

# **Displacement Hull Catamaran**

July 26, 2006

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Ocean Engineering Design Project

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## Letter of Transmittal

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TO: Dr. Stephen Wood  
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FROM: Displacement Hull Catamaran Design Team  
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RE: Displacement Hull Catamaran Project

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Dr. Wood,

The following design report on the displacement hull catamaran project is being submitted for your review. The completed report includes all relevant data collected and obtained over the course of the project, from conception to completion. All of the sections were written to the best of our ability, with all relevant references present as in-text citations.

We would like to thank the Department of Marine and Environmental Systems for the funds given during the project, as well as Structural Composites Inc. of West Melbourne for all the manufacturing assistance given.

Thank you and please contact us if you have any further questions.

Sincerely,

Clay Danielson \_\_\_\_\_

Brian Daly \_\_\_\_\_

John Montgomery \_\_\_\_\_

Andrew Stern \_\_\_\_\_

## **Executive Summary**

The purpose of the displacement catamaran project was to design and build a prototype displacement catamaran vessel to the scale of the existing planing catamaran hull, the LOMAC, created by a previous DMES student design group. The main objective of the project was to test the displacement catamaran hull and acquire meaningful performance data using multi-axis accelerometers from an instrumentation package, designed by a graduate level ocean engineering student, to quantify its sea-kindliness. The hull efficiencies and sea-kindliness characteristics of the LOMAC planing hull and the displacement hull were then to be compared; however, little information was found in the research phase of the project on the LOMAC. Once the LOMAC was acquired by the group, it was found to be missing a motor and was in poor condition, rendering the group unable to perform accelerometer tests on it to determine its sea-kindliness.

The design team performed extensive accelerometer tests on the displacement hull catamaran, comparing the vessels accelerations in calm water to those in rough water. While the accelerations in rough water were greater than those in calm water, they were not as significant as a planing catamaran's would have been, as predicted by the design team, which proved the benefit of the displacement catamaran in heavy sea conditions.

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## **Acknowledgements**

We would like to thank the following people and organizations for all the help they offered to the design group. This project would not have been possible without their help.

We would like to thank the Department of Marine and Environmental Systems (DMES) for the initial \$1000 in funds to use for the project. This helped get the project going and covered most of the manufacturing and electronics costs. We would also like to thank the College of Engineering for an additional \$400 in funds to use for supplies over the course of the manufacturing process during the summer term.

We would like to extend our gratitude to Structural Composites Inc. of West Melbourne, including Eric Roehl, Director of Testing Services, and Ron Reichard, CEO, for the use of their CNC mill, fiberglass cloth and matte donations, and careful guidance throughout the manufacturing of the prototype.

We would like to thank Eduardo Gonzalez for his insight into the project and guidance, as well as his background knowledge of the LOMAC project and help with the propeller shaft created. We would also like to thank Brendan Keane for his assistance with the instrumentation pack used for testing the prototype.

Finally, we would like to thank Dr. Stephen Wood of the Department of Marine and Environmental Systems for his guidance over the course of the project, from inception to completion.

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## **1.0 Introduction**

Catamaran hull designs have within the last decade made a name for themselves in the recreational powerboat sector, and they have presented formidable competition in the market for their monohull counterparts. Known for their unsurpassed stability, good sea-keeping, and modest fuel consumption (efficiency), power catamarans have created a popular and somewhat unique niche in the offshore sport fishing industry that several production boat companies have entered. This scope of this project encompasses the design, construction, and testing of a scaled displacement catamaran hull. Comparative analysis of efficiency and sea-keeping was conducted on the displacement catamaran, and similar testing was intended to be conducted on the planing Littoral Operating Multi-Purpose Auxiliary Craft (LOMAC) catamaran owned by the Department of Marine and Environmental Systems. Final testing was not conducted on the LOMAC due to missing motors, speed controllers, and other major electrical and mechanical components essential to its operation.

### **1.1 Planing Hull Theory**

Planing hulls are typically high speed vessels capable of operation at high Froude numbers (Savitsky). The hull geometry of planing boats is basic, and it usually consists of either a completely flat bottom or a v-shaped bottom with constant or variable deadrise. Planing boats are unique in that when the vessel is stationary or moving very slowly, the hull remains in the water at its fixed displacement; however, as added power increases the velocity of the vessel, it overcomes its bow wave and rises on top of the water surface. These dynamic lifting effects are caused by the principle of physics that states that any moving object that produces an asymmetrical flow pattern generates a lift force perpendicular to the direction of motion (Gillmer and Johnson).

Hydrodynamic lift is the controlling factor in the design and performance of planing hulls. The decrease in skin friction on the hull at planing speeds is advantageous to these vessels which are normally designed for high-speed; however, setbacks in the design

become apparent in heavy seas. Because planing hulls operate on the ocean's surface, they are very susceptible to the wave motions they are operating in. The high speed operation of planing hulls on a rough ocean is demanding on the vessel, its construction, and its crew, and efficiency rapidly decreases with operable speed. A viable solution to the design of high speed craft for heavy sea conditions is an appropriately designed displacement vessel (Saunders).

## **1.2 Displacement and Semi-displacement Hull Theory**

Displacement and semi-displacement hulls belong to a different breed of naval architecture theory as they are significantly less dependant on hydrodynamic lift while underway. Displacement hulls generally operate at Froude numbers less than 2.5, and they are supported only by their own fluid displacement while underway. Displacement vessels generally have round bilge hulls that reach a maximum hull speed at a point at which they operate most efficiently. Beyond this velocity, efficiency decreases exponentially as the vessel tries to overcome its bow wave (which it is unable to do because of its rounded hull geometry). Displacement vessels, despite their speed limitations, are better suited for operation in rough seas because unlike planing hull forms, their forward motion is not dependant on the sea surface.

Semi-displacement hull forms represent a hybrid theory in naval architecture that bridges the characteristics of planing and displacement hulls. The round bilge hull geometry of semi-displacement vessels is complemented with flat sub-surface chines which act as planing surfaces, making dynamic lifting effects appreciable while underway. Semi-displacement hulls are capable of higher operating speeds than displacement vessels; however, they still remain completely immersed across their full operating velocity spectrum, and thus are capable of high-speed operation in moderate to heavy seas (Saunders).

A major design parameter for semi-displacement hull design is a large length-to-beam ratio, which typically results in a long, slender hull (Saunders). While this is a major

compromise in stability for monohull vessels, it is of minimal concern in the design of a multi-hull vessel. It is for this reason that the displacement/ semi-displacement catamaran is a proven design which provides safe, high speed operation capabilities in littoral waters as well as on the high seas regardless of ocean conditions.

## **2.0 Background / Theory**

The design of a displacement catamaran for the research purposes of this project was based solely on parameters set by the LOMAC catamaran model and existing displacement catamaran hull shapes. Photographs of recreational displacement and planing catamarans were taken and used to outline the basic hull geometry of the prototype design. Every effort was made by the hull designers to keep all of the prototype's dimensions and ratios similar or identical to the LOMAC vessel. Naval architecture theories in planing and displacement speed and resistance predictions were extensively researched and the use of several design and analysis software packages for maritime applications were also used to predict the behavior of the prototype.

### **2.1 Specifications and Design Parameters**

The specifications for the displacement prototype were similar to the design specifications set forth by the LOMAC design team. A design speed of 7.5 knots was stipulated as the vessel's speed requirement, and it was required to support an instrument package weighing in excess of ten pounds. In order to conduct comparative sea-keeping analysis between the displacement catamaran and the LOMAC, the major dimensions of both vessels were kept the same.

### LOMAC / Displacement Parameter Comparison

<i>Parameter</i>	<i>LOMAC</i>	<i>Displacement</i>	<i>Units</i>
Length Over All	5.36	5.36	ft
Length at Waterline	5.19	5.07	ft
Hull Beam	5.95	5.28	in
Hull Spacing	11.37	12.69	in
Beam Over All	23.27	23.88	in
Draft (w/ electronics)	3.13	3.025	in
Draft (w/ instrument pack)	3.63	3.35	in
Displacement (w/ electronics)	36.30	26.80	lbs
Displacement (w/ instrument pack)	46.78	37.28	lbs
Volume of Displacement at TF	694.72	830.00	in <sup>3</sup>
Area of Mid-ship Section at TF	11.19	16.91	in <sup>2</sup>
Area of Max Section at TF	14.16	16.92	in <sup>2</sup>
Area of the Waterplane at TF	226.06	324.97	in <sup>2</sup>

*Table 2.1.1: LOMAC parameters and displacement hull parameters compared.*

*(LOMAC data courtesy E. Gonzalez)*

The displacement catamaran hull design began conceptually as a series of hand drawings which were then used to design the hull in *Prosurf*, a naval architecture software package created by New Wave Systems. The finished design was then exported to *AutoCad* for enhanced visual renderings and the design of the hull connecting structures. The *Prosurf* design was also exported as an IGES file to *Autoship*, a more sophisticated naval architecture program that most accurately calculated the hydrostatic properties of one hull before it was manufactured.

A major design decision that was made by the team during the final phase of the design process was to add chines to the hull. After researching chines extensively and finding little published data on them, a case study by the Sponberg Yacht Design group of St. Augustine, Florida was examined. In this study, Sponberg Yacht Design installed a single lifting strake on a heavy semi-displacement trawler, and the resulting effects that the added appendage had on the hull were impressive. The lifting strake's designed purpose

was twofold: to inhibit spray coming off the bow and to provide an additional lifting surface below the waterline while running at speed to reduce the drag on the vessel. Thorough analysis of the boat's performance both before and after the addition of the lifting strakes proved that they were instrumental in reducing spray and decreasing the overall resistance. From this conclusion, the design team decided to add small chines to the design in order to achieve similar performance results.

These convincing advantages led the design team to two final designs of the displacement catamaran hull. Both hull shapes had identical hull geometry, yet one was designed with one chine at the waterline and another located below the running surface of the vessel. Resistance tests were run using Kaper's Method for small displacement craft in *Prosurf* to determine the validity of the decrease in hull resistance caused by chines, and while the actual answers given by the computer were prone to be incorrect, the relationships calculated by the program served as a suitable beginning to determining the actual resistance on the hull and the vessel's approximate power requirements.

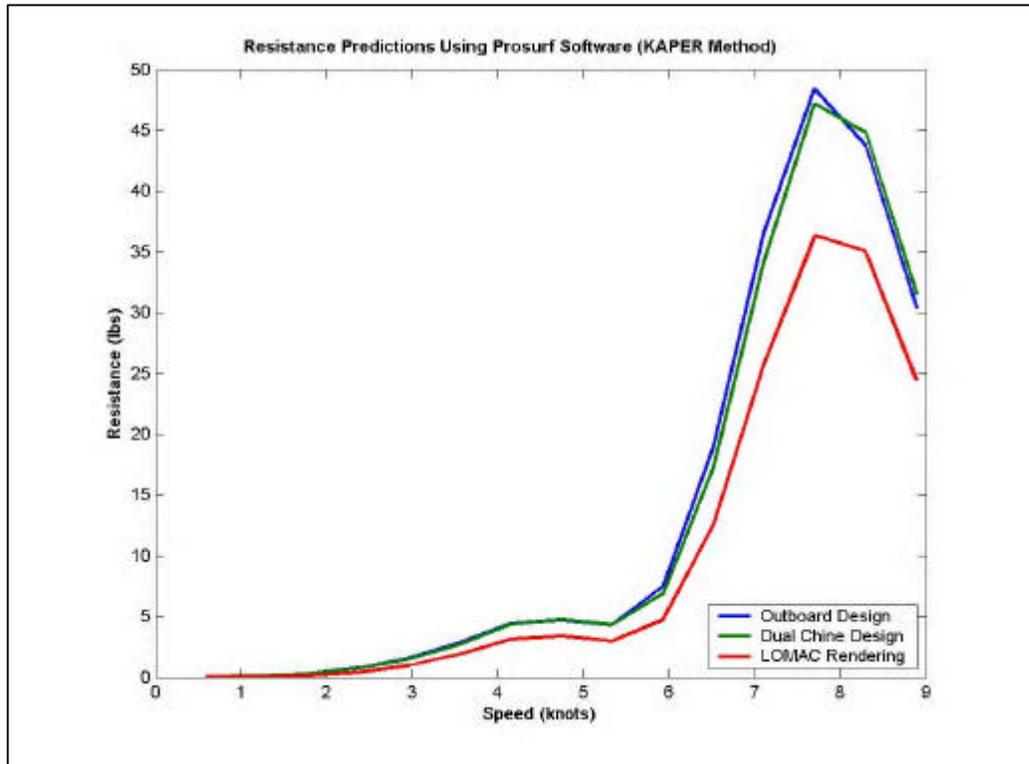


Figure 2.1.1: Resistance Predictions of the LOMAC planing hull and 2 versions of the semi-displacement final design, the outboard design (with no chines) and the dual chine design.

The iterations carried out to find a theoretical resistance for the three tested hull designs yielded inaccurate solutions; the curves generated were used for the sole purpose of comparison. As predicted by case studies conducted by Sponberg Yacht Design, the chines did decrease resistance appreciably in the dual chine design in comparison to the outboard design with no chines. Based on these conclusions and the conclusions made by Sponberg Yacht Design, chines were incorporated into the final displacement hull design.

## 2.2 Resistance Methods / Calculations

Little research has been done on predicting resistance for semi-displacement catamarans. For resistance calculations the interaction between hulls was ignored. Therefore, total resistance was calculated for one hull and doubled to obtain resistance of the entire

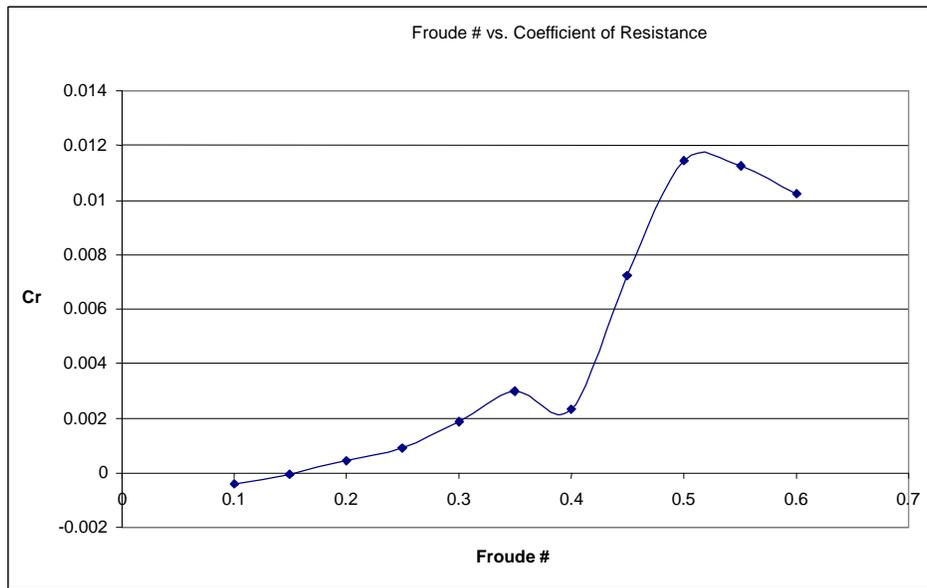
model. Several methods for determining resistance were attempted, but each encountered problems which made it unsuitable for the projects purposes.

### **2.3 Savitsky Method**

The first manual method attempted for calculating resistance was the Savitsky method. This method utilized a table to organize and consolidate calculations; however, several assumptions were made in the derivation of the theory which prevented it from being applicable to the displacement hull design. These assumptions included: the vessel being a planing design having constant dead rise, and being able to predict trim angle to a reasonable degree of accuracy.

