Stevens Institute of Technology Solar
Splash Team 2018

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Boat #4
I. Executive Summary

Stevens Institute of Technology participated in the 2017 competition, finishing 4th place overall, an outstanding achievement. The 2018 team identified four major areas of improvement, hull weight, loss of power from the battery to the motors, small propeller sizes, and the hull design for the endurance event. This year’s 2018 team consisting of four mechanical engineering students and two naval engineering students, have focused on the overall improvement of the system with the goal of placing first in the Solar Splash Competition.

Using a lightweight laminate schedule, a new hull was fabricated resulting in a final weight of 56 pounds (lbs). The hull consists of a Nomex Honeycomb core sandwiched by carbon fiber. With the assistance of a composites expert, the team rebuilt the hull, allowing the members to get hands on experience with composites. Other areas of modification to the hull include a seven inch freeboard reduction and hardening of the chines.

The 2017 team achieved a maximum of 77% of the expected power to the motors. The 2018 team has integrated a real-time data logger, to identify issues with the power supplied to the motors. This logger also provides the skipper with on-board data to better optimize battery life. The team has researched other options such as the integration of a supercapacitor and adjustments to the DC/DC converter to achieve a higher maximum power to the motors.

New propeller sizes were optimized for both the endurance and sprint/slalom configurations. To allow for larger propellers, modifications were made to the outboard motors lower unit.

The stern appendage was designed and modeled using Orca3D to be fastened to the transom during the endurance event. The added stern appendage temporarily alters the shape of the hull, reducing transom drag at slow speeds. Upon completion of model testing, a full sized model was created for additional testing.

Several tests have been performed to date, including model testing and full-scale on water-testing. The team first performed various controlled electrical tests at both low power and full power to identify where the lack of efficiency was located. A model scale stern appendage was tested in the Davidson Laboratory at Stevens Institute of Technology. Tests were performed at the hull’s new displacement with and without the appendage to determine optimal trim configurations and compare to last year’s team’s model results, identifying the approximate decrease in power required by the new hull. The new hull requires around 40% less supplied horsepower for the sprint and slalom events. The added appendage reduces the power required for the endurance event by 30%.

The team has performed several on-water tests at Lake Hopatcong in New Jersey to test the stability of the new hull, bypass of the DC/DC converter, the improvement at slows speeds with the stern appendage, and optimal LCG locations for both the endurance and sprint/slalom configurations.

The team has had a great deal of support from the Stevens community, various sponsors and donors, and last year’s Stevens Solar Splash team. Without this support, many of the achievements of this team would not have been possible. The team is proud of everything accomplished thus far, and are looking forward to demonstrating their hard work at competition. The team has already identified possible areas of improvement for next year’s team and are looking forward to providing them with the same support that was given to the team this year.
Table of Contents

Executive Summary 1

Overall Project Objectives 3

Solar System Design 3

Electrical System 4

Power Electronics System 6

Hull Design 7
  Hull Rebuild 7
  Stern Appendage 10

Drivetrain and Steering 12

Data Acquisition and/or Communications 16

Project Management 18

Conclusions and Recommendation 20

References 22

Appendices 23
  Appendix A: Battery Documentation 23
  Appendix B: Flotation Calculations 30
  Appendix C: Proof of Insurance 33
  Appendix D: Team Roster 34
  Appendix E: Hull Weight Estimate 35
II. Overall Project Objectives

The Stevens Institute of Technology inaugural team participated in the 2017 event, designing the entire system from scratch. This year’s team made several modifications to the existing design, including a reduction in hull weight to decrease drag and increase speed, increased propeller sizes and modifications to the existing outboard motors, development of a stern appendage to improve the endurance event performance, and adjustments to the current electrical system to provide real-time data to the skipper and optimize battery usage during the endurance event.

The main objective of this project was to utilize the existing system as created by the 2017 team and make adjustments, to bring the team from 4th place overall to 1st place. To achieve this, the team focused on each area of the design process, including the sprint, slalom, and endurance events. The team analyzed the top speeds of each category of winners to determine the desired increase in speed for this year. For the endurance event, the top finisher had an average speed of 5.18 knots, and the top place finisher for the sprint/slalom events had an average speed of 23.45 knots. To not only achieve these speeds, but surpass them, the team set to make several adjustments to the existing boat to achieve an average speed of 24 knots in the sprint/slalom events and an average speed of 6 knots for the endurance configuration. In comparison to the 2017 team, this is a 98% speed increase in the sprint/slalom configuration and a 56% speed increase in the endurance event.

III. Solar System Design

The Stevens Institute of Technology 2017 team created a simple and effective solar system, which utilized solar modules by KingSolar. The system includes four solar modules and a solar optimizer that connect to the battery bank. The solar optimizers ensure that each module is providing maximum power, even if another module is being shaded. These modules are all 120 watts (W), 18 volts (VDC) KingSolar Solar Panels, which are mounted to the top of the freeboard with two wooden frames. Two sets of two solar panels are connected in parallel, while each set is connected in series. This provides 13.33 amperes (A) at a nominal 36 VDC, meeting the requirements for charging the battery bank. The total power available from the panels in 480 W. The panels are thin film monocrystalline solar modules, which are lightweight and flexible. Fig. 1 below depicts a photo of the module and some of its components in detail.

![KingSolar Panel with MC4 Connectors and Grommets](image)

Fig. 1: KingSolar Panel with MC4 Connectors and Grommets
Since the competition limits the amount of power from the modules and the size and nominal voltage of the battery bank, there are no major adjustment from the 2018 Stevens team. Adjustments were made to the solar panel mounting system to allow for proper clearance of hardware with the new freeboard reduction. A layout of the solar panels and frames can be seen below in Fig. 2.

![Fig. 2: Layout of Solar Panels on Boat](image)

To ensure that the solar modules were still performing at their maximum efficiency of energy conversion, the team tested each panel with an overhead light and measured the voltages and amperages using a multimeter. The panels will be tested during on-water testing prior to competition.

IV. Electrical System

The 2017 Stevens team previously built an effective electrical system utilizing three batteries, a DC/DC converter, a charge controller, a motor controller, and fuses for overcurrent protection. Three 12 VDC batteries are connected in series to create a 36VDC battery bank with 150 amp-hour (Ah). These batteries are mounted to a flat surface with a strap and ratchet, and connected with 2/0 gauge wire to a water-proof housing. Refer to Appendix A for the battery documentation.

In this housing, the DC/DC converter, fuses, and On/Off switch, and charge controller, are all mounted to the bottom or side of the box. The DC/DC converter steps up the voltage of the battery bank from 36 to 48 VDC. This is necessary to provide sufficient energy potential to the motors, which operate at 48 VDC. This DC/DC converter has an efficiency of 96%, when operating at our amperage threshold.

Two 9.9 horsepower (HP) ELCO outboard motors are used to power the system. When combined, 180 A are required for maximum power output. In order to achieve this, the battery bank must supply 250 A at 36 VDC into the DC/DC converter. The total power into and out of the DC/DC step-up converter is equal (aside from the 4% power loss from efficiency), therefore the percentage that the amperage drops will be equal to the percentage that the voltage increases.

An issue with the electrical system is only 73% of the required amperage for full power is being provided to the motors. In testing, it was determined that the system only provides a
maximum of 140 A to the motors. This results in a major decrease in speed. See Fig. 3 below for a basic schematic of the electrical system sprint configuration.

![Fig. 3: Sprint Configuration Electrical Schematic](image)

The team designed several tests to determine the cause of the loss of power. A PLC and several sensors, donated by Automation Direct, were installed throughout the system to acquire data. Initially the system was run with the outboard fixed in a barrel of water. This tested the precision and accuracy of the sensors and to ensure the data was logging properly. The motors were only able to run at 17% of their maximum available power. At this lower amperage, there was no voltage sag. This test confirmed the PLC set up and allowed the team to move forward to a full scale test.

The PLC acts as a means to create a real time power management system to assist in the endurance race. The power management system compiles the sensor data from the PLC and provides the skipper with a real time display of data. This data includes the voltage and current at three critical parts of the systems; the solar panel output, before the converter, and after the converter. This data will then be analyzed and the amount of power available for the rest of the race will be calculated. The purpose of this system is to create the most precise calculations about power management and speed to allow for the batteries to be at minimum drain at the end of the endurance competition.

A bollard pull test was conducted to assess the electrical system in the Davidson Lab Tow Tank. The motor controls were throttled to full power and data was recorded to confirm the voltage sag seen by the 2017 team. Multiple iterations to reach full power were conducted to determine the optimal way to reach full throttle. The result from this testing showed the loss of power was the result of a drop in voltage at the battery bank, dropping from 36VDC to 29 VDC.
almost instantaneously. The hypothesis for this loss was thought to be a result of the high amperage pull at the batteries. This hypothesis was later confirmed; “voltage sag” is the cause of this loss in power.

