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The Physics of Floating (and Sinking)

By Tyler Helland

According to the legend, Archimedes of Syracuse (*c.* 287-*c.* 212 BC) discovered a way to determine the

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By Leaps and Bounds

By Mike Mangus

Volume 3: Brushless Motor Systems

In the first BLaB article I alluded to how brushless motor systems along with lithium battery chemistries have changed the face of electric powered aircraft. The lightweight high-capacity lithium batteries and powerful efficient brushless motors have allowed model aircraft to fly longer with more power than comparable combustion powered planes.

We have already touched on lithium batteries in previous articles. Let's explore the other latest technology finding its way into our ships: the brushless motor.

A brushless motor offers many advantages over brushed motors. Brushless can be up to 25-30 percent more efficient. Because there are no brushes to wear out brushless motors can last virtually forever with proper care. Additionally, the electronically-controlled precise timing in a brushless system promotes more available torque at most rpms.

For us, the torque advantage is the main selling point. With more torque comes better acceleration as well as speed during tight turning.

Notice I didn't mention lower maintenance. One of the brushless disadvantages is some extra maintenance to keep ball bearings from going bad. Additionally, brushless motor systems typically cost more than brushed motor systems. Lastly, choosing a motor out of the thousands of motors on the market can be daunting.

Luckily, this is where this article can help!

I've come up with a few guidelines for choosing a motor based on ship size and gearbox or direct drive setups. Most of these observations are based on testing and retesting in various ships the past year and a half. Note these recommendations are for 6 volt power systems.

Small ships (cruisers, PDNs, ACRs, etc.):

18-28mm diameter inrunner type

By Leaps and Bounds -Continued-

Medium ships (DNs, battlecruisers, etc.):
28-36mm diameter inrunner or outrunner type
Large ships (BBs):
36mm and larger diameter inrunner or outrunner type

Direct drive propulsion should aim for 700-1,400kv (rpm per volt) motors. Geared drive propulsion should aim for 1,800-2,200kv motors.

Notice there is two types of brushless motors: inrunner and outrunner. The difference is how the motors are constructed. Inrunner motors are designed like typical brushed motors with a fixed outside case and a spinning internal armature. Outrunner type motors have a fixed central core and a rotating outer case.

Performance wise, an inrunner motor typically has less torque and higher rpms than an outrunner.

Another factor in selecting a motor is voltage. All brushless motors are designed to operate best within a set voltage range. Small motors up to 42mm diameter typically run on 6.3v-14.1v. As motor size increase so does the voltage requirements. It is possible to go outside the voltage range if needed at the cost of motor efficiency. Frankly, I have not worried so much about the voltage requirements when trying to select a motor with the correct rpm.

The drive motor I'm using in most ships for the moment is: *Turnigy B36-56-04 2600kv Inrunner*
http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=6527

By Leaps and Bounds -Continued-

This motor pushes the gear boxed twin props on the Erin to 28 second speeds at only 44% throttle using 1.5” diameter props and two cell LiFE batteries at 6.6 volts. In the Verite on direct drive, it only takes around 28% throttle to make speed using 1” diameter props and two cell LiFE batteries at 6.6volts. A lower kv motor might be better, such as this one: *Turnigy B36-56-06 1800kv Inrunner* http://www.hobyking.com/hobbyking/store/uh_viewItem.asp?idproduct=6526
I haven’t tried the 1800kv motor yet but have a couple on hand for the next ship project.The Richelieu is running a pair of outrunners for direct drive: *Turnigy 500 H3126 1300kv Outrunner* http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idproduct=1182

These outrunner motors have amazing torque at lower rpm than the typical inrunner type brushless motor. The Richelieu makes 24 second speed at 55% throttle using 2” diameter props and two cell LiFE batteries at 6.6 volts. *Turnigy T600 880Kv Outrunner* http://www.hobbyking/hobbyking/store/__11143__Turnigy_T600_Brushless_Outrunner_for_600_Heli_880kv_.html
For the single prop drive, direct drive ships such as the Bismark or very large ships like the Yamato and Iowa, this motor is probably the best option. It is capable of 2600+ watts or 1.75hp and has monster torque.

