Carnegie Mellon
SOLAR RACING

Technical Report
Boat #5
May 07, 2019

VORTEX

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Executive Summary

Carnegie Mellon Solar Racing's (CMSR) goal for the Solar Splash 2019 competition is to improve VorteX for both the sprint and slalom, while still having the same performance ability in the endurance event. By improving performance in the two events, CMSR will have a more competitive, well rounded boat.

Using the team's traditional breakdown of four teams (Hull, Propulsion, Power and Optimization), CMSR was able to commit to several different sub-system goals in order to improve performance in the sprint and slalom.

This year's team has completed CMSR's first in house designed propulsion system and propeller system. Adjustments to the boat hull and power system were made to accommodate the new propulsion system. It is expected that the new system will have significantly higher speeds than the torqeedo system used in previous competitions. CMSR has also begun designing a new boat hull and has researched extensively on new fabrication methods to expedite the boat making process. The CMSR team has tested some of the new fabrication methods on smaller boat molds.

CMSR has laid down the groundwork to allow the team to regularly test the team's boat on the water. In the past, CMSR has been very limited with its testing capabilities because its boat weren't licensed by the state of Pennsylvania. CMSR is finishing its registration for VorteX and gained the experience on how to register new boats that are being manufactured.

CMSR has also seen a large increase in members this year. The CMSR team has grown from 17 members to 30 members. With the help from all members, the teams were able to meet their intended goals. However due to time, resource, and financial restrictions all subsystems were unable to be tested together before competition. Next year, this testing will become a focus of CMSR in order to prepare better for Solar Splash 2020.

CMSR has seen a large amount of support from Carnegie Mellon University and its various corporate sponsors. This support has enabled the team to continue pursuing its engineering activities and make large strides in the team's performance. The team is looking forward to another year of competition and identifying new areas to apply its engineering skills.

I. Overall Project Objectives

Carnegie Mellon Solar Racing will compete in Solar Splash this summer for the third consecutive year. This year's team made several improvements to the current boat, VorteX, through the development of a new outboard motor, enhancing the accuracy of the boat's data acquisition system, and improvements to the electrical system to improve overall energy efficiency and performance.

There are three main objectives for the team this year. The first objective is to make VorteX more competitive in the speed-based races. Historically the team has performed well in the solar endurance race, but lagged in sprint. The newly designed propulsion system and propellers will offer significant improvements to the boat's top speeds without sacrificing energy efficiency for cruising speeds. The second objective of the team is to gather more accurate data of the boat's performance to aid future engineers in this team. To achieve this objective, the team will have multiple on the water tests before competition and further enhance the "smart systems" in the boat. The third objective is to start designing a new hull for future competitions. The team has learned about the many strengths and limitations of the current boat design and will work on constructing a new boat for future competitions.

The following summarizes the goals in each of the four subteams:

- Hull: Prepare VorteX to mount the new propulsion system. Further remodels to the cargo bay and cockpit to accommodate the new electrical system. Begin designs for the new hull.
- Propulsion: Build the new propulsion system with custom designed propellers.
- Power: Design and build a new circuit that can power the propulsion system.
- Optimization: Develop new sensor systems that are significantly more accurate with data collection.

II. Solar System Design

A. Past Design

Last year the team purchased custom Solbian panels from Ocean Planet Energy using SunPower monocrystalline cells with 24% efficiency and 3.07 watts each. The back 4 panels are SP103 panels purchased off the shelf purchased from stock. The front panel was custom designed by CMSR members and sent to Solbian for final adjustments to fit the front portion of our boat effectively. The goal of the custom design was to have the solar system array adhere to the contour of the boat shape for improvements in drag and aesthetics. Last year's panels were very bulky and overhung the edges of the boat. The panels were flash tested by Solbian at their facilities and reported an output of 473 W. The panels are 21.8 Voc each. The total weight for these panels is only around 10 lbs. The panels came with adhesive backing, which the team glued onto sheets of polycarbonate reinforced with epoxy and fiberglass. The final weight is about 29 lbs., with marked improvements in power.

B. Current Design

After considering our options, our team decided to stick with our current solar panel design and specs. This was because we found not only that our solar panels were very efficient and are still performing optimally. Considering both the weight and efficiency of the panels, not changing our current solar panels was the most logical decision to make. However there were significant efficiency loss in our system at the charge controllers. After researching different charge controllers we found that The PowMr 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 our solar array and battery configuration, the MPPT charge controller is able to charge with around 99.8% efficiency consistently with little drop off after many iterations of uses. The new charge controllers were purchased and integrated into the system.

In addition to the benefits for the power design, the charge controllers have a small LED screen located on the top side of the controller. The information presented on the small LED screen provided the optimization team with the ability to analyze the real time data effectively rather than guessing the information through calculations and other tests.

III. Electrical System

A. Electrical Design

A new electrical system was designed to work with the new propulsion system. The goal of our team was to first analyze our current system look for places that the system can be improved for efficiency and a better performance, then tackle those areas with a new design. With the plans to design a completely new propoller created new challenges for the power team but also acted as an opportunity to redesign the existing system and make improvements. A new system was created to fit our new design requirements which can be seen in the Figure 1 below.

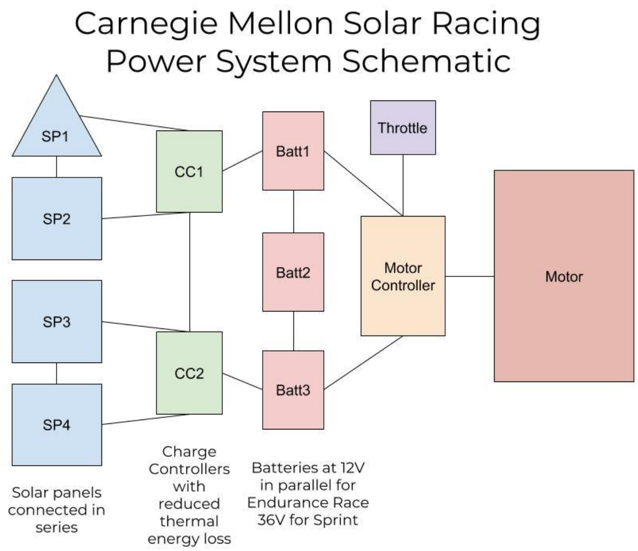

Figure 1: Overview electrical diagram of power system

1) Motor and Motor Controller: In previous years, the team had been using a Torqeedo motor system with a motor controller built in. This meant that the old motor system had to be removed from the boat and a new system had to be purchased. The team purchased a Saietta 119r motor system which was a stronger motor in hopes of performing better in the sprint competition. In addition to the purchase of the motor, a Alltrax motor controller was purchased since the Saietta motor did not have a motor controlling system built in. Both of these changes were completed with the goal of improving our placement in both the sprint and endurance races with an upgraded motor system.

2) Throttle: A standard hand throttle was purchased to interface with the Alltrax motor controller.

3) Charge Controllers: When examining the specifications for the charge controllers used in previous years, it was found that the system that was being used was only 93% efficient. This was seen as a problem for our competition ability since significant power was lost from the solar panels to the batteries.The PowMr Charge Controller, with >99% efficiency, was used to replace the old system. This new charge controller system had a greater efficiency in large part due to its internal cooling system which would turn on if the temperature is greater than 45 degrees and shut down if the temperature is less than 40 degrees and in between this temperature is the optimal thermal efficiency for the charge controller system.

4) Batteries: When considering the design setup for our battery configuration the competition limitation for the maximum voltage was 36 Volts of power. Knowing this limitation the best setup was created by our team was connecting three 12 Volt batteries in series for the sprint configuration. This would create a system with 36 Volts of power during the sprint race. This decision was made with the knowledge that with more voltage traveling to the motor system, the faster we can run the system. However, during the endurance race we are trying to conserve the power of the system as much as possible. That is why we chose to run the system at 12 Volts during the endurance race. This will effectively allow us to conserve energy in the batteries but still run the system at a fast enough speed to compete in the endurance race.