Additional testing was conducted on-water at Lake Hopatcong in New Jersey. These tests further confirmed the voltage sag was occurring once the throttles reached full power. To rule out a potential issue with the DC/DC converter, a DC/DC converter bypass test was completed. The electrical system was modified to use four 12 VDC batteries that were wired in series and directly powered the motors, bypassing the converter. This test provided the team with data demonstrating that the motors were capable of receiving 180 A for a steady period of time, while previous data demonstrated very choppy data at maximum power. These results indicate the DC/DC converter was throttling the input current at 266 A. The input current throttling means that the voltage drop of the batteries must be minimized in order to provide the motors with maximum power.

After speaking with multiple subject matter experts, the team determined two options that would allow for an increase in power efficiency to the motors. The first option was to purchase a new DC/DC converter that was rated for slightly higher amperage. The other option was to purchase a supercapacitor. A capacitor works much like a battery as it stores energy, but capacitors resist changes in voltage. The supercapacitor was spec'd out and the team is working to determine the means of acquiring a supercapacitor to meet the needs. Fig. 4 provides a visual of the Maxwell Supercapacitor, the chosen supercapacitor.

Unfortunately, the size and customizability of capacitor is currently out of the team’s budget, but the plans are being made to have this addition installed for the Stevens team during the 2019 year.

V. Power Electronics System

The power electronics system is comprised of two ELCO throttle controllers and two Sevcon Gen4 G4827 motor controllers, one for each electric outboard motor. These controllers were part of the electric motor kit donated to the 2017 team by ELCO Motor Yachts. The motor
controllers are preprogrammed by ELCO and as no motor components have changed, the controllers are also the same. A problem with the current setup is that when two motors are being utilized, both throttle controllers must also be used, requiring the skipper to use both hands. To improve the skipper’s control, the team researched alternative throttle controllers that could operate both motor controllers simultaneously, yet could not find one to fit out system. The team then analyzed the throttle controller wiring and designed a solution to wire both motor controllers in parallel to allow for full control from a single throttle.

After speaking with ELCO about the team’s design concept, they informed the team of their newly designed dual motor throttle, which they have offered to donate. The team chose to proceed with the ELCO produced dual motor throttle into the system as it will provide a more reliable solution to the problem at hand. Once this throttle is received, the team will conduct testing on the new throttle to ensure there are no disruptions to the system.

VI. Hull Design

A. Hull Rebuild

Last year’s team analyzed 21 hull iterations. Sixteen of the designs were planing hulls while the remaining five were high speed displacement hulls. The top planing and high speed displacement hull designs were chosen and further analysis was done to determine the final hull design. To get more accurate data, the team CNC cut a 1:4 scale model of the hull design with interchangeable chines (rounded and hard) to be tank tested in the Davidson Lab. The tank testing provided the team with accurate numerical data, as well as, visuals of the water flow around the model, chines and transom at various speeds. Upon the completion of the tank testing, the team determined that the hard chines allowed for clean separation of transverse flow at the stagnation line and reduction in drag. The tank testing also enabled optimal LCGs positions for the sprint and endurance events [1].

The problems the existing hull faces are weight, large radius chines, freeboard height, and transom stern for the endurance race. The existing hull weighs 326 lbs. The 2017 Team conducted model tow tank testing on the current hull to determine whether to use a hard or rounded chine. These results showed a hardened chine was optimal for the speeds seen by the craft. Unfortunately, in manufacturing of the current hull, a radius was put on the chines. To make up for this, the current design has a strip of aluminum adhered to the chines to allow for a sharp edge. After reviewing footage from the 2017 competition, it was determined that the freeboard for the current hull was much higher then needed. The current hull is a slender planing hull, which is appropriate for the slalom and sprint events, but not optimal for the endurance race.

To decrease the weight of the hull, multiple concepts were analyzed to determine the best way to reduce hull weight. One concept was to cut the freeboard down on the current hull. Analysis was done to determine the maximum amount of freeboard that could be removed while still adhering to the stability rule for competition. It was determined that seven inches (in) could be removed from the freeboard while still maintaining less than a 15° heel when 10 kilograms (kg) was placed at the sheer line. This freeboard removal would allow for a weight reduction of 28.8 lbs.

To determine the appropriate freeboard height reduction, a study was done using Rhino3D and Orca3D to compare height reduction and hydrostatic stability. Three reductions of
6, 7, and 8 inches were considered. After accounting for the change in displacement and longitudinal and vertical center of gravity, each reduction condition was analyzed. The seven inch height reduction was selected based on its favorable maximum heeling angle and righting arm. Fig. 5 below shows the maximum heeling angle and the righting arm at said angle for each condition.

![Fig. 5: Righting Arm Vs. Heel Angle](image)

The six inch reduction configuration was determined to be a safe design choice, but was more stable than deemed necessary. The eight inch reduction condition’s maximum heeling angle was deemed insufficient. Therefore, the team selected a seven inch freeboard height reduction.

Another option for weight reduction of the hull was to rebuild the hull with an ultra-lightweight laminate schedule. The team was given the opportunity to work with a retired composites professor and industry expert, Henry Elliot, on this rebuild. The two concepts for the hull rebuild were to rebuild the hull out of panels, or to reuse the previous built tooling generously made by Viking Yachts for the 2017 team’s hull. The panel build would require a longer build time, and would be built out of two-dimensional panels stitched together, limiting the curvature in the hull.

Fortunately, Viking Yachts was willing to donate the custom tooling for the 2017’s team’s hull to the 2018 team for the rebuild. Without this tooling, the rebuild would not have been possible with the team’s resources and timeline. The team coordinated with Viking Yachts, Henry Elliot and multiple industry leaders to acquire the needed material for the build. The new ultra-lightweight laminate schedule consists of carbon fiber with a Nomex Honeycomb core. A duratec coating was used in place of a gel coat, as the duratec coating allowed for a thinner layer and was less dense.

With the help of many industry leaders, materials were chosen for the laminate schedule. A 45° x 45° 240 g/m² carbon fiber was chosen for the shell layup. Eight millimeter Nomex Honeycomb was used for the core of the shell. A 200 g/m² two part epoxy was donated by Henry Elliot as well as many of the necessary process materials needed for vacuum bagging. Jamestown Distributors donated additional process materials including the tacky tape for vacuum bagging.
and abrasives. An estimate for the final weight of the new hull was determined using the average density of the materials, assuming a 1:1 ratio of epoxy to carbon, an industry standard. Based on these densities and the surface area of the hull, the final weight was estimated to be 58 lbs. These calculations can be seen in Appendix E.

After all the materials, tooling and a build space were acquired, the team began the rebuild with the guidance of Henry Elliot and Frank Poor. The shell of the hull was laid up in four stages, duratec coating, exterior carbon fiber layer, Nomex Honeycomb layer, and interior carbon fiber layer. Templates were made for the lay up of the carbon fiber and honeycomb to allow for a tight fit of the honeycomb and a 2 in overlap of the carbon fiber at the chines and sheer. After each composite layup, the form was left under vacuum to cure. Processing materials such as peel ply, perf ply and breather were used to distribute the vacuum across the surface, allow excess resin to escape and left the surface smooth for sanding or an additional layer of composite material. Fig. 6 displays an image of the team working on the rebuild.

Once the shell was completed, templates for the stiffeners were cut from 2D panels of the same laminate schedule as the new hull. These panels were designed to create an egg crate form for easy installation into the hull. The areas where the stiffeners were being installed were reinforced with a biaxial carbon fiber. Once installed, fillets were created using syntactic foam, to reinforce the places were the stiffeners met the inner surface of the hull. Carbon tape was then applied to cover the fillets and further reinforce the structure.

After completion of the stiffener installation, the hull was removed from the mold. Once out of the mold, the freeboard was trimmed to size. A sheer clamp was added on the interior of the sheer line to strengthen the edge of the hull and allow for an area to secure hardware to. The rounded chines were then back filled to allow for the desired hardening of chine. The hull was

Fig. 6: Laying Exterior Carbon
then sanded to maintain a smooth surface on both the interior and exterior of the hull. A final
weight of the hull was measured to be 55.3 lbs. The final build can be seen in Fig. 7.

Tank testing was conducted to determine the effects of the rebuild weight reduction. The
results of these tests can be seen in Fig. 8. This chart shows that the lightweight hull requires
40% less supplied horsepower for the sprint and endurance events.

Fig. 8: Performance Improvement - Reduced Hull Weight
B. Stern Appendage

The current hull design is primarily a planing hull, with chines, a steep forward deadrise, and a transom stern, all of which allow water to separate from the hull surface. These features are effective at high speeds but a low speeds, discontinuity creates additional drag, especially at the stern. The transom stern creates eddies and a turbulent wake. A displacement hull has a smooth shape, which allows water to continuously flow along the hull surface, and less drag at low speeds. To further bridge the gap between planing and displacement hull type, and to reduce drag at low speeds, the team developed a removable stern appendage which transitions the transom stern to a rounded one.

The design was created using Rhino3D, with the effort of having smooth waterlines. The shape takes the current transom stern and transitions the hard corner cross-sections to rounded sections. The choice of material was 10 lb/cu. in (pcf) rigid foam, which would be cut using a CNC. To reduce the overall weight of the appendage, the interior was shelled out, leaving a 0.5 in wall thickness. The freeboard height was limited to 8.5 in, as the maximum cutting depth of the CNC bit is 8 in.

