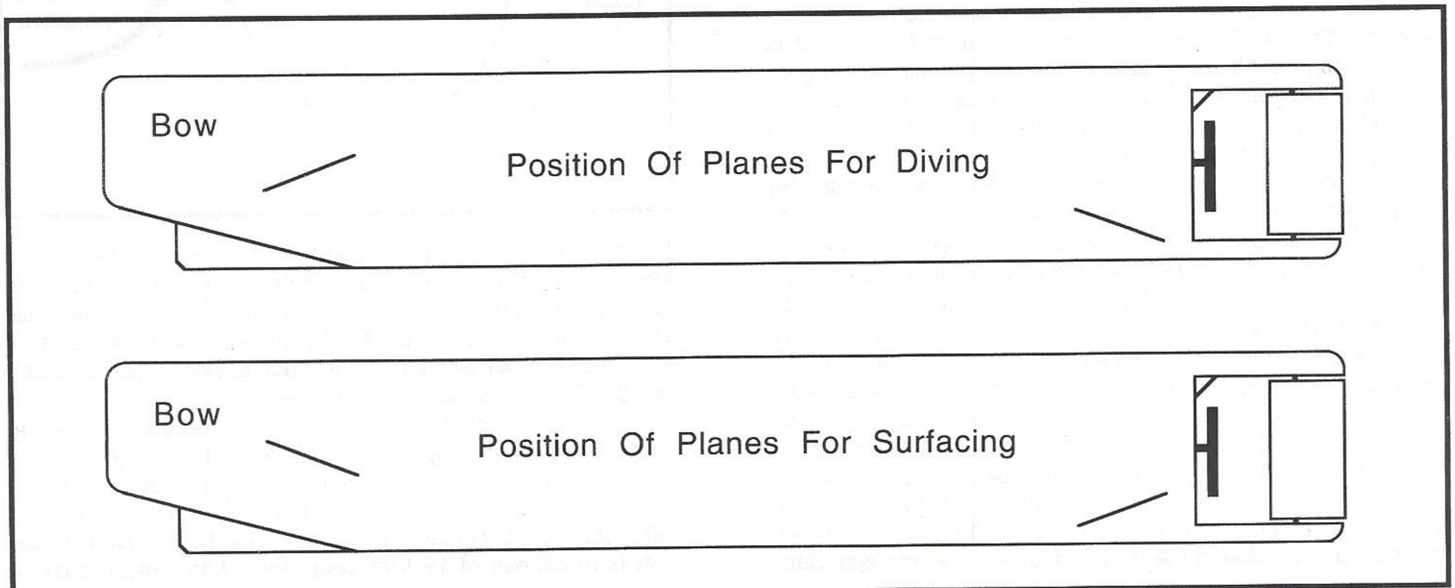
In previous installments, we covered how to make your submarine surface after patrolling the deep, and how to keep the insides dry while it was on patrol. Now we'll get into the systems which allow the boat to navigate beneath the waves and how best to use them. These systems include control surfaces as well as electronics.

I'm sure that if you're reading this article, you're interested in submarines and already have a basic knowledge of what the diving planes do, but how about a short refresher course first? As everyone knows, the rudder on any vessel controls whether the vessel itself turns left or right. On a submarine, this of course works the same way but for changes in depth and angle, the rudder must now be moved to the side of the boat and rotate up and down instead of left and right. Since before World War II, all submarine designers have used diving planes in the stern, some behind the prop(s) and some ahead of them. Since we're concerned primarily with scale models which already have these locations determined, I won't go into any detail about which location is best except to say that, basically, increased speed and noise reduction are the main reasons for putting the planes ahead of the prop on all subs designed since World War II. Not all submarines have had forward planes but the overwhelming majority have and these are not mounted at the extreme bow because of hydrodynamic considerations (they just won't work!) and dynamic center of gravity, but at some point behind the bow and ahead of midships. What is important for us to know is what the bow and stern planes do and how we can use that knowledge to make our boats perform underwater just like the full-size boats do.