### **2.4 Compton's Method**

A more suitable method for manually computing the resistance of the project hull was the Compton method. This method was specifically designed for displacement and semi-displacement vessels which made it ideal for application to the project. Although this method appeared ideal, it was highly dependant on the vessel's operating Froude number. Unfortunately, the application of the method was only applied for Froude numbers up to 0.6. At the design speed and specifications for the project vessel, the Froude number was 0.95. In an attempt to utilize the theory regardless of Froude number, the resistance was calculated at lower values and extrapolated to the higher design Froude number.



*Figure 2.4.1: A graph of Froude number versus the resistance coefficient*

Obviously, the curvature of the plot does not allow for a reasonable coefficient of resistance to be extrapolated at a higher Froude number. A reasonable interpretation of the plot would be that when the vessel is operating at a Froude number of above 0.55, the vessel is planing. However, when interpreting the meaning of the plot, one must consider that it is for a monohull, not catamaran. The narrow nature of the catamaran hulls makes them less susceptible to planing. As a result, Compton's method did not provide the project with a reasonable resistance prediction. Propulsion decisions were ultimately made based on other considerations, including what the LOMAC used as well as the options available in the remote control (RC) boat market.

### **3. Materials**

#### **3.1 Company Contacts**

Several companies were contacted throughout the course of researching hull materials to get advice on quality materials, quantities, and pricing. To get a general idea of total costs, retail prices of materials were researched. Many prices, fiberglass supplies specifically as they entail the largest cost for hull construction, were taken from the West Marine website and local store. After getting a general material list with costs, more specific companies were contacted.

The first major company contacted was Structural Composites, Inc., a local company in West Melbourne. The CEO, Ron Reichard, was contacted and said that the company was willing to help with material donations and also manufacturing. He directed the design team to speak with Eric Roehl, Director of Testing Services, for details on what specifically could be donated and how they could be of assistance.

The design team then met with Eric to discuss donations and also the possible use of Structural Composites three axis computer numerical control (CNC) mill. Scrap foam from a United States Navy rudder project under development at the company could be used to create the plug and fiberglass mat and cloth, used when laying the resin, could also be donated.

West System was then contacted for resin and hardener. After speaking with and emailing Kris Lore, it was found that nothing could be donated; however, an educational discount could be given for all West System supplies needed to build the prototype. To get the discount, paperwork had to be filled out and sent in before final pricing could be determined.

The next company contacted was Fiberglass Florida in Rockledge. After speaking with Jay Beardall, he requested a bill of materials and got back with a price quote for all the

fiberglass materials required. However, the resin in the quote was not West System brand, it was instead Eastman 6736 G.P. Resin. After speaking with Eric at Structural Composites, he advised that the Eastman resin was sufficient for the team's purposes. Another reason for choosing Eastman over West System was cost. The retail price of one gallon of West System resin was \$79.99 at West Marine. The price quote for five gallons of Eastman resin from Fiberglass Florida was \$98.99. Because of the cost difference and being unsure of the actual discount West System would give, Eastman was chosen.

To connect the two hulls together, aluminum square tube, flat bar, and angle gauge were used similar to the LOMAC project. Because a great deal of aluminum was not required, it was unnecessary to purchase these materials from a large company. It was decided that connection materials could be easily purchased locally at The Home Depot and after stopping in with a material list, the total cost of supplies was found to be approximately \$75.00.

### **3.2 Ordering**

After companies were contacted and many different supplies were researched, the necessary hull materials were ordered. It was decided that because of price and proximity, all fiberglass materials for the hull would be purchased from Fiberglass Florida. Jay Beardall was contacted and the price quote was modified for exactly what quantities were required. The remaining hull materials were purchased from Home Depot. Many materials were also purchased over the course of the project as they were deemed necessary, such as extra resin, paint brushes, mixing containers, etc. These materials were tracked and added to the projects total budget. For a complete list of materials ordered, quantities, and total costs, see Appendix B.

## **4. Manufacturing**

### **4.1 LOMAC Process**

In order to get an idea of the best way to build the hulls of the displacement catamaran, the LOMAC process was first researched. After speaking with Mischa Dembicki, an ocean engineering graduate student, it was found that the following was performed to create the hulls of the LOMAC.

The LOMAC design team did not use a CNC machine to create their mold. The group instead printed full scale offsets four inches apart on paper from their design which was modeled in *ProSurf*. These paper offsets were then pasted on pieces of wood and cut to create templates. Next, the templates were aligned and a block of foam was placed between each of them. The foam was then bonded to the wood to create a larger block of foam. This was cut and sanded down to exactly match the templates. Bondo was then used to fill in portions that had been sanded poorly.

To finish constructing the mold, epoxy and gelcoat were applied over the top of the foam to preserve its geometry. In addition, a water based latex paint was added over the gelcoat. The purpose of the latex paint was essentially a safety barrier. If the fiberglass that would be laid over the mold stuck due to a failure of the releasing wax, it would be easier to break away without damaging the mold if the latex paint was present. Fiberglass could be more easily pulled off of latex paint without damage as opposed to gelcoat, which could damage the mold, causing manufacturing delays. Finally, a releasing wax and PVA (polyvinyl alcohol) was added over the layer of paint so the prototype could be pulled off the mold.

Once the mold was complete, the prototype was created by laying fiberglass over the mold. The LOMAC used West System 105 Resin, West System 205 hardener, pumps, cups, and mixing sticks. Once the fiberglass hardened, the prototype was removed from the mold. The fiberglass was then be faired by hand sanding until a polished finish was

reached. Lastly, a layer of gelcoat was applied over the fiberglass to prevent it from being scratched.

Once this process was completed a second time to create a second prototype, bulkheads were placed in each hull. These were cut from wood using the same printed offsets used to build the mold. Decks were then added to each hull. They were cut from wood to match each hull and were sealed with Interlux Pre-Kote Primer.

The two hulls were finally attached according to the team's design specifications to complete the manufacturing process of the catamaran. The group screwed aluminum channel into the bulkheads in each hull, and aluminum strips installed from the forward bulkhead on one hull to the aft bulkhead on the opposite were used as reinforcement.

#### **4.2 Displacement Hull Process**

There were several flaws in the design process used by the LOMAC team. The major flaw came when sanding the foam to match the templates during mold manufacturing. This can be highly inaccurate and also labor intensive. It is nearly impossible to get an exact mold using this process and any inaccuracy will show up in the finished prototype as the fiberglass is laid directly over the top of the sanded foam of the mold. In addition, this method is only effective for simple hull designs. Sanding would become extremely tedious and inaccurate if chines were used in the design. In industry, this would not be the way companies would go about creating a hull prototype. Another flaw present in this process comes from the fact that the mold being used is a male mold, meaning the outside of the hull is not being shaped by the plug. Hence, extra attention must be given when fiberglass is laid to make sure it is exact so it will match the mold as closely as possible.

After seeing the flaws in the LOMAC process, it was decided that a more efficient and professional approach would be taken for the displacement catamaran project. A three step process was chosen, where a male plug would be milled, a female mold created from the plug, and a prototype generated out of the mold.

The first step was to determine where the hull could be manufactured. The Florida Tech machine shop owns a CNC mill, however, after researching its capabilities, it was found to be too small for the proposed dimensions of the hull. In order to use it to manufacture the foam plug, it would have to be cut in sections, milled on the CNC, and then bonded together, a lengthy and inaccurate process. Therefore, local companies would be contacted for help with manufacturing and the use of a CNC machine.

Structural Composites in West Melbourne was the first company contacted about the use of a CNC mill to create the plug. Based on the proposed dimensions of the hull model, approximately 5.5 feet in length, 6 inches wide, and 6 inches deep, their CNC could be used for the milling of the plug. In addition, the company was already willing to help with several donations.

The second company contacted was Vectorworks Marine, Inc., located in Titusville. The company has a five axis CNC mill big enough for the dimensions of the displacement hull and because the mill runs on five axes, it can be used for milling elaborate shapes. A head engineer was spoken with, and he passed the information regarding the project on to the vice president of the company.

After careful consideration of both companies, the design team chose to use the three axis CNC mill at Structural Composites for several reasons. First, the company was willing to help with fiberglass and foam donations, something Vectorworks did not mention, so staying with the company for manufacturing was a logical decision. Second, being located in West Melbourne, Structural Composites was close by which made travel easier. Lastly, Vectorworks was not as hospitable as Structural Composites proved to be. Vectorworks, after phone calls and emails, never responded to the design team, whereas Structural Composites did.

The question of the three axis CNC mill at Structural Composites versus the five axis CNC mill at Vectorworks was also considered. Three axis CNC mills cannot cut in on

themselves, while five axis mills can. After reviewing the design of the displacement hull, there was found to be no areas that would be a problem for a three axis CNC mill. Therefore, the mill at Structural Composites could cut the plug without a problem.

To create the plug, a final design of the displacement hull was completed using *ProSurf* computer software. Once the design was approved and finalized by the design team, it was converted to “.stl” code, which a CNC machine required, with the help of Eric at Structural Composites. The design was milled on the CNC out of the high density foam donated by the company.

The donation of foam from Structural Composites was extremely important to the progress of the displacement hull project as well. The LOMAC used Clark foam in the manufacturing process. However, after further research, it was found this company has since gone out of business for violations of EPA standards. With this foam unavailable, research was put into finding a source of foam that could be used when milling the plug. It appeared high quality foam that would not be damaged by the application of gelcoat would be difficult to find. Therefore, Structural Composites donation of high density scrap foam was greatly appreciated and extremely important to the project.



*Figure 4.2.1: The CNC mill cutting the foam for the plug.*



*Figure 4.2.2: The foam plug in between cuts on the CNC machine.*

It was thought that the foam would have to first be sanded extensively, however, the bit used on the CNC was very precise, leaving the finished plug smoother than expected. As anticipated, the use of the CNC machine reduced hand labor significantly and made the plug more accurate than the method implemented by the LOMAC group. Nevertheless, bondo was used to fill in imperfections in the foam plug. The CNC made several erroneous cuts that were corrected by filling with bondo and sanding to a smooth finish with the rest of the surface. The chines also needed to be sanded to smooth out lines created the mill.

To insure that the plug was manufactured correctly and ready for mold manufacturing, Structural Composites took it upon themselves to seal the plug. Having Structural Composites help with the plug saved time and money, as well as prevented the plug from sustaining damage if the sealing was not performed correctly. If the plug was not sealed properly with tooling gelcoat, the mold could stick to the foam when being laid and damage the plug, thus sending the project back several weeks of manufacturing time. To

insure this would not be the case, Structural Composites offered the further assistance, which was greatly appreciated by the team.

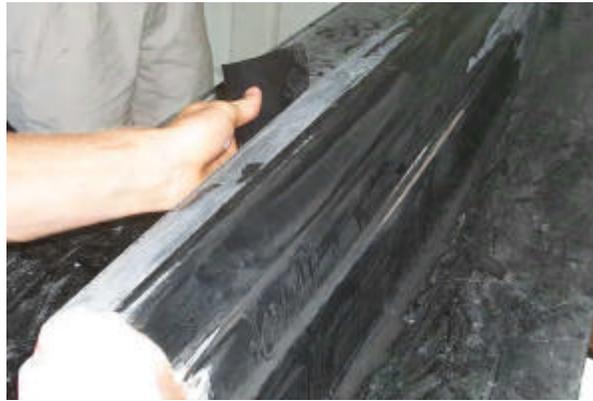
Once this initial sealing process was completed and returned to the design team, the coated foam was sanded with 180 and 220 grit sand paper to ensure it was smooth over the entire length. The initial seal left several small bubbles which were sanded to a smooth finish with the 220 grit sand paper. Bondo was also used to fill in portions of the plug where the CNC had made erroneous cuts, especially close to the chines. After drying, the bondo was sanded with 180 and 220 grit sand paper to match the rest of the hull. In addition, spot putty was used to fill in small imperfections. Once dry, it was sanded to match the finish of the rest of the hull.

Special attention was given to the stern portion of the plug. The CNC left this part with rough ridges that had to be corrected by hand. This was done by applying bondo and smoothing with a putty knife. Once dry, 220 grit sand paper was used to further smooth it and make the edges sharp and clean.



*Figure 4.2.3: The stern portion of the plug following bondo application and sanding.*

Upon completion of the 220 grit sanding, higher grit sand paper was utilized to give the plug a smooth finish. First, 320 grit sand paper was used to dry sand the plug, followed by wet sanding with 400 grit sand paper. This removed any scratches caused by the courser sand paper and left the hull smooth.



*Figure 4.2.4: Wet sanding with 400 grit sand paper to give the plug a smooth finish.*

Once the plug was sealed and smoothed, the next step was to apply six layers of paste wax. This was a mold releasing agent and allows for the mold to be removed from the plug without any damage to either piece. Extra attention was given at this step to ensure the releasing wax was present everywhere on the plug, especially in close to the chines. If any portion did not have wax, the mold could stick to the plug and severely damage it, causing a major set back.



*Figure 4.2.5: Plug after application of the paste wax, leaving a smooth shiny surface.*

Tooling gelcoat catalyzed at 1% by weight was then applied over the paste wax, to approximately 25 millimeters, to start the first phase of mold construction. Once tacky (i.e., after touching the gelcoat with a finger, nothing comes up but a fingerprint can be seen on the gelcoat surface), one ply of chopped strand mat (CSM), donated by Structural Composites, was laminated using resin catalyzed at 1% by weight. After this had cured overnight, it was lightly sanded with 220 grit sand paper and a second layer of CSM was applied and allowed to cure over night, followed by an additional two plies of CSM, also allowed to cure over night. At this point, one layer of directional fabric was applied, allowed to cure overnight, followed by a second layer of directional fabric.



*Figure 4.2.6: Layer one of fiberglass over plug to create the mold.*

As the fiberglass was applied, air bubbles would form between the fiberglass and the previous layer. To correct this, small holes were drilled through the newly cured fiberglass layer and resin was injected using a turkey baster to fill the hole completely and remove the air. These holes were important to fill because if there were any gaps between layers, the structural integrity of the mold would not be as strong, and would cause it to be more susceptible to breaking or cracking.



*Figure 4.2.7: Drilling holes in the mold over the air pockets*



*Figure 4.2.8: Injecting resin into the air pockets between fiberglass layers.*

After all the layers had been laid (four layers of directional fabric, two layer of directional fabric), a wooden frame was built around the mold. This was done using directional fabric and plywood so the mold shape can be maintained and provide a base to work from. Once the frame had cured, the mold was released from the plug using wedges to separate the two, beginning at the bow and continuing towards the stern.



*Figure 4.2.9: The wood being set around the mold to act as a base*

When the mold was separated from the plug, the foam portion of the plug delaminated from the wooden base, leaving the foam inside the mold. To remove the foam, it had to be chiseled out using screwdrivers, hammers, and a hatchet. Care was taken close to the sides so as to not damage the gelcoat inside the mold. Once much of the foam from the bow section had been removed, larger sections of foam could be chiseled out and the foam closer to the sides could be pulled free. Eric at Structural Composites informed the design team earlier that the delaminating of the foam would be a possibility and it did not cause any damage to the mold, but because the plug was destroyed, creating another mold was impossible without re-milling the plug.



*Figure 4.2.10: Foam portion of plug inside mold after delaminating from base*



*Figure 4.2.11: Foam being chiseled out of mold*

Once the foam had been completely removed from the mold, touch up repairs were performed to fix small imperfections in the mold. There were small cracks on the edge of the stern, in the bow, and the chines near the bow, in addition to small cracks in several places along the length of the mold. First, the mold was wet sanded with 400 grit sand paper to smooth the surface. Bondo and spot putty was used to fill in the holes in the gelcoat, which may have formed due to the gelcoat being too thin in some area or air bubbles that were not removed when the first layer of fiberglass was laid. A second layer of gelcoat could have been added over the plug before laying fiberglass for the mold to fix this problem.