The design was first created and tested at model scale (1:4) and was attached to the hull model. The combined configuration was then run in a model test, and was tested against the original hull without the appendage. The model was run in an even trim condition, with a model displacement of 9.38 lbs (600 lbs full scale). The low speed results, with and without the stern appendage, are compared to the 2017 team test results, and are shown in Fig. 9.

![Performance Improvement](image)

**Fig. 9: Performance Improvement - Stern Appendage**

At 6 knots (estimated endurance speed) the stern appendage results in a 12% reduction in drag. The design was deemed usable for the endurance configuration and the full scale appendage was cut.
To test the effectiveness of the stern appendage in real-scale, the team will be performing a series of on-water testing. The boat will be run for a controlled duration first without the appendage. The amount of charge of the batteries will be recorded at the start and end of several runs in calm water. The boat will then be run with the appendage on. Runs will be the same duration and the charge on the batteries at the start and end of the runs will be recorded. The differences in charge will be recorded and compared those produced by the boat without the appendage. The team expects the difference in battery charge to be less with the appendage attached. Fig. 10 shows an image of the final stern attached to the hull.

Fig. 10: Attached Stern Appendage

VII. Drivetrain and Steering

The current system uses two ELCO 9.9 hp outboard motors with a SeaStar mechanical steering system. For the sprint configuration, the two outboard motors are used with 7.25” x 7” 4 blade left and right hand propellers. For the endurance race, one motor is secured inside the hull, and only one motor is used for the race with a 7.25” x 7” 4 blade propeller.

The problem with this system is the limitations on propeller size. The fixed cavitation plate on the lower unit restricts the maximum allowable propeller to 7.5 inches diameter. It is known that a larger diameter will allow for a larger blade area ratio, thus more power. In turn this will increase the overall efficiency of the propellers.

It was also determined that there was only 77% efficiency to the motors during the 2017 testing and competition. This lack of efficiency could stem from a limitation in the electrical system or a limitation in the load on the propeller. Since the propeller is restricted to 7.5 inches in diameter, it could potentially not be requiring the maximum power of the motors to spin it. The goal of the drivetrain changes were to determine if this lack of efficiency was caused by the propeller and design a configuration that allowed for a larger diameter propeller.

To improve the efficiency of this system, the team focused on finding better propellers for both the sprint and endurance events. Last year’s team achieved an average speed of 12 knots in the sprint event and 3.9 knots for the endurance event; the goal for this year is to achieve a
maximum speed over 20 knots for the sprint event and maintain an average speed of 6 knots for the endurance event.

Various theoretical and empirical based tools were implemented to determine optimized propellers for these events. The *Propeller Selection and Optimization Program (PSOP)* was a key tool used to decide the dimensions of these propellers. [2] This program allows the user to input a wide variety of specifications including horsepower, maximum revolutions per minute (rpm), number of blades and desired speeds to get an optimal diameter and pitch. The motors have a horsepower of 9.9 and can turn a maximum of 2163 rpm at the propeller shaft. A range of speeds from 20-26 knots were tested. Based on these results, the most optimal propeller dimension was chosen, a 9.5” x 12” 3 blade resulting in a speed of 23.5 knots. A propeller efficiency plot can be seen in Fig. 11.

![Fig. 11:Sprint Propeller Efficiency Plot](image)

As for the endurance propeller, PSOP inputs were a little different since the boat will be running at a much slower speed of 6 knots. This is turn lowers the rpms needed to run at this speed. Through research and guidance from sponsors such as ELCO, it was determined that a square propeller with more blade area would be the most beneficial. More research was done specifically into two bladed propellers. A two bladed propeller was chosen as it has less drag acting on the propeller when compared to a three or four blade propeller. Spinning a large diameter propeller with two blades at a slow speed results in better overall propeller efficiency.

Finding the optimized size propeller that fit on the ELCO 9.9 hp motor was a challenge. These motors has a 9-spline locking mechanism on the propeller shaft. The maximum diameter for a standard 9-spline shaft is 7.5 in. To overcome this obstacle, research was conducted on different propeller repair companies. Precision Propeller, a company that specializes in propeller repair was able to assist the team is getting the proper sized propellers with a 9-spline hub. This company was able to order the stock 7.5” x 8” propellers and enlarged them to be 9.5” x 12” through a welding, grinding and repitching process.
Another company, Dewald Propellers specializes in making surface piercing propellers for small horsepower motors. Surfacing piercing propellers are more efficient than standard submerged propellers due to the decrease in drag. This decrease in drag comes from raising the motors out of the water enough so the centerline of the hub is at the waterline. Dewald Propellers provided the team with five different propellers for the team to test and determine the optimal size. Further testing will be done to determine if these propellers will assist in reaching the desired speed for the sprint event.

As stated previously, the current outboard motors used by the team uses a 9 spline shaft, adding difficulty to the potential modifications, due to its rarity. Once propellers could be found, the team knew that modifications were required for the lower unit to allow for enough clearance between the propeller and the cavitation plate. Three spacers were designed to be used, two one inch spacers for the sprint/slalom configuration, and one three inch spacer for the endurance event. The spacer is designed out of solid, aluminum 6061, shaped to match the current lower unit profile. Both lower units were cut, separating the cavitation plate from the remaining section containing the propeller hub. A locating pin, made of AISI 304, is placed at the front of the unit to keep the spacer aligned. Two 5/16”- 24 finely threaded bolts are to be used to connect the spacer to the cut lower unit.

First, the spacer was modeled and simulated in SolidWorks, testing the factor of safety of the spacer and the connected joint. Fig. 12 below displays the results of the simulation.

![Fig. 12: Lower Unit Spacer SolidWorks Simulation](image)

Knowing that the spacer would add distance between the motor and the propeller hub, a longer drive shaft was necessary due to the increase in length, and the rarity of 9 spline shafts, the route taken by the team involved splicing the current shafts, adding an extension, and welding the joint. Two holes were drilled into either end of the spliced shaft, allowing the pins of the extension to fit tightly and join both ends prior to welding. Fig. 13 demonstrates the extension before and after joining the spliced shaft.
After completing the shaft and the lower unit, the component was assembled and reattached to the motor. Fig. 14 below shows the assembled lower unit with the spacer and the enlarged propeller.

To test the durability of the shaft, the team first used the Davidson Laboratory Tank before testing the motors at Lake Hopatcong. The tests in the tank consisted of placing both motors on the tank dinghy, restraining the dinghy in place, and running the boat at full power. Both motors were then run at full speed to ensure that the spacers and the spliced shaft could withstand the torque of the motors. Once confident that the spacers were secure, the team tested the full-scale system at Lake Hopatcong, testing both low and high speeds with the spacers and the optimized larger propellers.

Although the team is aware that this issue could have been solved by purchasing new outboard motors, the budget of the team did not allow for a large purchase as this. The team
harnessed their engineering knowledge to design and fabricate a spacer to provide clearance for the propellers that were optimized previously.

VIII. Data Acquisition and/or Communications

To understand the system performance during testing and at the competition, an accurate power management system was crucial. The team determined the most necessary data was the voltage of the battery bank, the motors, and the solar panel output, and amperage draw from the battery bank, and the going into the motors. The team researched in electrical measurement devices such as multimeters and ammeters, but these provided little to no data collection abilities and would require an individual meter for each measurement. To achieve data collection capabilities, the team worked with Automation Direct to design a complete PLC system, capable of measuring, logging, and displaying all data in real time. The system is comprised of three voltage transducers, a bidirectional current transducer, single direction current transducer, four signal conditioners, a Do-More PLC unit, an analog expansion module, a C-More Digital Display unit, and a DC/DC converter. See Fig. 15 below for the electrical schematic of the power management system, which demonstrates how each module is wired together. The specification sheet for each component of the system was carefully analyzed to ensure that it was compatible not only with the chosen PLC unit, but the actual system loads. For example, the voltage transducers utilized are specified to operate within 0-50 VDC, which falls within the system maximum of 48 VDC.

Fig. 15: Power Management System Schematic

The team worked closely with the Davidson Laboratory to wire the system correctly and perform initial testing of the components. Prior to installing the PLC system into the electrical system of the boat, the PLC was programmed to read and scale each of the voltage and current...
transducers. The output of each transducer was an analog signal, which had to be converted by the analog expansion module to be read by the PLC. Testing determined that the analog expansion module was not precise enough, resulting in the addition of the signal conditioners to the system. With the PLC programmed, each voltage sensor was connected to a variable powersource to ensure the PLC reading matched the powersource. To test the current transducers, the same variable power source was used, however, a handheld ammeter was used to measure the current directly before the current transducer. The sensor reading was then compared to the reading on the ammeter to ensure its accuracy.

With the sensors tested and the PLC programmed, the power management system was integrated into the electrical system with voltage transducers measuring battery bank voltage, motor voltage, and solar output voltage, while the current transducers measured the current of the battery bank, solar output, and motor. A sample of the data collected by the PLC system is shown in Fig. 16 and Fig. 17 below; note that the solar system was not active during this test. This test data provided the team with confirmation that the batteries were experiencing voltage sag during periods of high amperage pull.

