Visual Arts in Boat Design

Spring 2008 Senior Project Final Report

Union College Engineering, MER 498

Jon Miller

Advisor: Andrew Rapoff Ph.D.

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Introduction

This spring I completed the 6 phases of the project. The first phase included research of basic boat design to establish a sense of what style boat I would be designing. It was important to understand the concepts of different boat styles and fundamental aspects of how the shape and size would affect the performance of the boat. I determined different physical goals for the shape of the boat that drove the visual design of the boat. The second phase of the project was focused around designing the shape, size, and appearance of the exterior of the boat. Based on research I knew that I wanted a boat with a center of gravity that is towards the bottom of the boat and is also slightly closer to the bow of the boat. I began drafting and sketching various designs to evaluate and approach the selection for the final design of the boat. By the end of this phase I had selected a design that I found visually attractive and projected that it met my goals based around the center of gravity and performance. The third phase of my design was to actually determine an estimate for the center of mass, the weight, and a better estimate of how the boat will perform based on the exterior design I selected. The fourth phase of the project was finalizing the design to prepare building the model. Once that was done I began the 5th phase which was building a model of the boat. The model is a 1/15 scale size replica of the boat. The model will serve as a 3-dimensional representation of the design. The model gives the best sense of the design beyond the drafting. The 6th and final phase reflects on the design, possible improvements and future work. The following report is more detail on the 6 phases of the project.

Phase 1: Research and establish goals for boat performance and stability.

Designs Considered:

The hull design of all boats depends entirely on the use of the boat. Flat bottom boats are very stable, steady boats. Due to their physical quality of having the largest bottom area they will be very balanced in calm waters. At the same time the large bottom area proposes problems in rough waters. Since the draw, the depth of the boat, is very low and flat; a small wave has the ability to cause a force on the boat. The low draw also causes the boat to have a high center of gravity and will not be effective when keeping the boat upright. Since the boat has a shallow hull it is dangerous to maneuver as high speeds. Flat bottom hulls serve great use in steam boats and boats used in calm rivers or marshes.

Another common hull type is the tri-hull or the tunnel hull. The tri hull is a base structure of a "V" hull with 2 extra hulls at the edges of the boat. This offers great stability and the boat can reach high top speeds. Due to the sharp profiled of the outside hulls, these style hulls have great handling at high speeds as well. Many Race boats use this type of hull design. This design, however, does not perform well in rough water. The flat section of the hull between the center hull and the two edge hulls generates high forces when waves crash into the hull. When traveling in rough waters a tri hull design would cause a uncomfortable ride.

Style of Choice: "V" Hull

Round bottom boats, or “V” hull boats serve as sea worthy designs. With a deep draw and low center of gravity, these designs perform well as high speeds and also create a smooth ride even in rough waters. The "V" Shape of the hull slices through waves to soften the ride. The hull causes waves to break to the sides of the boat and prevents harsh vertical movement. The “V” hull performs well at high speeds due to "Planing." When hull is moving through water, an upward force is created similar to a down force is created on race cars. This causes the boat to raise out of the water and less surface area of the hull is in contact with the water. The drag of the water decreases and the boat can glides with a low coefficient of friction from the water while saying balanced.

Boat Size and Specifications

Now that I have determined the style of boat, my next step is to become more specific for my target design. After researching and looking at different popular yacht companies, the models around 35-40 feet long offer the most opportunity for creativity and flexibility. A boat this size needs proper structural design since it will be displacing around 20000 lbs. A good fast cruising speed for a boat of this size is around around 35 knots. The draw will be 2-3 feet depending on the amount of fuel in the boat, or different loads the boat may be carrying. The beam or width of the boat is targeted to be 12-13 feet. A wide beam affects the top speed of the boat, but offers great stability. Since there will be no heel or extreme weighing, a wide beam helps prevent the boat from capsize.

A dual engine arrangement will be installed for several reasons. First of all, my design is going to be geared towards the ocean and will have the capability to travel to deep seas. It is standard practice to have a boat with 2 engines for safety reasons in case one of the engines runs into a problem. The second reason for dual motors is for maneuvering at low speeds. If the driver runs the engines in opposing motion, the boat gains the ability to spin in a small amount of space. Some yachts are using jet engines that can fully rotate under water to give exceptional handling and smooth acceleration. This design may be considered in the future, until I can find further information on the jet engine design I will plan to use dual diesel engines.

I plan to design a cabin with low weight to keep the draw and displacement as low as possible as well. This helps the boat have the ability to maneuver into places where similar sized yachts can go and also increase handling and top speed. More design goals for the cabin will be done next week.