In general, both fore and aft planes can do the same thing, that is they can change the attitude (or angle) of the boat. However, the rate of change differs greatly between them. For the purposes of this article, I won't waste any time on the engineering formulas to explain this. The bottom line is that in model form, reactions of the diving planes duplicate the full-size boats in that, generally speaking, the forward planes are used to control the depth of the boat and stern planes control the angle. I know there are many model subs that use forward planes only and there have even been articles written telling us that this is the way to do it, but this is just not true. In reality, a boat can be controlled by bow planes only but just barely. The stern planes are a completely different story, though. A submarine, whether full-size or model, can be controlled quite efficiently using stern planes alone. It's very much the same as an airplane. The control surfaces are located in the rear and change the angle of the fuselage and, more importantly, the wings. The wings want to keep going in the direction they're pointing, so to go up, the rear is dropped. To go down, the rear is raised. It's really much more difficult to pull the stern than it is to push the bow. How many vessels have the rudder in the bow? Now that we have that out of the way, let's get down to brass tacks.

I firmly recommend that if you are limited to only one channel for diving planes, you control the stern planes and, if the boat you are building has forward planes, they should be fixed in a neutral position. Don't fix them with any up or down angle since they will react differently to different speeds. I recommend that you do NOT link both fore and aft planes together on the same channel. Since the forces generated by the planes are greatly different, a great deal of time would be needed to properly synchronize them. The problem here is that these same forces vary according to speed and the net result is that the boat would work reasonably well at one speed and not so well at higher and lower speeds. It can be done, but it's just not worth it. If at all possible, try to use both sets of planes with each on its own channel.

One of the biggest problems with properly controlling a model submarine while it is submerged is to keep it level. Putting a boat under water is a whole new experience since we are now adding a third dimension - vertical movement. Trying to maintain a reasonable "periscope depth" when you can only see a small piece of tubing sticking out of the water and maybe a shadow under water is difficult, if not impossible. The reason for this is that if the boat takes on a two or three degree angle, it's almost impossible for you to see that little change from the shore. two or three degrees is enough to cause the boat to rise to the point of having the conning tower out of the water or dive to the point of going out of sight. By the time you notice that the angle is off, the damage has been done. Needless to say, this is not too realistic. The ideal solu-



tion is to have some form of help from within the boat itself. This help can be had in a variety of ways, from the simple to the ridiculous. What I used for many years was a modified model helicopter gyro which completely eliminated any "porpoising" when properly modified and wired in series with the stern planes. With this, at periscope depth the boat stays level by itself and all I have to do is maintain the depth with the forward planes. Please note that I said "level". The unit itself has absolutely no control of depth, only attitude. (See note 3)

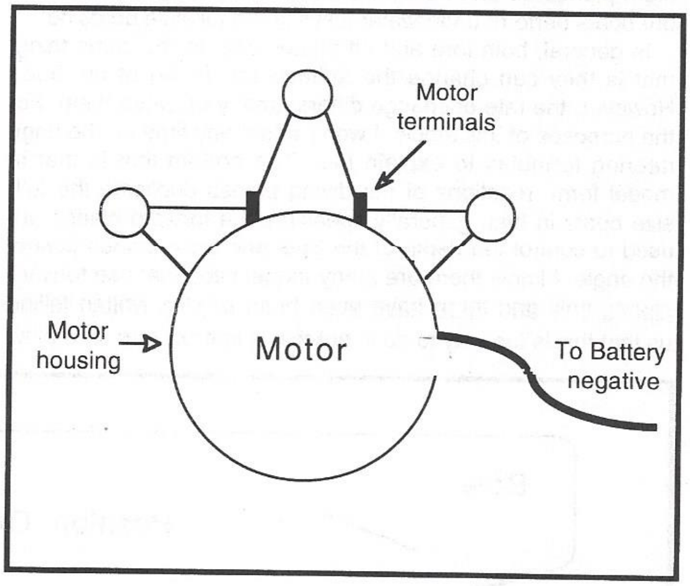
Except for the really humongous boats such as 32nd Parallel's 10 foot long Fleet-type "Gato", we're stuck with a fairly tight pressure hull making it difficult to pack everything we want inside. Don't feel alone. This is one of the biggest problems encountered by the designers of the full-size boats. One way to make better use of what little space we have is to eliminate the receiver battery. A voltage regulator such as those used by some of the car racers and electric airplane flyers, and commercially available as a "battery eliminator", can free up a lot of room. There's also the added benefit in that only one battery needs to be charged. (See note 4)