Table 1: Battery specification comparison between models

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 D34M	55	43.5	AGM (dual purpose)	$175
Vmax857	35	25	AGM	$110
Duracell SLI27MDP	80	49	Flooded	$115
Amstron AP12-75D	75	51.8	AGM	$140
Optima Red 75/25	44	33.1	AGM	$233

IV. Hull Design

A. Current Design

CMSR will be recycling the hull used in Solar Splash 2017 and 2018. The current hull is made of carbon fiber with a Nomex honeycomb core and is 17 feet long. The boat hull weighs about 88 lb. The fabrication process of this current hull consisted of creating a foam plug by CNCing 2-inch cross sections of the hull. The foam mold was then sanded down and prepped for a fiberglass layup. The fiberglass female mold was then used for the carbon fiber layups yielding the current hull. This manufacturing process produced a boat with well-defined corners and chines but was over-saturated with epoxy as well. This caused the boat to be heavier and more brittle. Improvements on this process are being considered for the build of a new hull in 2019. This year the focus on the current hull was to improve the cockpit pit area to reduce weight and add driver comfort.

B. Boat Improvements

One of the improvements done to the hull this year was redesigning the cockpit area. The previous dashboard was supported by a wooden cross-section panel which was not ideal, so it was removed and replaced with extrusion running across the top. A plastic angled mounting

piece was used to achieve a 45-degree angle and the dash was bolted through. A new steering cable was also purchased as to reduce the bend it had over the side of the boat.
The cargo bay area was also filled with expandable foam in order to follow competition protocols for buoyancy. The previous solar panel mounts were bars of aluminum extrusion that the solar panels slid onto using T-slotted bolts. This arrangement made it difficult to align and smoothly slide in the panels, and so they were replaced with c-channel to make the mounting process less cumbersome and quicker

C. Future Build

CMSR's next hull design aims to build on the lessons learned in our past hull iterations to create a smaller hull that excels in endurance races. We plan to accomplish these performance goals by utilizing computational tools and encouraging student participation throughout the design process.

1) Computational Tools: In order to achieve our hull design goals, we have decided to heavily lean on CFD and FEA software in order to create a more intentional hull design. So far, this means simulating drag forces acting on rudimentary 3D shapes in Solidworks to check and build upon our intuitions from basic fluid mechanics. We hope to continue this work by using more detailed CFD tools like ANSYS, SimScale, or ANSA to refine future drag and lift calculations. We also aim to begin using FEA tools to simulate boat stability, buoyancy, and center of mass.

2) Broadening Student Inclusion: In past years, hull design has been capitalized by the few students with prior experience with CAD and CFD. Our next design hopes to change this precedents by involving as many CMSR members as possible. We have already taught nine new members basic CAD and CFD skills and have assigned them with minor projects. The hope is that with more student involvement we can afford to explore more aspects of our hull's design.

3) Fabrication Goals: The current hull's fabrication technique as detailed in section A has room for improvement. For the new boat hull, the fabrication process will be improved by using 3D CNC routing the plug cross sections which will cut down on fabrication time and possible human error from sanding.

4) Testing Fabrication Techniques: In order to support the new boat's fabrication, we conducted a trial fabrication using miniature boat molds. The goal of these research projects was to gain practice as well as test out new fabrication ideas, such as a CNC routing a female mold which would eliminated the need for a plug, as well as to gain practice. The projects consisted of making miniature boat molds by CNCing foam cross sections and testing out various fabrication methods on each one.

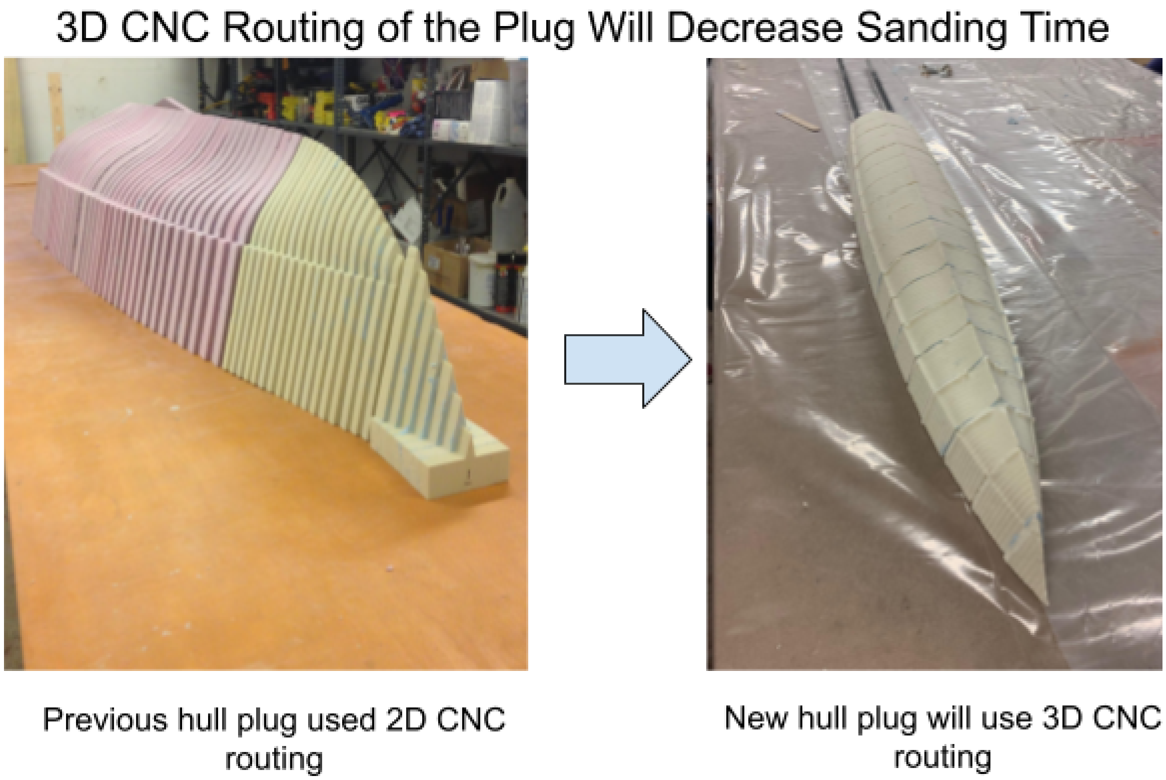

Figure 2: New process to CNC cross sections for male mold

VI. Drivetrain and Steering

A. Current Design

For Solar Splash 2018, CMSR competed using a Torqeedo Cruise 2.0 RS for the propulsion system and a Seastar SS137 20’ Safe-T Quick Connect for the steering system. There were no problems or issues with using the steering system, so it will be integrated into the drivetrain and steering system again for Solar Splash 2019.

As for the propulsion system, While the power drawn from the torqeedo made it highly efficient during endurance races, the speeds reached during the endurance races was fairly equal to those for slalom and sprint. Therefore, our propulsion system could not be further optimized for any races. From previous experience in researching propulsion systems, it was known that the Torqeedo was the most optimal for Vortex on the market, so in order to improve the propulsion systems performance, the team would need to build one. By building the propulsion system in house, it could be optimized for propeller design and size, power draw and use, and be made more optimal to support both the sprint and the endurance events.