Fig. 16: Plotted Voltage Test Data Collected by Power Management System
The C-More Digital display unit was programmed to read the data collected by the PLC unit and graphically display it to the skipper in real time. This part of the system will be critical during the endurance event, as it will allow the skipper to see exactly how much power is being consumed at any given time, remaining battery power, as well as confirmation that each part of the system is functioning without issues.

IX. Project Management

A. Team Members and Leadership Roles

At the beginning of the project, the team was broken up into subsystems based on the goals for this year’s project and the individual strengths of the team members. Sara was chosen to be the project leader, overseeing all aspects of the project and ensuring the different groups were staying on track. Ellysa was in charge of purchasing, and coordinated with subsystems to determine the proper components to order. Nick and Jason, two mechanical engineers were responsible for the changes to the electrical systems, data acquisition program and solar system. Sara and James were responsible for the hull changes, including the weight reduction and stern appendage. Ellysa and Drew were responsible for the changes to the drivetrain and steering system. All team members took on different responsibilities when major aspects of the group’s goals were being conducted, such as the hull rebuild. Further details on the team members and their responsibilities can be seen in Appendix D.

B. Project planning and schedule

To successfully design, build and test the system in time for competition, a strict timeline was adhered to. A Gantt Chart was created to layout the milestones for each of the project goals. Tasks were performed in parallel to reach these milestones in time for competition. Once in the building and assembling phases, a task list was created to set deadlines and responsible team members for any necessary tasks that needed to be completed. This task list was a more detailed...
breakdown of the Gantt Chart, with several tasks needed to be met for each milestone. The combination of the Gantt Chart and Task List allowed the team to have a visual of how long each milestone would take to reach, and which tasks were critical to this timeline.

Each task was organized by category, start date, end date, priority, and team member lead. The list could be filtered to see just tasks for one subsystem, tasks for one team member or which tasks were high priority. This list allowed for team members to gain a better understanding of their roles and responsibilities as well as the way their tasks altered the timeline for other subsystems.

While the team was broken up into subsystems, the entire team held weekly meetings to review all aspects of the project. These meetings allowed for stronger communication amongst the subsystems. Between these weekly meetings, communication was continued via a group messaging system to further discuss different tasks that the team was working on. If a subsystem needed more assistance with a task at hand, they could reach out to other members for help. All files for the project were organized on Google Drive to allow for the team to be able to review all aspects of the project at any time.

C. Financial and fund-raising

The finance and fundraising for the team was one of the biggest challenges. At Stevens Institute of Technology this project is a senior design project and is given a limited budget. An initial budget was put together based on the 2018 teams goals, but this budget was larger than the allotted finances. The team was given the option to limit the goals for the project or to find additional resources elsewhere.

Once the team was into the design aspect of the systems, a better understanding of the required components and materials was gained. Members of the team were able to reach out to manufactures and industry leaders to determine the options for educational discounts and donations. Fortunately enough, the team found many industry leaders who were more than willing to share their knowledge with the team members. After many discussions with different companies, multiple components, materials and labor were donated.

Henry Elliot was a large contributor for the hull rebuild. He worked with the team to consult on the laminate schedule and guided the team through the rebuild process. Frank Poor also guided the team through the hull layup process and graciously offered the team the needed build space to house the mold and materials. Viking Yachts generously donated the necessary tooling to allow for the team to rebuild the hull in a streamlined fashion. Multiple other companies assisted in the donation of materials and tools to assist with the build, including Jamestown Distributors, Bravolab, and Resolute Racing Shells.

ELCO Motor Yachts and Precision Propellers were big contributors for the drivetrain and steering system. ELCO Motor Yachts assisted the team in the design aspect of the outboard motor modifications. Precision Propellers assisted the team in making the adjustments to the shafts to allow for a longer lower unit and adjusted the current propellers to meet the optimized size for the sprint configuration. Continued support from both ELCO and Precision will be utilized to completed the modifications for the endurance configuration.

Automation Direct contributed to this year’s project by assisting with the design and implementation of a data acquisition system. They generously donated all of the necessary components and technical support to get the system running. Zahn Electronics assisted the team in determining the loss of power experience in the 2017 team’s system. Once the loss was
pinpointed, Zahn worked with the team members to determine the requirements for a super capacitor. Further work with Zahn and other distributors will be conducted in an effort to assist with the purchasing of a super capacitor for the system.

D. Strategy for team continuity and sustainability

Not only was it a goal of the team’s to build a successful boat and improve as many of the issues initially identified, but the team wanted to document as much as possible to make learning about the system easier for next year’s team. The Stevens rookie team created a wonderful system to start, making the process of improving the performance of the boat focused on only a few areas of weakness. Although the hull was rebuilt this year, the team used the existing design and mold, as last year’s team designed and optimized a hull that performed very well in the endurance, sprint, and slalom competitions. This hull will then be passed onto future teams to use. With its new weight, it allows the team to focus on improving other areas where there is loss, as this hull is durable and is able to be used for years to come.

Similar to last year, most components of the system were donated and will be passed onto future teams. The team this year has been documenting set-up of the components, especially for water testing, to allow the team to quickly comprehend the system and know how to integrate all components, rather than trying to base the set-up off of pictures that were passed down to them. Just like this year, next year’s team is in a great place to continue improving the system. The team this year has identified other issues that were not initially recognized and documented them to be passed onto next year’s team to start them off with potential areas of improvement.

E. Discussion and self-evaluation

The team addressed many different aspects during this project. The team was successful in focusing their attention on large scale issues, such as the hull weight reduction, making their main objective to complete these before the competition. The team planned for other smaller issues to arise, including areas that were not necessarily dire, but helped in other areas. The team did their best to communicate all changes with one another, especially when teammates had individual tasks to complete. The team was successful in identifying the issues that were to be modified, even if they came up along the way. Each member used the knowledge gained over the course of their time at Stevens Institute of Technology and applied it to this project. While each member had to learn new material, the team worked together and supported one another, making this project successful.

X. Conclusions and Recommendation

The team considers this project a success as they have completed the goals and objectives that were initially identified. The team considers the reduction in hull weight to be the biggest accomplishment and also the strength of the project. The new, lightweight hull is 17% of the weight of last year’s hull. This affects every other aspect of the competition as it helps to achieve increased speeds in all events. Another strength includes the increased propeller sizes as it will allow for the team to easily achieve faster speeds. Weaknesses of the project include the motors, since they had to be cut and modified. If the team had new larger outboard motors, the lower units would not have been cut for a bigger propeller. There are still some issues with the electrical system where there are areas of improvement that this team is working to address.
Also, although the appendage is helpful, it can still be considered a weakness as it weighs around 10 lbs, which is 20% of the weight of the hull itself. However, these are issues that can be resolved by teams in the future as they are minor and they have already been identified.

The team is satisfied with the work that has been put into this project. The team has accomplished the main goals of reducing hull weight, modifying the electrical system, improving endurance performance, and increasing propeller sizes. The team is pleased with the designs in this project as they believed that they have optimized everything currently. While it may be found by future teams that there are areas of improvement, the team still believes that they have made great strides with this project and believe they have created new designs that will allow them to place higher in competition. From here, the team will compile and document areas of weakness, including any issues encountered when at the competition to give to next year’s teams. The team already has suggestions, including researching new outboard motors to better optimize the power drawn from the motors, and overall eliminate the problems faced this year with non-standard sizes of propellers and shaft.

There were many lessons learned throughout the year, which included learning how to work with composites and build a lightweight hull, how to design in an area of knowledge that is unfamiliar, and learning how to support each teammate differently. The team had the opportunity to work with a Henry Elliot, a retired composites professor, receiving hands-on knowledge, and seeing the entire process through from start to finish. Additionally, the team was mixed with both naval engineering students and mechanical engineering students, allowing for overlapping of subjects. Each team member had the chance to work on aspects of the project outside of their knowledge base, causing members to perform extensive research and learn more about the other areas. Invaluable experience was gained throughout the whole process from technical to interpersonal. All team members are finishing the project with a new understanding the systems used.
References


Appendices

Appendix A: Battery Documentation

The team uses two sets of three 12 VDC Odyssey marine grade sealed lead acid batteries (PC1100).
### II. PRODUCT IDENTIFICATION

**Chemical Trade Name (as used on label):**
CyclePro, Odyssey, Genesis®, SHS, XEP®, AmSafe Pius®, MLPC, Nexsys or Large TIPPL.