Stability, Lateral Plane, Hydroplane.

The stability is based on the coupling forces from the center of gravity of the boat and the force of buoyancy pushing the boat out of the water. I will not necessarily have to determine the couple in all cases when the boat is heeling or steady, but I can base my design to have a low center of gravity. Having a light cabin is crucial to bring the center of gravity towards the water. Some boats have ballast which increases the stability by adding weight at a very low center of gravity in the hull. Lead is the most popular form of ballast. I will have to determine if a ballast correction will be needed for my design. Since

I want a faster low drawing yacht, I would prefer if the stability was effective without ballast.

The lateral plane of the hull will also be considered in design. The later plane refers to the vertical point of force under the boat. This is the point used in a free body diagram to represent the vertical point of pressure. It moves forward on the boat when it is moving, and can never be truly evaluated since the lateral resistance is not a calculated quality. When the boat is moving the lateral plane is positioned on the front of the hull and will tend to raise the bow when the boat is acceleration. A well designed hull will decrease the movement of the later plane for a smooth acceleration. This relies on the shape of the hull and again, the center of gravity. I plan to shift the center of gravity slightly towards the bow to increase the effect of the force of the later plane when the boat is in motion.

The hydro plane is another crucial physical characteristic that must be considered in design. Boats will find the most efficiency at high speeds if a proper hydroplane is formed under the hull. A steep “V” angle under the hull will create a significant hydroplane but lose all stability, a turn as high speed can cause the boat to heel over and capsize. A soft “V” design can prove to provide efficient hydroplaning forces while holding good stability at high speeds. If the boat has a low center of gravity, it has the ability to skim or slide while heeling and will prevent rolling.

Phase 2: Preliminary Design

I started designing the preliminary design of the boat by sketching and drafting a wide range of visually attractive boat designs. The designs are initially drawn for artistic character then I will be scaling them to determine general length, height, width, and potential waterline height. Then I will be evaluating the designs to determine if they are fundamentally efficient in terms of the lateral plane, stability and predicted draw. I will be basing the predicted waterline on the size of the cabin relative to the hull size and width. All cabins are based on a fiberglass and wood construction.

Drafting initial design

The initial design is treated as the current final model. I am calling it the initial design because I assume that I will be making changes in the future. The changes will be based upon the balance and weight of the boat and some minor changes in the appearance. Knowing the dimensions of the boat I can determine an estimated weight of the boat overall. By splitting the boat into 6 major components that make up the entire weight I can find ultimate weight of the boat and estimate the center of gravity. Using this I can determine how the boat will float and whether the design meets my expectations on how it may perform once in water.

Building Solid works model

Building the model in solid works is proves to be a difficult task. The complicated part of this task is that there are lines and curves that are hard to recreate on the computer. Using lofting in solid works I can create a 3 dimensional model of the hull. However this proved to be a very tedious and inefficient method of building the boat in SolidWorks. I have built only the very basic design and will add more detail in phase 4 of the project. The solid works model will serve as a 3-dimensional demonstration of my design. SolidWorks also has potential for use in stress analysis and further evaluation of the structure of my design.

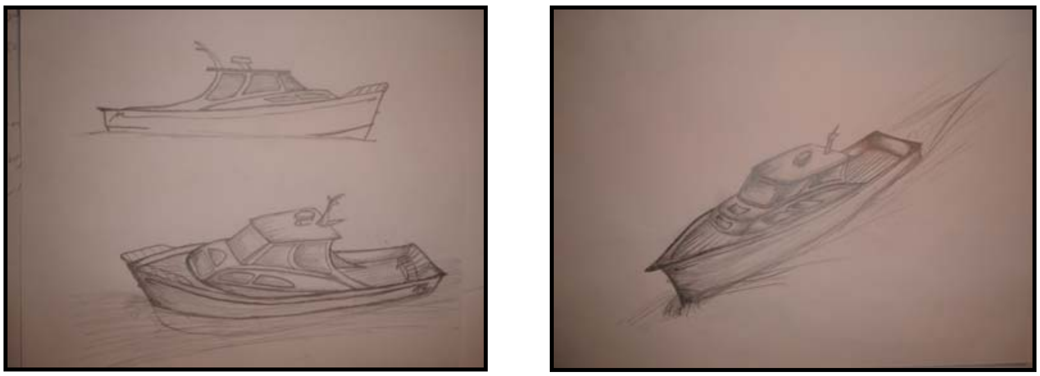

Figure 1: Sample Sketches of Possible Designs

Phase 3: Evaluation of initial design

The initial goals for my design were to design a lightweight, low center of gravity, where the center of gravity was also placed slightly forward. I can assume that my design satisfies these goals, however a more specific analysis is necessary to ensure that my design will have proper balance and performance. The four elements of the boat that account for nearly all the weight are the hull, cabin, flooring, and the engine. I evaluated the weight and estimated the center of gravity for each of these components to determine the overall estimate of the weight and center of gravity of the entire boat.

