Carnegie Mellon
SOLAR RACING

Boat #7

Technical Report

May 4 2021

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I. Executive Summary

Carnegie Mellon Solar Racing's (CMSR) goals for Solar Splash 2021 was to reconfigure our past competition hull (Vortex) to a feasibly manageable state given the covid restrictions from the past year. By winding down our competition boat to the essentials we are able to participate in Solar Splash 2021 despite our school's 12 month restriction on in-person activities.
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 implemented new data acquisition systems as well as new solar panel mount holders. CMSR has also begun building a new boat hull after an extensive year long design and fabrication research process. The new hull design is an iteration on Vortex and will be better suited for slalom.

CMSR has successfully pivoted to virtual meetings in order to follow social distancing guidelines. By doing so, CMSR was able to recruit and retain off-campus members with extensive design projects for next year's boat.

CMSR has seen a large amount of support from Carnegie Mellon University and its various corporate sponsors. Large scale renovations to our shop space have doubled our square footage and given subteams the resources they need to complete their projects. 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.

CMSR has a total of 19 members, largely focused in engineering disciplines (mechanical, electrical, etc). While Covid-19 took away a lot of our in-person work, the remote work we were able to accomplish will contribute greatly to our SS22 boat.

II. Table of Contents

III. Overall Project Objectives

Carnegie Mellon Solar Racing will compete in Solar Splash this summer for the fourth consecutive year. The subteam goals were as follows:

> Hull: Stringer and subsystems mounting designs for future boat, redesign of current solar panel mounts
>
> Power: Implement new charge controllers optimized for the hull and propulsion system.
>
> Optimization: Implement data acquisition systems for battery state of charge, temperature, boat acceleration and velocity, and motor speed
>
> Propulsion: Design adapter plate for future propulsion system, implement Torqeedo propulsion system for Vortex

The main objective for the organization as a whole was to have a competition-ready boat. Previous goals had to be pushed off due to Carnegie Mellon's restriction on in person activities from March 2020 to March 2021. With our limited time, we made member retainment and education our main goal. Members who had never even seen Vortex yet were given a crash course on everything related to maintaining their respective subteam as soon as COVID protocols allowed. Subteam funds were reallocated to better subsidize competition costs and encourage attendance.

The last time CMSR competed, Solar Splash 2019, we suffered a great malfunction with our in-house propulsion system. This caused us to lose valuable performance data and feedback because we had to sit out a number of events. This, combined with the cancellation of last year's competition, has made it even more imperative that this year runs smoothly. We can ensure so by pushing off new subsystem designs to next year and reusing many old subsystem designs.

IV. Power Electronics System

A. Current Design

Our current design has the following setup.

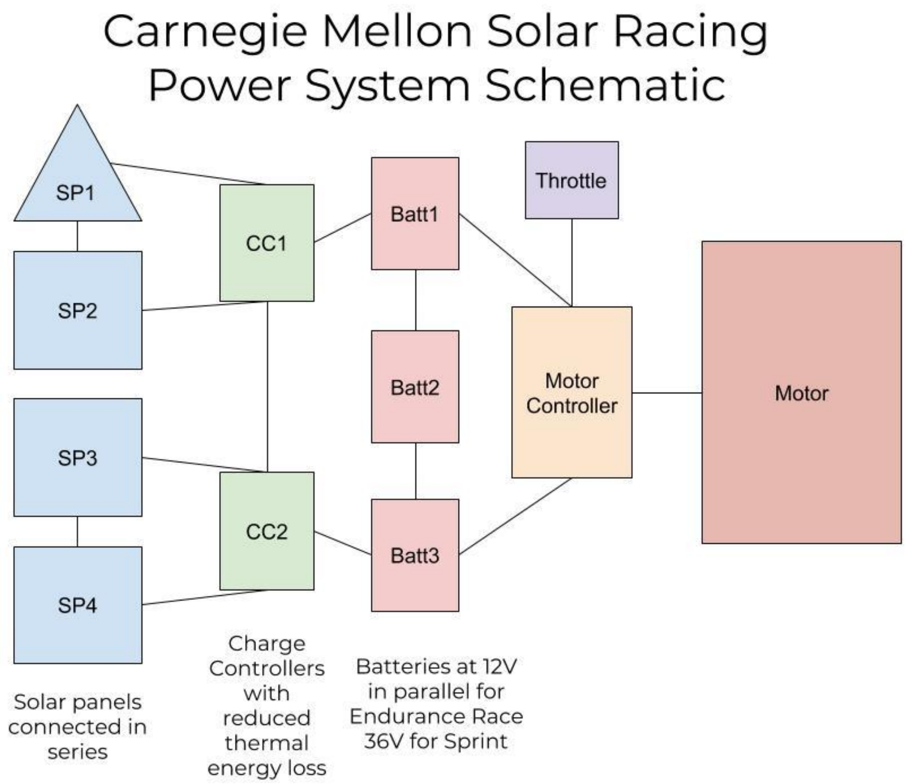


Figure 1: Power System Schematic

The primary issues with this design were unideal components and a lack of data to inform new purchases. Thus, our goal was to maximize the efficiency of our current circuit design and to integrate new data acquisition systems. This way, when we redesign the power circuit, we can make informed decisions.

