Stevens Institute of Technology

Solar Splash 2017 Team

Boat #15

Technical Report

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I. Executive Summary

This year, Stevens Institute of Technology has entered and will be participating in the Solar Splash competition for the first time. The rookie team consists of five mechanical engineers and two naval engineers who came together at the beginning of September 2016 to achieve one goal, to be competitive in Solar Splash 2017.

To understand the obstacles which would need to be overcome in the next nine months, a complete and in-depth technical review of the competition rules and requirements, along with a performance study on past champions was conducted. Based on the performance of these champions, specific design goals for each event were established, paying the most attention to sprint and endurance since those events weigh the heaviest throughout the competition. Achieving those design goals, however, were not the only challenges which would have to be overcome.

Unlike veteran teams, some who have had upwards of ten years to gather resources and perfect their current designs, everything needed to be developed from scratch. This included all system designs, inventory, intellectual and monetary support. To be able to successfully design, construct, and test an entire system that would be ready to compete at the end of the nine months, the team focused on fabricating their own custom hull design. However, for the majority of the other subsystems, the focus was to obtain and integrate commercially available components, instead of custom building those as well. Initially the team had little prior knowledge of electrical systems, which is heavily relied on for the subsystems. To select and integrate these components correctly, extensive research had to be conducted to grasp the fundamental electrical concepts of each subsystem. Only then could the design process begin.

Throughout the design process, numerous sponsors were obtained who helped develop and construct a modular design with interchangeable and moveable components to build two system configurations within one hull design. This was done to satisfy the strikingly different performance requirements of each of the on-water events. One configuration was designed for the sprint and slalom while the other was designed solely for the endurance.

Both configurations needed to be housed within one hull design that would be beneficial during both races. Due to manufacturers designing planing hulls to perform well at high speeds and displacement hulls for low speeds, it was next to impossible to find an off the shelf full which would accomplish both. Therefore, the team designed their own hull creating a balance between the two. Through the use of computational fluid dynamics and scale model tank testing in Stevens Institute of Technology's own Davidson Laboratory, a custom hull was designed and optimal centers of gravity were determined for each event. For each configuration, locations for each component have been designed to be adjusted to achieve these desired center of gravities.

Working closely with world renowned composite hull manufacturer Viking Yacht Company, the custom sixteen foot carbon-fiber hull utilizing materials from several other sponsors was fabricated. Carbon-fiber increases the structural strength of the hull while compromising little on weight. Keeping the weight to a minimum of the overall system, not just the hull, was a main concern throughout the entire design process.

Sponsors did not only provide materials and equipment, each one played a key role in the design process especially when it came to the power system designs.

The sprint event requires the system to release as much energy as possible to achieve competitive sprint speeds. However, during the endurance event energy needs to be conserved and consumed efficiently. A balance between speed, rate of battery drain, and energy produced by the panels had to be developed. After several discussions with Elco Motor Yachts and Zahn Electronics, two power system sponsors, a configuration was finalized for each event.

The sprint configuration consists of two Elco Motor Yacht outboard motors designed to be supplied their correct voltage and maximum rated amperage via a step-up DC/DC converter Zahn Electronics specifically built for the application. To conserve energy during the endurance event, only one of these outboard motors is to be utilized with a second DC/DC converter designed to perform efficiently at lower power.

Throughout the design process, focus was not only on the performance, but also on designing the boat to be flexible and user-friendly between events. Since the same motors and batteries are utilized for both configurations, it was vital that the connections to and from the motors, batteries, and converters could be disconnected and reassembled quickly and easily. This was accomplished by the use of Anderson Connectors provided by another team sponsor Anderson Power Products. As a result, switching from the sprint configuration to the endurance configuration and vice versa can be accomplished in mere minutes.

Once the boat was completely assembled, it was time for on-water testing to see if the performance of the boat met the design goals. Several times the boat was taken out on Lake Hopatcong in New Jersey to test the entire system and individual subsystems during sprint, endurance, and slalom scenarios. This included evaluating speed, amperage to the batteries from the solar panels, amperage to the motors from the batteries and voltage of each of the batteries throughout testing.

The team is excited and proud of what has been accomplished in under a year with the help of their generous sponsors and is eagerly awaiting the opportunity to compete in Solar Splash. However, the team is just as excited to have started a project to hand off to future teams and see how the performance and design of the boats progress and improves in the years to come.

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III. Overall Project Objectives

Although this was the first year for the Stevens Solar Splash 2017 Team, taking it easy and testing the waters the first time around was not an option. The team began with the mindset of developing a boat which could be competitive in all fronts. This meant focusing on the main scoring categories of the competition. The sprint and the endurance events weigh the heaviest in the competition making up 65% of all points available. Therefore, both of these events became the focus throughout the design process. There was no way to know how teams would perform in the 2017 competition, however, the performance of previous Solar Splash champions was available. Design goals for each event were created using the performance of previous year's champions, assuming performance would increase year after year.

For the sprint event, the goal is to produce enough output power to achieve speeds upwards of 24 knots. In endurance, the goal is to maintain a steady speed of 7 knots for each of the two, two hour trials, traveling a total distance of 52 kilometers.

To achieve these goals an extensive list of performance components and equipment was needed. Upfront Stevens Institute of Technology provides the same amount of funding to all senior design teams. However, to obtain everything needed to physically construct the boat and its subsystems a considerable amount of additional support was needed. Throughout the course of the project, manufacturers and organizations were contacted seeking support in the form of a donation, sponsorship or discounted prices, with the goal of obtaining all the desired components while remaining within budget.

Although winning the sprint and endurance events is the strategy for winning Solar Splash 2017 this does not mean the other scoring categories were neglected. As each system was built and integrated into the hull, careful attention was given to workmanship and visual presentation. The workmanship and visual presentation will illustrate the pride taken in the project and accomplishments that have been made.

IV. Solar System Design

Before a design for the solar system could be developed, calculations were conducted to determine the amount of solar insolation which could be expected during the competition in Ohio. These values would later help determine how much power could be produced by the solar panels and delivered to the batteries during the endurance and charging between events.

The endurance heats are run on the same day, at 10:00 AM - 12:00 PM, and 2:00 PM - 4:00 PM. To calculate the solar insolation at these times in Springfield, OH (39.8^{o} N), *Principles of Solar Engineering, Third Edition, by D. Yogi Goswami* [1], was used as a resource. Table A2.2c in Appendix B provides the average solar insolation at specific solar times on specific dates. The values of insolation that were used for interpolation were values for Lat. 40^{o} N, on May 21, and June 21 for a horizontal surface. The clearness ratio of Springfield, OH had to be incorporated into the calculations as well. The clearness ratio in Springfield, OH for the month of June, according to the *Solar Radiation Data Manual for Buildings* [2] is 0.53. This means 53% of the available insolation is available to be harvested by solar panels. The final values calculated can be seen in Fig. 1.

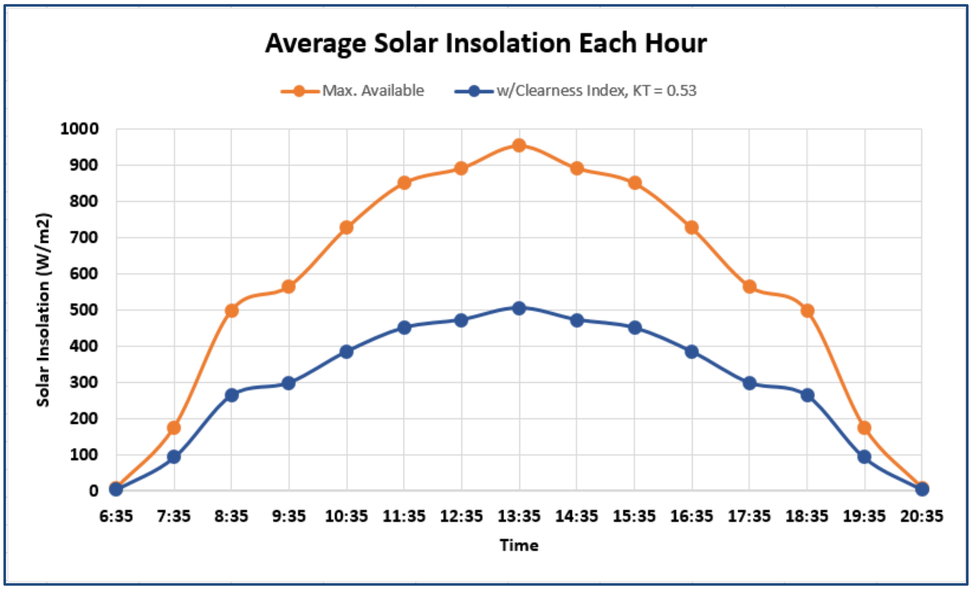


Fig. 1: Ideal vs. Expected Solar Insolation Values for Springfield, Ohio in June

The average insolation values for the 10:00 AM and 2:00 PM heats were ~ 406 W/m^2 and ~459 W/m^2, respectively. Incorporating the solar insolation and the two competition rules limiting nominal solar array output to 480 W and nominal source voltage to 36 V the solar system design could begin.

When selecting solar panels, the goal was to optimize the 480 W output limit and be capable of charging a 36 V battery bank after passing through the solar optimizer. In addition, throughout the search, the weight of the panels was always kept in mind. The weight concern made flexible solar panels much more attractive in comparison to rigid ones. After judging several different panels based on their wattage, voltage, weight, and price, KingSolar 120W 18V flexible solar panels, which each weigh less than five pounds, were selected. Four of these panels are incorporated into the design maximizing the solar array output limit of 480W.

To properly charge the batteries, a voltage exceeding the 36V battery bank needed to be generated from the solar array without exceeding the maximum 52V potential outlined in the Solar Splash 2017 rules. Several different devices were considered as possible solutions. A maximum power point tracking (MPPT) charge controller was first considered due to their ability to find and deliver the optimal voltage and amperage to charge batteries connected to the system. However, after contacting manufacturers of MPPT charge controllers and explaining the application, it was determined that the charge controllers were not capable of increasing the voltage as much as needed. Zahn was then contacted and informed of the challenges provided by the solar, they graciously offered to provide two solar optimizers which were capable of stepping up the voltage to a preset output.

Zahn's DCDC12/36/200OP solar optimizer is capable of increasing the voltage from the solar panels to a value anywhere between 40V and 55V by adjusting a potentiometer on the device. For this application the device has been set to 42 V which was found to be the optimal charge voltage of the 36 V battery bank after research. Each solar optimizer is only rated to be used with a solar array with an open circuit voltage up to 36V and a power rating of 200W, which means two solar optimizers needed to be used.

The four panels were divided into two pairs. Each pair is connected in parallel to provide 18 V at 6.66 A to the input of one of the solar optimizers, when considering the available solar insolation. On the output of each optimizer, the voltage is increased to 42 V at a decreased rate of 2.86 A. These outputs are then connected in parallel to deliver a total of 42 V at 5.72 A to the batteries.

After the technical design and analysis of the solar system was completed, it was time to design a system which would physically secure the panels, but allow for easy removal. Considering the design of the hull and position of the skipper in the boat, the available space for the solar panels allowed for a pair in the front and a pair in the back. To be able to connect each pair of solar panels in parallel MC4 Multi-Branch connectors were utilized.

The mounting system for the solar panels changed over time and was optimized to adhere to all competition rules while utilizing the materials which were available. The same system is used to secure both pairs of solar panels in the front and in the back of the boat. It incorporates three ½'' thick, 2'' high balsa wood boards stretching from port to starboard, connected down their centers to a larger 2'' X 2'' balsa wood spine.

The spine rises two inches above the hull which curves the solar panels slightly. This makes the solar panels more rigid to avoid wind shear. The balsa wood supports are connected to the hull using a system of brackets and pins. The brackets were 3D-printed and secured to the inside of the hull using adhesive. The brackets were designed with one edge angled to match the inner angle of the hull while the other edges form a slot for the balsa wood supports to fall right into place. Each bracket and each balsa wood support has a hole drilled through to allow for the clevis and cotter pins to secure the two pieces together. The finalized mounting structure can be seen in Fig. 2 below.

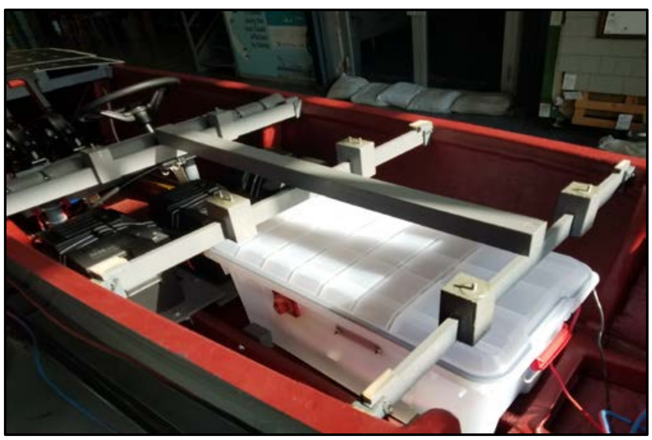


Fig. 2: Solar Mounting System

To mechanically fasten each solar panel to the mounting system, blocks of balsa were added to the supports and marine grade studs were attached to the top of each one to line up with rivet holes already manufactured into the solar panels. The solar panels would then be secured to the mounting system with lock nuts. The solar panels will be tethered to the hull using paracord.

Initially, the solar system was assembled outside of the boat. With the entire system assembled including solar panels and batteries, the voltages in and out of each converter were taken and their output voltages were fine-tuned by adjusting their potentiometers until an output of 42 V for each was achieved. Afterwards, the amperages in and out of each converter was measured. While taking these measurements the current weather conditions were noted. It was important to know how much amperage could expect on sunny days but also cloudy days.

