VorteX

CARNEGIE MELLON SOLAR RACING
JUNE 2017

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EXECUTIVE SUMMARY

Although the Carnegie Mellon Solar Racing (CMSR) club has competed in Solar Splash many times before, at the start of the 2015-2016 academic year the team consisted of only eight members with only one person with experience building a boat or competing in Solar Splash. All other experienced members had either graduated or left the club due to commitment issues. The club was also left in a $10,000 deficit from competing in solar races in Europe during the summer of 2014. Thus, CMSR has spent the last two years recovering from the deficit, focusing on recruitment, creating new documentation strategies, and building a strong foundation for the future of the team. Being able to compete at Solar Splash with VorteX this year is a milestone that we are excited to achieve.

The majority of the club's effort was spent constructing a new hull. A male plug was designed in SolidWorks based off of leftover boats from previous years. The team researched several ways to improve the performance of the hull--a significant change was the inclusion of a chine along the vertical center to improve hydroplaning. The plug was created by using CNC laser cutters to create two-inch cross-sections of foam that were glued together. After sanding the plug to a smooth finish and applying releasing agents, the team laid-up fiberglass over the plug to generate a female mold. The hull was then manufactured by laying-up four layers of carbon fiber and one sheet of Nomex honeycomb in the female mold.

Regarding the power and photovoltaic systems, no expertise was passed on from previous years. However, many supplies, including solar panels and batteries, were left over. The team focused on reusing these materials to conserve budget. The final design consists of two Sunpower panels operating at 40V and 215W each (maximum power point) charging a 24V battery bank of two Optima bluetop batteries. A Morningstar MPPT charge controller was chosen as the intermediary. These components were chosen to optimize performance given the Solar Splash regulations, such as limits on battery weight and solar panel power. The panels and charge controller were recovered from the leftover materials, saving the team $1,000. To monitor the status of the various systems, an Arduino microcontroller collects data through a variety of sensors and sends the data to an onboard tablet that presents the information to the skipper.

With the focus on building the hull, the team decided to purchase a propulsion system for Solar Splash 2017. The propulsion system consists of a Cruise Torqeedo 2.0RS outboard motor and a Seastar SS137 20' Safe-T Quick Connect steering cable. The goal for Solar Splash 2018 will be to compete with a propulsion and steering system made by the team. This will give the organization more flexibility with design, which we hope will result in better competition performances as well as an enhanced learning experience for members that is applicable to engineering work in the industry.

The team's goals for this competition is to gain member experience in competing and to gather data on our systems to improve them for next year. After reviving the club with new members, funds, and accomplishments, the team hopes to improve the organization's reputation on campus and to reinstate the team as a regular competitor at Solar Splash competitions.

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I. PROJECT OBJECTIVES

Carnegie Mellon Solar Racing (CMSR) suffered a financial deficit and a significant loss in membership during academic year 2014-2015. Starting the 2015-2016 year, only one member had any experience building a boat. Therefore, the team's main objective was to build a functioning boat and compete in Solar Splash. Doing so would help re-establish the team's campus presence, and secure finances and member involvement in future years. The team has also strived to reorganize management, set up better documentation, and build a better sense of community and family, to avoid another shortage of funding and membership. This new boat consists of a hull made by the team, a purchased propulsion systems and a power system built from reused materials.

II. CURRENT DESIGNS

A. Solar System

1) Current Design: CMSR's system uses two SunPower Model SPR-215-WHT-U solar panels. These panels are rated at 215 W_{mpp}, 39.8 V_{mpp}, and 5.4 A_{mmp} each. Combining the two allows for a 430 Watt system, which is within the maximum allowed power rating of 480 Watts. Each panel weighs 33 lbs, has a maximum efficiency of 17.3%, and has dimensions (61.4 x 31.4 x 1.8) inches.

The team owns other types of panels (Table 1), but the SunPower panels were primarily chosen for high maximum power point voltage, low weight, and efficiency. The V_{mpp} is high enough to efficiently charge a 24V battery bank, allowing them to be placed in parallel instead of series, to avoid the 52V open circuit regulation. The alternatives had various issues. Two panels of the LG285N1C would exceed the power regulation and four Kyocera panels, for the desired target of 480W, would be too heavy.

Table 1: Solar panels that our club owns. The Sunpower panel was selected for our boat this year.

Solar Panel	Watts	Efficiency	Rated Voltage (V_{mpp})	Rated Current (A_{mpp})	Open Circuit Voltage (Voc)	Weight (lb)
Sunpower SPR-215-WHT	215	17.30%	39.8	5.4	48.3	33
LG285N1C-G3	285	17.40%	31.6	9.09	39	37
Kyocera KC120-1	120	14%	16.9	7.1	21.5	26.3

2) Testing and Evaluation: As a simple test of the solar panels, they were wired to the charge controller (see section B. Electrical System) and placed under direct sunlight. Under bright sunlight at noon, the solar panels were able to provide current of 17A into the charge controller with a terminal voltage of 42V, consistent with the manufacturer specifications.

3) Future Improvements: The current design has problems with the weight of the solar panels. Most of the weight of the solar panels comes from a heavy frame, designed primarily for stationary usage. The focus for next year for the Power Team will be working on making custom solar panels designed for solar boat racing, focusing on a reduction in overall weight. This will also allow the team to take advantage of the 10% power allowance for custom-made panels.

B. Electrical System

1) Current Design: The power system utilizes a Morningstar TriStar 45 MPPT Charge Controller as an intermediary between the panels and batteries. The TriStar MPPT Charge Controller was chosen for its ability to charge batteries with significantly lower voltage than the solar panels without loss of efficiency. According to the data provided by Morningstar, for a solar array rated at 430 Watts and 39.8 Volts, the MPPT charge controller is able to charge a 24V battery system with around 95% efficiency [2]. A TriStar unit was found in storage leftover from previous years, so alternatives were not considered for this year.

2) Testing and Evaluation: A preliminary test was conducted by wiring a single Sunpower panel (from above) to the charge controller, charging a single 12V lead-acid battery. Under weak sunlight, the panel output .5A at 42V, which the charge controller converted into a 1.5A at 13V charging current. The power conversion in this test is

$$(1.5A * 13V) / (.5A * 42V) = 93\% ,$$

suitably close to the rated efficiency. A full system test with both panels, the motor, and a 24V battery bank, will be conducted after the submission of this report.

3) Future Improvements: Alternatives to the TriStar should be considered. With a new budget next year, the team should be able to purchase a more efficient charge controller if one exists. The TriStar's LED battery monitor is also non-functional when the batteries are discharging.

C. Power Electronics System

1) Current Design: The propulsion system requires a 24V input, so the electronics design utilizes two 12V lead-acid batteries that are wired in series. To choose the batteries, old batteries from previous years were tested. Each was tested for 10 seconds using a 100 amp load tester by NOKO. The testing showed that most of the batteries failed to maintain a high voltage under load, likely indicating damage. This could be due to the fact that most of the batteries had been left uncharged for a long period of time, and might have crystallized.

Several commercial batteries were considered (Table 2). Many were unfavorable because their weight was not optimal given the Solar Splash limit on 100lbs of battery. Ideally, two 50lb batteries would be ideal to maximize capacity and stay within the weight limit (since weight is roughly proportional to capacity). We also sought deep-cycle batteries since in racing conditions the batteries will often be discharged significantly.

The decision was narrowed down to a 80Ah Duracell battery and a 55Ah Optima. Although the Duracell has significantly higher capacity, the Optima was eventually chosen as it is absorbent glass mat, durable, and maintenance free. Meanwhile the Duracell is flooded and unsealed, and would require routine maintenance.

Table 2: Comparison chart of different batteries the team considered. The final choice, the Optima D34M, is highlighted in green.

Battery	Capacity (20-hr) Ah	Weight (lb)	Type	Price
Sigma 12-35	35	23.59	AGM	In storage
UB12500	50	30.2	AGM (deep cycle)	In storage
Optima Red 75/35	44	33.1	AGM	In storage
Optima Red 75/25	48	37.8	AGM (deep cycle)	In storage
Duracell SLI27MDP	80	49	Flooded	115.99
Amstron AP12-75D	75	51.8	AGM	139.99
Optima D34M	55	43.5	AGM (dual purpose)	175.45

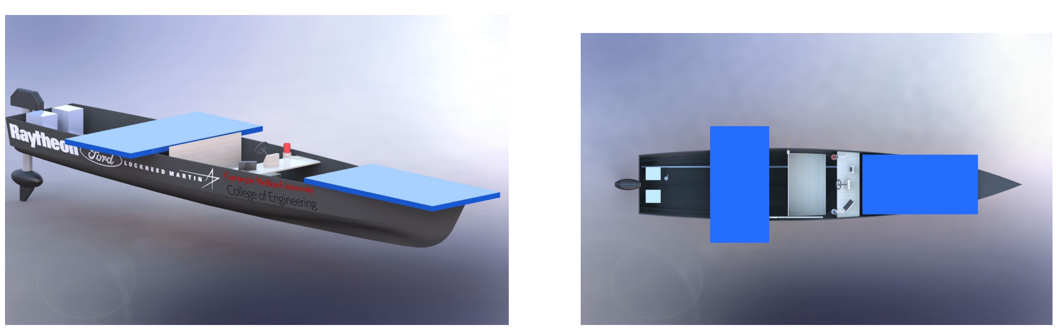
2) Future Improvements: In our design considerations this year, battery discharge rates, lifetime, and many other factors were neglected. The team will try to account for this for future optimizations.

D. Hull Design

1) Past Years Design: In previous years, the CMSR team has utilized a narrow hull, which required a pontoon on either side for stability. The goal was that the pontoons would stay out of the water and only provide support when the hull turned or otherwise needed stabilization. This would allow the team to minimize surface area contact with the water, and therefore drag. However, because of the weight of internal components and the lack of buoyancy that comes with the hull's narrow design, this was never achieved and the pontoons rested in the water with the hull. When in motion, the pontoons successfully provided stability while significantly increasing drag. With a lack of symmetry, the pontoons also caused issues with steering.