**Chemical Family Classification:**
Sealed Lead Battery

**Stability:**
Sealed Lead Acid Battery, VRLA Battery

**Manufacturer’s Name/Address:**
EnerSys Energy Products Inc.
617 N Ridgeview Drive
Watersburg, MD 21695-5901

**Telephone:**
For information and emergencies, contact EnerSys Energy Products
Environment, Health & Safety Dept. at 609-429-2165

**24-Hour Emergency Response Contact:**
CHEMTREC DOMESTIC: 800-424-9300 CHEMTREC INTL: 703-527-8877

### III. HAZARDS IDENTIFICATION

<table>
<thead>
<tr>
<th>HEALTH</th>
<th>ENVIRONMENTAL</th>
<th>PHYSICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Toxicity</td>
<td>Aquatic Chronic 1</td>
<td>Explosive Chemical, Division 1.3</td>
</tr>
<tr>
<td>Oral/Inhalation</td>
<td>Cat. 4</td>
<td>Aquatic Acute 1</td>
</tr>
<tr>
<td>Skin Corrosion/ Irritation</td>
<td>Cat. 1A</td>
<td></td>
</tr>
<tr>
<td>Eye Damage</td>
<td>Cat. 1</td>
<td></td>
</tr>
<tr>
<td>Reproductive</td>
<td>Cat. 1A</td>
<td></td>
</tr>
<tr>
<td>Carcinogenicity (carcinogenic substances)</td>
<td>Cat. 1B</td>
<td></td>
</tr>
<tr>
<td>Carcinogenicity (carcinogenic substances)</td>
<td>Cat. 1A</td>
<td></td>
</tr>
<tr>
<td>Specific Target Organ Toxicity (repeated exposure)</td>
<td>Cat. 2</td>
<td></td>
</tr>
</tbody>
</table>

### IV. GHS LABEL

#### HEALTH

**Hazard Statements:**
- DANGER: Causes severe skin burns and serious eye damage. Wash thoroughly after handling.
- May cause cancer if ingested or inhaled. Avoid breathing dust/fume/gas/mist/vapors/spray.
- May cause cancer if ingested or inhaled. Use only outdoors or in a well-ventilated area.
- May damage fertility or the unborn child if ingested or inhaled. Avoid contact with internal organs. Obtain special instructions before use.
- May cause death if exposed to high pressures. Do not handle until all safety precautions have been read and understood.
- Explosive, fire, blast, or projection hazard. Avoid contact during pregnancy/while nursing.
- Harmful if swallowed, inhaled, or contact with skin.
- Causes skin irritation, serious eye damage.

**Precautionary Statements:**
- Do not eat, drink or smoke when using this product.
- Avoid breathing dust/fume/gas/mist/vapors/spray.
- Avoid contact with eyes, respiratory system, and skin.

#### ENVIRONMENTAL

**Hazard Statements:**

#### PHYSICAL

**Hazard Statements:**

### V. COMPOSITION/INFORMATION ON INGREDIENTS

<table>
<thead>
<tr>
<th>Components</th>
<th>CAS Number</th>
<th>Approximate % by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic Lead Compound:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>7439-92-1</td>
<td>45 - 60</td>
</tr>
<tr>
<td>Lead Oxide</td>
<td>1309-48-7</td>
<td>15 - 25</td>
</tr>
<tr>
<td>Tin</td>
<td>7440-31-5</td>
<td>0.1 - 5.2</td>
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<tr>
<td>Sulfuric Acid Electrolyte (Sulfuric Acid/Water)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5664-93-6</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Case Material:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyvinyl</td>
<td></td>
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</tr>
<tr>
<td>Polyurethane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polycarbonate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### VI. EXPOSURE CONTROLS/PERSONAL PROTECTION

- Respiratory protection: Usually not required. Use personal protective equipment if dust level is excessive.
- Protective clothing: Wear protective gloves and protective clothing, eye protection, fire protection.
- Protective equipment: Use only outdoors or in a well-ventilated area.

### VII. STABILITY AND REACTIVITY

- Stable under normal conditions.
- May react violently with strong oxidizing agents.

### VIII. DISPOSAL CONSIDERATIONS

- Disposal: Contact local authorities for disposal instructions.
- Label as required by local authorities.

### IX. TRANSPORT INFORMATION

- Transport Risk Group: 6.1
- Packing Group: III
- UN Number: 2908
- Special Precautions: None

### X. REGULATORY INFORMATION

- Hazardous Waste Identification: None
- Local, State, Federal, and International Regulations: None

### XI. OTHER INFORMATION

- Electronic Product Code: 1808099
- Company: EnerSys Energy Products Inc.
- Date of Revision: 04/27/2004

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Stevens Institute of Technology - Boat #4

24
## SAFETY DATA SHEET

### Absorbent Glue Mat

Inorganic lead and sulfuric acid electrolyte are the primary components of every battery manufactured by EnerSys Energy Products.

There are no mercury or cadmium containing products present in batteries manufactured by EnerSys Energy Products.

### FIRST AID MEASURES

#### Inhalation:
- **Sulfuric Acid:** Remove to fresh air immediately. If breathing is difficult, give oxygen. Consult a physician.
- **Lead:** Remove from exposure; gargle, wash nose and lips; consult physician.

#### Ingestion:
- **Sulfuric Acid:** Give large quantities of water; do not induce vomiting or aspiration into the lungs may occur and can cause permanent injury or death; consult a physician.
- **Lead:** Consult physician immediately.

#### Skin:
- **Sulfuric Acid:** Flush with large amounts of water for at least 15 minutes; remove contaminated clothing completely, including shoes; consult a physician.
- **Lead:** Wash contaminated clothing before reuse; discard contaminated shoes.

#### Eyes:
- **Sulfuric Acid and Lead:** Flush immediately with large amounts of water for at least 15 minutes while lifting lids. Seek immediate medical attention if eyes have been exposed directly to acid.

### FIRE FIGHTING MEASURES

#### Flash Point: N/A

<table>
<thead>
<tr>
<th>Flammable Limits</th>
<th>LEL: 4.1% (Hydrogen Gas)</th>
<th>UEL: 52.2% (Hydrogen Gas)</th>
</tr>
</thead>
</table>

#### Extinguishing Media:
- Carbon dioxide, foam, dry chemical. Avoid breathing vapors. Use appropriate media for surrounding fire.

#### Special Fire Fighting Procedures:
- If batteries are on charge, shut off power. Use positive pressure, self-contained breathing apparatus. Water applied to electrolyte generates heat and causes it to spatter. Wear acid-resistant clothing, gloves, face and eye protection.

Note that strings of series connected batteries may still pose risk of electric shock even when charging equipment is shut down.

#### Cause of Fire and Explosion Hazards:
- Highly flammable hydrogen gas is generated during charging and operation of batteries. To avoid risk of fire or explosion, keep sparks or other sources of ignition away from batteries. Do not allow metallic materials to simultaneously contact negative and positive terminals of cells and batteries. Follow manufacturer's instructions for installation and service.

### ACCIDENTAL RELEASE MEASURES

#### Spill or Leak Procedures:
- Stop flow of material, contain with absorbent small spills with dry sand, earth, and vermiculite. Do not use combustible materials. If possible, carefully neutralize spilled electrolyte with soda ash, sodium bicarbonate, lime, etc. Wear acid-resistant clothing, boots, gloves, and face shield. Do not allow discharge of unneutralized acid to sewer. Acid must be managed in accordance with local, state, and federal requirements.

Consult state environmental agency and/or federal EPA.

### HANDLING AND STORAGE

#### Handling:
- Unless involved in electrolyte operations, do not handle the casing or empty the contents of the battery.

There may be increasing risk of electric shock from strings of connected batteries.

- Keep containers tightly closed when not in use. If battery case is broken, avoid contact with internal components.
- Keep vent caps on and cover terminals to prevent short circuits. Place cardboard between layers of stacked automotive batteries to avoid damage and short circuits.

- Keep away from combustible materials, organic chemicals, reducing substances, metals, strong oxidizers and water. Use bundling or stretch wrap to secure items for shipping.

#### Storage:
- Store batteries in cool, dry, well-ventilated areas with impervious surfaces and adequate containment in the event of spills. Batteries should also be stored under roof for protection against adverse weather conditions. Separate from incompatible materials. Store and handle only in areas with adequate water supply and spill control. Avoid damage to containers. Keep away from fire, sparks and heat. Keep away from metallic objects which could bridge the terminals on a battery and create a dangerous short-circuit.

- Charging:
- There is a possible risk of electric shock from charging equipment and from strings of series connected batteries, whether or not being charged. Shut-off power to chargers whenever not in use and before detachment of any circuit connections. Batteries being charged will generate a non-flammable hydrogen gas.

- Charging space should be ventilated. Keep battery vent caps in position. Prohibit smoking and avoid creation of flames and sparks nearby.

- Wear face and eye protection when near batteries being charged.

### EXPOSURE CONTROLS/PERSONAL PROTECTION

Exposure Limits (mg/m3): N.E. = Not Established

<table>
<thead>
<tr>
<th>INGREDIENTS (Chemical/Common Names)</th>
<th>OSHA PEL</th>
<th>ACGIH</th>
<th>US NIOSH</th>
<th>Quebec PEL</th>
<th>Ontario OEL</th>
<th>EU OEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead and Lead Compounds (nonmisfit)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>Tin</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>N.E.</td>
</tr>
<tr>
<td>Sulfuric Acid Electrolyte</td>
<td>1</td>
<td>0.2</td>
<td>1</td>
<td>1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Polysulphate</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Stylene</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Bromine Acrilonitrile</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Acrylonitrile Butadiene</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
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<td>N.E.</td>
</tr>
</tbody>
</table>

Page 2
## SAFETY DATA SHEET

### STEVENS INSTITUTE OF TECHNOLOGY - BOAT #4

|--------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|

### NOTES:
- (b) As inhalable aerosol
- (c) Throat: fraction

#### Engineering Controls (Ventilation):
- Store and handle in a well-ventilated area. If mechanical ventilation is used, components must be acid-resistant.
- Handle batteries cautiously to avoid spills. Make sure vent caps are secured. Avoid contact with internal components. Wear protective clothing, eye, and face protection when filling, charging, or handling batteries. Do not allow metallic materials to simultaneously contact both the positive and negative terminals of the battery. Change the batteries in areas with adequate ventilation. General dilution ventilation is acceptable.

