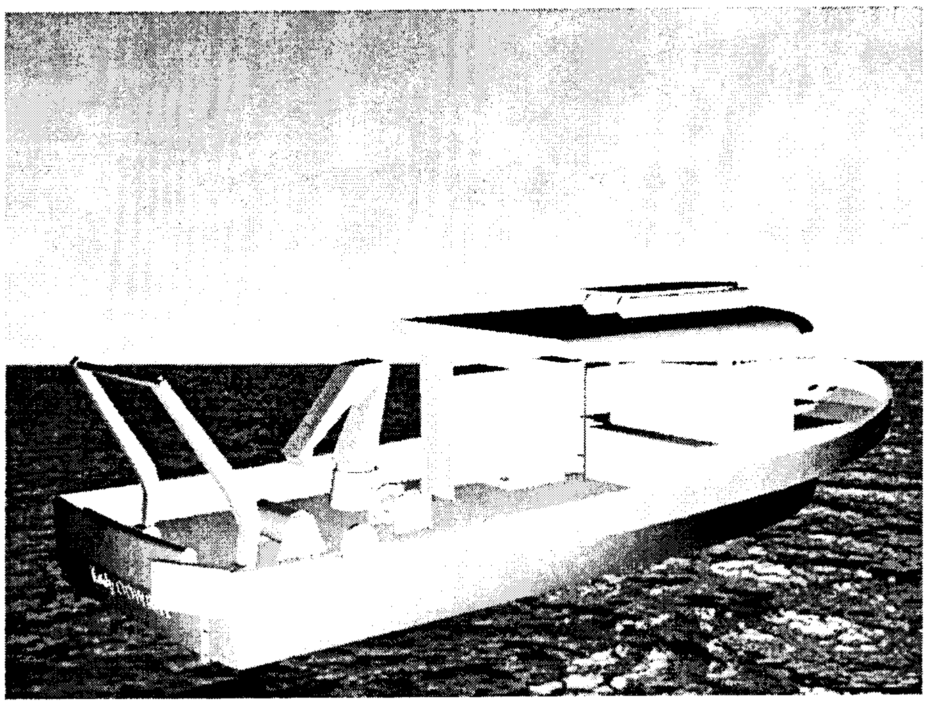
Open Ocean Aquaculture Work and Research Transport Project (OOWRAT)



Compiled Undergraduate
Ocean Research Project
Tech 797
April 23, 2004

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Sea Grant
New Hampshire

ACKNOWLEDGMENTS

A special thanks to:

M. Robinson Swift for guidance and being a valuable resource.

Cory Guimond for generations of experience and examples from industry.

Mike Chambers for general guidelines and connections in industry.

The Captains and Crew of the Gulf Challenger for hands on experience.

Brett Fullerton as a valuable resource for the Ocean Engineering department.

Judson DeCew guiding us in the ways of OPI

Michael Routhier CSRC group for use of plotters and computer throughout year

Ken Baldwin for your interest and enthusiasm.

John Scott for your help with our budget and all around support.

Robert Jerard for polyurethane foam donated for NC machining of model.

Clarke Davis for guidance on watercraft fabrication,contacts in industry and advice

Jackson's Hardware Supplier of epoxy resins, gel coat, and application advice.

"This research project is sponsored in part, by the National Sea Grant College Program, NOAA, Department of Commerce, under grant #NA76RG0084 through the University of New Hampshire Sea Grant College Program." UNHMP-TR-SG-04-08

ABSTRACT

Currently there are three vessels in use by the Open Ocean Aquaculture Project at the University of New Hampshire. Unfortunately none of these vessels meet the full operational needs of the project. These operations include fish farming maintenance off the Isles of Shoals, deploying and servicing a variety of marine equipment, and conducting a variety of research excursions. To solve this problem the Open Ocean Work and Research Aquatic Transport Project (OOWRAT) was created to design a new vessel to these needs. The primary vessels now in use are the Gulf Challenger, the Rock and Roll II, and the Jet Boat. The Rock and Roll II and Jet Boat are both owned by the Open Ocean Aquaculture Project and the Gulf Challenger is a UNH research vessel that is rented on a daily basis at a rate of $1090 per day. Although the Gulf Challenger is ideal for research purposes it is costly to rent and not well suited as a workboat. The final design made by the OOWRAT team, named The Shoals Runner, implements a fiberglass reinforced hull, which minimizes weight and operating costs. The Shoals Runner has a top speed of 25 knots and a cruising speed of 20 knots making it a faster and more reliable vessel than those currently available. There is also an abundance of deck space, which the Gulf Challenger and Jet Boat lack. This allows for more work to be done in a safe and efficient manner.

The goals of this project are to design a vessel that combines low price with functionality. The cost of the boat must not exceed $1,000,000. A functional and safe diving platform must be implemented and an articulating deck crane and A-frame are part of the design making the vessel capable of lifting up to 6 tons. The deck on the designed Shoals Runner is large enough for full classes to be taught on board and to store all necessary equipment for offshore fish farming. There is also a raised pilothouse with room for 7 occupants.

The current research vessel, the Gulf Challenger is very capable, but it lacks in certain areas: It is constructed of marine grade aluminum, which is expensive to build and costly to repair. Aluminum hulls are also heavier than fiberglass hulls. The layout of the deck on the Gulf Challenger is impractical due to a centrally located pilothouse. The dive deck does not allow for easy re-entry onto the boat, which leads to lost time and possible injuries. The Shoals Runner design features a hull form with high bow flare and a flat stern, which creates minimal wave friction and excellent stability. The overall length of 51.5 feet is similar to that of the Gulf Challenger. The beam is 18 feet and it has a draft of 3.5 feet. It features a single 950 hp diesel engine for propulsion, and a 200 hp four-cylinder diesel to power all on board hydraulics. To assist with maneuverability a 60 hp hydraulically powered bow thruster is being used.

The Shoals Runner is the ideal work vessel that incorporates all of the necessary functions needed to manage the fish farm at the Isles of Shoals. The total cost of the vessel is approx. 600,000 dollars, far less than the desired maximum. With its speed and power, this vessel will be able to service all technical needs for most any marine project. This vessel is very capable of replacing the existing Rock and Roll II and the Jet Boat as well as decreasing reliance on the Gulf Challenger.

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INTRODUCTION

The Open Ocean Work and Research Aquatic Transport project (OOWRAT) was conducted to improve the Open Ocean Aquaculture Projects efficiency and safety in fish farming and research tasks through the design of the optimal vessel to conduct these tasks. Located on the New England coast of New Hampshire, marine and aquatic research proves to be valuable resource. Having a vessel that can appropriately operate in the northern Atlantic Ocean is essential. The final design, named the Shoals Runner, is equipped for all aspects of fish farming as well as estuarine and coastal research work.

The need for a vessel that will be used for both research and as a workboat for servicing the fish nets located off the coast of New Hampshire has been established. There are currently several boats being used to service these nets; however none of these are ideal for all operations being undertaken. The University of New Hampshire's current research vessel the Gulf Challenger (**Figure 1**), which has been rented on a daily basis by the Open Ocean Aquaculture project, is capable of doing various estuarine and marine/coastal research since its launch in 1993. However this vessel must be rented far in advance and at a rate of $1090.

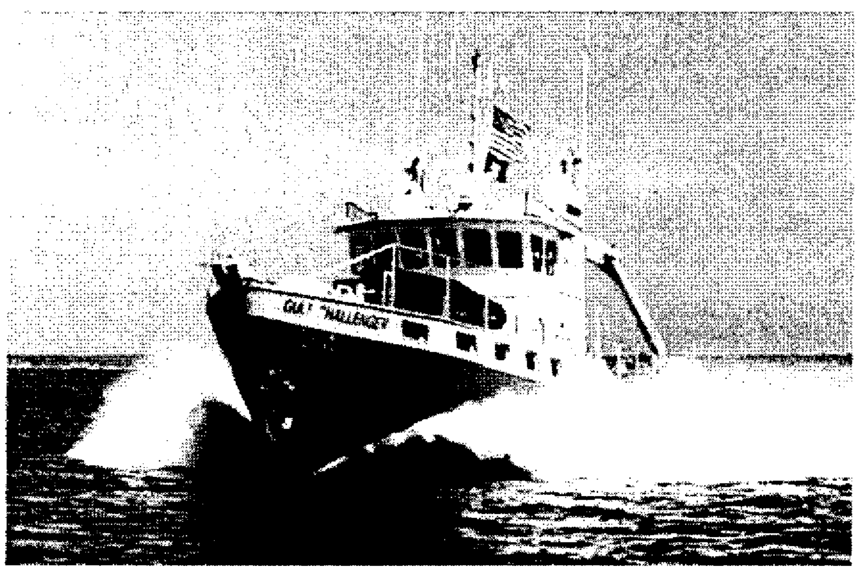

Figure 1 - Gulf Challenger Research Vessel

Background

The Open Ocean Aquaculture project performs numerous tasks off the coast of New Hampshire. Recent projects include the halibut, and cod fish farming in large nets, mussel line harvesting, new fish net deployment, and buoy/anchor placement involving the towing of nets and tensioning of a weighting system. The design of the ideal vessel to perform these tasks was conducted to help improve the safety and efficiency of the project as well as minimize reliance on the Gulf Challenger.

A high percentage of the work done from the Gulf Challenger vessel consists of diving. This is the area in which the Gulf Challenger is most lacking. The freeboard height of the ship is very high for divers to leave and return safely and comfortably. It is essential that divers using the platforms can leave and return to the vessel as close to water level as possible.

Workspace is another issue cited with the Gulf Challenger. Due to its inconvenient mid-ship placement of the pilothouse much of the fish farming work cannot be done efficiently and is often conducted in a cluttered space. Much of the work consists of moving large objects in and out of water, for this to be carried out without hassle a large open deck space is essential. This must be implemented keeping in mind that space is still needed for passengers and other accessories such as dive-suits, an inflatable boat, and a deck crane.

The main purpose of this study is to develop a new workboat design that is practical and efficient and that can benefit the Open Ocean Aquaculture Project. This is proven through testing of a scale model of the vessel. Using the Ocean Engineering center's wave tank, numerous tests were conducted that simulate the speeds, drag forces and wave effects the actual vessel would experience. From this report we hope to gain support from key individuals at the Ocean Engineering center.

The report is broken into six main sections:

(1) Alternative Designs - discusses the three original designs and compares the advantages and disadvantages of each design and also covers the design panel meeting where the final design criterion was outlined.
(2) Final Design - covers the design process followed to complete the necessary hull lines, table of offsets, and various other plans needed in order to build a vessel. Also discussed is vessel concepts
(3) Model Design and Fabrication - covers the factors involved in making a scaled model as well as the techniques implemented to build an accurate scaled model of the full sized vessel.
(4) Design Verification and Experimental Procedures – discusses the types of experiments run and their purposes. Also covered is the accuracy and results of these experiments
(5) Cost Analysis - the different costs associated with building the vessel illustrated.
(6) Discussion of Results - restates the purpose of the project as well as the conclusions that were made.

The scope of this report is to give the optimal hull form as well as layout and configuration of a vessel to service the fishnets at the Isles of Shoals. The report is not a complete design ready to be fabricated. The goal is to provide an exact definition of what the Ocean Engineering Center is looking for in a vessel in order for them to convey this idea to the manufacturer of the vessel. Our intent is to provide a general understanding of the functions of the research vessel and all of its duties, and characteristics

ALTERNATIVE DESIGNS

To determine the ideal hull form to meet all the needs of the aquaculture vessel three initial designs were taken through various stages of the design process. All three of these hull forms were designed in the Rhinoceros 3-D® Marine Design Package. Rhinoceros 3-D® is NURBS modeling for Windows that includes rendering, animation, drafting, engineering analysis, and manufacturing capabilities (see www.rhino3d.com). The following criteria were considered for the alternative designs.

Design criteria

1. Cost of boat must be under $1,000,000.
2. For vessels over 50 feet an aluminum hull will be implemented.
3. Diving platform must allow for divers to get out of the water standing comfortably and safely to avoid injury.
4. A net reel should be included that is easily removable.
5. A J-frame or A-frame should be included with a capacity around 6 tons.
6. An articulating crane with a capacity of 1.25 tons at 20 feet should be implemented. The Crane must have interior housed hydraulics to minimize corrosion and allow for continuous rotation.
7. Removable hydraulic deck winches with 1 ton pulling capacity for deck crane and 2 ton pulling capacity for A-frame with emergency stops in pilothouse.
8. Boat load capacity should be around 15 tons.
9. The living quarters should be sufficient for at least 4 people to spend the night comfortably.
10. A shower should be placed so it can be entered from the deck as well as from the cabin area.
11. Top cruise speed should be over 20 knots (unloaded).
12. Boat must be able to service mussel lines.
13. Boat will have overall length between 50 and 75 feet.
14. Boat will have a bow thruster or dual engines allowing for superior maneuverability.
15. The engine room must be easily accessible and easy to work in.
16. The deck needs a large storage space for diving equipment etc.
17. The work deck should be at least 20 feet by 15 feet including space for 6-8 4'x4'x4' fish transports.
18. Boat will have two sets of pressure washers with 50 feet of hose each to clean both the deck and the nets.
19. Lots of hydraulics must be included for control of the star wheels, A-frame, deck crane, etc. These may have to be powered by an additional diesel engine.
20. There is to be a raised pilothouse with adequate communication to workers as well as indoor stairs to below deck.
21. Standard electronics with at least two devices (depth finders) for depth monitoring.
22. Safety rails by dive area and around deck.

23. Pumps for feeding fish, bilging, hot and cold water transfer, etc.

The Fish King

Vessel Specifications

LOA: 70
Beam: 22
Draft: 5
Minimum Clearance: 19, with mast and antennas lowered.
Max Displacement: 260,000
Min Displacement: 190,000
Payload: 70,000
Freeboard: 8
Berths: 6
Hull Type/Construction: Mono-Hull, Coated Marine Grade Aluminum.
Clear Deck Space: 625
Laboratory Area: 200
Head: One below with shower and sink, additional shower on deck for divers.
Main Engines: dual 1100 hp Diesels
Main Engine Consumption: 31 gal/hr each.
Fuel Capacity: 1300 gallons diesel.
Auxiliary Generators: 8.5kVA, 2500W inverter.
Top Speed: 21
Cruising speed: 16
Endurance: 3 days or 425 miles.
Fresh Water: 1500
Life Saving: 40 adult and 30 children's lifejackets with lights and whistles.
Water Tight Compartments: 4, 1 can be flooded.

*Units (ft, gallons, hp, knots, lbs).

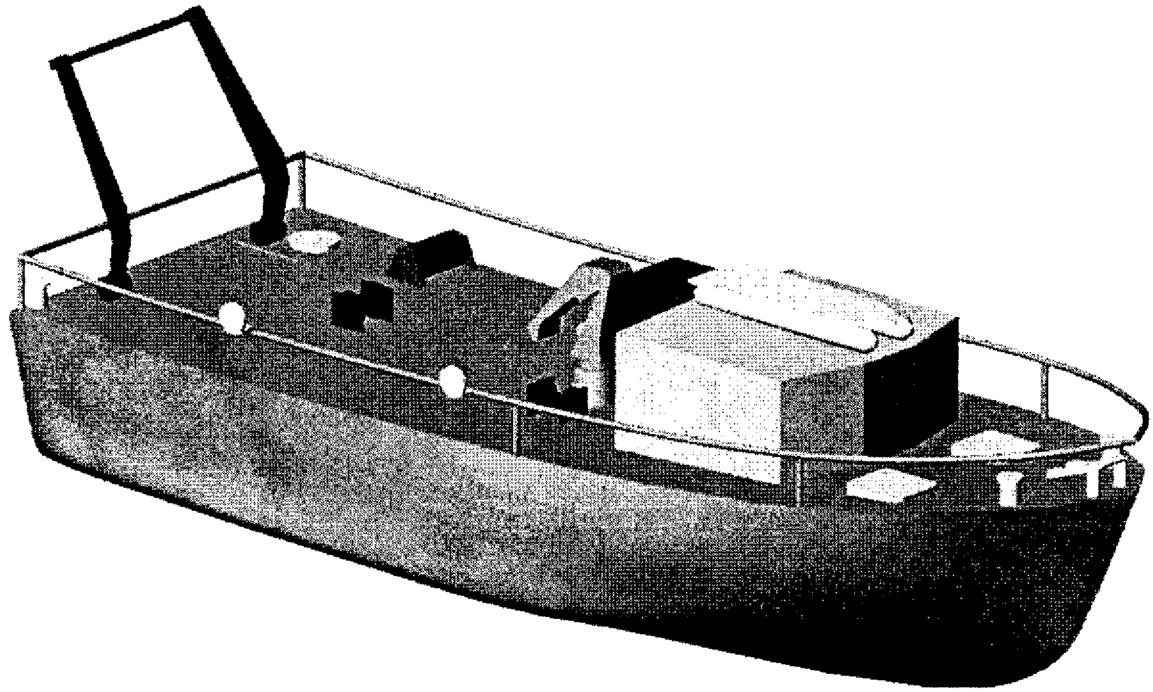

Figure 2 - Alternative Design "Fish King".

The first hull form designed was a mono-hull, called the Fish King (see **Figure 2**), to be made of coated marine grade aluminum. This design was dubbed the Fish King. It is the most massive design with lots of deck space and excellent overnight capabilities. There are several disadvantages associated with this design. One major disadvantage is that it is time consuming and laborious to get in and out of the water when diving. This is a major disadvantage since the majority of the vessels use is for general maintenance on fishnets, which always includes diving. Some other disadvantages include being expensive to build, run, and maintain and difficulties in maneuvering in tight places. One advantage of this design is that it has a nice laboratory area below deck with space for 5 people to work and six people to sleep. This gives the Fish King huge advantages for research capabilities. There is also enough space for up to 7 people in the pilothouse. Other advantages include lots of payload, plenty of engine power, and high pulling and lifting capacities. The Fish King would be the ideal vessel for research and large group or class outings.

The Fisher Cat

Vessel Specifications

LOA: 55
Beam: 24
Draft: 4
Minimum Clearance: 18, with mast and antennas lowered.
Max Displacement: 190,000
Min Displacement: 140,000
Payload: 50,000
Freeboard: 4.5
Berths: 6
Hull Type/Construction: Catamaran, Coated Marine Grade Aluminum.
Clear Deck Space: 525
Laboratory Area: 175
Head: On deck with shower and sink
Main Engines: dual 800 hp Diesels
Main Engine Consumption: 22 gal/hr each.
Fuel Capacity: 900 gallons diesel.
Auxiliary Generators: 8.5kVA, 2500W inverter.
Top Speed: 22
Cruising speed: 16
Endurance: 3 days or 375 miles.
Fresh Water: 1000
Life Saving: 40 adult and 30 children's lifejackets with lights and whistles.
Water Tight Compartments: 4, 1 can be flooded.

*Units (ft, gallons, hp, knots, lbs).

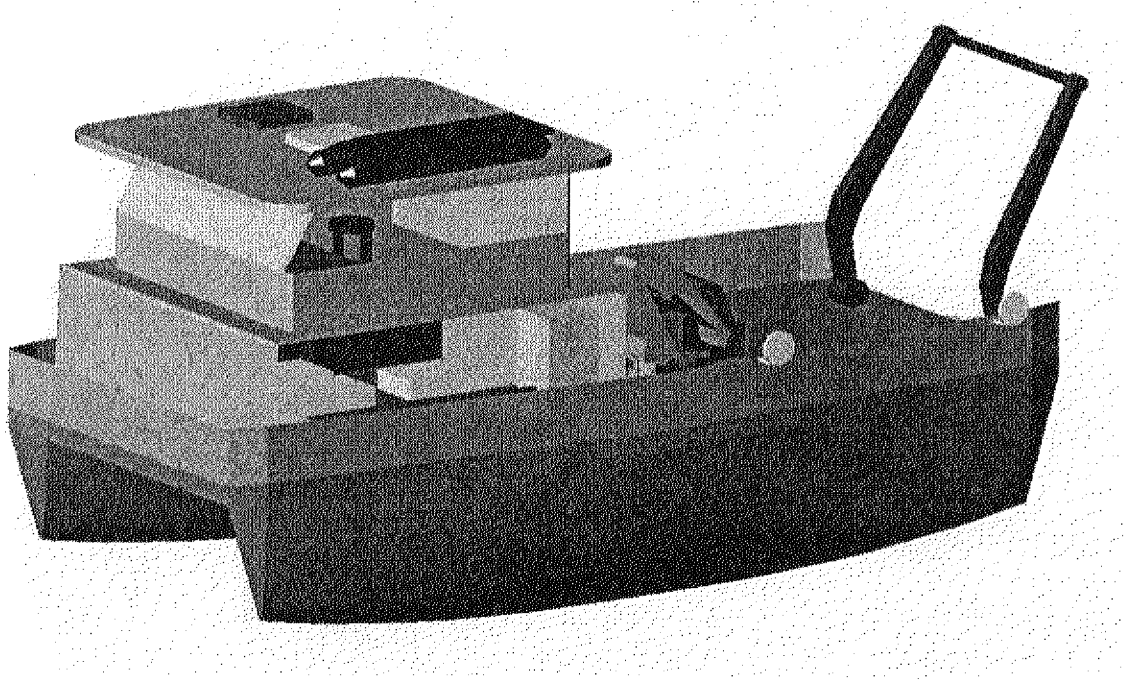

Figure 3 - Alternative Design "Fish King".

The Fisher Cat (see **Figure 3**) is the second largest vessel we designed and is very unique. The catamaran design minimizes frictional forces making for more efficient fuel use and a wide beam providing ample deck space. This design would be easy to dive off of with overnight capabilities rivaling the Fish King with lower construction costs and run costs. However, maintenance on this design would be expensive and difficult since there are few if any catamarans of this size in the area. The necessary lifts and mounts to work on this boat out of water might be difficult to find and would probably have to be custom built. This boat would be excellent for research and large group trips but might not be ideal for New England winters and icy conditions. Also catamarans tend to have stability problems concerning roll as opposed to many mono hull designs, which will even upright themselves when totally inverted.

