

## Pros and Cons of the Grand Lake Sailing Barge

For a description of this barge, visit my website at <http://www.wright.edu/~guy.vandegrift/>. There are many boat designs available for the first-time boatbuilder with modest skills. In spite of my enthusiasm for this design, I think most first-time builders would probably choose to build a different boat. Here are the “pros” and “cons” of this sailing barge, as I see them:

### Pros

1. **This boat can be built cheap but very strong.** The strength is due to the boat’s most unusual feature: All the plates are flat – no wood is bent, anywhere. Unbent wood can be as thick as the builder wishes it to be. Another and very famous overbuilt wooden boat is the Nordic Folkboat. Of course, the venerable Folkboat is to this barge as French cuisine is to prison slop. Nevertheless, I like to think of this barge as the French cuisine of prison slop.
2. **All the extra weight is situated where it needs to be.** Part of this heavy construction is justified by the fact that we use the more economical polyurethane glue, while most boatbuilders agree that epoxy is stronger. With an extra thick bottom panel that would induce larger stresses when warped by the intrusion of water, we felt a need to maximize the surface area upon which the glue held the panel in place. The 2x4 inch boards at the bottom not only give us this surface area, but also serve as ballast. The upper pair of 2x4s serve as seats. These upper boards also keep the boat stable, though to a lesser degree. This is because, like the Folkboat, this barge has very low freeboard, meaning that the boat rides low in the water. Any weight situated slightly above the waterline, gives a boat stiffness and stability up to perhaps 30 degrees of heel
3. **The boat is a tinkerer’s dream.** It should be no surprise that most amateur boatbuilders like to modify the plans. With this boat, the amateur boatbuilder can get into the water immediately, then add a cabin later. Then, the cabin can be removed and replaced by a deck. More opportunities for tinkering involve the straight barge-like sides, which permit great flexibility in the placement of the sideboards. Flexibility in sideboard location translates into flexibility in sailplan. One could even add ballasted sideboards that stay down permanently, turning a heavy dinghy into the equivalent of a keelboat.
4. **The boat needs further study.** My primary goal here is educational. By studying a new and untried boat design, we open up countless research opportunities for students at all levels.

*[See the following essay on the boat’s most unusual feature, which is the 12 degree discontinuity in the bottom slope, below the waterline. Also, the much sharper 45 degree discontinuity at the bow is above the waterline. It serves primarily to enhance the boat’s appearance, but we also hope it helps the boat cope with large waves striking the bow.]*

### Cons

1. **Not everybody wants a heavy “overbuilt” sailboat.** Two other boat construction methods will be more attractive to most boatbuilders: The “instant” or “stich-n-glue” boats employ plywood panels connected by epoxy chines, and are quite strong for their weight. Also, barge-like boats such as Bolger’s *Brick*, the *PDRacer*, and Dave Zeiger’s *Trilobyte* are more likely to serve most boat-

builders' needs. In our case, the boat's heaviness is no great problem because our Lake Campus has a small dock that could support several boats. Furthermore, keeping wooden boats in the water for months at a time will permit critical tests regarding the boat's resistance to rot and stresses due to water intrusion.