How to increase your time in the water is another consideration worth looking at. I don't know about you, but I don't want to go to the lake and after only 15-30 minutes have to take my boat out to recharge or replace the batteries. I know that not everybody wants to spend all day at the lake but why not make things easier for yourself? The 2 big areas to look at for "slimming down" battery usage are the ballast system (pump motors, solenoids) and the main drive motor(s). Once you've decided which ballast system you are going to use, there isn't too much to do to reduce battery drain. But the main drive system is another matter entirely. For some reason, most boat builders (surface ships, too) seem to equate large boat = large motor. Unfortunately, the reality is usually large motor = heavy current drain. What we need to drive the boat is the thrust from the propellor. This thrust can be achieved by either spinning the prop at high rpm's or by using a larger diameter prop. A 1 1/2 inch 3 blade prop will supply the same thrust as a 1 inch prop spinning faster or a 2 inch prop spinning slower. So, if we have a boat that requires a 2 inch prop, why use a motor that is capable of spinning it far faster than it needs and then throttle back with the speed control? Why buy a high performance sports car if you're looking for fuel economy? No matter how carefully you drive, you still won't even come close to what you'd have if you bought the economy car to begin with. The same thing holds true with our motor/prop combination. By gearing down, we almost get the best of both worlds. A major part of horsepower is torque and that can be boosted considerably by allowing the motor to turn faster than the prop. It is sometimes possible to actually turn the prop faster with a gear reduction than with direct drive! That is because the prop load is so great that it won't allow the motor to reach its optimum rpm where it is most efficient. This is, of course, somewhat rare but on direct drive with a scale size prop we aren't too far away from it. Unless we OVER power. With my 1/24 scale Type XXIII U-Boat, I originally used a 4 to 1 gear drive with a Dumas motor and a 2 3/4 inch 3 blade prop with a very coarse pitch. This gave substantially more than scale speeds which lead me to increase to 5 to 1 and, later, 6 to 1. The boat is still capable of far more than scale speed but at the same time, the endurance has almost doubled! With 5 amp hour Gates cells, I can spend over 4 hours in the water continuously. (Yes, the transmitter has larger batteries so it can last that long, too.) There is no hard and fast rule to use to determine every application, but I haven't seen very many boats, except racing boats, that couldn't use at least a 2 1/2 to 1 reduction. An added benefit is that in the lower speed ranges and especially with larger diameter props, there is more gradual response to stick movement at the transmitter. Please remember that all of this concerns scale-sized as well as scale-shaped props and not 2 blade racing props. (See note 5)

Gearing the motor to achieve lower current draw has another plus, as well. The speed control doesn't have to be as large in current capacity which usually means it will be smaller physically which also helps in the area of space inside the hull. Cost of the smaller controls is usually much less, as well. We gain all the way around! One thing to watch out for, though, is to stay away from mechanical rheostat-type speed controls or servo operated electronic controls. If the radio malfunctions in almost any way, the motor will keep running and, in a large and/or cloudy lake, you could lose the boat if it's underwater at the time. I speak from experience! A friend and I spent many hours looking for his boat in a crystal clear lake with a depth of 5 feet and light sandy bottom and finally found it quite a distance from where it went down. It seems that when it hit the bottom, it just motored along until it hit a small sand dune and stopped. Needless to say, he uses only electronic speed controls that automatically stop the motor on loss of signal now!

There are several devices on the market which automatically move the servo to a predetermined position if the signal is interrupted for any reason and these work quite well, but from a financial point of view, an electronic speed control would be more effective and would also take up less space in the hull than a mechanical speed control, servo, and "servo setter".