The Shoals Runner

Vessel Specifications

LOA: 50
Beam: 18
Draft: 3.5
Minimum Clearance: 12, with mast and antennas lowered.
Max Displacement: 160,000
Min Displacement: 110,000
Payload: 50,000
Freeboard: 4
Berths: 4
Hull Type/Construction: Mono-Hull, Reinforced Fiberglass construction.
Clear Deck Space: 450
Laboratory Area: none
Head: One below with sink, Shower on deck.
Main Engines: 850 hp Diesel
Main Engine Consumption: 17 gal/hr
Fuel Capacity: 400 gallons diesel.
Auxiliary Generators: 8.5kVA, 1500W inverter.
Top Speed: 25
Cruising speed: 20
Endurance: 2 days or 500 miles.
Fresh Water: 250
Life Saving: 15 adult and 10 children's lifejackets with lights and whistles.
Water Tight Compartments: 1

*Units (ft, gallons, hp, knots, lbs).

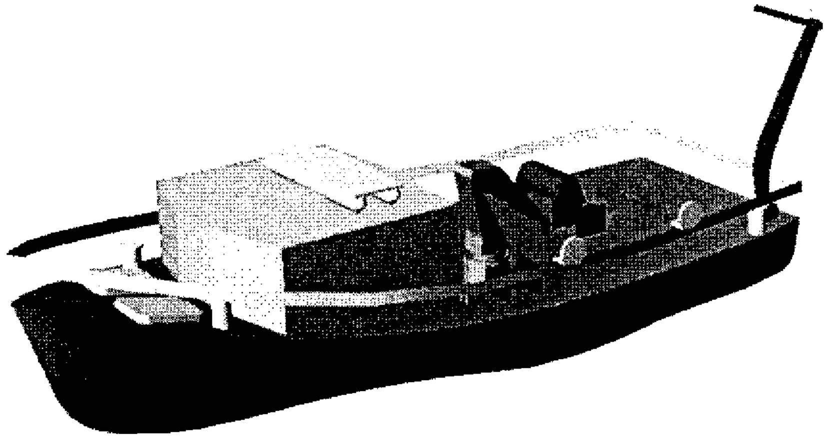

Figure 4 - Alternative Design "Shoals Runner".

The Shoals Runner (see **Figure 4**) is the smallest and most conventional design for commercial fishing vessels in the New England area. This vessel incorporates lots of bow flair and a flat bottom stern allowing for minimal wave friction and excellent stability. This is our only single propeller vessel, but it does incorporate two engines one being a four-cylinder engine designated solely to power the hydraulics on board. There is also a hydraulic powered bow thruster that offers even better maneuverability than the other twin propeller designs. Probably the most alluring attributes to this design are it's relatively low cost to build and maintain while still offering excellent diving capabilities and the all around performance needed as a workboat. Some of the disadvantages of this design are that it is not over night friendly with four cramped bunks and there is no room for a laboratory. There is much less room below deck than with the Fish King, however the vessel is much lighter due to fiberglass and composite construction.

Design Review

The three alternative designs were taken in front of a panel of UNH Professors and Ocean Engineering Center employees to assess the effectiveness of each design. The designs were discussed and evaluated and a final design criteria was completed. It was decided that the most important factors in the decision were going to be the costs to build, run, and maintain the vessel as well as the ability to quickly and effectively perform the day-to-day work involved in fish farming. The Fish King and the Fisher Cat are both much more expensive due to their powering requirements, overall size and additional on-board equipment. They are also slower to maneuver and less suited for the day-to-day diving and required fish farming maintenance. These two criteria were the deciding factors in the decision to choose the Shoals Runner as the optimal design for the needs of the vessel. Further discussion on the layout of the vessel and minor changes to dimensions and equipment on the vessel were made. At this point Michael Chambers, who works for the Open Ocean Aquaculture project introduced the boat building company Guimond Boats Ltd. out of New Brunswick Canada as the potential builders of the vessel to be purchased by UNH. The sales manager for this company, Cory Guimond provided support for the final design of our vessel. He donated some plans of a similar vessel as well as visiting UNH to discuss the vessel he plans to build and give additional comments on our design.

FINAL DESIGN

Design Concept

The vessel chosen for the final design was a 51.5-foot fiberglass mono-hull vessel. This size was chosen since the boat is to be built in Canada and the maximum length boat to be purchased internationally from within the United States is 51.5 feet. The boat building company contracted to build this vessel is Guimond Boats Ltd. out of New Brunswick, Canada. Cory Guimond, who is the sales manager for the company was contacted for help with the hull design for the vessel. Some important traits Mr. Guimond emphasized was that the design should have lots of bow flare and built in spray rails. Bow flare is essential in minimizing wash or spray by throwing it away from the boat outward rather than upward. The built in spray rails offer both extra lift and minimal pounding cutting energy losses making the vessel as efficient as possible. The spray rails are to be rounded outward in order to redirect water continuously and efficiently. Another adopted suggestion was to use composite materials for deck support and to mount the lifting equipment to steel plates under the deck. These composites share some similar properties to the rest of the hull and are more reliable to permanently attach. Unlike Aluminum, composite material are not thermally sensitive, therefore there is minimal concern of unwanted forces from expanding or contracting. Mr. Guimond also provided a set of hull lines to aid in the design process.

Determination

The approach for determining the shape of the final hull was dependent on several factors. The driving force behind the hull shape of the Shoals Runner was the criteria set forth by the prospective users. As earlier discussed these specifications necessitated a loaded vessel capable of cruising at approximately 20 knots, having a suitable workspace on deck (approximately 350 square feet), acceptable lifting capacities, and maneuverability.

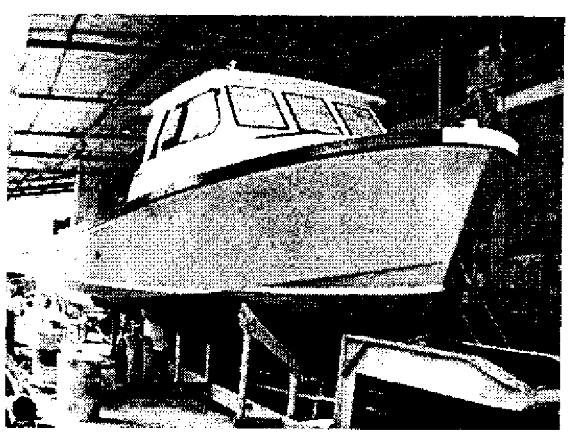

Figure 5 - Typical fishing boat (http://www.oceanmarine.com/bow37.jpg)

The most common vessels constructed with these criteria are commercial fishing and lobster boats (**Figure 6**). These crafts embody the desired functionality of a work vessel and tend to be semi-displacement hulls. In the bow, the form tends to have significant flare and gradually tapers to a flat-bottomed stern. The material tends to be fiberglass, but wood, aluminum or steel can also employed. Specific details (such as chines and spray rails) differ depending on preference and operating conditions.

During the design alternative phase of the project, the idea of outfitting an existing lobster/fishing boat with the necessary components became a plausible approach, mainly due to its cost effectiveness. The major drawbacks to this method were that by the additional required equipment deck space and speed (added weight slows down a vessel) would be sacrificed. Moreover a sub frame would be necessary in order to support lifting desired loads without over stressing the glass hull to the point of failure.

Finally the decision was made to create a new form with extreme flare and a hard chine. These two parameters would cause the vessel to plane on the surface of the water at a certain velocity. With such a hull shape the superstructure could be built forward, maximizing the amount of workspace on deck.

Approach

Historically boat designs have been completed by hand. In recent years technology and the use of computers has significantly streamlined the process. In creating the Shoals Runner, modeling software called Rhinoceros 3D® was used to complete the design.

In order to define a surface, a set of descriptive curves must be defined and then linked together. These curves are called stations (**Figure 7**) and the CAD process of putting them together is called lofting.

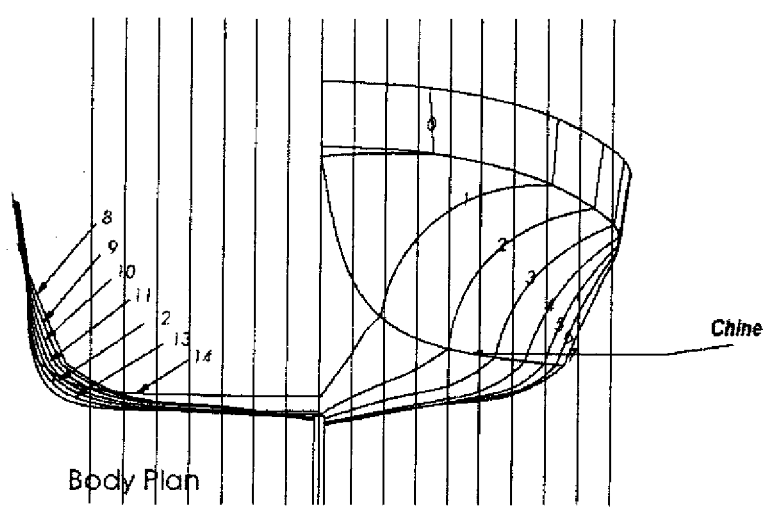

Figure 6 - Hard chine and station lines illustrated via section line plan

Another key to designing an acceptable hull is making sure the surface is fair. The characteristic of having a "fair" hull is difficult to describe, but in essence it is making certain the surfaces defining the hull are simple and do not contain minute indentations or bumps. These slight distortions would be detrimental to the hydrostatics and overall performance of the vessel. The following steps were taken to ensure fairness of the surface.

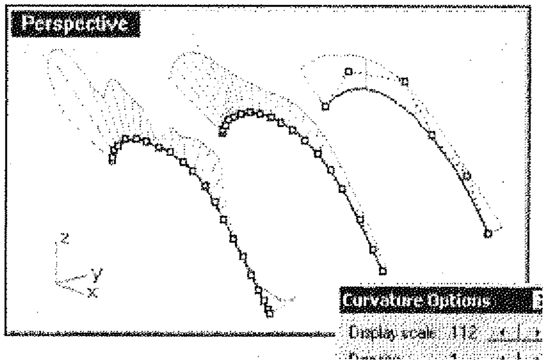

Figure 7 - Curvature analysis graph, fair curve shown on far right.

- The least amount of points was used when defining a station. A curvature analysis (**Figure 8**) was also utilized to ensure "smooth" curves. This analysis was included with the CAD software used and amplified indentations and bumps. Once significant problem sections were found the proper action could be taken to repair the unfair curve.
- Only the necessary amounts of curves were used in defining the hull shape. Over-defining the hull by creating too many stations often led to an unfair surface. This proved to be difficult due to the extreme flair in the bow of the vessel.
- Ensuring the difference between stations was at gradual increments also guaranteed that there was no serious fluctuation in surface curvature.

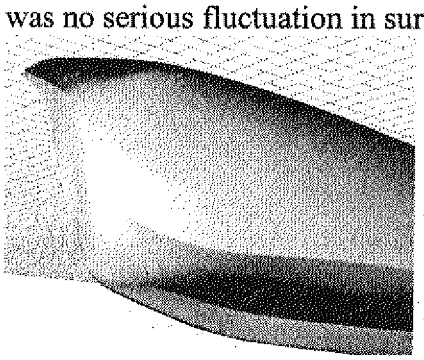

Figure 8 - Hull form lofted as one continuous surface

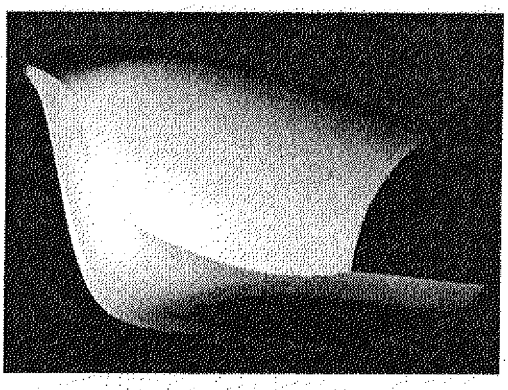

Figure 9 – Lofted three surfaces joined together

Once a set of fair stations was produced they were lofted together to create the hull. This was an iterative process, which involved a significant amount of redefining the stations in order to achieve the desired surface. One of the initial difficulties in making the surface come out fair was assembling the hard chine, flare and skeg into one smooth surface. Because these three surfaces all have different curvatures the CAD software would create bumps near the intersection of these surfaces in an attempt to follow the stations accurately (Figure 9). To correct this error the surfaces were lofted separately and then joined together after creation (Figure 10). Once an acceptable hull shape was achieved the excess surface over the centerline was trimmed away and the remaining surface was mirrored to create the final hull shape.

With the hull form developed, a set of hull lines and table of offsets could be extracted. Hull lines define the shape of the hull in two dimensions by creating sets of lines found by intersecting spaced planes with the hull. A detailed version can be found in Appendix A.

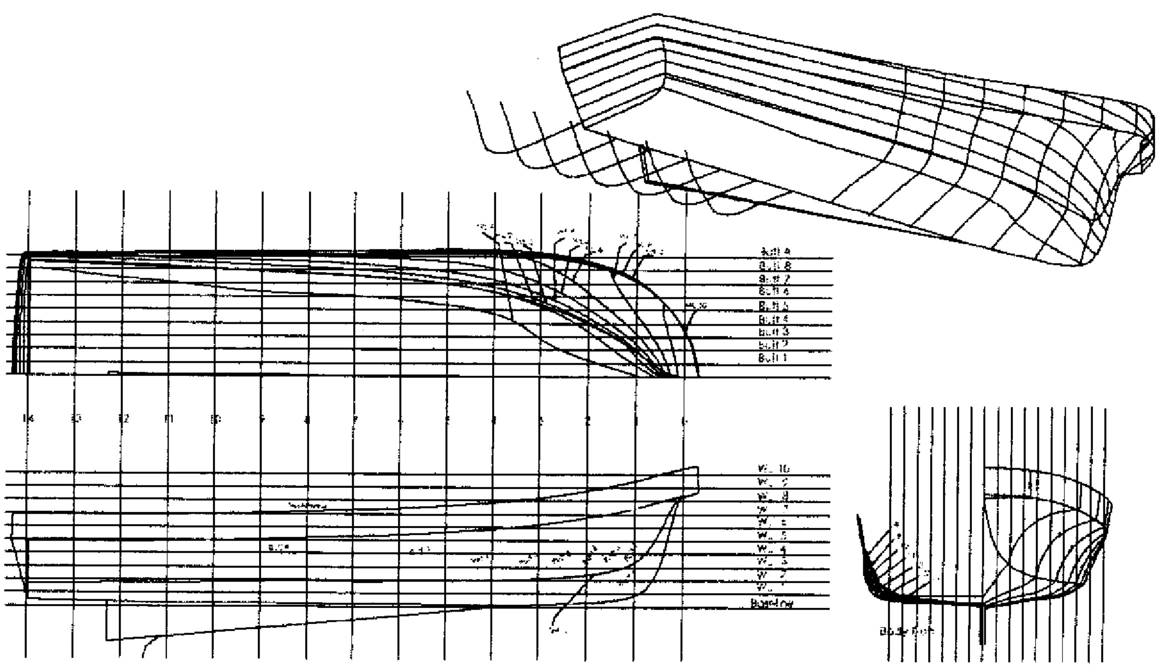

Figure 10 - Hull lines of final design

Functionality

With the hull defined, general arrangements of deck configurations and construction plans could proceed. The panel of prospective users aided in determining the below deck accommodations the location of the pilothouse, and the equipment on deck.

On Deck Equipment

A rolled portion of the transom in the stern creates a snag-free surface for pulling in nets, chains, or other types of line using the net reel. The articulating deck crane has a twenty-six foot reach and can nearly reach to the bow. It can be used in succession with the

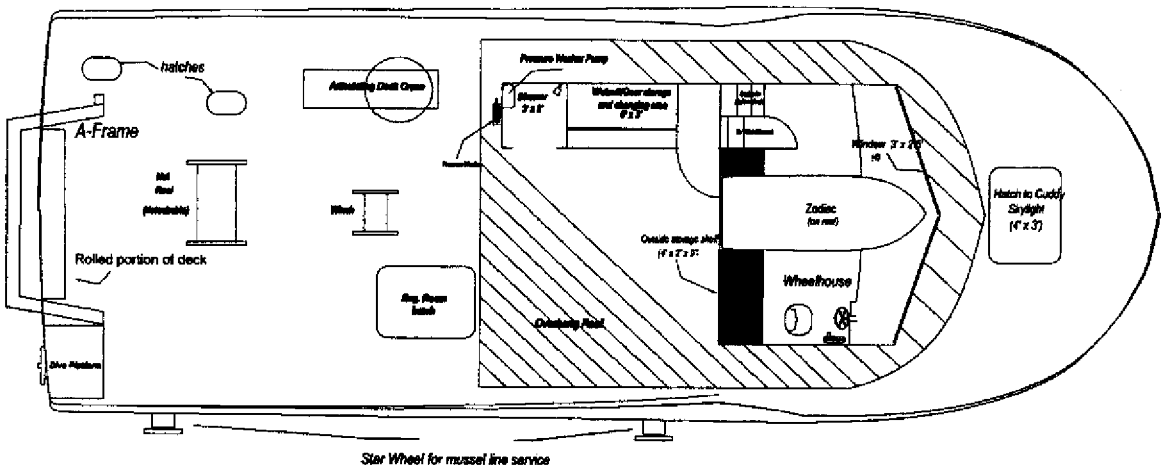

Figure 11 - Above deck configuration

winch and A-Frame to pull in metal buoy lines in a safe manner. On the starboard side there are star wheels used to service mussel lines. Behind the deck crane there is a hydraulically powered 2000-PSI pressure washer to be used in cleaning saltwater off equipment as needed.

Diver Revisions

Located at the aft starboard corner is a dive platform, which has a hinged door for easy deployment into the water. This platform is also set into the deck approximately a foot, making it closer to water level easing the diver's effort of getting onboard. There is also a detachable ladder for diver use. Located behind the deck crane is a shower and changing/storage area for the divers and equipment. This follows through a short hallway to a ladder leading to the cuddy.

Other On Deck Features

The wheelhouse is located forward maximizing deck space. An overhung roof makes it possible for work to be done in rain or snow. Atop the roof is an inflatable safety raft for emergency use. Four hatches are located along the deck making it possible to access each of the below deck areas from above.

Below Deck Description

A ladder leads into the cuddy, which has a large table and 3 stacked berths. A sink and head are located at the end of the berths. A Hydraulically powered bow thruster is located at the very front of the vessel; this will make stationary maneuvering simple and will benefit operations when reaching out over the deck is necessary.

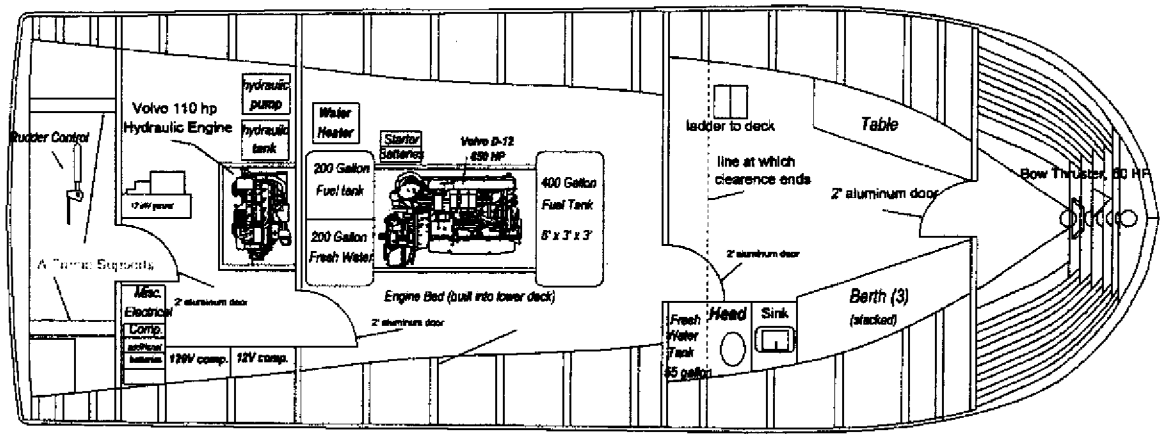

Figure 12 - Below Deck setup

The cuddy has a door that leads to the main engine room. This room houses the fuel tanks and main engine. Another door leads to the hydraulics and electrical room. Shown in Figure 14, the below deck is split into four portions, each of which is separated with a bulkhead. In the event of a collision any one of these sections can be sealed off from the rest of the vessel, preventing sinkage.

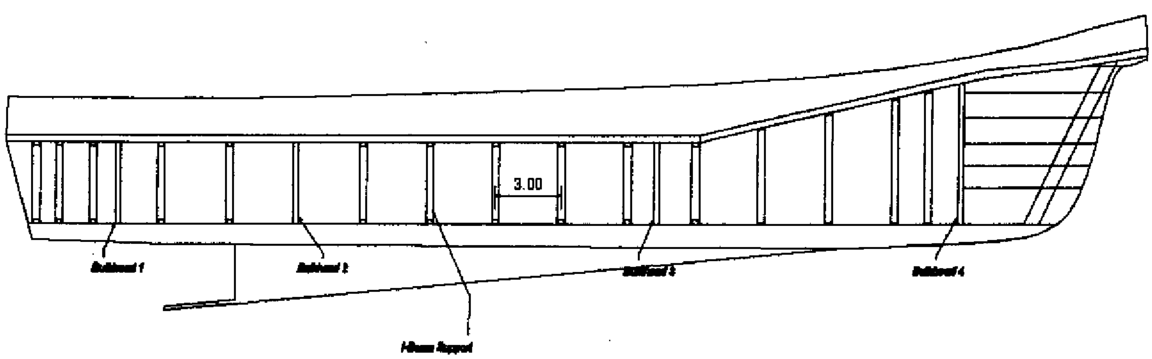

Figure 13 - Cross section showing supports

MODEL DESIGN AND CONSTRUCTION

Model Machining

Once the 3-D model was finished in Rhino 3d®, the next step was to begin the manufacturing process of our model. The ideal model size for testing at the facilities available in the Chase Ocean Engineering building at UNH is approximately three feet. This size is ideal due to the amplitude and wavelength of the waves that can be produced by the wave tank as well as the acceptability of Reynolds number associated with this size. The Reynolds number is of particular importance when scaling the data obtained up to the full-scale size.

As a manufacturing technique CNC machining (**Figure 14**) was chosen as the optimal method to obtain the necessary tolerances of the complex hull form. Ben Nichols (project leader) runs experiments and works as an NC machinist and research technician at the UNH Design and Manufacturing Center in Morse Hall room 163. With his knowledge of CNC machining and a donation of two six inch thick 2' x 4' blocks of polyurethane foam by Professor Robert Jerard the model was to be rough milled out on the CNC machine.