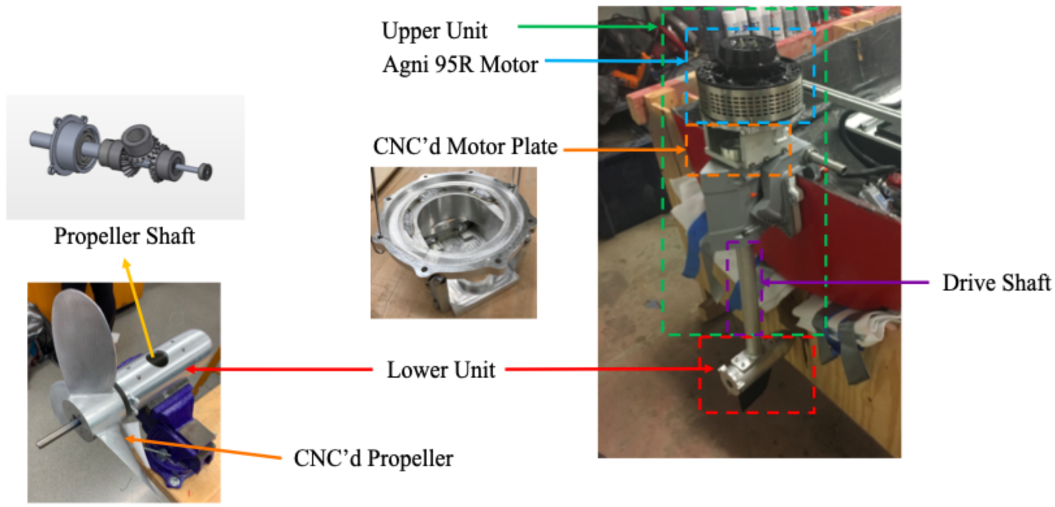

Figure 3: Diagram of manufactured components in new propulsion system

B. Analysis of Design Concepts

The design for this year consists of three main parts: the lower unit, the upper unit, and the propellers. The rationale behind designing a new propulsion system was to allow our design to become more flexible. It allows for changing out the gears and the propeller to suit the competition. This flexibility also allows for ease of fixing and modifications during testing. Overall, this system should operate better than the Torqeedo for Vortex.

1) Lower Unit: The lower unit includes a casing, a propeller shaft, a propeller, gears that connect the driveshaft to the propeller shaft, and bearings that allow the propeller shaft to spin freely. The main consideration when designing the lower unit was waterproofing, as water would reduce the efficiency of the gears and bearings. To design around this, gaskets were purchased and custom cut to seal the connection areas that were not welded. The original idea for the casing was to 3D print a metal housing. However, upon looking into it, it was discovered that it would be time intensive and costly for the team. Instead, it was decided to CNC the casing in parts and weld them together. There are drawbacks of weight and required simplicity of the design, but the casing would be finished on time and within budget. Having a heavier part will damage time in the endurance race but allows for sturdier connections. In addition, due to the relatively simple construction, the casing will be easier to improve and iterate on.

2) Upper Unit: The upper unit is primarily made up of the motor housing, the connection to the boat, and the steering attachment. For the connection to the boat, an old Torqeedo case was adapted to house the driveshaft. Similarly, an on old Torqeedo steering attachment and cable was repurposed so that the pre-existing steering system could be reused. The motor housing is designed to be adjustable so that we a switch can be made between a 24-24 and a 24-36 gear ratio. This way, the motor can be geared down for the endurance race, allowing for increased efficiency with a lower RPM. The second gear is connected to the driveshaft, which travels through a casing to protect it from the water, to connect to the lower unit.

3) Propeller: This year the CMSR team, researched, designed, and manufactured their own propellers for the sprint and endurance races. The initial designs for the propellers were designed using OpenProp [4], an open software developed by MIT and Dartmouth to aid with propeller design and analysis. The propellers were then imported into SolidWorks, and simulations were conducted to assess their stress and performance. Finally, the propellers were manufactured at Carnegie Mellon University using a three-axis CNC machine mill and wax fixturing process.

C. Design, Testing, and Evaluation

Before manufacturing the propulsion system, all parts were designed inside of SolidWorks and fitted together to approve proper dimensions and to prevent manufacturing error. The propeller was additionally tested using fluid simulations and stress analysis to determine failure modes. The team unfortunately did not have enough time to test the new system on the water at this time because of the schedule needed to complete the system.

VII. Data Acquisition and Communications

A. Current Design

During the competition, both the driver and the rest of team need live updates on the status of the boat. This includes crucial information for planning such as battery state of charge and temperature of the electrical system, which determines everything from the boat's predicted distance to any indications of the system overheating. In addition to these, additional sensors and modules provide information on the boat's approximate location as well as the location of surrounding boats. This helps the driver and the ground team make decisions on when to speed up or slow down the boat to more optimal speeds.

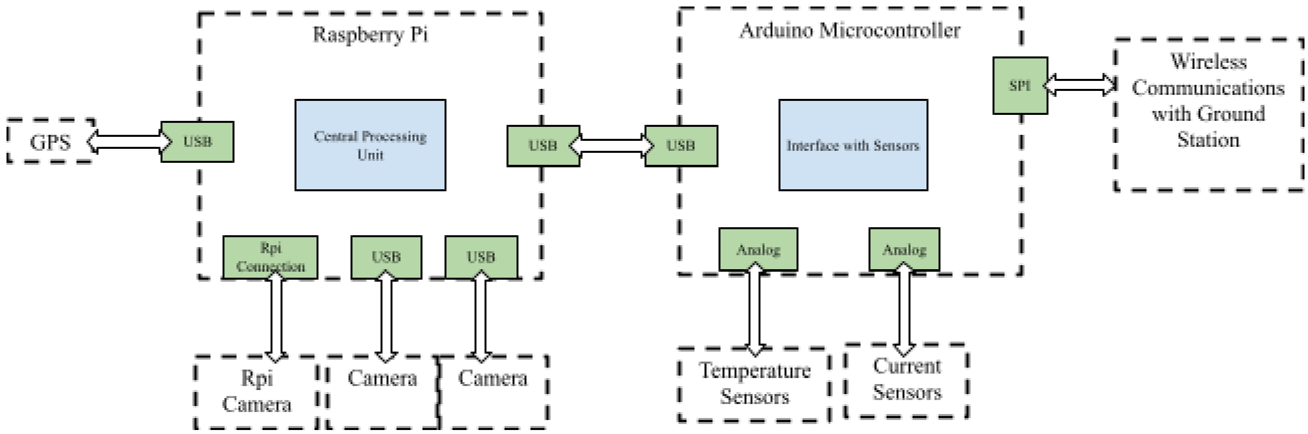

Figure 4: High-level schematic of our system of sensor readings with the Arduino as well as GPS and camera data processing by the Raspberry Pi.

1) Battery State of Charge: Initial attempts involved measuring battery state of charge simply with voltage readings, but this required the calculation of voltage-to-charge models beforehand and assumed that the batteries would perform identically during the race as during testing. Instead, state of charge is calculated using Coulomb Counting, which integrates the discharge current of the batteries over time to calculate total charge consumed.

$$Q_{total} = \int_0^t I dt$$

Since our system will only periodically measure current at select intervals, total charge consumed is approximated:

$$Q_{total} = I\Delta t + Q_{total}$$

To measure current, our sensor box contains an Arduino Uno micro-controller that reads the output of open-loop ammeters at timed intervals using timed interrupts between low-power mode. Specifically, the ammeters output varying voltages depending on the measured current; our Arduino reads this in through analog input as a value ranging from 0 to 1023 and computes measured current with a linear equation determined during testing. We use the CSLA2DE current sensors from Honeywell for their linear voltage output with respect to current measurements.

During testing with low currents, we used an inverting op-amp to amplify the signals output by our hall-effect sensor. With this, we were able to collect current and voltage readings to approximate the linear parameters of the sensor, as shown in figure 5.

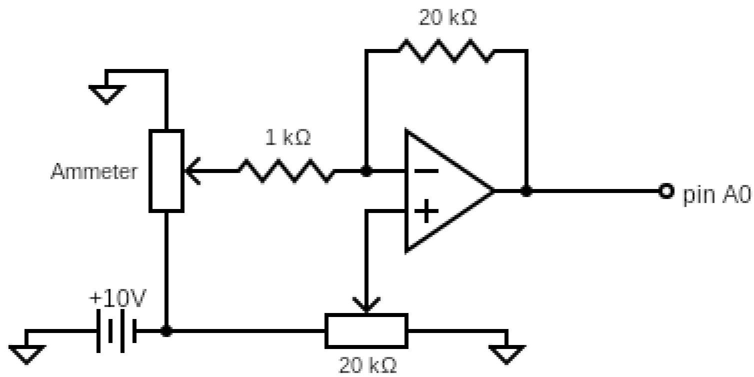

Figure 5: Testing diagram to measure low currents in system

The hall-effect sensor needs a 10V input, and will output 5V when there is no detected current. Therefore, as indicated by the above diagram, we set the op-amp's positive terminal to a tuned voltage around 5V (done with a voltage divider / potentiometer). This allows the output to be with respect to the change in voltage from the initial 5V. In testing, we found that a gain of 20 was appropriate to ensure that the analog read pin on the arduino can detect the changes in current (as reported by the sensor) with greater precision.