2. **The hydrodynamics of this barge are not ideal.** This is quite an understatement: Three "rules" of sailboat design have been violated: (1) the sides are parallel, (3) the bottom is flat, and (2) the water flows past sharp corners. Phil Bolger's principles of equal curvature on the bottom and sides have been rejected, not as false, but as being too much trouble. I broke these rules because I was looking for something different. I also had experience in plasma physics, where all "improvements" in hydrodynamic stability seemed to yield only marginal results. So, I reasoned that degradations in hydrodynamic principles should yield only marginally reduced performance in a sailboat that is not designed to go fast. I am not much experienced in sailing, but I can say the boat seems OK, and we have fun on it. And, it will also be fun to study the hydrodynamics of this unusual hull shape.
3. **The boat pounds mercilessly in heavy waves.** But it does make for a fun ride! The design could be easily modified to have a V-shaped hull. But we are keeping the bottom flat because we hope to make a bigger version of the same boat that serves dual purposes: (1) Coastal cruising as a sailboat, and (2) collecting geological specimens on smooth rivers as a motorized barge. If we succeed in melding of these two disparate functions into a single boat, we may find that Wright State University possesses one of the last wooden sailboats to also serve as an actual **working** vessel.
4. **Some will find the boat unattractive.** But I don't! In fact, I see this as a beautiful mix of modern and traditional. Barges are traditional in the Great Lakes and along the canals of Ohio. It is also traditional to design boats on a solely functional basis. There is also something very "*21<sup>st</sup> century*" and modern about this design. At this very late stage in the Industrial Revolution, almost everything we touch is mass produced. Trees are harvested by machines that look like giant robot invaders from outer space, cut by computer-controlled sawmills, and delivered to home improvement stores in large trucks using computer-run inventory. Today, amateur builders of cheap and simple plywood boat don't actually **make** boats. Instead, they **assemble** them from readily available materials. But this is exactly what boatbuilders have been doing for centuries. In the past, they used trees and copper nails, while now we use computer cut boards, manufactured plywood, and glue.
5. **The design needs further study.** Though the novel nature of this design makes for research that is fun, educational, and useful, the potential builder should be warned that the concept has not been fully tested.

## *Plausibility argument that sharp bends below the waterline have minimal influence on small boat performance*

Further study will be required to verify this, but I don't think the 12 degree angle at the bottom has much influence on the boat's speed. I have noticed that trucks and cars have structures that are clearly in violation of aerodynamic rules. If a smooth hydrodynamic shape and the absence of small imperfections were essential for good gas mileage, and great pains would be taken to streamline side mirrors and such. Also, they say you should keep the car windows closed to maximize gas mileage. I don't notice the change when I open a window on the highway, (although I do notice the change when I turn on the air conditioner.)

I also have a simple calculation that suggests that for small sailboats, such departures from the ideal smooth shape will have minimal impact on performance. My argument involves the Reynolds number,  $Re = LV/\nu$ . Here  $V$  is the boat's speed,  $L$  is its length, and  $\nu \approx 10^{-6} \text{ m}^2/\text{s}$  is the kinematic viscosity of water. Since  $\nu$  is a constant for a given water temperature, we see that  $Re$  depends only on the boat's speed and length. Another important number for a sailboat is the Froude number,  $Fr = V/\sqrt{Lg}$ , where  $g \approx 10 \text{ m/s}^2$  is Earth's gravitational acceleration. The Froude number tells us the extent to which the boat creates a wake so large that the boat cannot further increase its speed. For many boats, including ours, the maximum speed is estimated by setting,  $Fr = 1/\sqrt{2\pi}$ . This result is called the boat's hull speed:

$$V_{\text{HULL}} = \sqrt{\frac{g}{2\pi}} L^{1/2} .$$

At this speed, the Reynolds number can be expressed in terms of length alone,

$$Re = \sqrt{\frac{g}{2\pi\nu^2}} L^{3/2} \approx 1.25 \times 10^6 L_{\text{METER}}^{3/2} .$$

For a 14-ft boat the Reynolds number at hull speed is about  $10^7$ . If the length doubles to 28-ft, the Reynolds number at hull speed almost triples to about  $3 \times 10^7$ . How does this influence frictional drag due to turbulence on a boat? I have no definitive answer as yet. An old formula for estimating the force of this frictional drag is,

$$\text{Drag Force} = \frac{1}{2} \rho V^2 S_A \left\{ \frac{.075}{(\log_{10} Re - 2)} \right\}$$

Here,  $\rho$  is the mass density of water, and  $S_A$  is the wetted surface area. [Equation taken from "Hydrodynamic optimization of hull ship forms" by Perceval, Hendrix and Nobelesse in Applied Ocean Research 23 (2001) 337-355]

This equation tells us that the drag force is only weakly dependent on Reynold's number, and hence the fluid's viscosity. This is consistent with turbulent drag, in which eddies carry away the energy associated with the "frictional" drag.

But the real issue is not resolved by this formula. Instead, we are interested in how a discontinuity in the bottom's slope affects the drag force, and in whether the discontinuity's influence is enhanced or diminished as we make the boat larger. Though I am sure such studies have been completed, I have not yet found an analysis of turbulent flow that approximates the geometry of a barge with a discontinuous 12-degree change in the bottom's slope.