B. Analysis of Design Concepts

1) *Motor:* Our current motor, purchased in a previous season, is a Torqeedo Cruise 2.0 RS. This motor had a low top speed, causing us to be non-competitive for the sprint competition. Because of this, we purchased a new motor that would have been better suited to our boat; however, because of delays caused by COVID-19, we were unable to finish the design of the new propulsion system. Thus, we have decided to stick with the current Torqeedo motor. The Torqeedo motor performance analysis is thoroughly described in the Hull section of the technical report.
2) *Motor Controller:* The Torqeedo motor has an onboard controller built-in, so no extra weight is required for a motor controller in the current iteration of the boat. Because our new motor does not have an onboard computer, we also purchased an Alltrax SR model motor controller so that the steering system could interface with the motor.
3) *Wire Gauge:* Our old system used 4 gauge and 2 gauge wires throughout the system. However, these were clearly poor choices due to low ampacity. Thus, we decided to

increase our gauge to 2/0. This will allow us to minimize the resistive losses of the wires for our boat during the sprint event. One drawback is increased weight, so components which do not conduct high current will continue to use lower gauge wires.

4) *Throttle:* Our throttle from the previous year had the drawback where the driver had to hold down the throttle's handle in order to provide power to the motor. For long stretches of time, such as in the endurance section, constantly holding down the throttle got exhausting. Because of this, we implemented a new throttle for this season that does not have this problem. Furthermore, this new throttle has safety features, such as the ability to stop the motor in the event that the driver falls overboard.

C. Design Evaluation

Much of our progress on updating the components of the power electronics system was halted by COVID-19. Because of this, there are many problems with this current system. Our main focus for the power electronics system of the current iteration is to ensure functionality over optimality. Next season, we hope to improve the components and thus performance of the power electronic systems. Furthermore, we want to integrate more data acquisition components into the electrical system to better understand where losses occur.

V. Solar System Design

A. Current Solar System Design
The CMSR solar system consists of 5 solar panels connected in series. four of the panels are located at the back of the hull, while the fifth is placed at the front.

B. Analysis of Design Concepts
During the 2018-2019 school season, the CMSR team purchased Solbian solar panels from Ocean Planet Energy using SunPower monocrystalline cells with 24% efficiency and 3.07 watts each. The back 4 panels are stock SP103 panels. The front panel was custom designed by the CMSR team at the time, and sent to Solbian for final adjustments. This was done so that the panel could fit the contours of the boat, minimizing the panels' effect on drag. The total power from the panels (flash tested by Solbian) had a nominal output of 473W. 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 HDPE. The final weight is about 29 lbs., with marked improvements in power.

C. Design Evaluation
Our new hull design (which we were not able to finish due to delays caused by COVID-19, such as university and shop space closure) does not mesh well with our current solar panel setup, so new solar panels are being designed to accurately mesh with the new hull. The new solar panels are being selected to improve power output beyond 473W, in addition to maximizing the flexibility of the panels to create more aerodynamic curvature across the boat.

VI. Electrical System Design

A. Current Electrical System Design

The CMSR electrical system utilizes three batteries and a charge controller. The batteries are charged via the charge controller by the Solar System. The batteries then provide power to our Power Electronics system.

B. Analysis of Design Concepts

1) *Batteries:* Our batteries have a parallel configuration for the endurance event and a series configuration for the sprint event. For the sprint event, we want to maximize the power to the motor system; putting the batteries in series allows for a 36V source to power the boat. Furthermore, in the endurance event, we want to maximize the battery life so we place the batteries in parallel. This way, we can maximize the efficacy of our batteries based on the event.
2) *Charge Controllers:* Our previous charge controllers (Genasun GVB-8 350W) were not performing up to their peak efficiency. Because of this, we decided to purchase the Victron SmartSolar 150/35 MPPT charge controller, with a rated peak of >98%. Victron is the industry leader in charge controllers, and the new charge controller comes with advanced features such as Bluetooth/LoRa monitoring of battery voltage and temperature, and an advanced MPPT algorithm that takes into account external factors such as partial shading of the solar panels. Furthermore, this controller uses convection cooling so no extra power is required to cool the controller.

Figure 2: Victron SmartSolar 150/35 Charge Controller

3) *Data Acquisition Integration:* This electrical system is also heavily integrated with new data acquisition technology that we have developed. In particular, we have developed a battery monitoring system designed to give consistent and accurate reports regarding the current charge level of the battery, the power consumed by the power electronics system, and the power generated by the solar system.

C. Design Evaluation

Our batteries provide a good balance of power output. reliability, and capacity. Future designs will likely focus on new topologies to maximize power output for the sprint section. In addition, more data acquisition systems will be implemented to determine inefficiencies in components.

4) Hull Design

A. Current Hull System Design

Like many other areas of CMSR, progress on the hull was impeded heavily by the COVID-19 pandemic and restrictions. In the Fall semester of 2019, we started construction on our fifth hull, which we planned to have ready for the 2021 Solar Splash competition. However, from March 2020 to March 2021, CMU prohibited in-person activities, not leaving enough time to finish construction on the new hull. Thus, the team decided to reuse the hull from the 2017, 2018, and 2019 competitions again for the 2021 competition. With the little time for construction this year, the team chose to remake the supports for our solar panels to make them easier to attach and remove.