After these tests were conducted outside of the boat, the system was incorporated into the boat and tested while the motors were running inside water barrels. This testing configuration has only been performed once on a partially cloudy day. The maximum amperage measured that day was 5.89 A into the batteries, which is higher than the calculated value of 5.72 A. During testing on May 8 at Lake Hopatcong, the solar panels provided 42 V at 11.1 A to the batteries while running in the endurance configuration. Similar tests will be conducted over the next month to optimize the system and develop a full understanding of how the solar system can be expected to perform during competition.

V. Power Electronics Design

The power electronics system was designed to convert and deliver power in the most efficient manner from the battery bank to the motors. This was accomplished using three 12V batteries, two DC/DC converters and a series of Anderson connections. To aid in the analysis of this system, a MATLAB model was developed which allowed us to better analyze system integration and expected performance.

Batteries requirements were identified after analysis of weight, discharge characteristics and power capacity. It was determined that UB12500 12 V 50Ah batteries would provide the benefits needed for the application. Three of these batteries were purchased and are connected in series to create a 36 V battery bank weighing a total of 90.6 pounds – which adheres to both competition limitations on battery voltage and weight. This battery bank is utilized for all on-water events. The configuration is not changed between events unlike some of the other subsystems.

After the batteries, comes the DC/DC converters. Since the motors, which will be discussed in the Drivetrain and Steering section later in the report, require 48V to operate the voltage needed to step-up the 36 V from the batteries to 48 V. However, for the sprint configuration two of these 48 V motors will be utilized while for the endurance configuration only using one. In addition, to produce the output power needed to achieve the desired speed during the sprint 90A needed to be delivered to each motor - a total of 180 A. While during the endurance, only 17.5 A was needed to produce the output power to achieve the desired speed. These striking differences in amperage requirements drove the use of two different converters.

For the sprint, a DC/DC36/48/9000 model Zahn Electronics converter is utilized and designed to operate at 8.6kW. For the endurance, a DC/DC6350-SU model Zahn Electronics converter is utilized and designed to operate at 840 W. Both of these converters have an efficiency of over 93%.

Since the batteries, converters, and motors were now all selected, a MATLAB SimuLink model could be developed to accurately simulate power consumption for both events. The block diagrams for both the sprint and endurance can be seen in Appendix E. These models utilize discharge curves of generic sealed lead acid batteries, which were then adjusted to accurately represent the chosen batteries. It then takes into account solar energy produced by the solar array (endurance), voltage drops, and efficiencies of components throughout the system.

Fig. 3 & 4 below are results from the endurance model illustrating state of charge and battery voltage over time, respectively. Delivering 17.5 A to the motor results in draining the batteries to 20% in a little over two and a half hours - which is what is desired during the endurance. Attention was paid to when the batteries drained to 20% because draining them further could potentially damage them.

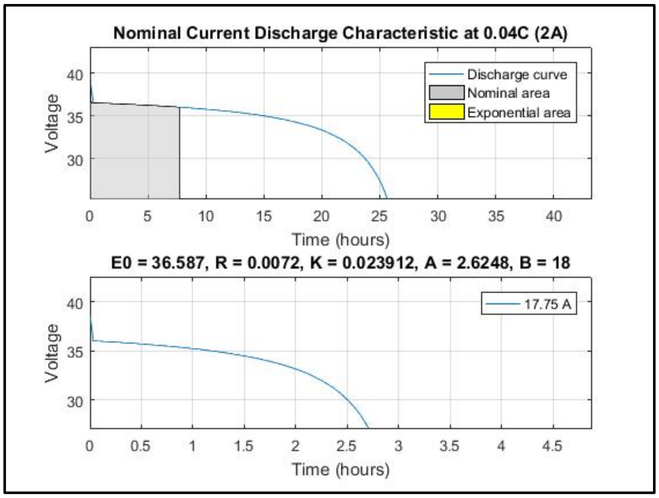


Fig. 3: Endurance Battery Voltage vs. Time MATLAB Output

Fig. 4 below was produced by the sprint model and illustrates that delivering 180 A to the motors will drain the batteries to 20% in about 15 minutes. Considering the sprint event is expected to only last 30 seconds, the results were satisfactory.

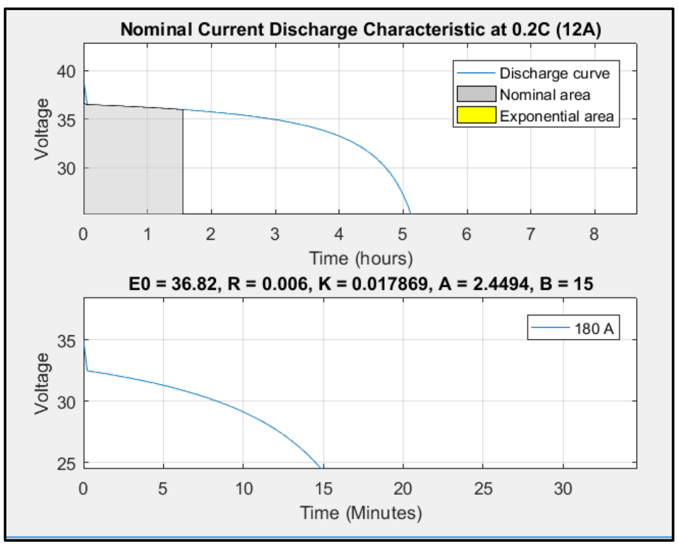


Fig. 4: Sprint Battery Voltage vs. Time MATLAB Output

These two models confirmed that the designs could perform as expected and provided confidence to move forward and begin the implementation process.

To assemble the power electronics system, the appropriately sized wire and all necessary electrical safety components needed to be utilized. The required wire size was based off of the expected amperage and length of each wire. 4/0 AWG wire was required for connections between the batteries and the converters due to the high amperage draw during the sprint event, 2/0 AWG was required for the connection between the converter and the split point to the motors, and 2 AWG was required for the connection from the split to the motor. To provide protection to the circuit, a 300 A fuse was placed in series with the battery bank. A Blue Sea System single circuit 350 A On/Off switch was placed in series with the battery bank. Each motor was also fit with a 150 A fuse in series after Anderson connectors 9 and 10. Each throttle is equipped with a deadman switch to meet safety requirements.

To make the changeover from sprint to endurance and vice versa quick, secure and safe, Anderson connections were utilized. Contacts on the Anderson connectors were installed using a pneumatic hydraulic crimping tool lent to use by Anderson Power Products to ensure that each connection was made properly. The Anderson connections are strategically placed on the wiring to allow conversion from one to two motors. Both the sprint and endurance arrangements can be seen on Fig. 5 & 6.

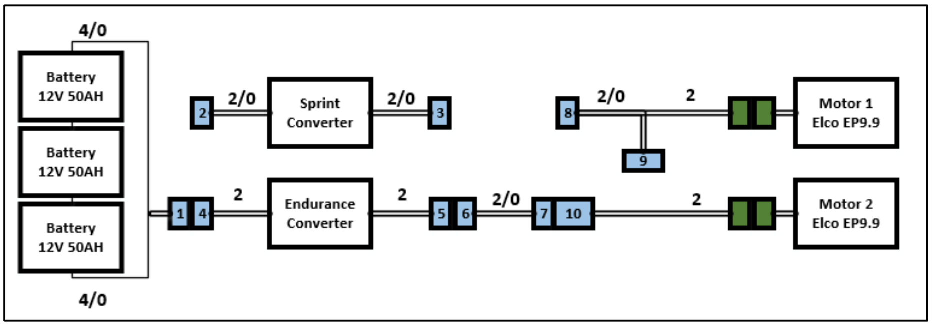


Fig. 5: Endurance Anderson Connection & Wiring Configuration

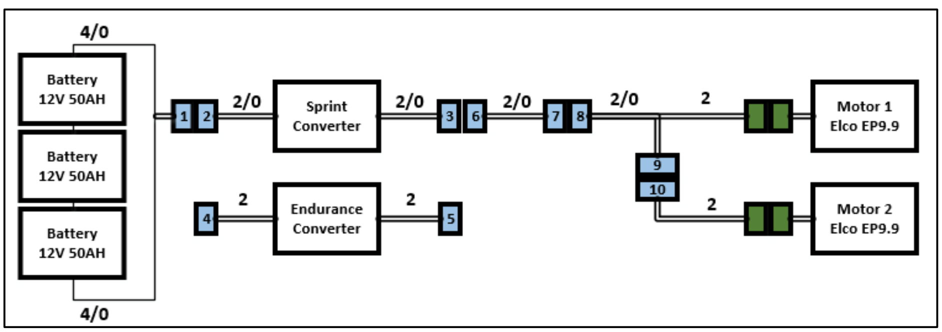


Fig. 6: Sprint & Slalom Anderson Connection & Wiring Configuration

Based on a weight study and analysis, which will be discussed later in the Hull Design section of the report, the batteries and converters were placed within the hull accordingly at the front of the boat in front of the skipper. Each battery is enclosed within its own battery box secured to the boat using a 1 ½ inch strap as required by the competition and each converter is placed and secured within a water resistant box which is also secured to the hull.

To accurately test this system, the motors need to be running but for the motors to run they need to be in water. Multiple times in the lab barrels of water were utilized to test the motors, mainly to ensure that the system would turn on and function properly. However, accurate test data for the sprint and endurance for the power electronics system itself cannot be obtained from this kind of step up. The performance of the system during each event relies on the load applied to the system. The load within the barrels is much different than the load on open water. Therefore, to collect accurate data, on-water testing was conducted. To this day, on-water testing has been conducted three times to collect preliminary data. However, over the next month before competition several more tests simulating sprint, slalom and endurance will be conducted. During these tests, the charge of the batteries will be monitored over time with a custom-made

Arduino battery monitor. In addition, the amperage from the converters will be measured periodically. The most important test will be to see if during the system can maintain desired speeds during endurance.

VI. Hull Design

The Solar Splash competition has a few restrictions regarding the overall dimensions of the hull. These include a maximum length overall of 6m (19.68 feet), a beam of 2.4m (7.87 feet) including the solar arrays, and a maximum running freeboard of 1.5m (4.92 feet). These are the first parameters that were used to start creating a hull design. The next step was to start creating several iterations of hull types to determine the most efficient design for low and high speeds.

To determine the effects of these hull characteristics, the 3D computer design program Rhino was used in collaboration with the Orca3D plugin and the Michlet program. Orca3D is a plugin that assists in hull design and analysis using the Savitsky and Holtrop methods. Michlet is a numerical analysis program that is more accurate in predicting hull drag for slender body hulls at low speeds. Both of these analysis programs were utilized to create a full spectrum prediction of the performance of each hull iteration to determine the most effective hull for the competition.

Taking into consideration the systems needed on board, the amount of space each item was going to take up, and the safety requirements for the skipper, the length and beam dimensions were determined. From there, more specific and intricate characteristics were changed such as: deadrise, chine width, bow rake angle and chine rounding. These characteristics were analyzed with small shifts in the length and beam to converge on the most effective parameters. Overall, 21 hull iterations were created and analyzed, 16 of which were planing hulls and 5 high speed displacement hulls. In the end, it was decided to take the top high speed displacement hull design and top planing hull design, both which can be seen in Fig. 7 & 8 respectively below, and compare them further to make a more definitive decision.

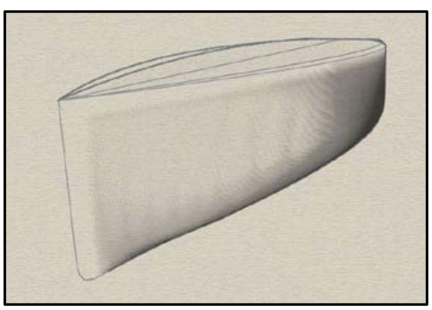


Fig. 7: Top Displacement Hull Design

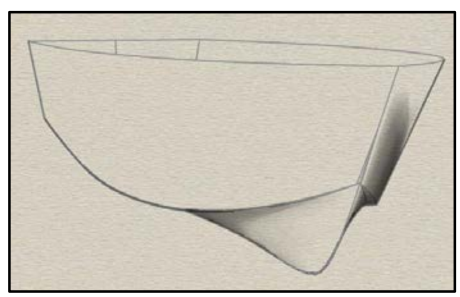


Fig. 8: Top Planing Hull Design

3D modeling and analysis software is extremely helpful in the development of a hull design. The 2 methods of hull analysis in Rhino that were used during hull generation use a database of information from tank testing to predict resistance and powering. The problem that lies within these programs arises when you have a unique design that is not geometrically similar to the models the database results are made from. Unfortunately, this was the case for the model. There was some confidence in the higher planing speeds, but anything in the pre-planing and lower speed regions were outside of Michlet's geometric parameters because the hull still had a transom section. To get more accurate data specific to the unique hull design, a more advanced testing method was needed. Model tow tank testing was a way to obtain accurate data that could add confidence to the development of the powering predictions.

A ¼ scale model was CNC cut in a high density foam with a modular chine section. This allowed testing of two different chine designs (rounded and hard) without having to build two separate models.

Model tank testing provided accurate numerical data but also provided visual data on how the water flows around the model, chines, and transom at different speeds. This showed if there was any unexpected behavior that could not have been predicted by a computer program such as run up.

Through tank testing, it was possible to change the longitudinal center of gravity (LCG) to determine its optimal location for each event. In addition, the amount of weight needed to be shifted to achieve the ideal LCG locations was determined. This was an important part of the testing as one of the ideas to mitigate some additional drag at low speeds with the hard chines was to load the bow to lift the transom out of the water. It was quickly found that this would not be possible as the required weight to do that is more than what was available to shift.