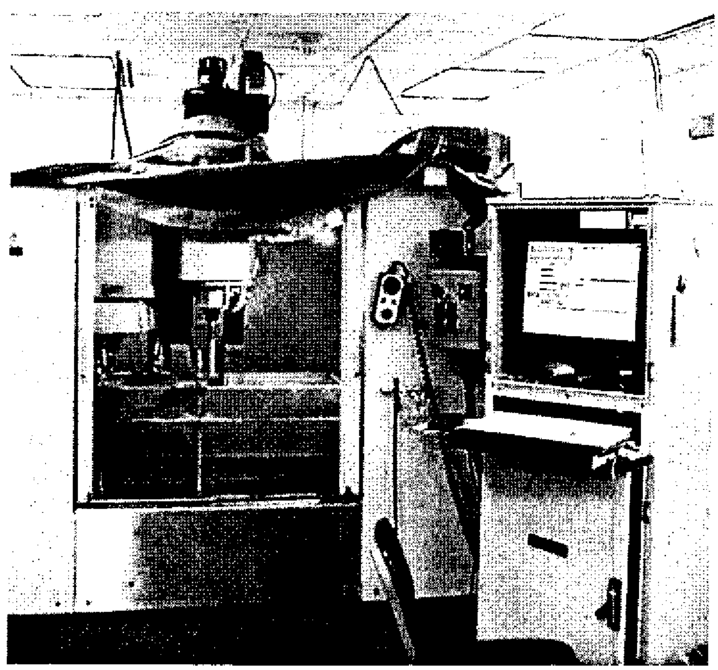

Figure 14 - Fadal CNC Machine

The CNC machine used was a Fadal three-axis machine. This milling machine has the capacity to build parts up to 20 inches long, 16 inches wide and 14 inches tall. Since our model is too long for this machine the first step in this process is to cut the three foot Rhino 3d® model in half along its length. This allows the model to be milled in four separate sections (two for the hull and two for the top of the boat). Once the model is split into two18 inch sections it is saved as an IGES file. This file can then be opened as a part in Pro-Engineer 2001. The two parts are then run through Pro-Engineers Pro-Manufacturing software where the necessary G-Codes are obtained to mill out the sections of the model.

There are several difficulties associated with this process. The first problem is selecting the surfaces to machine. If there are any intersecting lines in the model the manufacturing software will not be able to select both of the intersecting lines. Once the model was modified to have no intersecting lines, this problem was solved. Next, the feed rates and spindle speeds must be tested along with the axial depth of cut and the length between passes (effectively radial depth of cut). Once safe feeds, speeds, and depths are found and the surface finish is acceptable other cutting parameters may be assessed. For a project as large as this a tool with a large cutting diameter must be implemented. This helps to minimize machining times. The tool must also have a long enough overall length as to make sure there is proper clearance between the work piece and the tool holder. Dozens of tool paths, lengths between passes and tools were simulated until finally the right balance was made between machining time, surface finish, and feasibility of the manufacturing process.

Before machining the work piece was made by cutting two 37 inch by 17.5 inch pieces of the six inch thick foam on the band saw in the machine shop in Kingsbury Hall. These two pieces of foam were then sanded on the bottoms in order to be glued; making sure the open cell portion of the foam was showing for maximum adhesion. The two pieces were then ready to be glued together. Prior to gluing the foam was cleaned and wetted with a sponge. Next Elmer's polyurethane glue was spread on both sanded surfaces and they were clamped together to dry for 24 hours. This method proved extremely strong even to the point as to make the glued section of the foam significantly harder to machine. Next, the top of the work piece had one inch of material faced off to allow for proper clearance between the work piece and the tool magazine in the NC machine, which had to be emptied.

The most difficult part of the machining process was getting the different sections of the model to line up exactly (**Figure 15**). To line up the front and back sections of the model a grid of points was made down the length of the foam. This grid acted as a reference for lining up the work piece when it had to be moved between machining the bow and the stern. This was a fairly successful technique, although there was still about a .25 inch misalignment between the bow and stern of the hull. To line up the top and bottom sections of the model proved to be even more difficult. The method used for this task was to drill two holes at one end of the work piece all the way through the work piece. These holes were used to line up the grid points on the top with new grid points on the bottom of the work piece. Unfortunately there was no drill that would go all the way through an eleven inch thick piece of foam. Instead the holes had to be milled in from the side on both the top and bottom and lined up as best as possible. If lined up properly this process would give two points in the same x, y location on both the top and bottom of the work piece. Then a matching set of grid points is easily made using these two points as a reference. In reality these points did not line up perfectly but engineering is never an exact science so we went ahead with the plan.

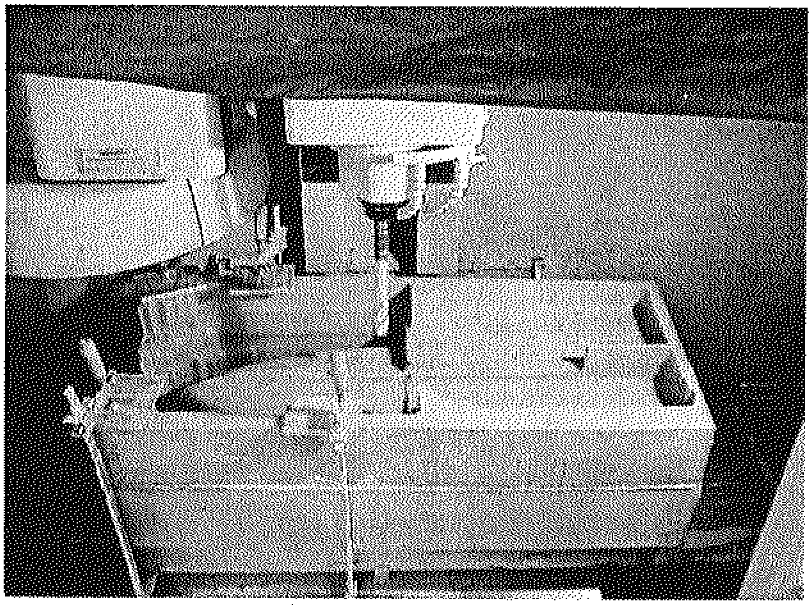

Figure 15 - Hull Form Machining

The actual machining of the model took two full days and created over ten gallons of polyurethane foam dust. This was the first time a model of this size and complexity had ever been machined at the Design and Manufacturing Center. The first sections to be machined were the inside of the model, which was all cut with a seven inch long one inch diameter flat end mill. This flat end mill was ideal for these sections since the inside of the model was mostly flat surfaces with square corners. These sections were done first since they were the simplest sections to machine. The machining of the inside of the model went flawlessly and all parts lined up without problems. On day two the machining of the hull of the model was done with the 10.5 inch long one inch diameter ball end mill. This ball end mill was chosen since it allowed for the proper clearance between the work piece and the tool holder and the ball end shape was able to machine the complex sculptured surfaces of the hull. On this second day of machining there were two unfortunate mistakes encountered. The first problem was that the bow and stern sections did not line up exactly. This was unfortunate but was fixable by sawing the model in half at the midsection and realigning the two sections. The final problem did not arise due to machining mistakes but rather as a design flaw. When the model was changed to eliminate any intersecting lines it was not noticed that this change made sections of the bow of the hull infinitesimally thin. Due to minor misalignment between the inside of the model and the hull this resulted in a hole in the bow about 12 inches long and 1.5 inches tall. Although these mistakes were definite setbacks none proved to be critical and the overall shape of the model was done. Once the CNC machine was cleaned and returned to its normal operational setup the finishing of the hull form and fiber glassing and gel coating were to be done.

Model as Machined

The model as received from milling is a rough outline of the hull with ½" grooves defining the surface of the hull. Since machine time at UNH is at a premium, we had to compromise the 50 extra hours to fine finish the hull. The rest is left to hand crafting – including cutting the hull from the surrounding block, sanding the machining gouges, and forming the final hull shape from the machining outline.

Since the model is machined in four quarters misalignment was possible and occurred at the bow / stern division. Also, due to this misalignment, the bow incurred a 2" by 13" rift where the machining tool went through the hull. Thus significant hand fabrication becomes necessary.

Figure 17 - Hull as Machined

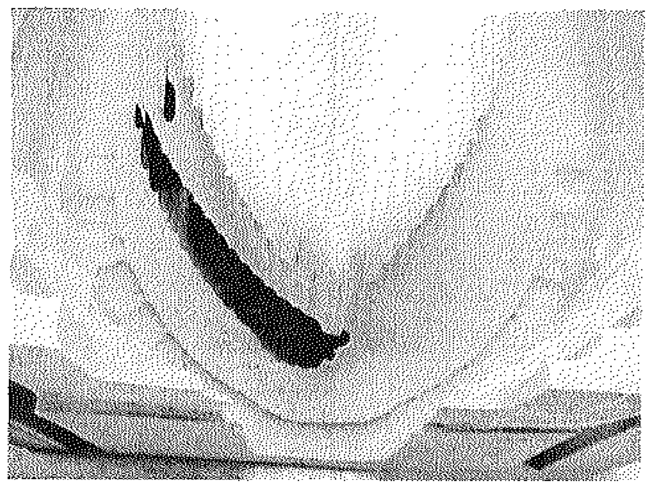

Figure 16 - Machining Error

Jig to cut the skeg square

The skeg as machined is inexact, and must be cut square to the side of the machining block. To accomplish this, the "box" containing the model is cut around its periphery making it square, then a jig is used to cut the skeg square.

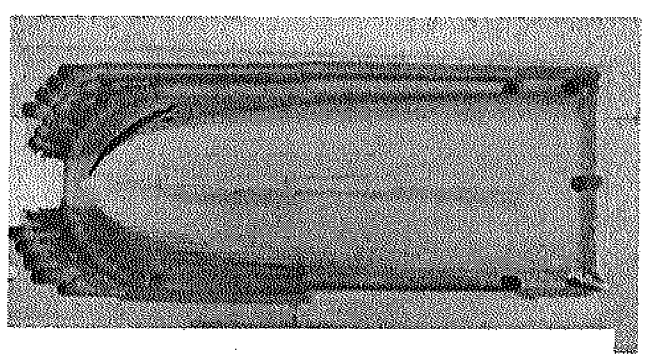

Figure 18 - Skeg as Machined

Realignment

To correct the above problems, the hull had to incur an extensive overhaul with hand working and woodworking techniques. Of highest importance is to fix the hull misalignment so the model will track straight in the water during testing. To accomplish this a jig is made to establish a square cut line.

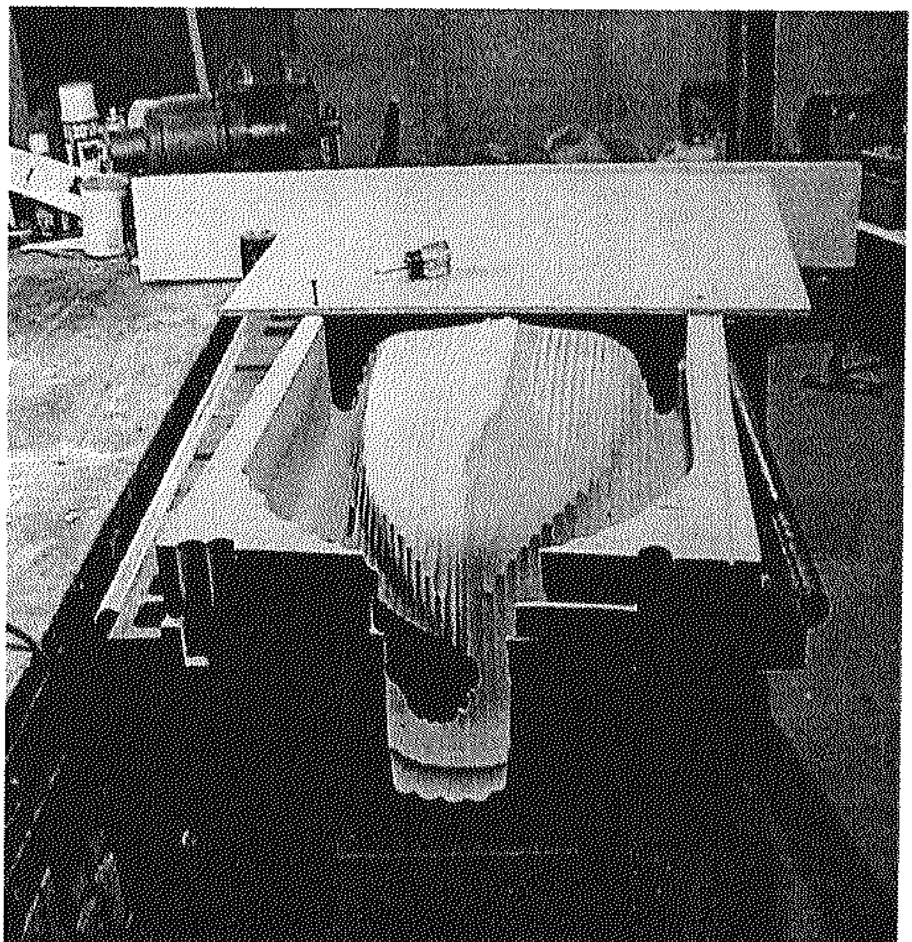

Figure 19 - Cutting Jig with Fence on Table Saw

From here, a new fence is fabricated from MDF to accommodate the height of the model and cutting jig. The model is then cut in half from gunwale to gunwale along the intersection line of bow and stern as shown below.

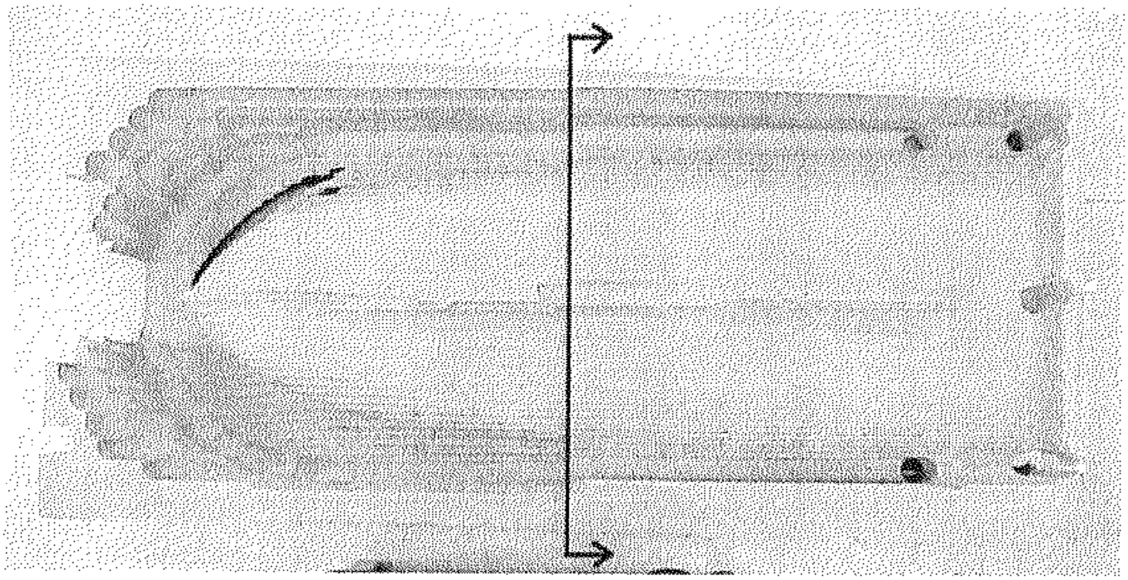

Figure 20 - Cutting Plane to Separate Misaligned Halves

Rejoining the Hull

The model is then re-glued at the correct angle with sides flush. An adhesive filler is constructed by mixing a 1 to 4 ratio of polyurethane glue and foam dust from machining. The model is then glued using a plank of MDF screwed into each inside wall of the foam block, where the machined walls are in consistent relationship with the corresponding bow and stern sections. The glue now dries for 24 hours before it is ready to be released from the jig.

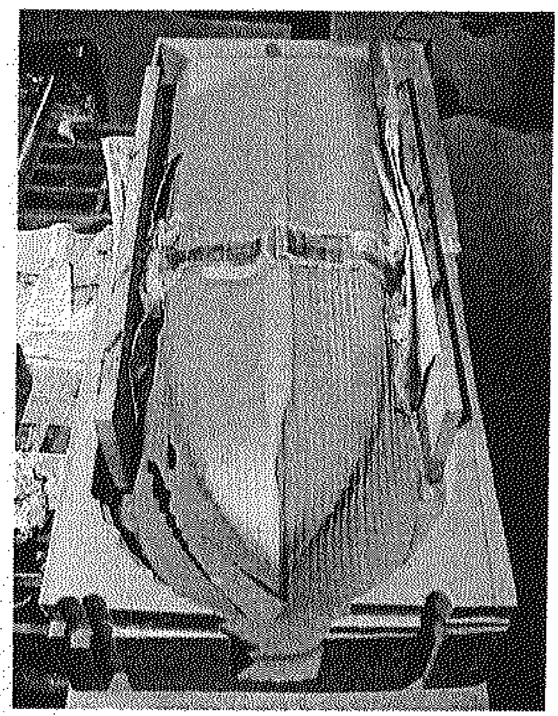

Figure 21 - Realigned Hull in Glue Jig

Separation from the surrounding foam

After the realignment is completed, the hull must be cut from its surrounding foam block to sever the basic model form from extra material. The model as machined is encased in a foam box which is affixed to the box through the thickness of the gunwale. This one inch thickness is where the hand crafting commences. From "iges" files (a universal C.A.D. format file), Pro Engineer® is employed to locate the exact location and height of the gunwales. From this, marks are scribed on the model as cutting reference points. A Japanese wood working is used to make a cut about 1/8 inch from the scribe marks of the gunwale and thus separates the box of foam from the basic hull.

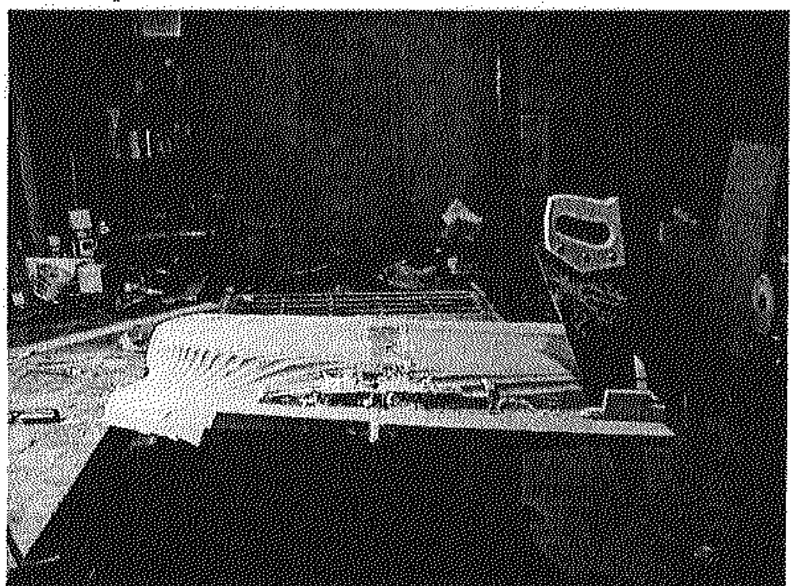

Figure 22 - Cutting the Hull from the Block

From here a right angle sanding block is constructed from ¾" Medium Density Fiberboard (MDF) sheeting, and used to sand the gunwales square to the plain of the plan view of the hull.

This is accomplished by installing two model stands which loft the inverted hull about two inches off the workbench, and insure a square relationship to the sanding plane. MDF sheeting is cut as a base for these stands so that the sanding jig can be easily slid around the periphery of the gunwale at a 90% angle. MDF is used for its stiffness, and continuous properties, which make excellent jigs, guides and sanding blocks. MDF is easily sanded to contours, routered, or squared as well thus making it sufficient for fairly exact counter guides.

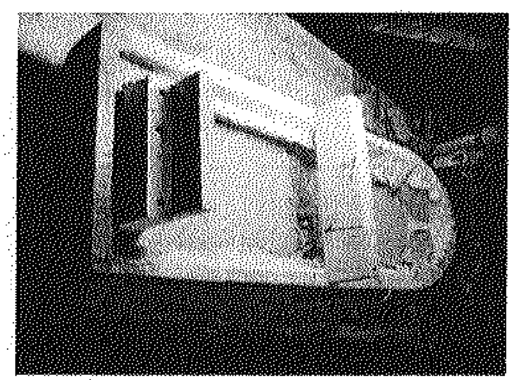

Figure 23 - Model Work Stands

Sanding down the machining

After the hull is separated from the surrounding block, the machined grooves must be sanded down in an exact manner to expose the intended hull form beneath. To facilitate this a careful examination of the CAD file is frequently performed throughout the sanding / forming process. Scribe marks must be carefully etched in the trough of each machining mark at the exact location where the hull is to meet the chord of the trough. Several sanding tools and jigs are used throughout this painstaking process, and one must remain "fresh" to keep concentration at a premium. One misinterpreted contour can mean a day worth of filling, patching and reforming. The picture here shows the difference between the hull as machined, and the hull after finish forming.

Repairing the Hull

The hull section to be repaired takes place in two steps. The first takes place before the finish sanding/ forming occurs, and the second after. The first process involves making a backing inside the boat to support the repair. This is done by shaving about ten sections of scrap foam to a 1/8 thickness and then cutting / forming them to mimic the other side of the hull (on the inside.) These pieces are then screwed into the surrounding solid material and serve as an inside guide for the repair foam to be poured.

From here the boat is inverted (hull up) and polyurethane foam is poured from a spray foam can, and left overnight to harden. This foam expands into all of the crevices and is a material used to form the basis for the repair. (The foam itself is not structurally sufficient but serves as a sculpting agent over which a permanent surface can be cast)

Figure 24 - Bow after Repair and Final Hand Sculpting

The foam is then sculpted in the sanding/forming step to form the basic shape and finally a thin coat of structural filler (fiberglass dust based) is catalyzed and applied to fill the open cells of the foam, forming a hard, smooth surface which is sanded exactly to the surrounding contour. The repair is now complete and ready for the fiberglass coat and gel coat.