Engine

I want my design to be a high performance yacht. This means that the design will be light weight and have a engine that will provide enough power to give the boat a cruising speed around 40mph. I did not actually determine what kind of hp is needed given the boat size shape and weight; instead I research similar yachts that are currently in the market and looked at the engines that they use. I would want to install dual engines. This is for safety reasons and maneuverability. I found that for a boat this size to have a high cruising speed it would need engines generating around 550hp. A popular diesel engine company, Coastal Marines, sells 270 hp engines that each weigh around 1500lbs (Coastal Marine). The engine would be positioned in the middle of the hull under the center of the yacht.

Boat Cabin

The most significant initial goal for my design was to create a lightweight, low center of gravity design. Given this, I designed a very simple cabin that takes on the characteristics of a stylish lobster boat. I determined there are three materials that make up almost all the weight of the cabin. Since the design has a significant amount of wood paneling this will account for a large amount of the cabin. Oak wood has a density of around 45 lbs/ft^3. I estimate that there will be around 72ft^2 of wood covering the cabin. At an average thickness of 2.5inches the weight of the wood in the cabin is 675lbs.

The next component of weight in the cabin is the Plexiglas windows. Plexiglas is a very durable yet high density material. The density of Plexiglas is 75lbs/ft^3. Given that the windows will be half inch thick sheets and the estimated area of the windows is 48ft^2 the overall weight of the windows is 150 lbs.

The third material component of the cabin is fiberglass. The fiberglass used for the cabin is deferent from the hull. This would be a lower grade, lower density fiberglass that would have a density of about 5lb, ft^3. It is not as strong as other higher test fiberglass, but since it will be used for the walls of the cabin, the strength will be very sufficient. I estimated the volume of the fiber glass used in the cabin to be 330 cubic feet. This generated a weight of 1675 lbs.

The over all weight of the cabin comes to 2500lbs, and a center of gravity 22 ft from the stern. This is due to balance from the 3 materials. The wood is centered around 19 ft from the stern while the fiberglass and Plexiglas center around 23 feet form the stern. The entire boat is symmetrical from right to left of the boat; therefore all balance will be evaluated from the stern to the bow.

Flooring

Surprisingly, the floor counts for the majority of the weight in the boat. Floor designs are generally constructed of fiberglass to cut down on weight. However, I wanted my design to be a traditional looking appearance with a great deal of wood work. Having the floor be constructed of wood contradicts my goal of having a light weight boat, but the appearance that is gained from a stained wood floor is worth the disadvantage in weight. The floor takes over an area of 410 ft squared. Including the side paneling around the interior walls of the boat I estimate there is around 515 square feet of flooring wood. At a density of 45lbs per ft^3 this creates a weight of 3800 lbs. The center of gravity of the flooring is around 18 feet from the stern.

Hull

The hull is constructed of a higher grade, higher strength fiberglass than used in on the cabin. The density of the hull is around 15lbs/ft^3. I approximate that the hull has an area of 650 square feet. Taking into consideration of the support beams and thick areas around the center of the hull I estimate that the hull will have a volume of fiberglass around 215ft^3. This generates a weight of 3250 lbs. The center of gravity of the hull is 24 feet from the stern.

Ballast

In order to lower the center of gravity towards the water and to also move the center of gravity slightly towards the front of the boat I would want to put ballast 14 feet from the bow of the boat. This will help increase the stability of boat and since the boat is build relatively light for its size, the ballast is easily added without affect the performance.

Additional Loads

Now that I found the weight of the major components of the boat I must factor the amount of weight that was not considered. A significant weight that should be considered is gas capacity. Gasoline is 6.16 lbs per gallon. A boat this size would have a fuel capacity of 350 gallons. This generates a weight around 2000 lbs. This also includes equipment such as electronics, luxury (seats, benches, tables, etc), steering, propeller, radar equipment, and the list could go on. I predict that these extra weights would add up to around 5200 lbs assuming the center of this weight is at the center of the boat hull.

Overall Boat Weight and Center Gravity

The entire weight of the boat comes to 21750lbs. This is a low weight and I am satisfied with the amount of water it will draw. The lowest depth that the boat will reach in the water will be around 24 inches. This estimation is based on boats this size and weight constructed by other yacht companies. Given the predicted weights and center of gravity of the 6 components listed above I can determine that the overall center of gravity of the boat is 22 feet from the stern. This is a great result. This will help the boat stay low when accelerating and once in motion.