The boat hull, which was not changed, is constructed from carbon fiber with a Nomex honeycomb core. It is 17 feet long, 4 feet at its widest, and weighs 88 pounds.

The previous design for the solar panel holders used metal C-channels as a path for solar panels. The solar panels are attached to a plastic backing for structure. Each of the C-channels was connected to the hull with an L-bracket with a single hex screw and nut. After sliding them in, the solar panels were fixed in-place by attaching a nut on the screw above and below the solar panel.

It was found that it was very hard to insert and remove the solar panels for charging in this design, particularly because of the two nuts above and below the panel. The solar panel holders themselves were also unstable because there was only one point of connection between the hull and the L-bracket. The team wanted to figure out a way to solve both of these issues while keeping the weight low and system easy to attach.

B. Analysis of Design Concepts

The new design simplified and shifted elements from the old design. We replaced the metal channels with flat metal strips to reduce weight. The screws are fixed in place on the bottom of the metal strip using epoxy resin and the solar panels are dropped in place on top of them before being secured with the nuts. Additionally, we widened the L-brackets so we could screw them into the hull at two places, so the brackets do not rotate during operation.

This design not only reduces the weight by replacing the channel with a strip, it also makes it much easier for ingress and egress of the solar panels. The downsides are that the edges of the solar panels are no longer shielded by the c-channel and the solar panels are fixed in place and cannot avoid vibrations from the boat.

Because we still have the plastic backing to protect the solar panels and keep a buffer for contact, we decided to go with our new design in light of other improvements it will offer.

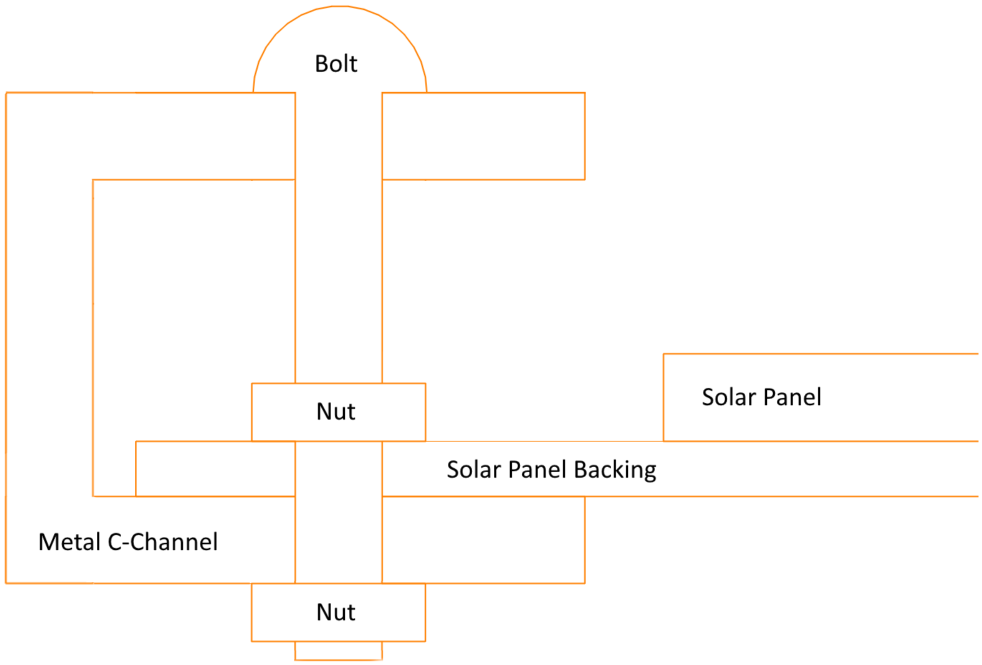


Figure 3 : Cross-sectional view of the old design of the solar panel holders. L-brackets are attached to the C-channel and hull at the ends, with one nut and bolt to the C-Channel and one to the hull.

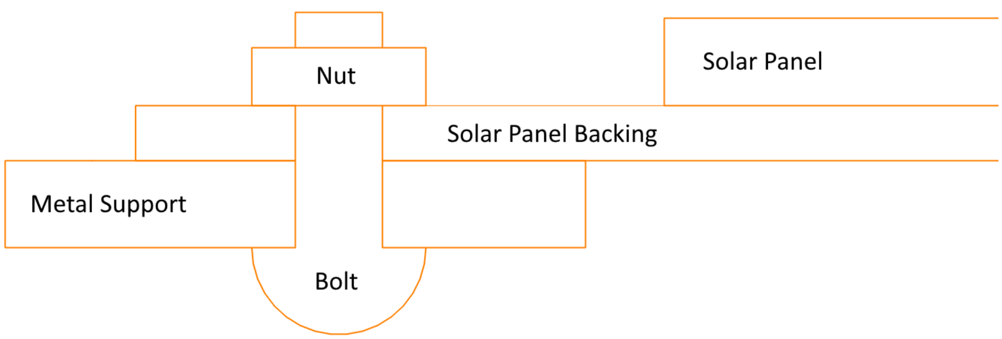


Figure 4: Cross-sectional view of the new design of the solar panel holders. L-brackets are attached to the support and hull at the ends of the support, with one nut and bolt to the C-Channel and two of each attached to the hull. Bolt is fixed with epoxy to the support, so it remains after the solar panels are removed.