Another issue the team has faced in the past has been mounting and the effect of mounting on the vessel's overall rigidity. Without predetermined mounting locations, the team screwed into the side of the hull where necessary and used nuts and bolts to mount everything from pontoons, to propulsion system, to electrical components. Without the use of a filling compound, the nut and bolt assembly caused weaknesses in the honeycomb core, which gave in and reduced some of the hull's rigidity.

2) Analysis of Design Concepts: In this year's design, the CMSR team sought to eliminate each of the issues mentioned earlier. First, the team sought to eliminate the need for stabilization pontoons and the negative side effects introduced in previous designs. The team accomplished this by increasing the width of the boat, which also increased buoyancy and the boat's ability to maintain stability when stationary. In addition to eliminating the excess drag introduced by the stabilization pontoons, the Hull team set a goal of decreasing weight by utilizing more efficient epoxy saturation techniques when laminating carbon fiber. The hull also features a single chine around the perimeter of the boat, which in addition to the light design, will allow the boat to quickly transition to hydroplaning.



Figures 1 & 2: CAD model of VorteX

3) Design Construction: The initial prototype of the boat was designed and tested with a combination of SolidWorks and Matlab. Once the prototype was completed and fit all criteria, the team started constructing the hull. In constructing the prototype, the team used a CNC to complete 2-axis cuts on 2-inch thick foam. After cutting was complete, the foam cross-sections were stacked to create a 17-foot male mold of the model. Because 2-axis cuts were used for the cross-sections (Fig.1), much sanded was needed to reach the desired three-dimensional shape (Fig.1).

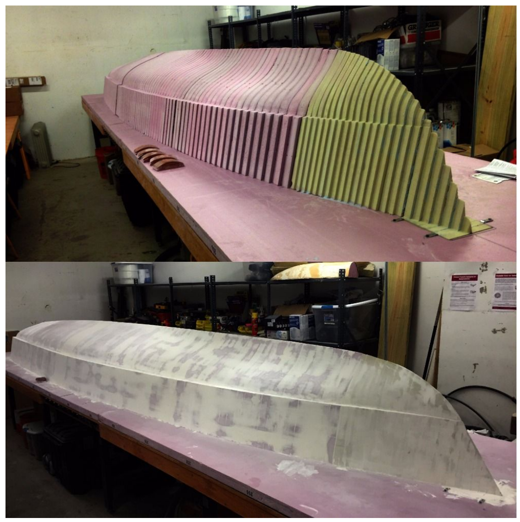


Figure 3: 17-Foot Male Mold Before and After Sanding

After repeatedly sanding and applying spackling paste, the desired shape was achieved and the team was able to move on to priming the plug. After applying several coats of primer, the plug was wet-sanded to a smooth finish (Fig.3).

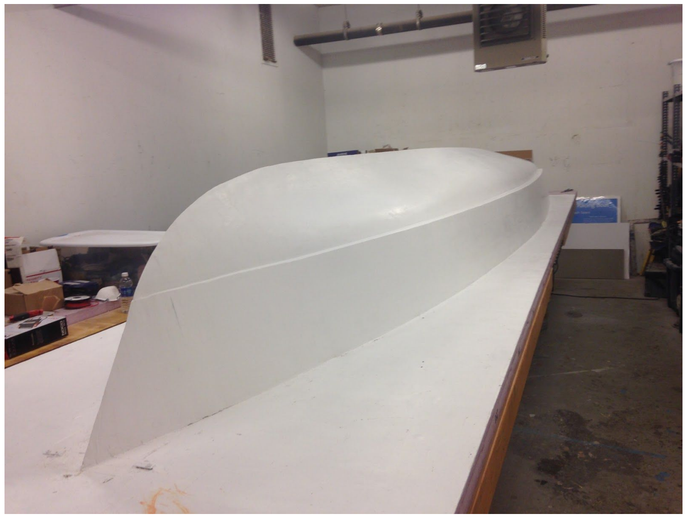


Figure 4: Female Mold for VorteX

Following priming, gel coat and PVA release were applied to the plug and the team began construction of the female mold.

Figures 5-7: Application of PVA Release and Gel Coat.

Two layers two layers of fiberglass mat and four layers of woven fiberglass were applied to the plug. Next, the foam male plug was removed from the fiberglass female mold. Hull Team then flipped the female mold so that the smooth inner surface was accessible.

Figures 8 & 9: Preparing for fiberglass layup.

An additional layer of PVA Release was applied to the fiberglass female mold. Hull Team completed a total of seven carbon fiber layups. The layups were conducted with epoxy resin and vacuum seal to minimize imperfections. Between the fourth and fifth layers of Carbon Fiber a layer of Honeycomb was added for structural integrity. Between the following layers of Carbon Fiber a pre-laid up sheet of carbon fiber was placed in the stern in order to reinforce the hull support the propulsion system.

Figures 10 & 11: Laying down the carbon fiber and setting up the vacuum seal.

After finishing the seven layers of carbon fiber, the hull was inspected, waterproofed and imperfections touched up. After finishing detailing and touch ups, the Hull Team primed and painted the boat.

Before testing for leaks, we reinforced the bow of the boat by filling the front 16 inches with expanding foam. The bow was further reinforced while making it more streamline by adding a carbon fiber layer on top of the expanding foam.

Figures 12: Mix and pour foam reinforcement

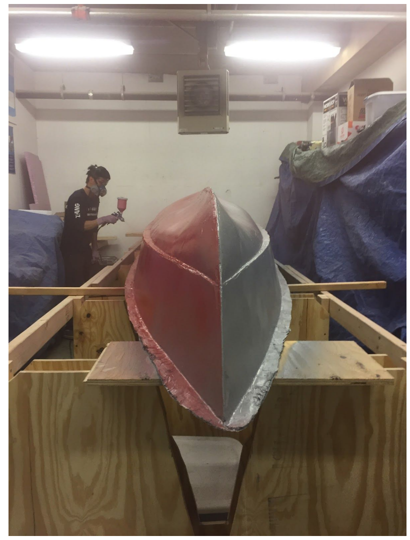
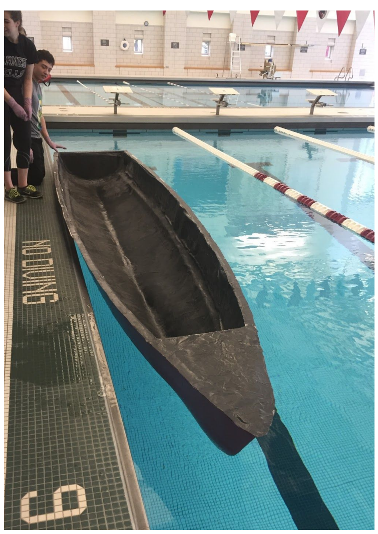


Figure 13: Applying first layer of paint

Upon the completion of waterproofing, painting the hull, and reinforcement, we proceeded to test the hull stability and water tightness by testing in the university pool. We tested the hull without any of the components inside it to ensure that nothing got damaged in the testing process. We were able to confirm that there were no leaks in the hull and that our boat is capable of supporting more than the weight of all the components that will be implemented in the final product.



Figures 14 & 15: Testing Vortex for leaks and stability

To increase the strength of hull, waterproofed wooden cross-sections were inserted across select points in the hull. These cross-sections will also double as supports for components within the boat. At this point in the fabrication process, the Hull Team collaborated with Propulsion Team and Power Team to properly install all of the electrical and steering components.

E. Drivetrain and Steering

1) This Year's Design:

a) Steering kit: Our steering system uses the Seastar SS137 20’ Safe-T Quick Connect to control the boat’s direction of travel using an outboard motor. The steering cable connects from the steering wheel to the front of the outboard motor, which has a connection to facilitate the attachment. Turning the steering wheel elongates or shortens the cable depending on the direction of rotation. The cable will then push or pull the outboard motor, causing it to experience rotary motion about the front of the propeller shaft [3]. Since the propeller constantly provides thrust in the direction that the outboard motor is facing, the boat will turn based on the angle of the outboard motor relative to its neutral position.

b) Propulsion system: The team purchased the Torqeedo Cruise 2.0 RS propulsion system for VorteX with the consideration of cost, limitations of power supply, and high thrust. Due to budget constraints, with a large portion of budget saved for the hull, the system chosen needed to be within an allocated budget. The chosen system also matches the batteries total nominal voltage at 24 V, allowing a connection to the system using a DC wiring setup. The system can output up to 6 HP of thrust with a maximum efficiency of 56%. The efficiency is very high, allowing power to be used efficiently in the endurance race. Furthermore, the entire system weighs 15.3 kg. It’s low mass allows us to minimize the weight of the overall propulsion and steering system consume less power [1].

2) Problem and Issues: Finding and purchasing a propulsion system that used 24V, was under budget, and was a good fit for VorteX was a challenge. After intensive research many options were viable, and the best option chosen, but no option was a perfect fit. In order to resolve this issue, the Propulsion Team plans to build their own propulsion system for the 2018 Solar Splash competition with more funds and member availability.

3) Design Testing and Evaluation: Due to time constraints, the Propulsion Team also helping with the construction of the Hull, and the lack of resources, few tests were done. The power system was connected and the propulsion system turned on, but since it could not be placed in water and the system is water cooling, no extensive tests were run.

F. Data Acquisition and Communication

1) Previous Designs: In previous years, the team has used a scheme consisting of a microcontroller to collect sensor data and a Windows tablet to process and render the data. This worked generally well, but there were a few issues that cropped up:

- Windows tablets are expensive
- Windows tablets are difficult to configure
- Windows tablets are fragile

This was particularly an issue during the team's most recent race: the Data Acquisition team poured lots of time into getting their application to work just right on a $1000 Windows tablet and had left it in the cockpit of their boat, ready for their skipper. However, the skipper promptly hopped in the boat and sat on the tablet, cracking the screen irreparably.