Phase 4: Affirm Final Design

The dimensions of the boat used for analysis in the previous phase were not changed in this stage. At this point I modified only the exterior physical appearance. The final design used is shown below.

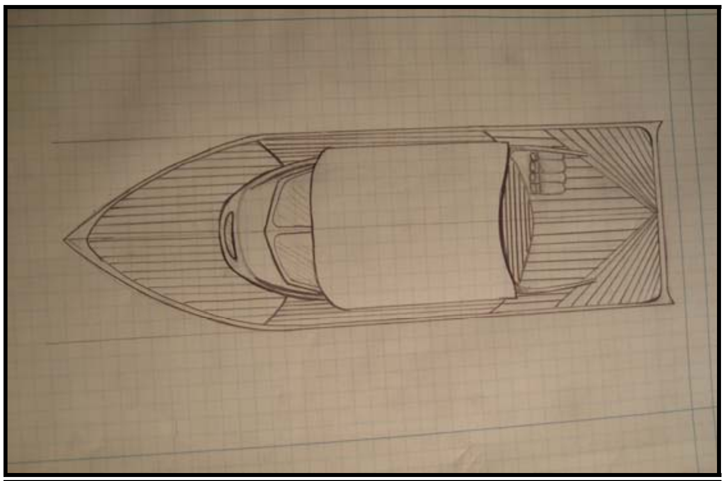

Figure 2: Top Profile

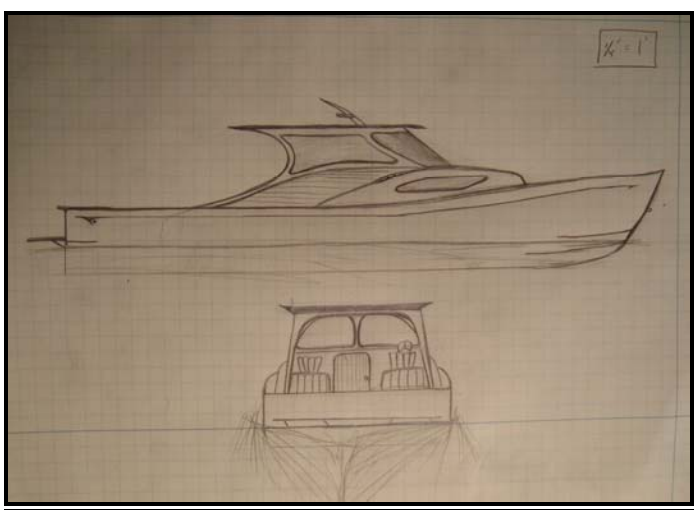

Figure 3: Side and Back Profile

Figure 4: Isometric View

The dimensions from these drawings are what I will be following to build the model. However over the course of building the model some slight changes were made. As can be noted in pictures of the finished model at the end of this report the windows were modified, the wood paneling on the side of the cabin changed slightly, and the shape of the front of the cabin is also different on the model.

Phase 5: Fabrication of Model

Building a model of the design is the most important part of expressing the appearance of the boat. The two dimensional drawings do not fully represent what the boat will actually look like. The model gives the best representation of the design. Being a 1/15 scale size of the boat the model is just over 30 inches long. Over the course of building the model the design was slightly changed as my opinion of the appearance of the boat changed. There were two main tasks to constructing the model. The first is building a dimensionally correct hull out of fiberglass. The second task was replicating the cabin.

Building the Hull

The hull proved to be the hardest part of creating the model. Making it out of fiberglass is the best way to create an accurate representation of the design. Building the hull took 3 different stages. First I had to make an inverted replication of the hull using clay. This required that a frame be made to mold the clay in. The clay was molded to the correct specifications by using card board cutouts. The outline of the cardboard represented the shape of the hull at a assigned point of the hull. Using the cardboard I molded a replication of the hull as is looking into the open side. Below are pictures showing the clay in the molding process.

Figure 5: Shaping the clay cast of the hull

The next step in fabricating the hull was pouring plaster into the clay mold to create a cast I could lay fiberglass on. On the first attempt to do this I used the wrong type of plaster that contracted as it dried. This caused the plaster cast to have cracks and a finish that was not suitable to lay the fiberglass on. After speaking with the Art department I learned to use molding plaster. Molding plaster hardened with no cracks and volume of the plaster stayed the same as it dried.