*Figure 4.2.12: Mold after foam removal.*

The bondo was first sanded with 220 grit sandpaper in a similar manner to the plug followed by wet sanding with 400 grit sandpaper. When the mold surface was smooth, it was cleaned using acetone, and then a layer of tooling gelcoat was brushed on too fill in small air bubbles, as well as cover the bondo. After curing overnight, the tooling gelcoat was wet sanded to a smooth finish using 400 grit sandpaper, making the mold ready for the first prototype hull to be cast. After cleaning the surface with acetone, seven layers of paste wax were applied to the mold and buffed so the first prototype hull could be easily removed. Care was taken when patching the mold because the inside of the mold had a direct effect on the prototype hull and the mold needed to be as flawless as possible to generate a quality prototype.



*Figure 4.2.13: Completed mold after bondo and sanding work*

The prototype was created in a similar fashion as the mold. Once the seven layers of the releasing wax were applied to the inside of the mold and buffed, three layers of standard white gelcoat were applied. Each layer of gelcoat was allowed to become tacky before the next layer was brushed on over top. Once the third layer had become tacky, micro-balloon powder was added to a container of catalyzed resin to give it a putty consistency. This was put along the chines to smooth them out and allow the fiberglass to be laid in larger portions without having to force the fiberglass down onto a ninety degree angle. This helped prevent air bubbles from forming under the first layer of chopped strand

matte. The first layer of chopped strand matte was laminated using resin catalyzed at 1% by weight and allowed to cure over night. One layer of chopped strand matte was used, followed by two layers of directional fabric, and completed with a fourth layer of directional fabric which was used to hold the three bulkheads in place.



*Figure 4.2.14: First layer of fiberglass curing in the mold*

The bulkheads were created from pieces of pine wood. To get the sizing correct, a piece of cardboard was cut to approximately fit the inside of the hull. This was then traced onto the pine wood and cut using a jig saw. The bulkheads could then be trimmed and sanded down to fit into the hull. Micro-balloon powder was then added to catalyzed resin to give it a putty consistency. This was put around the sides of the bulkheads to prevent air bubbles from forming and help hold the bulkheads in place. A fourth layer of directional fabric fiberglass and resin was then added over the bulkheads to further hold them in place and make the hull more rigid. The bulkheads were put in place while the prototype hull was still in the mold so the shape of the hull could be maintained and give it more rigidity. In addition, the bulkheads were used as connection points between the two hulls to help form the catamaran.



*Figure 4.2.15: Adding bulkheads to prototype using resin with a putty consistency.*

Once the fiberglass had cured, the first prototype could be removed from the mold using wedges, starting from the bow and moving towards the stern. The design team attempted to use stir sticks, screwdrivers, putty knives, and a hammer to wedge under the lip of the fiberglass, however, after several hours of work, the first prototype hull could still not be pulled free of the mold. Eric at Structural Composites was called and he told the design team to bring the mold over so he could help.



*Figure 4.2.16: Attempting to release the first prototype hull from the mold.*

The mold, with the first prototype hull still inside, was brought to Structural Composites and with the help of Eric, removed. This was done by using a sledge hammer to pound several large plastic wedges and wooden sticks under the fiberglass lip of the hull. This began to break the edges of the hull free from the mold. The mold was then turned over and the sledge hammer was used to strike the bottom, helping to loosen the bond between the fiberglass hull and mold. After several wedges were underneath the lip of the hull, it began to come free. It was finally removed by holding down the mold and pulling up by hand from underneath the fiberglass lip.

After the first hull was removed from the mold, it needed to be sanded, several portions needed to be filled in with bondo, and then sanded again to a smooth finish. The edges were sanded with a belt sander to give a smooth finish with no sharp surfaces. After the hull was smooth and the imperfections were removed, a layer of gelcoat was brushed over and after curing overnight, sanded to a smooth finish.



*Figure 4.2.17: First prototype hull after removal from the mold.*

After releasing the first hull, the mold needed minor bondo repair and sanding, beginning with 220 grit sandpaper, followed by wet sanding with 400 grit. Several small areas had portions of gelcoat from the prototype that stuck to the mold, and these were removed by chiseling them off with a screwdriver. Once the mold surface was smooth, it was waxed with six layers of paste wax and buffed so the next hull could be cast inside.



*Figure 4.2.18: Mold after removal of the first prototype hull.*

The second prototype hull was cast in the same manner as the first prototype. First, three layers of gelcoat were applied. Next, putty resin, made by mixing micro-balloon powder into catalyzed resin, was put along the chines to prevent air bubbles from forming and to allow the fiberglass to be rolled on smoother. Finally, a layer of chopped strand mat was laid and allowed to cure overnight, followed by two layers of directional fabric and the bulkheads. To ensure that both hulls would weight about the same, so less ballasting would be requiring during testing, the fabric used on each hull was cut at the same time so the amount of fabric would be approximately the same.

The second prototype hull was removed from the mold much easier than the first, with no assistance needed from Structural Composites. A putty knife was used along the edge of the hull to begin breaking the bond between it and the mold. After the edges were lifted, several stir sticks were hammered between the fiberglass of the hull and the mold. Once the bow had several stir sticks wedges under it, it was pulled up while holding the mold down and the prototype lifted free. It appeared that as the mold continued to be used, prototype removal becomes easier.



*Figure 4.2.19: Second prototype hull after removal from the mold.*

Once the second hull was removed, it needed minor bondo work and sanding. First, bondo was added to the bow and stern to make them sharper. Sanding with 220 grit sandpaper was done to remove rough spots along the hull and begin to smooth it. Once this was completed, wet sanding with 400 grit sandpaper was done to finish the surface.



*Figure 4.2.20: Sanding the stern portion of the second prototype hull*

The lip of each hull was then cut down to one inch using a jig saw. Once this was completed, a power sander was used to finish the edges and make them as smooth as possible. The purpose of the hull lip was to attach the decks to each hull through the fiberglass using nuts and bolts.



*Figure 4.2.21: Using a jig saw to cut the edges of the prototype hull*

Once the lip of each hull had been cut and the surface of each had been smoothed, two layers of gelcoat were applied. This was done to help cover the bondo that had been added when fixing the hulls after mold removal, as well as to give the hull a glossy white finish. Once the gelcoat was allowed to cure overnight, it was wet sanded with 400 grit sandpaper to finish the hulls.



*Figure 4.2.22: Hulls after the application of a layer of gelcoat*

After each individual hull has been fabricated, they had to be connected together to create the catamaran. This process was similar to the LOMAC. First, a deck was cut out of pine wood by tracing the outline of each hull and then cutting it out using the jig saw. Once the deck for each hull had been cut, they were stained and several coats of polyurethane

were applied. Finally, the decking was cut at the aft most bulkhead of either hull. This was done so the engines and electronics could easily be accessed.



*Figure 4.2.23: Staining the decks for each hull*

Following the completion of each deck, the connection system was assembled. Aluminum angle gage, tube, and flat bar was used to create the system. The connections were laid out on the decking and screwed into place. Similar to the LOMAC, aluminum tubing was used to attach the two hulls near the bulkheads. Aluminum angle gage was also run from the forward to the aft tube down the centerline of each hull to make the connection system more rigid. This was then further reinforced by placing an aluminum flat bar from the forward port side bolt, which holds the connections to the deck, to the aft bolt on the starboard side.

Finally, aluminum angle gauge was chosen as a mount for the instrumentation pack to be used. The two pieces of angle gauge initially ran in the transverse direction and allowed the instrument pack to sit securely in between. However, after later speaking with Branden Keane, an ocean engineering graduate student, the design team learned that the instrument pack should run in the longitudinal direction in order to record data properly. This was accounted for before the hulls were tested to give accurate results. Aluminum flat bar could also be bent around so the instrumentation can fit securely in and be tied down using zip-ties, however this was not deemed necessary. The group instead chose to use bungee chords, securely wrapped around the instrument pack and angle gauge, to keep

the pack in place. See Appendix C for the CAD drawing of the finished connection system.



*Figure 4.2.24: Finalized connection system bolted to the decking*

Once the connections were completed, the decking was mounted to the hulls. This was done by screwing the decks into the lips of each hull using eight machine screws forward for the aft most bulkheads.



*Figure 4.2.25: Forward portion of the deck mounted to the hulls*

Once the forward portion of the deck was mounted on the hulls, the stern portion of the deck could be mounted as well. A hinge was placed where the hulls were cut so the deck in the stern could be lifted to access the engines and electronics. To hold the stern decking down to the hull, as well as add a watertight seal around the length of the hull and add to the overall aesthetic appearance of the project, a rub rail was created out of a

garden hose. The hose was cut open using a knife and the sides of the hull were measured so the rub rail would fit securely.



*Figure 4.2.26: Prototype after rub rails were cut and added around the lips of the hulls.*

Next, the drive shaft housing was fit into the keel of the hull. Using a drill, a large angle hole was cut into the keel near the stern in the same location for each hull. A piece of 1/8" PVC was used to fit the drive shaft through, and this was placed into the drilled hole. After the shafts were in the proper positions, with both shafts having the same angle, two layers of bondo were added to help hold the shafts in place and make them watertight against the hull. A layer of chopped strand mat was then added over the bondo, allowed to cure, and sanded to a smooth finish.



*Figure 4.2.27: Adding chopped strand mat over drive shafts to seal them*

With the drive shafts in place, the hull could be sanded one final time to remove imperfections and create a smooth finish. First, 180 grit sand paper was used to remove large blemishes, followed by wet sanding with 400 grit sand paper to leave the hulls as smooth as possible.

Before the decks were screwed down, the aft most bulkheads of the hulls were cut in a u-shape using a jig saw. This was done to give access to the compartment ahead of the hatch. Small pieces of wood were cut and glued in place just behind the opening in the bulkhead so the batteries could be placed on top. This gave a location to store the batteries and not have to remove the deck to access them, since they would not be able to fit under the hatch due to their size.

Once the hulls were sanded smooth, they could be assembled for electronic installation. The decking, with connections already tightened in place, was screwed down to the hull lips. With the decking in place, the rub rails were placed around the sides to give a watertight seal. The final product turned out to be extremely accurate and on target with the initial *ProSurf* design due to the care and effort put forth by the team over the course of manufacturing.



*Figure 4.2.28: Completed hull with instrumentation in place*



Figure 4.2.29: Detailed view of chine running down the port side hull

## 4.2 Quality Control

In order to control the quality on the displacement hull project, a professional manufacturing process was chosen so the final product could give the best possible testing results. By having a female mold, the final prototype created was extremely close to the design created in *ProSurf*, producing the results the design team was aiming for.

The most important step in quality control of the design in manufacturing came in the creation of the plug, as it was the basis for the mold and hence the prototype. By having the plug professionally milled on a CNC machine by Structural Composites using a very precise bit, it left the plug smooth so minimal hand sanding had to be performed. The only sanding performed was on portions of the plug that have blemishes. By reducing the amount of sanding that was performed, it reduced the risks and imperfections that result from hand sanding a product, and hence, left the hulls as close to the computer model as possible.

In addition, quality was controlled by taking time in the sanding and fiberglass stages of manufacturing. By paying attention to detail when sanding and laying fiberglass, the final prototype created was more accurate and produced the desired results without any major errors being present.

## **5. Propulsion / Electronics**

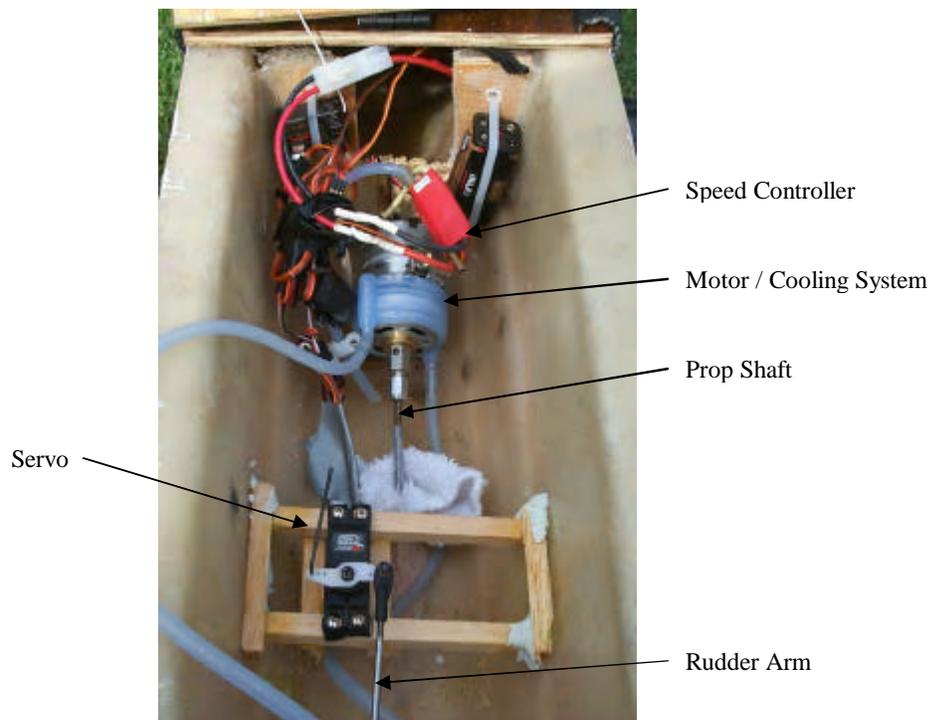
### **5.1 LOMAC Difficulties**

Once the hull was completely manufactured, the issue of powering the vessel needed to be overcome to complete the displacement hull project. With the recent surge in remote control cars and boats, there were many different ways to go about powering the displacement hull catamaran; however, the design team made propulsion choices based on the mistakes made by the LOMAC design team. Vessel maneuverability and powering were addressed separately. The LOMAC design team initially utilized differential propulsion for steering which ultimately failed, and they then switched to a two rudder system mounted on the stern which turned the vessel more effectively (Gonzalez). Another problem the LOMAC encountered was the overheating of the motors and controllers. This problem was addressed in the displacement hull project by incorporating a water cooling system into the hull and electronics.

### **5.2 Propulsion / Maneuvering Systems Design**

The displacement hull catamaran was powered by two Graupner Speed 700 Turbo electric motors, coupled to straight shafts and capped by a propeller on each shaft. The motors had an output of 372 watts each, and produced approximately 3-5 pounds of thrust, depending on the propellers used, while drawing 25 amps. To control the motors, two JETI “Navy” Speed controllers were used, which allowed the user to control the speed electronically rather than mechanically. The units were also incorporated into the on-board cooling system.

The controllers were fed an electronic signal by an on-board receiver, which in turn got a signal from the remote transmitter held by the operator. The remote control transmitter used to operate the vessel was a Futaba Magnum, which featured an LCD screen and three channel outputs. Two channels were used to control the steering and throttle functions on the vessel, while the third channel was left unused.



*Figure 5.2.1: Internal electronics of the displacement hull*

To avoid the same problems the LOMAC encountered, it was necessary to cool the motors and major electronic components. Machined into each rudder was a small pinhole that functioned as a water pick-up for the cooling system. Water pressure created from the forward movement of the vessel was used to feed the entire cooling system with an adequate stream of water. From the pick-ups on the rudders, silicone tubes carried the water to the engine cooling coils, which were wrapped around the outside of the engine. After passing around the engine, the water traveled through the attached cooling tube on the speed controllers, and then out of a waste fitting at the stern of the vessel. The servos were cooled by the ambient air because they were not under a heavy load.

Two straight shafts were attached to the motors, which effectively transmitted the engine power to the propellers. There were many different options of electronic propulsion, including but not limited to outboard motors and jet-drives. The direct drive system was chosen with inboard motors because it most effectively delivered the power to the propellers, and it gave important engineering flexibility when mounting the motors, as the length and angle of the shafts could be adjusted.