Unfortunately, the team did not have the resources to purchase a brand-new Windows machine. Instead, they opted to hardwire several multimeters up to various points on the boat, providing critical information about the boat to the skipper, albeit in an unintuitive and haphazard way. This manifested the need for a more **cost-effective** solution.

Another consequence of having to change from our Windows solution to an array of multimeters was that we realized how deeply integrate out Windows data collection was with the overall power system. Current-data collection is a good example. Our data collection for sensing currents involved putting a chip in series with the line we wished to sample. Naturally this meant that if something went wrong with the chip (or if we wanted to remove the chip, like we did in transitioning systems), then we broke the circuit altogether. We decided from this that we must make future systems more **robust**.

After this incident, we tried to get our Windows application to run on a different Windows machine, but we had a great number of issues installing libraries and getting the configuration to match that of the tablet. This motivated us to create a system that is more **modular and portable**.

2) Analysis of Design Concepts: This year, because of a gap in competing, we were presented with the opportunity to start fresh and design a new and improved system. As mentioned above, we identified three core areas that we wish to improve our performance in:

- Cost-effectiveness: we wanted to drive down the total cost of our data collection system and also identify and eliminate "bottleneck" components that are too expensive to replace.

- Modularity and Portability: we strived to make the data collection software less configuration-dependent and the overall data collection system easier to repair and replace parts in.
- Robustness: since data collection is ultimately the least system-critical subsystem of the boat, we ensured that our design would only *add* to other systems, never creating a dependency of another subsystem on the data collector.

With these design objectives in mind, we came up with a system that shared basic concepts with years past but innovated in key dimensions. The core concept is the same: a microcontroller gathers analog and digital data from hard-wired sensors and communicate them to a central processor. This central processor cleans and renders the information in a way that is simple for the skipper to understand at a glance.

We picked the Arduino platform[1] for our microcontroller and, in a shift from our Windows days, decided on Android[2] as our central processor platform. This was a calculated decision that helps both cost-effectiveness and portability since Android tablets are cheaper than Windows and also provide a stable API (with fewer optional libraries) to develop on. The Android tablet was picked specifically because of its considerable power, excellent battery life, and low price point. (A recent search found our model for less than $200 USD.)

Table 3: Data acquisition sensors and their purposes.

Sensor Type	Chosen Part	Purpose
Voltage Sensor	Custom-made	Sense battery voltage, solar panel output.
Current Sensor	Honeywell CSLA Series (two kinds: one small and one big)	Sense solar panel output, charge controller output, and motor draw.
Temperature Sensor	DS18B20 Waterproof	Determine if components are overheating
Light Sensor	TMP36	Judge ambient light level (to corroborate solar panel output readings.)
GPS	On-board chip in tablet	Determine speed of craft.

We decided on four types of sensors that we would require, as is shown in Table 3. The most critical sensors are the voltage and current sensors. These are what give us information about how much charge we are getting from the panels, how much juice is in our batteries, and how

[1] Specifically, the Arduino Mega 2560 which provides more I/O options -- a key requirement for the variety of sensors we use.
[2] We opted for the Asus Zenpad 10, which provides both reasonable specifications and an incredibly low price point.

much energy our motor is drawing. With these readings, the skipper is better able to make judgements about throttle and pacing.

Besides the current sensor, the parts we used this year were moderate improvements on previous years'. The Honeywell sensor was specifically chosen because it is non-invasive. The sensor reads the current of a wire (even an insulated wire) threaded through it.[3] This means that there is no more dependency of the Power subsystem on Data Acquisition, a great improvement of our robustness.

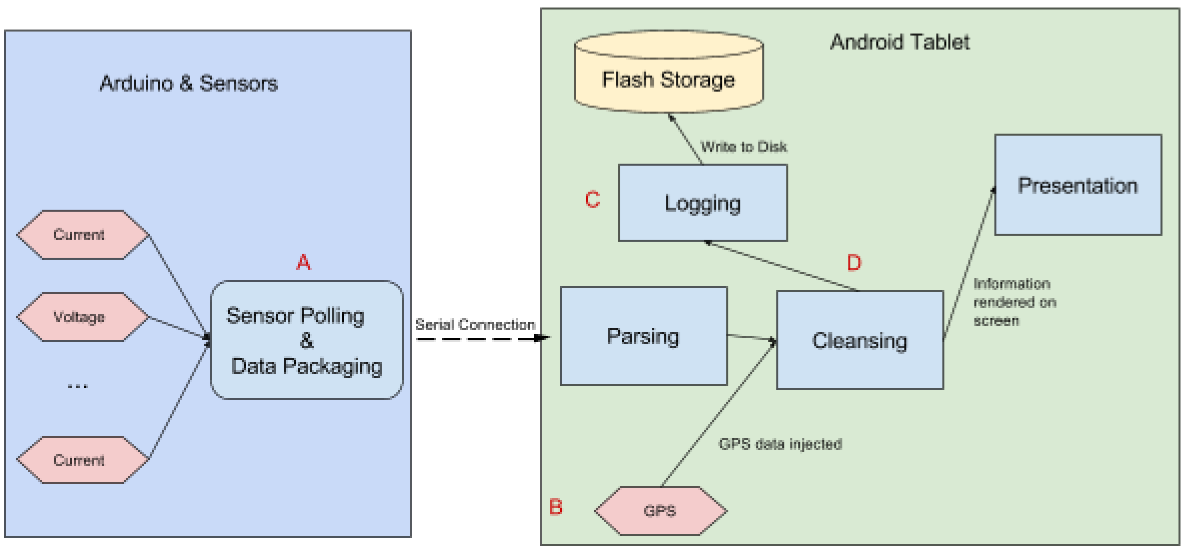


Figure 16: Data acquisition system overview

In keeping with tradition from previous years, we chose to delegate nearly all of the heavy-lifting of data cleansing and analysis to the Android tablet. This is with the intention of keeping the amount of logic running on the microcontroller to an absolute minimum so as not to tax its limited resources. The Android tablet, with its comparatively greater performance, is responsible for essentially everything besides collecting the raw data. The microcontroller simply polls its I/O for readings from the sensors, packages them up in a simple JSON format, and sends them along a serial connection to the tablet (process A in Figure 16). The Android tablet then parses this raw data, cleanses it, and renders it to the user. There are several notable features of this pipeline:

- GPS data is collected on the tablet (rather than from the Arduino like all other sensor information). This is represented by process B in Figure 16.
- The Data Acquisition system automatically logs all readings to a file on the internal storage of the tablet. This is shown as process C in Figure 16.

[3] It does this with the help of the Hall Effect, which involves the magnetic field produced by a current along a wire.

- The raw data from the microcontroller must be processed before it can be rendered. This includes data normalization and scaling. For instance, we "zero" each current sensor before rendering its reading.

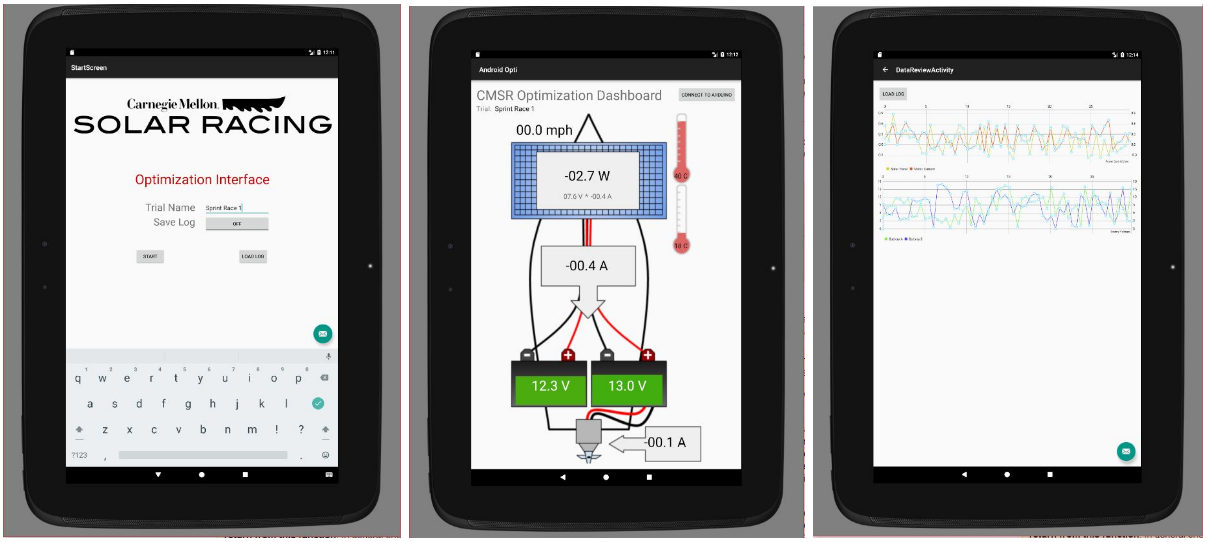


Figure 17: The Data Acquisition front end (screen caps from Android emulator)

After traveling through this processing pipeline, the data is finally presented to the user in an easy-to-understand format, as shown in Figure 17. The middle image of Figure 18 shows the main UI, a graphic showing all of the cleansed information at once. The right image of Figure 18 shows the "replay" functionality in which you can look at the data recorded over a given trial.

3) Design Testing and Evaluation: In service of our "robustness" goal, we attempted to be as thorough as possible in testing components and their interactions. This involved a various forms of testing and quality assurance:

a) Software unit tests: Like any software system, it was incredibly helpful to write unit tests for many of the components of our code. Because we decided to put most of the programmatic complexity on the Android tablet, we focused on writing unit tests here. Specifically, we wrote test cases that exercised the data cleansing and presentation pipelines. In order to separate the microcontroller communication logic from the processing logic, we mocked out the communication components.

b) Execution of software on multiplate device profiles: In order to advance our portability goal and avoid a repeat of our Windows tablet issues, we made sure to test the functionality of the Android code on multiple device profiles. Specifically, we targeted Android APIs revision 23-25 and screen sizes ranging from 6" to 13". We did this with the help of hardware emulation and a couple of teammate's physical devices.

c) Stress testing sensors: On the data collection side of things, we needed to make sure that sensors outputted consistent readings regardless of time configuration. To do this, we set up various combinations of the sensors and let them run for an extended period of time (up to half an hour) to check that their output was as expected. Additionally, we exercised specific components such as the current sensors by running various levels of current (powered by a controllable power source) through them.

d) Functional end-to-end tests: Throughout the process, we periodically would bring up the whole system to make sure that the end-to-end sensing, communication, and presentation was as intended.

