Carnegie Mellon
SOLAR RACING

Technical Report
Boat #3

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Executive Summary

Carnegie Mellon Solar Racing's (CMSR) goal for the Solar Splash 2018 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 become a more competitive, well rounded competition 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. The four teams goals were:

- Hull: Remove blemishes from the outside of the hull and remove unnecessary weight from the structural support in order to reduce drag.
- Propulsion: Build a new propulsion system optimized specifically for VorteX and the different competition races.
- Power: To purchase new solar panels with marked power improvements and optimized for the hull and propulsion system.
- Optimization: To create a better communication system that gives high quality data to the skipper.

CMSR had a total of seventeen members, largely with a focus of study in Mechanical Engineering. All members held at least one membership in a team, and ten of the seventeen held a larger administration or design role within the organization. With the help from all members, the teams were able to meet their intended goals, but due to time, resource, and financial restrictions all sub-systems 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 2019.

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I. Overall Project Objectives

Based on competition results from the 2017 Solar Splash competition, Carnegie Mellon Solar Racing (CMSR), needed to improve in both the sprint and slalom races. To address these, the organization overall project objectives were to build a propulsion system that could provide more thrust, a power system that could provide more power, and a hull that had reduced weight and drag. Other smaller objectives within improving the boat include improving the communication system, cargo bay, cockpit, and solar panel attachments. Based on the overall team objectives the sub-system objectives were as follows:

- Hull: Remove blemishes from the outside of the hull and remove unnecessary weight from the structural support. Remodel the cargo bay, cockpit, and solar panel attachments for a better configuration and comfort for the skipper.
- Propulsion: Build a new system that has an optimized propeller, more power draw and use, and better suited for all competition races.
- Power: To purchase new solar panels optimized for the hull and propulsion system.
- Optimization: To create a better communication system that gives high quality data to the skipper.

CMSR is not a large team and has a limited source of funding. At the beginning of each year the Executive Committee decides which sub-system within the organization will receive the most resources. In order to achieve the overall objectives for the Academic Year 2018, CMSR decided to take resources away from the Hull, where they were last year, and move them towards Propulsion and Power. Both Power and Propulsion received a large portion of the funding, and membership for the Propulsion team was increased. If extra support was needed, the other three teams gave their support to Propulsion.

II. Solar System Design

A. Past Design

Last year we used two SunPower Model SPR-215-WHT-U solar panels. These panels are rated at 215 W_{mpp} each. Combining the two allows for a 430 Watt system. Each panel weighs 33 lbs, and has a maximum efficiency of 17.3% [1]. These panels are relatively old, with rather poor efficiency and high weight, and are meant for household applications. The Power team sought to improve the solar panels for higher efficiency, lighter weight, and to take advantage of the entire 480 Watt limit.

B. Current Design

This year the team purchased custom Solbian panels from Ocean Planet Energy using SunPower monocrystalline cells with 24% efficiency and 3.07 watts each, as described in Appendix E. The back 4 panels are SP103 panels purchased off the shelf. The front panel was custom designed by CMSR members and sent to Solbian for final adjustments. 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 (Appendix E). 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.

III. Electrical System

A. Current Design

The power system utilizes the same Morningstar TriStar 45 MPPT Charge Controller as last year. It acts as an intermediary between the panels and batteries. The TriStar MPPT Charge Controller was chosen for its ability to charge batteries with significantly lower voltage than the solar panels without loss of efficiency. According to the data provided by Morningstar, for our solar array and battery configuration, the MPPT charge controller is able to charge with around 95% efficiency [2].

IV. Power Electronics System

A. Current Design

The propulsion system requires a 24V input, so the electronics design utilizes two 12V lead-acid batteries that are wired in series. Several commercial batteries were considered (Table 1). Many were unfavorable because their weight was not optimal given the Solar Splash limit on 100lbs of battery. Ideally, two 50lb batteries would be used to maximize capacity and stay within the weight limit (since weight is roughly proportional to capacity). The team also sought deep-cycle batteries, since in racing conditions the batteries will often be discharged significantly. The Optima Redtop 75/25, the same batteries used for Solar Splash 2017, fit these conditions almost perfectly and are the batteries the team implemented for use on VorteX for Solar Splash 2018.

Table 1: Comparison chart of different batteries the team considered. The final choice, the Optima Redtop 75/25, is highlighted in green.

Battery	Capacity (20-hr) Ah	Weight (lb)	Type	Price
Sigma 12-35	35	23.59	AGM	In storage
UB12500	50	30.2	AGM (deep cycle)	In storage
Optima 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

B. Future Improvements

In design considerations for this year, battery discharge rates, lifetime, and many other factors were neglected. The team will try to account for this for future improvements.

V. Hull Design

A. Current Design

CMSR will be recycling the hull from VorteX used in Solar Splash 2017, with further improvements to remove blemishes and mistakes from the construction of the hull from last year. The main problems with last year's boat was the unnecessary weight coming from the wooden structural supports, the increased drag from blemishes on the outside of the boat, and items inside the hull could not be moved around because everything was either bolted or epoxied in place. The layup process for the 2017 hull went well with the exception of the first layer containing multiple air bubbles and the Nomex Honeycomb layer not fully adhering to the carbon fiber. There were two major air bubbles on the sides that could not be fixed and had to be reinforced for competition. The sides were also unstable, so three wooden cross-sections were epoxied into the boat to increase rigidity. This added unnecessary weight. The cockpit was made out of wood and bolted on to the side of the boat. This also added more weight and took away from aesthetics. Also, the solar panels were bolted onto brackets which were difficult to line up properly and not reliable in allowing proper attachment. Addressing these issues were the main improvements to construction of the Solar Splash 2017 hull for this year.