Figure 6: Plaster Cast Poured Into The Clay Mold

Once the plaster cast was dry I disassembled the frame and peeled the clay off the plaster. Despite molding the clay with detail to the dimensions the plaster needed to be sanded and shaved for sharper edges. I measured the cast to ensure accurate dimensions for the 1/15th scale.

Figure 7: Detailing the plaster cast of the hull

Now the fiberglass is ready to lay on the plaster. Using resin hardener and 1.5mm glass the hull required 3 layers of fiberglass to ensure that it is strong. For the first layer I used strips of glass that were placed across the hull from wall to wall. The second layer used strips that went from the stern to the bow. Making a cross pattern increased the strength and consistency of the fiberglass. The third layer was laid mostly around the stern of the model where there were a few blemishes.

Figure 8: Dry Fiberglass and Fiberglass with Resin Hardener

It can be seen on the right picture in figure 6 the top edge of the hull walls needed to be trimmed off and the surface needs to be smoothed out. The edges were trimmed with a band saw. Despite using a last layer of resin with wax in it the consistency of the surface of the hull needed to be improved. This was done by sanding the blemished and using “Bondo” filler. After the Bondo was added in the areas where the surface was depressed I sanded it smooth. Several Bondo additions and surface sanding was done to ensure a consistent smooth surface.

Figure 9: Fiberglass With Sanded “Bondo” and Hull With One Coat of Paint

The surface of the hull was then painted and coated in a clear protective layer. Unfortunately the clear coat did not react will with the blue paint and needed to be sanded and repainted without that specific type of polyurethane. At this point the hull is completed and the flooring and cabin are ready to be built to complete the model.

Flooring and Cabin

This is the second part of constructing the boat model. One of the key aspects to the design is the detailed wood flooring. Popular yachts companies take pride in having traditional woodwork in their style of design. This was a quality I aimed this design to have as well. There are three tiers of the flooring offering a gradual incline as the decking moves toward the bow. The model uses wood planks that are larger than they actually would be on the full scale design. However the model is able to express the angles and curved transition from each level of the decking.

Figure 10: Unstained Deck of Model

Building the cabin was the last phase of creating the model. It is made of 3 main parts: The front section of the cabin, the walls, and the top. The front section was made by gluing sections of wood together to create a block of wood 4 inches thick. I was then able to sand the edges and corners down to the shape I desired. The walls were fitted to the front cabin using cardboard cut-outs representing the walls. Once the cardboard fit well with the flooring and the front cabin I traced and cut the shapes in wood. The top of the cabin or the roof is a three quarter inch plank of pine. I shaped the edges to give it an arching appearance. Then using "Bondo" filler I smoothed out any gaps or blemishes in the wood.

The design has wood planking going up the side of the cabin wall again taking on the style of stained woodwork. In the model there is not planking but there is stained wood reaching up the cabin wall inside the white areas of the cabin. This effectively replicates the wood on the full size design.

Figure 11: Building the Cabin

Lastly, painting and detailing the boat concluded the model. Painting the hull dark blue with white trim is a popular style that I feel offers a great traditional lobster boat appearance. Staining all of the wood with an oak stain turned out to be attractive; and the white cabin and trim compliment everything well.

Figure 12: Front and Back View of Finished Model

Figure 13: Side and Isometric View of Finished Model

Phase 6: Evaluation of Design

Overall the design turned out well. The visual aspect of the boat is as desired and the style is that of traditional lobster boat sense. The most visually effective part of the design is the flooring. Possible changes to the design are making the hull more dominant and decreasing the height of the cabin. The performance for a boat of this size and shape would have great potential. The cabin is simple enough to build lightweight along with the rest of the boat. The only aspect of the visual design that takes away from the performance is the heavy wood flooring. The design demonstrates a deep “V” hull best for rough waters and calm cruising. If equipped with proper power and controls this boat would have a maximum speed around 40 mph with a cruising speed in the high 20 mph range.

Conclusion

Further work to be done for my progress in boat design is developing more models. Designs are only ideas on paper, however a model has the ability to truly express the appearance of the design. For this particular model there is room to improve the accuracy of the appearance by installing seating and controls in the cabin. There is also the opportunity to make this model operational with a motor and remote control. At this point the model is not at an accurate weight for the 1/15 scale ratio. The model is actually lighter than the design calls for and if I ever installed remote control there would be weighting added to increase the balance of the boat.

Over the course of this project I learned a great deal, but only a taste, of turning a design on paper into a model representation. It has been a great experience developing my design, estimating the essential parts of the boat, and building the model. I have effectively developed an attractive and potentially functional boat design that I am satisfied with.

APPENDIX

- Drafting and sketches of designs considered