This rigorous testing procedure greatly helped us chase down bugs early and fast. Because of it, our Data Acquisition system has substantially improved portability and robustness.

V. PROJECT MANAGEMENT

A. Team Members and Leadership Roles

The Carnegie Mellon Solar Racing Team is composed of undergraduate students from different background and majors across campus. Most members are from engineering, physics and computer science, but other majors such as business and design are active and have brought a dynamic perspective to CMSR. Structurally, we have a executive committee and a design committee overseeing all aspects of the organization. The executive committee consists of a President, Secretary, Vice President of Finance, Vice President of Programming, Vice President of Marketing, and Vice President of Member Development. The committee oversees general organization matters including sponsorships, public relations, etc. The design committee is composed of a Head of Design, which is customarily the President, and a design lead for each of the four subsections of our design process: Propulsion, Power, Optimization, and Hull. The executive committee met once a week to update each other on ongoing tasks and discuss future ones. The design committee met every other week to update the Head of Design on progress and ensure that deadlines were being met. CMSR's faculty advisor, Kurt Larsen, helps with the paperwork, waivers, and communications outside of CMU when needed.

B. Project Planning and Schedule

Each subteam design leaders created a timeline that included specific objectives with deadlines. The teams were able to follow and stay on track during beginning of the building process in 2015-2016 school year. Afterwards a new timeline was created at the beginning of Fall 2016 to complete the boat for the 2017 competition. The schedule for academic year 2016-2017 is included in Appendix E. The primary plan was to complete the Hull by April and complete the entire boat by the end of the school year in May.

C. Finances and Fundraising

To fund the materials, equipment, and transportation required to attend Solar Splash competition, funding was requested from several sources. CMSR members asked family and acquaintances for donations and received a total of $5989.93. The team also sought grants from corporations such as Raytheon, Ford, SEER, and Lockheed Martin, receiving a total of $2,800. CMSR also applied for funding from Carnegie Mellon's Joint Funding Committee and received $11,576.86. Along with $350 in membership dues and the remaining funding from previous year, the organization started the 2017-2018 year with a total of $25,654.06.

D. Strategy For Team Continuity and Sustainability

After a big loss in members and documentation in the academic year 2014-2015, team sustainability became a crucial goal for the past two years. To recruit new members the Vice President of Member Development created the "New Member Project". During the project new members built miniature, radio-controlled boats. All teams competed in an event that simulated the sprint and slalom events of the Solar Splash competition. By going through this, new members were able to learn about CMSR's process for constructing the hull, as well as quickly establish themselves as members of the team. CMSR had immense success with the project, recruiting over 30 members for academic year 2015-2016. It is the organization's plan to continue the project every year, ensuring that the team always has new and engaged members.

To help prevent future loss of documentation when members leave the team, CMSR created a google folder that contains all documents, from design files to presentation posters. All members have access to the folder.

E. Discussion and Self-Evaluation

Over the past two years, Carnegie Mellon Solar Racing has grown as a team, having gone from an eight member team with only one person with experience, to a team of more than twenty members and a fully built boat named VorteX. With the addition of a google folder, with all member access, and the rebuilding of our reputation both on campus and with the companies that fund us, we have a stable foundation for team continuity. While we have struggled, the organization has reached all goals of completing a hull, reusing materials for power and optimization, and buying an appropriate propulsion system. We now hope to compete well at this years Solar Splash competition and be able to use the experience to help make modifications to the hull and rebuild our power, optimization and propulsion systems.

VI. CONCLUSIONS AND RECOMMENDATIONS

The boat making process this year produced strong results, however there are still areas in the overall design that can be improved upon for future competitions. The overall weight of the boat is heavier than the team expected. It is estimated to be about 355 lb total. The team hopes to cut down this weight in future competitions by designing lighter propulsion and power systems that can be utilized with the boat. More frequent inter-team communications can be improved upon to allow better integration of the subsystems into the boat. The final improvement that the team can undertake is more robust testing of the complete boat for performance data. Due to the labor intensive process associated with fabricating the boat hull, the team had to construct VorteX until the month before competition. After making these improvements for future boats, the team is confident that it can continuously improve its results at subsequent Solar Splash competitions.

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[3] "Safe-T® QC Rotary « SeaStar Solutions." *SeaStar Solutions*. SeaStar Solutions, n.d. Web.

[4] "Optima Bluetop Specification Sheet." *Optima Batteries*, 2008. http://182.160.156.94/~batterie/wp-content/uploads/2015/12/OPTIMA.pdf

[5] "Material Safety Data Sheet for All Optima Batteries." *Optima Batteries,* 2004. https://www.interstatebatteries.com/content/product_info/msd/optima_msds_010930.pdf

APPENDIX

Appendix A: Battery Documentation

Battery Model: D34M
Part Number: 8016-103
Nominal Voltage: 12 volts
NSN: 6140 01 475 9355
Description: High power, dual purpose engine start and deep cycle, sealed lead acid battery

Physical Characteristics:

Plate Design: High purity lead-tin alloy. Wound cell configuration utilizing proprietary *SPIRALCELL*® technology.
Electrolyte: Sulfuric acid, H_2SO_4
Case: Polypropylene
Color: Case: Light Gray
Cover: "OPTIMA" Blue
Group Size: BCI: 34

	Standard	Metric
Length:	10.018"	254.46 mm
Width:	6.829"	173.46 mm
Height:	7.925"	201.30 mm (Height at the top of terminals)
Weight:	43.5 lb	19.7 kg

Terminal Configuration: SAE / BCI automotive and 5/16"-18UNC-2A threaded stainless steel stud.

Performance Data:

Open Circuit Voltage (Fully charged): 13.1 volts
Internal Resistance (Fully charged): .0028 ohms
Capacity: 55 Ah (C/20)
Reserve Capacity: BCI: 120 minutes
(25 amp discharge, 80°F (26.7°C), to 10.5 volts cut-off)

Power:

CCA (BCI 0°F): 750 amps
MCA (BCI 32°F): 870 amps

Recommended Charging:

The following charging methods are recommended to ensure a long battery life: (Always use a voltage regulated charger with voltage limits set as described below.)

Model: D34M
These batteries are designed for starting and deep cycle applications and for use in vehicles with large accessory loads.

Figure A.1: Optima Battery Specifications Sheets [4] (1 of 2)

Recommended Charging Information:

Alternator:	13.65 to 15.0 volts
Battery Charger (Constant Voltage):	13.8 to 15.0 volts; 10 amps maximum; 6-12 hours approximate
Float Charge:	13.2 to 13.8 volts; 1 amp maximum; (indefinite time at lower voltages)
Rapid Recharge: (Constant voltage charger)	Maximum voltage 15.6 volts. No current limit as long as battery temperature remains below 125°F (51.7°C). Charge until current drops below 1 amp.
Cyclic or Series String Applications:	14.7 volts. No current limit as long as battery temperature remains below 125°F (51.7°C). When current falls below 1 amp, finish with 2 amp constant current for 1 hour. **All limits must be strictly adhered to.**

Recharge Time: (example assuming 100% discharge – 10.5 volts)

Current	Approximate time to 90% charge
100 amps	35 minutes
50 amps	75 minutes
25 amps	140 minutes

Recharge time will vary according to temperature and charger characteristics. When using Constant Voltage chargers, amperage will taper down as the battery becomes recharged. When amperage drops below 1 amp, the battery will be close to a full state of charge.

(All charge recommendations assume an average room temperature of 77°F (25°C).

Always wear safety glasses when working with batteries.

Always use a voltage regulated battery charger with limits set to the above ratings. Overcharging can cause the safety valves to open and battery gases to escape, causing premature end of life. These gases are flammable! You cannot replace water in sealed batteries that have been overcharged. Any battery that becomes very hot while charging should be disconnected immediately.

Not fully charging a battery can result in poor performance and a reduction in capacity.

Shipping and Transportation Information:

OPTIMA batteries can be shipped by AIR. The battery is nonspillable and is tested according to ICAO Technical Instructions DOC. 9284-AN/905 to meet the requirements of Packing Instructions No. 806 and is classified as non-regulated by IATA Special Provision A-48 and A-67 for UN2800. Terminals must be protected from short circuit.

BCI = Battery Council International

OPTIMA Batteries Product Specifications: Model D34M
December 2008

Figure A.1 (cont.): Optima Battery Specifications Sheets [4] (2 of 2)

	Title:	Date:	Rev:	Page:	File Name:
OPTIMA BATTERIES THE ULTIMATE POWER SOURCE	Material Safety Data Sheet for All Optima Batteries	1/14/14	M	1 of 5	MSDS battery

MSDS No.	L 8A
Date Issued	**Feb. 20, 1990**
Date Revised	**Jan. 14 2014**

Chemical/Trade Name (identity used on label)	Chemical Family/Classification	HMIS Rating
Sealed Lead Acid Battery/ OPTIMA BATTERY TM	**Electric Storage Battery**	HMIS Rating for Sealed, Lead Acid Battery **0 0 0;** For sulfuric acid **3 0 2**

Synonyms/Common Name	DOT, IATA and IMO Description
Sealed Lead Acid Battery	**Non-Spillable Battery , Exempt from UN2800 Classification**

Company Name / Division or Department	Address
Company Name: **OPTIMA Batteries, Inc.**	**5757 N. Green Bay Avenue**
Division or Department: **Wholly- owned subsidiary of Johnson Controls Inc.**	**Milwaukee, WI 53209**

CONTACT	TELEPHONE NUMBER
Questions Concerning MSDS **OPTIMA Batteries, Environmental, Health & Safety Department**	**Day:** **(800) 333-2222, Ext. 3138**
Transportation Emergencies **CHEMTREC**	**24 Hours: (800) 424-9300** **International: (703) 527-3887 (Collect)**

NOTE: The OPTIMA sealed lead acid battery is considered an article as defined by 29 CFR 1910.1200 © OSHA Hazard Communication Standard. The information on this MSDS is supplied at customer's request for information only.