We used the TL071 Op-Amp for its low power consumption and immediate availability at our electrical lab.

In order to measure the current of the power consumed by the motors and supplied by the solar panels, we need to wire the external cables of the batteries directly through these loops, which complicates the design by forcing the sensor to hang on the wire. We considered having a smaller wire somehow branch from the batteries, but the high current running through this would most likely create a fire hazard.

2) Temperature: Various temperature sensor probes are inserted throughout the boat's electrical system, which include the sensor box itself and the chamber for the batteries. These sensors can be read through analog ports in the same fashion as the ammeters, only this time using parameters specified by the product manufacturer.

3) Localization of Boat and Opponents: Our team's boat position can be determined with enough accuracy using an inexpensive GPS connected to a raspberry pi via USB. Using the Google Maps API, our ground dashboard shows the location of the boat as a red dot on a map with information on velocity.

4) Android App for Sensor Visualization: An Android app parses data sent by the Arduino over USB Serial interface, which includes temperature of batteries, charge rate of solar panels, and charge percentage left in batteries.

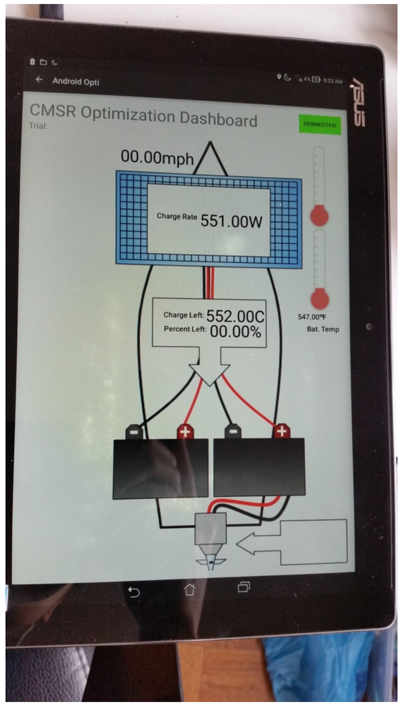

Figure 6: Dashboard of CMSR's android tablet that tracks data from sensors

5) Long-distance Communication: Our team chose to use the RFM96W LoRa Radio to transmit sensor data from the boat back to the ground station for several reasons. First, our Arduino will periodically transmit small packets of data rather than video streams and images, which matches the radio's intended use case. Second, the LoRa supports 2 km communications in direct line-of-sight, sufficient for all of the races. Lastly, LoRa consumes relatively low power compared to wifi. Overall, this radio module will provide our onshore team constant status updates on the race.

VIII. Project Management

A. Team members and leadership roles

Carnegie Mellon Solar Racing has a total of 30 active members in the club that regularly attends meetings. As an inclusive organization on campus, CMSR aims to mentor any and all students that join the team.

This year's team has a new design lead called the Head of Design. In previous years, the president oversaw both the team's logistics as well as boat engineering. However as the team grows in size and undertakes more projects, it becomes evident that there needs to be a member dedicated to managing the team's design process. The other roles are unchanged and listed below. The executive committee meeting has been split into two separate meetings. The first meeting consists of the president, head of design, secretary, and the team's vice presidents to discuss logistics. The second meeting consists of the president, head of design, and design leads to discuss only engineering projects in the club. This separation allows meetings to be both more focused and more concise.

Table 2: Executive Committee roles and descriptions of duties.

Role	Description
President	Determines the overall vision and expectation of the organization for the given year. Oversees the progress of all members and officers.
Head of Design	Manages all of the design leads and engineering projects inside of the club. Ensures that the design leads are undertaking productive projects for the team.
Secretary	Manages logistics for general body meetings, design meetings, and Executive Committee meetings. Responsible to update members on all organization meetings and changes.
Vice President of Finance	Develops and enforces the final budget and timeline. Works with the Student Life Involvement and Civic Engagement office on campus for funding needs.
Vice President of Marketing	Promotes the public perception of CMSR through preparing for outreach events and for sponsors.
Vice President of Member Development	Works to obtain new members, develop their abilities, and integrate them into the organization through the New Member Project.
Vice President of Programming	Manages logistics for Solar Splash competition and any other large events. Also, oversees management of the shop, storage cage, and off campus storage locations.
Hull Fabrication Lead	Leads fabrication and management of the boat hull.
Hull Design Lead	Leads design and simulations on new boat designs
Propulsion Design Lead	Leads design and fabrication of the drivetrain and steering.
Optimization Design Lead	Leads design and fabrication of the communications system.
Power Design Lead	Leads design and fabrication of the electrical and power systems.

B. Project Planning and Schedule

Each design lead organizes their own meetings in order to achieve their goals. The frequency of meetings varies depending on the subproject timelines. The executive committee and design leads meet bi-weekly to discuss updates, engineering timeline, and overall management of the club.

C. Financial and fund-raising

In order to finance the design, development, and manufacturing of components for the 2018 boat, the team drew from two primary funding sources: university-allocated student organization and corporate sponsorship.

Every year the team requests funding from the Joint Funding Committee (JFC) within Carnegie Mellon Student Government. Through advocating the vision and project needs of CMSR, collaborating with CMSR's assigned Joint Funding Committee representative, and submitting a detailed itemized budget of expected expenses, the organization was able to gain $12,177 for Carnegie Mellon's student organization fund. Also, the organization has continued a partnership with Ford Motor Company. By maintaining relations with an alumnus of the organization, who now works for Ford, the organization is given opportunities for funding. This year, CMSR received $5000 as part of Ford's Blue Oval Scholarship program. General Motors has also begun to sponsor the team starting this year. The team has been given a $2500 sponsor to aid engineering activities. Other institutions that helped support CMSR through donation of physical, informational, and digital materials are College of Engineering, Ocean Planet Energy, Saietta, Simscale, Solbian, SolidWorks, and Steinbrenner Institute for Environmental Education & Research. While none contributed direct funds, by supporting the club through other means, they has reduced overall financial costs.

CMSR's strategies have enabled the organization to obtain significant funding with very manageable effort, the organization strongly recommends networking and partnering with companies, and requesting university funding for collegiate Solar Splash teams. While establishing corporate relationships can involve more effort and uncertainty, more benefits can potentially be gained since companies may offer financial support, but also take interest in recruiting team members for internships and full-time employment. If corporate networking is not the most preferred option, then utilizing university resources is always a sound strategy, as universities tend to place high importance and dedicate significant resources toward helping students' educational endeavors succeed.

D. Strategy for team continuity and sustainability

Carnegie Mellon Solar Racing strategy for continuity and sustainability is to maintain team organization, recruit and develop new members, maintain sponsor relationships, recycle resources to reduce future costs, and to document the building process within a shared drive to pass down information.

1) Maintain Team Organization: CMSR consists of four teams: propulsion, hull, optimization, and power. Each team is required to provide a timeline of their work to ensure prompt completion of necessary tasks. Each year these schedules are evaluated and passed down to be examples to future years. In addition, an executive committee, made of students from different graduation year, discusses and organizes club logistics. Having a large and diverse executive committee helps provide a path for students to gain leadership skills and advance in the group. It also makes it so that positions are filled by students from all years and the entire leadership team will not graduate at the same time.

2) Recruit New Members: Every year, members of Carnegie Mellon Solar Racing attend two university sponsored activity fairs to meet and recruit new students. Potential new members can attend Computer Aided Design tutorials, a General Body Meeting, and work on a New Member Project. The New Member Project is geared to both introduce CMSR's building process, and to help integrate new members into the organization. Throughout the New Member Project, new students design and build a miniature racing boat using very similar techniques as to what are used to build the boat that races at Solar Splash.

3) Maintain Sponsor Relationships: Throughout the course of the year, new relationships with sponsors and solar panel producing companies were made. This foundation will allow future teams to keep in contact with these sponsors to gain additional support either through resources of funding. In addition, a strong performance in Solar Splash 2017 and 2018 has retained all previous sponsors and attracted new ones for this year.