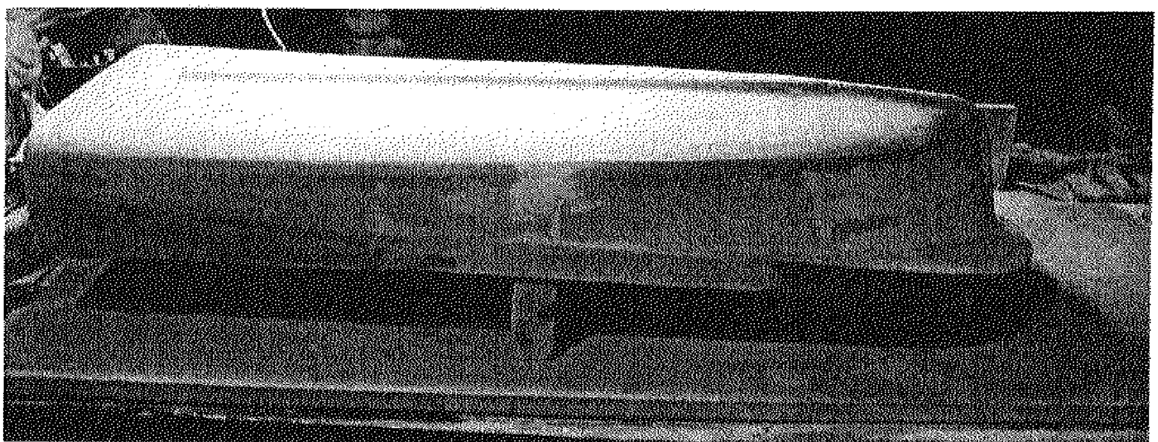

Figure 25 - Hull after Filler Applied

Once the model has been sanded to its intended form, any small gaps must be filled with a fiberglass filler material. Usually this is finely ground fiberglass powder in a liquid suspension, which hardens with a resin type catalyst / "hardener." Once the hardener is mixed, it is applied to all areas that are discontinuous on the hull. These include any gaps left by the glued halves, small areas in the stern gouged by machining errors, etc. Only a small amount is needed, as the overall hull shape is quite good. After sanding the filler down to contour, the model is ready for fiber glassing.

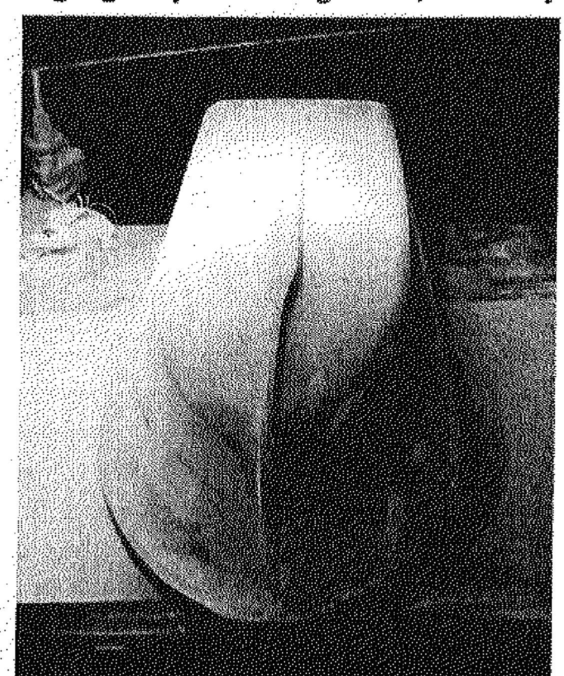

Figure 26 - Hull Ready for Fiberglass

Fiberglass Application

Before fiberglass cloth and resin are applied, the model is vacuumed to remove any loose dust. Medium weight, square weave fiberglass matt is then fitted to the model and trimmed accordingly. West System epoxy and hardener are mixed and brushed into the cloth until the entire surface is wetted. Trapped air is then worked out to the hull extremities with a soft brush during the remainder of the drying process. The surface is also smoothed by hand using vinyl gloves to insure a perfect adhesion until the epoxy starts to tack. 24 hours are allotted so the epoxy may fully off gas. This is critical for the epoxy to reach full harness and strength. Sufficient curing time also prevents residual off gassing from seeping into the final gel coat causing discoloration. After curing, excess fiberglass is trimmed and the entire model is sanded with 60 grit so the gel coat will adhere.

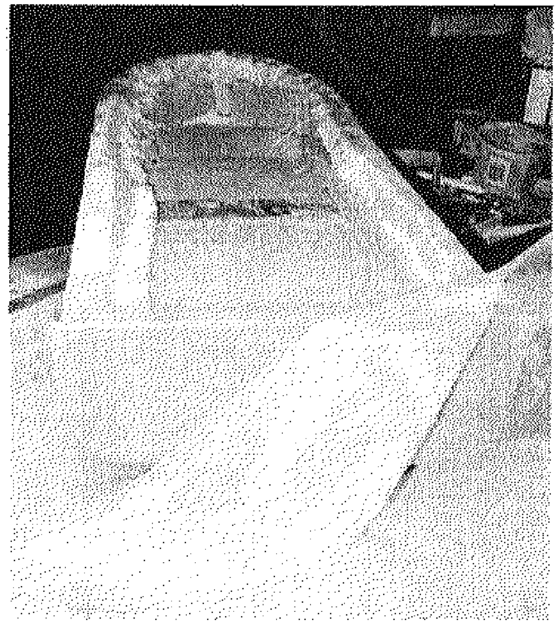

Figure 27 - Fiberglass with Release Paper

Gel Coat

Before gel coat application, the model and its environment must be free of any sanding debris. The model is brushed down with a lightweight paintbrush, and then vacuumed. The surrounding shop is then completely vacuumed to remove excess dust, which may settle on the gel coat.

To insure proper adhesion, the hull is swabbed with acetone, wiped with a towel and allowed to flash off. An *Evercoat* brand gel coat is then catalyzed and made ready to apply. Areas under the boat are protected with release paper.

An initial 1-mil coat is brushed onto the hull surface and allowed to cure to a tacky consistency. This insures complete coverage and allows the applier to check for adherence. A final mixture is then catalyzed and brushed on to build up a 20-mil thickness. The gel coat is allowed to cure to a tack again.

Since gel coats are often applied in a mold, they are formulated to cure anaerobically. To promote a cure in the open air, a layer of release agent is brushed on, which acts as an oxygen barrier. The agent is applied in two coats, and checked routinely through the remainder of the curing process for complete coverage.

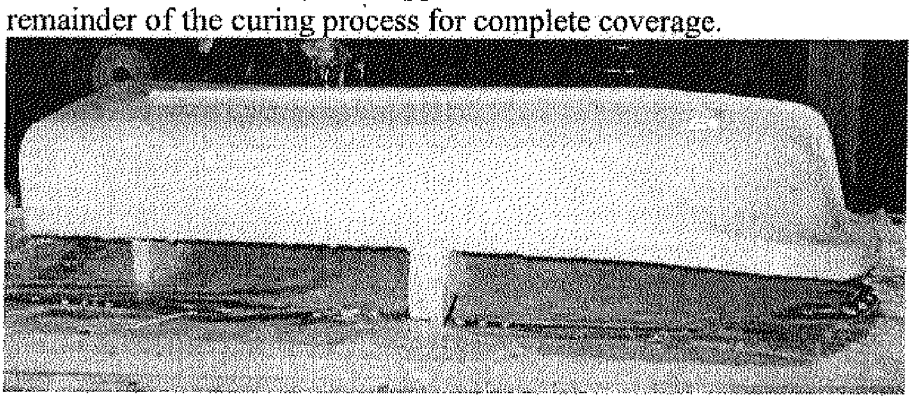

Figure 28 - Gel Coat Drying

Below the pink model is seen with a pink hue from the release agent as it dries.

Tow Hook

In order to perform tow tests, an adjustable eyehook is mounted through the gunwale of the bow. This allows adjusting the height of the tow hook above the waterline to allow for differing hull weighting schemes and trim angles.

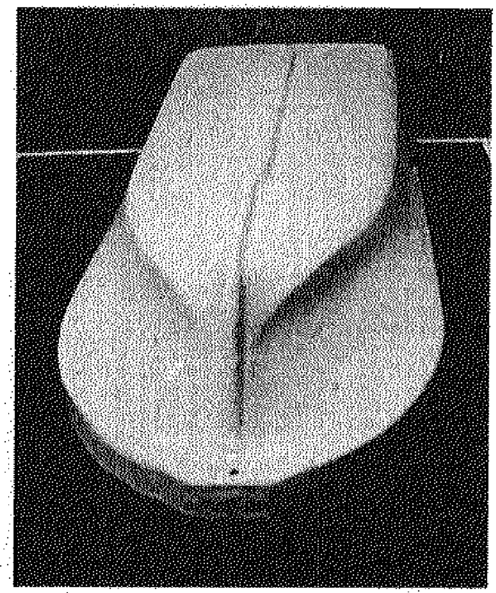

Figure 29 - Tow Hook

Finish Sanding and Polishing

The gel coat is then allowed to cure for 24 to 36 hours to sufficiently harden throughout its thickness. Then entire model is then color sanded (wet sanded) with successive grits: 350, to 600. The hull is the washed down with water and dried. A polish is applied by hand, followed with a high carnauba wax. The hull is now finished.

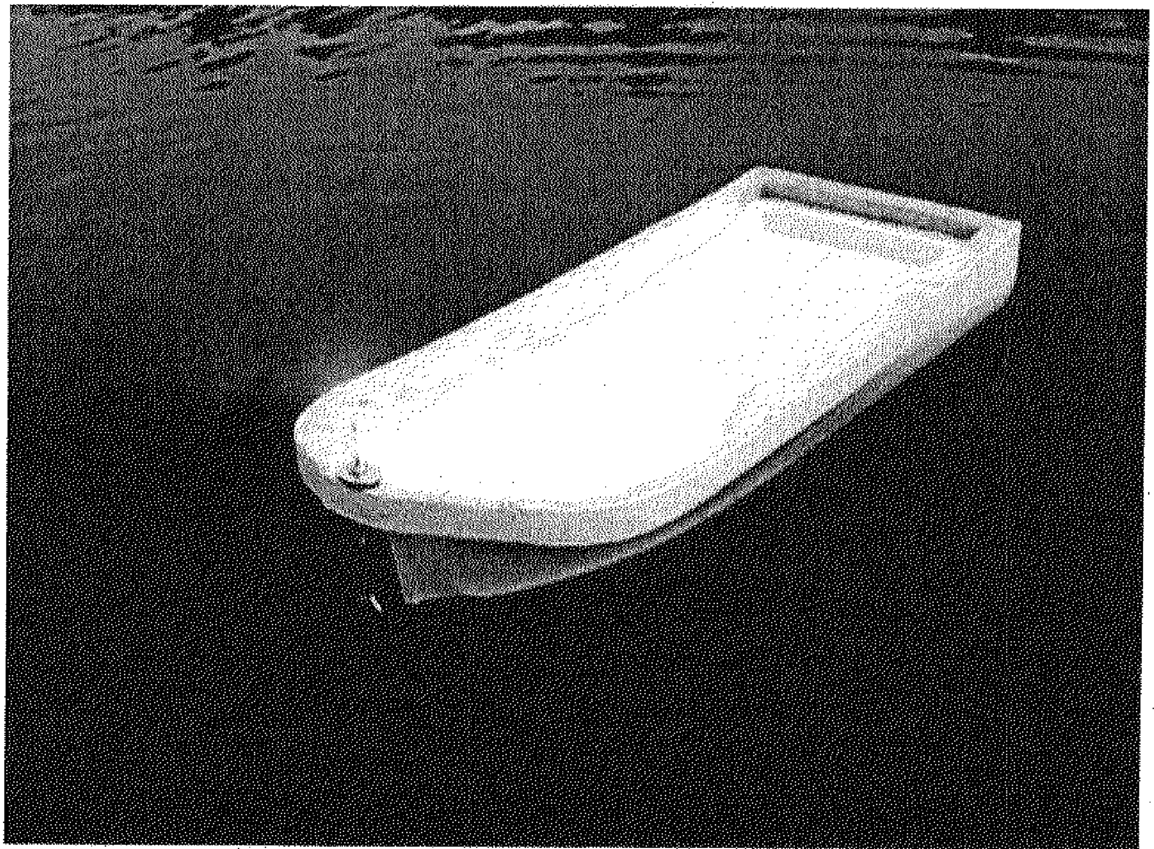

Figure 30 - Finished Model

DESIGN VERIFICATION AND EXPERIMENTAL PROCEDURES

Sea keeping

Determining the performance of a vessel in a seaway is a significant process in the design of hull structure. This evaluation is also critical for the placement of on-board equipment. With the growing concern for passenger comfort, knowledge of wave-induced motions and accelerations is important for designers of passenger-carrying vessels.

The behavior of motions pertaining to sea keeping are categorized for ease of use in the marine industry. Three primary motions are pitch, roll and heave. Pitching can be defined as the oscillatory (teeter-totter) motion of a vessel, with bow and stern moving vertically in opposite directions. Roll is defined as the transverse angular motion (port to starboard back to port) of the vessel in waves. Heave is simply the vertical translational motion of a vessel. The periods (T_H, T_P and T_R) of oscillation for each of these motions are what create a "sea-kindly" vessel. For instance, a ship with a short period of roll is said to be "stiff" and one with a long period of roll is termed "tender." A balance of behaviors where the boat is neither stiff, nor tender is desired. This means the vessel will not be subject to wave slap (stiff), nor will it be subject to the whims of every single variation in the water surface (tender.)

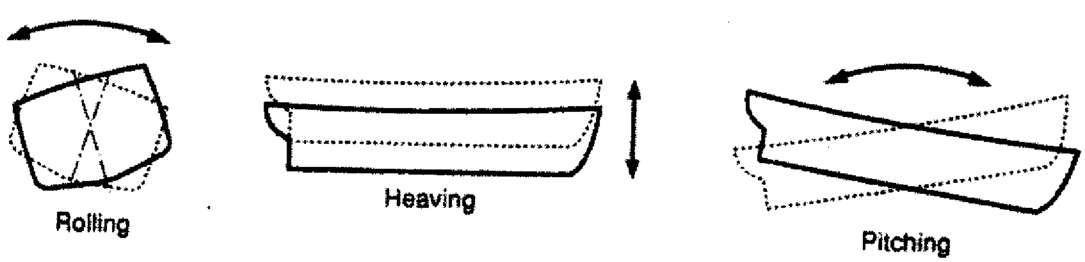

Figure 31- Three Motions Tested

A fundamental parameter in each of the above responses is the natural period of oscillation. Using optical positioning tests, as are performed in industry; it was possible to obtain the data needed to calculate these parameters. A system developed by the UNH Ocean Engineering department is used for data acquisition. This system, known as OPIE (Optical Positioning Instrumentation and Evaluation), uses a CCD camera, frame grabber, and custom software.

The software package has been designed "to analyze the images and generate practical depiction of the models kinematics" (OPIE User Guide). The model to be analyzed must have a white hull. For heave and pitch data collection, black reference dots are mounted to the port side of the vessel (one at near the stern, one near the bow). These black dots are what OPIE uses to track position; the white gel coat of the hull provides a contrast, so the software can locate and track the dots.

For each degree of motion (pitch, heave and roll) a minimum of three data trials are performed. The first test performed is for pitch. To facilitate this test, the model simply is first held steady until the water assumes a near static position. The bow is then loaded to impart an initial displacement, and the water is again allowed to reach equilibrium. The data recorder is triggered, and the model is then released. Data is collected until steady state is again reached.

The figure below shows the initial positioning of the craft during pitch testing. It is often necessary to run the software in "threshold image" mode. In this mode shades of grey are eliminated, and all areas are interpreted as either 100% white or 100% black. (Thus the lack of definition in the figure.) This mode is used when lighting conditions yield insufficient light and thus insufficient contrast. The larger dot is used for calibrating a know dimension, and the tow other dots below are the bow and stern references, respectively. The black column to the left of center is a pole used to impart the initial displacement.

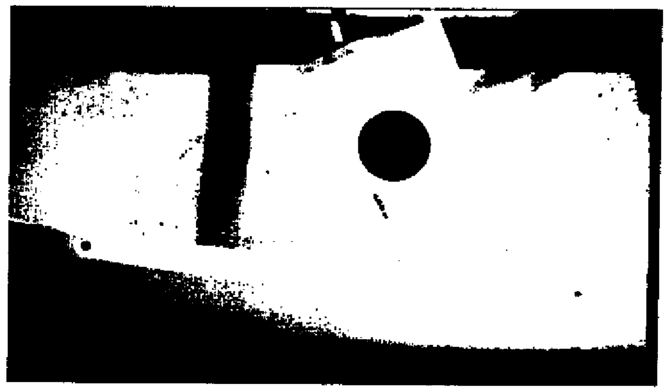

Figure 32 - The initial threshold image of the pitching test

The software included with OPIE asks for a certain timeframe in which to record data. By trial test runs, it was evident that about 4 seconds of data is ample time for most sea keeping tests with this model. The camera has a natural frequency of 30 frames per second; therefore it captures 120 images over the span of 4 seconds. Once a data run is complete, MATLAB is used to convert the video images into useful data.

The two smaller dots (bow and stern) are positioning references. These are tracked as the motion ensues. Once a tracking file has been created, the data can be analyzed. This file has the necessary parameters needed to calculate the periods of oscillation; displacement in Z and θ as functions of number of frames. Plots are now produced showing sea-keeping behavior, which is interpreted using standard systems analysis.

The same sequence of data acquisition is used for all three motions. Improved lighting conditions for these tests provide easier tracking; therefore the normal image configuration was used. Below, **Figure 33** shows the normal grayscale operation mode of OPIE. This frame is the initial position of the video used for roll tests (notice the two dots on the stern and the calibration dot above. In this test the model is displaced to port, after which it is released and allowed to oscillate freely while data is recorded.

The second order graphs generated from these tests, allow calculation of the period of oscillation for each behavior. Using the equation $T = \Delta t / n$: where n is the number of cycles and Δt is the difference in time from the 1^{st} cycle to the n^{th} cycle the data is analyzed. Using Froude scaling, the period of motion were calculated for the actual life-sized vessel. The equation relating model period, T_M to vessel period, T_A is:

$T_A = T_M \bullet \lambda^{0.5}$ where λ is the ratio of $Length_{FULLSCALE}$ / $Length_{MODEL}$

Table 1 – OPIE Test Parameters

Test	T_{M1}	T_{M2}	T_{AVG}	T_{ACTUAL}	
Roll	0.6539s	0.6152s	0.6345s	2.629s	T_R
Heave	0.6050s	0.5599s	0.5825s	2.413s	T_H
Pitch	0.6389s	0.5137s	0.5760s	2.386s	T_P

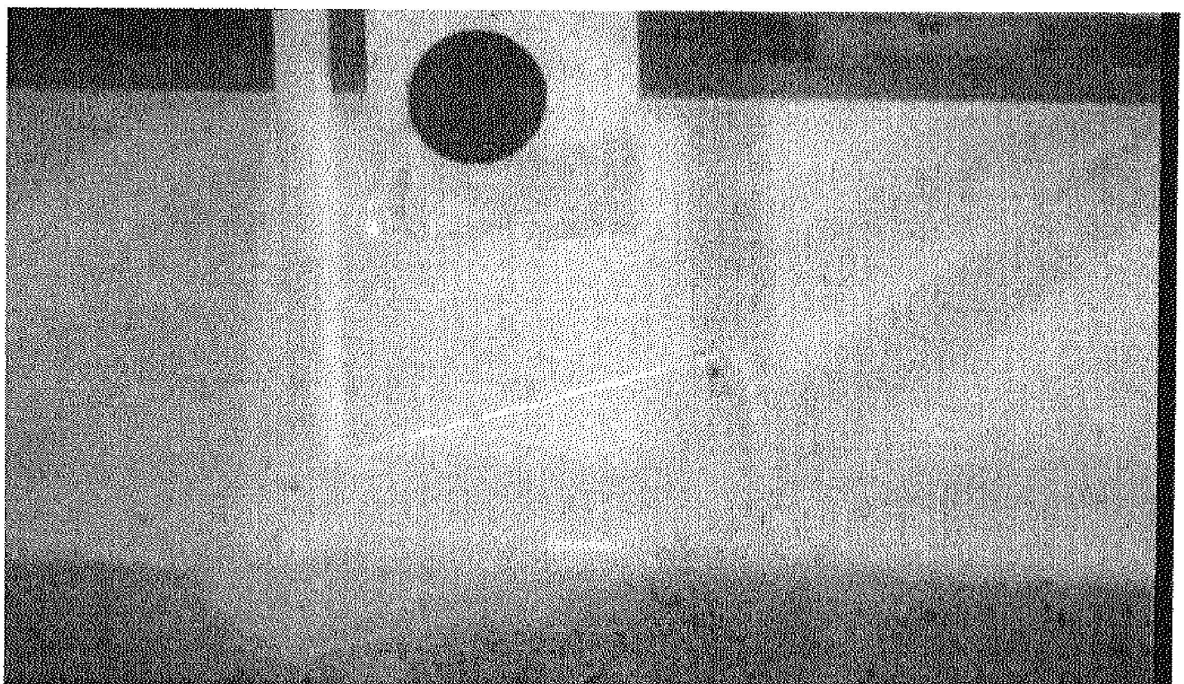

Figure 33 - Initial image of the Roll testing

The above results (detailed in **Table 1**) show the periods of oscillation in the full-scale production model are acceptable. The periods show that the full-scale boat will exhibit a slight wave following behavior. This is preferable, as the boat will rise with swells, rather than being swamped or jolted with each wave passing. The periods are also far enough removed from resonance that the hull should be stable in most ocean conditions. Storm waves (8 to 9 second period) are beyond the period of the boat, so it should be stable under extreme conditions.

Periods are calculated theoretically for the same full size vessel (**Appendix F**). The differences are slight for roll and larger for pitch and heave. This is to be expected, as the actual model is somewhat over the anticipated model weight.

Power Requirements Through Tow Testing

In order to determine the proper power plant for the vessel tow testing was conducted in the Chase Ocean Engineering Building. Through the method of Froude Scaling and by making several assumptions, the power required to tow the model can be scaled up to obtain the power required for the full sized vessel. With well-made assumptions this method of determining the engine power is accurate.