II. Hazardous Ingredients

Material	% by Wt.	CAS Number	Eight Hour Exposure Limits		
			OSHA PEL	ACGIH TLV	NIOSH REL
Specific Chemical Identity **Lead & lead compounds**	63-81	7439-92-1	50 $\mu g/m^3$	150 $\mu g/m^3$	100 $\mu g/m^3$
Specific Chemical Identity **Sulfuric Acid (35%)** **Common Name** **Battery Electrolyte (Acid)**	17 - 25	7664-93-9	1mg/m^3	0.2 mg/m^3 (respirable thoracic fraction)	1 mg/m^3
Common Name **Case Material Polypropylene**	2-6	9010-79-1	--	--	--
Common Name **Separator/Paster Paper Fibrous Glass**	1-4	65997-17-3	--	--	--

NOTE: The contents of this product are toxic chemicals that are subject to the reporting requirements of section 302 and 313 of the Emergency Planning and Community Right-To-Know Act of 1986 (40CFR 355 and 372).

III. Physical Data

Material is (at normal temperatures) **☑Solid ☑Liquid**		Appearance and Odor **Battery Electrolyte (acid) is a clear to cloudy liquid with slight acidic odor. Acid saturated lead oxide is a dark reddish-brown to gray solid with slight acidic odor.**
Boiling Point (at 760 mm Hg) **Lead 1755°C Batt. Electrolyte (Acid) 110-112°C**	Melting Point **Lead 327.4°C**	
Specific Gravity (H_2O =1) **Battery Electrolyte (Acid) 1.210 - 1.300**		Vapor Pressure ☑(mm Hg at 20°C) Ž(PSIG) **Battery Electrolyte (Acid) 11.7**
Vapor Density (Air =1) **Battery Electrolyte (Acid) 3.4**		Solubility is H_2O **Lead and Lead Dioxide are not soluble. Battery Electrolyte (acid) is 100% soluble in water.**
% Volatile By Weight **Not Determined**		Evaporation rate (Butyl Acetate = 1) **Not Determined**

Figure A.2: Optima Battery MSDS Sheets [5] (1 of 5)

	Title:	Date:	Rev:	Page:	File Name:
OPTIMA BATTERIES THE ULTIMATE POWER SOURCE™	Material Safety Data Sheet for All Optima Batteries	1/14/14	M	2 of 5	MSDS battery

IV. Health Hazard Information

NOTE: Under normal conditions of use, this product does not present a health hazard. The following information is provided for battery electrolyte (acid) and lead for exposure that may occur during battery production or container breakage or under extreme heat conditions such as fire

ROUTES AND METHODS OF ENTRY

Inhalation
Acid mist may be generated during battery overcharging and may cause respiratory irritation. Seepage of acid from broken batteries may present inhalation exposure in a confined area.

Skin Contact
Battery electrolyte (acid) can cause severe irritation, burns and ulceration.

Skin Absorption
Skin absorption is not a significant route of entry.

Eye Contact
Battery electrolyte (acid) can cause severe irritation, burns, and cornea damage upon contact.

Ingestion
Hands contaminated by contact with internal components of a battery can cause ingestion of lead/lead compounds. Hands should be washed prior to eating, drinking, or smoking.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

Acute Effects
Acute effects of overexposure to lead compounds are GI (gastrointestinal) upset, loss of appetite, diarrhea, constipation with cramping, difficulty in sleeping, and fatigue. Exposure and/or contact with battery electrolyte (acid) may lead to acute irritation of the skin, corneal damage of the eyes, and irritation of the mucous membranes of the eyes and upper respiratory system, including lungs.

Chronic Effects
Lead and its compounds may cause chronic anemia, damage to the kidneys and nervous system. Lead may also cause reproductive system damage and can affect developing fetuses in pregnant women. Battery electrolyte (acid) may lead to scarring of the cornea, chronic bronchitis, as well as erosion of tooth enamel in mouth breathers in repeated exposures.

POTENTIAL TO CAUSE CANCER

The National Toxicological Program (NTP) and The International Agency for Research on Cancer (IARC) have classified "strong inorganic acid mist containing sulfuric acid" as a Category 1 carcinogen, a substance that is carcinogenic to humans. The ACGIH has classified "strong inorganic acid mist containing sulfuric acid" as an A2 carcinogen (suspected human carcinogen). These classifications do not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist (sulfuric acid mist) is not generated under normal use of this product. Misuse of the product, such as overcharging, may result in the generation of sulfuric acid mist.

The NTP and the IARC have classified lead as an A3 carcinogen (animal carcinogen). While the agent is carcinogenic in experimental animals at relatively high doses, the agent is unlikely to cause cancer in humans except under uncommonly high levels of exposure. For further information, see the ACGIH's pamphlet, *1996 Threshold Limit Values and Biological Exposure Indices.*

EMERGENCY AND FIRST AID PROCEDURES

Inhalation
Not expected for product under normal conditions of use. However, if acid vapor is released due to overcharging or abuse of the battery, remove exposed person to fresh air. If breathing is difficult, oxygen may be administered. If breathing has stopped, artificial respiration should be started immediately. Seek medical attention immediately.

Skin
Exposure not expected for product under normal conditions of use. However, if acid contacts skin, flush with water and mild soap. If irritation develops, seek medical attention immediately.

Eyes
Exposure not expected for product under normal conditions of use. However, if acid from broken battery case enters eyes, flush with water for at least 15 minutes. Seek medical attention immediately.

Ingestion
Not expected due to physical form of finished product. However, if internal components are ingested:
Lead/Lead compounds: Consult a physician immediately for medical attention.
Battery Electrolyte (Acid): Do not induce vomiting. Refer to a physician immediately for medical attention.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Inorganic lead and its compounds can aggravate chronic forms of kidney, liver, and neurologic diseases. Contact of battery electrolyte (acid) with the skin may aggravate skin diseases such as eczema and contact dermatitis.

Figure A.2 (cont.): Optima Battery MSDS Sheets [5] (2 of 5)

OPTIMA BATTERIES THE ULTIMATE POWER SOURCE	Title: Material Safety Data Sheet for All Optima Batteries	Date: 1/14/14	Rev: M	Page: 3 of 5	File Name: MSDS battery

V. Fire and Explosion Data

Flash Point (test method)	Autoignition Temperature	Flammable Limits in Air, % by Vol.
Hydrogen - 259°C	**Hydrogen 580°C**	**Hydrogen LEL - 4.1 UEL - 74.2**

Extinguishing Media
Dry chemical, foam, or CO_2

Special Fire Fighting Procedures
Use positive pressure, self-contained breathing apparatus.

Unusual Fire and Explosion Hazard
The sealed lead acid battery is not considered flammable, but it will burn if involved in a fire. A short circuit can also result in a fire. Acid mists, smoke and decomposition products may be produced. Remove all ignition sources. Cool battery(s) to prevent rupture.

VI. Reactivity Data

Stability	Conditions to Avoid
☐ Unstable ☑ Stable	**Sparks and other sources of ignition may ignite hydrogen gas.**

Incompatibility (materials to avoid)
Lead/lead compounds: Potassium, carbides, sulfides, peroxides, phosphorus, sulfur.
Battery electrolyte (acid): Combustible materials, strong reducing agents, most metals, carbides, organic materials, chlorates, nitrates, picrates, and fulminates.

Hazardous Decomposition Products
Lead/Lead compounds: Oxides of lead and sulfur
Battery electrolyte (acid): Hydrogen, sulfur dioxide, sulfur trioxide

Hazardous Polymerization	Conditions to Avoid
☐ May Occur ☑ Will Not Occur	**High temperature. Battery electrolyte (acid) will react with water to produce heat. Can react with oxidizing or reducing agents.**

VII. Control Measures

Engineering Controls
Store sealed lead acid batteries at ambient temperature. Never recharge batteries in an unventilated, enclosed space. Do not subject product to open flame or fire. Avoid conditions that could cause arcing between terminals.

Work Practices
Do not carry battery by terminals. Do not drop battery, puncture or attempt to open battery case. Avoid contact with the internal components of a battery.

PERSONAL PROTECTIVE EQUIPMENT

Respiratory Protection
None required for normal handling of finished product.

Eyes and Face
None required under for finished product under normal conditions of use. If necessary to handle broken product, chemical splash goggles are recommended.

Hands, Arms, and Body
None required for normal handling of finished product. If necessary to handle broken product, Vinyl-coated, PVC, gauntlet-type gloves with rough finish are recommended..

Other Special Clothing and Equipment
Safety footwear meeting the requirements of ANSI Z 41.1 – 1991 is recommended when it in necessary to handle the finished product.

VIII. Safe Handling Precautions

Hygiene Practices
Wash hands thoroughly before eating, drinking, or smoking after handling batteries.

Protective Measures to be Taken During Non-Routine Tasks, Including Equipment Maintenance
Do not carry battery by terminals. Do not drop battery, puncture or attempt to open battery case. Do not subject product to open flame or fire and avoid situations that could cause arcing between terminals.

SPILL OR LEAK PROCEDURES

Figure A.2 (cont.): Optima Battery MSDS Sheets [5] (3 of 5)

OPTIMA BATTERIES THE ULTIMATE POWER SOURCE	Title: Material Safety Data Sheet for All Optima Batteries	Date: 1/14/14	Rev: M	Page: 4 of 5	File Name: MSDS battery

Protective Measures to be Taken if Material is Released or Spilled

Remove combustible materials and all sources of ignition. Avoid contact with acid materials. Use soda ash, baking soda or lime to neutralize any acid that may be released.

If battery is broken, wear chemical goggles and acid-resistant gloves for handling the parts.