4) Recycling Resources: All of the components within the boat will be passed on to future teams. Future members will be able to test old parts and reuse everything that they deem necessary. Some key components that are being passed on include the hull, the female mold of the hull, the propulsion system and the brand new solar panels. The female mold will allow future teams to construct new hulls to improve the integrity of the boat and to practice those construction skills. In addition, passing down all of the new propulsion system will inform future members how to design and build their own system. Also, future members will have full access to our new solar panels to assess the benefits compared to the panels used two years ago.

5) Documenting Information: The team also makes use of a shared Google Drive that contains documentation on design and research completed each year. This drive was created in 2016, and gives the ability to members to search through old files to learn what older teams did for their building process. This folder was created after CMSR lost all information in 2015 when returning members left the organization and only new members were there to continue the building process. From documenting information over the last two years it has made it easier to write the technical report, predict annual financial costs, and determine proper timeline and scheduling.

E. Discussion and self-evaluation

This year's new member retention has significantly improved when compared to previous years. Last year's team only consisted of about ten regularly attending members. The team size has effectively tripled for the 2018-2019 academic year. However, this brings new challenges as well because the majority of the team are now underclassmen. With a large recruitment this year, the team focused mainly on mentoring and passing engineering skills down in preparation for a stronger CMSR team in future years. As a result, some trade-offs had to be made with the team's normal engineering activities.

IX. Conclusions and Recommendations

A. Strengths and Weaknesses

The strengths for Carnegie Mellon Solar Racing this academic year were:

- Building a new propulsion system: This is CMSR's first in house designed system and this will allow the team to further iterate and improve the system's performance.
- Preparing to build a new hull: The team has started to establish enough continuity and financial stability to begin to iterate on its hull design.
- Member recruitment: This year's recruitment has been one of the largest and gives CMSR a high growth potential in the upcoming competitions.

The weakness for Carnegie Mellon Solar Racing this academic year were:

- Inability to fully test system on the water: The team was not able to finish the boat registration process before the start of competition. As a result, CMSR wasn't able to confirm the performance of its various subsystems.
- Not having a driver who is comfortable driving a truck: This prevents the team from being able to test the boat and requires us to have the Faculty Advisor transport the boat to competition. The team is still uncertain on how to best handle this problem.

B. Meeting Sub-System Objectives

The team's sub-system objective were as follows:

- Hull: Prepare VorteX to mount the new propulsion system. Further remodels to the cargo bay and cockpit to accommodate the new electrical system. Begin designs for the new hull.
- Propulsion: Build the new propulsion system with custom designed propellers.

- Power: Design and build a new circuit that can power the propulsion system.
- Optimization: Develop new sensor systems that are significantly more accurate with data collection.

Carnegie Mellon Solar Racing was able to meet all of the goals for the 2019 competition.

C. Reflections on Design Process

The team has successfully completed the new propulsion system and the various sub-systems needed to support it. However, the team needs to help encourage the new members to learn many of the advanced manufacturing techniques such as welding and CNC. The average age in CMSR will be relatively young starting next year and needs to fill in the gaps of the graduating seniors.

D. Where do we go from here?

The team will begin to regularly test the full boat starting in the next academic year. Furthermore, the team will begin to invest heavily into the hull sub-teams to finance building a new hull. Improvements in the propulsion and electrical systems can be made as well because CMSR had a lot more control on all of the components inside of the boat this year with the team's in house designed components.

E. Lessons Learned

The largest lesson learned is that the team needs to focus its resources more with on the water testing. Starting next year, CMSR should have the capabilities to begin full system tests in Pennsylvania. CMSR has also learned and developed many of its engineering skills. The team managed to design and fabricate its first propulsion system. The team is also further iterating on the new boat hull design and making improvements with the fabrication process. CMSR has also improved from its previous years of member retention and increased the team size substantially.

X. References

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XI. Appendices

Appendix A: Battery Documentation

The specifications of the batteries are detailed below for Optima 75/25 redtop batteries.

Battery Model: 75/25
Part Number: 8022-091
Nominal Voltage: 12 volts
NSN: 6140 01 475 9361
Description: High power, sealed lead acid, engine starting 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: Dark Gray
Cover: "OPTIMA" Red
Group Size: BCI: 75/25

	Standard	Metric
Length:	9.340"	237.24 mm
Width:	6.772"	172.01 mm
Height:	7.697"	195.50 mm (Height at the top of terminals)
Weight:	33.1 lb	15.0 kg

Terminal Configuration: SAE / BCI automotive and GM style side terminal (3/8"-16UNC-2B threaded nut).

Performance Data:

Open Circuit Voltage (Fully charged): 12.8 volts
Internal Resistance (Fully charged): .0030 ohms
Capacity: 44 Ah (C/20)
Reserve Capacity: BCI: 90 minutes
(25 amp discharge, 80°F (26.7°C), to 10.5 volts cut-off)

Power:

CCA (BCI 0°F): 720 amps
MCA (BCI 32°F): 910 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: 75/25
These batteries are designed for engine starting applications. They are not recommended or warranted for use in deep cycle applications.

Figure A.1: Optima Battery Specification Sheets (1 of 2)

Recommended Charging Information:

Alternator:	13.3 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. **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.

Manufacturing Location:

Enertec Exports S. de R.L. de C.V.
RFC: EEX020516KU2
Avenida. del Parque No. 2155
Monterrey Technology Park
Cienega de Flores, N.L. 65550
MEXICO
Phone: 52 (81) 81542300
Fax: 52 (81) 81542301

BCI = Battery Council International

OPTIMA Batteries
Product Specifications: Model 75/25
December 2008

Figure A.1 cont.: Optima Battery Specification Sheets (2 of 2)

Johnson Controls

Safety Data Sheet

1. IDENTIFICATION

Product Name: Sealed Lead Acid Battery/ Optima Battery ™ Synonyms: Sealed Lead Acid Battery	Product Use: Vehicle Electrical System Manufacturer/Supplier: Johnson Controls Battery Group Address: P.O. Box 590 Milwaukee, WI 53201 US
General Information Number: (800)-333-2222 ext. 3138 Contact Person: Industrial Hygiene & Safety Department	Emergency number: CHEMTREC: 800-424-9300

NOTE: The Johnson Controls sealed cell/battery is considered an article as defined by 29 CFR 1910.1200 (OSHA Hazard Communication Standard). The information contained in this SDS is supplied at the customer's request for information only.

2. HAZARD(S) IDENTIFICATION

Health		Environmental		Physical	
Acute Toxicity (Oral, dermal, inhalation)	Category 4	Aquatic	Chronic 1	Explosive Chemical	Division 1.3
Skin corrosion/irritation	Category 1A	Aquatic	Acute 1		
Eye Damage	Category 1				
Reproductive	Category 1A				
Carcinogenicity (lead)	Category 1B				
Carcinogenicity (acid mist)	Category 1A				
Specific target organ toxicity (repeated exposure)	Category 2				

Label Elements:

Health	Environmental	Physical

Hazard Statements	Precautionary Statements
DANGER! Causes severe skin burns and eye damage. Causes serious eye damage. May damage fertility or the unborn child if ingested or inhaled. May cause cancer if ingested or inhaled. Causes damage to central nervous system, blood and kidneys through prolonged or repeated exposure.	Wash thoroughly after handling. Do not eat, drink or smoke when using this product. Wear protective gloves/protective clothing, eye protection/face protection. Avoid breathing dust/fume/gas/mist/vapors/spray. Use only outdoors or in a well-ventilated area. Causes skin irritation, serious eye damage. Contact with internal components may cause irritation or severe burns. Avoid contact with internal acid. Irritating to eyes, respiratory system, and skin.

PS-HTR-ST-49-E_Sealed Lead Acid Battery / OPTIMA Battery ™ SDS US
Version #: 07 Issue Date: 04/01/2015 Revision Date: 03/16/2017 1 of 10

Figure A.2: Optima Battery Safety Data Sheet (1 of 10)

May form explosive air/gas mixture during charging. Extremely flammable gas (hydrogen). Explosive, fire, blast or projection hazard.	