Our initial setup involved mounting two steel bars to the tow carriage clamping an additional aluminum bar over the tow tank. One hole was drilled at the bottom of the bar and a carabineer was mounted to redirect the line connecting the model to our load cell. The load cell was mounted at the top of the steel bar to be close in proximity to the laptop on the carriage. The load cell outputs strain data, which is automatically converted to force data. This data is then read into the laptop where it can be analyzed. Unfortunately, the load cell obtained with the ideal sensitivity was a 0 – 10lb load cell that had been overloaded and was unable to obtain good data. There were several working 0 – 100 lb load cells that were also tested but unfortunately the sensitivity was not good enough to get the precise data at the needed range of 0 – 5 lbs. Rather than purchase a new 0 – 10 lb load cell that would require calibration and tedious testing procedures the use of a hanging tubular spring scale was implemented. The model chosen was the Super Samson with a capacity of 4 lbs and divisions for each ounce. The estimated max forces were on the scale of 2 lbs. A video camera was used to record the output of the scale during towing as well as record the test velocity and performance of the vessel. This method was accurate to within a half ounce and very time and labor efficient. To obtain the proper weight distribution the model weight tested had to be 13.5 lbs. When this number is scaled to full vessel weight the weight of the vessel is 35 tons. The actual vessel weight is 14.5 tons light ship. With a dead weight of 15 tons the fully loaded vessel still only weighs 29.5 tons. This leads to the conclusion that the power requirements calculated will be approximately twice the actual power requirement of the vessel. Therefore by dividing the tested maximum horsepower by two and applying a factor of safety of 2.5 the required horsepower of our vessel is approximately 1000 hp.

Table 2 - Tow Testing data

Tow Velocities for Tank Testing				
Velocity (knots)	Model Drag Force (oz)	Model Power Required hp	Full scale hp	Full Scale Velocity (knots)
1.514	4	0.00116	24.232	6.270
2.090	10	0.004	83.557	8.654
2.074	10	0.004	83.557	8.589
2.533	18	0.00881	184.035	10.491
3.016	23	0.013	271.561	12.491
3.603	27	0.019	396.897	14.920
3.474	26.5	0.018	376.008	14.387
3.954	36.5	0.028	584.901	16.376
4.546	39	0.034	710.237	18.825
4.989	42	0.04	835.573	20.659
5.053	43	0.042	877.352	20.927

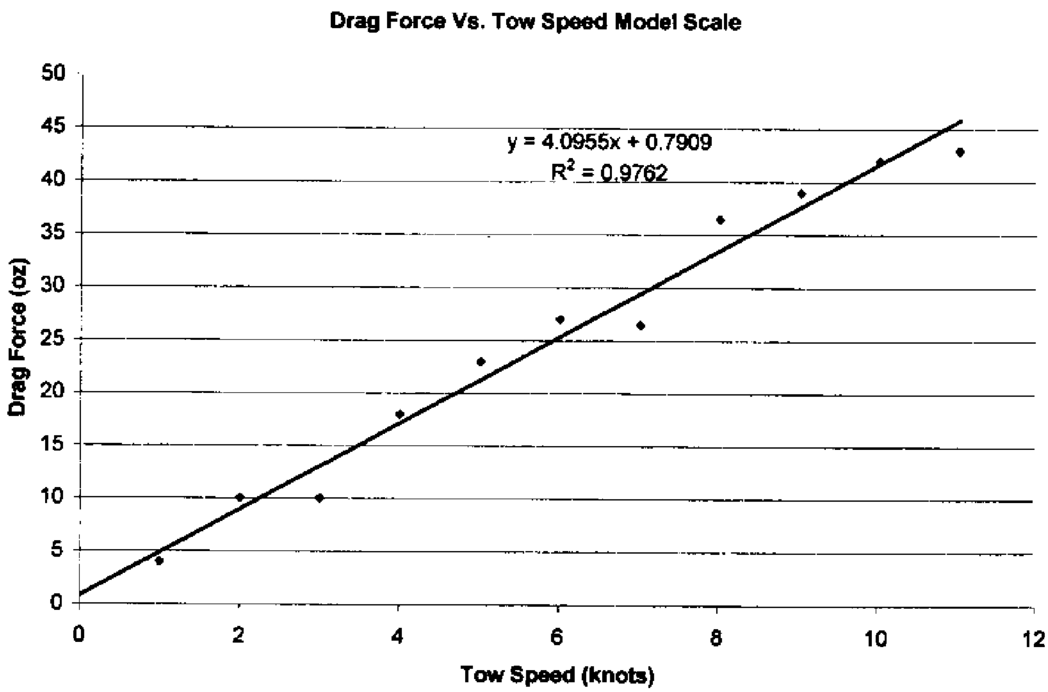

Figure 34 - Drag versus Velocity Plot

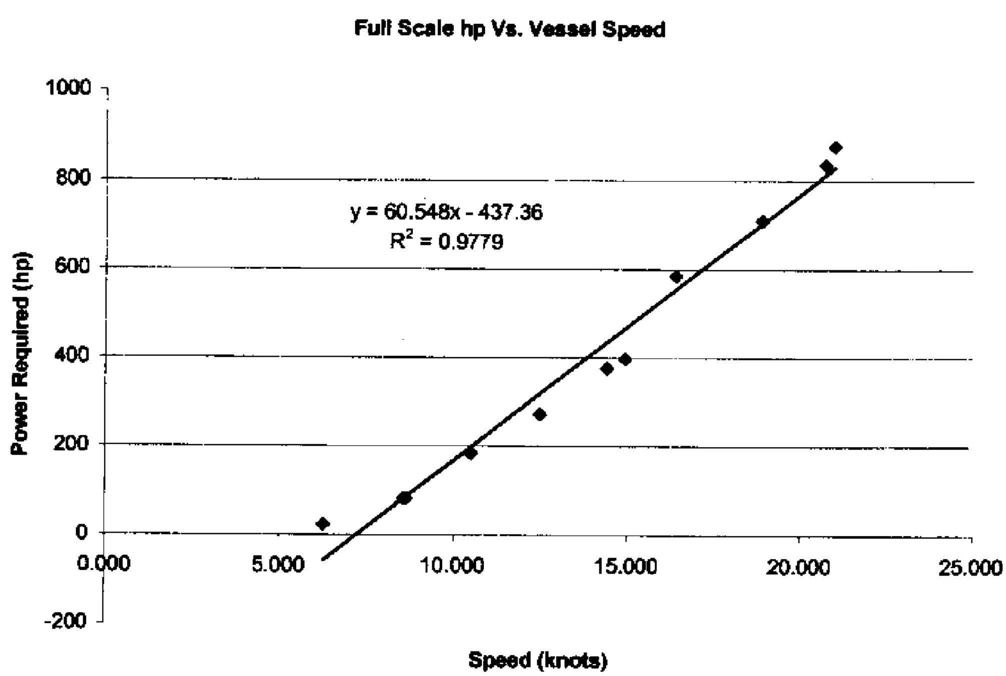

Figure 35 - Power Versus Velocity Plot

In the process of tow testing the vessel performed exceptionally well. The spray rails and bow flare shot water to the sides gracefully and efficiently. The ideal performance was obtained around 3.5 knots. This speed scales up to just under 15 knots.

Payload Testing

Another test that was run was to find the max payload of the vessel. By testing the model maximum payload this value can be scaled up to the full size vessel.

Table 3 - Payload Data

Payload and Freeboard Data for Model			
Freeboard (inches)	Load (lbs)	Full scale equivalent Load (tons)	Freeboard full scale (ft)
3.5	0	0	5.002083333
3.25	4	10.08840175	4.644791667
3.2	5	12.61050219	4.573333333
3	7	17.65470306	4.2875
2.875	10	25.22100438	4.108854167
2.6	13	32.78730569	3.715833333
2.375	15.5	39.09255678	3.394270833
2.3	18	45.39780788	3.287083333
2.2	19.5	49.18095853	3.144166667

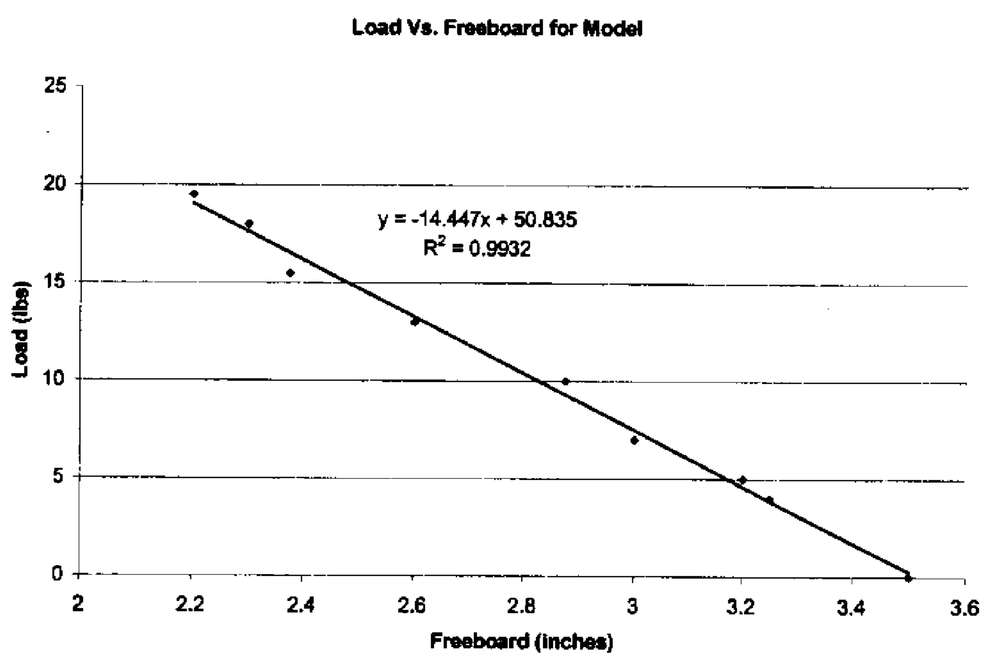

Figure 36 - Load Versus Freeboard Plot

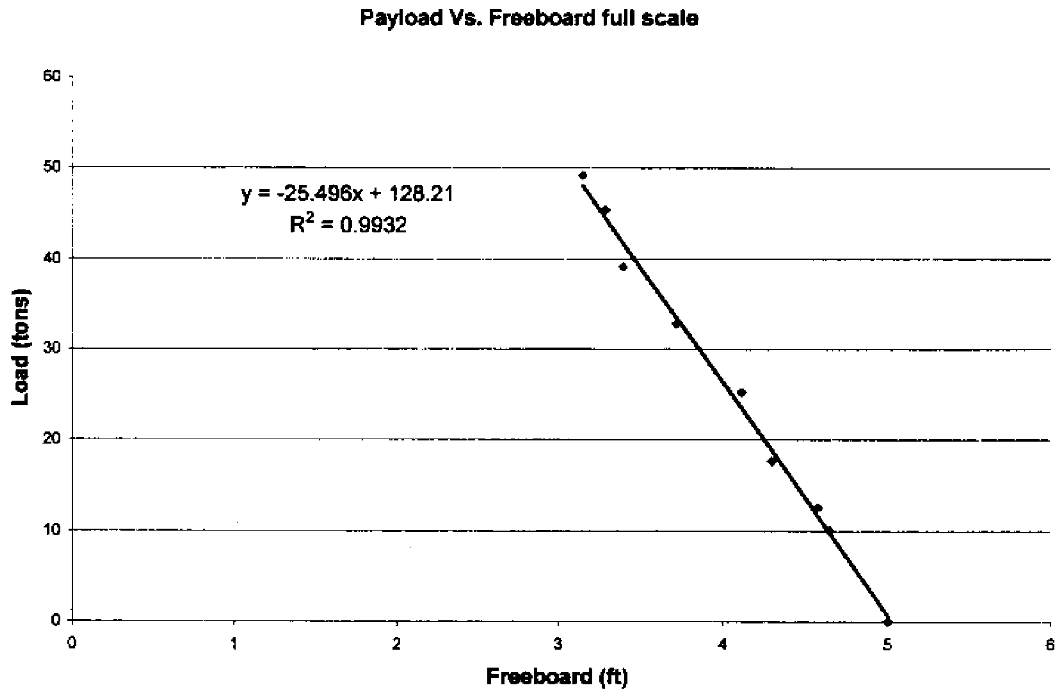

Figure 37 - Payload versus Freeboard, Full Scale

The use of an anti-roll tank or ballast may be essential with the use of larger, heavier vessels such as the Fish King. These tanks provide added stability in rougher waters. "They produce oscillating transverse flows of water so timed as to generate loads that are opposite to the perturbing force". In laymen's terms they produce added weight opposite to the higher rolling side of the vessel. These tanks will not fully eliminate rolling but will drastically reduce it. Downsides to these tanks are their size, and added mass. When looking at designing vessels in the 50-foot range, such as the Shoals Runner, it is next to impossible to consider adding such a device. The lack of below deck space will not allow for such an addition. Also the weight of two additional water tanks below deck creates other buoyancy problems. However in ME 747 Senior Lab, we were able to examine the effects of anti-roll tanks. In our tests it was observed that the rotation of the ballast was not a smooth transition. The motion, when analyzed turned out to be in the form of a 3rd order system. This effect is seen in **Figure 38**, the plot is in the form of a 1st order system, but yet it has the oscillations of a second order system.

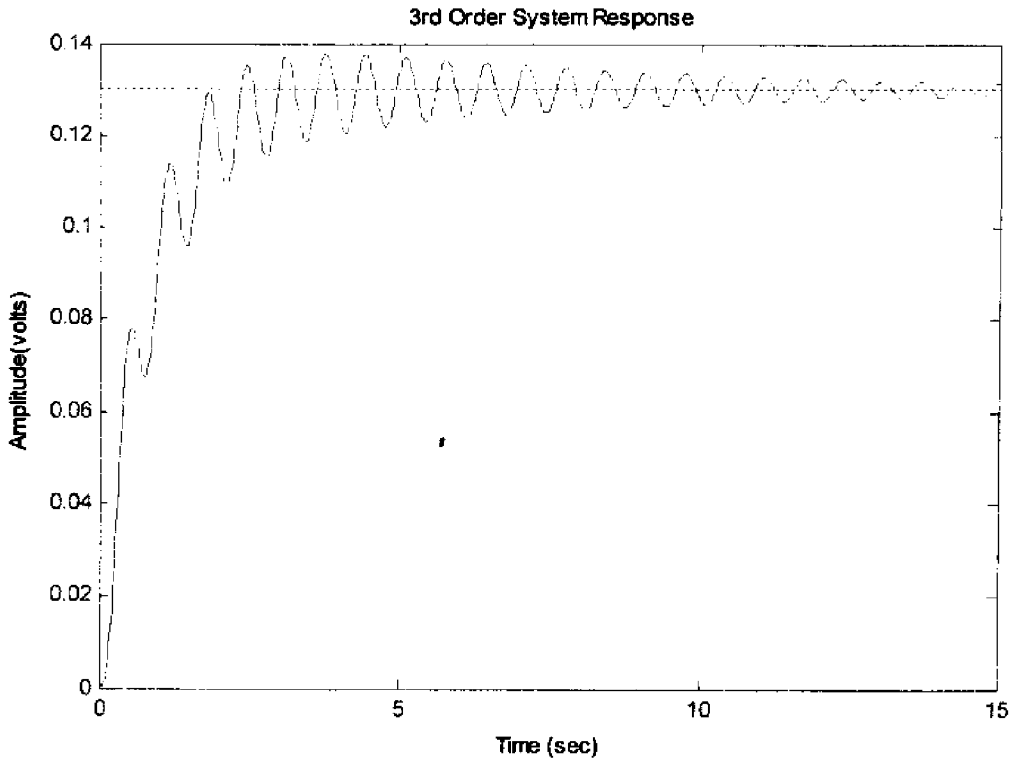

Figure 38 - Scaled Model Ballast System Response

COST ANALYSIS

A detailed cost estimation was determined for the construction of the vessel. With an estimated budget of 1,000,000 dollars there were some significant economic advantages and disadvantages associated with the Shoals Runner.

Budgetary Advantages

- Cost of hull material was significantly less using fiberglass than aluminum.
- Due to hull characteristics only a single engine was needed to achieve desired velocity.

Disadvantages

- Due to amount of hydraulic equipment, stand alone engine needed to supply enough power to hydraulic pump.
- A number of batteries will be needed to adequately start engines and generator
- Construction of custom design is expensive

Although there are some monetary disadvantages, having a vessel that will meet all users needs is more important. Having the ability to perform the necessary tasks at sea in a timely and safe manner is highly preferable compared to current operations.

Many of the items on the equipment list are specialty items, which are made to specifications. For instance an A-Frame is not a typical item found in a marine supply catalog. Estimates for these costs were made as accurately as possible, either by contacting the manufacturer or by finding similar equipment in online catalogues. There are also many miscellaneous costs unaccounted for in this list. Examples of these would be shipping costs, miscellaneous fasteners/seals, and any other operating materials. The approximate final cost for the Shoals Runner is $556,000.

Table 4 - Cost Overview

Equipment Subtotal					**$149,838.43**
Labor Subtotal					**$22,000.00**
Net Equipment Cost					**$171,838.43**
Hull Construction Subtotal					**$332,93.65**
Custom Hull construction					**$350,000**
Labor					
Net Hull Construction Cost					**$383,293.65**
Final Cost Estimate for OOWRAT Vessel					$555,132.08

CONCLUSION

In conclusion the Shoals Runner is the ideal work vessel that incorporates all of the necessary functions needed to manage the fish farm at the Isles of Shoals. The total cost of the vessel is approx. 600,000, far less than the desired maximum. With its speed and power, this vessel will be able to service all technical needs for most any marine project. This vessel is very capable of replacing the existing Rock and Roll II and the Jet Boat as well as decreasing reliance on the Gulf Challenger.

References

Alexandrou, Andreas. Principles of Fluid Mechanics. Prentice Hall Inc., NJ 1998.

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Gibbs and Cox, Inc. Marine Design Manual For Fiberglass Reinforced Plastics, McGraw-Hillm NY, 1960

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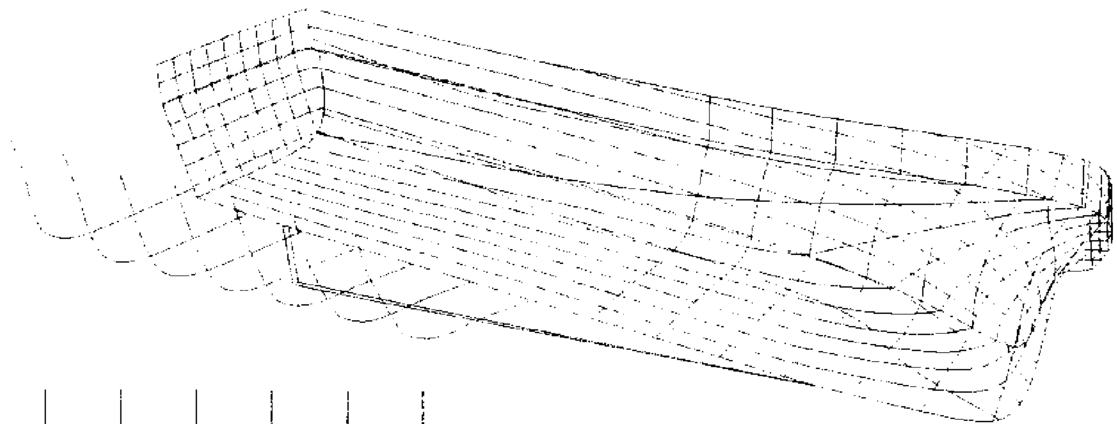
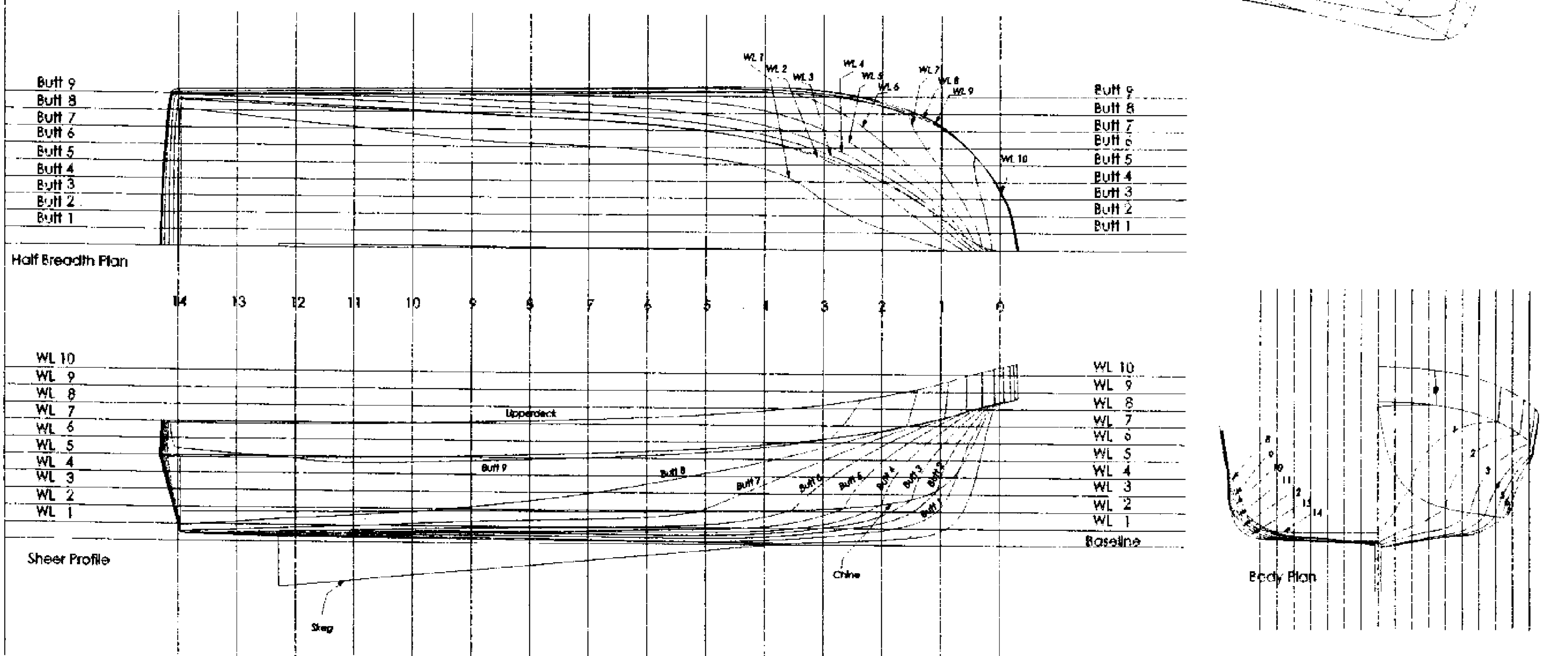
APPENDIX A – BUILDING PLANS

