what makes a good canoe

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The canoe is a superb example of functional evolution. It is simple, versatile, functional and aesthetically pleasing. Yet after all these years there is still debate as to what is or isn't a "good" canoe. That the general tone of these debates is subjective does not detract from the validity of any conclusions reached since science is not the only road to truth. Still, it would be nice to know the "why" of the matter at least as far as science is capable of providing the answers. Even naval architects disagree on the finer points (thus explaining the wide variety of shapes) but there is a wide body of fundamental knowledge based on full size ship testing and model testing which we can use to evaluate the relative merits of different canoes. It is these fundamentals that I will cover in this article that will give us the working knowledge to understand why canoe "A" is easier to paddle than canoe "B".

Some 100 years ago William Froude proposed the simple but important suggestion that the total resistance of a floating body to motion was the sum of two parts, frictional resistance and residual resistance and that these two parts could be analysed seperately. Frictional resistance is that which ~~occur~~ occurs between the hull and the water and residual resistance is the sum of wavemaking, leeway, appendage, air, and heeling resistance. For our purposes, only the first two are important although I will discuss the others briefly later on.

Froude also determined that the potential speeds of floating bodies were related to their waterline lengths and that similarly shaped bodies of differing lengths would generate similar wave patterns and have proportional resistances. This relationship is expressed as the Speed/Length ratio or $V/\sqrt{L}$ where V= the speed in knots and L= the length in feet. What this means is that a 36' canoe traveling at $1.0\sqrt{L}$ or 6 knots will have the same wave patterns and proportionally the same resistance as a model of the canoe that is 4' long and traveling at the same speed/Length ratio or, in this case 2 knots. It is this fact that ~~allow~~ allows naval architects to predict the performance of full size ships from data obtained from model tests.

Frictional Resistance

The frictional resistance of a body is the sum of the effects of wetted surface, the condition of the surface, the length of the surface and the speed. The total frictional resistance is calculated from the formula:

$$R = .97 \times C \times V \times A$$ where

R= Resistance
C= The coefficient of friction
V= The speed in ft./sec
A= the wetted surface

The coefficient of friction depends upon the roughness of the surface and the Reynold's number. The Reynold's number is:

$$Re = \frac{VL}{\nu}$$ Where

v = The speed in ft/sec.
L = The length over which the water is flowing
v = The kinematic viscosity of water (normally 1.3 (10) ft/sec.)

As the water passes over the hull, it is slowed down due to friction and a layer of water called the boundary layer is built up. This layer is carried along with the hull and gradually increases in thickness until at the stern, it breaks away in the form of eddies. In fact the friction generated is not between the hull and the water but between the water particles attached to the hull and the particles sliding past. Initially, this flow is laminar (the particles are traveling parallel to the surface of the hull) but it quickly becomes turbulent at Reynold's numbers of between 10^6 and 10^7. On the average canoe, this is a point about 2 feet from the bow. As this layer gets thicker, more and more kinetic energy is lost in imparting motion to the water particles within the boundary layer. If the surface is hydrodynamically smooth the coefficient of friction drops as the Reynold's number increases (either speed or length increases can cause the Reynold's number increase) but this situation is highly unlikely as few surfaces are so smooth. Figure A shows the relationship between Reynold's number, roughness, and friction coefficient.

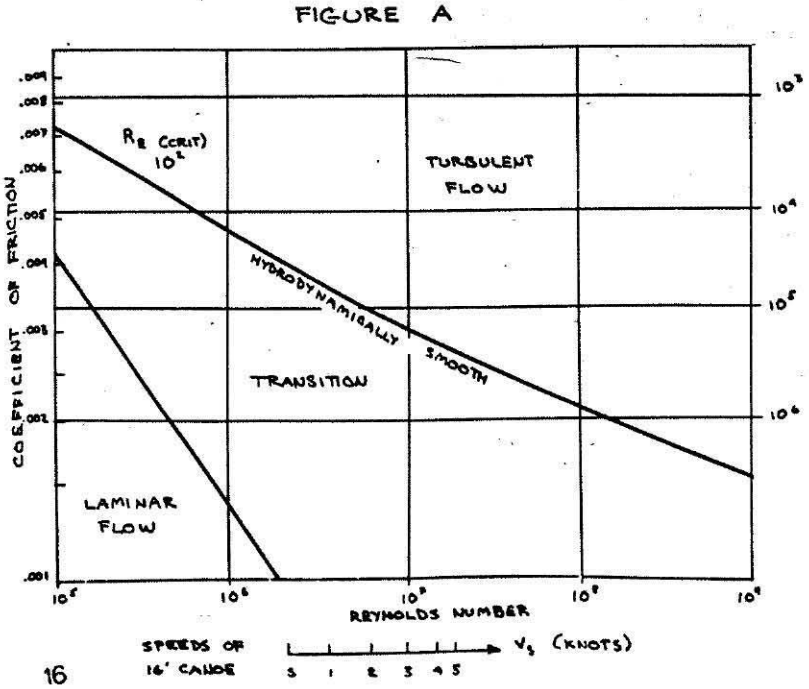
Along the bottom of the graph is the practical speed range of a 16' canoe. It can be seen that the friction coefficient range is quite small, being between .004 at the low speed range and .003 at the high speed end.