The first goal was to find reasonable and achievable LCG's to run during the endurance event that would be efficient at 7-9 knots. The first idea was to load the bow of the model high enough to have no transom immersion. This would allow the boat to act like a displacement to reduce transom immersion. Tests were run with a design LCG of 18 inches and were compared with drag results of the bow down LCG to the design LCG at low speed. The initial bow down LCG location was 30 inches forward of the transom. This location caused excessive drag in the first few runs and with water coming over the bow, which can be seen in Fig. 9, the remainder of the runs were stopped.

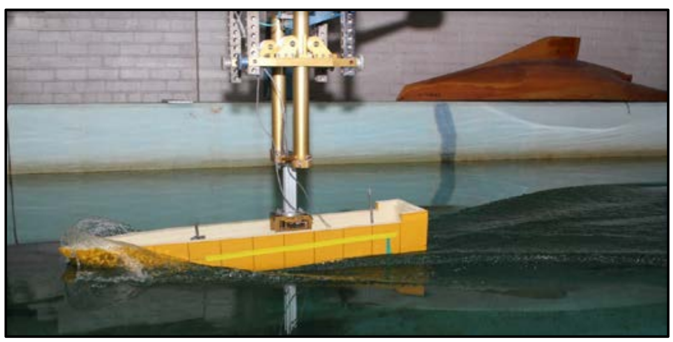


Fig. 9: An LCG of 30'' Causing Water to Come Over the Bow

The model was set back to design conditions and weight was shifted to create a 26 inch LCG. This LCG location kept the transom out of water at rest however as the speed increased the suction on the hull pulled the model down and caused a small section of the transom to be immersed. It was evident soon after that the suction on the hull was causing more drag than the design LCG as the model approached pre-planing speeds of 8-12 knots.

A third bow down LCG was then set up and tested at 22 inches forward of the transom. The results of the 22 inch LCG showed lower drag at 5 and 6 knots than the design LCG however that ceased to be the case at 7 and 8 knots.

Finally, a fourth change in LCG of 15 inches was tested. The results from the 15 inch LCG proved to be similar to those of the 22 inch. However, the benefits of the design LCG at low speed showed that even a small change of 1 foot, full scale, would help the hull perform better at low speeds. Therefore, both the 18 & 15 inch LCG's were considered as possibilities and were used during further tests to determine which chine design would be best for the application. Each chine design was tested at the same load and LCG locations and were compared to one another. Fig. 10 below, shows that at both LCG locations, hard chines had a better overall performance than the round chines.

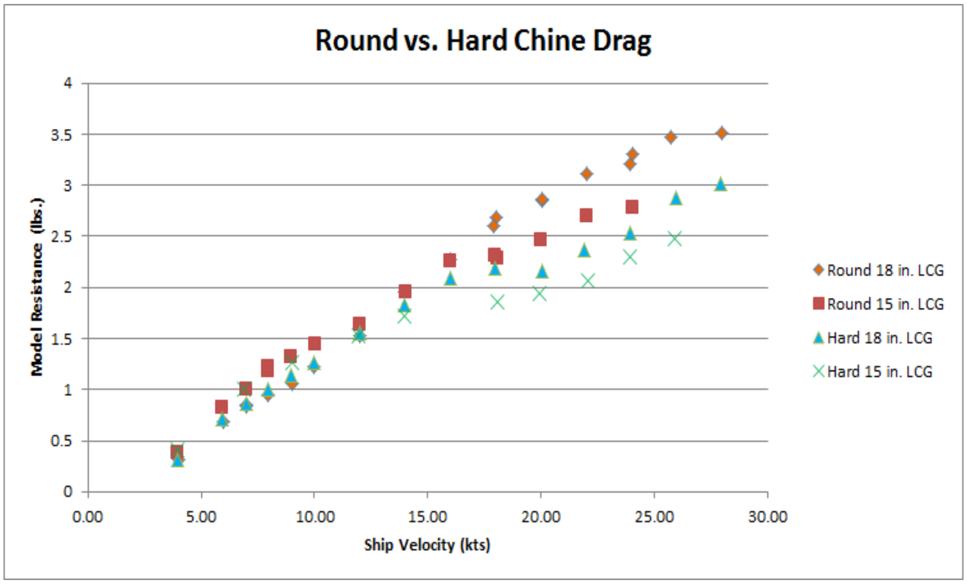


Fig. 10: Chine Type & LCG Location with Respect to Velocity & Resistance

The photos in Fig. 11 & 12 below were taken during a run with the same weight and LCG condition but different chine styles. It is evident that with the rounded chines the water is unable to separate from the hull and rides right up the sides. This creates additional drag at these higher speeds. The hard chines allow for the water to shear off the hull and reduce the drag.

Fig. 11: Water Unable to Separate from Hull with Rounded Chines

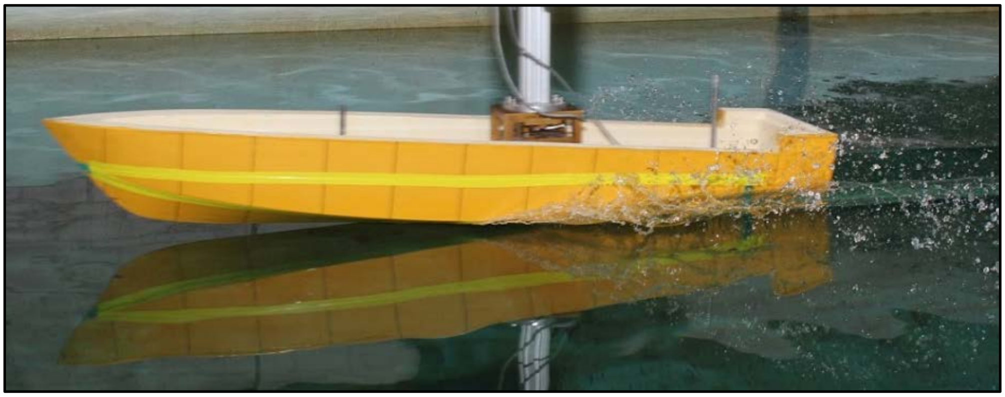


Fig. 12: Water Properly Separating from Hull with Hard Chines

As a result, hard chines would be used for the hull design. The focus now turned back to LCG location to find the optimal design conditions using these hard chines for each event. When analyzing the 15 and 18 inch LCG it was noticed that there was potential for a LCG between that may be efficient for both, allowing there to only design one configuration. Therefore, tests were done at a 16.5 inch LCG as well.

Fig. 13 below, shows that at lower speeds, an 18 inch LCG performs much better than the other two more aft LCGs. At higher speeds, both 16.5 and 15 inch LCGs perform better than the 18 inch. This means that less weight may need to be moved around to achieve the 16.5 in LCG from 18 inches and still get the same performance as a 15 in LCG.

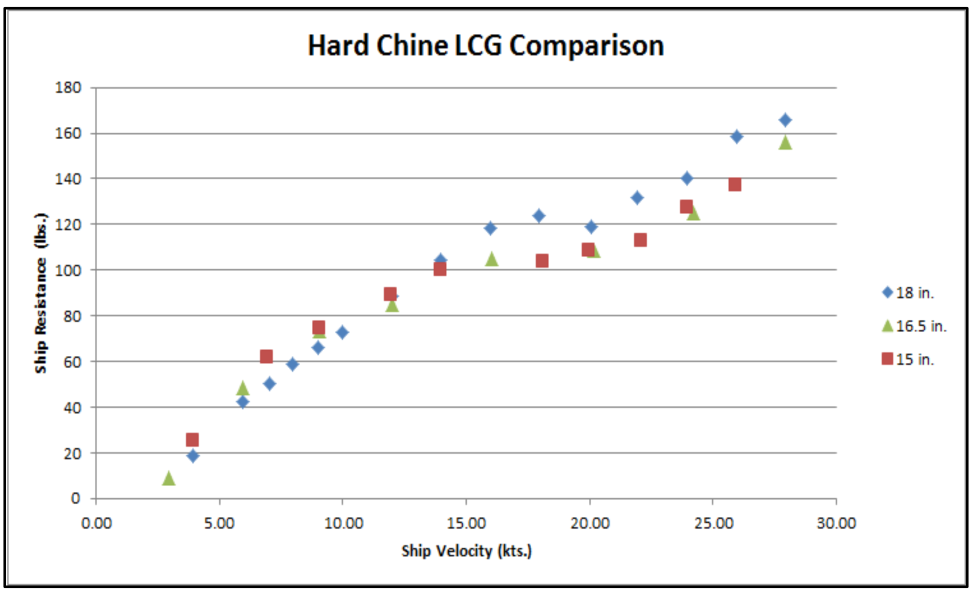


Fig. 13: Hard Chine & Longitudinal Center of Gravity with respect to Velocity & Resistance

Power requirements for each LCG needed to be considered as well. The following two graphs, Fig. 14 & 15, illustrate the power requirements at low and high speeds, respectively.

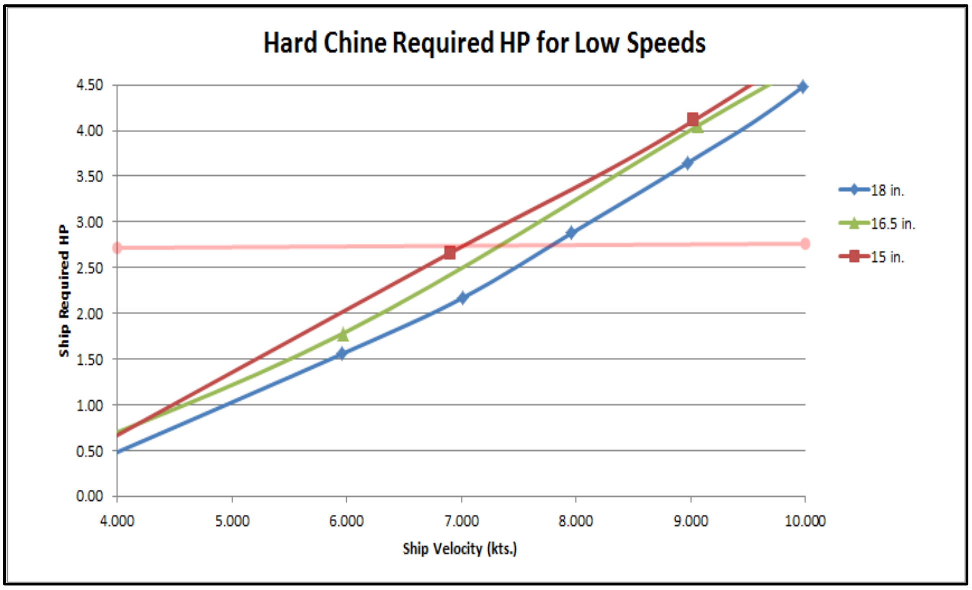


Fig. 14: Hard Chine Power Requirements at Low Speeds

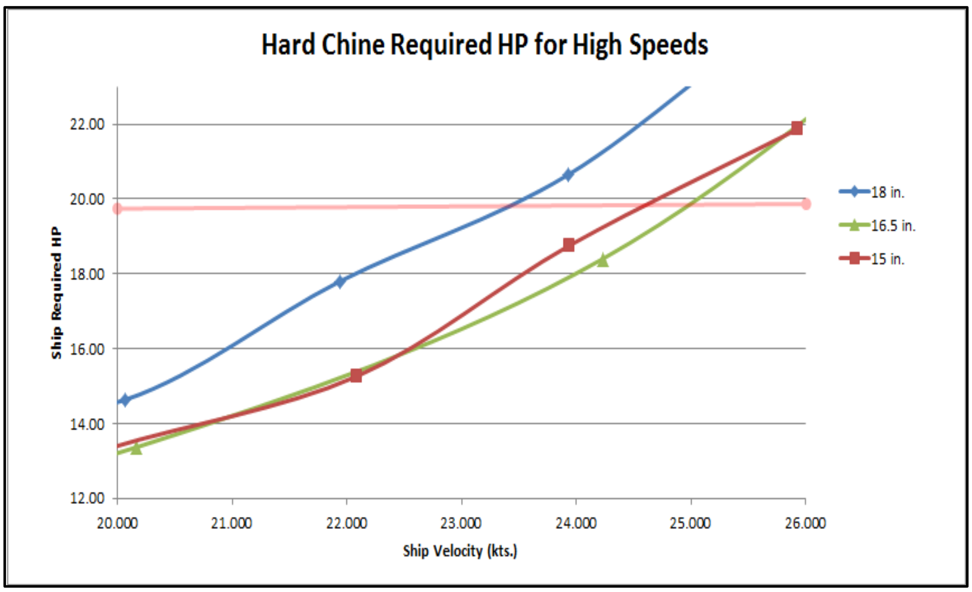


Fig. 15: Hard Chine Power Requirements at High Speeds

Based off of preliminary predictions of available power from the power electronics system, it was believed that about 2.5 HP for 2 hours could be supplied for the endurance, and about 19.8 HP could be supplied for the sprint. It can be seen that for low speeds, an LCG of 18 inches is the most efficient projected to achieve a speed of about 7.5 knots at the predicted horsepower, which is faster than the goal of 7 knots. However, for high speeds, an LCG of 16.5 inches proved to be the most efficient projected to achieve a speed of about 25 knots at the predicted horsepower, faster than the goal of 24 knots. Unfortunately, during production of the hull a heavier carbon fiber cloth was used and the total weight ended up being much heavier than expected. Worried about the possible implications this might have to the achievable speeds, tank testing was done for a second time. While finding that 5 knots was still achievable for the endurance event and 20 knots for the sprint, it was also found that an 18.75 inch LCG was more efficient for the low speeds. Therefore, an LCG of 75 inches became the goal for the endurance and an LCG of 66 inches became the goal for the sprint.

To achieve these desired LCG's a weight study was conducted for both the sprint and the endurance. SolidWorks models which included the hull and all its main components were developed for both events which can be seen in Fig. 16 & 17, respectively.