C. Hull Design Testing

First, the new connection to the hull was tested by creating the wider L-brackets and attaching them to the old C-channel system. There was much less rotation possible with two attachment points to the hull. The new system was added, and then tested by attaching and detaching the solar panels. It was observed that the solar panels were consistently easy to remove or reattach.

For the main hull, because it has performed well in the past, we expect it to also perform well in the upcoming competition. We were not able to run any major tests this year.

VII. Drivetrain and Steering

A. Current Design

CMSR is using a Torqeedo Cruise 2.0 RS for the propulsion system and a Seastar SS137 20' Safe-T Quick Connect for the steering system, both shown in Fig. 5. The system can output up to 6 HP of thrust with a maximum efficiency of 56%. It only weighs 15.3kg which minimizes the overall weight of the boat, consuming less power. The steering cable connects 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 and therefore turning the boat.

Figure 5 : The Torqeedo propulsion system and Seastar steering system

In 2019, we used the same steering system, however we used a propulsion system that was made in-house. Problems arose from this propulsion system during the 2019 competition including gear grinding and propellor shaft bending due to its thin diameter. These problems arose due to the absence of on-water testing as well as lack of in-depth force analysis. Due to these issues, we decided to redesign our propulsion system in the beginning of the 2020 academic year in hopes to use it in the 2020 Solar Splash. This was delayed due to COVID, and currently we are still in the design phase of this new propulsion system. However, we don't want to miss out on competition due to this, so we decided to use the Torqeedo propulsion system as a temporary replacement for the 2021 competition.

B. Analysis of Design Concepts

The torqeedo works well in endurance races, however it is not competitive in sprint or slalom races because it doesn't output enough thrust. We are currently designing a new propulsion system that contains a retrofitted propeller system and a motor housing with interchangeable gear ratios that will be manufactured in-house. The interchangeable gear system will allow the motor to be geared up or down depending on testing results. As an example of the work we have been doing this year, Table 1 shows our analysis of different types of drivetrains for our new propulsion system.

Table 1: Drivetrain Analysis

Criteria	**Weight**	**Belt Drive**	**Bevel Gear**	**Retro-fit**
Hydroefficiency	5	3	3	5
Constraints	3	4	1	5
Fabrication	3	3	3	5
Manufacturing complexity/time	4	1	3	3
Manufacturing cost	3	3	2	1
Assembly/disassembly	4	3	1	2
Iteration/modification	3	3	3	2
Efficiency	5	3	4	5
Reliability	4	3	3	5
Design time	4	1	4	4
Total points		**101**	**106**	**145**

From this analysis, the retrofit design comes out the highest, so we are currently designing a propulsion system around a retrofitted lower unit that we purchased in 2020. We hope to use this system next year and provide more information about our design and testing evaluations then.

C. Design Testing and Evaluation

We used the same Torqeedo and the Seastar systems in our 2018 competition, and it worked reliably. We did a dry run in our shop prior to this year's competition, but most of our time was devoted to designing and CAD-ing our new propulsion system for 2022 competition.

VIII. Data Acquisition and Communication

A. Current Design:

To inform an optimal strategy during competition, both the driver and the rest of the team need live updates on the status of the boat. This includes information such as battery state of charge, temperature of the electrical system, acceleration and velocity of the boat, and speed of the motor. With this data, we can potentially optimize the use of the motor for either endurance or speed races, and we can prevent critical conditions on the boat such as the system overheating.

In recent years, our team has mostly been focused on methods to consistently monitor the state of the batteries in the power system. Additionally, some side projects have included incorporating more advanced sensors such as cameras to track the location of other boats, and a tilting solar panel mount to point the panels more directly at the sun. While exciting, these were slightly more ambitious projects that ultimately did not see much success. This year, we have focused our efforts on the battery monitoring system as our main priority. We have nearly finished implementing this system, and soon we will begin testing it out to determine its effectiveness.

B. Analysis of Design Concepts

1) Battery State of Charge:

There are several ways to go about monitoring a battery's state of charge. In the past, we have considered using a circuit to measure the voltage across the battery's terminals as a direct indication of the amount of charge left, but this method can be difficult because of the non-linear voltage-to-charge models. Another method is to use what is called "coulomb counting", which integrates measurements of current flowing out of the batteries over time to calculate total charge consumed:

$$Q(t^*) = \int_0^{t^*} I\,dt$$

The benefit of this method is that it gives us a direct value related to the amount of charge left in the batteries. If the batteries start with some initial charge amount, Q_{init} , then we can derive the amount of charge left in the batteries at time t^* as:

$$Q_{remaing}(t^*) = Q_{init} - Q(t^*) = Q_{init} - \int_0^{t^*} I\,dt$$

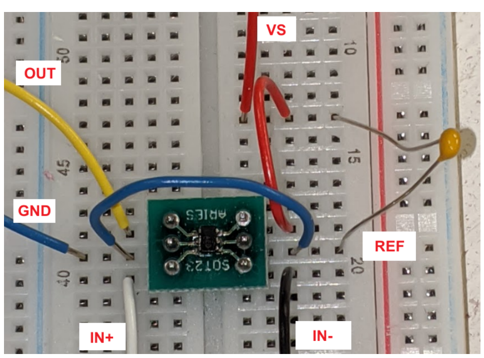
While this seems like a fairly straightforward concept, implementing coulomb counting still requires a method of measuring the current flowing out of the batteries, as well as a way to integrate the current readings over time. Since our system ultimately will be processing the current measurements digitally, we will have to use a discretized approximation for the integral:

$$Q[t^*] = I\Delta t + Q[t^*-1]$$

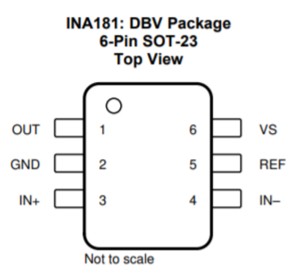
In the above formula, Δt is the difference in time between two consecutive measurements. This "running sum" is essentially a Riemann sum. While the above equation demonstrates the general purpose, we actually use a trapezoidal rule version of the Riemann sum to get more accurate approximations of the integral.

We still have not addressed the issue of actually measuring the current flowing out of our batteries. In previous years, our team used a Hall Effect sensor fitted around the cable leaving the positive terminal of the batteries. In theory, this solution should be viable, but our team experienced many issues with this type of sensor. The sensor data would fluctuate as the cable moved inside the sensor, and it was difficult to find a sensor that had reliable documentation. This year, we decided to introduce shunt resistors into our power circuit as an alternate means for measuring current. These are essentially plates of metal with a precisely calibrated resistance. Specifically, we are using shunts that register a 75mV drop across their terminals when a 250A current is flowing through them. Then, even though we are trying to measure current, we ultimately are using the voltage differential across the shunt to do so (using Ohm's Law, we can calculate the current as I = V / R). While splicing a shunt resistor into the main power circuit will dissipate power, the amount dissipated is relatively minimal since the shunts are highly conductive.

To measure the voltage drop across the shunt resistor, we need an amplifier circuit to get the voltages on a more appropriate scale. Specifically, we mounted an INA181 current sense amplifier onto a commercially available breakout board and constructed a basic circuit using the recommended components to produce a gain of 50 V/V.



a.)



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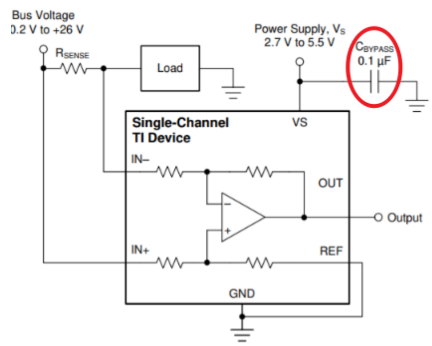


c.)

Figure 6 : Current Sense Amplification Circuit. a) Our Construction, b) The IC, c) Circuit Diagram

Then, this signal should be approximately in the range of 0-5V. The output of the amplifier goes to an Analog to Digital Converter (ADS1115), which then communicates over I2C to a Raspberry Pi. In previous years, we used an Arduino Uno for data processing which then communicated to an Android Tablet mounted on the driver's dashboard. This system was very difficult to work with since the arduino was running independent from the tablet, meaning we had to program a separate Android App for the user interface. This year, we are leveraging the Raspberry Pi's graphical desktop capabilities to display the user interface on an LCD screen connected via HDMI. This new system is much simpler because it is centralized (everything runs on the Raspberry Pi). We run Python scripts to read the values over I2C, and calculate the battery state of charge using the discretized coulomb counting method discussed above. Finally, we leverage the Plotly Dash library to generate a simple user interface such as the one shown below.

CMSR Driver Dashboard

BSoC reading: 46.72 %

BSoC Live Graph (%)

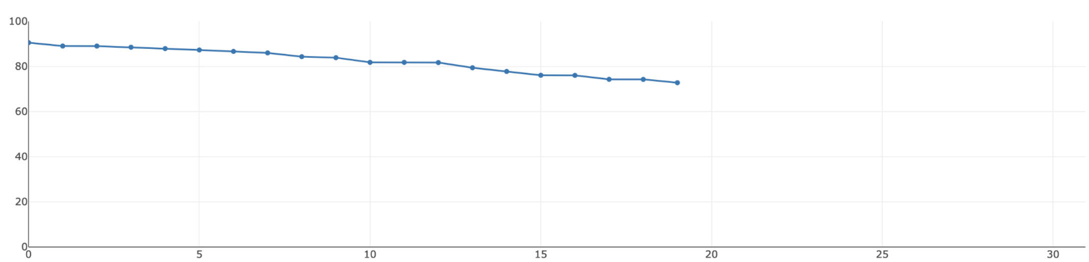


Figure 7 : Driver's Dashboard Display Example

2) Temperature:
By adding thermistors or other temperature probes throughout the boat's electrical system (especially near the batteries), we could ensure that nothing on the boat is getting dangerously hot. In the case of a dangerous thermal condition, we could alert the driver via the LCD display.