DO NOT RELEASE UNNEUTRALIZED ACID!

Waste Disposal Method

Battery Electrolyte (Acid): Neutralize as above for a spill, collect residue, and place in a drum or suitable container. Dispose of as a hazardous waste.

DO NOT FLUSH LEAD-CONTAMINATED ACID INTO SEWER.

Send spent or broken batteries to a lead recycling facility or smelter that follows applicable Federal, State and Local regulations for routine disposition of spent or damaged batteries. The distributor / user is responsible for assuring that these "spent" or "damaged" batteries are disposed of in an environmentally sound way in accordance with all regulations. OPTIMA batteries are 100% recyclable by any licensed reclamation operation..

LEAD RETURN RECYCLE

SUPPLEMENTAL INFORMATION

Proposition 65 Warning (California) Proposition 65 Warning: The state of California has listed lead as a material known to cause cancer or cause reproductive harm (July 9, 2004 California List of Chemicals Known to Cause Cancer or Reproductive Toxicity) Battery posts, terminals and related accessories contain lead and lead compounds. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

TSCA Registry: Ingredients listed in the TSCA Registry are lead, lead compounds, and sulfuric acid.

Transportation: Sealed Lead Acid Battery is not a DOT Hazardous Material.

Other: Per DOT, IATA, ICAO and IMDG rules and regulations, these batteries are exempt from "UN2800" classification as a result of successful completion of the following tests:

1) **Vibration Tests**
2) **Pressure Differential Tests**
3) **Case Rupturing Tests (no free liquids)**

US MILITARY NATIONAL STOCK NUMBER (NSN)

Model Number	P/N	NSN
34/78	8004-003	6140-01-374-2243, 6140-01-457-4339
34	8002-002	6140-01-378-8232, 6140-01-493-1962
34R	8003-151	6140-01-475-9357
34VX	8008-158	6140-01-534-6466
25	8025-160	
35	8020-164	
75/25	8022-091	6140-01-475-9361
78	8078-109	
850/6 -1050 SLI	8010-044	6140-01-475-9414
DS46B24R	8171-767	
850/6 - 950 (DC)		
D51	8071-167	6140-01-523-6288
D51R	8073-167	6140-01-529-7226
D35	8040-218	
D75/25	8042-218	

Figure A.2 (cont.): Optima Battery MSDS Sheets [5] (4 of 5)

OPTIMA BATTERIES THE ULTIMATE POWER SOURCE	Title: Material Safety Data Sheet for All Optima Batteries	Date: 1/14/14	Rev: M	Page: 5 of 5	File Name: MSDS battery

D34	8012-021	6140-01-450-0141
D34/78	8014-045	6140-01-441-4272
D27F	8037-127	
D31T	8050-160	6140-01-457-5469
D31A	8051-160	6140-01-502-4973
34M	8006-006	6140-01-441-4280, 6140-01-526-2605
D34M	8016-103	6140-01-475-9355
D27M	8027-127	6140-01-589-0622
D31M	8052-161	6140-01-502-4405

Disclaimer: This information has been compiled from sources considered to be dependable and is, to the best of our knowledge and belief, accurate and reliable as of the date compiled. However, no representation, warranty (either express or implied) or guarantee is made to the accuracy, reliability or completeness of the information contained herein. This information relates to the specific material designated and may not be valid for such material used in combination with any other materials or in any process. It is the user's responsibility to satisfy himself as to the suitability and completeness of this information for his own particular use. We do not accept liability for any loss or damage that may occur, whether direct, indirect, incidental or consequential, from use of this information.

Figure A.2 (cont.): Optima Battery MSDS Sheets [5] (5 of 5)
***Model number is boxed in yellow.**

Appendix B: Flotation Calculations

Table B.1: Flotation Calculations Weight Values

System	**Volume (in^3)**	**Buoyant Force (lb)**
Torqeedo System	0	0
Batteries	1099.1	39.7
Wood Cross Sections	983.1	35.5
Foam	1590.2	57.4
Dashboard	568.4	20.5
Chair	0	0
Solar Panels	482.0	17.4
Boat	2351.8	100.7
Total	**7074.7**	**255.4**

γ_{Water} = specific weight of water = 0.0361 lb/in^3
$F_b = V_{Total} \text{ x } \gamma_{Water}$
= 7074.7 in^3 x 0.0361 lb/ft^3 = 255.4 lb

Equation B.1: Buoyancy of Boat in Pounds

$$W = \text{Total weight x } 1.2$$
$$= 355.0 * 1.2$$
$$= 426.0$$

Equation B.2: Calculating volume of airbags needed

$$V_{Air\ Bags} = (W - F_b)/\gamma_{Water}$$
$$= (426 - 255.4)/0.0361$$
$$= 4725.8\ in^3 = 2.73\ ft^3$$

Findings: We will need about 2.73 cubic feet of air, in the form of airbags, in order to ensure that our boat will stay afloat if it submerges.

Appendix C: Proof of Insurance

Page 1 of 1

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY) 05/03/2017

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 have ADDITIONAL INSURED provisions or 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
Willis of Pennsylvania, Inc.
c/o 26 Century Blvd
P.O. Box 305191
Nashville, TN 372305191 USA

CONTACT NAME:
PHONE (A/C, No, Ext): 1-877-945-7378
FAX (A/C, No): 1-888-467-2378
E-MAIL ADDRESS: certificates@willis.com

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : United Educators Insurance a Recip Risk Ret. Group	10020
INSURER B :	
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

INSURED
Carnegie Mellon University
Risk Management & Insurance, WH 417
5000 Forbes Avenue
Pittsburgh, PA 15213

COVERAGES CERTIFICATE NUMBER: W2214977 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 INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	X COMMERCIAL GENERAL LIABILITY; CLAIMS-MADE X OCCUR; GEN'L AGGREGATE LIMIT APPLIES PER: X POLICY PRO-JECT LOC; OTHER:			CGL201600052200	10/01/2016	10/01/2017	EACH OCCURRENCE	$ 1,000,000
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 1,000,000
							MED EXP (Any one person)	$ 5,000
							PERSONAL & ADV INJURY	$
							GENERAL AGGREGATE	$ 3,000,000
							PRODUCTS - COMP/OP AGG	$
								$
	AUTOMOBILE LIABILITY; ANY AUTO; OWNED AUTOS ONLY; SCHEDULED AUTOS; HIRED AUTOS ONLY; NON-OWNED AUTOS ONLY						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; ANYPROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH); If yes, describe under DESCRIPTION OF OPERATIONS below	N/A					PER STATUTE / OTH-ER	
							E.L. EACH ACCIDENT	$
							E.L. DISEASE - EA EMPLOYEE	$
							E.L. DISEASE - POLICY LIMIT	$

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)
Division/Branch: Student Organizations (Carnegie Mellon Solar Racing Club)

The participation of "Carnegie Mellon Solar Racing Club"in the SOLAR SPLASH 2017 Competition at the Clark County Fairgrounds in Springfield, Ohio from June 7-11, 2017.This event is an international intercollegiate solar/electric boat regatta.

CERTIFICATE HOLDER

Solar Splash
c/o Jeffrey H. Morehouse, PhD, PE
309 Newridge Road
Lexington, SC 29072

CANCELLATION

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

ACORD 25 (2016/03) The ACORD name and logo are registered marks of ACORD

SR ID: 14509079 BATCH: Batch #: 313704

Figure C.1: Certificate of Liability Insurance for Solar Splash Rule 2.8

Appendix D: Team Roster for Fall 2015-Spring 2017

Member Name	**Degree Program**	**Year**	**Team Role**
Abbey Mui	Undeclared	May-20	Hull Team
Aditya Acharya	Major in Mechanical Engineering	May-18	Hull and Propulsion Team
Alaaddin Ismail	Major in Mechanical Engineering, Minor in Physics	May-16	Propulsion Team
Brandon Takao	Major in Electrical and Computer Engineering	May-18	Hull, Propulsion, Optimization, and Power Team
Cesar Quinones	Major in Mechanical Engineering	May-19	Hull and Propulsion Team
Clement Wong	Double Major in Mechanical Engineering and Engineering and Public Policy	May-18	Power Team
David Oke	Major in Mechanical Engineering	May-20	Power and Optimization Team
David Zeng	Major in Computer Science	May-19	Power and Optimization Team
Declan Kelly	Major in Mechanical Engineering, Minor in Physics	May-18	Hull Team
Dhruv Khurana	Major in Computer Science	May-19	Optimization and Power Team
Elizabeth Kuo	Major in Mechanical Engineering	May-19	Hull Team
Eric Chang	Major in Electrical and Computer Engineering	May-19	Power and Optimization Team
Eric Chen	Major in Electrical and Computer Engineering	May-20	Hull and Propulsion Team
Evan Myers	Major in Mechanical Engineering	May-19	Hull Team
Fernando Melean	Double Major in Mechanical Engineering and Robotics	May-19	Hull, Propulsion, and Power Team
Frances Tso	Double Major in Economics and Computer Science	May-17	Vice President of Finance 2016-17, Optimization Design Lead 2015-16
George Lu	Major in Computer Science	May-19	Power Team
Greg Miller	Mechanical Engineering	May-19	Propulsion Team
Indu Korambath	Double Major in Electrical and Computer Engineering and Engineering and Public Policy	May-19	Hull, Propulsion, Optimization, and Power Team
Jack McCambridge	Major in Mechanical Engineering	May-19	Hull Team
Jack Sampiere	Major in Mechanical Engineering	May-20	Hull Team
James Zhang	Double Major in Mechanical Engineering and Engineering and Public Policy	May-19	Secretary 2016-17, Hull and Propulsion Team
Jasmine Lim	Double Major in Mechanical Engineering and Engineering and Public Policy	May-19	Vice President of Marketing 2016-17, Propulsion Team
Jeremy Huang	Major in Computer Science	May-19	Power Team
Jessica Cheng	Major in Computer Science	May-19	Propulsion and Optimization Team
Jiaxuan Li	Double Major in Mechanical Engineering and Robotics	May-19	Hull, Propulsion, Optimization, and Power Team