3. COMPOSITION / INFORMATION ON INGREDIENTS

INGREDIENTS (Chemical/Common Names):	CAS No.:	% by Wt:
Lead	7439-92-1	63 - 91
Sulfuric Acid	7664-93-9	17 - 25
Case Material Polypropylene	9010-79-1	2 - 6
Separator/Paster Paper Fibrous Glass	65997-17-3	<1 - 4

Composition Comments All concentrations are in percent by weight.

4. FIRST AID MEASURES

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

Inhalation Sulfuric Acid: Remove to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Consult a physician.
Lead: Remove from exposure, gargle, wash nose and lips; consult physician.

Skin contact Sulfuric Acid: Flush with large amounts of water for at least 15 minutes; remove contaminated clothing completely, including shoes. If symptoms persist, seek medical attention. Wash contaminated clothing before reuse. Discard contaminated shoes.
Lead: Wash immediately with soap and water.

Eye contact 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.

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 physician.
Lead: Consult physician immediately.

5. FIRE FIGHTING MEASURES

Flash Point Hydrogen – 259 °C

Auto ignition Temperature Hydrogen – 580 °C

Flammable Limits LEL = 4.1% (Hydrogen Gas in air) ; UEL = 74.2%

Extinguishing Media CO_2; foam; dry chemical. Do not use carbon dioxide directly on cells. Avoid breathing vapors. Use appropriate media for surrounding fire.

Special Fire Fighting Procedures Use positive pressure, self-contained breathing apparatus. Beware of acid splatter during water application and wear acid-resistant clothing, gloves, face and eye protection. If batteries are on charge, shut off power to the charging equipment, but note that strings of series connected batteries may still pose risk of electric shock even when charging equipment is shut down.

Unusual Fire and Explosion Hazard Highly flammable hydrogen gas is generated during charging and operation of batteries. If ignited by burning cigarette, naked flame or spark, may cause battery explosion with dispersion of casing fragments and corrosive liquid electrolyte. Carefully follow manufacturer's instructions for installation and service. Keep away all sources of gas ignition and do not allow metallic articles to simultaneously contact the negative and positive terminals of a battery. Follow manufacturer's instructions for installation and service.

6: ACCIDENTAL RELEASE MEASURES

Figure A.2 cont.: Optima Battery Safety Data Sheet (2 of 10)

Protective Measures to be Taken if Material is Released or Spilled	Stop flow of material, contain/absorb 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 un-neutralized acid to sewer. Acid must be managed in accordance with approved local, state, and federal requirements. Consult state environmental agency and/or federal EPA.
Waste Disposal Method	Dispose of as a hazardous waste. Dispose of in accordance with applicable local, state and federal regulations.

7. HANDLING AND STORAGE

Handling	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. Do not subject product to open flame or fire and avoid situations that could cause arcing between terminals.
Storage	Store batteries under roof in cool, dry, well-ventilated areas separated from incompatible materials and from activities that may create flames, spark, or heat. Store sealed lead acid batteries at ambient temperature.
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 may generate and release flammable hydrogen gas. Charging space should be ventilated. Prohibit smoking and avoid creation of flames and sparks nearby. Wear face and eye protection when near batteries being charged.
Other	Follow Manufacturers Recommendations regarding maximum recommended currents and operating temperature range. Do not overcharge beyond the recommended upper charging voltage limit. Applying pressure or deforming the battery may lead to disassembly followed by eye, skin and throat irritation.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Occupational exposure limits

US OSHA Specifically Regulated Substances (29 CFR 1910.1001 – 1050)

Ingredient	CAS Number	Type	Value
Lead	7439-92-1	TWA	0.05 mg/m^3

US OSHA Table Z-1 Limits for Air Contaminants (29CFR 1910.1000)

Ingredient	CAS Number	Type	Value
Sulfuric Acid	7664-93-9	PEL	1 mg/m^3

US ACGIH Threshold Limit Values

Ingredient	CAS Number	Type	Value	Form
Lead	7439-92-1	TWA	0.05 mg/m^3	
Sulfuric Acid	7664-93-9	TWA	0.2 mg/m^3	Thoracic Fractions

US NIOSH: Pocket Guide to Chemical Hazards

Ingredient	CAS Number	Type	Value	Form
Sulfuric Acid	7664-93-9	TWA	1 mg/m^3	
Separator/Paster Paper Fibrous Glass	65997-17-3	TWA	3 fibers/cm^3 5 mg/ m^3 5 mg/ m^3	Fiber Fibers, total dust Fiber Total
Lead	7439-92-1	TWA	0.05 mg/m^3	

Figure A.2 cont.: Optima Battery Safety Data Sheet (3 of 10)

International Exposure Limits (mg/m³)

*Chemical & Common Name	Quebec PEV	Ontario OEL	EU OEL
Lead and Lead Compounds (inorganic)	0.05	0.05	0.15 (a)
Electrolyte (H_2SO_4/H_2O)	1	0.2	0.05 (b)

(a) As inhalable aerosol (b) Thoracic fraction

Biological limit values

ACGIH Biological Exposure Indices

Ingredient	Value	Determinant	Specimen	Sampling Time
Lead	300 µg/l	Lead	Blood	*

* - For Sampling details please see the source document.

Engineering Controls (Ventilation):
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.

Respiratory Protection (NIOSH/MSHA approved):
NONE REQUIRED FOR NORMAL HANDLING OF THE FINISHED PRODUCT.
When concentrations of sulfuric acid mist are known to exceed PEL, use NIOSH or MSHA-approved respiratory protection.

Skin Protection:
NONE REQUIRED FOR NORMAL HANDLING OF THE FINISHED PRODUCT.
If battery case is damaged, use rubber or plastic acid-resistant gloves with elbow-length gauntlet, acid-resistant apron, clothing and boots.

Eye Protection:
NONE REQUIRED FOR NORMAL HANDLING OF THE FINISHED PRODUCT.
If necessary to handle damage product where exposure to the organic electrolyte is a possibility, chemical splash goggles and a face shield are recommended.

Other Protection:
Safety footwear meeting the requirements of ANSI Z 41.1 is recommended when it is necessary to handle the finished product.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance and Odor	Manufactured article; no apparent odor. Electrolyte is a clear liquid with a sharp, penetrating, pungent odor.	
Odor Threshold	Not applicable.	
pH	Not applicable	
Boiling Point	Not applicable unless individual components exposed. Battery Electrolyte (Acid) - 230 - 233.6 °F (110 - 112 °C) Lead - 3191 °F (1755 °C)	
Melting Point	Lead - 621.32 °F (327.4 °C)	
Specific Gravity (H_2O = 1)	1.215 to 1.350	
Flash Point	498.2 °F (259.0 °C) Hydrogen	
Evaporation Rate (Butyl Acetate = 1)	< 1	
Vapor Pressure (mm Hg @ 20 ° C)	Battery Electrolyte (Acid) 11.7	
Flammability		
Upper/lower flammability or explosive limits	Hydrogen	Flammability Limit Lower- 4.1 % Flammability Limit Upper – 74.2 %
Vapor Pressure	Not applicable.	

Figure A.2 cont.: Optima Battery Safety Data Sheet (4 of 10)

Vapor Density	3.4 (Air = 1) Battery Electrolyte (Acid)
Relative Density	1.21 - 1.3 Battery Electrolyte (Acid)
Solubility	Lead and Lead dioxide are not soluble. 100 % Battery Electrolyte (Acid).
% Volatile by Weight	Not applicable unless individual components exposed.
Partition coefficient (n-octanol/water)	Not applicable
Auto-ignition temperature	1076 °F (580 °C) Hydrogen.
Decomposition temperature	Not applicable
Viscosity	Not applicable

10. STABILITY AND REACTIVITY

Stability	The sealed battery is considered stable.
Conditions to Avoid	Sparks and other sources of ignition; high temperature; over charging.
Incompatibility (materials to avoid)	Electrolyte: Contact with combustibles and organic materials may cause fire and explosion. Also reacts violently with strong reducing agents, metals, sulfur trioxide gas, strong oxidizers, and water. Contact with metals may produce toxic sulfur dioxide fumes and may release flammable hydrogen gas. Lead compounds: Avoid contact with strong acids, bases, halides, halogenates, potassium nitrate, permanganate, peroxides, nascent hydrogen, and reducing agents.
Hazardous Decomposition Products	Electrolyte: Sulfur trioxide, carbon monoxide, sulfuric acid mist, sulfur dioxide, hydrogen sulfide. Lead compounds: Temperatures above the melting point are likely to produce toxic metal fume, vapor, or dust; contact with strong acid or base or presence of nascent hydrogen may generate highly toxic arsine gas.
Hazardous Polymerization	Will not occur.