B. Boat Improvements

This year, focus was put on iterating previous designs to make the cockpit, cargo bay, and solar panel attachment more modular, while removing unnecessary weight. Additionally, blemishes were fixed and gaps filled in to improve the aerodynamics of the hull. The first step in the improvement process was to remove everything that was epoxied inside the hull except for the front cross-section. This was a tedious task that took longer than expected, reducing time for testing after completion. Fortunately, about 90% of everything epoxied inside of the hull was removed without damage. The other 10% was epoxy residue that collected on the bottom and scraps of wood that could not be removed without damaging the hull.

1) Fixing blemished and gaps: The red paint and primer from last year was removed in order to fix gaps on the outside surface of the hull. Three gallons of Klean Strip paint stripper was used for the majority of the hull to remove paint and primer, and then the rest was removed with sanding. Unfortunately paint strippers damage epoxy if they make contact for extended periods of time. Work was done quickly in order to stop the paint stripper from going through the primer. After sanding the gaps were ready to be filled on the hull. Four packets of Marine-Tex Epoxy Putty were used in order to fill holes. The process was straightforward, first one a layer of putty was added and then in the next meeting it was sanded and then another layer added. This was then repeated until completion. The reason for layers was because the putty was not viscous enough to cover the gaps all the way to the top.

The team chose to continue using the red and white color scheme to imitate the schools colors the closest. Three layers of gray primer, then four layers of red paint, were added with an hour to dry between each layer (Fig. 1). The difference between this year and last year's paint job was the number of layers. Last year there was five layers of primer and seven layers of red paint which was decided to be excessive. It was also the reason the paint looked runny up close. Another difference is the techniques used while painting. Last year if a small area was missed, it was sprayed over creating and extra layer on the surrounding. This year there was only one slow pass around the entire boat at a time. It was more time consuming and difficult, but it paid off. This year's paint job is more even and is more aesthetic than last years.

The last addition to outside of the boat is the logos which are yet to be painted. Similar to last year, the team will be laying up blue painters tape on a sheet of polycarbonate and laser cutting the logos. The painters tape will be stuck to the sides of the boat and act as a stencil for the white spray paint. This year there will be eight sponsors on the starboard side and the boat's name on the port side (Fig. 2). This is a much larger than the design from last year. Afterwards the logos will be coated with an acrylic spray to make it waterproof and to prevent damage.

Figure 1: Applying primer and paint to the hull.

Figure 2: Prepare logo and detail design to be completed for Solar Splash 2018

2) Adding a Cargo Bay: The purpose for adding the cargo bay was to provide better flotation as well as a place to store the electrical system. Two 54” extruded aluminum T-Slot rail run down the cargo bay along with four bolt holes for carabiners and rope to act as attachment points. The top of the cargo bay is 4 pieces of ½ inch high density polyethylene King StarLite. King StarLite was chosen for its similar properties to wood, but lower susceptibility to rot, lower weight, and higher ease of usability. Additionally, it has an anti-skid texture that makes it harder for the components mounted on it to move. The cargo bay is supported by five pieces of 2 x 4 which were epoxied to the side of the boat. To secure the cargo bay 1.5” brackets were screwed into the wood, which simultaneously secured the T-slots. To make the cargo bay watertight four cartridges of marine grade caulk were used to seal the gaps between the King StarLite. Black Flex Seal was sprayed on the wood in order to match the color of our boat and prevent rot.

3) Improvements to the Cockpit: The cockpits this year focuses on adjustability and aesthetics. Last year it was a wooden panel with components bolted or epoxied on. It was difficult to reach the bolts and it could not be adjusted. This year a ½ in King StarBoard is used as a base. King StarBoard was chosen for its similar density to wood, but higher tensile strength, which allowed for less material. It also looks more professional than stained wood and easier to create add additional screw holes. The base was supported by T-slot rails set in a triangular shape. The cockpit can be slid up and down by 6 inches and moved back and forth by 6 inches in order to adjust to the driver. The steering wheel, throttle, tablet, and on/off switch is installed similarly to last year.

4) Solar Panel Attachments: As described in section II, the team is using custom flexible Solbian panels instead of the heavy SunPower panels used last year. The solar panels came with an adhesive backing to apply to any chosen frame. It was decided to use a 8mm Twin-Wall Polycarbonate as a support to the panels, however it was found to be too flexible. A fiberglass layup on the opposite side worked out well and made gave the polycarbonate a proper rigidity. The panels are attached to the boat on T-slot rails across the hull. The T-slot rails provide some rigidity while allowing for flexible mounting options.

VI. Drive Train and Steering

A. Current Design

For Solar Splash 2017, 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 was no problems or issues with using the steering system, so it will be integrated into the drivetrain and steering system again for Solar Splash 2018. As for the propulsion system, it was decided that the Torqeedo was not optimal for competition. While it was good for endurance, the system did not have enough thrust to allow the boat to be competitive in either the sprint or the slalom.

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.

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 bearing that allow the propeller shaft to spin freely. A main consideration when designing the lower unit was waterproofing, as water would reduce the efficiency of the gears and bearings. 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. 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.

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. 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. For further information on the propeller design, analysis, and manufacturing process refer to Appendix F.

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. For more information on propeller analysis refer to Appendix F.