Fig. 16: Sprint SolidWorks Model

Fig. 17: Endurance SolidWorks Model

The weight and individual LCG's were input into SolidWorks for each component and the location of each of the components within the hull were adjusted until an acceptable LCG value was achieved. The detailed weight studies for both events with a list of all the components, their weights, and their final locations can be found in Appendix F. During physical assembly, each of the components were placed accordingly.

Due to the slender hull with a high length to beam ratio stability was a major concern. Orca3D provided static stability curves which were confirmed during on-water testing by conducting an inclining experiment. However, as the boat begins to move static stability is no longer accurate. Therefore, dynamic stability was calculated empirically utilizing *The Dynamics of Marine Craft, by Edward Lewandowski*. [3] The empirical results were verified using model scale testing in Davidson Laboratory Tank 3. The results of both static and dynamic stability tests show that the hull is stable at all conditions expected during Solar Splash 2017.

VII. Drivetrain and Steering

The design of the drivetrain started with researching and comparing the use and installation of electric inboard and outboard motors. At the same time, the naval engineers were conducting preliminary calculations based on predicted size and weight of the system to determine the output power needed to achieve the speeds desired. After target output power values were obtained motors could be narrowed down by voltage input and power output ratings. The predicted output horsepower needed for the endurance event was around 3 HP while for the sprint the horsepower needed was predicted to be about 20 HP.

Continuing to look at both inboard and outboard motors, it was determined that an inboard system due to its complexity and the time constraint would be too difficult. While researching commercially available outboard motor systems, Elco Motor Yachts was discovered.

Three different outboard systems were available that ran on a 48 V input - one rated for 9.9 HP, 14 HP and 20 HP.

After discussing in detail the needs and constraints, a system for each event was finalized. This set-up consisted of two 48V EP-9.9 motors to satisfy the needs of the sprint event, but for the endurance one of the 48 V motors would be removed and set inside the boat to achieve the optimal center of gravity.

After determining that the two Elco EP 9.9 outboard motors would be used, the search began for a steering system that would be compatible. Along with donating the two outboard systems, Elco also supplied two throttles and a hydraulic steering system. Although the hydraulic steering system was more than enough to turn both Elco outboards, it was very heavy and the hydraulic line was much too long for the boat adding unnecessary weight to the boat. Reaching out to SeaStar Solutions for an alternative steering system and explaining the needs, SeaStar donated their model #SH5094B mechanical steering system with a custom length cable. Not only is the system strong enough to withstand a total output power of 20 HP but it is also half the weight of the hydraulic steering system. Along with these technical benefits, the mechanical steering system was very easy to integrate and install into the boat.

When predicting speed, output power from the motor is only half the picture. The propeller curves and efficiencies also needed to be considered. The Elco 9.9 HP motor has geometry which makes for a small propeller area, allowing for a maximum propeller diameter of just 7.5 inches. With this small of a propeller, the prop design was going to be critical to meeting the goal speeds. The two motors came with stock 3 blade, 7.5 inch diameter, 7 inch pitch propellers. Using the University of Michigan's *Parson Propeller Optimization Program (POP)*, The operational requirements needed to hit the desired speeds and their associated efficiencies were found. It was concluded that the boat could not reach the required RPM to achieve the desired speeds. The two Elco motors have a maximum RPM of 4500 with a reduction gear of 2.08 which provides an operational maximum RPM of 2163 (RPS = 36.06) as seen in Fig. 18 below.

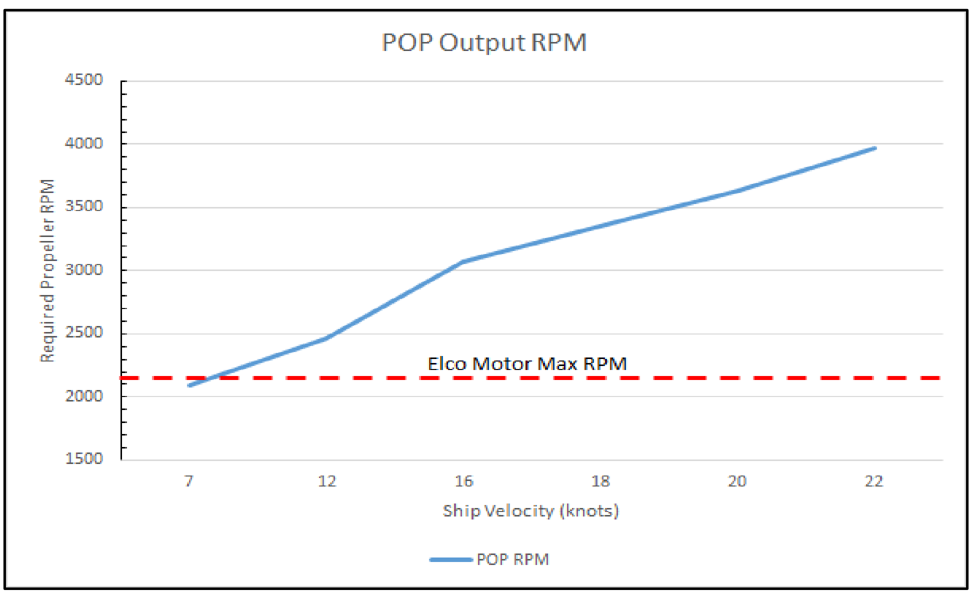


Fig. 18 Output RPM from POP

Knowing the achievable RPM, the equation for the advance coefficient, J, to determine the adjusted J values could be used:

$$J = \frac{Va}{nD}$$

Where:

$$Va = Velocity\ of\ Advance\ (ft/sec)$$
$$n = Revolutions\ per\ second$$
$$D = Propeller\ Diameter\ (ft)$$

Using the propeller performance curves of the stock prop, the results showed that most of the adjusted J values for the achievable RPM were not even on the curves. This means there is a 0% efficiency and the speed cannot be reached for the given prop design. The highest attainable speed was 12 knots with and efficiency of 58%. This was not a winning configuration.

Working with professors from both Stevens and Webb Institute, a custom prop design was created using the same optimization program and adjusting the J values for the accurate prop speeds. A 4 blade high pitch propeller was found to be the best option that would work for both sprint and endurance. A 3D rendering was created using the PropCad program with help from Webb Institute. With the custom design and adjusted RPM values, an open water efficiency of approximately 72 % can be reached. This is a 14% increase from the stock props.

As illustrated in Fig. 19 below, for the sprint speeds, an estimated 16 to 20 knots can be achieved. 18 knots seems to be the most efficient speed with an open water efficiency of approximately 75%, however it is right on the hump of the efficiency curve and any fluctuation towards a higher J value result in a large decrease in efficiency.

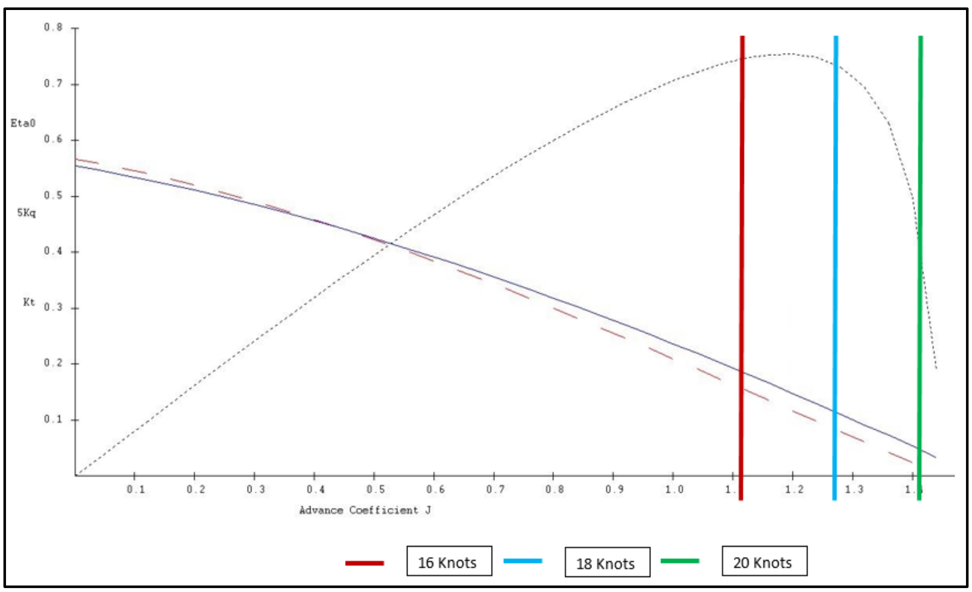


Fig. 19 Speed vs. Propeller Efficiency of Custom Propeller

The efficiencies of the two prop designs can be seen below in Fig 20. for speeds expected for the endurance and the sprint and slalom events.

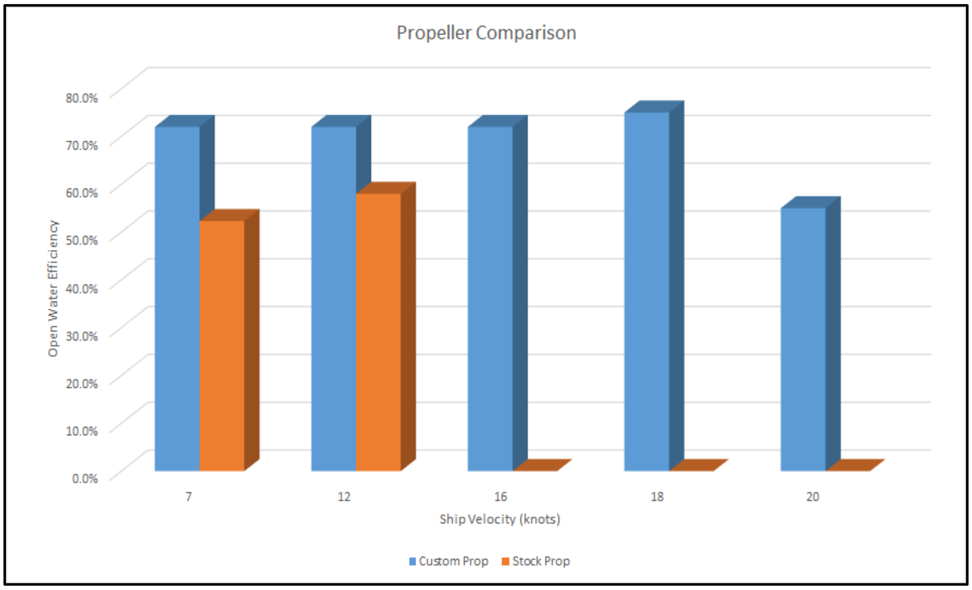


Fig. 20 Stock Prop Efficiency vs. Custom Prop Efficiency

Designing a propeller was only half the battle. Finding a way to get it made was much more difficult half. Typically, propellers are made by a single cast die to ensure strength through continuity. With a custom design for such a small, irregular prop, a mold was not going to be found or made in time. With the help from some new developing technology and sponsorship from Bell Engineering the propellers were 3D printed with a Digital Metal Laser Sintering machine. This allowed for the production of both a left and right handed prop for the sprint and slalom configurations when dual outboards are utilized.

VIII. Data Acquisition & Communications

A system to monitor power consumption was necessary for testing and for the competition. It allows the skipper to make adjustments to the throttles ensuring the batteries do not reach a minimum voltage of 25V which could permanently damage them. Using an Arduino Uno, five simple circuits, and an LCD screen, a custom battery monitor was built to display the voltage, current and percentage on the dashboard.

The first three circuits were built using Ohm's Law. Measuring the voltage drop across a shunt and dividing by the resistance to calculate current. Resistance in a shunt is small making the voltage drop across it minimal. To overcome the small voltage drop a differential amplifier (LM358P) was used to boost the voltage drop by a desired gain. One was placed at the 300A fuse to monitor converter input and the other two were placed on the 150A fuse for each motor. Arduinos are capable of measuring up to 5V which is much lower than the 36V battery or 48V motor. The easiest method of reducing the voltage is with a voltage divider, which divides the voltage drop across each resistor proportionally to the resistance. The reduced voltage is measured and multiplied proportionally to the resistance, outputting the desired voltage.

IX. Project Management

A. Team Members and Responsibilities

At the start of the project responsibilities were divided into groups for developing an understanding of the fundamental concepts and needs of specific subsystems. Both naval engineers, Spenser and Austin, focused on the hull design, two mechanical engineers, Brad and Jesse, focused on the solar system, and the other three mechanical engineers, Mason, Leo and Christina, focused on the propulsion system. As the project progressed and subsystems began to merge with each other team members began to take on different responsibilities especially when it came to hands on assembly and testing. The following is a list of each team member and their contributions to the project.

B. Project Planning and Schedule

To successfully design, construct and test the boat within the nine month time limit to be ready for the competition, careful attention was given to project planning and adherence to the project schedule. Throughout the entirety of the project several tasks were performed simultaneously and needed to be completed at specific times so that the project could progress. This was especially important when it came time to physically assembling and testing the boat. If a certain component or piece of equipment was missing assembly and testing could not be performed and time was lost. To minimize the time lost and to ensure all tasks were being performed and completed at the appropriate times the team created and adhered to several different Gantt Charts.

Each task was inserted into the Gantt Chart with specific start dates, end dates and indication of any predecessors. The chart then illustrated how long each task should take and whether or not the start date of a task was dependent on the completion of another one. Each team member knew which tasks they were responsible for and every week throughout the course of the project weekly meetings were conducted to discuss progress and ensure adherence to the schedule.

Since no subsystem is completely independent of one another, communication was vital to adherence to the schedule and overall project progression. Designs and updates needed to be constantly shared between team members to make sure all subsystems would be compatible with one another and achieve the design goals. The weekly meetings were good opportunities to share this information. However, a constant line of communication was maintained throughout the entire process. During the day, discussions could occur through the group messaging to inform everyone of certain updates right away. In addition, a folder was created on Google Drive specifically for the project where all work was saved and shared and anyone in the group could look up specific calculations or information on any of the subsystems.