11. TOXICOLOGICAL INFORMATION

NOTE: Under normal conditions of use, this product does not present a health hazard. The following information is provided for organic electrolyte and lead exposure that may occur due to container breakage or under extreme conditions such as fire. Organic electrolyte – reacts with moisture/water to produce hydrofluoric acid in trace quantities. Hydrofluoric acid is extremely corrosive and toxic. In severe exposures it acts as a systemic poison and causes severe burns. The reaction may be delayed. Any contact with this material, even minor, requires immediate medical attention.

ROUTES AND METHODS OF ENTRY	
Inhalation	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** Sulfuric Acid: Breathing of sulfuric acid vapors or mists may cause severe respiratory irritation. Lead Compounds: Inhalation of lead dust or fumes may cause irritation of upper respiratory tract and lungs.
Skin Contact	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** Sulfuric Acid: Severe irritation, burns and ulceration. Lead Compounds: Not absorbed through the skin.
Skin Absorption	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** In the event of overcharging or damage to the unit, exposure to organic electrolyte solution/mist is possible. Extreme exposures to the organic electrolyte can be absorbed through the skin.
Eye Contact	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** Sulfuric Acid: Severe irritation, burns, cornea damage, and blindness. Lead Compounds: May cause eye irritation.
Ingestion	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** Sulfuric Acid: May cause severe irritation of mouth, throat, esophagus and stomach.

Figure A.2 cont.: Optima Battery Safety Data Sheet (5 of 10)

	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.

SIGNS AND SYMPTONS OF OVEREXPOSURE

Acute Effects	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** Sulfuric Acid: Severe skin irritation, damage to cornea, upper respiratory irritation. Lead Compounds: Symptoms of toxicity include headache, fatigue, abdominal pain, loss of appetite, muscular aches and weakness, sleep disturbances and irritability
Chronic Effects	**EXPOSURE IS NOT EXPECTED FOR PRODUCT UNDER NORMAL CONDITIONS OF USE.** Sulfuric Acid: Possible erosion of tooth enamel, inflammation of nose, throat & 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 µg/100 ml or higher. Heavy lead exposure may result in central nervous system damage, encephalopathy and damage to the blood-forming (hematopoietic) tissues.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Overexposure to sulfuric acid mist may cause lung damage and aggravate pulmonary conditions. Contact of sulfuric acid with skin may aggravate diseases such as eczema and contact dermatitis. Lead and its compounds can aggravate some forms of kidney, liver and neurologic diseases.

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: wash hands, face, neck and arms thoroughly before eating, smoking or leaving the work site. 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 EC Directive 67/548/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.

Toxicological Data

Constituents	**Species**	**Test Results**
Sulfuric Acid (CAS 7664-93-9)		
Acute		
Oral		
LD50	Rat	2140 mg/kg

CARCINOGENICITY

Sulfuric Acid: The International Agency for Research on Cancer (IARC) has classified "strong inorganic acid mist containing sulfuric acid" as a Category I carcinogen, a substance that is carcinogenic to humans. This classification does 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.

Lead Compounds: Lead is listed as a 2B carcinogen, likely in animals at extreme doses. Proof of carcinogenicity in humans is lacking at present.

IARC Monographs. Overall Evaluation of Carcinogenicity

Lead (CAS 7439-92-1)	2B Possibly carcinogenic to humans.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Reproductive toxicity	May damage fertility or the unborn child.
Specific target organ toxicity -	No data available.

Figure A.2 cont.: Optima Battery Safety Data Sheet (6 of 10)

single exposure	
Specific target organ toxicity - repeated exposure	Lead: May cause damage to organs (blood, central nervous system) through prolonged or repeated exposure.
Aspiration hazard	Not classified.

12. 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
Ecotoxicity	Very toxic to aquatic life with long lasting effects. However, no ecological impacts expected under normal use conditions.

Constituents			**Species**	**Test Results**
Inorganic Lead/Lead Compounds (CAS 7439-92-1)				
	Aquatic			
	Fish	LC50	Rainbow trout, Donaldson trout (Oncorhynchus mykiss)	1.17 mg/l, 96 hours

Persistence and Degradability	No data available
Bioaccumulative potential	No data available
Additional Information	No known effects on stratospheric ozone depletion Volatile organic compounds: 0% (by Volume) Water Endangering Class (WGK): NA

13. DISPOSAL CONSIDERATIONS

Waste disposal method	Material should be recycled if possible. Lead-acid batteries are completely recyclable. Dispose waste and residues in accordance with applicable federal, state, and local regulations.
Hazardous waste code	D008: Lead
Waste from residues / unused products	Dispose of in accordance with local regulations. Empty containers or packaging may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).
Contaminated packaging	Empty containers should be taken to an approved waste handling site for recycling or disposal.

14. TRANSPORT INFORMATION

Note: Transportation requirements do not apply once the battery pack has been installed in a vehicle as part of the vehicle's functional components.

Transportation: Sealed Lead Acid / OPTIMA 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)**

GROUND – US-DOT/CAN-TDG/EU-ADR/APEC-ADR:

Not regulated as dangerous goods per 49 CFR 173.159a

AIRCRAFT – ICAO-IATA:

Not regulated as dangerous goods per Special Provision A67

I VESSEL – IMO-IMDG:

Not regulated as dangerous goods per exception 238

Figure A.2 cont.: Optima Battery Safety Data Sheet (7 of 10)

15. REGULATORY INFORMATION

This product is an article pursuant to 29 CFR 1910.1200 and as such is not subjected to the OSHA Hazard Communication Standard. The information on this SDS is supplied at customer's request for information only.

TSCA

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

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Lead (CAS 7439-92-1)	Reproductive toxicity
	Central nervous system
	Kidney
	Blood
	Acute toxicity

CERCLA Hazardous Substance List (40 CFR 302.4)

Lead (CAS 7439-92-1)	LISTED
Sulfuric Acid (CAS 7664-93-9)	LISTED

Superfund Amendment and Reauthorization Act of 1986 (SARA)

Hazard Categories	Immediate Hazard – Yes
	Delayed Hazard – Yes
	Fire Hazard – Yes
	Pressure Hazard – Yes
	Reactivity Hazard – Yes

SARA 302 Extremely hazardous substance

Chemical Name	CAS Number	Reportable Quantity	Threshold Planning Quantity	Threshold Planning Quantity – Lower value	Threshold Planning Quantity – upper value
Sulfuric Acid	7664-93-9	1000	1000 lbs.		

SARA 311/312 Hazard Categorization:

EPCRA Section 312 Tier Two reporting is required for non-automotive 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 40 CFR 370.40

SARA 313 EPCRA Toxic Substances:

40 CFR section 372.38 (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 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.