3) Acceleration and Localization:
Our boat's position can be determined with a simple GPS module (MTK3339 Chipset). Additionally, accelerometers or IMU devices such as Adafruit's BNO055, would provide our team with information about the boat's acceleration, orientation, and velocity. Ideally, we could combine testing data on the boat's acceleration and velocity to further inform the optimal use of the main motor during a race. This will likely not be employed until a future year.

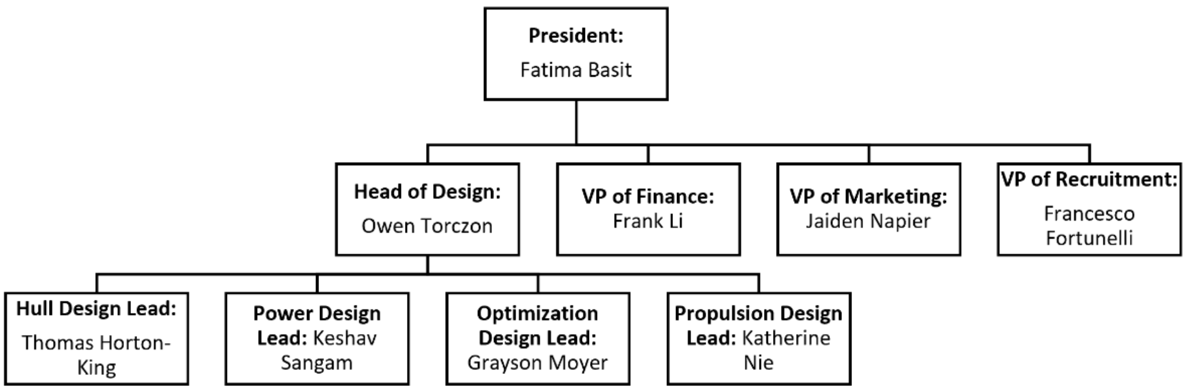
4) Long-distance Communication:
We will be using RFM96W LoRa Radio modules to transmit sensor data from the on-board Raspberry Pi back to another Raspberry Pi on land. Overall, this radio module will give our on-shore team constant updates on the status of our boat.

C. Design Testing and Evaluation
As mentioned, we still need to do more testing of this battery monitoring system. Once the system is fully integrated into the power system, we can run tests to determine the actual total amount of charge in our batteries after they have been fully charged. Then, we should be able to provide fairly accurate measurements of the amount of charge remaining (with some tuning of course). After this, we will move on to other potential projects such as monitoring temperature readings of the electrical system, and establishing communication between the boat and the rest of the team on land (to send data such as the current battery level, boat velocity, etc.). As we add to our system, we will be updating the driver's user interface to include any new helpful data.

IX. Project Management

A. Team Members and Leadership Roles
Carnegie Mellon Solar Racing is a student organization made up of entirely undergraduate students across CMU's School of Computer Science, College of Engineering, School of Business, and Robotics Institute. The organization is split into four major sub-teams: optimization, power, hull, and propulsion, each with its own design lead(s). The sub-teams are managed by the Head of Design, who offers a system wide perspective to the development of new products. Supporting the technical side of the club is our executive committee that handles

the administrative side of running a student organization. Executive committee positions include VP of Finance, VP of Recruiting, and VP of Marketing. Overseeing both the administrative and technical part of the organization is the president. See the following figure for a visualization of these positions and who currently holds them.