C. Financial Planning and Fundraising

From the beginning, it was known that funding was going to be one of the biggest challenges. Every year Stevens Institute of Technology provides a budget to each senior design project, however, as a rookie team starting out with no components or equipment to work with this budget was not going to go far.

As the design process began and each team member started to understand the main components that were going to be needed for each subsystem, manufacturers of those components were contacted directly via e-mail. The team explained how the components would be used for the project and asked them if they would be interested in sponsoring the project.

Many companies were interested in learning more about the project and joining the team as sponsors. A majority of the mechanical and electrical sponsors were gained using this method including Elco Motor Yachts, Zahn Electronics and Anderson Power Products.

The majority of the naval engineering sponsors were gained through experience working with the companies. The two naval engineers previously interned at Viking Yacht Company and from knowing Spenser and Austin were excited to help them succeed in any way they could. They agreed to manufacturer the hull and utilized their own personal connections to gain additional sponsorships and donations for the materials to fabricate the hull. This included materials from Ashland, Vectorply, 3A Composites and Mahogany Company. Similarly, the project's advisor Michael DeLorme reached out to several of his colleagues to gain additional sponsors and donations.

Several months into the project considerable amount of support had been obtained. However, gaining sponsorship for batteries and solar panels proved to be the most difficult. In addition, funding was also needed to purchase miscellaneous materials and equipment for construction of mechanical mounting systems within the boat.

So, the university was reached out to for additional support. After providing a background on the project, the current progress made in regards to the design and gaining support, the Stevens Development Office and the Stevens Mechanical Engineering Department provided additional funding. This allowed for the purchase of the remaining components and materials needed, including the two sets of batteries and the solar panels which were the two main system components that had still been missing.

D. *Team Continuity and Sustainability*

This year a great baseline for future teams to learn and build upon was created, not just in regards to design but also support. Throughout the course of the project, many great relationships with sponsors were created which is expected to be maintained. In addition, participation in the competition this year is expected attract some additional sponsors for the future especially considering the progress made in less than a year.

The majority of the components within the boat have been donated for the project and therefore will be passed onto future teams. They will be able analyze the current performance and re-use designs and components as they see fit. The only components within the boat that will not be passed on are the two Elco outboard systems and the Elco throttles which were loaned for the competition. The key component that will be passed onto future teams is the hull. Having the hull fabricated by a world renowned yacht manufacturer was a rare opportunity for which the team is grateful. The quality of the hull and its performance characteristics will prove to be beneficial and a huge asset to the team for many years to come.

E. *Self-Evaluation*

As a team day-to-day the main challenge was making sure all project updates were shared with as much detail as possible. The project had many different moving parts that needed to come together perfectly in order for the entire system and team to function. Based on information from sponsors or just research conducted by individual team members, subsystem designs could change within the course of a day. If this information was not shared right away, the designs of the other subsystems would continue and time would be wasted developing a design that would need to be changed eventually to be compatible with the new changes.

X. Conclusions and Recommendations

A. Team Reflection

Throughout the course of the project many of the project's greatest challenges became the greatest successes. The project started with no designs to use as reference, no materials or components to work with, and little financial support. However, in less than year, competitive designs were able to be developed, these designs constructed thanks to the support of fifteen generous sponsors, and the team will be competing in the competition confident in the project's success.

Looking back on the last nine months, there were definitely times and aspects of the process that could have been improved. Some weeks there was struggle with communicating design updates, and other weeks there were struggles with technical concepts and details of designs which set the project back a little bit. However, the goal of being ready to compete in June was always kept in focus. Long days and nights in the lab were worked when necessary to complete tasks on time and several different resources would be reached out to whether it be sponsors or professors at the university to help overcome some of the technical hurdles.

B. Lessons Learned

One of the main lessons learned throughout the course of this project is that communication is key. Better communication could have elevated many struggles much earlier. Less time could have been lost if design updates were shared sooner and if more clarifying questions were asked through the group message or during meetings to avoid mistakes and technical misunderstandings. Updates to designs could have been completed sooner allowing the project to progress quicker and smoother. In addition, not being afraid to ask for help is important. Within an interdisciplinary project like this one, no one is going to know everything. Asking for help sooner from other team members, sponsors and/ or professors could have sped up the design process and would have helped avoid some of the technical hiccups that occurred along the way.

Having the opportunity to work on an interdisciplinary team provided some valuable lessons as well. While studying within a specific discipline of engineering it is sometimes hard to see how much each discipline actually relies on one another in real life applications. No subsystem within the boat was completely independent of the others. Therefore, each team member learned how their discipline merges with the others along with learning the fundamentals of these other disciplines - an opportunity that was not provided through regular coursework.

C. Next Steps

Throughout the next month preparations for the competition will be completed. It will be made sure that all required equipment according to the competition rules is at hand to qualify to compete. On-water testing will also continue and the system will be fine-tuned to optimize its performance and get a good understanding of how it can be expected to perform during the competition so there are not too many surprises.

After the competition, the performance will be analyzed and areas of improvement will be identified. Since each team member this year is a senior and will be graduating within the next few weeks, project advisor Michael DeLorme will share this information with the new team in September.

Next year's team will focus on these opportunities for improvement but will also be expected to eliminate some of the commercially available components utilized this year and design and construct their own components. Since the two Elco outboard systems and throttles were only a loan for this year's competition, building custom motors whether it be inboard or outboard motors will be encouraged. In addition, for the naval engineers on the team, the addition of hydrofoils to the hull design will also be encouraged.

XI. References

[1] Goswami, D. Yogi. *Principles of Solar Engineering*. Boca Raton, FL: Taylor and Francis Group, 2015.

[2] Marion, William F., and Stephen Wilcox. *Solar Radiation Data Manual for Buildings*. Edited by Mary Anne. Dunlap. Golden, CO: National Renewable Energy Laboratory, 1995.

[3] Lewandowski, Edward. *The Dynamics of Marine Craft: Maneuvering and Seakeeping*. Singapore: World Scientific Publishing Co. Pte. Ltd., 2004.

XII. Appendices

Appendix A: Battery Documentation

SECTION 1: PRODUCT NAME

Valve regulated lead-acid batteries.

SECTION 2: HAZARDOUS COMPONENTS

COMPONENTS	%WEIGHT	TLV	LD50 ORAL	LC50 INHALATION	LC50 CONTACT
Lead (Pb, PbO_2, $PbSO_4$)	About 70%	N/A	(500) mg/Kg	N/A	N/A
Sulfuric Acid	About 20%	1 mg/m^3	(2.140) mg/Kg	N/A	N/A
Fiberglass Separator	About 5%	N/A	N/A	N/A	N/A
ABS or PP	About 5%	N/A	N/A	N/A	N/A

SECTION 3: PHYSICAL DATA

COMPONENTS	DENSITY	MELTING POINT	SOLLUBILITY (H2O)	ODOR	APPEARANCE
Lead	11.34	327.4°C (Boiling)	None	None	Silver-Grey Metal
Lead Sulfate	6.2	1070°C (Boiling)	40 mg/L(15°C)	None	White Powder
Lead Dioxide	9.4	290°C (Boiling)	None	None	Brown Powder
Sulfuric Acid	About 1.3	About114°C (Boiling)	100%	Acidic	Clear Colorless Liquid
Fiberglass Sep.	N/A	N/A	Slight	Toxic	White Fibrous Glass
ABS or PP	N/A	N/A	None	No Odor	Solid

SECTION 4: PROTECTION

EXPOSURE	PROTECTION	COMMENTS
SKIN	Rubber gloves, Apron, Safety shoes	Protective equipment must be worn if battery is cracked or otherwise damaged.
RESPIRATORY	Respirator (for lead)	A respirator should be worn during reclaim operations if the TLV exceeded.
EYES	Safety goggles, Face Shield	

SECTION 5: FLAMMABILITY DATA

COMPONENTS	FLASHPOINT	EXPLOSIVE LIMITS	COMMENTS
Lead	None	None	
Sulfuric Acid	None	None	
Hydrogen	259?	4% - 74.2%	Batteries can emit hydrogen only if over charged (float voltage> 2.4 VPC). The gas enters the air through the vent caps. To avoid the chance of a fire or explosion, keep sparks and other sources of ignition away from the battery. Extinguishing Media: Dry chemical, foam, CO_2.
Fiberglass Sep.	N/A	N/A	Toxic vapors may be released. In case of fire: wear self-contained breathing apparatus.
478 Polystyrene	None	N/A	Temperatures over 300 °C (572°F) may release combustible gases. In case of fire: wear positive pressure self-contained breathing apparatus.

SECTION 6: REACTIVITY DATA

COMPONENT	Lead/lead compounds
STABILITY	Stable
INCOMPATIBILITY	Potassium, carbides, sulfides, peroxides, phosphorus, sulfurs.
DECOMPOSITION PRODUCTS	Oxides of lead and sulfur.
CONDITIONS TO AVOID	High temperature, Sparks and other sources of ignition
COMPONENT	Sulfuric Acid
STABILITY	Stable at all temperatures
POLYMERIZATION	Will not polymerize
INCOMPATIBILITY	Reactive metals, strong bases, most organic compounds
DECOMPOSITION PRODUCTS	Sulfuric dioxide, trioxide, hydrogen sulfide, hydrogen
CONDITIONS TO AVOID	Prohibit smoking, sparks, etc. from battery charging area. Avoid mixing acid with other chemicals.

SECTION 7: CONTROL MEASURES

1. Store lead/acid batteries with adequate ventilation. Room ventilation is required for batteries utilized for standby power generation. Never recharge batteries in an unventilated, enclosed space. 2. Do not remove vent caps. Follow shipping and handling instructions that are applicable to the battery type. To avoid damage to terminals and seals, do not double-stack industrial batteries. **STEPS TO TAKE IN CASE OF LEAKS OR SPILLS** If sulfuric acid is spilled from a battery, neutralize the acid with sodium bicarbonate (baking soda), sodium carbon (soda ash), or calcium oxide (lime). Flush the area with water discard to the sewage systems. Do not allow unneutralized acid into the sewage system. **WASTE DISPOSAL METHOD:** Neutralized acid may be flushed down the sewer. Spent batteries must be treated as hazardous waste and disposed of according to local state, and federal regulations. A copy of this material safety data must be supplied to any scrap dealer or secondary smelter with battery. **ELECTRICAL SAFETY** Due to the battery's low internal resistance and high power density; high levels of current can be developed across the battery terminals. Do not rest tools or cables on the battery. Use insulated tools only. Follow all installation instruction and diagrams when installing or maintaining battery systems.

SECTION 8: HEALTH HAZARD DATA

LEAD: The toxic effects of lead are cumulative and slow to appear. It affects the kidneys, reproductive, and central nervous system. The symptoms of lead overexposure are anemia, vomiting, headache, stomach pain (lead colic), dizziness, loss of appetite, and muscle and joint pain. Exposure to lead from a battery most often occurs during lead reclaim operations through the breathing or ingestion of lead dusts and fumes. THIS DATA MUST BE PASSED TO ANY SCRAP OR SMELTER WHEN A BATTERY IS RESOLD.
SULFURIC ACID: Sulfuric acid is a strong corrosive. Contact with acid can cause severe burns on the skin and in the eyes. Ingestion of sulfuric acid will cause GI tract burns. Acid can be release if the battery case is damaged or if the vents are tampered with.
FIBERGLASS SEPARATOR: Fibrous glass is an irritant of the upper respiratory tract, skin and eyes. For exposure up to 10F/CC use MSA Comfort with type H filter. Above 10F/CC up to 50F/CC use Ultra-Twin with type H filter. NTP or OSHA does not consider this product carcinogenic.

SECTION 9: SULFURIC ACID PRECAUTIONS

INHALATION: Acid mist form may cause respiratory irritation. Remove any individual from exposure, and apply oxygen if breathing is difficult.

SKIN CONTACT: Acid may cause irritation, burns or ulceration. Flush with plenty of soap and water, remove contaminated clothing, and see physician if contact area is large or if blisters form.

EYE CONTACT: Acid may cause severe irritation, burns, cornea damage and blindness. Call physician immediately and flush with water until physician arrives.

INGESTION: Acid may cause irritation of mouth, throat, esophagus and stomach. Call physician. If patient is conscious, flush mouth with water, have the patient drink milk or sodium bicarbonate solution.

DO NOT GIVE ANYTHING TO AN UNCONSCIOUS PERSON.

SECTION 10: TRANSPORTATION REGULATIONS

We hereby certify that all UPG Valve Regulated Lead-acid Rechargeable batteries conform to the UN2800 classification as " Batteries, wet, Non-Spillable, and electric storage" as a result of passing the Vibration and Pressure Differential Test described in D.O.T., 49 CFR 173.159(d), and IMO/IMDG, and ICAO/IATA packing instruction 806 and note A67.

Batteries having met the related conditions are EXEMPT from hazardous goods regulations for the purpose of transportation by DOT, and IATA/ICAO, and therefore are unrestricted for transportation by any means. For all modes of transportation, each battery outer package is labeled "NON-SPILLABLE". All our Batteries are marked non-spillable.

Updated: Feb. 18, 2010

UPG

Let us power you.®

Sealed Lead-Acid Battery

UPG No. 45977

UB12500

Maintenance-Free

Absorbant Glass Mat (AGM) technology for superior performance. Valve regulated, spill proof construction allows safe operation in any position. Approved for transport by air. D.O.T., I.A.T.A., F.A.A. and C.A.B. certified. U.L. r ecognized under file number MH 20567.