#### Respiratory Protection (NIOSH/MSHA approved):
- None required under normal conditions. When concentrations of sulfuric acid mist are known to exceed the PEL, use NIOSH or MSHA-approved respiratory protection.

#### Skin Protection:
- If battery case is damaged, unexposed plastic or acid-resistant gloves with elbow-length gauntlets, acid-resistant apron, clothing and boots.

#### Eye Protection:
- If battery case is damaged, use chemical goggles or face shield.

#### Other Protection:
- Under severe exposure emergency conditions, wear acid-resistant clothing and boots.

### IX. PHYSICAL AND CHEMICAL PROPERTIES

**Properties Listed Below are for Electrolyte:**
- **Boiling Point:** 233 - 240°F
- **Specific Gravity (H₂O = 1):** 1.215 to 1.350
- **Melting Point:** N.A.
- **Vapor Pressure:** (mm Hg): 1.0
- **Solubility in Water:** 100%
- **Vapor Density (AIR = 1):** Greater than 1
- **Evaporation Rate:** (Butyl Acetate = 1) Less than 1
- **% Volatile by Weight:** N.A.
- **pH:** 4 to 2
- **Flammability:** (Below room temperature [no hydrogen gas])
- **LEL (Lower Explosive Limit):** 4.5% (Hydrogen)
- **UEL (Upper Explosive Limit):** 74.2% (Hydrogen)
- **Appearance and Odor:** Manufactured article; no apparent odor.
- **Electrolyte is a clear liquid with a sharp, penetrating, pungent odor.

### X. STABILITY AND REACTIVITY

**Stability:** Stable

**Unstable:**

**Conditions To Avoid:** Prolonged overcharge, sources of ignition.

**Incompatibility:** Materials to avoid:
- Sulfonic Acid: Contact with combustibles and organic material may cause fire and explosion. Also reacts violently with strong reducing agents, metal, sulfur trioxide gas, strong oxidizers and water. Contact with water may produce toxic sulfur dioxide fumes and may release flammable hydrogen gas.
- Lead Compounds: Avoid contact with strong acids, bases, halides, halogenates, potassium nitrate, permenthanic, peracids, acetic acid and reducing agents.

**Hazardous Decomposition Products:**
- Sulfonic Acid: Sulfur trioxide, carbon monoxide, sulfuric acid mist, sulfur dioxide, and hydrogen sulfide.
- Lead Compounds: High temperatures likely to produce toxic metal fumes, vapor, or dust; contact with strong acid or base or pressure of sodium hydrogen may generate highly toxic sodium gas.

**Hazardous Polymerization:**
- Will not occur

### XI. TOXICOLOGICAL INFORMATION

**Routes of Entry:**
- Sulfonic Acid: Harmful by all routes of entry.
- Lead Compounds: Hazardous exposures can occur only when product is heated, oxidized or otherwise processed or damaged to create dust, vapor or fumes. The presence of sodium hydrogen may generate highly toxic sodium gas.

**Inhalation:**
- Sulfonic Acid: Breathing of sulfuric acid vapor or mists may cause severe respiratory irritation.
- Lead Compounds: Inhalation of lead dust or fumes may cause irritation of upper respiratory tract and lungs.

**Ingestion:**
- Sulfonic Acid: May cause severe irritation of mouth, throat, esophagus and stomach.
- Lead Compounds: Acute ingestion may cause abdominal pain, nausea, vomiting, diarrhea and severe cramping. This may lead rapidly to systemic toxicity and must be treated by a physician.

**Skin Contact:**
- Sulfonic Acid: Severe irritation, burns and ulceration.

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**Page 3**
SAFETY DATA SHEET

Lead Compounds: Not absorbed through the skin.

Eye Contact:
Sulfate Acid: Severe irritation, burns, corneal damage, and blindness.
Lead Compounds: May cause eye irritation.

Effects of Overexposure - Acute:
Sulfate Acid: Severe skin irritation, damage to cornea, upper respiratory irritation.
Lead Compounds: Symptoms of toxicity include headache, fatigue, abdominal pain, loss of appetite, muscle aches and weakness, sleep disturbances and irritability.

Effects of Overexposure - Chronic:
Sulfate Acid: Possible erosion of tooth enamel, inflammation of nose, throat and bronchial tubes.
Lead Compounds: Anemia, neuropathy, particularly of the motor nerves, with wrist drop, kidney damage; reproductive changes in males and females. Repeated exposure to lead and lead compounds in the workplace may result in nervous system toxicity. Some toxicologists report abnormal conduction velocities in persons with blood lead levels of 50 mcg/100 ml or higher. Heavy lead exposure may result in central nervous system damage, neuropathy and damage to the blood-forming hematopoietic tissues.

Carcinogenicity:
Sulfate Acid: The International Agency for Research on Cancer (IARC) has classified "strong inorganic acid mist containing sulfic acid" as a Group 1 carcinogen, a substance that is carcinogenic to humans. This classification does not apply to liquid forms of sulfic acid or sulfic acid solutions contained within a battery. Inorganic acid mist (sulfic acid mist) is not generated under normal use of this product. Misuse of the product, such as overcharging, may result in the generation of sulfic acid mist.
Lead Compounds: Lead is listed as a Group 2A carcinogen, likely in animals at extreme doses. Per the guidance found in OSHA's 29 CFR 1910.1200 Appendix F, this is approximately equivalent to OSHA Category III. Toxicity of inorganic lead in humans is lacking at present.

Medical Conditions Generally Aggravated or Exacerbated by Exposure:
Overexposure to sulfuric acid mist may cause lung damage and aggravate pulmonary conditions. Contact of sulfuric acid with skin may aggravate skin diseases such as eczema and contact dermatitis. Lead and its compounds can aggravate some forms of kidney, liver, and neurologic diseases.

Acute Toxicity:
Inhalation LD50:

- Acidic conditions: LC50: 375 mg/m3; LC50: guinea pig: 510 mg/m3

- Elemental Lead: Acute Toxicity Point Estimate = 4500 ppmV (based on lead bullion)

Oral LD50:

- Acidic conditions: 2140 mg/kg

- Elemental Lead: Acute Toxicity Estimate (ATE) = 580 mg/kg body weight (based on lead bullion)

Additional Health Data:
All heavy metals, including the hazardous ingredients in this product, are taken into the body primarily by inhalation and ingestion.

Most inhalation problems can be avoided by adequate precautions such as ventilation and respiratory protection covered in Section 8.

Follow good personal hygiene to avoid inhalation and ingestion with hands, face, neck, and arms thoroughly before eating, smoking or leaving the workplace. Keep contaminated clothing out of non-contaminated areas, or wear cover clothing when in such areas. Restrict the use and presence of food, tobacco and cosmetics to non-contaminated areas. Work clothes and work equipment used in contaminated areas must remain in designated areas and never taken home or laundered with personal non-contaminated clothing. This product is intended for industrial use only and should be isolated from children and their environment.

The 19th Amendment to EO Directive 87/548/EEC classified lead compounds, but not lead in metal form, as possibly toxic to reproduction. Risk phrase 61: May cause harm to the unborn child; applies to lead compounds, especially soluble forms.

VI. ECOLOGICAL INFORMATION:

Environmental Fate:
Lead is very persistent in soil and sediments. No data on environmental degradation. Mobility of metallic lead between ecological compartments is slow. Bioaccumulation of lead occurs in aquatic and terrestrial animals and plants but little bioaccumulation occurs through the food chain.

Most studies include lead compounds and not elemental lead.

Environmental Toxicity: aquatic Toxicity:

- Sulfate acid: 24-hr LC50: freshwater fish (Brachydanio rerio): 82 mg/L

- 96-hr LC50: freshwater fish (Cyprinus carpio): 22 mg/L

- Lead: 48-hr LC50 (predicted for aquatic invertebrates): ≤1 mg/L, based on lead bullion

Additional Information:
- No known effects on stratospheric ozone depletion.
- Volatile organic compounds: 9% (by Volatile), 99% (by Volatile)
- After Use, Epersonal:
Place sterilized waste into sealed containers and handle as applicable with state and federal regulations. Large water-diluted spills, after neutralization and testing, should be managed in accordance with approved local, state and federal requirements. Consult your disposal agency and/or federal EPA.

Specifications:
Spent batteries: Send to secondary battery dealer for recycling. Spent lead-acid batteries are not regulated as hazardous waste when the requirements of 40 CFR Section 266.80 are met. This should be managed in accordance with approved local, state and federal requirements. Consult state environmental agency and/or federal EPA.