The closest geometry I can find on the internet involves the flow of water through a pipe. Essentially we warp the flat hull into a circle and study the change in pressure along a long, circular pipe. Instead of a discontinuity in slope, we study the well-known affect that surface roughness has on frictional drag. This is analyzed using the Moody diagram shown at the end of this document. *[Note: the diagram is best viewed in color.]*

From the Moody diagram, we can compare the drag at two Reynolds numbers,  $10^7$  and  $3 \times 10^7$ , corresponding to the 14 and 28-ft boats, respectively. I have no idea what surface roughness corresponds to the 12 degree discontinuity in slope. Let us make the entirely arbitrary assumption that the 12 degree discontinuity causes the drag to increase by a factor of 1.23. This corresponds to the length of the red line-segment in the diagram. For rough pipes, the Moody diagram shows that after the threefold decrease in Reynolds number, the discontinuity increases the drag by a smaller factor, namely 1.13 (see the green line-segment in the figure). The ratio in the drag enhancement is  $1.23/1.13 = 1.09$ , which on a log scale, corresponds to the difference in lengths between the red and green segments, shown in blue. In other words, doubling the length of the boat makes the drag worse by 9%.

The preceding discussion was made for an arbitrarily chosen increase by a factor of 1.23, which corresponds to a surface roughness,  $\epsilon/d$ , of  $10^{-5}$ . If the same analysis is performed for,  $\epsilon/d = .05$ , the doubling of the boat's length makes the drag worse by 15%. Unfortunately, this would not be a meaningful reason to make even a small boat with such enhanced surface drag because the drag enhancement has decreased from a factor of 10.4 to a factor of 9. Any factor in drag enhancement due to the discontinuity in bottom slope much greater than two would probably be unacceptable.

This analysis suggests that if the discontinuity degrades a boat's performance excessively on a 28-ft boat, the discontinuity will be unacceptable on a 14-ft boat. On the other hand, while the range in length contemplated by the owner or builder of a sailboat is typically less than a factor of 3, small dinghies and large ships can vary in length by factors larger than 50. Such a change in length increases Reynolds number at hull speed by a factor of  $50^{3/2} \approx 353$ . Here, an unacceptable degradation of a factor of 2 due to surface roughness on a large ship might correspond to an acceptable factor of only 1.25 on the much smaller dinghy (arbitrarily taking the surface roughness to be  $10^{-4}$ ). This is shown as the magenta arrow in the diagram.

People who make small and cheap sailboats do not place a high priority on speed, especially if the wind is blowing so hard that the boat is approaching hull speed. Also, designers of ships would be very interested in the fuel savings associated with a change in drag of only a few percent, while much larger improvements in a homebuilt boat might be not considered worth the bother. Therefore, the mindset of the designer of a small home built sailboat should be much different than the mindset of the ship designer, with regard to hull resistance.

It would make for an interesting student exercise to compare the ship's hull resistance formula quoted above with an analogous formula based on the Moody diagram, using the pipe's surface area for the wetted area of the hull, and the product of pressure and area as the force.

When an adequate study of this discontinuity in slope is accomplished, we will probably obtain a diagram qualitatively similar to the Moody diagram. If that occurs, then one of the following outcomes is likely:

1. We will find that the discontinuity is unacceptable for a 14-ft boat and even worse for a 28-ft boat. This seems unlikely because the 14-ft boat feels OK to those who have sailed or paddled Malaspina....though none of us are truly "experienced" boaters.
2. We will find that the discontinuity is unacceptable for a 28-ft boat, but acceptable on a 14-ft boat. Though our analysis using surface roughness in pipes did not yield this result, we should not be surprised if the different geometry puts the two boats into different regimes.
3. We will find that the discontinuity is acceptable for both boats. If so, I suggest we make a 28-ft version of this barge, sail it to Europe, and visit the wooden Folkboat fleets. I think we could make our barge for under \$5,000. And I think the boat will probably survive the crossing.

Moody Diagram