*Figure 5.2.2: Rudder (with attached cooling system) and propeller used for steering*

Most model boats use plastic propellers which are directly threaded onto the shaft. This option was deemed insufficient for the project. Instead, metal propellers were used that were attached to the shaft using a nut and dog providing a more secure connection. Also, to avoid the complications the LOMAC had with steering, a dual rudder system was chosen to steer the displacement hull. The heart of the system was two hi-torque servos which were connected by a threaded rod to the rudder through the transom. These servos outputted approximately 142 ounce-inches of torque, and they were adequately sufficient in turning the rudders. The servos were secured to the hull using spruce rails which were fastened to the hull with epoxy.

## **6. Results**

### **6.1 Tests Conducted**

#### *Sea Keeping Test*

##### *Purpose*

A major advantage of the semi-displacement hull is the sea keeping ability of the design. Sea keeping has come to be known as how it feels to be on the boat. Quantitative measurement of this characteristic will be done by measuring accelerations on the boat. The less acceleration the vessel incurs while underway, the smoother the ride and therefore the better the sea keeping ability of that vessel.

##### *Background*

The semi-displacement design allows for the ship to have waves pass underneath the vessel without as much harsh impact as a planing hull. Also, the catamaran design allowed for long narrow hulls without sacrificing stability. The long narrow hulls allow waves to pass underneath without increasing the buoyant force on the vessel as greatly as a mono-hull which tends to have wider hulls. This means that the vertical forces and therefore accelerations on the catamaran will be less than the mono-hull or planing design counterpart.

##### *Theory/Procedure*

The instrument pack currently owned by DMES and used on the LOMAC contains two accelerometers. This device measures the accelerations it experiences along each principle axis, X, Y and Z. The instrument pack was taken into consideration during the design phase of the project so it could be installed on the displacement model as well as the LOMAC. Unfortunately, the LOMAC was in such poor condition during the testing phase of the displacement catamaran that it could not be tested without refurbishing its hull and electronic system. The data collected from the displacement catamaran was instead compared to similar accelerometer testing of Glacier Bay displacement hull catamarans.

## **6.2 Results Obtained**

Accelerometer data was collected during the testing of the displacement catamaran using the instrumentation package owned by DMES and developed by graduate student Doug Guardino. The graphs below show accelerations on the displacement hull in calm conditions, rough conditions, and a graph comparing the two. For a sample of raw data collected by the instrumentation, as well as the calibrated form of the data used to create the graphs, see Appendix E.

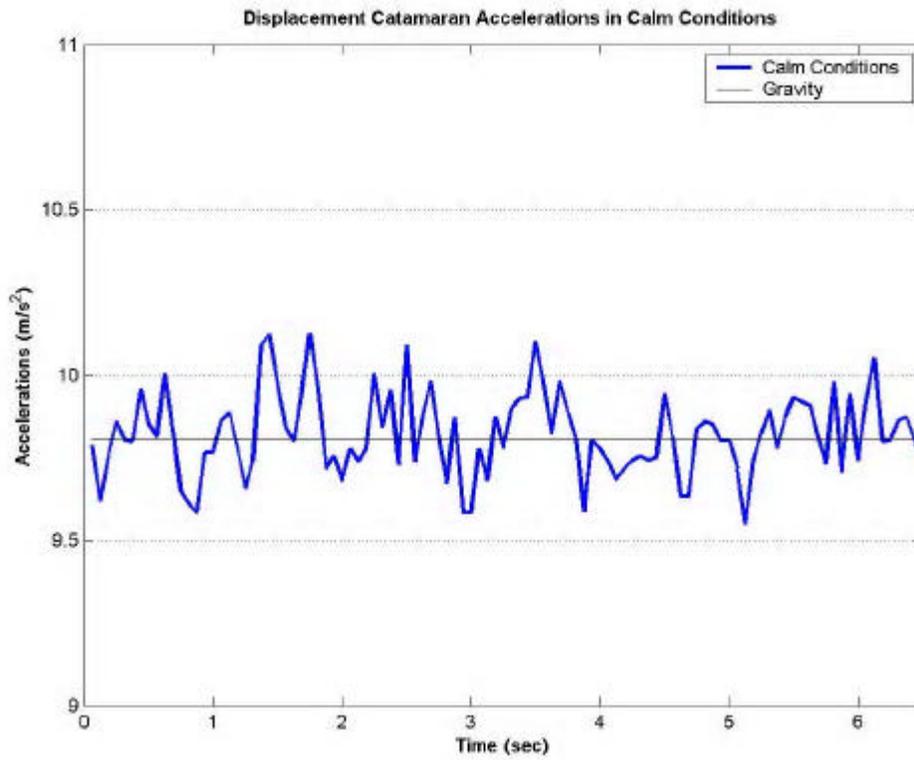


Figure 6.1.1: Graph of calibrated accelerometer data collected during the calm water test of the displacement catamaran



Figure 6.1.2: Displacement hull being tested in calm water

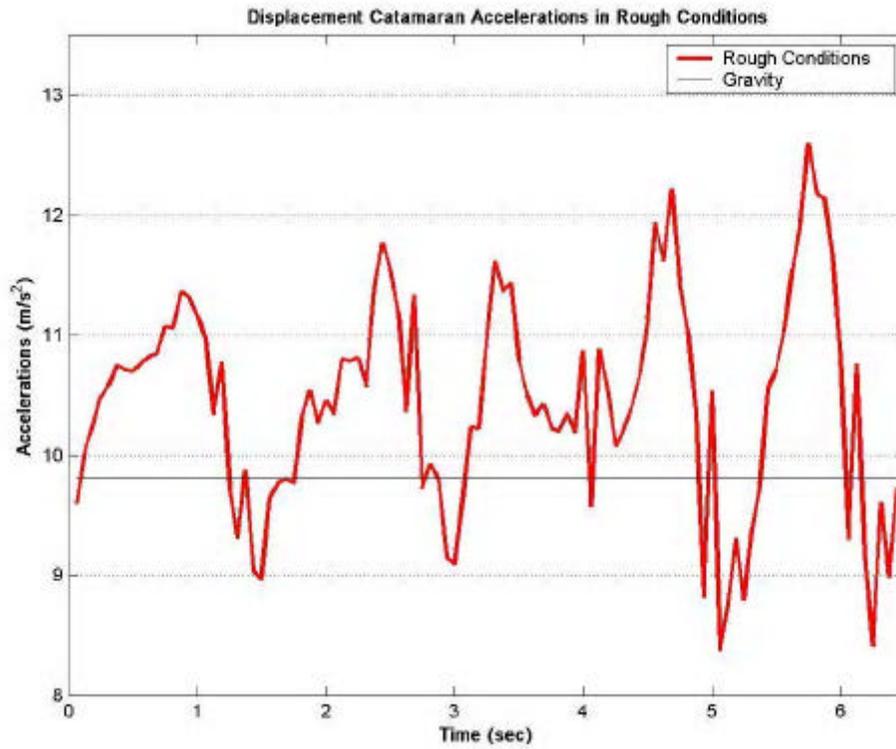


Figure 6.1.3: Graph of calibrated accelerometer data collected during the rough water test of the displacement catamaran



Figure 6.1.4: Testing in the rough conditions of the Indian River Lagoon

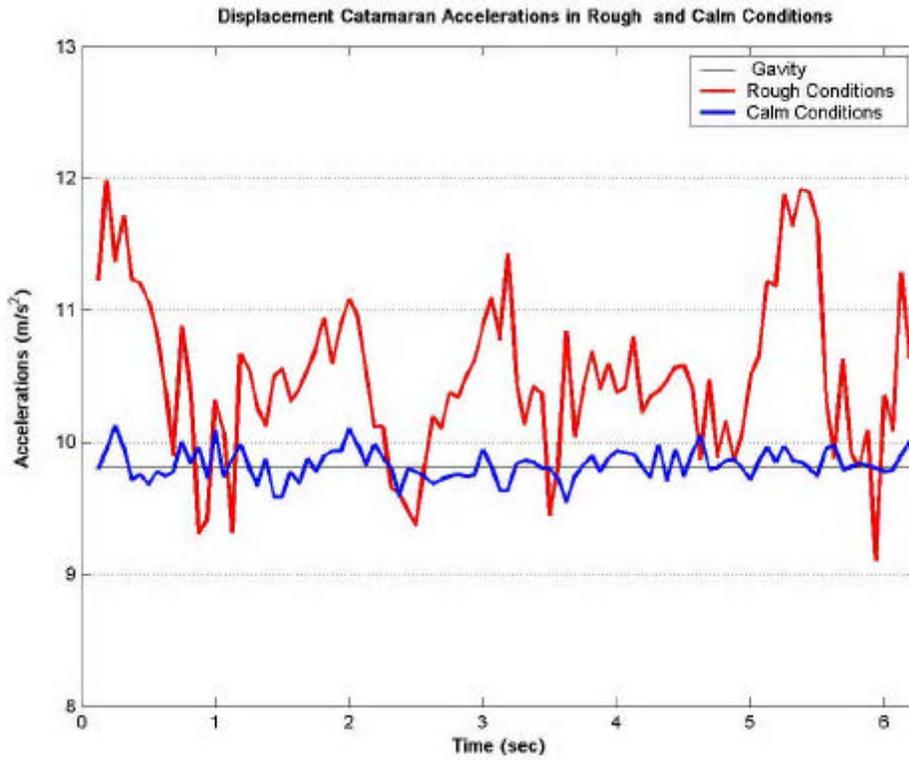


Figure 6.1.5: A comparison of the accelerometer results obtained in calm conditions and rough conditions

**Dimension Ratios**

<i>Parameter</i>	<i>Symbol</i>	<i>LOMAC</i>	<i>Displacement</i>
Length/Beam Ratio	L/B	10.46	10.96
Length/Beam Overall Ratio	L/BOA	0.27	0.22
Length/Draft Ratio	L/T	1.72	1.77
Beam/Draft Ratio	B/T	0.16	0.16
Beam Overall/Draft Ratio	BOA/T	6.41	7.89

Table 6.2.1: Comparison of dimension ratios between LOMAC and displacement hull  
(Courtesy E. Gonzalez)

## 7. Discussion

### 7.1 Instrumentation

In order to acquire meaningful accelerometer data for the displacement catamaran, the instrumentation package developed by graduate student Doug Guardino was utilized. With the help of ocean engineering graduate student Brendan Keane, the instrument pack was reviewed and tested to ensure it ran correctly before data collection on the displacement hull began.



*Figure 7.1.1: Instrumentation pack used during testing*



*Figure 7.1.2: Internal components of the instrumentation pack*

The instrumentation package contains such useful sensors as accelerometers, a GPS, compass, and an inclinometer. For the purposes of the displacement catamaran hull testing, the accelerometer sensors were the design teams only focus. The instrumentation sends data wirelessly to a land based laptop in real-time using TCP/IP and wireless Ethernet using Telnet (Guardino, iii). The program to read the accelerometer data and send it wirelessly is on a PIC microchip controller located onboard the instrument package. The complete program, written in C language, can be found in Appendix D, courtesy of Brendan Keane.

In order to collect data from the instrument pack, a laptop computer with wireless capabilities is used. Once the instrumentation is turned on, via a switch inside the pack, the wireless network can be detected by the computer. The user then clicks “run” from the Start menu, and types “Telnet”. When the prompt window appears, the user types “set logfile filename.txt,” where filename is the name you want to save the data as. Once this is complete, the user types “open 192.168.1.50” and data should begin to stream from the pack and be saved as a text file on the computer’s hard drive.

The accelerometer data appears with the coordinate systems of Z, Y, Z, and X when it is being streamed. The first two coordinates, Z and Y, correspond to one accelerometer, while the Z and X coordinates correspond to the other. The Z coordinate appears twice since two accelerometers are mounted in the instrumentation pack, hence the axis is duplicated (Guardino, 38).

## **7.2 Data Interpretation**

The accelerometer data obtained from Doug Guardino’s instrument package was downloaded to a laptop computer via a wireless network connection as a text file which was then imported as a spreadsheet into Microsoft Excel. Three experimental trials were conducted using the instrument package; a calibration trial with the instrument package set on a table not in motion, a trial in smooth water, and a trial in rough water. The

calibration trial was necessary to determine the output of the accelerometers when the instrument package was not in motion, a value determined to be 0.38 G's. This value was subtracted from the average accelerometer values obtained from the instrument package while it was in motion to give the true accelerations experienced on the catamaran.

The instrument package included two onboard accelerometers that gave acceleration readings in G's along the principle axes, X, Y, and Z. In order to most accurately quantify the way a human being would perceive these accelerations while onboard the catamaran, the directional acceleration readings at each reading (or moment in time) were averaged to give a meaningful value of what the human body would perceive. These measurements, recorded by the instrument package in G's, were converted to accelerations in meters per square second on the surface of the Earth to demonstrate the relationship between what the human body perceives at rest compared to the higher and lower accelerations experienced on a boat in wave conditions. Our results are surprisingly comparable to accelerometer testing done by Glacier Bay catamarans, especially after the laws of scaling were applied to the project.

Similar testing would have allowed for comparative sea-keeping analysis to be performed on the LOMAC planing catamaran had it been left in working order by previous researchers. Our expected results, based on naval architecture theories presented earlier in this report, would have found smaller accelerations in the displacement catamaran than in the LOMAC when tested side by side at the same speed in the same wave conditions. There is tremendous potential for comparative analysis and research to be done in this field.

The vessel was specifically designed in a manner which would allow for the greatest speed of the vessel while minimizing the effects of the sea condition on the boat. Length to beam ratio is an important quantity of the displacement boat design. A high length to beam ratio allows for the vessel to achieve a maximum velocity for a minimum amount of drag. This occurs because the displacement boat will not exceed hull speed which is a quantity based on the length of the boat. Planing vessels are able to achieve a speed

greater than hull speed, and therefore length to beam ratio is less important in their design.

### 7.3 Future Studies

The displacement projects only shortcoming was a direct comparison between the sea keeping abilities of the displacement hull and the planing hull catamarans. After refurbishing the mechanical and electronic systems of the LOMAC, accelerometer data should be gathered from both hulls types at the same speed in the same wave conditions. Ideally, the two vessels could collect data simultaneously while running side-by-side.

Another test the design team was interested in conducting but was unable to perform due to time constraints was a tunnel test of the displacement catamaran to determine the hydrodynamic lifting effects that are produced by the tunnel. The primary benefits of catamaran design are stability and decreased hull resistance split between two hulls. It has been proposed that one of the secondary benefits of catamaran design is the “cushioning” effect produced by the tunnel between the twin hulls.



*Figure 7.3.1: The tunnel of a Glacier Bay Canyon Runner 2665*

As waves pass under the vessel, the air space between the hulls changes in volume. As this air space contracts the pressure in it should increase, which would help support to the

vessel so that it does not impact the water surface with as much force. Therefore, it has been theorized that the vertical accelerations of the boat will be less severe when a tunnel system has been fitted to the vessel.

In order to perform this test, a tunnel system must first be installed on the vessel. Next, the sea keeping test could be performed on the modified vessel. Comparison between the accelerometer data for the original data and modified vessel would indicate the significance of the tunnel on sea keeping.

Finally, the relationship between hull spacing and turning capability is an aspect of the project in which further study can be done. A simple turning test could be performed at hull spacing intervals. The hull connections of the displacement catamaran were specifically designed to allow for the distance between the hulls to be adjusted without having to remove the decks.

## **8. Conclusions**

The manufacturing of the displacement hull catamaran was a success; the prototype which was constructed was both accurate and precise. The final prototype created was exactly like the design originally generated in *ProSurf* because of the manufacturing process chosen by the group. This process, used extensively in the fiberglass boat industry, proved highly efficient and was easily implemented for the mass production of a product.

Testing of the catamaran with the instrument package was also successful. The meaningful accelerometer data obtained proved the hulls' efficiency and sea-kindliness. As the displacement hull was originally designed to be compared to the LOMAC planing hull, the overall dimensions and ratios of both nearly match. This facilitates a future comparative study between the two projects if the LOMAC is refurbished. The displacement hull, because of the accuracy with which it was manufactured, can now be used for future studies by the university in catamaran sea-keeping and technology.