Description	4/20/2004
COWPAT Offshore Services	
51.5 Foot Fiberglass Vessel	
254/163 Morse Hall - UNH	
Lines Plan	
Design NO. RAT-4	

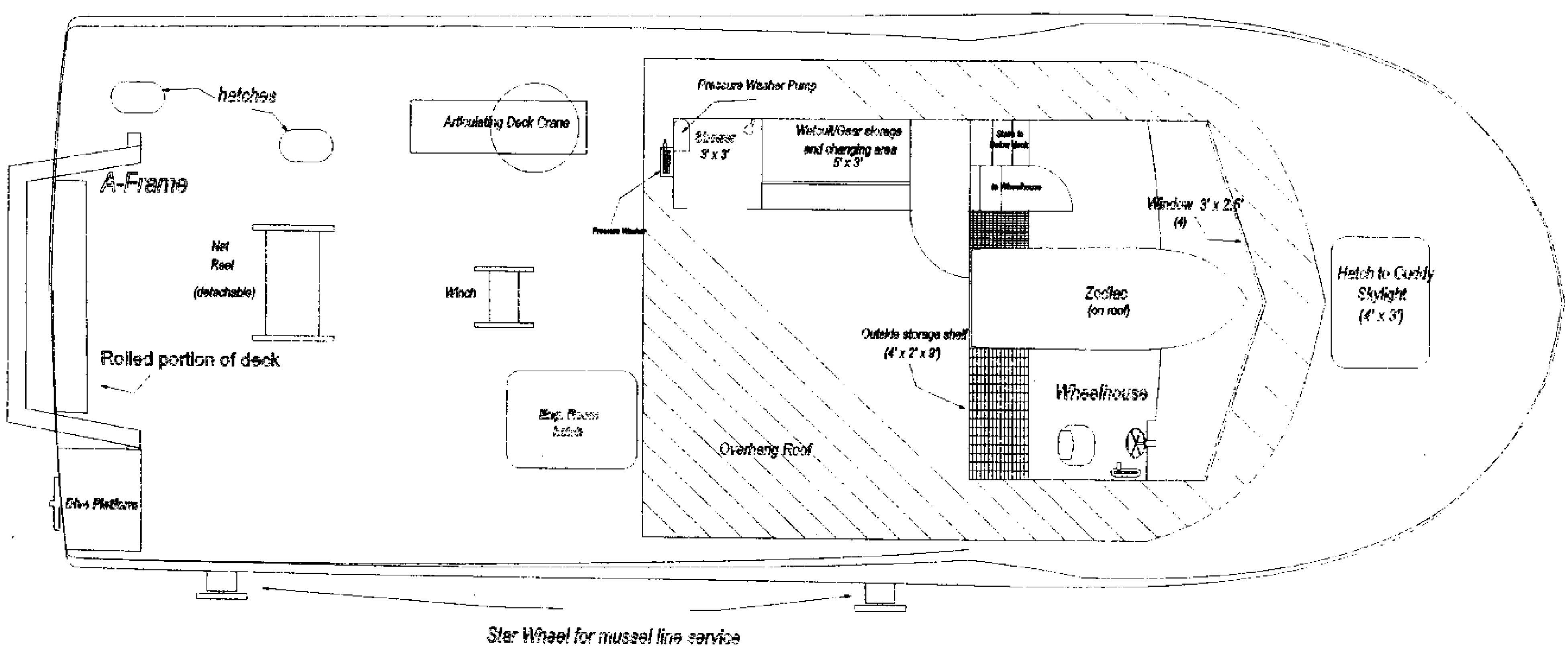




	Sta 0	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10	Sta 11	Sta 12	Sta 13	Sta 14
Position	-01-00-00	-04-06-00	-08-00-00	-11-06-00	-15-00-00	-18-06-00	-22-00-00	-25-06-00	-29-00-00	-32-06-00	-36-00-00	-39-06-00	-43-00-00	-46-06-00	-50-00-00
								Heights Above Baseline							
								Half-Breadths							
Butt 9	--------	--------	--------	06-02-02	05-08-03	05-04-05	05-02-01	05-00-03	04-11-00	04-09-06	04-08-02	04-07-05	04-10-03	05-01-04	--------
Butt 8	--------	--------	06-07-06	05-08-03	04-10-02	04-01-07	03-06-01	02-11-03	02-06-01	02-01-05	01-09-07	01-07-01	01-04-05	01-02-00	--------
Butt 7	--------	07-05-03	06-04-00	04-11-03	03-06-02	02-01-01	01-07-01	01-05-05	01-04-06	01-03-04	01-01-04	00-11-05	00-10-01	00-08-03	--------
Butt 6	--------	07-04-04	05-09-05	03-07-06	01-07-07	01-02-02	01-00-05	00-11-06	00-11-02	00-10-05	00-09-06	00-08-04	00-07-04	00-06-05	--------
Butt 5	--------	07-01-04	04-10-04	01-09-01	01-01-00	00-11-00	00-10-02	00-09-04	00-08-07	00-08-05	00-08-01	00-07-00	00-06-02	00-05-06	--------
Butt 4	--------	06-07-05	02-05-02	01-02-07	00-10-01	00-08-07	00-08-06	00-08-04	00-08-00	00-07-07	00-07-03	00-06-02	00-05-04	00-05-02	--------
Butt 3	08-04-07	05-09-03	01-09-01	01-00-02	00-08-01	00-06-06	00-06-06	00-07-01	00-07-01	00-07-01	00-06-04	00-05-03	00-04-06	00-04-07	--------
Butt 2	08-05-00	03-11-02	01-04-00	00-09-05	00-05-06	00-04-04	00-04-05	00-05-02	00-05-05	00-05-05	00-05-02	00-04-04	00-04-01	00-04-05	--------
Butt 1	08-04-05	02-03-01	00-10-05	00-06-01	00-03-02	00-02-02	00-02-03	00-03-01	00-03-05	00-04-00	00-03-07	00-03-04	00-03-05	00-04-04	--------
Wl 10	03-05-00	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Wl 9	03-05-04	07-03-02	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Wl 8	--------	07-02-02	08-07-02	09-03-07	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Wl 7	--------	04-08-02	08-05-06	09-02-00	09-05-00	09-05-04	09-05-01	09-04-07	09-04-06	09-04-05	--------	--------	--------	--------	--------
Wl 6	--------	03-02-04	06-03-07	08-06-05	09-03-01	09-03-04	09-03-02	09-03-00	09-02-07	09-02-06	09-02-05	09-02-04	09-02-01	09-01-05	--------
Wl 5	--------	02-05-01	05-01-02	07-00-05	08-01-06	08-07-06	08-10-04	08-11-06	09-00-03	09-00-06	09-00-06	09-00-05	09-00-02	08-11-06	--------
Wl 4	--------	02-00-01	04-05-05	06-02-04	07-03-05	07-10-06	08-03-00	08-05-06	08-07-05	08-09-00	08-10-00	08-10-06	08-11-00	08-11-01	--------
Wl 3	--------	01-05-04	04-01-03	05-08-04	06-08-07	07-04-03	07-09-01	08-00-02	08-02-04	08-04-04	08-06-03	08-07-07	08-09-00	08-09-07	--------
Wl 2	--------	00-10-00	03-04-07	05-03-06	06-04-03	06-11-05	07-04-02	07-07-01	07-09-03	07-11-02	08-01-02	08-03-03	08-05-02	08-06-07	--------
Wl 1	--------	00-01-02	01-02-06	02-10-03	04-08-07	05-04-05	05-09-04	06-00-06	06-02-02	06-04-02	06-08-02	07-01-01	07-04-07	07-09-01	--------
Edges	03-05-07	07-01-05	08-05-03	09-00-05	09-02-07	09-02-06	09-02-01	09-01-05	09-01-02	09-01-00	09-00-06	09-00-04	09-00-00	08-11-04	08-11-00
Edges	03-05-07	07-01-05	08-05-03	09-00-05	09-02-07	09-02-06	09-02-01	09-01-05	09-01-02	09-01-00	09-00-06	09-00-04	09-00-00	08-11-04	08-11-00

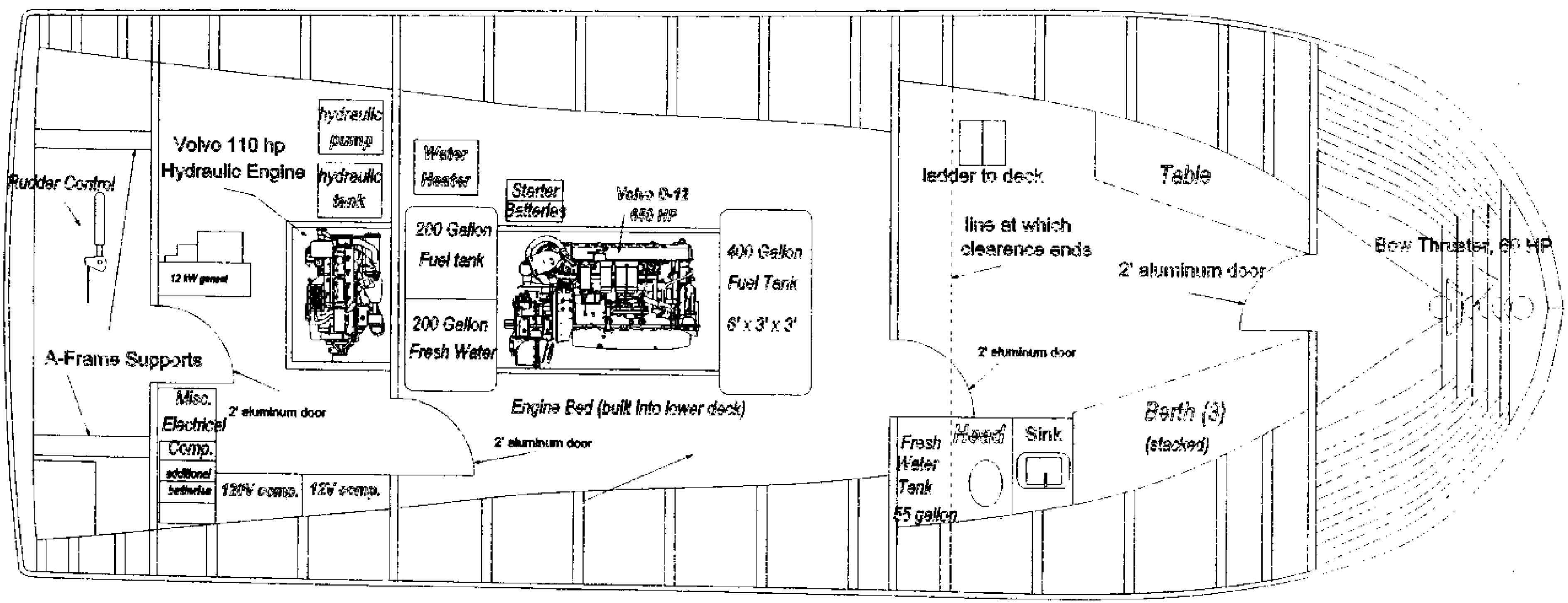
Offsets in Feet-Inches-Eighths.

Description	4/20/2004
COWRAT Offshore Services	
51.5 Foot Fiberglass Vessel	
254/163 Morse Hall - UNH	
Above Deck Setup	
Design NO. RAT-4	



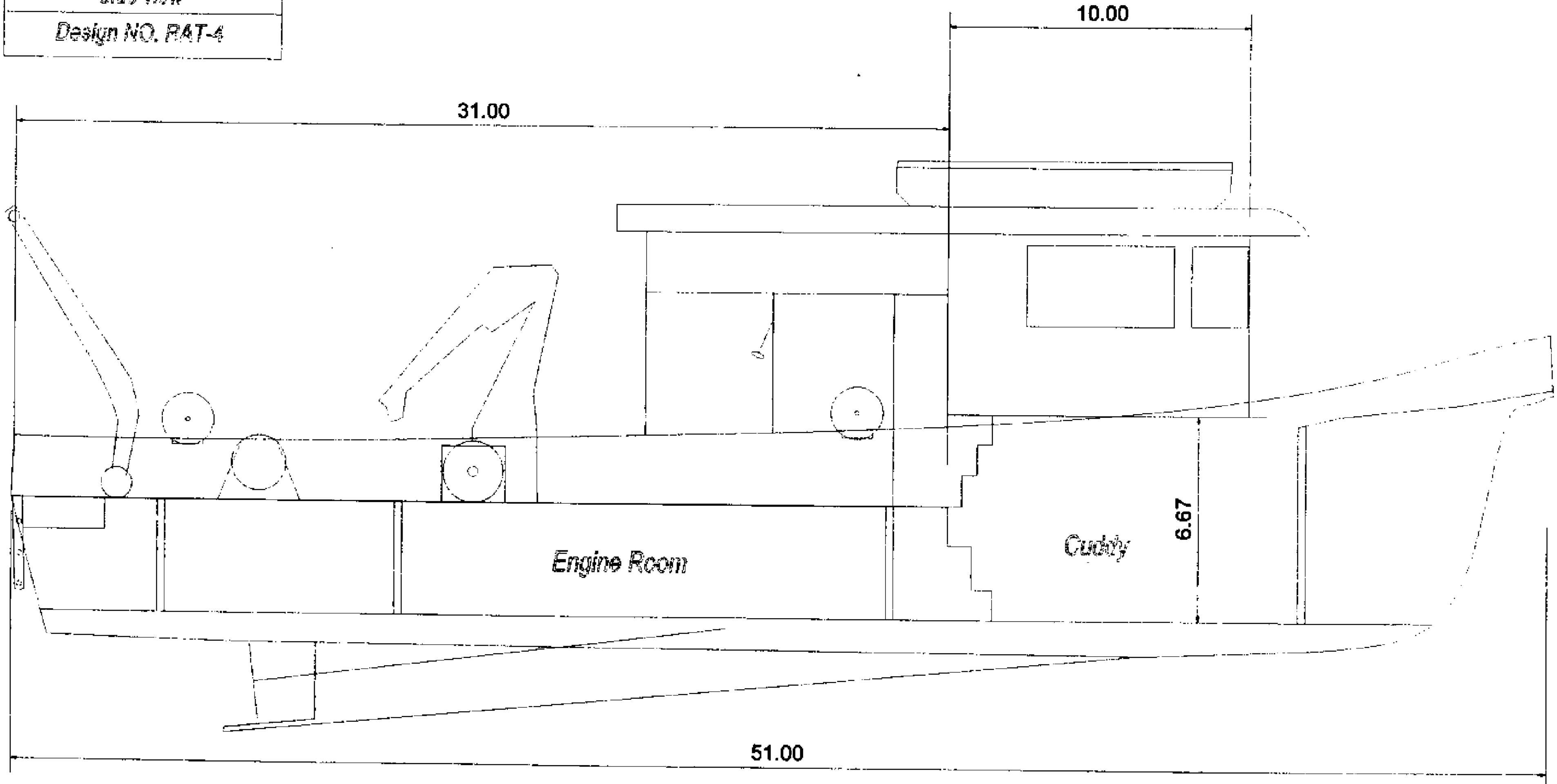
3/16" = 1'

Description	4/20/2004
OOWRAT Offshore Services	
51.5 Foot Fiberglass Vessel	
254/163 Morse Hall - UNH	
Below Deck Setup	
Design NO. RAT-4	



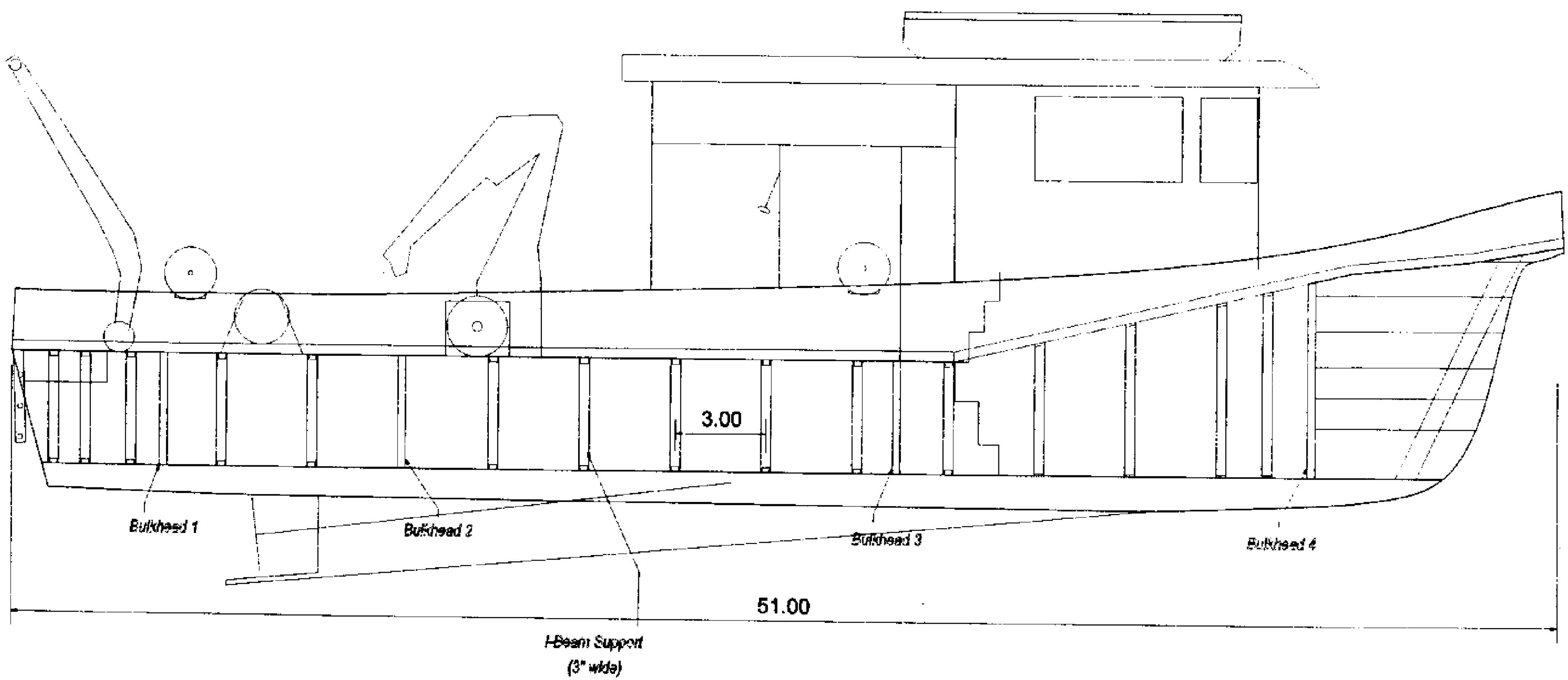
3/16" = 1'

Description	4/20/2004
OOWRAT Offshore Services	
51.5 Foot Fiberglass Vessel	
254/163 Morse Hall - UNH	
Side view	
Design NO. RAT-4	