VII. TRANSPORT INFORMATION:

Stevens Institute of Technology - Boat #4

Page 2
SAFETY DATA SHEET

U.S. DOT:
Excepted from the hazardous materials regulations (HMR) because the batteries meet the requirements of 49 CFR 173.159(f) and 49 CFR 173.159g of the U.S. Department of Transportation's HMIS. Battery and outer package must be marked "NONSPILLABLE" or "NONSPILLABLE BATTERY". Battery terminals must be protected against short circuits.

ATA Dangerous Goods Regulations (DG):
Excepted from the dangerous goods regulations because the batteries meet the requirements of Packing Instruction 872 and Special Provisions A67 of the International Air Transportation Association (IATA) Dangerous Goods Regulations and International Civil Aviation Organization (ICAO) Technical Instructions. Battery terminals must be protected against short circuits.

IMDG:
Excepted from the dangerous goods regulations for transport by sea because the batteries meet the requirements of Special Provision 238 of the International Maritime Dangerous Goods (IMDG CODE). Battery terminals must be protected against short circuits.

Requirements for Safe Shipping and Handling of Cylindrical Cells:
Warning – Electrical Fire Hazard – Protect against shorting. Terminals can short and cause a fire if not insulated during shipping. Cyclotrons must be insulated "NONSPILLABLE" during shipping. Follow all federal shipping regulations. See section 4.1.1 of this sheet and CFR 49 Part 171.

Requirements for Shipping Cylindrical Product as Single Cells:
Protective caps or other durable inert material must be used to insulate each terminal of each cell unless cells are shipped in the original packaging from EnerSys in full box quantities. Protective caps are available for all cell sizes by contacting EnerSys Customer Service at 1-800-966-2837.

Requirements for Shipping Cylindrical Product Assembled Into Multistack Batteries:
Assembled batteries must have short circuit protection during shipping. Exposed terminals, connectors, or lead wires must be insulated with a durable inert material to prevent exposure during shipping.

V. REGULATORY INFORMATION

UNITED STATES:
EPA SARA Title III:
Section 302 EPCRA Extremely Hazardous Substances (EHS):
Sulfuric acid is a listed "Extremely Hazardous Substance" under EPCRA, with a threshold planning quantity (TPQ) of 1,000 lbs. EPCRA Section 302 notification is required if 1000 lbs or more of sulfuric acid is present at one site (40 CFR §370.10). For more information consult 40 CFR Part 370. The quantity of sulfuric acid is 1586 kg or 3496 lbs. Contact your EnerSys representative for additional information.

Section 305 CERCLA Hazardous Substances:
Reportable Quantity (RQ) for sulfuric acid under CERCLA (Superfund) and EPCRA Omnibus Planning and Community Right to Know Act is 1,000 lbs. State and local reportable quantities for sulfuric acid may vary.

Section 313 Toxics Release Inventory:
EPCRA Section 313 Tier Two reporting is required for on-site batteries if sulfuric acid is present in quantities of 500 lbs or more and/or if lead is present in quantities of 10,000 lbs or more. For more information consult 40 CFR §370.10 and 49 CFR §390.81.

Section 313 EPCRA Toxic Substances:
40 CFR section 372.58 (b) states: If a toxic chemical is present in an article at a covered facility, a person is not required to consider the quantity of the toxic chemical present in such an article when determining whether an applicable threshold has been met under § 372.25, § 372.27, or § 372.28 or determining the amount of release to be reported under § 372.30. This exemption applies whether the person received the article from another person or the person produced the article. However, this exemption applies only to the quantity of the toxic chemical present in the article.

Supplier Notification:
This product contains toxic chemicals, which may be reportable under EPCRA Section 313 Toxic Chemical Release Inventory (Form R) requirements. If you are a manufacturing facility under SIC Code 20 through 39, the following information is provided to enable you to complete the required report:

<table>
<thead>
<tr>
<th>Toxic Chemical</th>
<th>CAS Number</th>
<th>Approximate Pct. Wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>7439-92-1</td>
<td>45 - 60</td>
</tr>
<tr>
<td>Sulfuric Acid Electrolyte</td>
<td>7664-93-9</td>
<td>15 - 29</td>
</tr>
<tr>
<td>(Sulfuric Acid/Water)</td>
<td>7446-31-5</td>
<td>0.1 - 0.2</td>
</tr>
</tbody>
</table>

See 40 CFR Part 370 for more details.

If you distribute this product to other manufacturers in SIC Codes 20 through 39, this information must be provided with the first shipment of each calendar year.

The Section 313 supplier notification requirement does not apply to batteries, which are "consumer products".

TSCA:
TSCA Section 8b – Inventory Status: All chemicals comprising this product are either exempt or listed on the TSCA Inventory.

TSCA Section 12(b) (40 CFR Part 707.60(b)): No notice of export will be required for articles, except PCB articles, unless the Agency so requires in the context of individual sections 5.6. or 7 actions.

SAFETY DATA SHEET

Spent Lead Acid Batteries are subject to streamlined handling requirements when managed in compliance with 40 CFR section 266.10 or 40 CFR, part 273.
Waste sulfuric acid is a characteristic hazardous waste: EPA hazardous waste number D002 (corrosivity) and D008 (delay).

CAA:
EnerSys supports preventative actions concerning ozone depletion in the atmosphere due to emissions of CPCs and other ozone-depleting chemicals (ODCs), defined by the US EPA as Class I substances. Pursuant to Section 611 of the Clean Air Act Amendments (CAAAS) of 1990, promulgated on January 19, 1993, EnerSys established a policy to eliminate the use of Class 1 ODCs prior to the May 15, 1993 deadline.

STATE REGULATIONS (US):
Proposition 65:
Warning: Battery posts, terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

INTERNATIONAL REGULATIONS:
Distribution into Quebec to follow Canadian Controlled Product Regulations (CPR) 24(1) and 24(2).
Distribution into the EU to follow applicable Directives in the Use, Import/Export of the product as sold.

A. OTHER INFORMATION
Revised AC (94-25-37)

NTPA Hazard Rating for Sulfuric Acid:
Flexibility (Red) = 0
Health (Blue) = 3
Reactivity (Yellow) = 2
Sulfuric acid is water-reactive if concentrated.

DISCLAIMER:
This Safety Data Sheet is created by the manufacturer to comply with the requirements of 29 CFR 1910.1200. To the extent allowed by law, the manufacturer hereby expressly disclaims any liability to any third-party, including users of this product, including but not limited to, consequential or other damages, arising out of the use of, or reliance on, this Safety Data Sheet.
Appendix B: Flotation Calculations

The 2018 Stevens Solar Splash competition race boat will weight 407 lb in its heaviest configuration without the skipper. Rules require 20% factor of safety to be included in the buoyancy calculations (Rule 7.14.2 - Buoyancy of Craft). Therefore, the boat must include an extra 81.4 lb of buoyancy, for a total of 488.58 lb of buoyant force.

<table>
<thead>
<tr>
<th>Buoyancy (lbs.)</th>
<th>20% Reserve (lbs.)</th>
<th>Total (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>407.15</td>
<td>81.43</td>
<td>488.58</td>
</tr>
</tbody>
</table>

**Hull Buoyancy**

First, the total buoyant force of the hull, if it were to be submerged, was calculated using Rhino3D mass properties and the following calculations. The total area of the hull \(A_{	ext{Hull}}\) is 73.46 ft\(^2\). The maximum thickness \(t_{	ext{hull}}\) of the hull is 0.4 in, which was recorded during the hull rebuild. Multiplying the area by the thickness gives the total enclosed volume of the hull \(V_{	ext{Hull}}\) of 2.45 ft\(^3\).

\[
A_{	ext{Hull}} = 73.46 \text{ ft}^2
\]
\[
t_{	ext{hull}} = 0.40 \text{ in} = 0.033 \text{ ft}
\]
\[
V_{	ext{Hull}} = A_{	ext{Hull}} \times t_{	ext{hull}} = 73.46 \times 0.033 = 2.45 \text{ ft}^3
\]

The thickness of the hull is not uniform. The first 3.5 inches under the freeboard is 0.05 in thick. To account for this, we took 90% of \(V_{	ext{Hull}}\) to represent the actual enclosed volume, making our actual volume 2.2 ft\(^3\). The specific weight of water \((\gamma)\) at 65°F is 62.3 lb/ft\(^3\). By multiplying the specific weight with the actual volume, the total buoyant force of the hull was calculated to be 137.3 lb.

\[
F_{	ext{Buoyant|Hull}} = 0.9V_{	ext{Hull}} \times \gamma = 2.2 \times 62.3 = 137.3 \text{ lb}
\]

**Internal Structure**

The volume of the hull structure \(V_{\text{Internal}}\), which includes longitudinal and transverse stiffeners, was calculated using SolidWorks mass properties, and is 651.98 in\(^3\). By multiplying the specific weight of water with \(V_{\text{Internal}}\), the total buoyant force of the internal structure was calculated to be 23.5 lb.

\[
V_{\text{Internal}} = 651.98 \text{ in}^3 = 0.38 \text{ ft}^3
\]
\[
F_{	ext{Buoyant|Internal}} = 0.38 \times 62.3 = 23.5 \text{ lb}
\]