## 9. Recommendations

### *Prototype Release*

Releasing the first prototype hull from the newly constructed mold proved to be a time consuming and difficult task. Problems occurred in releasing the hull because the mold release wax was insufficiently buffed off, improper tools were initially used to remove the hulls, and the group was hesitant to use a sufficient amount of force to extract the hull for fear of damaging the prototype.

Applying mold release was a tedious task in which paste wax was applied to the mold, allowed to set for approximately ten minutes, and buffed off. The mold was then allowed to sit for thirty minutes, and the process was repeated at least five more times. Although it may appear to be a fruitless task, all of the time and effort put into properly waxing the mold was beneficial and helped insure a smooth release of the fiberglass prototype hull from the mold. When the first hull was extracted from the mold, wax was present on the hull, which indicated that it was not completely buffed off. In the future, more time should be taken during the buffing stage of wax application.

The first attempt to remove the hull from the mold failed because insufficient tools were used to extract the hull. The group tried to use screw drivers as wedges to dislodge the prototype. The problem when using screw drivers was they did not provide a wide enough surface to distribute the lifting load required. Also, the screw drivers were metal and therefore could mar the gel coat finish of the prototype. To properly remove the hull from the mold, plastic wedges and wooden stir sticks should be used. The plastic wedges should be wide enough to distribute the lifting force and therefore not damage the fiberglass structure. Wooden stir sticks are beneficial because they are able to break as they are hammered between the mold and prototype and therefore can be wedged into the complex geometry of the boat hulls more effectively than the plastic wedges alone. It should also be noted that a large amount of force may be necessary to remove the prototype.

The first prototype hull was difficult to extract and required a large amount of effort and assistance from Structural Composites. By applying the knowledge gained while extracting the first hull from the mold, the second hull was removed much more efficiently with only a minimal amount of effort.

#### *Tooling Gelcoat Application*

Tooling gelcoat was applied to the inside of the mold to help achieve a smooth finish; however, the group applied only a single layer. It would have been beneficial to have applied multiple layers because the gelcoat chipped easily. Also, the single layer of tooling gelcoat was too thin and during sanding was completely removed in some areas.

#### *Gelcoat Application*

The design team learned that gelcoat should not be used as paint. Gelcoat was applied as the first layer of the hull and was done so by painting it into the mold. Once the hull was removed from the mold, no more gelcoat should have been applied to the boat hull. Painting additional coats of gelcoat onto the exterior of the hull created runs in the finish which then had to be sanded. Painting on the gelcoat, allowing it to harden, and then sanding it to remove the imperfections was a large investment of both time and effort which did not result in any forward progress of the project. Therefore, all layers of gelcoat should be applied to the inside of the mold to ensure a good finish.

#### *Filling Air Bubbles in Fiberglass*

The combination of little experience working with fiberglass and complex hull geometry caused fiberglass work to have many air pockets present. The mold was the first fiberglass structure the group created and therefore contained the most air pockets. Fortunately, the aesthetics of the mold are of no importance and therefore air bubbles were only significant because they could reduce the structural integrity of the mold.

The most efficient way to fill the air pockets and therefore increase the strength of the mold was to use a drill and turkey baster filled with resin to inject the pockets full of resin. It should be noted that acetone was a good solvent for resin and can be used in the future to clean the baster and therefore prevent money from being wasted on multiple turkey basters.

#### *Applying Fiberglass to the Chines*

The prototype hull design incorporated a thin keel, subsurface chine, and another chine at the design waterline. Although all aspects of the boat were designed in proportion, the small scale of the project caused these hull features to be small and therefore difficult to fiberglass. To avoid difficulties in applying the fiberglass to these features, a thickening agent was added to the resin, which was in turn applied to the chines to smooth these potential problem areas. Once the features were rounded, applying the fiberglass was a relatively easy procedure.

## 10. References

Compton, R. H., "Resistance of a Systematic Series of Semiplaning Transom-Stern Hull,"  
Marine Technology, October, 1986.

Connor, Casey, et al. LOMAC Monohull. DMES. Florida Institute of Technology. 2004.

Gilmer, Thomas C. and Johnson, Bruce. Introduction to Naval Architecture. Annapolis,  
MD: Naval Institute Press

Gonzalez, Eduardo. Development of Experimental Techniques and Sea-keeping Tests of  
Catamaran Model in Open Water. DMES. Florida Institute of Technology. 2002.

Guardino, Douglas. Design of Sensor and Wireless Data Acquisition System For Field  
Testing of Hull Models. DMES. Florida Institute of Technology. 2002.

Saunders, HE. "The Preliminary Hydrodynamic Design of a Motorboat."  
Hydrodynamics in Ship Design. 1957.

Savitsky, D., "Hydrodynamic Design of Planing Hulls," Marine Technology, 1964.

Sponberg, Eric. "New Lifting Strakes for Blue Bill." Available online.  
<http://www.sponberg yacht design.com/Bluebill.htm>. February 22, 2007.

## **Appendix A – Gantt Chart**









## Appendix B – Bill of Materials

<i>Material</i>	<i>Supplier</i>	<i>Size</i>	<i>Price</i>	<i>Quantity</i>	<i>Total Cost</i>
Tooling Foam	Structural Composites	-	600.00	1	Donated
Fiberglass	Structural Composites	-	100.00	1	Donated
CNC Time	Structural Composites	-	640.00	-	Donated
Eastman 6736 G.P. Resin	Fiberglass Florida	5 Gallon	98.99	1	98.99
Eastman 6736 G.P. Resin	Fiberglass Florida	5 Gallon	95.66	1	95.66
MEKP Catalyst	Fiberglass Florida	16 oz.	7.33	1	7.33
Tooling Gelcoat	Fiberglass Florida	1 Quart	16.78	1	16.78
Standard Gelcoat	Fiberglass Florida	1 Gallon	25.48	1	25.48
High Gloss Gelcoat Compound	Fiberglass Florida	1 Gallon	37.53	1	37.53
TR-104 Hi-Temp Paste Wax	Fiberglass Florida	14 oz.	12.21	2	24.42
Plastic Measuring Container	Fiberglass Florida	1 Quart	0.62	11	6.82
Paper Tub (Unwaxed, White)	Fiberglass Florida	32 oz.	0.48	5	2.40
Stir Sticks	Fiberglass Florida	1"x12"x1/8"	0.11	27	2.97
Latex Gloves	Fiberglass Florida	12	10.26	2	20.52
Aluminum Roller	Fiberglass Florida	1/2"x3"	7.13	3	21.39
Plastic Roller	Fiberglass Florida	1/2"x3"	7.38	2	14.76
180 Grit Sandpaper	Fiberglass Florida	9"x11" (50)	12.26	1	12.26
220 Grit Sandpaper	Fiberglass Florida	9"x11" (50)	12.26	1	12.26
320 Grit Sandpaper	Fiberglass Florida	9"x11" (50)	12.26	1	12.26
400 Grit Sandpaper	Fiberglass Florida	9"x11" (50)	15.79	1	15.79
2x4 Wood	Home Depot	2" x 4"	2.67	2	5.34
Aluminum Square Tube	Home Depot	1/16", 3/4" x 3'	9.96	2	19.92
Aluminum Flat Bar	Home Depot	1/8", 3/4" x 3'	3.19	1	3.19
Aluminum Angle Gauge	Home Depot	1/16", 1" x 4'	4.67	3	14.01
Screws	Home Depot	2"	4.47	1	4.47
Bolt	Home Depot	1/4" x 1 1/4"	0.13	11	1.43
Washer	Home Depot	1/4"	0.07	11	0.77
Hex Nut	Home Depot	1/4"	0.04	11	0.44
Liquid Nails Adhesive	Home Depot	-	2.67	1	2.67
Pine Wood	Home Depot	4' x 8' x 3/8"	17.96	1	17.96
Scissors	Ace Hardware	-	2.49	2	4.98
Protective Mask	Ace Hardware	-	3.29	1	3.29
1'x8' Wood for Mold Frame	Home Depot	-	5.45	2	10.90
Brush	Home Depot	2"	0.87	8	6.96
Hinge	West Marine	-	5.49	1	5.49
Silicone	West Marine	3 oz	7.99	1	7.99
Washer	West Marine	-	0.30	4	1.20
Wing Nut	West Marine	-	0.99	4	3.96

Bolt	West Marine	-	0.50	4	2.00
Lead Shot	Ammo Attic	25 lbs	26.45	1	26.45
Wood Stain	Home Depot	-	11.98	1	11.98
Foam Brushes	Home Depot	-	0.76	6	4.56
Motor Mounts	Hobby Lobby	-	18.90	2	37.80
Switch Cover	Hobby Lobby	-	5.50	1	5.50
Speed 700 BB Turbo	Hobby Lobby	-	44.90	2	89.80
Silicone Tubing	Hobby Lobby	-	3.40	2	6.80
Cooling Water Pick up	Hobby Lobby	-	5.90	2	11.80
Cooling Coil	Hobby Lobby	-	10.90	2	21.80
JETI Navy Speed Controller	Hobby Lobby	-	74.90	2	149.80
Shipping for above	Hobby Lobby	-	7.99	1	7.99
Adjustable wire stripper	Space Coast Hobby	-	8.45	1	8.45
Servo extension wire	Space Coast Hobby	-	4.31	2	8.62
Standard switch	Space Coast Hobby	-	6.29	1	6.29
One foot black wire	Space Coast Hobby	-	1.44	10	14.40
One foot red wire	Space Coast Hobby	-	1.26	10	12.60
Y-Harness	Space Coast Hobby	-	6.29	1	6.29
Servo, Hi-Torque	Space Coast Hobby	-	33.99	2	67.98
Reciever/Transmitter 3CH	Space Coast Hobby	-	142.49	1	142.49
Y Harness	Space Coast Hobby	-	8.50	1	8.50
Heat Shrink Wrap	Space Coast Hobby	-	1.49	1	1.49
Battery Connector	Space Coast Hobby	-	1.49	2	2.98
Machined Aluminum Rudder	Tower Hobbies	-	12.99	2	25.98
Servo Linkage w/connects	Tower Hobbies	-	16.99	2	33.98
Rudder Support	Tower Hobbies	-	10.99	2	21.98
Aluminum Rudder Control Arm	Tower Hobbies	-	8.99	2	17.98
700 Size Motor Water Jacket	Offshore Electronics	-	19.99	2	39.98
Octura 5mm Hex Flex Coupler	Offshore Electronics	-	8.95	2	17.90
Assembled Flex Cable Prop Shaft	Offshore Electronics	-	19.99	2	39.98
10 Cell 2400SCR Nicad Battery	Hobby Lobby	-	72.90	2	145.80

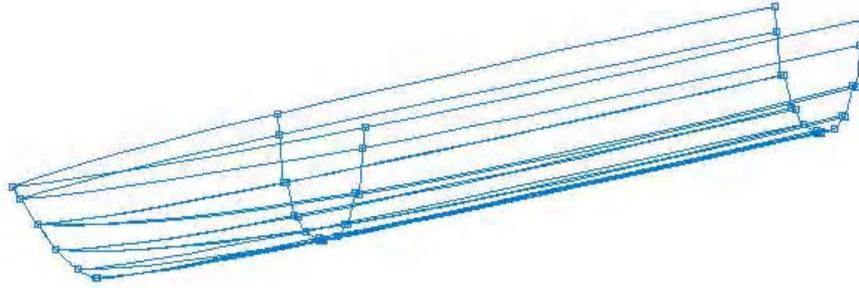
**Project Total: \$1548.83**

**Project Total w/ Donation: \$2888.83**

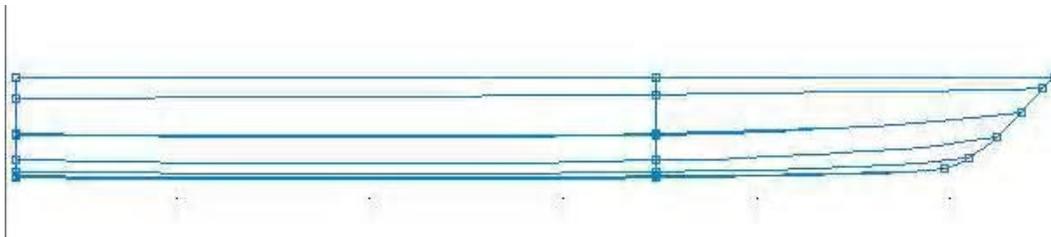
## Appendix C - Prosurf / CAD Drawings



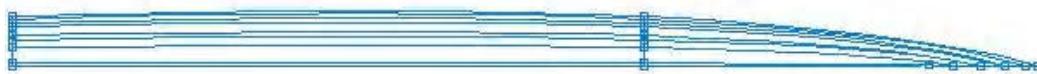
*Figure 1: Rendered view of displacement hull catamaran from ProSurf.*



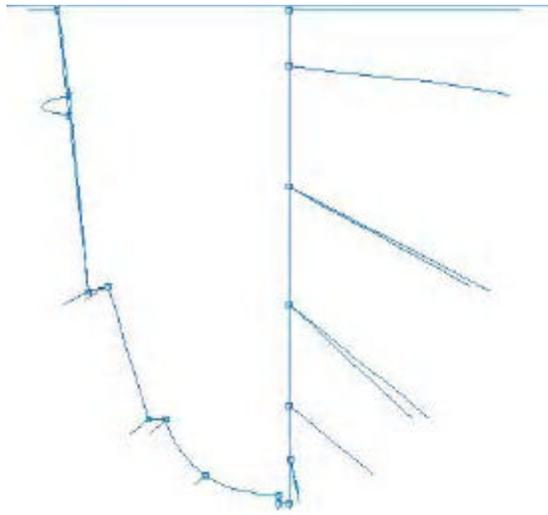
*Figure 2: 3D view of displacement hull.*



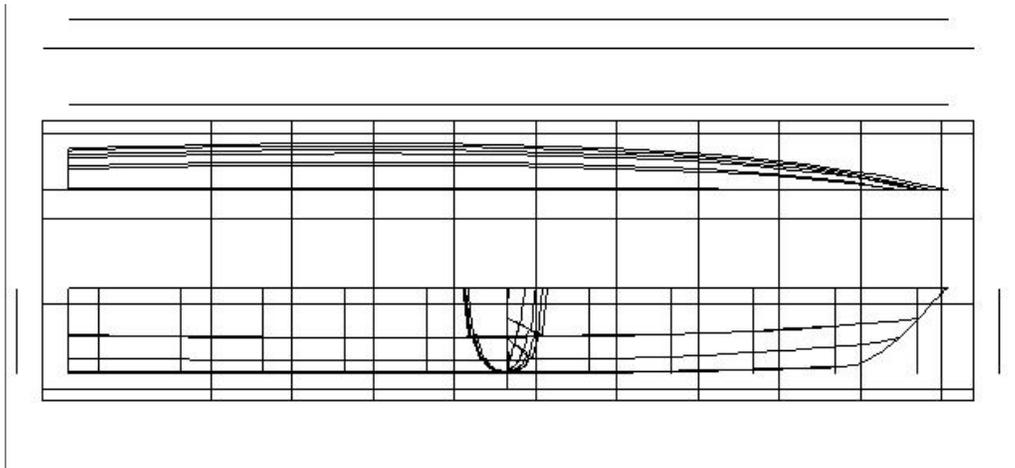
*Figure 3: Shear view of displacement hull.*