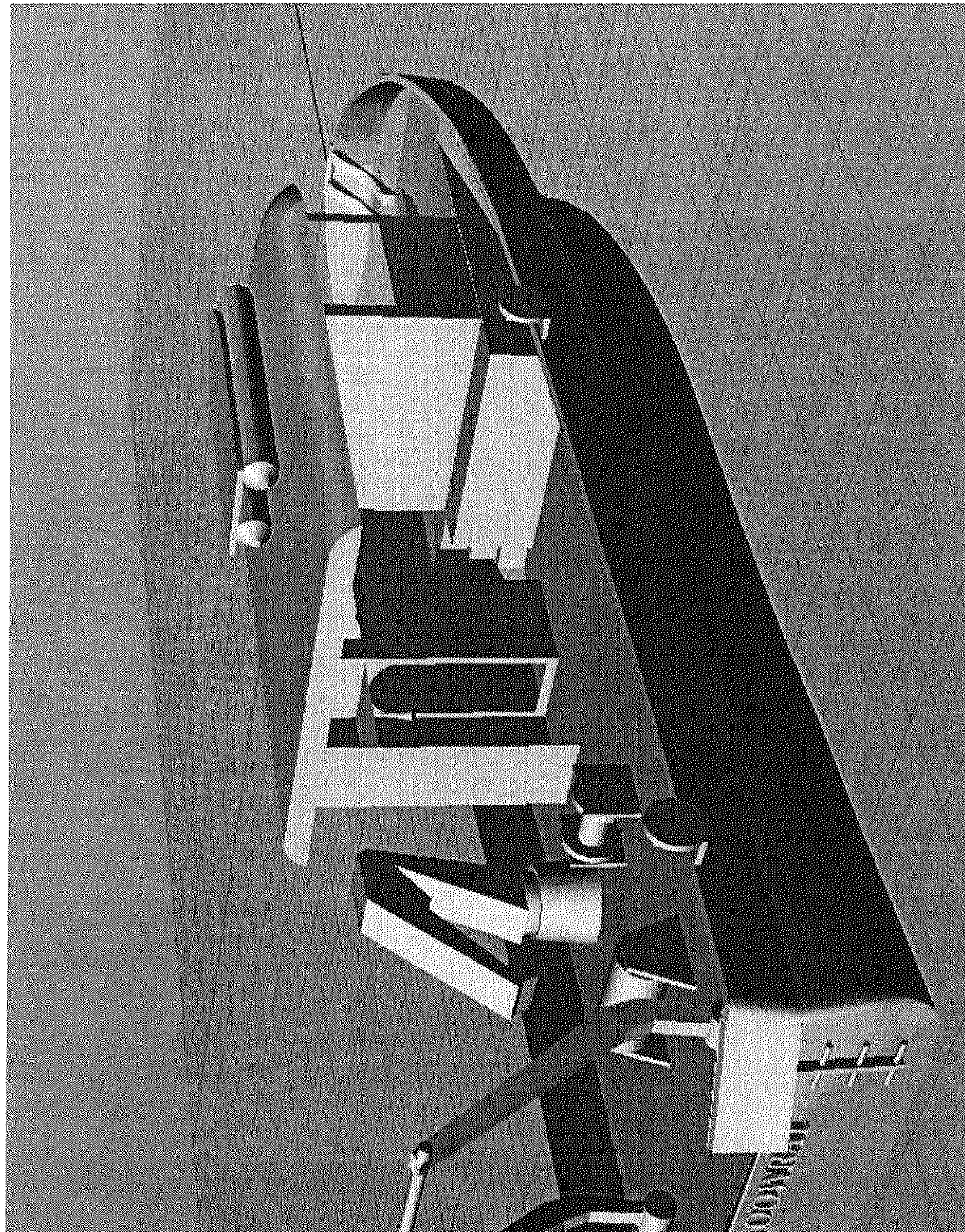


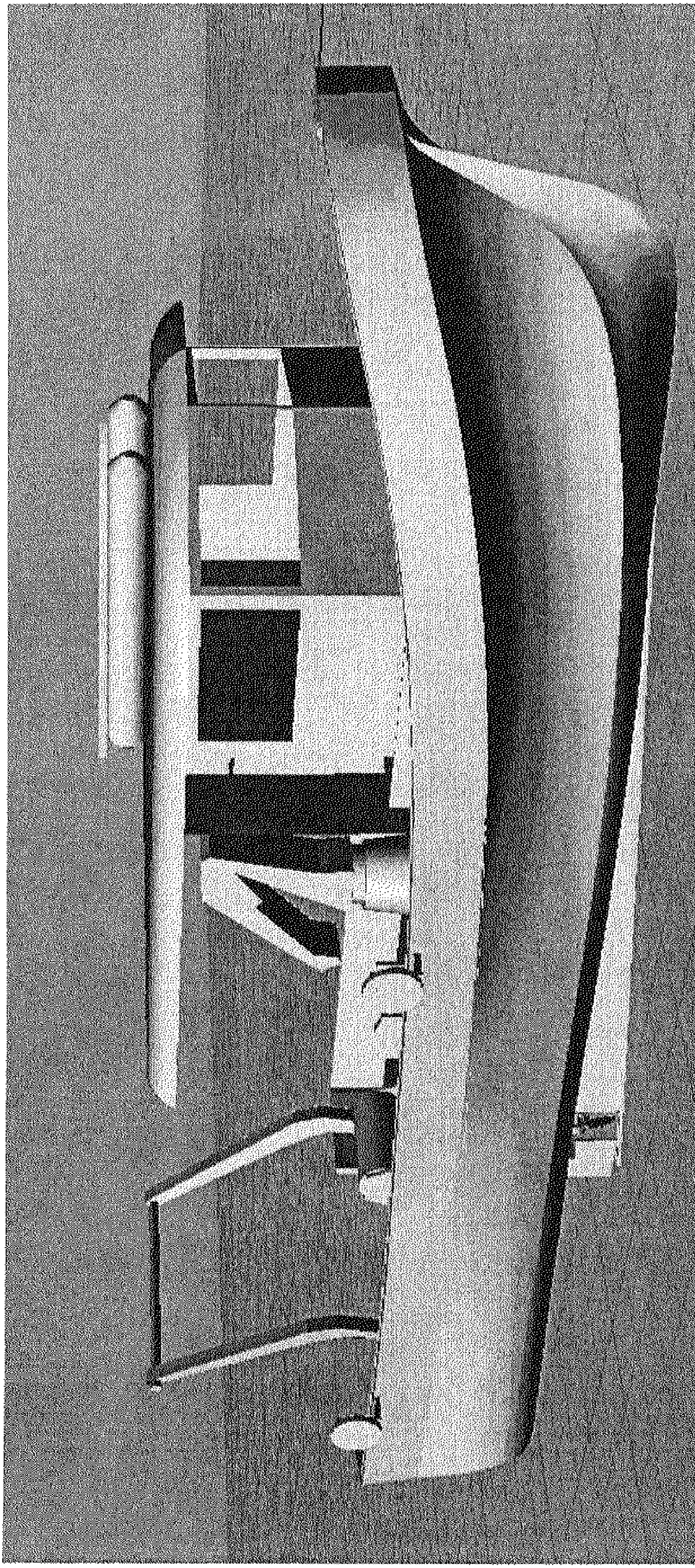
3/16" = 1'

	Description	4/20/2004
OOWRAT Offshore Services		
51.5 Foot Fiberglass Vessel		
254/163 Morse Hall - UNH		
General support setup		
Design NO. RAT-4		



3/16" = 1'





COST ANALYSIS

Category	Device	Amps	Unit COST	Quantity	Total Cost	web	descrip.	model
Communications	CB Receiver	1	$349.95	$1.00	$349.95	http://boatantenna.com/ssb/544-SS.html	16' Fiberglass SSB Antenna. High performance Single Side Band antenna combines length with exceptional communication over the entire HF frequency range, with the use of a tuner.	544-SSB
Communications	SSB Receiver	1.5	500	1	$500.00	http://www.boatersworld.com		Icom - Icom At-140 Tuner F/Ic-M802 Ssb Part# ICM30201
Communications	SSB Transmit	25	159.95	1	$159.95	http://www.boatersworld.com		Icom - M302 VHF Radio
General Lighting	Cabin Light (40W)	3.5	26.5	4	$106.00		Plastic surface halogen light with switch. Frosted plastic lens. Size: 6.68" x 1".	INTERCON MARKETING SATURN
General Lighting	Fluorescent Light (26W)	1.8	5.24	4	$20.96	http://www.1000bulbs.com/category.php?category=325	30 Watts, Slimline (Instant Start) Fluorescent Lamp, Single Pin(fa8) Base, Bulb Type T12, Length 48.00", Diameter 1.10", Kelvin 4100, CRI 70, Average Life Hours 9,000, Approximate Initial Lumens 2,575, Approximate Mean Lumens 2,350,	F48T12/SPEC41/EW/ALTO **Philips
General Lighting	Fluorescent Light (8W)	0.7	1.88	4	$7.52		8 Watts, Preheat Fluorescent Lamp	F8T5/COOL WHITE
General Lighting	Hand Held Spotlight	10	35.23	1	$35.23	http://www.shootnhunt.com/anderson_halogen_handheldspot_boatlight.	Powered by H3, 55 watt halogen bulb. Impact resistant ho	ANDERSON HALOGEN HANDHELD SPOTLIGHT HANDHELD OR FREE STANDING
General Lighting	Spreader Light	8	22.4	2	$44.80	http://www.shipstore.com/ss/html/AND/ANDE513.html	DECK FLOOD LAMP white polypropylene housing with sta	AND E513
Heat	Forced Air (44,000 BTU)	3	759.87	1	$759.87	http://www.ducktec.com/itm00058.html	40,000 BTUH 120 Volt AC Park Model Propane Gas or Natural Gas Fired	P-40 Suburban
Instrument	Knotmeter	0.1	419	1	$419.00	http://www.signetmarine.com/products/pricelist/comp_price.html		SL267A Digital Knotlog
Instrument	Wind Speed Sensor	0.1	$545	$1	$545.00	http://www.signetmarine.com/products/pricelist/comp_price.html		SL225 Wind (Wind Speed/Direction)
Instrument	Wind Speed Indicator	0.1	525	1	$525.00	http://www.signetmarine.com/products/pricelist/comp_price.html		SL254 Wind Speed/Direction
Misc..	Anchor		770	1	$770.00	http://outfittersparadise.com/a/Boat_Anchors/Fortress_Guardian_Ancho	High-tensile aluminum magnesium alloy Durable anodized finish	Fortress - Guardian Anchor - G125
Misc/	Anchor Roller		259.95	1	$259.95	http://www.foreandaftmarine.com/GD-626RC.htm	30" Boom & Base Anchor Roller Assembly (20 to 80 lbs.)	30" Boom & Base
Misc..	Auto Pilot	4	550	1	$550.00	http://www.raymarine.com	Compact SmartPilot push button autopilot control head with a 3" LCD and instrument repeater capabilities	E12098
Misc..	Bilge Pump	5	53.56	2	$107.12	http://www.sailnet.com/store/item.cfm?pid=14316	Heavy-Duty Electric Bilge Pump	Shurflo 1600GPH
Misc..	Cabin Fan	1	52.25	1	$52.25	http://www.budgetmarine.com/pdf/122.pdf	Hella Turbo Fan Fan Turbo 12v 6.5w	HEL/003-361-001
Misc..	Fuel Pump	3	85	1	$85.00	http://www.moyermarine.com/cgi-bin/shopper.cgi?keywords	Electric fuel pump	FPMP_02_194
Misc..	Horn	3	$65.85	$1.00	$65.85	http://www.budgetmarine.com/pdf/122.pdf	Single Trumpet Electric Horn 12vd	AFI/10010
Misc..	Inverter (Sm. Microwave)	100	459.99	1	$459.99	http://www.majorpower.com/inverters/mhl_quasi.html	The Xantrex Prowatt 1750W inverter is designed for operating resistive loads, such as lighting. The solid-state circuitry precisely regulates the voltage and frequency	XAntrex Prowatt 1750 Power Inverter
Misc	Wiper Motor	2	$184.95	$1.00	$184.95	http://www.budgetmarine.com/pdf/122.pdf	Wiper Motor 5/8" Shaft 2 1/2" Long 80 Degrees	AFI/34000
Misc	Wiper Blade		24.4	4	$97.60	http://www.budgetmarine.com/pdf/122.pdf	H.d. Wiper Blade	UNT/BD721011-20
Navigation	Depth Sounder	0.1	$69.95	$1.00	$69.95	http://www.starmarinedepot.com/	Uniden QT206 Depth Sounder	
Navigation	Loran	1	299.95	1	$299.95	http://www.starmarinedepot.com/	Furuno GP32 WAAS GPS Navigator	
Navigation	Radar	4	1,754.95	1.00	$1,754.95	http://www.starmarinedepot.com/	Furuno 1722 NavNet Radar Chart Plotter	
Navigation	Steering System		8,000.00	1.00	$8,000.00		All necessary steering components, connecting to rudder, wheel	
Navigation Light	Masthead/Steaming Light	1	28.95	2	$57.90	http://www.starmarinedepot.com/	Perko Masthead Light	PE1803
Navigation Light	Running Lights	3	$380.00	$1.00	$380.00	http://www.cmsquick.com/prod_13_dock.html	12VDC Light Assembly List/Pair	TYPE - R
Navigation Light	Tri-Color Light	2	100.51	1	$100.51	http://www.iboats.com/mall/index.cgi?prod_id=21647	Available in the time proven quickfit mounting system which is especially useful for transporting trailing or storage. Dismounts without tools and disconnection of cable. Protective cover is supplied. 12V. Lights combine all statutory lights in one with a maximum consumption of 25W. Easy bulb replacement without tools. Minimum range visibility of two nautical miles.	Aqua Signal 40 Tri-Color Sailing Navigation Lights 406067
Pump	Fresh Water Pump	5	$114.80	$1.00	$114.80	http://www.iboats.com	Multi-outlet water pressure pump serves 3 or more 1/2" outlets at any one time. Snap-fit ports simplify both installation and removal for routine service. 3.5 gpm open flow output. Self-priming up to 10 feet. Four piston diaphragm sealed for smooth and quiet operation. Thermal overload protection automatically stops motor should it overheat due to overload, with auto restart feature. Diaphragm design allows extended dry running	Jabsco Par Max 3 Water System Pump31600-0092
Pump	Toilet		$580.95	$1.00	$580.95	http://www.iboats.com	Push button flush. Efficient macerator and high capacity scavenger pump grinds up waste and pumps it out. White vitreous bowl baked enamel seat and cover. Corrosion resistant materials throughout. Built-in backflow preventer in discharge. Installed above or below waterline. Base assembly can be rotated for most convenient plumbing connections. Use with holding tank or with flow-through treatment devices	ITT Jabsco Electric Marine Toilet 370100090

Pump	Head Pump	18	$153.11	$1.00	$153.11	http://www.iboats.com	Rotary cutter shreds waste before it is pumped into or out from the holding tank. The pump should be connected either direct to the holding tank discharge outlet or the bowl discharge outlet	Johnson 12V Macerator Pump
Pump	Wash Down Pump	10	153.52	1	$153.52	http://www.iboats.com	Completely encapsulated with a waterproof coating. UL marine listed with ignition protection. Self priming to 12'. Runs dry without damage. Complete with non-corrosive heavy duty hose spray nozzle. Pump 3.4 gpm @ 45 psi. Permanent magnet motor with a positive displacement 3 chamber pump. 12V/6amp. 1/2' MPT inlet and outlet ports	Shurflo Blaster Washdown Pump
Deck Equipment	Articulating D.C.	hydraul.	$2,000.00	$1.00	$2,000.00	http://www.cranepower.com/pk-12080-ld.htm	2.75 ton at 13 ft. 1.4ton at 26 feet	PK12080-MA
Deck Equipment	Winch	hydraul.	1000	1	$1,000.00	http://www.pullmaster.com/products/description.cfm?stock_id=55	135937lb-in torque, 49 RPM	M25-7-86-14
Deck Equipment	A-Frame	hdraul.	5000	1	$5,000.00		6 ton capacity at maximum reach, reinforced attachment to deck	
Deck Equipment	Net Reel	hydraul.	1500	1	$1,500.00		3 feet wide, detachable, aluminum	
Deck Equipment	Pressure Wash	hydraul.	1488	1	$1,488.00	http://www.hydraclean.net/hydrac/PRESSUREWASHERHYDRAULIC.htr	Water pressure 2000 psi, direct drive, 50 foot hose	3020
Propulsion	Main Engine	1000	60000	1	$60,000.00	http://www.volvo.com/volvopenta/global/en-gb/marineengines/powerforc	See Appendix	Volvo d-12 650 HP
Propulsion	Transmission		15000	1	$15,000.00	http://www.volvo.com/volvopenta/global/en-gb/marineengines/powerforc	See Appendix	Volvo d-12 650 HP
Propulsion	Exhaust		2000	1	$2,000.00			
Propulsion	Propeller and Shaft to Engine		12000	1	$12,000.00		3' prop, 4" stainless shafting, associated bearings and seals	
Propulsion	Bow Thruster	hydraul.	4000	1	$4,000.00	http://www.go2marine.com/frameset.jsp?servletPath=/g2m/action/GoBPage/id/84781F//hitLiteSku/84781/categoryId/13984/		http://www.go2marine.com/frameset.jsp?servletPath=/g2m/action/GoBPage/id/84781F//hitLite
Hydraulic Sys.	Hydraulic Engine	500	15000	1	$15,000.00	http://www.volvo.com/volvopenta/global/en-gb/marineengines/powerforcommercialcraft/diesel_inboard/tamd31/		Volvo 110HP
Hydraulic Sys.	Hydralic Tank		150	1	$150.00	http://www.northerntool.com	50 steel Gallon hydraulic oil holding tank	50 Gallon Steel tank
Power	Starter Batteries	1600	547	3	$1,641.00	http://www.oksolar.com/n_cart/product_details.asp?ProductID=40446&cat=Components&subcat=Batteries		6-CS-17PS By SURRETTE
Power	Generator		5100	1	$5,100.00	http://www.polarpowerinc.com/products/pdf/genset_prices.pdf	12kw gas genset	Kawasaki 750
Power	additional batteries		547	4	$2,188.00	http://www.oksolar.com/n_cart/product_details.asp?ProductID=40446&c	for use with generator start and house operations	6-CS-17PS By SURRETTE
Misc	Misc.		4000	1	$4,000.00			
Equipment Subtotal					$149,838.43			
Labor	Engine Installation		12000		$12,000.00			
Labor	Genset/Electrical Instal.		10000		$10,000.00			
Labor	Misc		2000					
Labor Subtotal					$22,000.00			
Net Equipment Cost					$171,838.43			
Name	Material	Unit Cost	Quantity	Total Cost	Description	Part	Distributor	
Hull	Fiberglass	30.53	200	6106	Fiberglass Cloth 10oz		http://www.jamestowndistributors.com/eserv/eclipse.ecl?PROCID=WEBDISP.WOEB.MAIN&ID_1=3&ID_2=750&ID_3=759&CLEV=4&TRACKNO=J13206	
Deck Core	Honeycomb core	$55	137	7535	Polypropylene hone	48047	http://www.fibreglass.com/core.htm	
Deck Outer layers	Carbon Composite	15.15	300	4545	CARBON & S-GLAS	3350-30PFQ	http://www.carb.com/enter.html	
Deck I beam Supports	Carbon Composite	15.15	11	166.65	CARBON & S-GLAS	3350-30PFQ	http://www.carb.com/enter.html	
Outer hull coat	Gelcoat	100	1	100	404 Isophthalic Resin			
Deck Hatches		195.5	2	391	GRAY LOW PROFILE MOLDED POLYCARBONATE HATCHES 24" x 24"	7959 927-10B	http://www.nautical-outfitters.com/shopping/browse.aspx?cat=2578&SiteID=2	
Superstructure								
Superstructure	windows	100	4	400				
Superstructure	doors	700	2	1400				
Superstructure	other materials	5000	1	5000				
Superstructure	chair	300	2	600				
Below Deck	Bulkhead hatches/doors	700	4	2800				
Below Deck	Berths	50	3	150				
Below Deck	Table	100	1	100				
Misc	zodiac	2000	1	2000				
Misc.	Misc	2000	1	2000				
Subtotal				33293.65				
Custom Hull construction				350000				
Labor								
Net Hull Construction Cost				383293.65				
Final Cost Estimate for OOWRAT Vessel				$555,132.08				

APPENDIX B - FINITE ELEMENT OF ALUMINUM VESSEL

A finite element analysis was completed on the lobster hull in order to test structural integrity in cases of extreme loading. This process was completed more as an exercise in determining an acceptable FEA model to use for a stress analysis of a hull rather than a design verification. The ability to use the methods and software associated with Finite Elements enables a number of parameters to be implemented and modified easily. For instance, once a working model is developed stresses, hydrostatic loads, and strain results can determined with ease. Due to time constraints this analysis was not completed for the final chosen design.

Implementation

The implementation process involved taking half of the hull from a solid model (Figure 1) made in Rhinoceros 3.1, developing a working model in Marc/MENTAT, and setting up a simple static loading scenario.

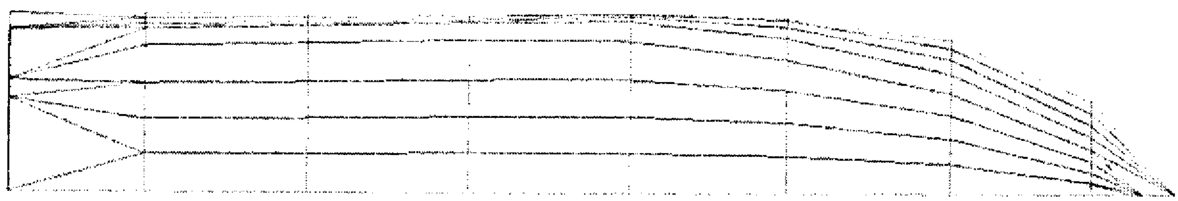


Figure 39 - Imported from Solid Model as DXF file

The main dilemma with this process is that the file exported out of Rhinoceros creates a model combining triangular elements with quadrilateral elements. The presence of differently shaped elements could potentially yield an inaccurate model because the software needs all nodes to be connected only once. By combining three and four sided elements many intersections come to a point in the bow and the stern, which was a concern. The model was modified by hand in MENTAT to incorporate only quadrilateral elements (Figure 2). The total number of elements was 365.

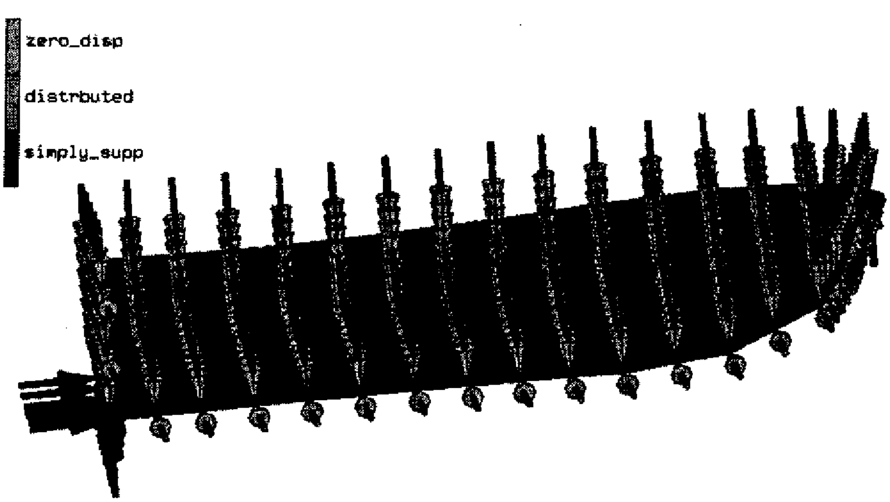


Figure 40 - Boundary Conditions and quadrilateral element set up

The hull model worked, and two loading cases were simulated. One case was if the hull was simply supported on both ends (Figure 2), and the second case was if the hull was only supported from the center (Figure 6). These cases were chosen because they would be the two extreme wave-loading scenarios for a sea faring vessel. A uniform force was applied locally at each element, which was representative of an empty vessel.

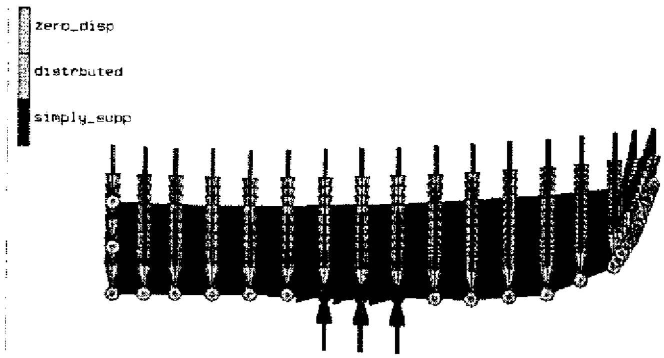


Figure 41 - Boundary conditions used for centrally supported hull.

As Figure 7 shows, the hull deflected as expected, with the hull being put in to compression. The deflection results seem to be within the right order of magnitude, ranging from 0.5 to 1.5 inches (Figure 7). The material used was aluminum with a thickness of one inch.