At this time, the propulsion system is not complete. Its expected completion data is the second week of May after the technical report is due. After completion of the propulsion system, both dry and water tests will be done to confirm that the system works and will not receive water damage when used. Due to time constraints, money, and resource availability the propulsion system will not be tested on the boat before Solar Splash 2018 competition.

VII. Data Acquisition and Communications

A. Current Design

This year, the optimization team improved upon the data acquisition and communication system created last academic year. After competition experience last year, it was decided that the team should focus on addressing two major issues: reliability of data and interpretability. As a result, the goal of this year's system was to provide high quality data that would be useful to the skipper.

The setup uses an Arduino microcontroller for sensor data aggregation. Relevant data is forwarded to an Android tablet for display. This different acquisition sensors used in the system and their purpose are shown in Table 2.

Table 2: Data acquisition sensors and their purposes.

Sensor Type	Chosen Part	Purpose
Voltage Sensor	Custom-made	Sense battery voltage, solar panel output.
Current Sensor	Honeywell CSLA Series (two kinds: one small and one big)	Sense solar panel output, charge controller output, and motor draw.
GPS	On-board chip in tablet	Determine speed of craft.

The team focused on improving the reliability of the two main sensors: voltage and current. These two sensors give information about the charge from the panels, how much juice is in the batteries, and how much energy the motor is drawing. With these readings, the skipper is better able to make judgements about throttle and pacing. The Honeywell sensor was specifically chosen because it is non-invasive. The sensor reads the current of a wire (even an insulated wire) threaded through it. This means that there is no more dependency of the Power subsystem on Data Acquisition.

This year, the team set out to build a state of charge estimator for the boat batteries. The goal was to take in voltage and past current measurements and produce a reasonably accurate estimate of the state of charge of the battery. This was accomplished using a combination of the voltage and current integration. Since specific lead acid batteries will have varying voltage to state of charge curves, a model was built from data that was collected on the open circuit voltage to state of charge. The model was then combined with current integration to create a reasonably accurate model for state of charge.

B. Analysis of Design Concepts

1) State of Charge Estimation: Estimating the state of charge of a lead acid battery is a inherently difficult task. Lead acid batteries are designed to provide a relatively steady voltage source, regardless of state of charge. Thus, predicting state of charge directly from voltage is difficult. In addition, the total amount of ampere hours of the battery depends on the rate of current draw. Discharging the battery over a period of three hours will yields fewer ampere hours than discharging over a period of ten hours. To address these problems, the team took the approach of gathering as much data as possible.

C. Design Testing and Evaluation

1) Current Sensor: To improve the robustness and accuracy of the current measurements, various tests were performed on the Honeywell sensors. One major problem addressed this year was sensor drift. It was discovered that this could be alleviated by stabilizing the voltage source to the current sensors, with the addition of a voltage regulator and a warm up period for stabilization. Accuracy was improved by performing more calibration tests and using calibration data to guide the state of charge estimate described in the section above.

2) Battery Testing: The state of charge estimator required gathering data when draining the battery. In the experimental setup to analyze voltage over elapsed time, shown in Fig. 3, one of the Optima batteries was set up with a four-ohm resistor, and voltage was recorded over time when the current was under a three amp draw rate. A different experimental setup will also be used, where open circuit voltage was recorded rather than closed circuit voltage. This test will be completed after the submission of the technical report.

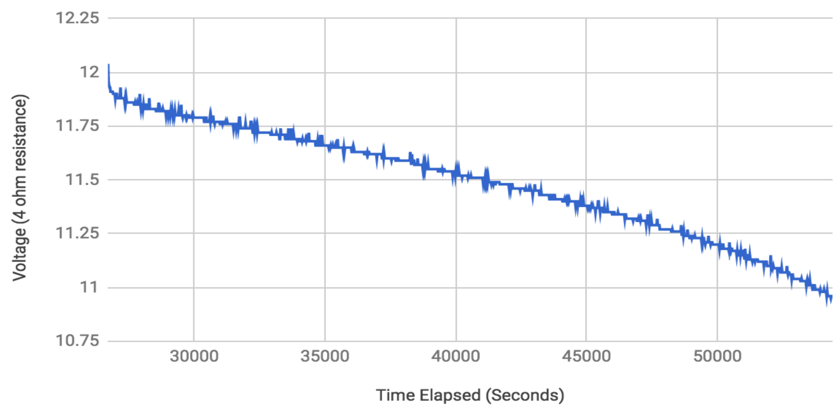

Figure 3: Optima battery voltage over time elapsed.

VIII. Project Management

A. Team members and leadership roles

Carnegie Mellon Solar Racing has a total of seventeen members that regularly attend meetings. As an inclusive organization on campus, CMSR aims to have a great diversity of members across all majors, but the organization tends to have the highest percentage in Mechanical Engineering. For a full list of members, their majors, and their graduation years refer to Appendix D.

Similar to the 2017 Academic Year, the organization had six administrative roles and four design roles that made up the Executive Committee. These roles are as listed and described below in Table 3.

Table 3: 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.
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 Design Lead	Lead design and fabrication of the hull.
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

The commitment to each project (Hull, Propulsion, Optimization, and Power) was determined by the The Executive Committee during the first two weeks of the academic year. To make sure that commitments were being met, and the entire project was going to be completed on time, the Executive Committee had bi-weekly meetings to discuss updates.

After the initial decision on the level of commitment to each project within the organization, the project and planning within each team was determined and controlled by team leads. Design leads decided how often meetings for their teams needed to be held. Generally throughout the academic year Propulsion and Hull team met once to twice weekly while Power and Optimization met once bi-weekly.