SARA 313 (TRI Reporting)

Chemical Name	CAS Number	% by weight
Lead	7439-92-1	63 - 91
Sulfuric Acid	7664-93-9	17 - 25

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Lead (CAS 7439-92-1)

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Sulfuric Acid (CAS 7664-93-9)

Safe Drinking Water Act (SDWA)

Not regulated

Drug Enforcement Administration (DEA). List 2, Essential Chemicals (21 CFR 1310.02(b) and 1310.04(f)(2) and Chemical Code Number

Sulfuric acid (CAS 7664-93-9) 6552

Drug Enforcement Administration (DEA). List 1 & 2 Exempt Chemical Mixtures (21 CFR 1310.12(c))

Sulfuric acid (CAS 7664-93-9) 20 % WV

DEA Exempt Chemical Mixtures Code Number

Sulfuric acid (CAS 7664-93-9 6552

Figure A.2 cont.: Optima Battery Safety Data Sheet (8 of 10)

US State Regulations
US. Massachusetts RTK – Substance List
Lead (CAS 7439-92-1)
Sulfuric Acid (CAS 7664-93-9)
US New Jersey Worker and Community Right-to-know Act
Lead (CAS 7439-92-1)
Sulfuric acid (CAS 7664-93-9)
Separator/Paster Paper Fibrous Glass (CAS 65997-17-3)
US Pennsylvania Worker and Community Right-to-know Law
Lead (CAS 7439-92-1)
Sulfuric acid (CAS 7664-93-9)
US Rhode Island RTK
Lead (CAS 7439-92-1)
Sulfuric acid (CAS 7664-93-9)
US. California Proposition 65
WARNING: This product contains chemicals known to the State of California to cause cancer.
Battery posts, terminals and related accessories contain lead and lead compounds, chemicals known to the state of California to cause cancer and reproductive harm. Wash hands after handling.

*Battery companies not party to the 1999 consent judgment with Mateel Environmental Justice Foundation should include a Proposition 65 Warning that complies with the current version of Proposition 65.
US - California Proposition 65 - Carcinogens & Reproductive Toxicity (CRT): Listed substance
Lead (CAS 7439-92-1)
Sulfuric acid (CAS 7664-93-9)
International Inventories

Country(s) or Region	Inventory Name	On inventory (yes/no)*
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

* A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s).
A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

16. OTHER INFORMATION

Issue Date: 04/01/2015
Further information: NFPA Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3=Serious 4 = Severe
NFPA ratings

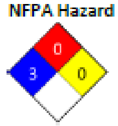

Figure A.2 cont.: Optima Battery Safety Data Sheet (9 of 10)

US Military National Stock Number (NSN)

Model Number	P/N	NSN
34/78	8004-003	6140-01-374-2243
34	8002-002	6140-01-378-8232
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	
D34	8012-021	6140-01-450-0141
D34/78	8014-045	6140-01-441-4272
D27F	8037-127	6140-01-600-5785
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

Johnson Controls Battery Group, Inc. cannot anticipate all conditions under which this information and its product, or the products of other manufacturers in combination with its product, may be used. It is the user's responsibility to ensure safe conditions for handling, storage and disposal of the product, and to assume liability for loss, injury, damage or expense due to improper use. The information in the sheet was written based on the best knowledge and experience currently available.

Figure A.2 cont.: Optima Battery Safety Data Sheet (10 of 10)

Appendix B: Flotation calculations

Table B1: Buoyancy calculation values

System	Volume [in^3]	Buoyant force [lb]
Hull	2351.8	84.9
Foam (front + cargo)	2974.2+ 7688.9 = 10663.1	107.4+277.56 = 384.9
Propulsion	279.6	10.09
Batteries	1099.1	39.7
Total	**14363.6**	**519.63**

$$\gamma_{Water} = \text{specific weight of water} = 0.0361\ lb/in^3$$
$$F_b = V_{Total} \times \gamma_{Water}$$
$$= 14363.6\ in^3 \times 0.0361\ lb/ft^3$$
$$= \mathbf{519.63\ lb}$$

$$W = \text{Total weight} \times 1.2$$
$$= 354.09 * 1.2$$
$$= \mathbf{424.9\ lbs}$$

Findings: The final flotation calculated was 519.63 lbs. The cargo bay foam we added is a great improvement to aid in buoyancy. We will be above the limit by 94.73 lbs and do not require any air bags.

Appendix C: Proof of insurance

Page 1 of 1

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 10/02/2018

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 Reciprocal Ri	10020
INSURER B :	
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

INSURED
Carnegie Mellon University
Attn: Insurance Services Dept
Diane Patterson - Warner Hall #400D
5000 Forbes Avenue
Pittsburgh, PA 15213

COVERAGES **CERTIFICATE NUMBER:** W8310220 **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:			G09-40R	10/01/2018	10/01/2019	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/MEMBEREXCLUDED? (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)

Appendix D: Team Roster

Included in Table D.1 and D.2 below are all the team members, their majors, year, and team role, as well as the team advisors.

Table D.1: Team Member Roster

Name	***Degree Program***	***Year***	***Team Role***
Basit, Fatima	*Mechanical Engineering*	*Sophomore*	*Hull Fabrication Lead*
Byun, Hojun	*Electrical and Computer Engineering*	*Sophomore*	*Hull and Power Member*
Chan, Jesse	*Electrical and Computer Engineering*	*Sophomore*	*Power Member*
Chou, Theodore	*Mechanical Engineering*	*Senior*	*Vice President of Finance*
Chua, Sabrina	*Mechanical Engineering*	*Freshman*	*Hull and Propulsion Member*
Kamath, Seema	*Mechanical Engineering*	*Sophomore*	*Hull Member*
Kleinman, David	*Mechanical Engineering*	*Sophomore*	*Power Lead*
Kovacs, Benjamin	*Physics*	*Freshman*	*Optimization Member*
Lamprinakos, Nicholas	*Material Science and Engineering/Biomedical Engineering*	*Senior*	*Hull Member*
Lance, Jack	*Mechanical Engineering/Robotics*	*Senior*	*Propulsion Member*
Lauer, Casey	*Mechanical Engineering*	*Sophomore*	*Hull Member*
Legelis, John	*Mechanical Engineering*	*Sophomore*	*Hull Member*
Long, Madelynne	*Mechanical Engineering*	*Senior*	*Hull Member*
Masciopinto, Zack	*Mechanical Engineering*	*Senior*	*Vice President of Member Development and Hull Member*

Moyer, Grayson	*Electrical and Computer Engineering*	*Freshman*	*Optimization Member*
Napier, Jaiden	*Mechanical Engineering*	*Sophomore*	*Hull Member*
Neimark, Gabriel	*Mechanical Engineering/Engineering and Public Policy*	*Freshman*	*Hull Member*
Nie, Katherine	*Mechanical Engineering*	*Freshman*	*Propulsion Member*
Oke, David	*Mechanical Engineering*	*Junior*	*Secretary and Propulsion Lead*
Quinones, Cesar	*Mechanical Engineering*	*Senior*	*Head of Design*
Shah, Tanvi	*Mechanical Engineering*	*Junior*	*Propulsion Member*
Sharma, Dhruv	*Mechanical Engineering*	*Sophomore*	*Propulsion Member*
Shek, Alvin	*Electrical and Computer Engineering*	*Sophomore*	*Optimization Lead*
Shim, Stuart	*Mechanical Engineering*	*Freshman*	*Vice President of Public Relations*
Sung, Hyun Jee (Chloe)	*Mechanical Engineering/Biomedical Engineering*	*Freshman*	*Hull Member*
Tasogolu, Muzaffer Cuneyd	*Mechanical Engineering*	*Freshman*	*Propulsion Member*
Torczon, Owen	*Mechanical Engineering*	*Sophomore*	*Hull Design Lead*
Wang, Xinyu	*Mechanical Engineering*	*Freshman*	*Vice President of Programming*

Xiao, Raymond	*Mechanical Engineering*	*Freshman*	*Propulsion Member*
Zhang, James	*Mechanical Engineering/Engineering Public Policy*	*Senior*	*President*

Table D.2: Team Advisors

Name	***College/Institution Affiliation***	***Title***	***Role***
Dr. Kurt Larsen	*Carnegie Institute of Technology (CIT)*	*Assistant Dean for Undergraduate Studies*	*Faculty Advisor*
Shae Sealey	*Thyssenkrupp*	*Project Lead*	*Alumni Advisor*
John Antanitis	*IDeATE*	*Technical Assistant*	*Fabrication Advisor*

Appendix E: Email confirming solar panel output from correspondent with solar panel company

Hi James - The 393 watts <u>were</u> the result of the flash test on the four panels. This is @ 3.07 watts per cell. 26 more cells yields @ 80 watts, so hence the projected 473 watt total.
Best, Tom