This "servo setter" (Missing pulse detector failsafe) can be very useful and certainly worth the space it takes up in another area, though. Why not use one on the servo which operates the ballast system? This would not work if you are using a pump-type system which requires a tube of some sort above



the water to get air, (unless you rigged a servo to drop a lead keel, etc.) but it would certainly work with Propel, I.V. bags, and the MRC/Sun Lane "cans". This way, if signal is lost while you are submerged, the boat will automatically surface and I'm sure everyone will agree that it is much easier to recover a surfaced sub than a submerged one. (See note 6)

And last, but certainly not least, the receiver antenna. Contrary to popular opinion, it has never been necessary to have the antenna sticking out of the water to be able to receive a signal on any of my own boats. I know that many of you will cringe at that statement but there is a lake here in New Jersey that is in excess of 12 feet deep and I know of at least 10 model submarines that have been purposely put on the bottom and then brought back up again ON COMMAND. Those boats included 4 belonging to Bud Lederer, a well-known model submariner, Manny Duran, a builder who is not as well known but certainly an extremely capable "bubble head", and three of mine. There is also a quarry which has seen 2 boats operate at depths of over 30 feet! This was with a diver swimming with the model to verify the depth and recover the boat if necessary. These were all different models but all had one thing in common - the antennas were all ENTIRELY INSIDE the pressure hull. This was nothing more than the antenna wire inside a plastic tube (Nyrod) which was then molded around the inside of the pressure hull. Almost sounds too simple, doesn't it? It is, but the bottom line is that it works. For those curious about range, I've been as far as 100 yards away from two different boats that were submerged to periscope depth and could go no further but that was because I couldn't see them and not because of radio problems. None of the radios used in the boats mentioned above had any modifications to the output. Out of the box and into the boat and the frequencies used were 27, 53, 72 and 75. I hope this can calm any fears some of you might have. All of the previous refers to FRESH WATER ONLY!

To prevent potential interference from the motor, capacitors should be placed between the two terminals and between each terminal and the case, and a wire should be connected between the case and the main drive battery ground (negative). Study the sketch below.

Another area to keep in mind is the transmitter stick functions. There's enough to think about when your boat is submerged without having to think about which stick does what when it's moved in which direction. Try to keep everything as natural and relative to the boat itself as possible. In other words, don't use a left/right stick for the planes or use a forward/backward stick for the rudder. The diagram shows a comfortable layout which is adaptable for those of you who are left-handed. The main thing is that the forward planes and the rudder are on the same stick which makes submerged maneuvering a matter of using just one finger (with an A.P.C.). In this situation, one finger does it all. Since I use an A.P.C. in all my boats, I don't really use the stern planes except when diving and surfacing. It's still very easy to control the stern planes if you aren't using an A.P.C. since you would be using your other hand. I know that this explanation might sound somewhat picky, but in view of some of the layouts I've seen, it's best that I get into it. (See note 7)