C. Financial and funding-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. 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 have 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 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

The level of commitment to each sub-system, decided by the Executive Committee during the first two weeks of school, was effective in completing the boat to the intended goals. However, on the side of administration, the organization had a low retention of new members. Normally the organization has about ten to fifteen new members, with about ten willing to continue onto the next year. This year CMSR has three new freshman, one sophomore, and one junior, making a total of only five new members. While all do intend to continue onto next year, the organization does not consider this level of recruitment sustainable to maintaining sustainability of CMSR. To improve new member retention next year, the Vice President of Member Development and the newly elected President will evaluate the New Member Project.

IX. Conclusions and Recommendations

A. Strengths and Weaknesses

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

- Building a new propulsion system: By optimizing the propulsion system to the rest of the boat, it should improve the boats performance at competition.
- Purchasing a new solar system: By optimizing to the shape of the hull and maximizing to the allowable wattage, it should improve the boats performance at competition.
- Making further improvements to the hull: This had many positive effects such as making the driver more comfortable and optimizing better for weight, strength, and drag.
- Preparing for Solar Splash 2018 competition: After documenting everything from last year's competition, CMSR is more prepared to compete and anticipate challenges that may occur.

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

- A reduction in new member recruitment: The team will have an effect on team continuity in future years. The new member project will be evaluated for next year.
- Not having the boat registered with the state for testing: This lead to being unable to test the completed boat before competition. The organization is now going through the process to register VorteX for testing next academic year.
- 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 Sub-system Objectives were as follows:

- Hull: To improve the hull that was used during Solar Splash 2017 competition
- Propulsion: To build an entirely new propulsion system and the integrate the old steering system into it.
- Power: To purchase new solar cells.
- Optimization: To improve last year's communications system.

Carnegie Mellon Solar Racing was able to meet the goals set at the beginning of the 2018 academic year.

C. Reflections on Design Process

The boat was successful in completion by having a newly built propulsion system, a lighter hull, a new solar power system, and an improved optimization system for this year's competition. However, due to finishing the boat in early May and not having the boat registered in time to test in the local waterways, the testing and evaluation portion of the design process will not be complete.

D. Where do we go from here?

With the successful completion of designing a propulsion system this year, the organization will switch to re-designing the Hull for Solar Splash 2019. While adjustments will be made on the propulsions system, the power and electrical system, and the optimization system, they will all take a back seat in both time and finance for the next upcoming year.

E. Lessons Learned

The two major weaknesses this year focused on new member retainment and registering the boat with the state to be able to test it in Pennsylvania's rivers and lakes. From this, the two major lessons learned are:

- To improve the new member recruitment strategies and the new member project for future years.
- To register VorteX with the state, as well as all future boats, at least six weeks in advance from when the team wants to do full boat testing.

[1] SunPower. (2009). *215 Solar Panel: Exceptional Efficiency and Performance* [PDF]. RevoluSun. Retrieved from http://www.revolusun.com/wp-content/uploads/2016/04/Sunpower-SPR-215-WHT-U.pdf

[2] Morningstar Corp. (2014). *Heat Dissipation of the TriStar & TriStar MPPT Controller inside Enclosures* [PDF]. Morningstar. Retrieved from https://2n1s7w3qw84d2ysnx3ia2bct-wpengine.netdna-ssl.com/wp-content/uploads/2014/02/TechTip-EnclosureHeatDissipation.pdf

[3] Gerr. D. (1989). Propeller Handbook: The Complete Reference for Choosing, Installing and Understanding Boat Propellers. Camden: International Marine.

[4] OpenProp (N.D.). OpenProp. *Dartmouth University*. Retrieved from http://engineering.dartmouth.edu/openprop/

[5] Amrita University. (N.D.). Peukert Law. *Amrita University*. Retrieved from http://vlab.amrita.edu/?sub=77&brch=270&sim=1760&cnt=1

X. Appendices

Appendix A: Battery Documentation

Figure A.1 provides battery documentation for the Optima Redtop 75/25 that will be used for Solar Splash 2018 competition.

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

Physical Characteristics:

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

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

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

Performance Data:

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

Power:

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

Recommended Charging:

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

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

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

Recommended Charging Information:

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

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

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

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

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

Always wear safety glasses when working with batteries.

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

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

Shipping and Transportation Information:

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

BCI = Battery Council International

OPTIMA Batteries Product Specifications: Model D34M
December 2008

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

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

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

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

Synonyms/Common Name **Sealed Lead Acid Battery**	**DOT, IATA and IMO Description** **Non-Spillable Battery , Exempt from UN2800 Classification**
Company Name **OPTIMA Batteries, Inc.**	Address **5757 N. Green Bay Avenue**
Division or Department **Wholly- owned subsidiary of Johnson Controls Inc.**	**Milwaukee, WI 53209**
CONTACT	TELEPHONE NUMBER
Questions Concerning MSDS **OPTIMA Batteries, Environmental, Health & Safety Department**	**Day:** **(800) 333-2222, Ext. 3138**
Transportation Emergencies **CHEMTREC**	**24 Hours: (800) 424-9300** **International: (703) 527-3887 (Collect)**