By Leaps and Bounds -Continued-

Brushless waterproof ESCs with instant reverse are difficult to find. Most have a limited or delayed reverse unsuitable for the fast paced throttle changes we do during battle. There are a few that we can use though. Each motor will require its own ESC. Unlike brushed motors, multiple brushless motors cannot be run from one ESC. The most common ESC we are using is:

HK Brushless ESC 100A with reverse

http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idproduct=8993

This is a low cost R/C car ESC with instant reverse. The Hobby King ESC will require waterproofing, either with resin epoxy, Scotchkote® or using your favorite waterproofing method. I do not recommend the lower amp version of the ESC. We found the lower amp models do not like to stay synced to the receiver when powering up high amperage motors. I have went as far as to separate the drive motors and the pump motors into separate battery packs to eliminate the de-sync issue.

Mtroniks™ makes a brushless Marine ESC for 'scale ships'. It has reverse but we do not know if it is an instant reverse. Rob Stalnaker is checking on it and we will let everyone know if it will work as soon as possible.

For the people with lots of money Castle Creations make a very high end brushless Marine ESC.

http://www.castlecreations.com/products/hydra.html

The Hydra is completely programmable with reverse. It would take an atom bomb to destroy one of these in our ships!

Before drawing this article to a close I have to say something about maintenance. Brushless motors have ball bearings. Ball bearings do not like corrosion. Corrosion WILL happen if the bearings are not oiled every evening after a day's battling. Within a couple of days after a weekend battle, pull the motors out of the ship and spray soak the bearings with WD-40 or LS-1. If this is not done the bearings WILL go bad! You have been warned!

So if the idea of having better acceleration, deceleration and turning speed sounds like something your ship needs and you do not mind the higher cost or maintenance look into installing a brushless motor system. The advantages outweigh the disadvantages.

If anyone needs help selecting a motor please feel free to contact me via the email lists or at pbpow@hotmail.com.

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The Physics of Floating -Continued-

volume of irregularly shaped objects by measuring the amount of fluid displaced when said object was submerged in water. He supposedly thought of the idea when he observed that when taking a bath the water level rises when entering and subsides when exiting the tub. Using the volume calculated in this way along with the weight of an object, which could be easily measured at the time, one could calculate the density of an object. Density is an inherent property of matter and has to do with the size of an atom or molecule and how it arranges itself with other atoms or molecules in a substance. Though it is actually dependent on the state of mater and thus the temperature, in reality, density in many instances can be treated as a constant. Most substances, especially solids don't have much variability through the temperature ranges experienced on earth's surface. For instance, gold atoms pack themselves together in its purified solid state in a regular and predictable way that nearly always results in a density of 19.3g/cm^3 at room temperature. Knowledge of the density of a known standard material, gold in this case, allowed him to compare the measured density of the king's crown in order to determine if it was truly made of gold or if it was counterfeit. Archimedes also realized through this type of experimentation that objects submerged in water weigh less than they do outside of water. He observed that two stones that weigh the same on the surface but have different volumes, and thus different densities, will weight differently when submerged in water. To explain the difference he concluded that there must be some upward acting force imposed by the water on the objects that is dependent on their volume. Archimedes' stated in his treatise on floating bodies that any object, wholly or partially immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by an object. For a submerged object, one can imagine that if it weren't for that object occupying that space, water would be occupying that space. One way to visualize this is to think of the water desperately trying to get itself back into that occupied space and thus exerting a force. Likewise, for a floating object, one can imagine that the water is being pushed out of the way, or displaced from where it would otherwise be to make a continuous surface. The weight of the water that is being displaced by the submerged part of the object is equal to the weight of the object. A derivation of this can allow one to deduce that in order to float, the density of the object must be less than the density of water.