**Stern Appendage**

Next, the total buoyant force of the stern was calculated using Rhino3D mass properties and the following calculations. The total area of the stern \(A_{\text{stern}}\) is 10.93 ft\(^2\) plus a 1.0 ft\(^2\) middle section which divides the stern in half. This is a result of manufacturing the stern by assembling two half sections. The thickness of the stern is 0.5 in (0.042 ft). The middle section is 1 in (0.083 ft) thick, as
it is the meeting of two 0.5in walls. The volume of the stern \( V_{\text{Stern}} \) is therefore 0.543 ft\(^3\), given by the equation below:

\[
V_{\text{Stern}} = 10.93 \times 0.042 + 1.0 \times 0.083 = 0.543 \text{ ft}\(^3\)
\]

By multiplying the specific weight of water with \( V_{\text{Stern}} \), the total buoyant force of the stern was calculated to be 33.83 lb.

\[
F_{\text{Buoyant|Stern}} = 0.543 \times 62.3 = 33.83 \text{ lb}
\]

**Batteries**

Since the batteries are watertight and remain attached to the boat, they were included in the total buoyancy. Each battery volume was measured to be 280.4 in\(^3\) (0.162 ft\(^3\)). By multiplying the specific weight of water with \( V_{\text{Battery}} \), the total buoyant force of each battery was calculated to be 10.1 lb. Since 3 batteries are used, the total buoyant force for all of the batteries is 30.3 lb.

\[
V_{\text{Battery}} = 3.75\text{ in} \times 7.63\text{ in} \times 9.8\text{ in} = 280.4 \text{ in}^3 = 0.162 \text{ ft}^3
\]

\[
F_{\text{Buoyant|Battery}} = 0.162 \times 62.3 = 10.1 \text{ lb}
\]

\[
\Sigma F_{\text{Buoyant|Battery}} = 3 \times F_{\text{Buoyant|Battery}} = 30.3 \text{ lb}
\]

**Electrical Box**

The electrical box will be made watertight and will remain attached to the boat. The exterior dimensions of the box were measured and the total volume \( V_{E-\text{Box}} \) was calculated at 5,265 in\(^3\) (3.05 ft\(^3\)). By multiplying the specific weight of water with \( V_{E-\text{Box}} \), the total buoyant force of the box was calculated to be 189.8 lb.

\[
V_{E-\text{Box}} = 13\text{ in} \times 15\text{ in} \times 27\text{ in} = 5265 \text{ in}^3 = 3.05 \text{ ft}^3
\]

\[
F_{\text{Buoyant|E-Box}} = 3.05 \times 62.3 = 189.8 \text{ lb}
\]

**Additional Buoyancy**

The remaining buoyancy of 73.85 lb will be accounted for by using two foam rectangular sections of dimensions 4.5”x10”x24”, and will be attached to the boat on either side of the electrical box. The volume of each section is 1080 in\(^3\) (0.63 ft\(^3\)). By multiplying the specific weight of water with \( V_{\text{Added}} \), the total buoyant force of each foam segment was calculated to be 38.94 lb. The total added buoyancy from the two foam sections will therefore be 77.88 lb.

\[
V_{\text{Added}} = 4.5\text{ in} \times 10\text{ in} \times 24\text{ in} = 1080 \text{ in}^3 = 0.63 \text{ ft}^3
\]

\[
F_{\text{Buoyant|Added}} = 0.63 \times 62.3 = 38.94 \text{ lb}
\]

\[
\Sigma F_{\text{Buoyant|Added}} = 2 \times F_{\text{Buoyant|Added}} = 77.88 \text{ lb}
\]
### Final Buoyancy

<table>
<thead>
<tr>
<th>Item</th>
<th>Total Volume (ft$^3$)</th>
<th>$F_{\text{Buoyant}}$ (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull</td>
<td>2.20</td>
<td>137.31</td>
</tr>
<tr>
<td>Internal Structure</td>
<td>0.38</td>
<td>23.51</td>
</tr>
<tr>
<td>Stem Appendage</td>
<td>0.54</td>
<td>33.83</td>
</tr>
<tr>
<td>Batteries (3)</td>
<td>0.48</td>
<td>30.30</td>
</tr>
<tr>
<td>Added Foam (2)</td>
<td>1.25</td>
<td>77.88</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>492.67</strong></td>
</tr>
</tbody>
</table>

(121.1%)
Appendix C: Proof of Insurance

Proof of general liability insurance is provided.

---

**CERTIFICATE OF LIABILITY INSURANCE**

**DATE:** 04/01/2018

**PRODUCER:**

Fred C. Church, Inc.
41 Whitney Street
Lowell, MA 01851
(800) 225-1002

**INSURED:**

The Trustees of the Stevens Institute of Technology
Castle Point Avenue
Hoboken, NJ 07030-0001

**INSURERS AFFIRMING COVERAGE**

<table>
<thead>
<tr>
<th>INCURER</th>
<th>Company Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Adams Specialty Insurance Company</td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>

**COVERAGE**

**CERTIFICATE NUMBER:** 64103

**REVISION NUMBER:**

**GENERAL LIABILITY**

- Commercial General Liability:
  - Claim-made: $1,000,000
  - Occurrence: $1,000,000
- Aggregate Limit Applies Per Policy: $2,000,000

**AUTOMOBILE LIABILITY**

- Bodily Injury Per Accident: $1,000,000
- Property Damage Per Accident: $500,000
- Aggregate Limit: $2,000,000

**EXCESS LIABILITY**

- Aggregate Limit: $1,000,000

**WORKERS' COMPENSATION AND EMPLOYERS' LIABILITY**

- State Law Limits: State Law Limits
- Each Accident: $1,000,000
- Each Disease - Employee: $1,000,000
- Each Disease - Policy Limit: $1,000,000

**DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES**

<table>
<thead>
<tr>
<th>VEHICLE</th>
<th>TYPE OF隈VHICLE</th>
<th>RETAIL VALUE</th>
<th>DEDUCTIBLE</th>
<th>EXCESS LIABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Boats</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DATE OF ISSUE:** 04/11/2017

**DATE OF EXPIRATION:** 11/11/2018

**CANCELLATION**

**EVIDENCE OF INSURANCE**

Hoboken, NJ

**AUTHORIZED REPRESENTATIVE**

[Signature]

---

Stevens Institute of Technology - Boat #4
Appendix D: Team Roster

As a senior design project, all members of the team are graduating in May 2018 with a BE in their respective fields.

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Degree Program</th>
<th>Year</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew Hanke</td>
<td>BE in Naval Engineering</td>
<td>Senior (4/4)</td>
<td>Drivetrain and Steering</td>
</tr>
<tr>
<td>Nicholas Hohorst</td>
<td>BE in Mechanical Engineering</td>
<td>Senior (5/5)</td>
<td>Electrical System</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solar System</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Data Acquisition</td>
</tr>
<tr>
<td>Ellysa Lamperti</td>
<td>BE in Mechanical Engineering</td>
<td>Senior (5/5)</td>
<td>Drivetrain and Steering</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Purchasing</td>
</tr>
<tr>
<td>James Lassi</td>
<td>BE in Naval Engineering</td>
<td>Senior (4/4)</td>
<td>Hull Design</td>
</tr>
<tr>
<td>Jason Pastuzyn</td>
<td>BE in Mechanical Engineering with an ME in Engineering Management</td>
<td>Senior (5/5)</td>
<td>Electrical System</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Solar System</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Data Acquisition</td>
</tr>
<tr>
<td>Sara Poor</td>
<td>BE in Mechanical Engineering</td>
<td>Senior (5/5)</td>
<td>Project Leader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hull Design</td>
</tr>
</tbody>
</table>
Appendix E: Hull Weight Estimate

The team used a lightweight laminate schedule to fabricate this year’s hull. This is the original estimated weight before conducting the build. This estimate is based off of materials weight and the hulls surface area.

<table>
<thead>
<tr>
<th>Hull Outer Surface Area (m²)</th>
<th>8.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Weight (g/m²)</td>
</tr>
<tr>
<td>Duratec</td>
<td>200</td>
</tr>
<tr>
<td>Duratec</td>
<td>200</td>
</tr>
<tr>
<td>Duratec</td>
<td>200</td>
</tr>
<tr>
<td>Carbon Twill</td>
<td>200</td>
</tr>
<tr>
<td>Epoxy</td>
<td>200</td>
</tr>
<tr>
<td>Nomex Honeycomb</td>
<td>384.4</td>
</tr>
<tr>
<td>Carbon Twill</td>
<td>200</td>
</tr>
<tr>
<td>Epoxy</td>
<td>200</td>
</tr>
<tr>
<td><strong>Total Shell Weight</strong></td>
<td><strong>14.28</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stiffeners Area (m²)</th>
<th>5.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Weight (g/m²)</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>200</td>
</tr>
<tr>
<td>Epoxy</td>
<td>200</td>
</tr>
<tr>
<td>Nomex Honeycomb</td>
<td>384.4</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>200</td>
</tr>
<tr>
<td>Epoxy</td>
<td>200</td>
</tr>
<tr>
<td><strong>Total Stiffeners Weight</strong></td>
<td><strong>5.92</strong></td>
</tr>
</tbody>
</table>

| Estimated Total Hull Weight after Fillets + Chines | 57.89 |