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

II. Hazardous Ingredients

Material	**% by Wt.**	**CAS Number**	**Eight Hour Exposure Limits**		
			OSHA PEL	**ACGIH TLV**	**NIOSH REL**
Specific Chemical Identity **Lead & lead compounds**	63-81	7439-92-1	50 μg/m³	150 μg/m³	100 μg/m³
Specific Chemical Identity **Sulfuric Acid (35%)** **Common Name** **Battery Electrolyte (Acid)**	17 - 25	7664-93-9	1mg/m³	0.2 mg/m³ (respirable thoracic fraction)	1 mg/m³
Common Name **Case Material Polypropylene**	2-6	9010-79-1	--	--	--
Common Name **Separator/Paster Paper Fibrous Glass**	1-4	65997-17-3	--	--	--

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

III. Physical Data

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

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

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

IV. Health Hazard Information

NOTE: Under normal conditions of use, this product does not present a health hazard. The following information is provided for battery electrolyte (acid) and lead for exposure that may occur during battery production or container breakage or under extreme heat conditions such as fire
ROUTES AND METHODS OF ENTRY
Inhalation Acid mist may be generated during battery overcharging and may cause respiratory irritation. Seepage of acid from broken batteries may present inhalation exposure in a confined area.
Skin Contact Battery electrolyte (acid) can cause severe irritation, burns and ulceration.
Skin Absorption Skin absorption is not a significant route of entry.
Eye Contact Battery electrolyte (acid) can cause severe irritation, burns, and cornea damage upon contact.
Ingestion Hands contaminated by contact with internal components of a battery can cause ingestion of lead/lead compounds. Hands should be washed prior to eating, drinking, or smoking.
SIGNS AND SYMPTOMS OF OVEREXPOSURE
Acute Effects Acute effects of overexposure to lead compounds are GI (gastrointestinal) upset, loss of appetite, diarrhea, constipation with cramping, difficulty in sleeping, and fatigue. Exposure and/or contact with battery electrolyte (acid) may lead to acute irritation of the skin, corneal damage of the eyes, and irritation of the mucous membranes of the eyes and upper respiratory system, including lungs.
Chronic Effects Lead and its compounds may cause chronic anemia, damage to the kidneys and nervous system. Lead may also cause reproductive system damage and can affect developing fetuses in pregnant women. Battery electrolyte (acid) may lead to scarring of the cornea, chronic bronchitis, as well as erosion of tooth enamel in mouth breathers in repeated exposures.
POTENTIAL TO CAUSE CANCER
The National Toxicological Program (NTP) and The International Agency for Research on Cancer (IARC) have classified “strong inorganic acid mist containing sulfuric acid” as a Category 1 carcinogen, a substance that is carcinogenic to humans. The ACGIH has classified “strong inorganic acid mist containing sulfuric acid” as an A2 carcinogen (suspected human carcinogen). These classifications do not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist (sulfuric acid mist) is not generated under normal use of this product. Misuse of the product, such as overcharging, may result in the generation of sulfuric acid mist. The NTP and the IARC have classified lead as an A3 carcinogen (animal carcinogen). While the agent is carcinogenic in experimental animals at relatively high doses, the agent is unlikely to cause cancer in humans except under uncommonly high levels of exposure. For further information, see the ACGIH's pamphlet, *1996 Threshold Limit Values and Biological Exposure Indices.*
EMERGENCY AND FIRST AID PROCEDURES
Inhalation Not expected for product under normal conditions of use. However, if acid vapor is released due to overcharging or abuse of the battery, remove exposed person to fresh air. If breathing is difficult, oxygen may be administered. If breathing has stopped, artificial respiration should be started immediately. Seek medical attention immediately.
Skin Exposure not expected for product under normal conditions of use. However, if acid contacts skin, flush with water and mild soap. If irritation develops, seek medical attention immediately.
Eyes Exposure not expected for product under normal conditions of use. However, if acid from broken battery case enters eyes, flush with water for at least 15 minutes. Seek medical attention immediately.
Ingestion Not expected due to physical form of finished product. However, if internal components are ingested: Lead/Lead compounds: Consult a physician immediately for medical attention. Battery Electrolyte (Acid): Do not induce vomiting. Refer to a physician immediately for medical attention.
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE
Inorganic lead and its compounds can aggravate chronic forms of kidney, liver, and neurologic diseases. Contact of battery electrolyte (acid) with the skin may aggravate skin diseases such as eczema and contact dermatitis.

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

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

V. Fire and Explosion Data

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

Extinguishing Media
Dry chemical, foam, or CO_2

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

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

VI. Reactivity Data

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

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

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

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

VII. Control Measures

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

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

PERSONAL PROTECTIVE EQUIPMENT

Respiratory Protection
None required for normal handling of finished product.

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

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

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

VIII. Safe Handling Precautions

Hygiene Practices

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

Protective Measures to be Taken During Non-Routine Tasks, Including Equipment Maintenance

Do not carry battery by terminals. Do not drop battery, puncture or attempt to open battery case. Do not subject product to open flame or fire and avoid situations that could cause arcing between terminals.

SPILL OR LEAK PROCEDURES

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

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

Protective Measures to be Taken if Material is Released or Spilled

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

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

DO NOT RELEASE UNNEUTRALIZED ACID!

Waste Disposal Method

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

DO NOT FLUSH LEAD-CONTAMINATED ACID INTO SEWER.

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

LEAD RETURN RECYCLE

SUPPLEMENTAL INFORMATION

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

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

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

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

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

US MILITARY NATIONAL STOCK NUMBER (NSN)

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

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

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

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

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

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

Appendix B: Flotation Calculations

To prove that VorteX will still float, if filled with water, Tab. B.1 and Equations B.1 and B.2 were used for calculations.