B.   Project Planning and Schedule

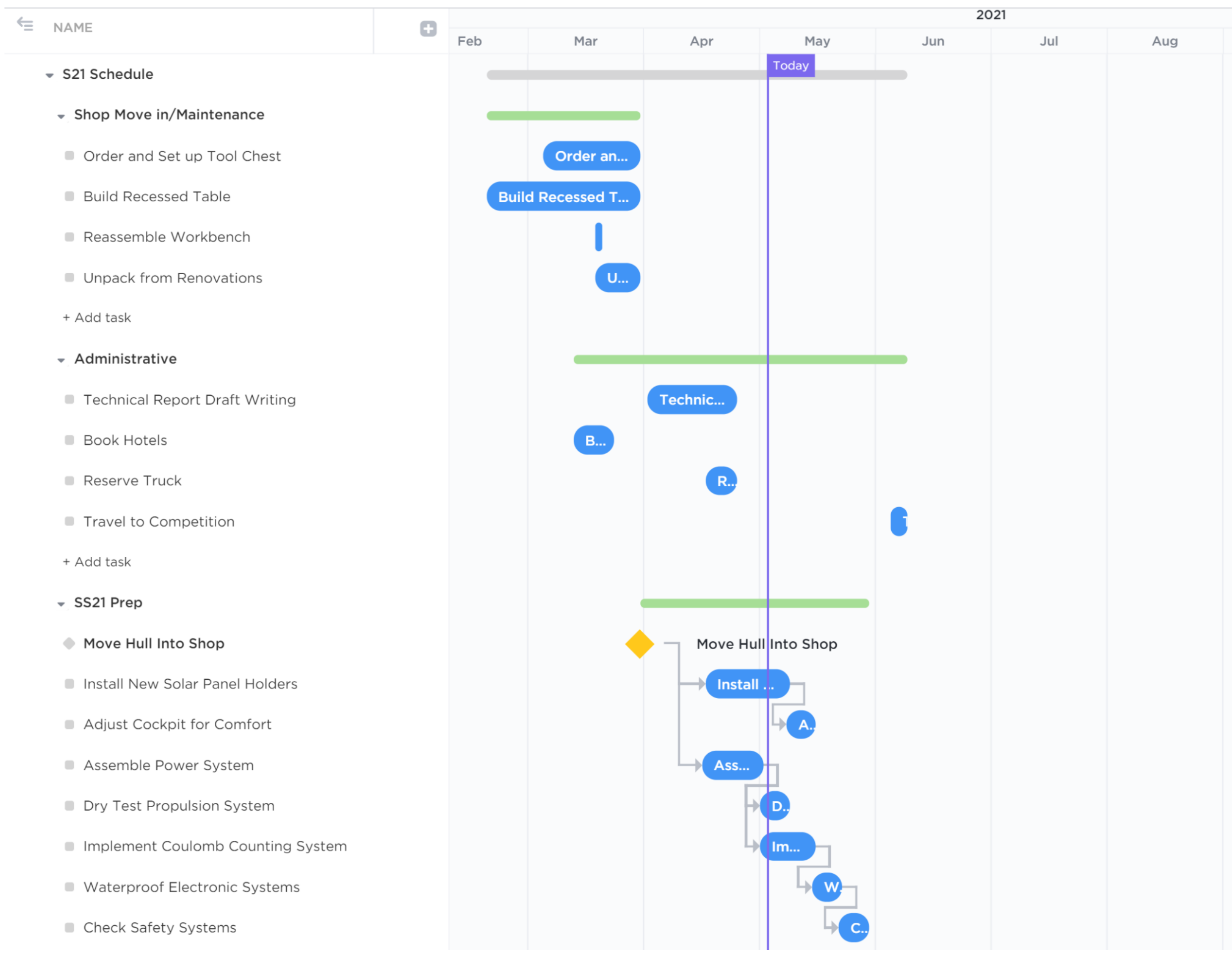
The COVID-19 pandemic created a number of unique project management challenges. From March of 2020 to March of 2021 we were entirely unable to access any of our work or storage spaces. Changes in course schedules and the virtual nature of classes meant some students took semesters off. There was constant uncertainty of when and where we would be able to resume work; so, we made contingency plans.

With the fall semester seemingly destined to be virtual, we pivoted all of our work to more research based tasks we could complete remotely. Virtually leading projects turned out to be a huge challenge. A huge draw of CMSR is it provides opportunities for students to get hands-on experience. Recruiting new members and keeping existing members engaged all via Zoom was riddled with issues. Teaching new members CAD or work shopping ideas becomes infinitely harder when you can’t stand around the same computer to discuss.

Despite the slog that was the fall semester, there were a few positives to come out of it. All the time spent researching and planning gave us an opportunity to more deeply develop our design process. For example, we began implementing a formalized design review process to provide system wide feedback on subteam projects. The design reviews have also become an opportunity for experienced members to contribute their knowledge to a wider range of projects.

With the new design review process, our sub-teams began shifting from our traditionally waterfall style project planning to a more iterative and agile workflow. Every few weeks sub teams would present on their current design, receive feedback via the design review, and then iterate on their design. The result has been designs that are more robust and easier to implement.

Upon regaining access to our shop in the spring, our focus shifted to moving into our newly renovated space and preparing last year's boat for competition. We built out the following schedule to ensure the boat is ready for Solar Splash 2021.



C. Financial and Fund-Raising

Carnegie Mellon Solar Racing receives its funding through Carnegie Mellon's Joint Funding Council (JFC) and sponsorship. JFC is the part of the student government responsible for allocating money to student organizations. To receive money from JFC, Carnegie Mellon Solar Racing submits an itemized budget every year. For 2020-2021 we received $13,002.55 from JFC.

Outside of JFC we receive $2,500 from both Ford and GM. We also receive subsidies from suppliers including Ray EO and OceanPlanet Energy. CMSR did not do any other types of fund-raising in the past year.

D. Strategy for Team Continuity and Sustainability

Over the past few years one of the biggest challenges CMSR faces is recruiting new members. Not only are CMU students incredibly busy academically, but they also have a number of different options of engineering project organizations to join. We address the competitive nature of recruitment at CMU by promoting the club across a number of platforms and fostering a unique community within the organization.

Within the past year promotion of CMSR has manifested itself in more virtual means. We hosted Zoom recruitment events surrounding the fall and spring virtual activities fair like Among Us and Skriblio games, informational sessions, and professional development opportunities with corporate sponsors. We also virtually presented in a number of introductory level engineering courses across all majors in the College of Engineering.

Once we capture students' interest, we look to differentiate our group's experience by building a community that is more inclusive and nurturing than other technical organizations on campus. For example, we do not have dues we expect new members to pay, and we work diligently to help all students, regardless of previous knowledge, make a meaningful contribution to the project. Our design reviews are also built to feel more like discussions and opportunities for knowledge transfer between members than harsh critiques. Our goal is to focus more on helping students learn and grow than achieving total technical superiority.