Floating your boat:

With an intact water tight hull skin, floating is accomplished by upward buoyant forces pushing the boat out of the water in balance with the downward force of the ship due to its weight. The floating waterline is determined by the point in which the volume of the hull that sits under water is at a depth such that the water that would otherwise be occupying that space would have a weight that is equal to the total weight of the model. For floating to occur

The Physics of Floating -Continued-

the total average density of the ship must be less than the density of water. It is important to realize the massive contribution of air to the average density of the ship. Air is not very dense when compared to water and takes up a large percentage of the internal volume of a floating ship. The low density air balances out the higher densities of other smaller ship components like batteries. Now let's imagine adding weight to the ship. As weight is added to the ship the amount of displaced water and thus the amount of the hull volume under water must increase to compensate for the extra weight. There is typically some reserve free board so the end result is that the ship sits lower in the water. Eventually there will become a point where the weight of the ship is too great and the spare volume that was above the water is unable to further compensate and thus leads to a sink. In our hobby the weight being added is in the form of water. An alternative way to think about it is that since the volume of this ship is changing but the mass is increasing, the density is also increasing and approaching the density of water. Adding weight to the point where the total average density of the ship exceeds the density of water will result in a sink. With this knowledge one can see that with no holes or leaks, only the volume of the ship and the weight of the ship matter in the ships ability to float. The volume of the ship is a constant determined by the construction of the shape of the hull and the weight of the ship as a whole is regulated at a maximum by our rule set and otherwise by builder's choice. The density of the individual components inside the ship doesn't matter, only the total weight and total volume matter. It doesn't matter whether the ship is an empty hull full of lead or an empty hull full of an equal mass of popcorn, only the total weight and total volume matter. However something interesting happens when you take on damage. When there are holes in the ship the inside and the outside of the ship are semi-continuous with water flowing predominantly into the hull. Here the reserve buoyancy of the ship is what is important. Reserve buoyancy is determined by a few primary factors:

1. How much extra weight in the form of water can the ship take on at the expense of volume before the weight of the ship exceeds the weight of water that would otherwise be in its place until it sinks? This is basically determined by the amount of freeboard. Ships that are not weighed down as much to start with, that battle at a lighter weight, can give up some volume before they sink. This is probably the easiest way to take more damage, just make the ship lighter. However the downside to this is that with more ship sitting out of the water you are easier to hit with stern guns so there is some compromise to be had.

2. What is the inherent buoyancy or density of the individual components of the ship? When water is on the inside of the ship individual components of the ship will float or sink depending upon the density and can help sink your ship slower or faster. For instance, it is probably a moot point to think about density of the battery you have. Different styles of batteries have different densities and different volumes but in the end the battery is many times denser than water and will

The Physics of Floating -Continued-

have a strong tendency to sink regardless. Another example is watertight boxes. Sealed radio boxes contain air and electronics. The combination is much less dense than the batteries and may be less dense than water and therefore float to various degrees depending upon the size and contents. There actually is legislation within our rules banning the use of excessively large radio boxes for this reason. Also, for this reason, I affix my radio box to the bottom of the hull so the upward force of buoyancy of the radio box as the ship fills with water is able to transfer to the buoyant force of the ship itself, gaining an incremental advantage in survivability. Another example is the density of water channeling.

Water channeling:

In our hobby the main purpose of water channeling is to force water flowing into your ship to settle where you want it to settle. It is a structural component that is continuous with the hull. Commonly ships have a two inch wide by ¼ inch deep water channel running the length of the boat from approximately the bow turrets to the stern turrets. This allows the pump to be placed farther down in the hull relative to other components so that it will prime and begin pumping water out with only a small amount of water in the hull. Water channeling also allows water to flow freely from the bow to the stern, under rather than around or over things like batteries and radio boxes. Additionally it is common to install water channeling in the extreme bow and stern of the ship so water doesn't collect in the extreme edges of the ship where it can't be pumped out easily and where it can affect ship performance in the form of forcing a sinking ship to settle by the bow or stern. Let's consider again a ship that has some holes in it and has some water beginning to build up inside of it. When the ship is taking on damage and filling with water the water channeling starts to become completely submerged. Because the water on the outside of the ship is somewhat continuous with the water on the inside of the ship we can now consider the water channeling as an independent component of the ship that is physically attached to it. Using the principles of buoyancy discussed above on the water channeling alone one can appreciate the advantage of a less dense material being permanently attached to the ship. As the water channeling is surrounded above, below and on both sides by water, the water exerts an upward buoyant force on the water channeling and since the water channeling is attached to the ship that force is applied to the ship making it sink slightly slower. Remember this case is different than a ship with no holes in which only the total average density of the ship matter and the density of the components do not. But with enough damage the buoyant forces acting on the individual internal components can be distributed to the hull, theoretically resulting in increased survivability. Water channeling made from denser materials like concrete filler are slightly inferior to water channeling made of less dense materials like foam or balsa. Interestingly enough our rules forbid the use of material for water channeling that will "interfere with the inherent … sinkability of the ship." I argue that using any material that has a density larger or smaller than that of water interferes with the