Table B.1: Flotation Calculations Weight Values

System	Volume (in^3)	Buoyant Force (lb)
Batteries	1099.1	39.7
Foam	2874.2	103.8
Boat	2351.8	84.9
Cargo Bay	7688.9	277.6
Total	**14014**	**505.9**

γ_{Water} = specific weight of water = 0.0361 lb/in^3

$F_b = V_{Total} \times \gamma_{Water}$

$= 14014\ in^3 \times 0.0361\ lb/ft^3 = 505.9\ lb$

Equation B.1: Buoyancy of Boat in Pounds

W = Total weight x 1.2

= 326.69* 1.2

= 392 lbs

Findings: The final flotation calculated was 505.9 lbs. The cargo bay we added is a great improvement to aid in buoyancy. We will be above the limit by 113.9 lbs and do not require any air bags.

Appendix C: Proof of Insurance

Fig. C.1 is the required certificate of liability insurance from Carnegie Mellon University.

Page 1 of 1

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 03/09/2018

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

INSURED	INSURER(S) AFFORDING COVERAGE	NAIC #
Carnegie Mellon University Attn: Insurance Services Dept Diane Patterson - Warner Hall #400D 5000 Forbes Avenue Pittsburgh, PA 15213	INSURER A: United Educators Insurance a Reciprocal Ri	10020
	INSURER B:	
	INSURER C:	
	INSURER D:	
	INSURER E:	
	INSURER F:	

COVERAGES **CERTIFICATE NUMBER:** W5483474 **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	10/01/2017	10/01/2018	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 ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) If yes, describe under DESCRIPTION OF OPERATIONS below	N/A					PER STATUTE OTH-ER	
							E.L. EACH ACCIDENT	$
							E.L. DISEASE - EA EMPLOYEE	$
							E.L. DISEASE - POLICY LIMIT	$

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

RE: The participation of "Carnegie Mellon Solar Racing Club"in the SOLAR SPLASH 2018 Competition at the Clark County Fairgrounds in Springfield, Ohio from June 5-19, 2018. This event is an international intercollegiate solar/electric boat regatta.

CERTIFICATE HOLDER	CANCELLATION
Solar Splash Attn: Jeffrey H. Morehouse, PhD, PE 309 Newridge Road Lexington, PA 29072	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

SR ID: 15733677 BATCH: 629435

Figure C.1: Certificate of Liability Insurance for Solar Splash Rule 2.9

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	CIT*/Mechanical Engineering	Freshman	Hull and Propulsion Member
Farney, Rhiannon	CIT/Mechanical Engineering and Engineering and Public Policy	Senior	President, Propulsion Design Lead
Feng, Victoria	CIT/Mechanical Engineering, SCS**/Human-Computer Interaction	Sophomore	Hull and Propulsion Member
Gamboa, Sebastian	CIT/Mechanical Engineering	Sophomore	Vice President of Programming, Hull Member
Kleinman, David	CIT/Mechanical Engineering	Freshman	Vice President of Marketing Spring Semester, Power and Opti Member
Lamprinakos, Nicholas	CIT/Mechanical Engineering and Biomedical Engineering	Junior	Hull Member
Lance, Jack	CIT/Mechanical Engineering, SCS/Robotics	Junior	Hull and Propulsion Member
Lim, Jasmine	CIT/Mechanical Engineering and Engineering and Public Policy	Junior	Vice President of Finance, Propulsion Member
Long, Madelynne	CIT/Mechanical Engineering	Junior	Hull Design Lead Fall Semester, Vice President of Marketing Fall Semester, Hull Member
Masciopinto, Zack	CIT/Mechanical Engineering	Junior	Vice President of Member Development, Hull Member
Oke, David	CIT/Mechanical Engineering	Sophomore	Hull and Propulsions Member
Quinones, Cesar	CIT/Mechanical Engineering	Junior	Hull Design Lead Spring Semester
Shah, Tanvi	CIT/Electrical & Computer Engineering	Sophomore	Hull and Propulsion Member
Shek, Alvin	CIT/Electrical & Computer Engineering	Freshman	Power and Optimization Member
Xu, Riley	MCS***/Physics	Senior	Power Design Lead, Optimization Member
Zeng, David	SCS/Computer Science	Junior	Optimization Design Lead, Power Member
Zhang, James	CIT/Mechanical Engineering and Engineering and Public Policy	Junior	Secretary, Hull, Propulsion, and Power, and Optimization Member

*Carnegie Institute of Technology (CIT), **School of Computer Science (SCS), ***Mellon College of Science (MCS)

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	Schindler Elevators Corp.	Project Lead PMDP	Alumni Advisor

Appendix E: Email Confirming Solar Panel Output from Correspondent with Solar Panel Company

Hi James - The 393 watts were 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

Appendix F: Propulsion System Propeller Supporting Design Calculations

The CMSR team is now aiming to design and manufacture their own propellers for competition. The following sections discuss the process for both the endurance and sprint propeller,.

Endurance Propeller Design

The endurance propeller was designed based on the expected performance of the current hull design, last year's performance at competition, and the expected performance of the electrical system. The ideal case is to have the batteries completely drained by the end of the 2-hour race. As a result, a simple power balance model was utilized to constrain the propeller design.