Specification

Nominal Voltage	12 volts
Nominal Capacity	77º F (25º C)
20-hr. (2.50A)	50.0 Ah
10-hr. (4.65A)	46.5 Ah
5-hr. (8.50A)	42.5 Ah
1-hr. (30.00A)	30.0 Ah
Approximate Weight	30.2 lbs (13.7 kgs)
Internal Resistance (approx.)	11 mΩ

Shelf Life (% of normal capacity at 77º F (25º C))

3 Months	6 Months	12 Months
91%	82%	64%

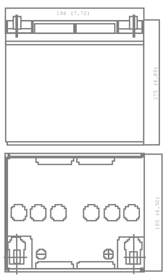
Temperature Dependancy of Capacity (20 hour rate)

104º F	77º F	32º F	5º F
102%	100%	85%	65%

Charge Method (Constant Voltage)

Cycle Use (Repeating Use)	
Initial Current	17.5 A or smaller
Control Voltage	14.5 - 14.9 V
Float Use	
Control Voltage	13.6 - 13.8 V

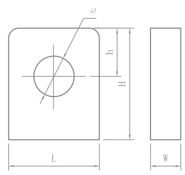
Physical Dimensions: in (mm)



L: 7.72in (196.1 mm)
W: 6.50in (165.1mm)
H: 6.89in (175 mm)
TH: 7.17in (182.1 mm)

Tolerances are +/- 0.04 in. (+/- 1mm) and +/- 0.08 in. (+/- 2mm) for height dimensions. All data subject to change without notice.

Terminals



L Series (L Type Terminal)

Dimension / Type	L	W	H	h	⌀
L2	17.0	9.0	17.0	9.0	6.5

Constant Current Discharge Characteristics Unit:A (25°C, 77°F)

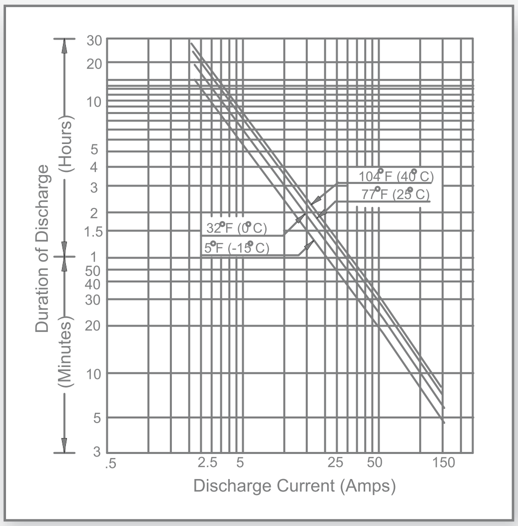
F.V/Time	5MIN	10MIN	15MIN	30MIN	1HR	2HR	3HR	4HR	5HR	8HR	10HR	20HR
9.60V	158.2	115.4	81.2	49.2	25.7	15.0	11.0	8.6	7.1	5.0	4.5	2.5
10.20V	139.4	105.2	72.7	46.6	24.1	14.3	10.7	8.3	6.9	4.9	4.4	2.5
10.50V	134.2	100.0	68.4	45.3	23.5	13.9	10.4	8.2	6.8	4.8	4.3	2.5
10.80V	129.1	94.9	64.1	44.0	22.7	13.6	10.2	8.1	6.7	4.7	4.3	2.3
11.10V	124.0	89.8	59.9	42.8	21.8	13.3	9.8	7.8	6.5	4.6	4.1	2.2

Constant Power Discharge Characteristics Unit:W (25°C, 77°F)

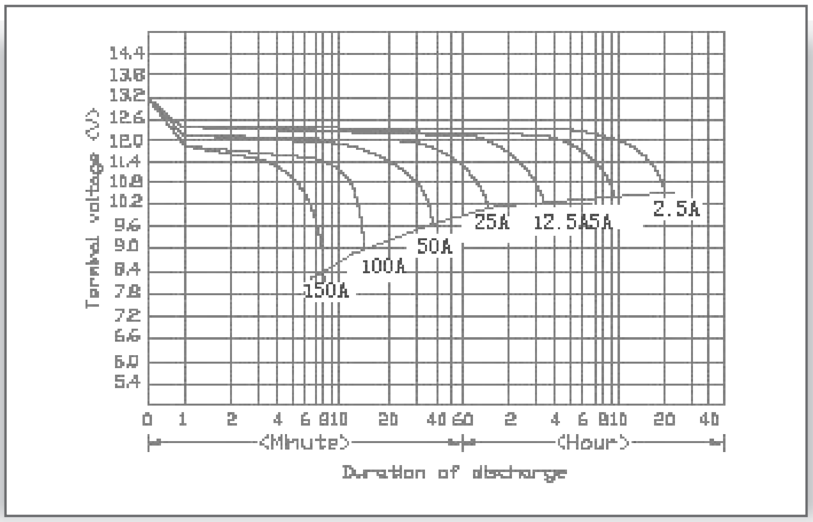
F.V/Time	5MIN	10MIN	15MIN	30MIN	1HR	2HR	3HR	4HR	5HR	8HR	10HR	20HR
9.60V	1679.6	1268.4	862.7	522.0	297.1	173.1	127.4	99.2	81.7	57.7	52.2	28.1
10.20V	1547.1	1167.5	806.7	517.3	279.2	165.4	124.0	96.6	64.2	56.4	50.9	27.4
10.50V	1522.3	1134.6	775.5	513.9	270.2	161.6	121.0	94.9	79.1	56.0	50.0	27.0
10.80V	1502.7	1104.7	746.4	512.6	262.9	158.2	118.4	93.2	77.8	54.7	49.6	26.9
11.10V	1475.3	1068.3	712.2	508.7	259.5	157.7	117.1	92.8	77.4	54.3	48.3	26.1

1720 Hayden Drive | Carrollton, Texas 75006 | P 469.892.1122 | T 866.892.1122 | F 469.892.1123 | sales@upgi.com

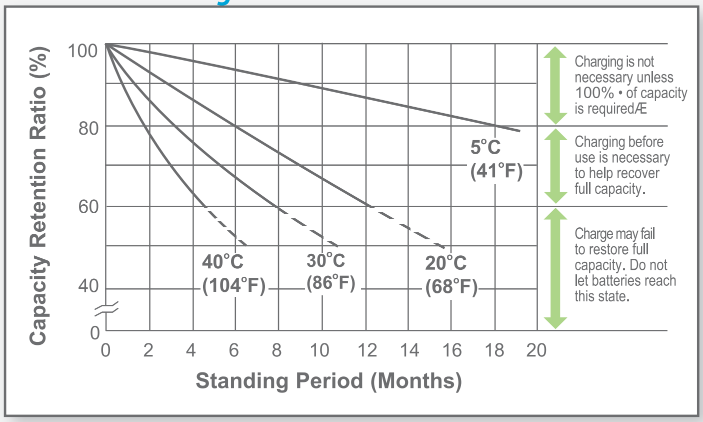
Discharge Time vs. Discharge Current



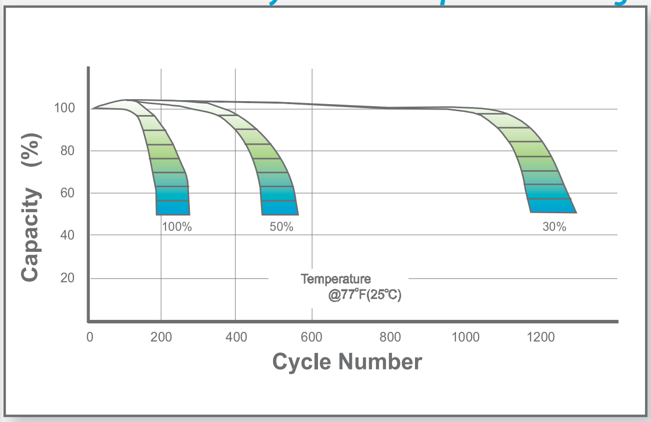
Discharge Characteristics



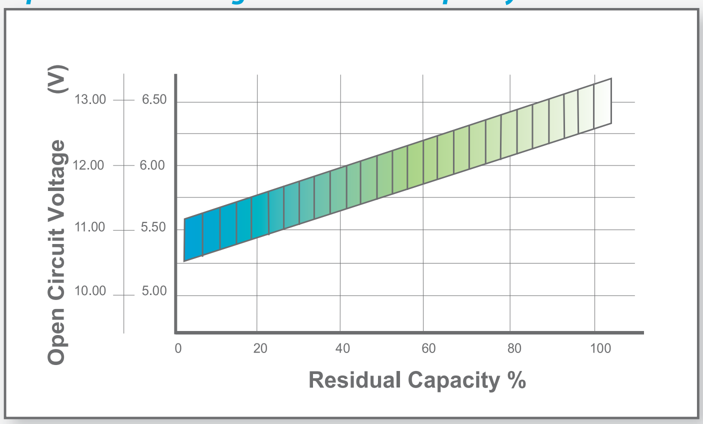
Shelf Life & Storage



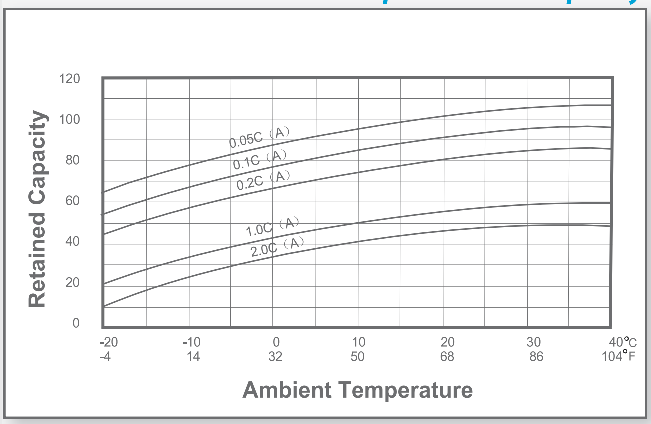
Cycle Life vs Depth of Discharge



Open Circuit Voltage vs Residual Capacity



Effect of Temperature on Capacity



Charge Current & Final Discharge Voltage

Application	Charge Voltage(V/Cell)			Max.Charge Current
	Temperature	Set Point	Allowable Range	
Cycle Use	25℃(77℉)	2.45	2.40~2.50	0.35C
Standby	25℃(77℉)	2.325	2.30~2.35	

Final Discharge Voltage V/Cell	1.75	1.70	1.60	1.30
Discharge Current(A)	0.2C>(A)	0.2C<(A)<0.5C	0.5C<(A)<1.0C	(A)>1.0C

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Appendix B: Flotation Calculations

The following calculations will go over the buoyant forces of the vessel to prove sufficient buoyancy with a 20% reserve. The heaviest configuration of the vessel comes to 678.8 pounds which does not include the skipper or the ballast required to meet the 70kg. requirement. For the purposes of the calculations the specific weight of fresh water at 70 °F was chosen which is 62.30 pounds per cubic foot.

Hull:

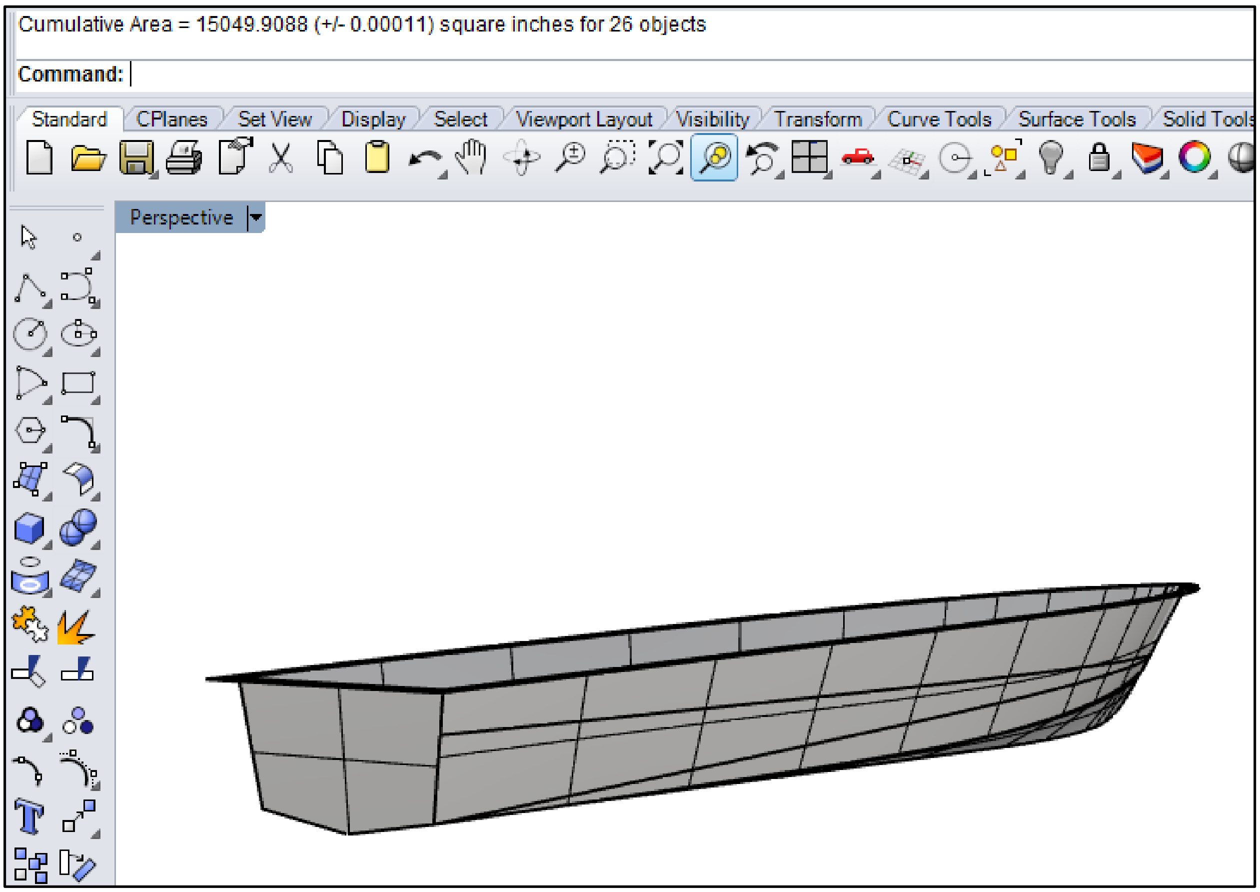


Fig. 1B: 3D Model of Hull

The entire hull is a closed volume with a width of at least 1 inch continuously. This creates a buoyant force from the hull itself. Finding the surface area of the hull from the 3D modeling program, as seen above in Fig. 1B, and multiplying by the thickness gives a volume of 15,049 cubic inches.

$$15{,}049\ in^3 = 8.7\ ft^3$$

$$8.7\ ft^3 * 62.3\ \frac{lbs}{ft^3} = 542.5\ lbs$$

The transom had a small section cutout to properly position the motors. This cutout measured 30”X1”X2.75”, totaling 82.5 cubic inches. This results in a 2.97 pound reduction in the total hull buoyant force, bringing it to a net total of 539.53 pounds.