Member Name (Cont'd)	**Degree Program (Cont'd)**	**Year (Cont'd)**	**Team Role (Cont'd)**
Jonathon Buckley	Major in Computer Science	May-17	Vice President of Finance 2015-16, Optimization Design Lead 2016-17
Kira Pusch	Major in Material Science and Engineering	May-19	Assistant Shop Manager
Madelynne Long	Major in Mechanical Engineering, Minor in Robotics	May-19	Hull Team
Nathan Walko	Major in Mechanical Engineering	May-18	Hull and Propulsion Team
Nick Lamprinakos	Double Major in Material Science Engineering and Biomedical Engineering	May-19	Hull and Power Team
Penelope Ackerman	Major in Material Science Engineering, Minor in Media Design	May-17	Vice President of Marketing, Hull Design Lead 2016-17
Pieter de Buck	Major in Mechanical Engineering, Minor in Robotics	May-19	Hull and Propulsion Team
Rahul Jaisingh	Major in Computer Science	May-19	Power Team
Rhiannon Farney	Double Major in Mechanical Engineering and Engineering and Public Policy, Minor in Environmental Science	May-18	Vice President of Marketing 2015-16, President 2016-17, and Propulsion Design Lead
Riley Xu	Major in Physics	May-18	Vice President of Member Development 2015-16, Power Design Lead
Sarah Shy	Double Major in Statistics and Human-Computer Interaction	May-18	Secretary 2015-16
Sebastian Gamboa	Major in Mechanical Engineering	May-20	Hull Team
Shae Sealey	Major in Mechanical Engineering, Minor in Business Administration	May-16	President 2015-16, Head of Design, and Hull Design Lead 2015-16
Shreyas Gatuku	Double Major in Electrical and Computer Engineering and Robotics	May-19	Optimization and Power Team
Silvia Giampapa	Major in Biological Sciences	May-19	Hull Team
Sunjeev Kale	Major in Chemical Engineering	May-19	Propulsion Team, Vice President of Member Development 2016-17
Suresh Manian	Major in Physics, Minor in Computer Science	May-17	Hull Team, Vice President of Programming 2015-17, Shop Manager
Tyler Quintana	Major in Mechanical Engineering	May-19	Propulsion, Optimization, and Power Team
Viren Bajaj	Major in Physics	May-18	Optimization Team
Xinna Liu	Major in Electrical and Computer Engineering	May-19	Power Team
Zachary Snow	Major in Computer Science, Minor in Business Administration	May-19	Optimization Team
Zack Masciopinto	Major in Mechanical Engineering, Minor in Robotics	May-19	Hull and Power Team, Vice President of Member Development 2016-2017

Appendix E: 2016-2017 Academic Year Timelines

Table F.1: 2016-2017 Academic Year Timeline for Hull Team

Phase	Item	Goal	Start Time	Duration (days)	End Time
Old Mold Demo	1) Remove fiberglass mat from plug. Dispose of debris (old fiberglass mat).	Minimize damage to the plug.	9/17/2016	1	9/18/2016
Plug Preparation	1) Clean the plug: remove old primer, gel coat, and wax.	Avoid significant alterations to plug exterior.	9/19/2016	5	9/24/2016
	2) Repair plug surface: apply spackling paste, sand, check for symmetry, and repeat as needed.	Achieve smooth and symmetrical plug surface.	9/24/2016	8	10/2/2016
	3) Prime the plug: roll on 3 layers of primer.	Seal the plug. [NOTE: Use a primer that will not react with foam.]	10/2/2016	1	10/3/2016
	4) Allow one day for drying.	--	10/3/2016	1	10/4/2016
	5) Wet-sand the primer (start with 220-grit and progress to 600-grit). Evaluate surface.	Achieve a smooth surface. Determine where further alteration is needed.	10/4/2016	3	10/7/2016
	6) Apply spackling paste, sand, check for symmetry, and repeat as needed.	Achieve smooth and symmetrical plug surface.	10/8/2016	6	10/14/2016
	7) Prime the plug: roll on 3 layers of primer.	Seal the plug. [NOTE: Use a primer that will not react with foam.]	10/14/2016	1	10/15/2016
	8) Wet-sand the primer (start with 220-grit and progress to 600-grit). Evaluate surface.	Achieve a near mirror finish (an extremely smooth surface). Determine if further alteration is needed.	10/15/2016	2	10/17/2016
	9) Depending on surface evaluation: (a) repeat from step 6, or (b) apply Meguiar's Mold Polish Conditioner and Release Wax (apply 5 layers using buffer).	Achieve a mirror finish.	10/17/2016	2	10/19/2016
	10) Apply PVA Release Film: spray on 5 layers of film.	Achieve an even layer of film.	10/19/2016	3	10/22/2016
Evaluate Schedule	Evaluate schedule timing and feasibility. Re-adjust schedule as necessary. Evaluate inventory.		10/22/2016	7	10/29/2016
Mold Construction	1) Apply Orange Tooling Gel Coat: roll on 4 layers of gel coat. Apply one layer of fiberglass mat.	Achieve an even layer of gel coat. Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles.	10/29/2016	1	10/30/2016
	2) Allow one day for drying.	Evaluate inventory.	10/30/2016	1	10/31/2016
	3) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	10/31/2016	1	11/1/2016
	4) Apply one layer of fiberglass mat.	Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles.	11/1/2016	1	11/2/2016
	5) Allow one day for drying.	Evaluate inventory.	11/2/2016	1	11/3/2016
	6) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	11/3/2016	1	11/4/2016
	7) Apply one layer of woven fiberglass.	Fully saturate fiberglass in Polyester Resin. Avoid air bubbles.	11/4/2016	1	11/5/2016
	8) Allow one day for drying.	Evaluate inventory.	11/5/2016	1	11/6/2016
	9) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass. Avoid penetrating sub-layers. Achieve clean surface for next layer. [NOTE: First full layer complete. A full layer is defined as two sub-layers of fiberglass mat and one sub-layer of woven fiberglass.]	11/6/2016	1	11/7/2016
	10) Apply one layer of fiberglass mat.	Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles.	11/7/2016	1	11/8/2016

	11) Allow one day for drying.	Evaluate inventory.	11/8/2016	1	11/9/2016
	12) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	11/9/2016	1	11/10/2016
	13) Apply one layer of fiberglass mat.	Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles.	11/10/2016	1	11/11/2016
	14) Allow one day for drying.	Evaluate inventory.	11/11/2016	1	11/12/2016
	15) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	11/12/2016	1	11/13/2016
	16) Apply one layer of woven fiberglass.	Fully saturate fiberglass in Polyester Resin. Avoid air bubbles.	11/13/2016	1	11/14/2016
	17) Allow one day for drying.	Evaluate inventory.	11/14/2016	1	11/15/2016
	18) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass. Avoid penetrating sub-layers. Achieve clean surface for next layer. [NOTE: Second full layer complete. With following layers, 3 sub-layers can be applied in one day. Allowing one day to dry and one day to prepare for the next layer are necessary between sessions.]	11/15/2016	1	11/16/2016
	19) Apply one layer of fiberglass mat.	Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles.	11/16/2016	1	11/17/2016
	20) Allow one day for drying.	Evaluate inventory.	11/17/2016	1	11/18/2016
	21) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	11/18/2016	1	11/19/2016
	22) Apply one layer of fiberglass mat. Apply one layer of woven fiberglass. Apply one layer of fiberglass mat.	Fully saturate fiberglass mat and woven fiberglass in Polyester Resin. Avoid air bubbles. [NOTE: Third full layer complete after woven fiberglass layer. The second fiberglass mat layer in this session marks the beginning of the fourth full layer.]	11/19/2016	1	11/20/2016
	23) Allow one day for drying.	Evaluate inventory.	11/20/2016	1	11/21/2016
	24) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	11/21/2016		11/21/2016
	25) Apply one layer of fiberglass mat.	Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles.	11/21/2016	1	11/22/2016
	26) Allow one day for drying.	Evaluate inventory.	11/22/2016	1	11/23/2016
	27) Prepare for next layer.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer.	11/23/2016	1	11/24/2016
	28) Apply one layer of woven fiberglass.	Fully saturate woven fiberglass in Polyester Resin. Avoid air bubbles.	11/24/2016	1	11/25/2016
	29) Allow one day for drying.	Evaluate inventory.	11/25/2016	1	11/26/2016
	30) Prepare for next layer. Apply two layers of fiberglass mat. Apply one layer of woven fiberglass.	Achieve an even surface by eliminating protruding fiberglass mat. Avoid penetrating sub-layers. Achieve clean surface for next layer. Fully saturate fiberglass mat in Polyester Resin. Avoid air bubbles. [NOTE: Fourth full layer complete after preparation for next layer. Fifth full layer complete after woven fiberglass applied.]	11/26/2016	1	11/27/2016
	31) Allow one day for drying.	Evaluate inventory.	11/27/2016	1	11/28/2016