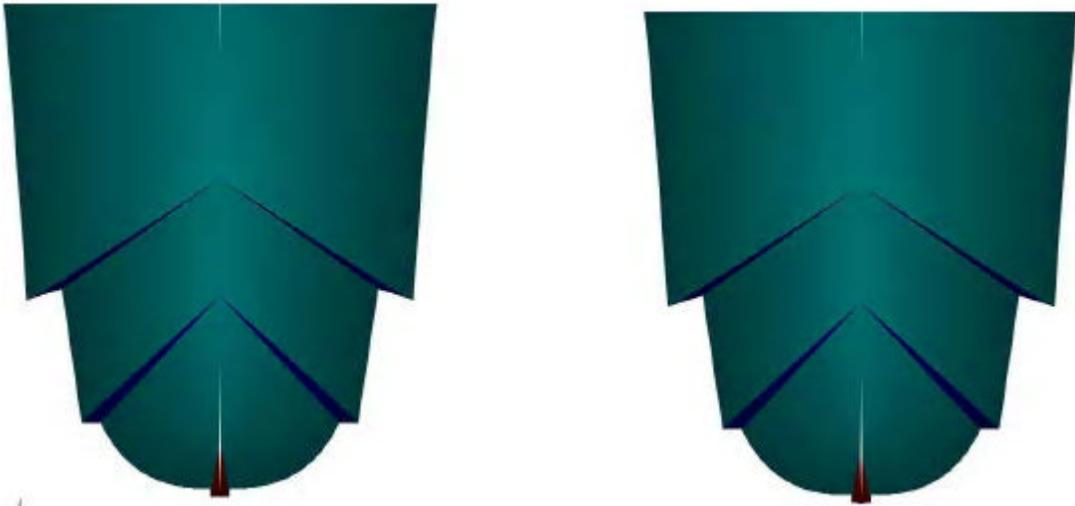
*Figure 4: Half Breadth view of displacement hull.*



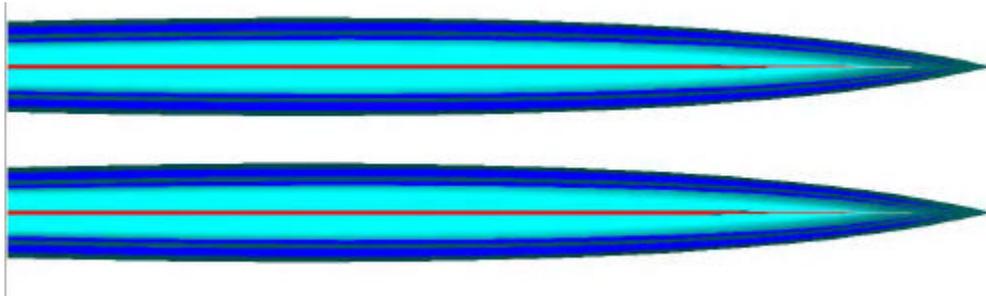
*Figure 5: Plan view of displacement hull.*



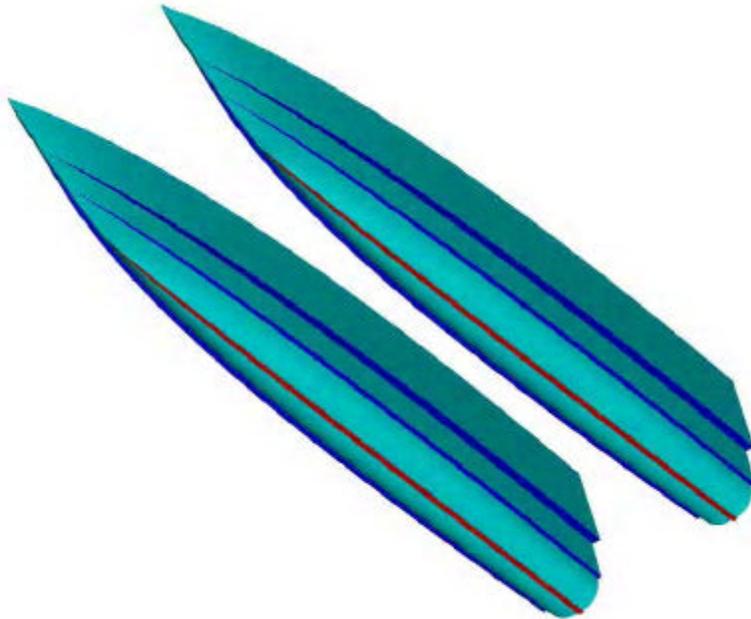
*Figure 6: Lines drawing of displacement hull.*



*Figure 7: CAD 3D plan view render of displacement hull catamaran.*



*Figure 8: CAD 3D render of keel (in red) of displacement hull catamaran.*



*Figure 9: CAD 3D render of displacement hull catamaran.*



## Appendix D – Accelerometer Program

The following program, written in C language, is used by the microchip in the instrumentation package to read the accelerometer data and transfer it wirelessly to a land based laptop computer. It was given to the design by ocean engineering graduate student Brendan Keane in the event the group could not find the correct microchip that had been preprogrammed and had to program one from scratch.

```
#include <p18f458.h>
#include <delays.h>
#include <usart.h>
#include <i2c.h>
#include <string.h>
#include <stdlib.h>
#include <adc.h>
#include <timers.h>

unsigned char status, buffer[80], temp[10];
char charbuff[10], ackstat = 0;
int          doug, time = 0, timelast;
unsigned long before, after;
rom char     initStMsg[]      = "Initilazation Status ";
rom char     socketInitStMsg[] = "Socket Initilazation Status ";
rom char     WaitConectMsg[]  = "Waiting for connection";
rom char     conectEstabMsg[] = "Connection Established";
rom char     welcomeMsg[]    = "Good Morning";

// high interupts
void int_handle (void);

#pragma code HIGH_INTERRUPT_VECTOR = 0x8
void high_ISR (void)
{
    _asm
    goto int_handle
    _endasm
}
#pragma code

#pragma interrupt int_handle
void int_handle (void)
{
    WriteTimer0(55535);
    time++;
    INTCON = 0b10100000;
}
```

// This code is written assuming a 40MHz Fosc.

```
void i2cTx( unsigned char control, unsigned char addressHigh,
           unsigned char addressLow, unsigned char *array,
           unsigned char length)
{
    unsigned char count;
    IdleI2C();
    StartI2C();
    while ( SSPCON2bits.SEN );
    control = control & 0xFE;
    WriteI2C ( control);
    IdleI2C();
    if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;      // bus device responded with NOT ACK
    }
    WriteI2C ( addressHigh);
    IdleI2C();
    if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;      // bus device responded with NOT ACK
    }
    WriteI2C ( addressLow);
    for(count = 0; count < length; count++){
        IdleI2C();
        if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
        {
            ackstat += 1;      // bus device responded with NOT ACK
        }
        WriteI2C ( array[count]);
    }
    IdleI2C();
    if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;      // bus device responded with NOT ACK
    }
    StopI2C();
    while ( SSPCON2bits.PEN );
}

unsigned char * i2cRx( unsigned char control,
                      unsigned char addressHigh,
                      unsigned char addressLow,
                      unsigned char *array,
                      unsigned char length)
{
    unsigned char count;
    IdleI2C();
```

```

        StartI2C();
        while ( SSPCON2bits.SEN );
        control = control & 0xFE;
        WriteI2C ( control);
        IdleI2C();
        if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;          // bus device responded with NOT ACK
    }

        WriteI2C (addressHigh);
        IdleI2C();
        if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;          // bus device responded with NOT ACK
    }

        WriteI2C ( addressLow);
        IdleI2C();
        if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;          // bus device responded with NOT ACK
    }

        StopI2C();
        while ( SSPCON2bits.PEN );

        control = control | 0x01;
        IdleI2C();
        StartI2C();
        while ( SSPCON2bits.SEN );
        WriteI2C ( control);
        if ( SSPCON2bits.ACKSTAT ) // test received ack bit state
    {
        ackstat += 1;          // bus device responded with NOT ACK
    }

        SSPCON2bits.RCEN = 1;

        for(count = 0; count < length; count++){
            IdleI2C();
            array[count] = ReadI2C();
            if (count == length -1){
                NotAckI2C();
            }
            else{
                AckI2C();
            }
        }

        IdleI2C();
        StopI2C();
        while ( SSPCON2bits.PEN );
        return(array);
    }

```

```

unsigned char InitWiznet( unsigned char control)
{
    unsigned char data;
    // initilise IINCHIP
    // Gatway Address
    buffer[0] = 192;           //80
    buffer[1] = 168;         //81
    buffer[2] = 1;           //82
    buffer[3] = 1;           //83

    // Subnet Mask
    buffer[4] = 255;         //84
    buffer[5] = 255;         //85
    buffer[6] = 255;         //86
    buffer[7] = 0;           //87

    //MAC Address
    buffer[8] = 0x00;        //88
    buffer[9] = 0xA0;        //89
    buffer[10] = 0x24;       //8A
    buffer[11] = 0xBB;       //8B
    buffer[12] = 0xD8;       //8C
    buffer[13] = 0x6A;       //8D

    // IP Address
    buffer[14] = 192;        //8E
    buffer[15] = 168;        //8F
    buffer[16] = 1;          //90
    buffer[17] = 50;         //91

    // Initial Retry Timer - value
    buffer[18] = 0x03;       //92 100ms
    buffer[19] = 0xE8;       //93

    //Retry Count
    buffer[20] = 255;        //94

    // RX data Memory size
    buffer[21] = 0b000011; //95 8kb to ch 0

    // TX data Memory size
    buffer[22] = 0b000011; //96 8kb to ch 0

    //Write all that to the IINCHIP
    i2cTx( control, 0x00, 0x80, buffer, 23);

    buffer[0] = 0x01;

    //Sends the initialize command

```

```

        i2cTx( control, 0x00, 0x00, buffer, 1);

        //Checks status of initialization
        i2cRx( control, 0x00, 0x04, &data, 1);

        //Returns the result of the initialization
        return(data);
    }

    unsigned char initSocketCh0(    unsigned char control,
                                    unsigned char hport,
                                    unsigned char lport)
    {
        unsigned char data;
        // set SOPR register
        data = 0x01; //TCP communications
        i2cTx( control, 0x00, 0xA1, &data, 1);

        // set SPR registers, sets the port to listen on
        buffer[0] = hport;
        buffer[1] = lport;
        i2cTx( control, 0x00, 0xAE, buffer, 2);

        // set TOSR register to 1
        // data alreadyt = 1 so it will not be set again
        i2cTx( control, 0x00, 0xB1, &data, 1);

        // set transmisoin pointers
        memset(buffer, 0, 10); // set first 10 buffer locations to 0
        // set C0_TW_PR 01 - 04 to 0
        // set C0_TR_PR 01 - 04 to 0
        i2cTx( control, 0x00, 0x40, buffer, 8);
        // set C0_TA_PR 01 - 04 to 0
        i2cTx( control, 0x00, 0x18, buffer, 4);

        // initilise socket
        data = 0b00000010;
        i2cTx( control, 0x00, 0x00, &data, 1);

        //clear interupts
        data = 0xFF;
        i2cTx( control, 0x00, 0x08, &data, 1);

        //check if socket initialized
        i2cRx( control, 0x00, 0x04, &data, 1);

        return(data);
    }

    void stringUARTS(char * string, unsigned char length){

```

```

        unsigned char x;
        for( x = 0; x < length; x++){
            while (BusyUSART());
            WriteUSART(string[x]);
        }
        return;
    }

int reciveData(unsigned char control)
{
    unsigned char  C0_RW_PR[4], C0_RR_PR[4], data, adhigh, adlow,
                  rxlength = 0;
    unsigned int   counter, rstart, rend;

    memset(C0_RW_PR, 0, 4);
    memset(C0_RR_PR, 0, 4);

    // get pointers for recived data
    //check shadow pointer C0_SRW_PR
    i2cRx( control, 0x01, 0xE0, &data, 1);

    //wait 20 clock cycles
    Delay10TCYx(2);

    //Get the C0_RW_PR pointers
    i2cRx( control, 0x00, 0x10, C0_RW_PR, 4);

    //check shadow pointer C0_SRR_PR
    i2cRx( control, 0x01, 0xE1, &data, 1);

    //wait 20 clock cycles
    Delay10TCYx(2);

    //Get the C0_RR_PR pointers
    i2cRx( control, 0x00, 0x14, C0_RR_PR, 4);

    //Convert pointer into offsets
    rstart = C0_RR_PR[2];
    rstart = rstart << 8;
    rstart &= 0x1F00;
    rstart += C0_RR_PR[3];

    rend = C0_RW_PR[2] ;
    rend = rend << 8;
    rend &= 0x1F00;
    rend += C0_RW_PR[3];
}

```

```

//Find length of information in buffer
if(rend > rstart){
    counter = rend - rstart;
    data = 0;
}
else{
    counter = (rend + 0x1FFF) - rstart;
    data = 1;
}
if(rend == rstart){
    return(0);
}
rxlength = 0;

while(counter){
    adhigh = rstart >> 8;
    adhigh += 0x60;
    adlow = rstart & 0x00FF;
    if( counter < 80){
        rxlength = counter;
    }
    else
        rxlength = 80;
    if ( (rstart + rxlength) > 0x1FFF){
        rxlength = 0x2000 - rstart;
    }

    i2cRx( control, adhigh, adlow, buffer, rxlength);

    stringUARTS((char *)buffer, rxlength);

    rstart += rxlength;
    if (rstart > 0x1FFF){
        rstart -= 0x2000;
    }
    counter -= rxlength;
}
i2cTx( control, 0x00, 0x14, CO_RW_PR, 4);
data = 0b01000000;
i2cTx( control, 0x00, 0x00, &data, 1);
return(1);
}

void trasmitData( unsigned char control, unsigned char * string,
                 unsigned char length){

    unsigned char CO_TW_PR[4], data, adhigh, adlow, txlength, offset = 0;
    unsigned char * TW;

    unsigned int counter, tstart, tend;

```

```

unsigned long  C0_TW;

char           y;

TW = (unsigned char *)&C0_TW;

// get pointers for received data
//check shadow pointer C0_STW_PR
i2cRx( control, 0x01, 0xF0, &data, 1);

//wait 20 clock cycles
Delay10TCYx(2);

//Get the C0_TW_PR pointers
i2cRx( control, 0x00, 0x40, C0_TW_PR, 4);

y = 3;

for(y = 3; y >= 0; y--){
    TW[y] = C0_TW_PR[3 - y];
}
before = C0_TW;
C0_TW += length;
after = C0_TW;

//Convert pointer into offsets
tstart = C0_TW_PR[2];
tstart = tstart << 8;
tstart &= 0x1F00;
tstart += C0_TW_PR[3];

while(length){
    adhigh = tstart >> 8;
    adhigh += 0x40;
    adlow = tstart & 0x00FF;

    if ( (tstart + length) > 0x1FFF)
        txlength = 0x2000 - tstart;
    else
        txlength = length;

    i2cTx( control, adhigh, adlow, string + offset, txlength);

    tstart += txlength;
    if (tstart > 0x1FFF){
        tstart -= 0x2000;
    }
    length -= txlength;
    offset += txlength;
}
for(y = 3; y >= 0; y--){

```

```

        C0_TW_PR[y]= TW[3 - y] ;
    }

    // Update the C0_TW_PR pointers
    i2cTx( control, 0x00, 0x40, C0_TW_PR, 4);

    // Execute a send comand
    data = 0b00100000;
    i2cTx( control, 0x00, 0x00, &data, 1);

    return;
}

char * asciAcell(int value, char * string){
    int letter;
    if (value < 0){
        value = value * -1;
        string[0] = 45;
    }
    else
        string[0] = 32;
    letter = value / 1000;
    value = value - (1000 * letter);
    string[1] = letter + 48;
    string[2] = 46;
    letter = value / 100;
    value = value - (100 * letter);
    string[3] = letter + 48;
    letter = value / 10;
    value = value - (10 * letter);
    string[4] = letter + 48;
    string[5] = value + 48;
    return(string);
}

char * getacell(char chan, char * outputB){
    int acell;
    unsigned int acell_16 = 0 ;
    char x;
    short long voltage;
    if( chan == 0)
        SetChanADC(ADC_CH0);
    if( chan == 1)
        SetChanADC(ADC_CH1);
    if( chan == 2)
        SetChanADC(ADC_CH2);
    if( chan == 3)
        SetChanADC(ADC_CH3);
    Delay10TCYx(7);
    for( x = 0; x < 16; x++){
        ConvertADC();
    }
}