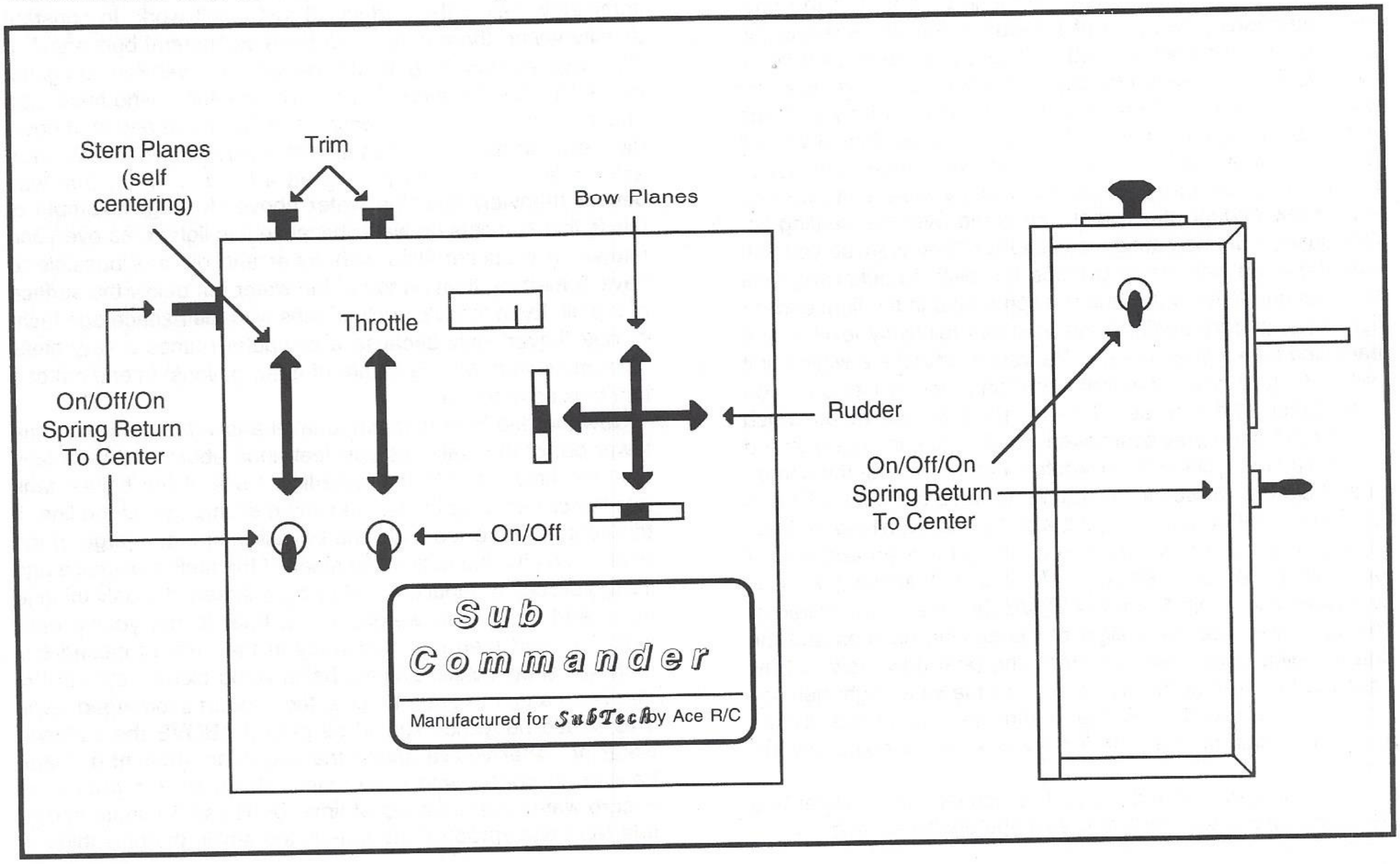
Note 3 - APC - 2 is the smallest, most efficient, and most reliable automatic leveling device on the market today and is the result of 17 years of learning the hard way - in the water.

Note 4 - The BE/VR (battery eliminator/voltage regulator) is designed for this and has the added benefit of being able to be used efficiently with a 6 volt battery.

Note 5 - The DRU combines small size, compatibility, and quiet operation into the ideal package for virtually any application.

Note 6 - SubSafe will operate a servo or any other device which is normally operated by a receiver signal. It also has an added benefit in that, during normal operation, the signal is "boosted" as it passes through which eliminates potential problems when using older servos with some of the newer radios.

Note 7 - The Sub Commander System uses all ACE R/C electronics but boasts a stick layout designed especially for submarines. (See sketch below)



What Do I Do The First Time In The Water?

Now that all the systems have been chosen, built and installed, we've come to that point which is sure to put butterflies in our stomachs. This has certainly got to be madness. After all, it's bad enough that I've built a model to "sink", but now you want me to actually put it in the water? Well, fear not. The first time for everything usually causes some jitters but believe me, like some other things I can think of, it's worth it!

It is strongly recommended that for the very first time you put your boat in the water you DON'T just go down to the local pond, throw it in, and see what happens. This is another area where a little extra time goes a long way toward making the end result something to be proud of. That extra time should be spent in a test box which can be a backyard swimming pool (shallow end with you IN the water), bathtub (if the boat is small enough), or a homemade box made with some planks from the local lumber yard. The object is to have the boat in a controlled situation so that YOU determine what's happening. That's why the local pond is not recommended and also why, if you are using a pool, you should be in it. Besides the question of depth and the fact that you would have to kneel down for an extended period of time (pretty uncomfortable after the first few minutes), there is the little matter of waves and current. When 1/4 of an ounce is important, it's best to make an extra effort to eliminate any outside influences.