	32) Clean mold. Evaluate mold thickness.	Eliminate surfaces that can cause injuries or damage to vacuum bags. Determine if further layers are required.	11/28/2016	5	12/3/2016
Evaluate Schedule	**Evaluate schedule timing and feasibility. Re-adjust schedule as necessary. Evaluate inventory.**		**12/3/2016**	**7**	**12/10/2016**
Mold Removal	1) Cut and sand edges of mold.	Eliminate surfaces that can cause injuries or damage to vacuum bags. Determine if further layers are required.	12/10/2016	1	12/11/2016
	2) Prepare shop and construct mold platform.	Center of shop needs to be used for mold platform. Construct mold platform to support mold.	12/11/2016	6	12/17/2016
	3) Place mold into mold platform.	Avoid damaging mold.	12/17/2016	1	12/18/2016
Evaluate Schedule	**Evaluate schedule timing and feasibility. Re-adjust schedule as necessary. Evaluate inventory.**		**1/17/2017**	**4**	**1/21/2017**
Mold Preparation	1) Remove plug from mold.	Avoid damaging mold.	1/21/2017	1	1/22/2017
	2) Clean interior of mold using hot water, washcloths, and sandpaper (if needed, only use high-grits).	Remove PVA Release film and remnants of plug. Avoid damaging gel coat.	1/22/2017	2	1/24/2017
	3) If needed, repair gel coat. Otherwise, apply Meguiar's Mold Polish Conditioner and Release Wax (apply 5 layers using buffer).	Achieve smooth layup surface (i.e. only apply to places where it is non-existent).	1/24/2017	2	1/26/2017
	4) Apply PVA Release Film: spray on 5 layers of film.	Achieve an even layer of film. [NOTE: From here on out, protect interior of mold by covering in plastic.]	1/26/2017	2	1/28/2017
Evaluate Schedule and Deep Clean Shop	**Evaluate schedule timing and feasibility. Re-adjust schedule as necessary. Evaluate inventory. Deep clean shop.**		**1/28/2017**	**7**	**2/4/2017**
Hull Fabrication	1) Apply one layer of 1K carbon fiber centered in mold.	Fully saturate 1K carbon fiber in Epoxy Resin with Kevlar Pulp. Avoid air bubbles.	2/4/2017	1	2/5/2017
	2) Prepare for next layer.	Allow previous layer to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.	2/5/2017	1	2/6/2017
	3) Apply one layer of 3K twill weave carbon fiber off center to port side in mold.	Fully saturate 3K carbon fiber in Epoxy Resin. Avoid air bubbles.	2/6/2017	1	2/7/2017
	4) Prepare for next layer.	Allow previous layer to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.	2/7/2017	1	2/8/2017
	5) Apply one layer of 3K twill weave carbon fiber off center to starboard side in mold.	Fully saturate 3K carbon fiber in Epoxy Resin. Avoid air bubbles.	2/8/2017	1	2/9/2017
	6) Prepare for next layer.	Allow previous layer to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.	2/9/2017	1	2/10/2017
	7) Reinforce chines, keel, bow, and stern using carbon fiber tape.	Fully saturate carbon fiber tape in Epoxy Resin. Avoid air bubbles.	2/10/2017	9	2/19/2017
	8) Prepare for next layer.	Allow previous layer to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.	2/19/2017	1	2/20/2017
	9) Reinforce stern using carbon fiber pre-layed up sheet.	--	2/20/2017	1	2/21/2017
	10) Apply one layer of 3K twill weave carbon fiber centered in mold.	Fully saturate 3K carbon fiber in Epoxy Resin. Avoid air bubbles.	2/21/2017	1	2/22/2017
	11) Prepare for next layer.	Allow previous layer to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.	2/22/2017	1	2/23/2017
	12) Apply Nomex Honeycomb.	--	2/23/2017	3	2/26/2017
	13) Apply one layer of 3K twill weave carbon fiber off center to starboard side in mold.	Fully saturate 3K carbon fiber in Epoxy Resin. Avoid air bubbles.	2/26/2017	1	2/27/2017

	14) Prepare for next layer.	**Allow to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.**	**2/27/2017**	**1**	**2/28/2017**
	15) Apply one layer of 3K twill weave carbon fiber off center to port side in mold.	**Fully saturate 3K carbon fiber in Epoxy Resin. Avoid air bubbles.**	**2/28/2017**	**1**	**3/1/2017**
	16) Prepare for next layer.	**Allow to dry. Achieve an even surface by eliminating protruding carbon fiber. Avoid penetrating sub-layers. Achieve clean surface for next layer.**	**3/1/2017**	**1**	**3/2/2017**
	17) Apply one layer of 3K twill weave carbon fiber centered in mold.	**Fully saturate 3K carbon fiber in Epoxy Resin. Avoid air bubbles.**	**3/2/2017**	**1**	**3/3/2017**
	18) Reinforce stern using carbon fiber pre-layedup sheet. Reinforce bow using high-density foam.	**--**	**3/3/2017**	**1**	**3/4/2017**
	19) Install L-Bracket and other components required by competition. Cover top of bow with carbon fiber pre-layedup sheet.	**--**	**3/4/2017**	**1**	**3/5/2017**
Evaluate Schedule and Deep Clean Shop	**Evaluate schedule timing and feasibility. Re-adjust schedule as necessary. Evaluate inventory. Deep clean shop.**		**3/5/2017**	**7**	**3/12/2017**
Finishing and Fairing	**1) Prepare staging area for hull's removal.**	**Prepare a soft resting surface that will not damage hull.**	**3/12/2017**	**2**	**3/14/2017**
	2) Remove hull from mold.	**Avoid damaging hull.**	**3/14/2017**	**1**	**3/15/2017**
	3) Remove excess material.	**Avoid damaging hull.**	**3/15/2017**	**4**	**3/19/2017**
	4) Clean interior and exterior of hull using hot water, washcloths, and sandpaper (if needed, only use high-grits).	**Avoid damaging hull. Achieve a smooth interior and exterior surface.**	**3/19/2017**	**1**	**3/20/2017**
	5) In CMU pool, test hull for leaks. Seal where necessary.	**Re-evaluation of schedule may be necessary depending on test results.**	**3/20/2017**	**1**	**3/21/2017**
	6) Clean hull. Paint hull.	**Install sponsorship stickers.**	**3/21/2017**	**7**	**3/28/2017**
Hull Complete!	**Hull is complete and ready for installation of electrical and propulsion system.**		**3/28/2017**	**--**	**--**

Table E.2: 2016-2017 Academic Year Timeline for Propulsion Team

Phase	Goal	End Time
Research	Find options propulsion system for VorteX	11/26/2016
Purchase System	Have system purchased.	12/3/2016
Shipping	-- .	1/17/2017
Test Steering System	Check to see if steering system works and if anything needs to built.	1/28/2017
Test Power System	Check to see if power system can run the propulsion system	2/5/2017
Build Frame for Boat	Build frame for Hull to be used after the final carbon fiber layup.	3/5/2017
Purchase Auxiliary Components	Purchase bilge pump, seat, tablet stand	3/25/2017
Design and Build Dashboard	Dashboard should have the steering wheel, throttle and tablet attached.	4/22/2017
Mounting Systems	Design, purchase materials, and build the mounting system for the solar panels and the dashboard.	5/10/2017
Propulsion Complete		5/10/2017

Table E.3: 2016-2017 Academic Year Timeline for Optimization Team

Phase	Goal	End Time
General System Design	Decide the goals of our system and what those goals will require at a high level.	10/01/2016
Determine Hardware Platforms	Decide on what platforms we will build our Data Acquisition applications on. Buy and order these platforms.	10/15/2016
Sensor Array Design	Determine what sort of data we will want to collect and from where.	10/22/2016
Research Specific Sensors	Pick sensors for light, temperature and current. Compare and contrast non-invasive current sensors and order prototypes.	10/29/2016
Test Sensors	Make sure each sensor behaves as desired. Order replacements if sensors do not fit needs.	12/1/2016
Build Production Data Sensor Array	Create scaffolding and organize sensors into logical array that will easily interface with Arduino and Android tablet.	1/1/2017
Write Arduino code	Make library for reading sensor data and serializing to Android	1/15/2017
Test Arduino code w/ Sensor Array	Debug any issues reading values from sensors. Make changes/improvements as necessary to configuration of hardware and arduino code.	2/1/2017
Write Android Communication Library	Write Android code for interfacing with Arduino	2/14/2017
Test Android Comms. Library	Make sure Android and Arduino interface appropriately	2/21/2017
Design Android UI	Decide what to show to the skipper and what to emphasize.	2/28/2017
Write Android Data Processing & Presentation code	Create Android system for processing and presenting information to skipper in digestible UI	4/1/2017
Test Android Data Processing and Presentation code	Make sure that Android app runs on myriad platforms and appropriately displays information	4/8/2017
Test Full System Pipeline	Test Sensors -> Arduino -> Android -> Display pipeline	4/22/2017
Mount Arduino System in Waterproof box		5/1/2017
Add Extra Features to Android App	Eg., data logging, graphing ability, further testing	5/8/2017
Optimization Team Finished		5/10/2017

Table E.4: 2016-2017 Academic Year Timeline for Power Team

Phase	Goal	End Time
General System Design	Decide the general layout of the system and the necessary components needed.	10/01/2016
Catalog and Determine Solar Panels	Organize the solar panels in the shop left over from previous years. Obtain specification sheets for each type of panel found and determine the most optimal panel for use this year, if any.	10/15/2016
Catalog and Determine Batteries	Organize the batteries in the shop left over from previous years. Obtain specification sheets for each type of battery found and determine the most optimal ones for use this year, if any.	10/22/2016
Catalog and Determine Charge Controllers	Organize the charge controllers in the shop left over from previous years. Obtain specification sheets for each controller found and determine the most optimal one for use this year, if any.	10/29/2016
Test Components	Test all panels, batteries, and charge controllers in storage to ensure that they can still perform and haven't been damaged.	11/15/2016
Research and Purchase Panels, Batteries, and Charge Controllers.	Research other commercial panels, batteries, and charge controllers for comparison with the ones in storage. Purchase needed or more optimal components as necessary.	12/1/2016
Research and Purchase all other Components	Research commercial options for all other components, such as wires, waterproofing tools, connectors, fuses, etc. Purchase as needed.	12/15/2016
Charging System Test	Test the panels, batteries, and charge controller for adequate charging capabilities	1/30/2017
Wiring Design	Determine the final wiring configurations and connections for installation in the boat.	2/15/2017
Hull Installation Design	Communicate with the Hull team to finalize installation design for the panels and batteries.	3/1/2017
Torqeedo Test	Test the battery to motor connection to ensure that the Torqeedo can be powered and operated.	3/15/2017
System Installation	Install and wire all power systems into the boat.	5/1/2017
Assist Optimization	Assist the Optimization team in sensor design, placement, and construction	5/1/2017
Full System Test	Test the entire system for operating capabilities.	5/10/2017
Power Team Finished		5/10/2017