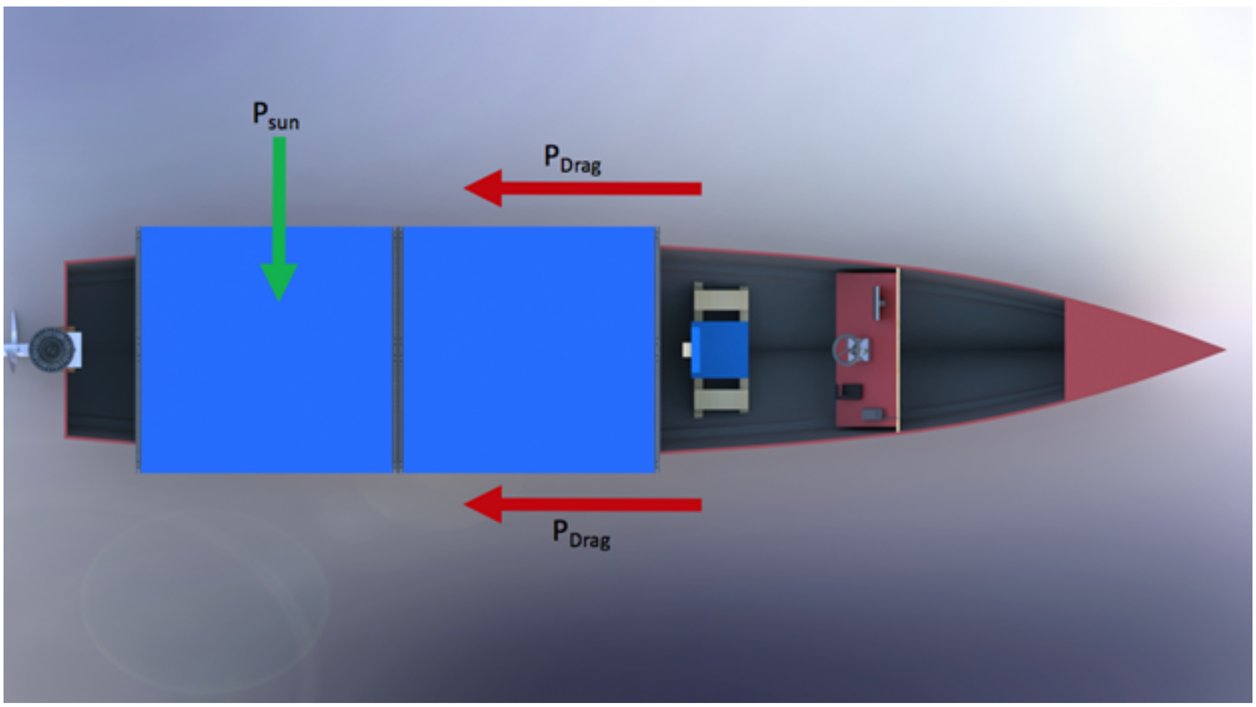

Figure F.1: Top View Force Body Diagram for the Boat

Equation F.1: Equation for Balance of Forces

$$P_{sun} + P_{battery} = P_{drag} + P_{efficiency\ losses}$$

Where:

P_{sun} = Expected power drawn from the solar panels

$P_{battery}$ = Power drawn from batteries

P_{drag} = Power dissipated from drag on the boat

$P_{efficiency\ losses}$ = Power dissipated from efficiency losses

Examples of power dissipated from efficiency losses include motor efficiency and gearbox efficiency.

To estimate the amount of power that can be drawn from the batteries, Peukert's law was utilized [5].

Equation F.2: Peukert's Law [5]

$$t = H\left(\frac{C}{IH}\right)^k$$

Where:

H = Rated discharge time in hours
C = Rated capacity at that discharge rate
I = Actual discharge current
K = Peukert constant for lead acid battery
t = Amount of time spent to discharge the batteries

By setting the time of discharge to two hours, which is the duration of one endurance heat, the current output of the batteries was calculated to be at 36 A. A sensitivity analysis was conducted to see how the power output of the solar panels varied with the solar intensity. The expected current drawn from the panels varied from 11 A to 33 A. Before efficiency drops, the total current that can be drawn by the motor varied from 47 to 69 A.

Dave Gerr's displacement speed-length ratio formulas were used to predict the speed of the boat [3].

Equation F.3: Speed-length Ratio

$$SL = \frac{10.665}{\left(\frac{L_b}{SHP}\right)^{1/3}}$$

$$SL = \frac{K_{ts}}{{W_l}^{1/2}}$$

Where:

SL = Speed length ratio

L_b = Displacement of water, in lbs

SHP = Shaft output in HP

K_{ts} = Boat speed in knots

W_l = Waterline length in feet

For the endurance race, the boat is assumed to have 0 trim and a water displacement of 450 lbs. More accurate data can be gathered in the future to iterate and fine tune these assumptions. The waterline length was estimated using Solidworks based on where the waterline would sit on the boat if it displaced 450 lbs. The shaft horsepower is related to the amount of current that the motor can pull from the previous calculations, and the efficiency of the system at turning electrical power into mechanical power. Based on these values, we found that our boat can move between 2.55 to 2.86 m/s depending on the intensity of sunlight. We found that these values have good agreement with the speeds we recorded for the endurance race in Solar Splash 2017 using the Torqeedo system. While the overall propulsion system may have worse efficiency ratings than the Torqeedo, it is offset by the extra wattage pulled from the new solar panels, leading to a similar prediction in performance.

Endurance Propeller Geometry

These values were then plugged into OpenProp, a MATLAB based software developed by MIT and Dartmouth to aid propeller design. A parametric study was first conducted to find how many blades, RPM of the propeller, and diameter of the propeller would maximize its efficiency. At larger diameters, lower RPMs have higher efficiencies according to the study. Based on this information, a 15 inch 3-bladed propeller was chosen at a RPM of 500. This is convenient because this corresponds to about a 1:2 gear reduction ratio from the motor to the propeller shaft. A text file was then exported from the MATLAB program into SolidWorks to generate the blade contour.