E. Discussion and Self-Evaluation

Over the past few years our efforts to grow CMSR's community have helped the club gain a more committed member base. For the first time in the past four years our two largest leadership roles, President and Head of Design, were both contested elections. While we still have issues keeping all our leadership positions filled, our member numbers and their passion for the organization seems to be headed in the right direction.

As we look forward to future semesters and aim to improve our organization further, a big area for potential growth is our documentation. Too often do graduating seniors leave the organization with stories of their experiences instead of written references for how to improve on them. Things as simple as who our corporate sponsor contacts are frequently lost in transition. Rough timelines of when to begin planning recruitment events or builds could be incredibly valuable if our leadership more consistently found the time to write up their actions. Building strong institutional and communal ties are important, but we cannot become over reliant on these structures to support our continued growth

X. Conclusion and Recommendations

A. Strengths and Weaknesses

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

- GPS/Acceleration Tracking: The optimization and power teams have implemented sensors for tracking boat speed and position.
- 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. The hull build had started but is paused due to covid and will resume after Solar Splash 2021.
- Virtual meetings: All four sub teams were able to successfully pivot to virtual meetings and remain productive

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

- Inability to fully test the system on the water: The team was not able to do any on-water testing this year due to travel constraints.
- Shop Restriction: Due to CMU's 12 month ban on in-person activities, sub-teams had to greatly simplify their subsystems to meet the time constraints.

B. Meeting Sub-System Objectives

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

- Hull: Continue subsystems design for new hull, improve on solar panel holders for vortex, add new sponsor logos
- Propulsion: Design new motor adaptor for future propulsion system retrofit
- 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 2020 competition.

C. Reflections on Design Process

This year we were forced to make the design process more collaborative over virtual meetings. Subteams have greatly improved in their ability to split up design tasks among members and have adopted the habit of regular design reviews. The optimization team even went as far to deliver individual raspberry pi kits to remote members.

D. Where do we go from here?

The team will focus on recruiting new members for Solar Splash 2022. By then, we hope to have an entirely new hull made in-house as well as a new propulsion system. Furthermore, the team will begin to invest heavily in on-water testing and incorporate more expansive and accurate data acquisition systems.

E. Lessons Learned

The largest lesson learned is that the team needs to focus its resources on member recruitment. With the tight timeline we were given, having a sufficient number of members was the bottleneck in our productivity. We hope that as covid restrictions open up, we can better recruit members with a larger variety of activities. The team has major subsystem redesigns such as the new boat hull and reworked fabrication process as well as the new propulsion systems. In the future we hope to better document subteams processes to retain member knowledge and facilitate smooth yearly transitions.

XI. References and 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:

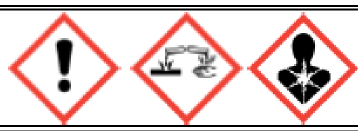
Health	Environmental	Physical
		
Hazard Statements **DANGER!** Causes severe skin burns and eye damage. Causes serious eye damage. May damage fertility or the unborn child if ingested or inhaled. May cause cancer if ingested or inhaled. Causes damage to central nervous system, blood and kidneys through prolonged or repeated exposure.	***Precautionary Statements*** 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.	

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	CO2; 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

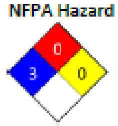


Figure A.2 cont.: Optima Battery Safety Data Sheet (9 of 10)

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/Containers	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: Solidworks modeling was used to find the volume estimates for each of the systems, while the total weight of the boat was found by weighing the boat. The final flotation calculated was 519.63 pounds, with most of the buoyancy coming from the foam bulkhead. The boat will be comfortably above the limit by 94.73 lbs and does 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

Appendix D: Team Roster

Name	Degree	Year	Team Role
Fatima Basit	Mechanical Engineering	Senior	President
Owen Torczon	Mechanical Engineering	Senior	Design Lead
Thomas Horton King	Electrical and Computer Engineering	Sophomore	Hull Lead
Seema Kamath	Mechanical Engineering	Senior	Hull Member
Casey Lauer	Mechanical Engineering	Senior	Hull Member
Jaiden Napier	Mechanical Engineering	Senior	Hull Member
Maddy Liu	Mechanical Engineering	Junior	Hull Member
Lance Miller	Chemical Engineering	Sophomore	Hull Member
William Qiu	Civil and Environmental Engineering	Sophomore	Hull Member
Grayson Moyer	Electrical and Computer Engineering, Robotics	Junior	Optimization Lead
Caroline Kasuba	Electrical and Computer Engineering	Freshman	Optimization Member
Rashi Kejriwal	Electrical and Computer Engineering	Freshman	Optimization Member
Kobe Zhang	Electrical and Computer	Freshman	Optimization Member

	Engineering		
Michelle Zhu	Computer Science	Freshman	Optimization Member
Katherine Nie	Mechanical Engineering, Robotics	Junior	Propulsion Lead
Rand Doane	Mechanical Engineering	Researcher	Propulsion Member
Sharon Chu	Mechanical Engineering	Junior	Propulsion Member
Madeline Hoedemaker	Mechanical Engineering	Junior	Propulsion Member
Keshav Sangam	Electrical and Computer Engineering	Junior	Power Lead
Stuart Shim	Mechanical Engineering	Junior	Propulsion Lead
David Oke	Mechanical Engineering	Masters	Propulsion Member