Borders Model Boat Club

www.bordersmodelboatclub.yolasite.com

About Scale Effects

The laws of physics make it impossible to construct a scale model of a ship which behaves in an identical manner to the full size prototype. The main reason is that while some properties scale linearly, others obey square laws (or higher powers).

Froude Scaling

When Naval Architects design a full size ship, they always resort to testing a scale model in a towing test tank. The scaling method they use for this is known as "Froude Scaling" proposed by William Froude in the 19th century.

When scaling a model, there are certain things which are inevitably the same for both the model and full size. There is nothing we can do about the density of water, and nothing we can do about gravitational acceleration.

It follows that for scale similarity, densities and accelerations must be the same for the model and the full size prototype. Newton's laws of motion then imply that time must be scaled as well, at the square root of the dimension scale. If we make a 1/36 scale model, scale time will be 1/6 of full size time. The scaling factor for "Scale Speed" also becomes the square root of the dimension scale.

As a result of all this, all dimensions are scaled by the scale factor and displacement (or weight) by (scale factor)^3.

Film makers often use models for sea scenes. They record using scale time, then slow down the results to get realistic waves and spray.

There are other factors as well. The viscosity of the water does not scale either, so the power needed to drive the model will not scale correctly, and propellers will behave differently.

All this really proves in terms of model boats is that "Scale Speed" is in the eye of the beholder, and is not a mathematical figure. If it looks right, then so be it !

When you see ship models being tested in a model basin, you will notice a lot of nails protruding at the bow. These are "Turbulators", and are used to create turbulence in the water around the model, in order to mitigate the effects of non scale water viscosity. (The turbulators reduce the drag of the model to make it more representative of full size.)

Propellers for Scale Models

Hydrodynamic theory for propellers is only approximate, basically because the water doesn't know the rules. The various formulae are made to work by a series of "Cooking Constants". The hull form in the vicinity of the propeller also has a huge effect which is difficult to quantify.

Froude scaling indicates that if the propeller diameter, pitch and blade area are scale size, then the propeller should be run at (full size rpm) x $\sqrt{}$(scale factor). However in practical terms, you have to use an available commercial model boat propeller whose blade form probably does not match the full size one, and whose pitch is probably unknown.

Commercial model boat propellers are only made in a relatively few configurations, and probably little or no development work was done on their design. Often the only data quoted is the outside diameter and a lot of meaningless blurb alleging high efficiency etc.

The biggest problem for model boat propellers is "Cavitation". When the propeller is turning, the pressure one side of the blades is increased, while on the other side it is decreased. Since the boiling point of water is pressure dependent, local boiling can occur, creating noise and bubbles.

There are three things that can be done to stop cavitation: Put the propeller deeper in the water, fit a finer pitch propeller, or run it slower by fitting a gearbox between the drive motor and the propeller shaft. Cavitation causes noise, vibration and loss of thrust, and can cause damage to the propeller.

For a scale model, you will probably want to use a propeller with a linearly scaled diameter, and run it at speeds up to 2000 - 3000 rpm, regardless of the scale speed.

Motor Size

Really this becomes a case of trial and error. The best you can do is to look at what is fitted to a model of similar size, which is performing well, and copy it.

Naval Architects have various ways of estimating the power requirements of a ship, based on tests on a scale model. This is based on Froude scaling, but with factors representing the difference between fresh and sea water, and viscosity effects.

For a model, basic Froude scaling uses $(\text{Linear Scale})^{3.5}$ x full size engine power, but there are other effects such as propeller efficiency, operating speed and hull drag, which can upset matters. So, for full size 500 HP modelled at 1/36 scale, the calculated motor requirement is:

$$\frac{(\text{Full Size Horse Power}) \times 746}{(\text{Scale Factor})^{3.5}} = \frac{500 \times 746}{36^{3.5}} = 1.3 \text{ Watts}$$

1 Horse Power = 746 Watts

Owing to the other effects, this should be interpreted as an absolute minimum estimate of the power required.

Electric motors if coupled directly to the propeller shaft will probably cause cavitation problems. Motors are usually geared down by a factor of between 2 and 5 in order to reduce cavitation.

If in doubt, go for the next size up in motors, as you will be gearing it to the speed you want, and the propeller thrust is proportional to rpm and not the power capability of the motor. You will not be too worried about efficiency.

Reynolds Scaling

The other method of scaling matches the properties which are dependent on viscosity effects. These include hull drag, wave induced and vortex shedding effects, and propeller performance. The way these effects are assessed is by calculating a “Reynolds Number” which is a function of speed, length and viscosity. The value tells you whether the craft is operating in “Laminar” or “Turbulent” conditions. Low Reynolds numbers imply “laminar” conditions, for which drag is very much higher. Rudders become less effective at low Reynolds numbers, Bilge keels become more effective. Models probably operate in “laminar” conditions, while full size vessels will operate in “turbulent” conditions,

Having said that, while Froude number and Reynolds number effects are very important to Naval Architects, they can be safely ignored by model boat builders, provided the models are not being used by the Film Industry, when the appearance of the bow waves etc becomes important.

Stability

The roll stiffness of a ship is gauged by its “Metacentric Height”. This is the vertical distance between the centre of gravity and the centre of buoyancy and determines its ability of the ship to stay upright. In waves, a ship tries to remain perpendicular to the water surface, and its roll stiffness determines how it responds to waves. The changes in slope of the water surface induce a rolling motion, whose amplitude will depend the natural roll frequency of the ship, and on motion damping from the hull and any bilge keels which are fitted. In waves, a ship with a large metacentric height will roll more than a ship with a small one. Hence full size ships are designed with small metacentric heights of, say, about 3 ft.

The metacentric height also determines the amount of roll induced by propeller torque, and the amount of heel in turns. Since our models will most likely be travelling much faster than Froude scale speeds, and be turning more sharply, we need to stiffen them up by making the centre of gravity as low as possible. As a result, the models will roll more in waves than full sized ships, but then the crew in the model don't get sea sick.

If a model has an unacceptable roll in a turn, the only cure is to increase the metacentric height by lowering the centre of gravity. Bilge keels cause damping and are fitted to reduce the amplitude of wave induced roll, but will not affect propeller torque induced roll, or roll induced by change of course.