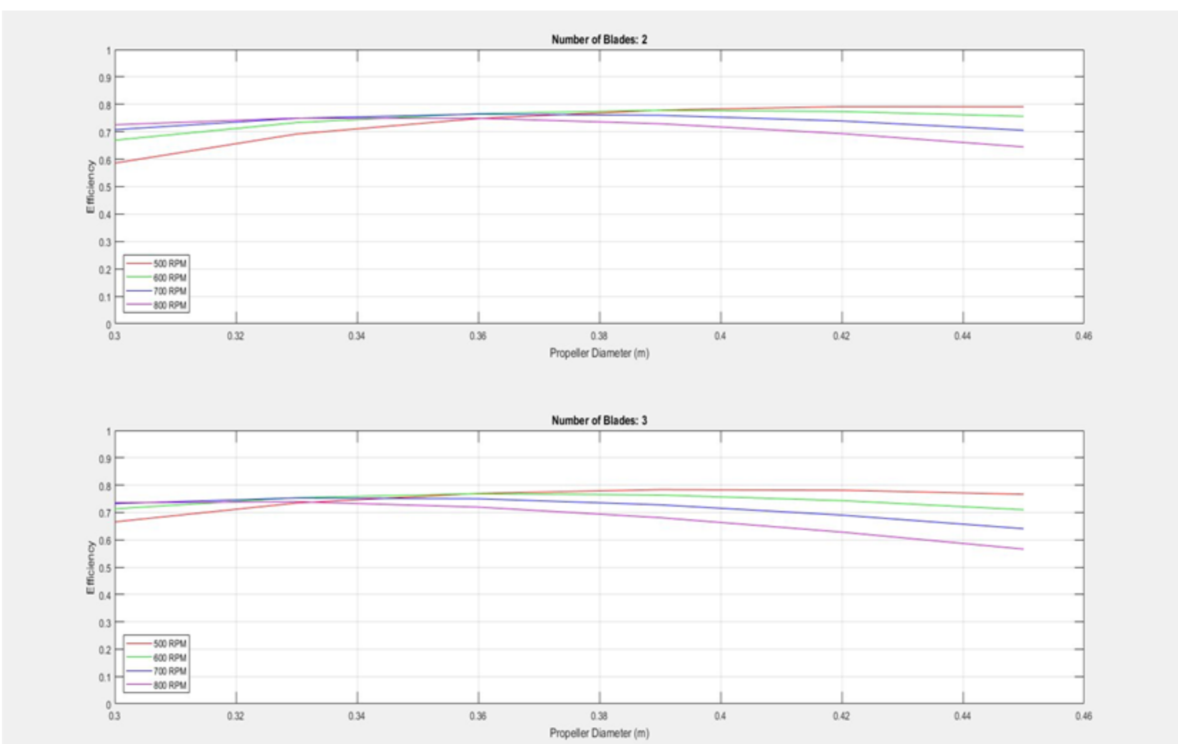

Figure F.2: Optimization Graphs for Propeller Diameter

SolidWorks Design and Analysis

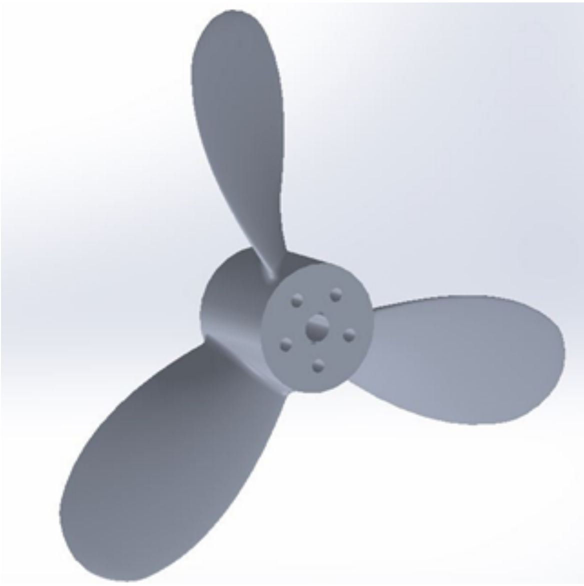

Figure F.3: SolidWorks View of Endurance Propeller

The blade contour was lofted and connected to the hub design. Fluids simulations and stress analysis was conducted on the propeller to predict its performance and ensure it wouldn't yield. The fluids simulation utilized the moving reference frame (MRF) model to predict the propeller's thrust and torque at 500 RPM. It was found that the values are generally larger than what was predicted in the OpenProp program, however are not differing in large magnitudes. Empirical data would be needed to qualify which is more indicative of the performance. The fluid pressure distributions on the blades were then imported in SolidWorks FEA simulation. It was found that the factor of safety for the blade designs were sufficiently high.

Manufacturing Process

It is ideal to manufacture these propellers by either 3D printing or by casting due to the unique and complex geometry. In order to do so, our propellers must be outsourced to an external company. The CMSR team instead is working on manufacturing the propellers at Carnegie Mellon University utilizing a 3-axis mill. Doing so would give members invaluable experience with manufacturing and make it easier for members to iterate on their designs. The 5 holes seen on the propeller hub are to aid in fixturing the propeller during the machining process.

Figure F.4: Picture of Endurance Propeller During Manufacturing Process