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inherent sink-ability of a ship. However, because this is relatively inconvenient to measure and as we will explore its relatively minor effects, it is not enforced.

Calculations:

Let's consider a Kongo. The example of the Kongo is convenient because a member recently built one and knows how much water channeling they put in. They used a self leveling concrete sealer for the water channeling. In total 25 fluid ounces of material was used. That's 45.12 cubic inches of volume added to the ship that can be thought of as an independent component that is continuous with the hull. According to the technical data found on the website for Loctite® PL® Polyurethane Concrete Crack & Masonry Sealant, the specific gravity is 0.88 meaning the material is 0.88 times the density of water at standard temperature and pressure, STP. STP is a definition that allows for direct comparison of the densities of materials on a relative scale which actually varies a bit with different industries. Because our approximation is for fun and does not require industrial grade precision we will use 32° F and 1 atmosphere as a close enough approximation for STP. The density of water at freezing and 1 atmosphere is 62.42 lb/ft^3 and thus multiplying 0.88 will give us a working density of 54.93 lb/ft^3 for concrete filler. For reference the density of birch wood is variable and lists anywhere between 34 and 44 lb/ft^3. Balsa wood is also variable and lists anywhere between 8 and 12 lb/ft^3. We will make a couple of assumptions: 1. because birch plywood often used for making water channeling in wood hulls includes glue, is compressed wood and has to be sealed with epoxy or some other product, the density is probably closer to 44 lb/ft^3 2. For similar reasons of sealing with epoxy and fiberglass mat, the density of balsa wood when used for water channeling is probably closer to 15 lb/ft^3.

A little mathematical manipulation will allow us to find how much extra buoyancy can be gained by using different materials. The standard we will compare against will be water at 62.42 lb/ft^3. The difference in density between water and concrete sealant is 7.49 lb/ft^3. The difference between water and birch plywood is 18.42 lb/ft^3 and the difference between water and sealed balsa wood is 47.42 lb/ft^3. Because we know how much volume of water channeling was used in our example we can make some calculations which allow us to compare the upward buoyant force exerted by the water onto the model. Simple multiplication finds the difference in buoyant force; actually we are calculating the difference in weight if we were to measure the materials under water using it as a proxy for buoyant force. The buoyancy gained in substituting a material as dense as water for one of the materials is as follows: concrete sealant = 0.1956 lbs, birch plywood = 0.4809 lbs and balsa wood = 1.2380 lbs. So the difference gained in switching equal volumes of concrete sealant to balsa wood in our model of the Kongo is 1.042 lbs. In other words, consider two ships that use different materials for water channeling but after ballast is added weigh the same on the ground. If you weighed the ships under water, a ship built with concrete sealant for water channeling

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will weigh 1.042 lbs more than a ship built with balsa for water channeling. That's 1.042 lbs of upward buoyancy resisting sinking. 1.042 lbs translates to just under two cups of water. Therefore, by switching from concrete sealant to balsa wood water channeling in this model of the Kongo one can theoretically take on an additional two cups of water before sinking.

How many holes is that:
Using a slightly more complex online calculator determined that the flow rate of water through a 0.177 inch diameter hole one inch below the water line is 0.174 gal/min = 2.78 cups/min. Therefore, assuming you had taken the maximum amount of damage that your pump could keep up with so that the amount of water coming into the model and the amount of water going out via the pump was exactly equal, and thus the density of the ship was exactly equal to water, so that you were on the verge of sinking but still floating, and someone came by and put one single hole in your ship 1 inch below the waterline, by using balsa water channeling instead of concrete filler you could stay afloat for 43 seconds longer. In theory of course.