For those who have built the boat already but not launched it yet, first make sure that all openings below the waterline are sealed (propshafts, linkage rods, wires, etc.). Also, make sure that everything inside the hull is where you want it and is secured properly so that it won't move around as the boat is handled. Now is also the time to make sure that, if the boat has free-flooding sections of the hull, there are holes in the keel area (at the lowest point) so that these areas CAN flood. Now, with the watertight hatches off, VERY carefully lower the boat into the water. Be sure to keep an eye on how level the boat is because even though it is sure to be too light, it will still ship water if placed in unevenly. Since the center of floatation has not been determined yet, it's also possible that one end will sit low enough that water can come over the sealing lip. Obviously, extreme caution is called for here! Now do you see why the pond isn't the best place for this? If necessary, take the boat out of the water and put some lead in the light end (or light side) and try again. If the boat sits relatively level, stand back and take a deep breath! The rest might take a while but it will be fairly simple. Now that it is sitting there on its own, you can double check to see if there are any little holes which might have been previously overlooked. You can't really spend too much time looking for unwanted water. The first thing to do is add lead to wherever is required to have the boat sit on an even keel, both fore and aft and side to side. Don't worry about getting down to the waterline yet, just get it even and level. I generally try to have it sit about 1/4 of an inch above the waterline (waterline about 1/4 inch ABOVE the level of the water) at this point because the weight of the sealing hatches and the free-flooding upper deck will bring the boat down lower. Now take the boat out of the water and put the water-tight hatches on and if you use the silicone method as I do let the silicone cure for at least an hour (preferably two) before going any further.

The next step is to put the hull completely under water and pressurize it to check for leaks, so if you don't wait long enough, you could break the silicone seal yourself. After you've satisfied yourself that there are no leaks or fixed whatever you may have found, flood the ballast tank completely and install the upper deck. Make sure if you are using airbrush propellant that the on-board tank itself is full. The boat should still be floating fairly high at this point and now it's decision time. Since I prefer to be able to work at scale speeds which are pretty slow, I trim the boat to float with the upper rim of the conning tower just touching the water's surface. Check the pictures for this. The theoretical ideal would be that a fly would not be able to touch a vertical surface, only horizontal. If this is your first time with a sub, it would probably be a good idea to have more of the tower out of the water which means there is more positive buoyancy. Until you are comfortable with running under water or if you are using windshield washer pumps which need a pipe sticking out of the water it's better to have a little reserve buoyancy. While the boat is sitting there with so little out of the water, don't forget to keep an eye on how level it is. THIS IS EXTREMELY IMPORTANT. Add lead weights to the bow and/or stern to get it level and also to get it to float as deep as you want it. Use a lot of patience when adding, subtracting or moving weight on a submerged boat. Being very close to the same weight as the water, it will tend to see/saw a bit before stabilizing. All of this added weight should be placed in the keel or at least as low as possible.(Actually, all batteries, etc. should be placed as low as possible).

This is probably the best time to get into the fallacy of "neutral buoyancy". Don't waste your time trying to trim your boat with weight so that it sits stationary at some particular depth completely below the surface. It just won't work. In constant density water, there is no such thing as "neutral buoyancy". If it's heavy enough to get below the surface it will keep on going down. I'm sure there are some of you out there who have read of submarines that sat at some particular depth and shut down their electric motors to evade depth charging, but they were able to do this only by resting on a layer of water that was denser (heavier) than the water above. A rough example of this is that oil floats on water because it is lighter, as everyone knows. In a bucket filled with water and oil, it is possible to have something float on top of the water but below the surface of the oil. Even today's nuclear subs with their space age technology "hover" only because a computer pumps a very small amount of water (only a matter of a few gallons) in and out of a trim tank as required.