Internal Structure:

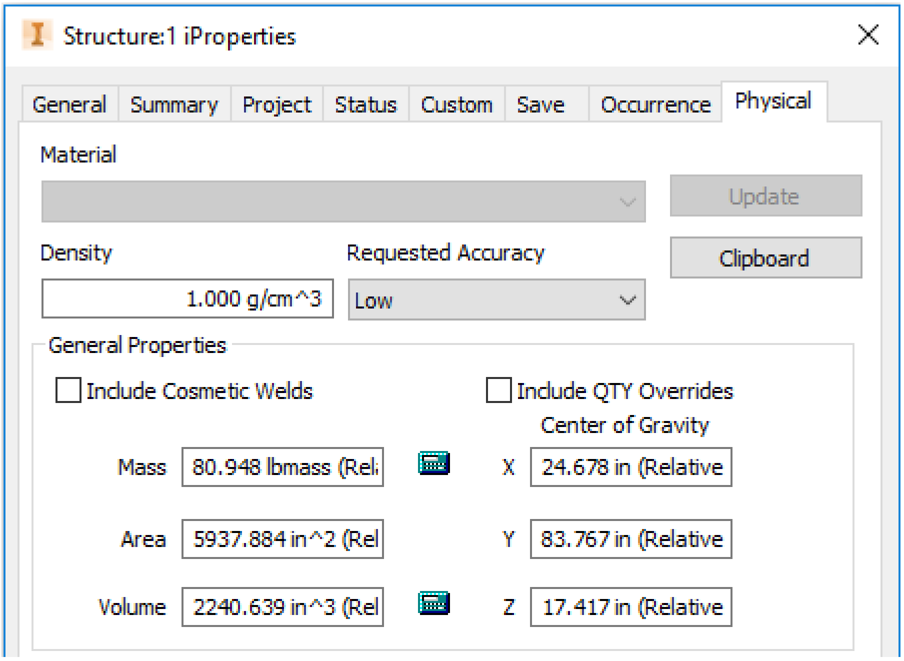


Fig. 2B: 3D Modeling Calculations for Internal Structure

The internal structure has been sealed with three layers of epoxy at any point where a hole or opening was made. This creates a watertight volume which also contributes a buoyant force. The volume was found using the 3D software program as seen above in Fig. 2B and is equal to 2,240 cubic inches.

$$2{,}240\ in^3 = 1.296\ ft^3$$

$$1.296\ ft^3 * 62.30 \frac{lbs}{ft^3} = 80.75\ lbs$$

Batteries:

The three batteries in the boat are closed volume which provides a buoyant force. Each battery is 326.17 cubic inches.

$$3 * 326.17\ in^3 = 978.51\ in^3$$

$$978.51\ in^3 = 0.566\ ft^3$$

$$0.566\ ft^3 * 62.30 \frac{lbs}{ft^3} = 35.26\ lbs$$

Added Foam:

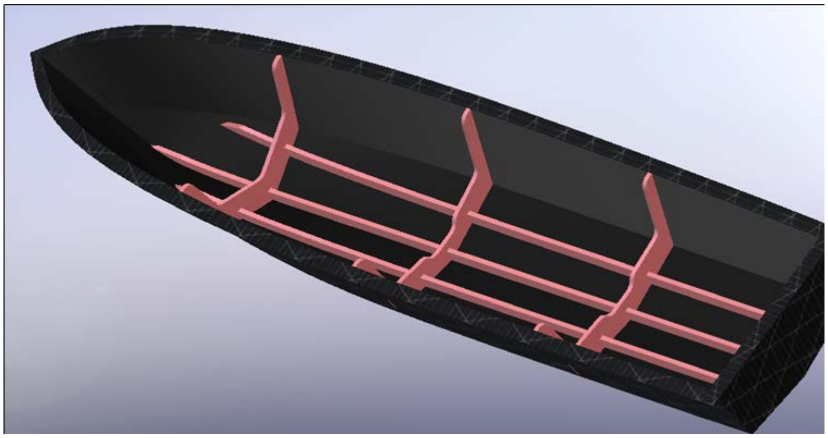


Fig. 3B: Stringers and Ribs of Internal Structure

In order to meet our 20% reserve buoyancy, we will be adding 2 inch thick foam pieces into each of the sections between the longitudinal stringers and the transverse ribs for the two aft sections which can be seen above in Fig. 3B. This gives us eight sections of buoyant volume whose calculations can be seen below in Table 1B. The two outside rear section will contain two layers of 2 inch foam. The total addition will not be less than 6,237 cubic inches, which provides 230.51 pounds of buoyant force.

Table 1B: Foam Buoyancy Calculations

Added Buoyancy	Length	Width	Height	Volume	
1	45.25	7	4	1267.00	in^3
2	45.25	7	2	633.50	in^3
3	45.25	7	2	633.50	in^3
4	45.25	7	4	1267.00	in^3
5	46.5	7	2	651.00	in^3
6	46.5	7	2	651.00	in^3
7	46.5	7	2	651.00	in^3
8	46.5	7	2	651.00	in^3

To account for some system modules that sit on the bottom of the hull or require room between the stringers, cutouts will be made and their volume reduction accounted for which can be seen in Table 2B.

Table 2B: Foam Cutout Calculations

Cutouts Needed					
Bilge Pump	8	4.5	2	72.00	in^3
Seat Rail STBD	1	24	2	48.00	in^3
Seat Rail PORT	1	24	2	48.00	in^3
Dash Mount STBD	2	3	2	12.00	in^3
Dash Mount PORT	2	3	2	12.00	in^3

The cutouts total 6.92 pounds of lost buoyant force and is already accounted for in the 230.51 pounds of force above.

The full set of calculations can be seen below in Table 3B.

Table 3B: Full Buoyancy Calculation

Sprint Weight	815.40	lbs			
Endurance Weight	833.10	lbs			
Water specific weight @ 60F	62.37	lbs/ft^3			
Water specific weight @ 70F	62.30	lbs/ft^3			
		Weight For Buoyancy (lbs.)	**20 % Reserve (lbs.)**	**Total (lbs.)**	**Water Tight Volume Needed (ft.^3)**
		678.80	135.76	814.56	13.07
Individual Calculations					
Added Buoyancy	**Length**	**Width**	**Height**	**Volume**	
1	45.25	7	4	1267.00	in^3
2	45.25	7	2	633.50	in^3
3	45.25	7	2	633.50	in^3
4	45.25	7	4	1267.00	in^3
5	46.5	7	2	651.00	in^3
6	46.5	7	2	651.00	in^3
7	46.5	7	2	651.00	in^3
8	46.5	7	2	651.00	in^3
Internal Structure				2240.00	in^3
Bare Hull				15049.00	in^3
battery 1	7.72	6.5	6.5	326.17	in^3
battery 2	7.72	6.5	6.5	326.17	in^3
battery 3	7.72	6.5	6.5	326.17	in^3
Cutouts Needed					
Bilge Pump	8	4.5	2	72.00	in^3
Seat Rail STBD	1	24	2	48.00	in^3
Seat Rail PORT	1	24	2	48.00	in^3
Dash Mount STBD	2	3	2	12.00	in^3
Dash Mount PORT	2	3	2	12.00	in^3
Transom	30	1	2.75	82.50	in^3
Net Added Buoyancy				24398.01	in^3
				14.12	ft^3
				879.63	lbs. of buoyancy
				129.59%	% over (min. 120%)

Appendix C: Proof of Insurance

CERTIFICATE OF LIABILITY INSURANCE

ACORD®

DATE (MM/DD/YYYY): 04/25/2017

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

IMPORTANT: If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must be endorsed. If SUBROGATION IS WAIVED, subject to the terms and conditions of the policy, certain policies may require an endorsement. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

PRODUCER Fred C. Church, Inc. 41 Wellman Street Lowell, MA 01851 (800) 225-1865	**CONTACT NAME:** Julie Price, MBA, CISR, CSRM **PHONE (A/C, No, Ext):** 978 3227269 **FAX (A/C, No):** (978) 454-1865 **E-MAIL ADDRESS:** jprice@fredcchurch.com
INSURED The Trustees of the Stevens Institute of Technology Castle Point on Hudson Hoboken, NJ 07030-5991	

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : Atlantic Specialty Insurance Company	27154
INSURER B :	
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

COVERAGES **CERTIFICATE NUMBER:** 61186 **REVISION NUMBER:**

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSR	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
	GENERAL LIABILITY COMMERCIAL GENERAL LIABILITY CLAIMS-MADE OCCUR GEN'L AGGREGATE LIMIT APPLIES PER: POLICY PRO-JECT LOC						EACH OCCURRENCE	$
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$
							MED EXP (Any one person)	$
							PERSONAL & ADV INJURY	$
							GENERAL AGGREGATE	$
							PRODUCTS - COMP/OP AGG	$
								$
	AUTOMOBILE LIABILITY ANY AUTO ALL OWNED AUTOS SCHEDULED AUTOS HIRED AUTOS NON-OWNED AUTOS						COMBINED SINGLE LIMIT (Ea accident)	$
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
	UMBRELLA LIAB OCCUR **EXCESS LIAB** CLAIMS-MADE DED RETENTION $						EACH OCCURRENCE	$
							AGGREGATE	$
								$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y / N ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? **(Mandatory in NH)** If yes, describe under DESCRIPTION OF OPERATIONS below	N / A					WC STATU-TORY LIMITS OTH-ER	
							E.L. EACH ACCIDENT	$
							E.L. DISEASE - EA EMPLOYEE	$
							E.L. DISEASE - POLICY LIMIT	$
A	Boats			B5JH53677	11/1/2016	11/1/2017	Protection & Indemnity Limit $1,000,000	

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (Attach ACORD 101, Additional Remarks Schedule, if more space is required)

Includes coverage for:
2017 17' Fiberglass Custom Boat with Outboards:
25,000/1,000 Deductible (Hull); 1,000,000/1,000 Deductible (Liability)

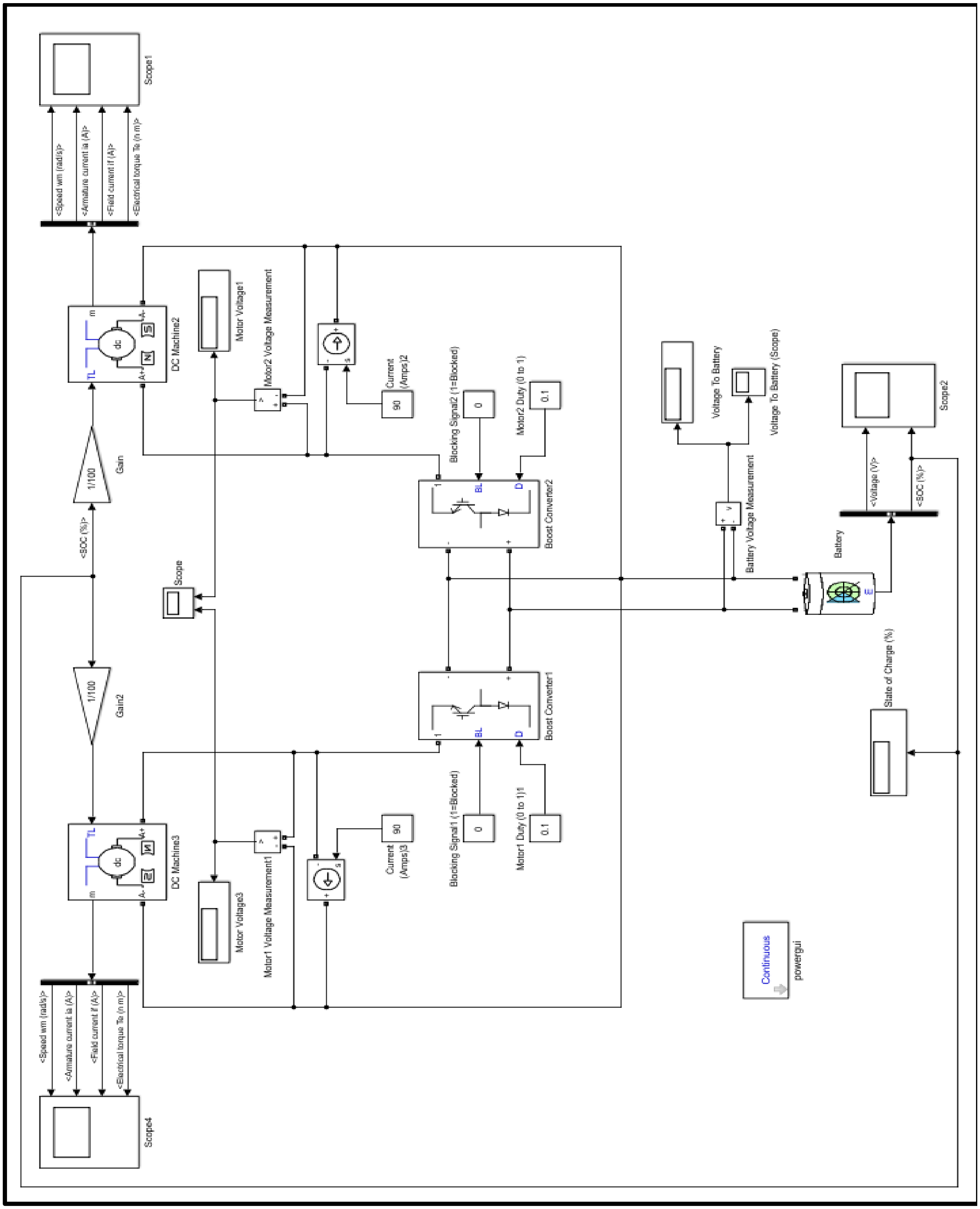
CERTIFICATE HOLDER	CANCELLATION
Evidence of Insurance Stevens Institute Hoboken, NJ 07030	**SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.** **AUTHORIZED REPRESENTATIVE** Michael J. [signature]