```

```

        while(BusyADC());
        acell = ReadADC();
        acell_16 += acell;
    }
    acell = acell_16 >> 4;
    doug = acell;
    acell -= 511;
    voltage = acell;
    voltage = voltage * 1000;
    voltage = voltage / 204; //205
    acell = voltage;
    asciAcell(acell, outputB);
    outputB[6] = 32;
    if( chan == 0)
        outputB[7] = 90;
    if( chan == 1)
        outputB[7] = 89;
    if( chan == 2)
        outputB[7] = 90;
    if( chan == 3)
        outputB[7] = 88;
    outputB[8] = 13;
    outputB[9] = 10;
    return(outputB);
}

char * getanalog(char * outputB){
    int NS = 0, EW = 0, power = 0, NS16 = 0, EW16 = 0, power16 = 0, x;
    char stringL;
    short long voltage;
    SetChanADC(ADC_CH4);
    Delay10TCYx(7);
    for( x = 0; x < 16; x++){
        ConvertADC();
        while(BusyADC());
        NS = ReadADC();
        NS16 += NS;
    }
    SetChanADC(ADC_CH5);
    Delay10TCYx(7);
    for( x = 0; x < 16; x++){
        ConvertADC();
        while(BusyADC());
        EW = ReadADC();
        EW16 += EW;
    }
    NS = NS16 >> 4;
    EW = EW16 >> 4;
    SetChanADC(ADC_CH6);
    Delay10TCYx(7);
    for( x = 0; x < 16; x++){

```

```

        ConvertADC();
        while(BusyADC());
        power = ReadADC();
        power16 += power;
    }
    power = power16 >> 4;
    itoa( NS, charbuff);
    strcpy(outputB, charbuff);
    stringL = strlen(outputB);
    outputB[stringL] = 32;
    outputB[stringL+1] = 0;
    itoa( EW, charbuff);
    strcat(outputB, charbuff);
    stringL = strlen(outputB);
    outputB[stringL] = 32;
    outputB[stringL+1] = 0;
    voltage = power;
    voltage = voltage * 1000;
    voltage = voltage / 205;
    power = voltage;
    asciAcell(power, charbuff);
    charbuff[6] = 32;
    charbuff[7] = 86;
    charbuff[8] = 0;
    strcat(outputB, charbuff);
    stringL = strlen(outputB);
    outputB[stringL] = 32;
    outputB[stringL+1] = 0;
    return (outputB);
}

void main (void){

    unsigned char wiznet = 0b10101010, length;
    unsigned int y;
    int pitch, roll;

    // initialize PIC peripherals

    OpenUSART( USART_TX_INT_OFF &           // TX interrupt off
               USART_RX_INT_OFF &         // RX interrupt off
               USART_ASYNCH_MODE &        // Asynchronous mode
               USART_EIGHT_BIT &          // 8-Bit
               USART_CONT_RX &             // Continuous receive
               USART_BRGH_LOW,             // Low Baud rate formula
               64);                         // set approximately 9.6 kbs

    OpenI2C( MASTER, SLEW_ON);             // I2C master mode 100kHz mode
    SSPADD = 99;

```

```

OpenADC(    ADC_FOSC_64 &
            ADC_RIGHT_JUST &
            ADC_8ANA_0REF,
            ADC_CH0 &
            ADC_INT_OFF);

TRISA = 0xFF;
TRISE = 0x0F;

OpenTimer0( TIMER_INT_OFF &
            T0_16BIT &
            T0_SOURCE_INT &
            T0_EDGE_FALL &
            T0_PS_1_1 );

TRISD = 0xFF;
LATD = 255;

WriteUSART( 12 );
// wait for screen to finish clearing
Delay10KTCYx(50);

while (BusyUSART());
putsUSART( welcomeMsg);

// wait .5 sec and then clear screen
Delay10KTCYx(250);
Delay10KTCYx(250);
WriteUSART( 12 );
// wait for screen to finish clearing
Delay10KTCYx(50);

status = 0;

// initilase the IINCHIP
status = InitWiznet(wiznet);

// clear buffer
memset(buffer, 0, 80);

// out puts result of initilazation to LCD
// a resut of 1 means the system initilized
while (BusyUSART());
putsUSART( initStMsg );
while (BusyUSART());
putsUSART( btoa(status, charbuff) );
while (BusyUSART());
WriteUSART( 10 );

while(1){

```

```

// socket initialization
// setting ch0 listen on port 23 for a connection
status = initSocketCh0( wiznet, 0, 23);

// clear buffer
memset(buffer, 0, 10);

// out puts result of initialization to LCD
// a result of 2 means the socket initializes
while (BusyUSART());
putsUSART( socketInitStMsg );
while (BusyUSART());
putsUSART( btoa(status, charbuff));
while (BusyUSART());
WriteUSART( 10 );

// now listen for a connection wait for a connection;
buffer[0] = 0b00001000;
i2cTx( wiznet, 0x00, 0x00, buffer, 1);

while (BusyUSART());
putsUSART( WaitConectMsg);
while (BusyUSART());
WriteUSART( 10 );

// check the Socket State Register for ch0
// a value of 0x06 means a connection has been established
while (status != 0x06){
//     Delay10KTCYx(1);

// before connecting display the accelerations for calibration
getacell(0, charbuff);
charbuff[8] = 13;
while (BusyUSART());
WriteUSART(32);
stringUARTS(charbuff, 9);
getacell(1, charbuff);
charbuff[8] = 13;
while (BusyUSART());
WriteUSART(32);
stringUARTS(charbuff, 9);
Delay10TCYx(100);
getacell(2, charbuff);
charbuff[8] = 13;
while (BusyUSART());
WriteUSART(32);
while (BusyUSART());
WriteUSART(32);
stringUARTS(charbuff, 9);
getacell(3, charbuff);

```

```

charbuff[8] = 13;
while (BusyUSART());
WriteUSART(32);
while (BusyUSART());
WriteUSART(32);
stringUARTS(charbuff, 9);
getanalog((char *) buffer);
length = strlen((char *)buffer);
while (BusyUSART());
WriteUSART(32);
while (BusyUSART());
WriteUSART(32);
stringUARTS((char *)buffer, length);
i2cRx( 0x08, 0x00, 0xA0, (unsigned char *)&pitch, 2);
itoa( pitch, (char *)buffer);
length = strlen((char *)buffer);
buffer[length] = 13;
length ++;
buffer[length] = 0;
stringUARTS((char *)buffer, length);

// wait .2 sec
Delay10KTCYx(200);

WriteUSART( 12 );

// wait for screen to finish clearing
Delay10KTCYx(60);

i2cRx( wiznet, 0x00, 0xA0, &status, 1);

}
while (BusyUSART());
putsUSART( conectEstabMsg);

// wait 1 sec and then clear screen
Delay10KTCYx(250);
Delay10KTCYx(250);
Delay10KTCYx(250);
Delay10KTCYx(250);
WriteUSART( 12 );

// wait for screen to finish clearing
Delay10KTCYx(50);

INTCON = 0b10100000;

// while the connection is open do all this stuff
while (status == 0x06){
// check the recive buffer to see if ther is any incomming data

```

```

//
// for the LCD screen and output it
recvData(wiznet);
if(time > 1000) time = 0;
timelast = time;

// reduces the number of transmissions

if ( timelast % 40 == 0){
    getacell(0, charbuff);
    charbuff[8] = 32;
    charbuff[9] = 0;
    strcpy((char *)buffer, charbuff);

    getacell(1, charbuff);
    charbuff[8] = 32;
    charbuff[9] = 0;
    strcat((char *)buffer, charbuff);

    getacell(2, charbuff);
    charbuff[8] = 32;
    charbuff[9] = 0;
    strcat((char *)buffer, charbuff);

    getacell(3, charbuff);
    charbuff[8] = 32;
    charbuff[9] = 0;
    strcat((char *)buffer, charbuff);
    length = strlen((char *) buffer);
    trasmitData(wiznet,buffer,length);

    getanalog ((char *)buffer);

    i2cRx( 0x08, 0x00, 0xA0, (unsigned char
*&pitch, 2);

    itoa( pitch, charbuff);
    strcat((char *)buffer, charbuff);
    length = strlen((char *)buffer);
    buffer[length] = 32;
    length++;
    buffer[length] = 0;
    length++;
    itoa( timelast, charbuff);
    strcat((char *)buffer, charbuff);
    length = strlen((char *)buffer);
    if(timelast == 1000){
        buffer[length] = 32;
        length ++;
    }
    else{
        buffer[length] = 10;
        length ++;
    }
}

```

```

        buffer[length] = 13;
        length ++;
    }
    trasmitData(wiznet,buffer,length);
}

if( timelast == 1000){ // 275

    // access the GPS and get last update
    i2cRx( 0x0F, 0x00, 0x00, buffer, 80);

    // transmit the last updata
    length = strlen((char *)buffer);
    trasmitData(wiznet,buffer, length);
    time -= 1000;

}
// Check the current conection status
i2cRx( wiznet, 0x00, 0xA0, &status, 1);
}
}
}

```

## Appendix E – Accelerometer Testing Data

The following sample of raw data was collected by the accelerometer during the displacement catamarans rough water test and represents the first two pages of data. A total of 7535 lines of data were recorded during the test.

0.196	Z	0.612	Y	0.514	Z	0.607	X
0.176	Z	0.607	Y	0.411	Z	0.504	X
0.264	Z	0.553	Y	0.49	Z	0.544	X
0.196	Z	0.627	Y	0.441	Z	0.495	X
0.102	Z	0.563	Y	0.397	Z	0.519	X
0.142	Z	0.602	Y	0.357	Z	0.485	X
0.181	Z	0.612	Y	0.406	Z	0.524	X
0.181	Z	0.676	Y	0.397	Z	0.485	X
0.191	Z	0.578	Y	0.392	Z	0.436	X
0.132	Z	0.612	Y	0.401	Z	0.441	X
0.122	Z	0.593	Y	0.352	Z	0.426	X
0.161	Z	0.612	Y	0.357	Z	0.446	X
0.191	Z	0.627	Y	0.387	Z	0.465	X
0.151	Z	0.632	Y	0.392	Z	0.48	X
0.122	Z	0.661	Y	0.377	Z	0.48	X
0.142	Z	0.686	Y	0.362	Z	0.485	X
0.137	Z	0.784	Y	0.446	Z	0.563	X
0.151	Z	0.735	Y	0.372	Z	0.49	X
0.176	Z	0.74	Y	0.431	Z	0.544	X
0.21	Z	0.705	Y	0.421	Z	0.514	X
0.338	Z	0.691	Y	0.529	Z	0.568	X
0.318	Z	0.632	Y	0.549	Z	0.558	X
0.377	Z	0.544	Y	0.544	Z	0.539	X
0.352	Z	0.475	Y	0.524	Z	0.504	X
0.367	Z	0.441	Y	0.534	Z	0.5	X
0.357	Z	0.401	Y	0.519	Z	0.475	X
0.323	Z	0.372	Y	0.48	Z	0.436	X
0.274	Z	0.382	Y	0.431	Z	0.401	X
0.22	Z	0.426	Y	0.397	Z	0.382	X
0.161	Z	0.475	Y	0.348	Z	0.338	X
0.137	Z	0.549	Y	0.338	Z	0.333	X
0.073	Z	0.725	Y	0.372	Z	0.387	X
0.053	Z	0.686	Y	0.294	Z	0.338	X
0.093	Z	0.73	Y	0.303	Z	0.352	X
0.122	Z	0.769	Y	0.348	Z	0.406	X
0.112	Z	0.779	Y	0.367	Z	0.455	X
0.196	Z	0.769	Y	0.397	Z	0.485	X
0.254	Z	0.74	Y	0.45	Z	0.524	X
0.264	Z	0.696	Y	0.455	Z	0.539	X
0.294	Z	0.671	Y	0.475	Z	0.544	X

0.279	Z	0.602	Y	0.455	Z	0.529	X
0.235	Z	0.563	Y	0.416	Z	0.49	X
0.191	Z	0.529	Y	0.367	Z	0.45	X
0.181	Z	0.49	Y	0.348	Z	0.426	X
0.142	Z	0.465	Y	0.308	Z	0.392	X
0.112	Z	0.544	Y	0.382	Z	0.465	X
0.098	Z	0.48	Y	0.274	Z	0.382	X
0.127	Z	0.485	Y	0.294	Z	0.411	X
0.117	Z	0.622	Y	0.431	Z	0.539	X
0.161	Z	0.534	Y	0.352	Z	0.47	X
0.279	Z	0.627	Y	0.45	Z	0.539	X
0.254	Z	0.647	Y	0.509	Z	0.578	X
0.308	Z	0.627	Y	0.495	Z	0.549	X
0.352	Z	0.666	Y	0.529	Z	0.563	X
0.328	Z	0.696	Y	0.563	Z	0.583	X
0.318	Z	0.656	Y	0.504	Z	0.519	X
0.299	Z	0.651	Y	0.485	Z	0.49	X
0.245	Z	0.627	Y	0.436	Z	0.45	X
0.21	Z	0.607	Y	0.392	Z	0.416	X
0.171	Z	0.588	Y	0.357	Z	0.392	X
0.127	Z	0.588	Y	0.333	Z	0.397	X
0.112	Z	0.558	Y	0.308	Z	0.416	X
0.112	Z	0.544	Y	0.299	Z	0.421	X
0.156	Z	0.544	Y	0.333	Z	0.465	X
0.205	Z	0.593	Y	0.377	Z	0.524	X
0.215	Z	0.583	Y	0.392	Z	0.509	X
0.264	Z	0.607	Y	0.45	Z	0.529	X
0.333	Z	0.647	Y	0.534	Z	0.549	X
0.367	Z	0.656	Y	0.563	Z	0.563	X
0.338	Z	0.598	Y	0.529	Z	0.558	X
0.338	Z	0.602	Y	0.509	Z	0.558	X
0.274	Z	0.612	Y	0.475	Z	0.568	X
0.269	Z	0.627	Y	0.446	Z	0.558	X
0.171	Z	0.647	Y	0.436	Z	0.553	X
0.147	Z	0.602	Y	0.338	Z	0.475	X
0.122	Z	0.602	Y	0.299	Z	0.475	X
0.102	Z	0.612	Y	0.299	Z	0.49	X
0.098	Z	0.578	Y	0.279	Z	0.48	X
0.078	Z	0.622	Y	0.348	Z	0.534	X
0.088	Z	0.563	Y	0.308	Z	0.514	X
0.142	Z	0.598	Y	0.377	Z	0.558	X
0.161	Z	0.583	Y	0.387	Z	0.558	X
0.289	Z	0.593	Y	0.465	Z	0.598	X
0.264	Z	0.627	Y	0.534	Z	0.637	X
0.318	Z	0.593	Y	0.514	Z	0.602	X
0.333	Z	0.598	Y	0.553	Z	0.612	X
0.348	Z	0.578	Y	0.529	Z	0.588	X
0.333	Z	0.612	Y	0.558	Z	0.612	X
0.294	Z	0.602	Y	0.504	Z	0.563	X
0.264	Z	0.593	Y	0.441	Z	0.534	X

The following data represents the calibrated form of the accelerometers raw data from the rough water test. It also represents the first two pages of data collected.