Now that the boat is trimmed level and with as much of the tower out of the water as you feel good about, blow the tank and see how close to the waterline it sits. If the ballast tank has the correct volume, we should be sitting right at the line. If the boat is sitting too high, the ballast tank is too large. If the boat is too low, the tank is too small. If the tank is oversize and it's too difficult to reduce for what ever reason, the only thing to do is add more lead weight to the boat to get your proper waterline and then add buoyancy in the form of closed cell foam (or small plastic bottles, balsa wood blocks, etc.) in the free flood areas to get it to sit at the desired submerged level. This added buoyancy should be placed ABOVE the surfaced waterline. After you've added the necessary amount of foam, be sure to coat it with epoxy since the foam (or wood) will absorb water over a period of time. Don't use 5 minute epoxy. It is NOT waterproof! If the tank is too small, the only thing to do is make it larger. While doing this part of the trimming and balancing, make sure that the ballast tank is completely filled with water with no air bubbles when you're submerged and completely empty of water when on the surface. Now is the time to check that the vent valve, etc. is properly located. Another thing to look for is whether there are any areas under the free-flooding deck that may retain air bubbles when you dive. A simple way to test for this is, after you've trimmed for proper submerged depth and blown the tank to check for surfaced waterline height, vent the tank and submerge again with the deck in place. If it does not go back under all the way or if the bow or stern is higher, there's a bubble trapped somewhere. The result is the same as not filling the ballast tank enough. It will probably be necessary to drill a small hole (1/8-3/16 inch) in the deck as far forward and another as far aft as possible since these points will be highest when either diving or surfacing. It breaks from scale a little, but in some cases these holes can be disguised (bullnose, etc.) To simulate actual diving under power, it might be wise to hold the stern up just a bit to duplicate the angle the boat would have at that time.

Now, we are finally ready to take a trip down to the pond. Make sure your batteries are charged and again, if you are using Propel, make sure the tank is full. Once in the water, run around a bit on the surface to get a feel for the way it handles and check basic controls (rudder, speed, etc.). Don't rush this part. Relax, get comfortable and enjoy the fruits of all your labor for awhile and then, if possible, have the boat run parallel to the shore and as close as possible before you flood the tank. Be sure you check for submerged rocks, logs or other obstructions first. Now, with a deep breath, a faint smile and crossed fingers (legs, toes, arms!), fill the ballast tank and see what happens. If you've built a WWII era boat with a wide flat deck, it might tend to stick there with just the conning tower out of the water. If so, move the stern planes to the "dive" position which should raise the stern, causing the bow to go completely under. The "dive" position is obvious for the bow planes but the proper angle for the stern planes is the exact opposite. In other words, the leading edge should be up with the trailing edge down. This helps to increase the dive angle by raising the stern. As soon as the conning tower goes under, pull back slightly on the stern planes and try to get the boat level. It might also be necessary to use the bow planes to get the bow under. If the boat doesn't want to go under completely, that may be because it needs to sit lower when the tank is full and the boat is stationary. If you left yourself with some extra buoyancy, you will probably have to increase speed.

Now it's up to you. If there is no A.P.C. or similar device to keep the boat level, then you will have to do it yourself and that means with the stern planes only at first. The idea here is to see how violently the boat wants to pitch up or down with the stick in the neutral position (hands off). Of course, it's assumed that when installing the radio all controls were set to neutral. If it is severe, move the trim lever in the appropriate direction to counter the pitch. That is, if the boat pitches down by the bow, the trailing edge should move up. If the boat wants to surface, the trailing edge should move down. During this, keep an eye on where you are going so you don't run into something. I speak from experience! When you achieve what you feel is the best position for the trim lever, then go to the forward planes and repeat the process. You will probably have to keep going back and forth between fore and aft planes until you reach a happy medium and by all means don't get upset if you don't master this the first day out. Once you have gotten the boat to run with some consistency when submerged, you'll probably notice that either the bow or stern planes, or both, are not at their neutral position. This is normal and varies primarily according to the form of the hull. Those with a full flat deck such as a U.S. fleet boat or a Type IX German U-Boat are generally further away from neutral than a tear drop shaped "nuke". The reason is that the earlier boats had a smooth well-shaped hull below the waterline and an awful lot of hydrodynamically inefficient upper works above the waterline. This generally causes the bow to pitch up when under water but just how much is pretty much determined by speed. From this point on, it is just a matter of trial-and-error and practice. In other words, just get out there and do it. And do it, and do it. Practice doesn't always make perfect, but it sure beats whatever is in second place!

If you have been following this series from the beginning, you should have enough hints now to get your boat to work well. I must emphasize that everything that I have written is a result of years of trial-and-error and many mistakes and, if done the way I have laid it out, will work. But there are very few things in life that are etched in stone and it is certain that improvements can be made. It is very much recommended that, for the beginner especially, use what I have supplied and get to know the basics first before you try to improve on anything.

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