Should the roughness exceed a certain level, the coefficient of friction becomes greater than that of the smooth surface condition and will not lower with increases in Reynold's number. The critical number is 100:

$$Re = \frac{Vk}{\nu} = 100$$ where

k = The roughness size in mils divided by the length of the surface in inches.

FIGURE A



The curve labelled 10^2 shows the friction coefficient as Reynold's number increases. When the roughness exceeds the critival value, the coefficient does not drop but levels off as indicated by the horizontal lines. A new 16' canoe fresh out of the mold will have a surface roughness of .02 mils. An aluminium canoe would have a surface roughness of 1 mil not allowing for rivets. Some ABS canoes have roughness of 1.5 mils. For a 16' canoe, the roughness cannot exceed $\frac{k}{L}$ of 10^2 or .0196 mils if the coefficient of friction is to drop with increased Reynold's numbers. At a surface roughness of 2 mils ($\frac{k}{L} = 10^{-3}$) the coefficient remains constant.

What all this means in real life is that a 16' canoe hot out of the mold and having 40 sq. ft. of surface area will generate 2.65 lbs. of frictional resistance and a similar aluminum canoe of the same surface area will generate 3.98 lbs. or 50% more.

As these figures are for "new" condition, your old rock crusher is going to be substantially worse and because the increase in coefficient of friction is logarithmic, the increase in friction is enormous. Keep in mind that the foregoing applies to smooth water only, but it should be food for thought.

Wave Making resistance

Earlier I hinted that canoes had limited speeds. The limiting factor is the wave making resistance. As the canoe passes through the water, it creates gravity waves and the energy required to create the waves is transfered to the canoe as resistance.

There are two types of waves, bow waves which spread out fanlike from the bow and transverse waves which are seen behind the hull and lying at right angles to the path of the canoe. It is the transverse waves that are important to our discussion of speed. The water pushed aside as the hull passes tries to fill back in behind the hull and the distance required for the water to return to its undisturbed state under the influence of gravity is the natural length of a wave traveling at the same speed as the canoe. (The length of waves is measured from crest to crest) Froude, who seems to have thought of everything, established that the speed of a wave was equal to $1.34\sqrt{L}$ in ft. Therefore if you could measure the length of the transverse waves behind you and do some quick math you would know how fast you were going. This fact, of course only applies to displacement hulls and not planing hulls which are governed by different rules as they are supported by dynamic pressures created by the motion of the boat.

Figure B shows a plot of resistance against speed and shows how there is a dramatic rise in resistance as the speed approaches $1.34\sqrt{L}$. One might think that this would make naval architecture cut and dried, but the architects have a few aces up their sleeves to justify their existance. The first is the prismatic coefficient which is the relationship between the volums of the hull and the volume of a prism having the same length and cross sectional area as the hull's largest cross section. The second is the displacement/Length ratio $\left(\frac{D}{(L/100)}\right)$ which is a convenient way of expressing the bulk or fineness of the hull. On the left of Figure B are various prismatic coefficients and the dashed line represents the ideal prismatic for a given $\frac{D}{L}$. It is obvious that no one prismatic will be satisfactory for all speeds. For instance, 8 man racing shells which operate at speeds averaging $1.2\sqrt{L}$ or 9.6 knots for the 64' shell would be best designed with a prismatic of .59 to allow them to maintain that speed with the least effort. A 16' canoe that cruises at around 3 knots would be best with a prismatic of .51.

You will note in Figure B that below $1.0\sqrt{L}$ there is little difference in wave making resistance between the two curved lines representing displacement/length ratios, but that the gap widens quickly at speeds above 1.2 L and that at 1.34 L a hull with a displacement/Length ratio of 60 has 20% more wave making resistance than a hull with a ratio of 40. For those of you who would like to plot your own canoe's Displacement/Length ratio, D is expressed in terms of long tons of 2240 lbs. and L is the waterline length.