But I need the ballast:
It is true that putting the bulk of the weight of the ship as low as possible is beneficial and likewise using a denser material for water channeling can allow the bulk of the weight used for ballast to be slightly lower in the ship. This in turn leads to more stability on the water. However, water channeling in the center of the ship should really only be ¼ inch tall with the heavy items like batteries and extra lead ballast sitting on top of that. The net result is an only slightly higher center of gravity and an only slightly less stable ship which doesn't translate very much to performance on the water. However, as we have seen, a less dense object has a greater upward force of buoyancy acting on it. In my approximation, it is slightly beneficial to use a less dense object for water channeling with a denser object used for ballast sitting on top of it to reach the same result of net model weight. Consider as an example, 10 lbs of lead verses 1 lb of lead glued to 9 lbs of foam. Both weigh the same however, what happens when you place them both in water? One floats and the other sinks because of the average density and thus the buoyancy.

Proceed with caution:
Well why wouldn't I use as much balsa or foam 'water channeling' as I could stuff into the boat because that will make me less likely to sink? First off, it would probably be seen as illegal in our hobby if it was excessive. In terms of physics however, as we touched on, the goal with center of gravity is to have the bulk of your heavy components as low in the ship as possible. Lifting the batteries ¼ inch off the bottom is not really noticeable but if you use too much water channeling and put your batteries place your batteries too high off the bottom, the ship will become unstable. Also since water is fairly dense, as you start to sink the extra water will sit higher in the ship and cause it to become even more unstable as you sink. There is a balance somewhere in there. I have not personally done enough experiments to make a judgment but a widely held standard seems to be no deeper than ¼ inch in the middle of the ship.

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Limitations:

Using Archimede's method to calculate buoyancy is actually a fairly simplified explanation of the forces at work. There are other forces acting on the ship that we neglected, mostly due to the complexity it would add to the calculations. In real life, water pressure and density varies somewhat with the depth of the water so ships with deeper hulls would have slightly increased buoyancy enacted on the water channeling when compared to ships with shallower drafts. However since the difference we deal with is at most inches this is probably a very minor difference. Along those same lines, the depth of water channeling used typically varies depending on the part of the hull. For example taller water channeling is typically installed in the extreme bow and stern of the ship so there will be instances where some but not all of the water channeling is submerged. Another limitation is the negligence of the effects of surface tension, or water's inherent property of polarity that allows it to be somewhat stickier on the surface. Again the effect of this is probably minimal and more importantly, much more difficult to calculate and determine how it interacts with floating and partially submerged bodies for the scope of this article. Another limitation is the fact that water is flowing inside of the ship. If the pump is on there is water coming in and going out. Furthermore, water flowing in from the majority of the damage we take has to flow down once it gets inside of the ship. We considered internal and external water to be continuous. However it probably isn't really very continuous until the water level inside of the ship rises to the level of the lowest holes, which in most models is a large amount of damage. Still another assumption is the variability in hulls. This example used a Kongo built by one captain. We have to assume that this captain used an amount of water channeling that is typical of what most of us would use. Other ships may use more or less depending upon the nature of the hull being a different shape because it is a different ship or because another builder might use a vastly different amount of water channeling in amidships, bow, stern and the bulges.

Summary:

In summary, due to the physics of floating, or more accurately the physics of trying to float when you are all shot up it is probably better to use the least dense material possible when creating solid structures within the hull, i.e. water channeling. The advantage gained however is likely only minimal. Is that incremental advantage enough to change your building habits? Perhaps. Will those 43 seconds of extra float time translate to making it off of five? Sometimes it might. How many times do we take just one extra hole or only miss coming off the water by a few seconds? Not very often. In the end I will leave it up to the individual captain to judge the quality of my argument and decide what is right for their ship. Anyone who has been in the hobby for even just a few months will easily recognize there isn't just one right way to do things.

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"Success is not final, failure is not fatal: it is the courage to continue that counts." - Winston Churchill