<i>Average Acceleration (G's)</i>	<i>Surface Acceleration (G's)</i>	<i>Surface Acceleration. Minus Calibration No.</i>	<i>Surface Acceleration (m/s<sup>2</sup>)</i>
0.48225	1.48225	1.097461	10.76241592
0.4245	1.4245	1.039711	10.19608188
0.46275	1.46275	1.077961	10.57118624
0.43975	1.43975	1.054961	10.34563329
0.39525	1.39525	1.010461	9.909237366
0.3965	1.3965	1.011711	9.921495678
0.43075	1.43075	1.045961	10.25737344
0.43475	1.43475	1.049961	10.29660004
0.39925	1.39925	1.014461	9.948463966
0.3965	1.3965	1.011711	9.921495678
0.37325	1.37325	0.988461	9.693491066
0.394	1.394	1.009211	9.896979053
0.4175	1.4175	1.032711	10.12743533
0.41375	1.41375	1.028961	10.09066039
0.41	1.41	1.025211	10.05388545
0.41875	1.41875	1.033961	10.13969364
0.4825	1.4825	1.097711	10.76486758
0.437	1.437	1.052211	10.318665
0.47275	1.47275	1.087961	10.66925274
0.4625	1.4625	1.077711	10.56873458
0.5315	1.5315	1.146711	11.24539343
0.51425	1.51425	1.129461	11.07622872
0.501	1.501	1.116211	10.9462906
0.46375	1.46375	1.078961	10.58099289
0.4605	1.4605	1.075711	10.54912128
0.438	1.438	1.053211	10.32847165
0.40275	1.40275	1.017961	9.982787241
0.372	1.372	0.987211	9.681232753
0.35625	1.35625	0.971461	9.526778016
0.3305	1.3305	0.945711	9.274256778
0.33925	1.33925	0.954461	9.360064966
0.38925	1.38925	1.004461	9.850397466
0.34275	1.34275	0.957961	9.394388241
0.3695	1.3695	0.984711	9.656716128
0.41125	1.41125	1.026461	10.06614377
0.42825	1.42825	1.043461	10.23285682
0.46175	1.46175	1.076961	10.56137959
0.492	1.492	1.107211	10.85803075
0.4885	1.4885	1.103711	10.82370748
0.496	1.496	1.111211	10.89725735
0.46625	1.46625	1.081461	10.60550952
0.426	1.426	1.041211	10.21079185
0.38425	1.38425	0.999461	9.801364216
0.36125	1.36125	0.976461	9.575811266

0.32675	1.32675	0.941961	9.237481841
0.37575	1.37575	0.990961	9.718007691
0.3085	1.3085	0.923711	9.058510478
0.32925	1.32925	0.944461	9.261998466
0.42725	1.42725	1.042461	10.22305017
0.37925	1.37925	0.994461	9.752330966
0.47375	1.47375	1.088961	10.67905939
0.497	1.497	1.112211	10.907064
0.49475	1.49475	1.109961	10.88499904
0.5275	1.5275	1.142711	11.20616683
0.5425	1.5425	1.157711	11.35326658
0.49925	1.49925	1.114461	10.92912897
0.48125	1.48125	1.096461	10.75260927
0.4395	1.4395	1.054711	10.34318163
0.40625	1.40625	1.021461	10.01711052
0.377	1.377	0.992211	9.730266003
0.36125	1.36125	0.976461	9.575811266
0.3485	1.3485	0.963711	9.450776478
0.344	1.344	0.959211	9.406646553
0.3745	1.3745	0.989711	9.705749378
0.42475	1.42475	1.039961	10.19853354
0.42475	1.42475	1.039961	10.19853354
0.4625	1.4625	1.077711	10.56873458
0.51575	1.51575	1.130961	11.09093869
0.53725	1.53725	1.152461	11.30178167
0.50575	1.50575	1.120961	10.99287219
0.50175	1.50175	1.116961	10.95364559
0.48225	1.48225	1.097461	10.76241592
0.475	1.475	1.090211	10.6913177
0.45175	1.45175	1.066961	10.46331309
0.3905	1.3905	1.005711	9.862655778
0.3745	1.3745	0.989711	9.705749378
0.37575	1.37575	0.990961	9.718007691
0.35875	1.35875	0.973961	9.551294641
0.3955	1.3955	1.010711	9.911689028
0.36825	1.36825	0.983461	9.644457816
0.41875	1.41875	1.033961	10.13969364
0.42225	1.42225	1.037461	10.17401692
0.48625	1.48625	1.101461	10.80164252
0.5155	1.5155	1.130711	11.08848703
0.50675	1.50675	1.121961	11.00267884
0.524	1.524	1.139211	11.17184355
0.51075	1.51075	1.125961	11.04190544
0.52875	1.52875	1.143961	11.21842514
0.49075	1.49075	1.105961	10.84577244
0.458	1.458	1.073211	10.52460465
0.4835	1.4835	1.098711	10.77467423
0.437	1.437	1.052211	10.318665
0.4345	1.4345	1.049711	10.29414838
0.45275	1.45275	1.067961	10.47311974

The following sample of raw data was collected by the accelerometer during the displacement catamarans calm water test and represents the first two pages of data. A total of 3160 lines of data were recorded during the test.

0.191	Z	0.544	Y	0.318	Z	0.421	X
0.205	Z	0.563	Y	0.338	Z	0.436	X
0.196	Z	0.553	Y	0.333	Z	0.436	X
0.196	Z	0.553	Y	0.338	Z	0.436	X
0.2	Z	0.549	Y	0.333	Z	0.426	X
0.196	Z	0.534	Y	0.323	Z	0.421	X
0.2	Z	0.539	Y	0.328	Z	0.431	X
0.2	Z	0.539	Y	0.328	Z	0.426	X
0.196	Z	0.539	Y	0.323	Z	0.421	X
0.196	Z	0.534	Y	0.323	Z	0.421	X
0.196	Z	0.544	Y	0.328	Z	0.426	X
0.196	Z	0.539	Y	0.323	Z	0.426	X
0.191	Z	0.539	Y	0.323	Z	0.426	X
0.191	Z	0.529	Y	0.313	Z	0.416	X
0.181	Z	0.519	Y	0.303	Z	0.406	X
0.181	Z	0.524	Y	0.308	Z	0.411	X
0.186	Z	0.519	Y	0.303	Z	0.406	X
0.191	Z	0.539	Y	0.323	Z	0.426	X
0.191	Z	0.544	Y	0.323	Z	0.431	X
0.196	Z	0.539	Y	0.323	Z	0.426	X
0.196	Z	0.534	Y	0.323	Z	0.421	X
0.196	Z	0.539	Y	0.328	Z	0.426	X
0.191	Z	0.539	Y	0.323	Z	0.421	X
0.196	Z	0.539	Y	0.318	Z	0.426	X
0.191	Z	0.539	Y	0.323	Z	0.426	X
0.196	Z	0.544	Y	0.328	Z	0.431	X
0.196	Z	0.539	Y	0.318	Z	0.421	X
0.196	Z	0.539	Y	0.323	Z	0.426	X
0.196	Z	0.539	Y	0.323	Z	0.426	X
0.186	Z	0.529	Y	0.313	Z	0.416	X
0.186	Z	0.534	Y	0.318	Z	0.421	X
0.191	Z	0.534	Y	0.318	Z	0.421	X
0.191	Z	0.529	Y	0.308	Z	0.411	X
0.186	Z	0.524	Y	0.303	Z	0.411	X
0.181	Z	0.519	Y	0.299	Z	0.406	X
0.186	Z	0.529	Y	0.308	Z	0.411	X
0.191	Z	0.529	Y	0.308	Z	0.406	X
0.181	Z	0.534	Y	0.318	Z	0.416	X
0.196	Z	0.529	Y	0.318	Z	0.416	X
0.196	Z	0.524	Y	0.318	Z	0.416	X
0.196	Z	0.519	Y	0.318	Z	0.416	X
0.191	Z	0.514	Y	0.313	Z	0.406	X
0.186	Z	0.529	Y	0.318	Z	0.416	X
0.181	Z	0.539	Y	0.318	Z	0.426	X

0.191	Z	0.539	Y	0.318	Z	0.421	X
0.2	Z	0.558	Y	0.333	Z	0.436	X
0.2	Z	0.553	Y	0.333	Z	0.436	X
0.2	Z	0.553	Y	0.333	Z	0.436	X
0.196	Z	0.544	Y	0.323	Z	0.426	X
0.191	Z	0.524	Y	0.308	Z	0.411	X
0.196	Z	0.529	Y	0.313	Z	0.411	X
0.191	Z	0.529	Y	0.313	Z	0.416	X
0.191	Z	0.524	Y	0.308	Z	0.411	X
0.186	Z	0.529	Y	0.308	Z	0.416	X
0.186	Z	0.524	Y	0.303	Z	0.411	X
0.186	Z	0.534	Y	0.313	Z	0.421	X
0.191	Z	0.524	Y	0.308	Z	0.411	X
0.181	Z	0.534	Y	0.313	Z	0.436	X
0.205	Z	0.544	Y	0.333	Z	0.475	X
0.2	Z	0.549	Y	0.318	Z	0.5	X
0.196	Z	0.539	Y	0.333	Z	0.509	X
0.196	Z	0.549	Y	0.362	Z	0.514	X
0.2	Z	0.529	Y	0.348	Z	0.5	X
0.23	Z	0.553	Y	0.357	Z	0.504	X
0.205	Z	0.544	Y	0.397	Z	0.529	X
0.215	Z	0.544	Y	0.372	Z	0.5	X
0.215	Z	0.563	Y	0.357	Z	0.504	X
0.2	Z	0.588	Y	0.377	Z	0.529	X
0.205	Z	0.563	Y	0.357	Z	0.514	X
0.2	Z	0.539	Y	0.328	Z	0.485	X
0.22	Z	0.553	Y	0.348	Z	0.504	X
0.2	Z	0.583	Y	0.377	Z	0.529	X
0.2	Z	0.549	Y	0.333	Z	0.49	X
0.23	Z	0.578	Y	0.362	Z	0.529	X
0.215	Z	0.553	Y	0.333	Z	0.495	X
0.2	Z	0.529	Y	0.333	Z	0.49	X
0.205	Z	0.529	Y	0.343	Z	0.49	X
0.22	Z	0.519	Y	0.333	Z	0.485	X
0.205	Z	0.509	Y	0.338	Z	0.485	X
0.23	Z	0.544	Y	0.357	Z	0.49	X
0.21	Z	0.544	Y	0.357	Z	0.475	X
0.191	Z	0.519	Y	0.318	Z	0.455	X
0.2	Z	0.563	Y	0.352	Z	0.504	X
0.225	Z	0.524	Y	0.338	Z	0.475	X
0.22	Z	0.534	Y	0.338	Z	0.48	X
0.181	Z	0.519	Y	0.318	Z	0.47	X
0.2	Z	0.504	Y	0.313	Z	0.455	X
0.186	Z	0.519	Y	0.308	Z	0.46	X
0.196	Z	0.539	Y	0.313	Z	0.47	X
0.2	Z	0.534	Y	0.313	Z	0.455	X
0.166	Z	0.539	Y	0.338	Z	0.485	X
0.205	Z	0.529	Y	0.318	Z	0.47	X
0.2	Z	0.553	Y	0.323	Z	0.475	X
0.191	Z	0.573	Y	0.357	Z	0.509	X

The following data represents the calibrated form of the accelerometers raw data from the calm water test. It also represents the first two pages of data collected.

<i>Average Acceleration (G's)</i>	<i>Surface Acceleration (G's)</i>	<i>Surface Acceleration. Minus Calibration No.</i>	<i>Surface Acceleration (m/s<sup>2</sup>)</i>
0.3685	1.3685	0.983711	9.646909478
0.3855	1.3855	1.000711	9.813622528
0.3795	1.3795	0.994711	9.754782628
0.38075	1.38075	0.995961	9.767040941
0.377	1.377	0.992211	9.730266003
0.3685	1.3685	0.983711	9.646909478
0.3745	1.3745	0.989711	9.705749378
0.37325	1.37325	0.988461	9.693491066
0.36975	1.36975	0.984961	9.659167791
0.3685	1.3685	0.983711	9.646909478
0.3735	1.3735	0.988711	9.695942728
0.371	1.371	0.986211	9.671426103
0.36975	1.36975	0.984961	9.659167791
0.36225	1.36225	0.977461	9.585617916
0.35225	1.35225	0.967461	9.487551416
0.356	1.356	0.971211	9.524326353
0.3535	1.3535	0.968711	9.499809728
0.36975	1.36975	0.984961	9.659167791
0.37225	1.37225	0.987461	9.683684416
0.371	1.371	0.986211	9.671426103
0.3685	1.3685	0.983711	9.646909478
0.37225	1.37225	0.987461	9.683684416
0.3685	1.3685	0.983711	9.646909478
0.36975	1.36975	0.984961	9.659167791
0.36975	1.36975	0.984961	9.659167791
0.37475	1.37475	0.989961	9.708201041
0.3685	1.3685	0.983711	9.646909478
0.371	1.371	0.986211	9.671426103
0.371	1.371	0.986211	9.671426103
0.361	1.361	0.976211	9.573359603
0.36475	1.36475	0.979961	9.610134541
0.366	1.366	0.981211	9.622392853
0.35975	1.35975	0.974961	9.561101291
0.356	1.356	0.971211	9.524326353
0.35125	1.35125	0.966461	9.477744766
0.3585	1.3585	0.973711	9.548842978
0.3585	1.3585	0.973711	9.548842978
0.36225	1.36225	0.977461	9.585617916
0.36475	1.36475	0.979961	9.610134541
0.3635	1.3635	0.978711	9.597876228
0.36225	1.36225	0.977461	9.585617916
0.356	1.356	0.971211	9.524326353
0.36225	1.36225	0.977461	9.585617916
0.366	1.366	0.981211	9.622392853

0.36725	1.36725	0.982461	9.634651166
0.38175	1.38175	0.996961	9.776847591
0.3805	1.3805	0.995711	9.764589278
0.3805	1.3805	0.995711	9.764589278
0.37225	1.37225	0.987461	9.683684416
0.3585	1.3585	0.973711	9.548842978
0.36225	1.36225	0.977461	9.585617916
0.36225	1.36225	0.977461	9.585617916
0.3585	1.3585	0.973711	9.548842978
0.35975	1.35975	0.974961	9.561101291
0.356	1.356	0.971211	9.524326353
0.3635	1.3635	0.978711	9.597876228
0.3585	1.3585	0.973711	9.548842978
0.366	1.366	0.981211	9.622392853
0.38925	1.38925	1.004461	9.850397466
0.39175	1.39175	1.006961	9.874914091
0.39425	1.39425	1.009461	9.899430716
0.40525	1.40525	1.020461	10.00730387
0.39425	1.39425	1.009461	9.899430716
0.411	1.411	1.026211	10.0636921
0.41875	1.41875	1.033961	10.13969364
0.40775	1.40775	1.022961	10.03182049
0.40975	1.40975	1.024961	10.05143379
0.4235	1.4235	1.038711	10.18627523
0.40975	1.40975	1.024961	10.05143379
0.388	1.388	1.003211	9.838139153
0.40625	1.40625	1.021461	10.01711052
0.42225	1.42225	1.037461	10.17401692
0.393	1.393	1.008211	9.887172403
0.42475	1.42475	1.039961	10.19853354
0.399	1.399	1.014211	9.946012303
0.388	1.388	1.003211	9.838139153
0.39175	1.39175	1.006961	9.874914091
0.38925	1.38925	1.004461	9.850397466
0.38425	1.38425	0.999461	9.801364216
0.40525	1.40525	1.020461	10.00730387
0.3965	1.3965	1.011711	9.921495678
0.37075	1.37075	0.985961	9.668974441
0.40475	1.40475	1.019961	10.00240054
0.3905	1.3905	1.005711	9.862655778
0.393	1.393	1.008211	9.887172403
0.372	1.372	0.987211	9.681232753
0.368	1.368	0.983211	9.642006153
0.36825	1.36825	0.983461	9.644457816
0.3795	1.3795	0.994711	9.754782628
0.3755	1.3755	0.990711	9.715556028
0.382	1.382	0.997211	9.779299253
0.3805	1.3805	0.995711	9.764589278
0.38775	1.38775	1.002961	9.835687491