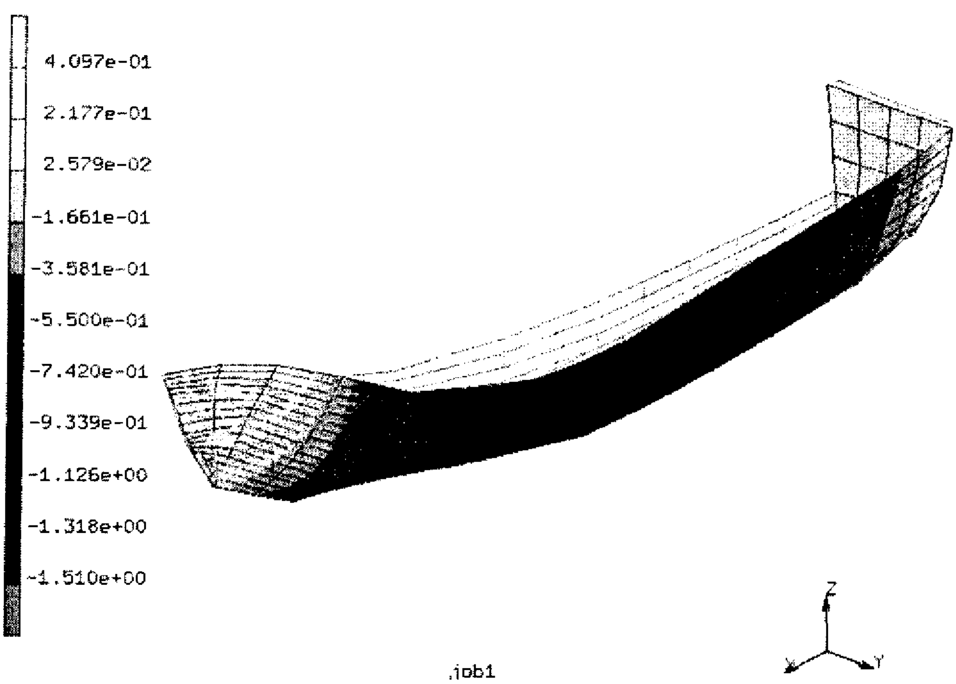


Figure 42 - Deflection from distributed load, 2 supports.

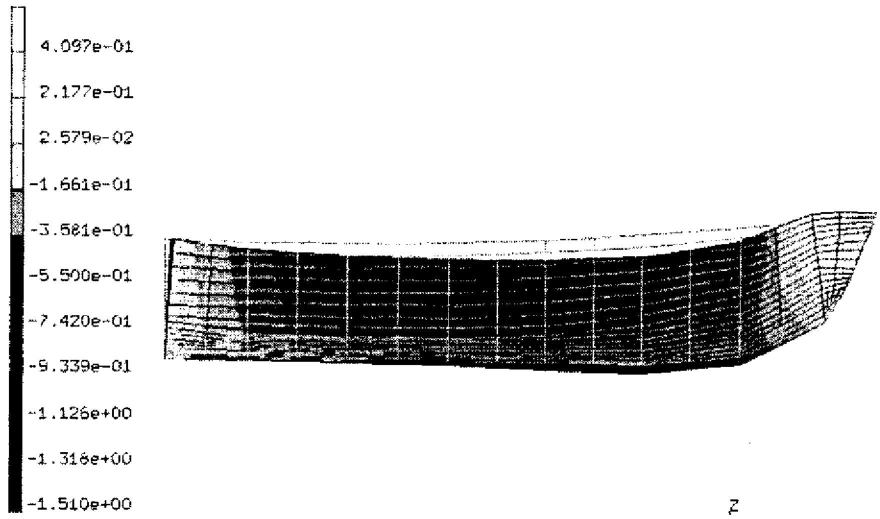


Figure 43 - Deflection from distributed load, centrally supported

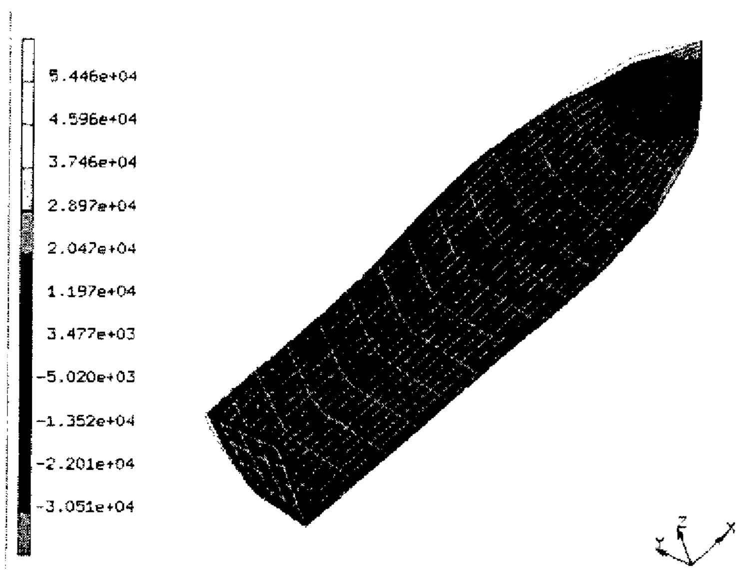


Figure 44 - Stress distribution of hull, 2 supports.

Conclusion

Stress results were also determined from the loading cases. These data could be used to ensure the hull would not break under this loading case. Impact reactions, cycle life, and temperature affects could also be determined using Mentat in this fashion. An acceptable Finite Element model was achieved for the chosen hull. From this model many analyses can be simulated and varied in order to speedily and accurately determine how hull properties will change depending on altering parameters.

APPENDIX C – HYDROSTATIC DATA

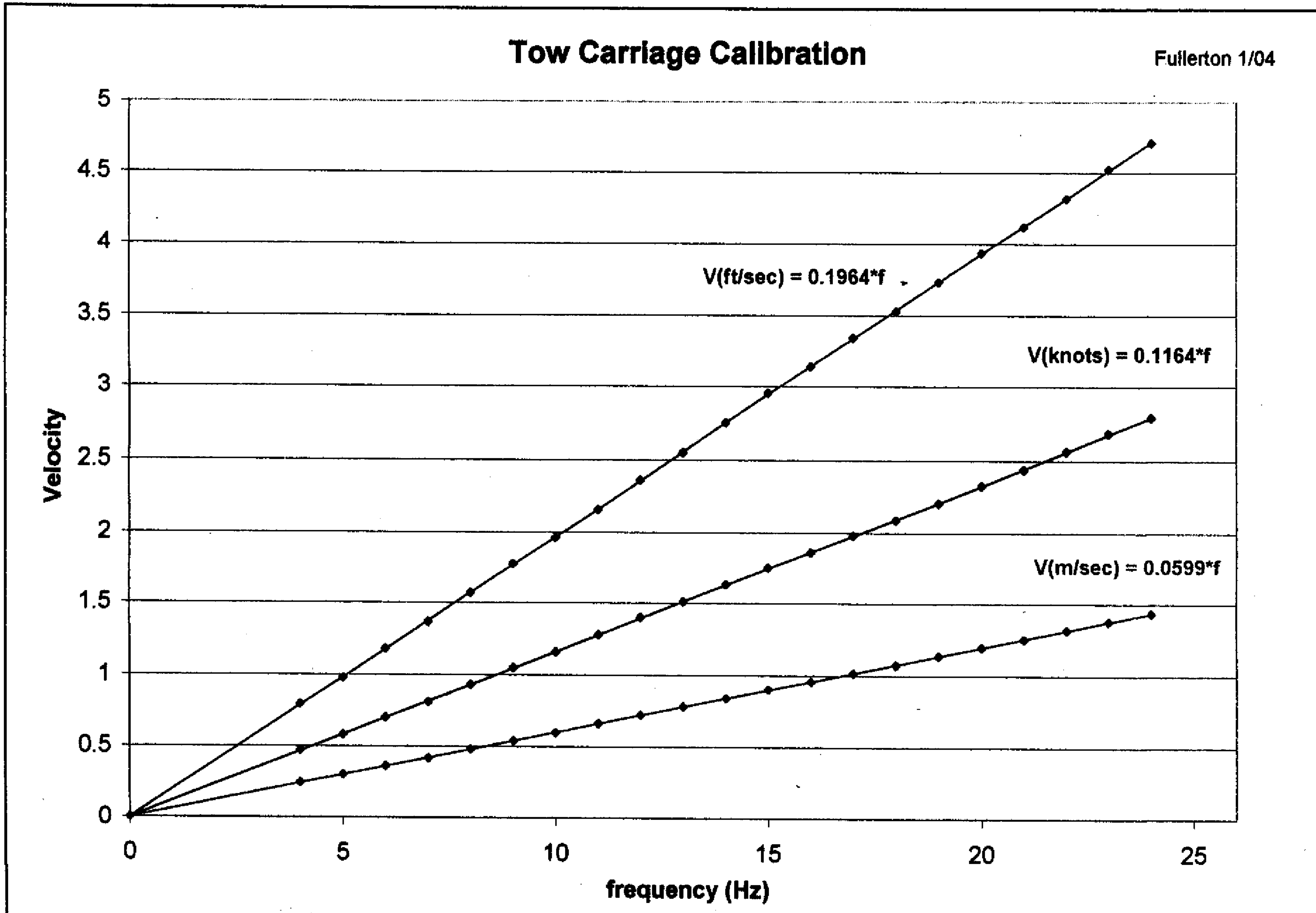
Date: 4/6/2004	UPRIGHT HYDROSTATICS	Time: 09:35 PM
Version	Phaser 3.0.6	
Project	OOWRAT	
Description	Paramters at varying Waterlines	
Part Name	Final_Hull	
Dimensions	feet, feet^2, feet^3, pounds, deg	
Fluid Density	64.0448447550668 pounds/feet^3	

NOTES
1. Dimensions are given relative to coordinate system origin, except for M Trans and M Long which are given relative to the resultant waterplan
2. Accuracy of calculations is affected by the density of points in the surface mesh.
3. All coefficients are based on LWL and maximum draft above.
4. The accuracy of the sectional area curve, maximum section area and location, and prismatic and midship section coefficients are affected b:
5. The displacement-length ratio is defined as the computed vessel displacement in long tons divided by the cube of one-hundredth of the wate
6. The moment to change trim is computed with the assumption that the center of gravity is at the flotation plane.

Table 5 - Hydro static Data from CAD model – units feet, tons, degrees

Waterline	-3	-3.5	-4	-4.5	-5
Weight	14.00	24.00	44.00	65.00	82.00
Long C.G.	-8.47	-11.3	-18.55	-23.41	-26.59
Transverse C.G.	0	0	0	0	0
Vertical C.G.	0	0	0	0	0
Transverse C.B.	0	0	0	0	0
Vertical C.B.	-15.43	-10.36	-7.39	-6.35	-6.02
Wetted Surface	2815.92	2748.52	2631.03	2489.60	2349.27
Wetted Centroid (X)	-28.54	-29.00	-29.34	-29.54	-29.73
Wetted Centroid (Y)	0.00	0.00	0.00	0.00	0.00
Wetted Centroid (Z)	-7.89	-8.01	-8.19	-8.42	-8.64
D-L Ratio	-13016.60	-4171.61	-1497.94	-2248.45	-2834.75
LOA	51.19	51.19	51.19	51.19	51.19
Length water Line	16.38	28.65	49.25	49.16	49.06
Beam Overall	19.13	19.13	19.13	19.13	19.13
Beam Waterline	19.12	18.96	18.80	18.64	18.48
Depth	10.65	10.65	10.65	10.65	10.65
Freeboard (	3.00	3.50	4.00	4.50	5.00
Draft	7.65	7.15	6.65	6.15	5.65
Weight To Immerse	210	375	646	540	360
Area Water Plane	472.3084	843.4733	1453.638	1215.833	809.1066
Length Central Floatation	-11.5788	-19.2555	-31.5914	-35.4926	-45.3244
Transverse C.F.	4.98E-17	-2.2E-15	6.42E-15	4.88E-15	-3.7E-15
Vertical C.F.	-3	-3.5	-4	-4.5	-5
Metacenter height trans	-42.4568	-40.6846	-35.3155	-20.0542	-11.0788
Metacenter long	-26.5111	-48.8178	-121.498	-23.013	74.86334
Beam Metacenter trans	-30.0284	-33.8255	-31.9296	-18.205	-10.0565
B.M. long	-14.0827	-41.9588	-118.112	-21.1639	75.88561
Wt To Immerse	2520.743	4501.676	7758.168	6488.987	4318.259
Mom To Trim	3768.329	6805.011	17970.17	5089.132	-20793.7
Neutral Axis	7.74E-15	3.53E-13	-2.1E-13	-3.1E-12	-6.8E-14
Block Coefficient	-0.18222	-0.19278	-0.2218	-0.36166	-0.49871
Waterplane Coefficient	1.508463	1.552704	1.569863	1.326847	0.892238

APPENDIX D


Tow Carriage Calibration
Fullerton 1/04
Velocity
frequency (Hz)
V(ft/sec) = 0.1964*f
V(knots) = 0.1164*f
V(m/sec) = 0.0599*f
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
5
10
15
20
25

Tow Carriage Calibration

Fullerton 1/04

Velocities averaged using two lightgates each set one meter apart near the center of the tank.

4 - 24 Hz measured

* 25+ assumes linear behavior maintained

Motor Freq. (Hz)	Velocity (kts)	Velocity (ft/sec)	Velocity (m/sec)
0	0	0	0
4	0.47	0.79	0.24
5	0.58	0.98	0.30
6	0.7	1.18	0.36
7	0.81	1.37	0.42
8	0.93	1.57	0.48
9	1.05	1.77	0.54
10	1.16	1.96	0.60
11	1.28	2.16	0.66
12	1.4	2.36	0.72
13	1.51	2.55	0.78
14	1.63	2.75	0.84
15	1.75	2.95	0.90
16	1.86	3.14	0.96
17	1.98	3.34	1.02
18	2.09	3.53	1.08
19	2.21	3.73	1.14
20	2.33	3.93	1.20
21	2.44	4.12	1.26
22	2.56	4.32	1.32
23	2.68	4.52	1.38
24	2.79	4.71	1.44
25*	2.91	4.91	1.50
26	3.03	5.11	1.56
27	3.14	5.30	1.62
28	3.26	5.50	1.68
29	3.38	5.70	1.74
30	3.49	5.89	1.80
31	3.61	6.09	1.86
32	3.72	6.28	1.92

Motor Freq. (Hz)	Velocity (kts)	Velocity (ft/sec)	Velocity (m/sec)
33	3.84	6.48	1.98
34	3.96	6.68	2.04
35	4.07	6.87	2.10
36	4.19	7.07	2.16
37	4.31	7.27	2.22
38	4.42	7.46	2.28
39	4.54	7.66	2.34
40	4.66	7.86	2.40
41	4.77	8.05	2.46
42	4.89	8.25	2.52
43	5.01	8.45	2.58
44	5.12	8.64	2.64
45	5.24	8.84	2.70
46	5.35	9.03	2.76
47	5.47	9.23	2.82
48	5.59	9.43	2.88
49	5.70	9.62	2.94
50	5.82	9.82	3.00
51	5.94	10.02	3.05
52	6.05	10.21	3.11
53	6.17	10.41	3.17
54	6.29	10.61	3.23
55	6.40	10.80	3.29
56	6.52	11.00	3.35
57	6.63	11.19	3.41
58	6.75	11.39	3.47
59	6.87	11.59	3.53
60	6.98	11.78	3.59

APPENDIX E

Overall Vessel Weight:

W = overall weight of vessel (in tons)
Wh = hull weight
Wm = weight of the power plant(s)
Wf = weight of the fuel
Wp = weight of the payload
Wo = weight of others

$W_p := 15$ $\quad W_f := 2$

$W_m := 3$ $\quad W_h := 5$

$W_o := 2$

$$W := W_h + W_m + W_f + W_p + W_o$$

$W = 27$ tons

Calculation of Power Requirements from Tow Testing:

Ten tow tests were run at tow motor frequencies ranging from 13 Hz to 43 Hz

f = motor frequency
Δt1 = time to travel between first gates
Δt2 = time to travel between second gates
Δ = distance between gates
V = carriage velocity in knots

from a previous calibration Done by Brett Fullerton the equation for the velocity of the tow carriage is V = .1164f. due to the fact that the slope of this line changes with the age and use of the motor we recalibrated the motor.

$\Delta t_1 := 1.285\text{s}$ $\quad \Delta t_2 := 1.287\text{s}$

$\Delta := 1\text{m}$ $\quad f := 13\text{Hz}$ $\quad \text{knot} := 6076.1\,\dfrac{\text{ft}}{\text{hr}}$

$$V_1 := \frac{\Delta}{\Delta t_1} \qquad V_2 := \frac{\Delta}{\Delta t_2}$$

$$V := \frac{V_1 + V_2}{2}$$

$V = 1.512\,\text{knot}$

Ships transverse metacentric height:

T = period for one complete cycle (over and back)
B = Beam (feet)
GM = transverse metacentric height

$B := 18 \qquad T := 2.6$

$$GM := \left(.42 \cdot \frac{B}{T}\right)^2$$

$GM = 8.455$

Here is another method for calculating GM using a load W located a distance d from the longitudinal center of mass of a vessel with bouyant force F.

$W := 8000\,lbf$

$d := 8ft$

$\theta := 8deg$

$F := 30000\,lbf$

$$GM := \frac{W \cdot d}{\sin(\theta) \cdot F}$$

$GM = 4.672\,m$

Scaling of Physical Model Tests:

Fr = Froude number = inertial forces over gravitational forces
Re = Reynolds number = inertial forces over viscous forces
u = velocity of boat
g = gravity
d = length
ν = kinematic viscosity of sea water
L = length of vessel
Lr = length ratio
Lp = prototype length
Lm = model length
Vp = prototype volume
Vm = model volume
ρ = density of sea water

all values taken at atmospheric pressure and 70 degrees F

$g := 9.80665 \dfrac{m}{s^2} \quad \rho := 1 \dfrac{g}{cm^3} \quad \nu := 1052 \cdot 10^{-5} \dfrac{ft^2}{s}$

$L_m := 3ft \qquad L_p := 51.5ft$

$knot := 6076.1 \dfrac{ft}{hr}$

$u_p := 21knot$ **this is the maximum running speed for the vessel**

$$L_r := \frac{L_p}{L_m}$$

$L_r = 17.167$

$$u_m = \frac{u_p \cdot \sqrt{g \, L_m}}{\sqrt{g \, Lp}}$$

$$u_m := \frac{u_p}{\sqrt{\dfrac{L_p}{L_m}}}$$

$u_m = 5.068\,knot$ **this is the maximum tow tank speed tested to measure drag forces**

$Fr = \dfrac{u}{\sqrt{g \cdot L}}$ **Froude number is equal to inertial forces over gravitational forces**

$Fr_m = Fr_p$

$Re = \dfrac{\rho \cdot u \cdot L}{\mu}$ **Reynolds number is equal to inertial forces over viscous forces**

$$\nu = \frac{\mu}{\rho}$$

$$Re = \frac{u \cdot L}{\nu}$$

$$\frac{\dfrac{Lp}{Tp}}{\dfrac{Lm}{Tm}} = Lr \cdot \frac{Tm}{Tp}$$

$$\frac{Tp}{Tm} = Lr^{.5}$$

since we have geometric similitude

$$\frac{Vp}{Vm} = Lr^3$$ same for weight and force

$$Lr^3 = \frac{mass_p}{mass_m}$$

as a check

$$\frac{F}{.5 \cdot \rho \cdot A \cdot u^2} = \frac{F}{.5 \cdot \rho \cdot A \cdot u^2}$$ left side is model parameters right side is prototype

$$\frac{F_p}{F_m} = Lr^3$$ when $\rho m = \rho p$

Wave Theory:

T = period
H = wave height
f = frequency
σ = radian frequency
a = amplitude
k = wave number
L = wave length
x = position of wave

$$\sigma := \frac{2\pi}{T}$$

$$f := \frac{1}{T}$$

$$k := \frac{2\pi}{L}$$

there is no flow through the surface since $\frac{d}{dz}\phi$ at z = 0 is equal to $\frac{d}{dt}n$

$$g \cdot k \cdot \tanh(k \cdot h) = \sigma^2$$ dispersion relation used to find characteristics of the wave tank unfortunately the wave maker was not working and we were unable to obtain data for sea keeping tests.

Propagating waves:

for t > 0 and points of equal phase

$$k \cdot x - \sigma \cdot t = k \cdot (x + \Delta x) - \sigma(t + \Delta t)$$

$$0 = k \cdot \Delta x - \sigma \cdot \Delta t$$

$$\frac{\Delta x}{\Delta t} = \frac{\sigma}{k} \qquad \frac{\sigma}{k} = \frac{L}{T}$$ L/T is the phase velocity i.e. wave speed

Deep water wave approximations:

kh>π or 2πh/L>π so that h/L>.5

dispersion relation

$$\sigma^2 = (g \cdot k \cdot \tanh(k \cdot h))$$ this is approximately equal to gk(1) = g(2π/L)

$$L_{deep} = L_o$$

$$L_o := g \cdot (2\pi) \cdot \frac{1}{\sigma^2}$$

$$L_o := g \cdot (2\pi) \cdot \left(\frac{T}{2\pi}\right)^2$$

$$L_o := \frac{g \cdot T^2}{2\pi}$$

$$u := \frac{L_o}{T}$$

$$u := \frac{g \cdot T}{2 \cdot \pi}$$

Calculation of Damping Ratio:

ζ = damping ratio
x1 = amplitude of first peak
xn = amplitude of nth peak
T = period of oscillation (s)
ωn = natural frequency (rad/s)
ωd = damped natural frequency (rad/s)
x(0) = initial displacement

$$\zeta = \frac{\frac{1}{n-1}\cdot \ln\left(\frac{x_1}{x_n}\right)}{\sqrt{4\pi^2 + \left[\frac{1}{n-1}\cdot\left(\ln\left(\frac{x_1}{x_n}\right)\right)\right]^2}}$$

$$\omega_n = \frac{\ln\left(\frac{x_1}{x_n}\right)}{\zeta\cdot T}$$

$$\omega_d = \omega_n\cdot\sqrt{1-\zeta^2}$$

Equation of motion:

$$X(s) = \frac{\left(s + 2\cdot\zeta\cdot\omega_n\right)\cdot x(0)}{s^2 + 2\cdot\zeta\cdot\omega_n\cdot s + \omega_n^{\ 2}}$$

since V(0) = 0 the simplified equation of motion is

$$x(t) = \frac{x(0)}{\sqrt{1-\zeta^2}}\cdot e^{-\zeta\cdot\omega_n\cdot t}\cdot\sin\left(\omega_d t + \tan\left(\frac{\sqrt{1-\zeta^2}}{\zeta}\right)^{-1}\right)$$