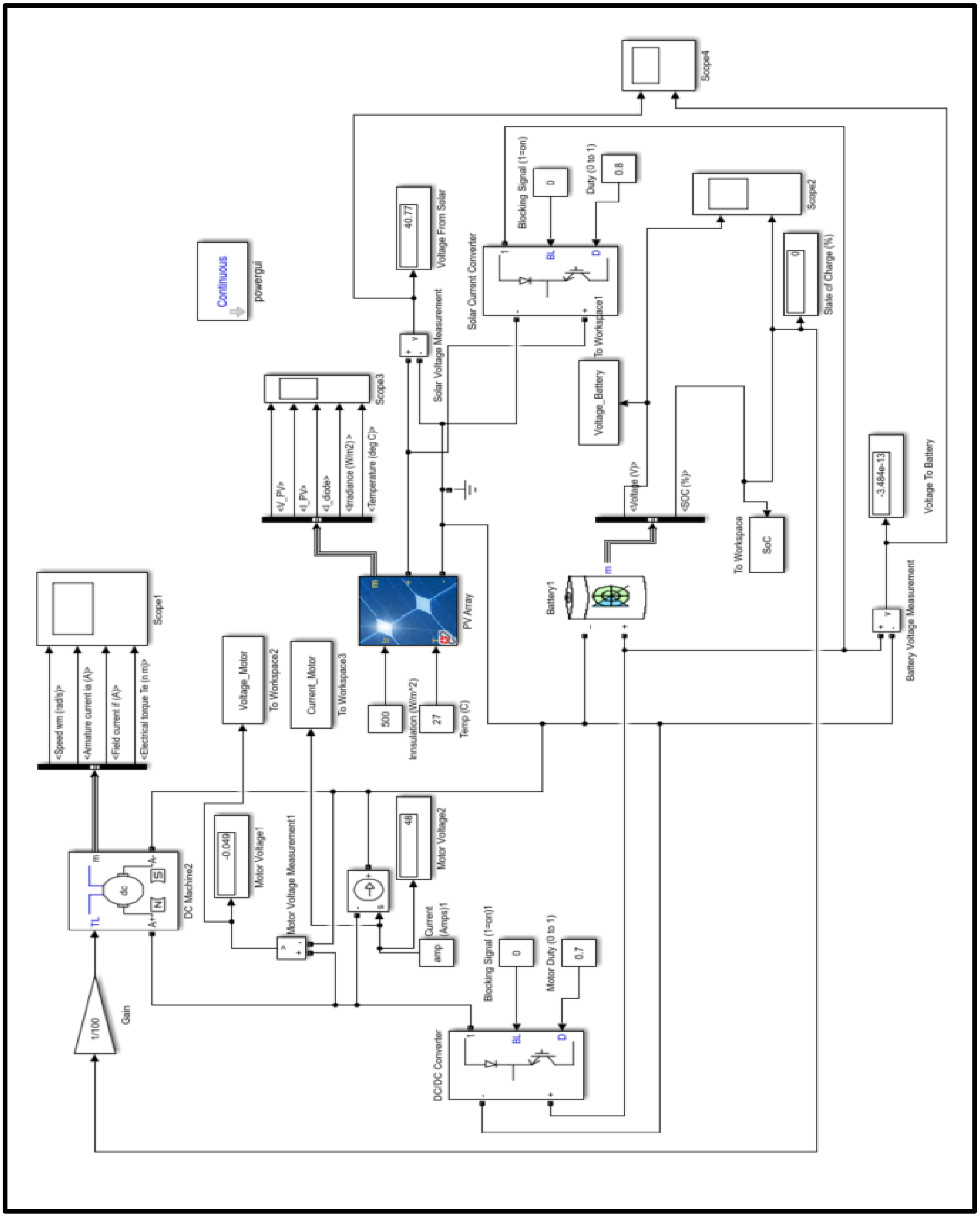
lie# 36561 Mst # 61186 Cert Holder # 84655

Appendix D: Team Roster

Name	Degree Program	Year	Team Role
Brad Applegate	Mechanical Engineering	Senior	• Solar System Design • Solar Mounting Design & Construction
Christina DiGiacomo	Mechanical Engineering	Senior	• Propulsion Selection • Solar System Design • Team Management
Mason Riemer	Mechanical Engineering	Senior	• Power Electronics Design • System Modeling & Analysis • Mechanical Mounting Design & Construction • Skipper
Jesse Squier	Mechanical Engineering	Senior	• Solar System Design • Power Electronics Design
Austin Swain	Naval Engineering	Senior	• Hull Design • Steering Design & Fabrication • Scale Model Testing • Student Team Leader
Spenser Swanton	Naval Engineering	Senior	• Hull Design • Propeller Design & Manufacturing • Scale Model Testing
Leo Wortman	Mechanical Engineering	Senior	• Propulsion Selection • Mechanical Mounting Design & Construction • Steering Design & Fabrication

Appendix E: MATLAB SimuLink Block Diagrams





Scope4
Scope2
Scope3
Scope1
Continuous
powergui
40.77
Voltage From Solar
Blocking Signal (1=on)
Duty (0 to 1)
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Solar Current Converter
Solar Voltage Measurement
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<I_PV>
<I_diode>
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<Temperature (deg C)>
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27
Innsulation (W/m^2)
Temp (C)
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<SOC (%)>
To Workspace
SoC
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Voltage To Battery
Battery Voltage Measurement
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<Armature current ia (A)>
<Electrical torque Te (n m)>
Voltage_Motor
To Workspace2
Current_Motor
To Workspace3
DC Machine2
-0.049
Motor Voltage1
Motor Voltage Measurement1
48
Motor Voltage2
Current
(Amps)1
amp
Blocking Signal (1=on)1
Motor Duty (0 to 1)
0.7
DC/DC Converter
1/100
Gain

Appendix F: Weight Study Details

Solar Splash 2017 Weight Study								
ENDURANCE								
Item	Weight	VCG	VCG Moment	LCG (fwd transom)	LCG Moment	TCG (neg. to port)	TCG Moment
Hull and Internal Structu	326.0	8.10	2640.60	83.69	27282.13	0.00	0.00
Skipper	140.0	19.00	2527.00	67.00	9380.00	0.00	0.00
Skipper ballast	14.3	2.00	28.60	173.00	2473.90		
Seat	4.0	4.00	16.00	67.00	268.00	0.00	0.00
Dashboard	20.0	19.79	395.80	86.16	1723.20	2.50	50.00
Throttle 1			0.00		0.00		0.00
Throttle 2			0.00		0.00		0.00
Steering Wheel			0.00		0.00		0.00
					0.00		0.00
Motor 1 (port)	61.2	20.63	1262.25	-4.75	-290.70	0.00	0.00
Motor 2 (stbd)	61.2	8.00	489.60	35.00	2142.00	0.00	0.00
Motor Holder	3.0	3.00	9.00	30.00	90.00	0.00	0.00
					0.00		
Battery 1	34.9	10.60	369.41	99.61	3471.41	0.00	0.00
Battery 2	34.9	8.75	304.94	99.61	3471.41	0.00	0.00
Battery 3	34.9	10.52	366.62	99.61	3471.41	0.00	0.00
					0.00		
Converters	37.2	5.01	186.12	112.87	4193.12		
Charge Controller 1			0.00		0.00	0.00	0.00
Charge Controller 2			0.00		0.00	0.00	0.00
Endur. DC/DC Converter			0.00		0.00	0.00	0.00
Sprint DC/DC Converter			0.00		0.00	0.00	0.00
Forward Solar Array	11.0	25.09	275.99	135.00	1485.00	0.00	0.00
2 Panels			0.00		0.00		0.00
Mounting Structure			0.00		0.00		0.00
Rear Solar Array	11.0	22.10	243.10	35.00	385.00	0.00	0.00
2 Panels			0.00		0.00		0.00
Mounting Structure			0.00		0.00		0.00
Wiring	30.0	4.00	120.00	67.00	2010.00	8.00	240.00
Aft Stbd Buoyancy	3.0	6.00	18.00	48.00	144.00	15.00	45.00
Aft Port Buoyancy	3.0	6.00	18.00	48.00	144.00	-15.00	-45.00
Mid Buoyancy	6.0	10.00	60.00	63.00	378.00	0.00	0.00
Forward Buoyancy	2.0	16.00	32.00	168.00	336.00	0.00	0.00
Total Weight	837.40	VCG	11.18	LCG (fwd Transom)	74.70	TCG	0.35
		Goal	12	Goal	75		

NOTES:

The VCG is taken from the Horizontal axis with the keel of the hull also running along the horizontal axis until its curvature deflects away from it

The LCG is taken from the outside of the transom wall forward. The centerpoint of the intersection between the outer transom wall and the keel is centered on the origin of the design field.

Solar Splash 2017 Weight Study

SPRINT/SLALOM

Item	Weight	VCG	VCG Moment	LCG (fwd transom)	LCG Moment	TCG (neg. to port)	TCG Moment
Hull and Internal Structu	326.0	8.10	2640.60	83.69	27282.13	0.00	0.00
Skipper	140.0	19.00	2660.00	59.00	8260.00	0.00	0.00
Skipper ballast	14.3	2.00	28.60	2.00	28.60		
Seat	4.0	4.00	16.00	55.47	221.88	0.00	0.00
Dashboard	20.0	19.79	395.80	86.16	1723.20	2.50	50.00
Throttle 1			0.00		0.00		0.00
Throttle 2			0.00		0.00		0.00
Steering Wheel			0.00		0.00		0.00
							0.00
Motor 1 (port)	61.2	20.20	1236.24	-4.75	-290.70	0.00	0.00
Motor 2 (stbd)	61.2	20.20	1236.24	-4.75	-290.70	0.00	0.00
Motor Holder	3.0	3.00	9.00	25.00	75.00	0.00	0.00
Battery 1 + mounting	34.9	10.60	369.41	99.61	3471.41	0.00	0.00
Battery 2 + mounting	34.9	8.75	304.94	99.61	3471.41	0.00	0.00
Battery 3 + mounting	34.9	10.52	366.62	99.61	3471.41	0.00	0.00
Converters	37.2	5.01	186.12	112.87	4193.12		
Charge Controller 1			0.00		0.00	0.00	0.00
Charge Controller 2			0.00		0.00	0.00	0.00
Endur. DC/DC Converter			0.00		0.00	0.00	0.00
Sprint DC/DC Converter			0.00		0.00	0.00	0.00
Forward Solar Array		25.74	0.00	141.97	0.00	0.00	0.00
2 Panels			0.00		0.00		0.00
Mounting Structure			0.00		0.00		0.00
Rear Solar Array		22.10	0.00	37.10	0.00	0.00	0.00
2 Panels			0.00		0.00		0.00
Mounting Structure			0.00		0.00		0.00
Wiring	30.0	4.00	120.00	50.00	1500.00	8.00	240.00
Aft Stbd Buoyancy	3.0	6.00	18.00	24.00	72.00	15.00	45.00
Aft Port Buoyancy	3.0	6.00	18.00	24.00	72.00	-15.00	-45.00
Mid Buoyancy	6.0	10.00	60.00	63.00	378.00	0.00	0.00
Forward Buoyancy	2.0	16.00	32.00	168.00	336.00	0.00	0.00
Total Weight	815.40	VCG	11.89	LCG fwd transom	66.19	TCG	0.36
		Goal	12	Goal	66		

NOTES:

The VCG is taken from the Horizontal axis with the keel of the hull also running along the horizontal axis until its curvature deflects away from it

The LCG is taken from the outside of the transom wall forward. The centerpoint of the intersection between the outer transom wall and the keel is centered on the origin of the design field.

Appendix G: Source Information

EP 9.9 HP Outboard Motor	Elco Motor Yachts	21 S Water Street, Athens, NY 12015
DCDC12/36/200OP Solar Optimizer	Zahn Electronics, Inc.	4133 Courtney Street, Unit #5, Franksville, WI, 53404
DCDC36/48/9000 Converter	Zahn Electronics, Inc.	4133 Courtney Street, Unit #5, Franksville, WI, 53404
DCDC6350-SU Converter	Zahn Electronics, Inc.	4133 Courtney Street, Unit #5, Franksville, WI, 53404
SH5094B Helm	SeaStar Solutions Inc.	640 N Lewis Road, Limerick, PA 19468
SSC6216B Steering Cable	SeaStar Solutions Inc.	640 N Lewis Road, Limerick, PA 19468
SB27484B Bezel and Mounting Kit	SeaStar Solutions Inc.	640 N Lewis Road, Limerick, PA 19468
RM500A Bilge Pump	Rule Pump Supply	253 NW 54th Street, Miami, FL, 33127