Solar Boat 2019
Electrical/Solar Array Report

Los Altos Academy of Engineering

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Introduction

The Los Academy of Engineering is heading into Solar Cup for a second consecutive year after a six year hiatus. For Solar Cup 2019, our plan is to score in the middle of the pack and to grow as a program. More importantly, we hope to instill a fascination for engineering in our program's students. Now that our program has upperclassmen who are experienced, we are teaching the younger members on both the competition itself and on issues from previous competitions.

In Solar Cup 2018, we encountered several challenges within our electrical system, but our team persevered and qualified minutes before the event came to an end. Our electrical system had a short circuit in the node connecting the deadman switch, contactor relay and the motor control, all crucial components of our boat's system. We also had a faulty dead man switch clip that would not hold the kill switch down, leaving the circuit open and unable to run. This short circuit and faulty clip prevented our team from running a full sprint heat and losing precious time in endurance and landing us in 28th place overall.

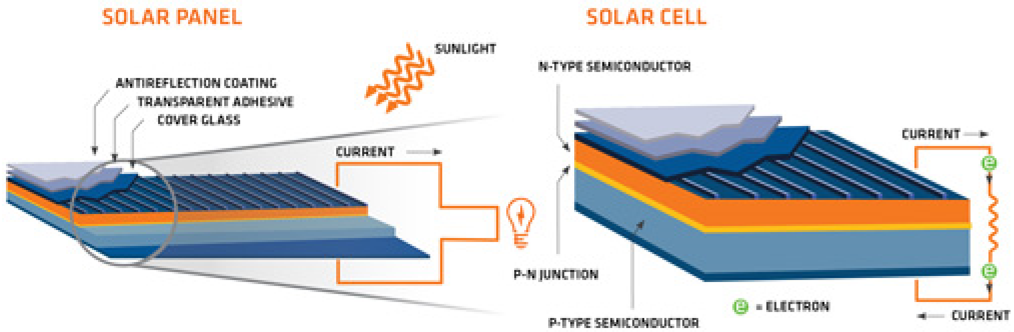
We have planned ahead and modified our systems to prevent any short circuits and faulty clip, as well as improved our troubleshooting skills. We have successfully constructed what is known to our program as a simulation table, in which we construct the boat's electrical system months before the competition begins in order to guarantee a working electrical system in advance and learn how to decipher any problems in the system before they occur.

We are extremely fortunate to have complete access to a shop with soldering stations, solar charging setups, battery testing systems, and much more. We have the ability to work with electrical systems and solar arrays at any given time.

Our greatest challenge will be to execute our ideas and improve on last year's performance for this upcoming competition to have an accurate system without flaws, a higher placement, and give our young engineers experience. We are heading into Solar Cup not with the goal of having a working boat, but a need to make our name known.

Physics of Photovoltaics

The Earth intercepts about 173,000 terawatts of solar power continuously. That is more than sufficient to power the entire world. The physics of photovoltaics is the process by which solar energy is converted into electrical power through multiple solar cells on a panel. On the average solar cell, about 15%-20% of the sunlight is absorbed and turned into an electrical current, while the rest of the sunlight is reflected. Sunlight comprises of minuscule light particles called photons, which radiate from the sun. A solar cell is composed of three layers, the middle layer guides the process as it absorbs the sunlight and directs the electrons and holes caused by the sunlight to create an electrical current. The top layer is made with mainly silicon and some phosphorus, silicon being a semiconductor, leads the loose electrons into the electrical circuit while the lower layer is composed of silicon and boron which collect the used electrons to fill up the holes created (Solar Cells, 2018). The process is repeated continuously with the presence of sunlight. Using this process, sunlight can be transferred into electricity while avoiding the creation of harmful pollutants.



(Figure 1) The conversion of sunlight into usable energy on both the solar cells and solar panels demonstrate the three layers used to create an electrical current.

Batteries

This year, our team considered the Optima Yellowtop D51s, the Odyssey Extreme Series PC950s, and the Odyssey Extreme Series PC1100s.

The Optima Yellowtop D51 rated at 38 ampere-hours and a weight of 25 lbs individually. With a rate of 38 ampere-hour our system would run at a greater amperage meaning more laps can be ran during the endurance event for the 90 minutes. The Optima batteries have the required weight and have demonstrated efficiency in the past.

In addition, we also looked into the Odyssey Extreme Series batteries and considered the Odyssey PC950 which run at 34 amps per hour at a 20 hour capacity and a weight of 20 lbs individually, meaning the pair is under the weight limit.

Finally, we also reconsidered the Odyssey PC1100, which our team used in last year's competition because we owned them already, we have been able to cycle them in our shop and collect data on their performance. We gathered data over the course of a year of the PC1100s performance in 90 minute intervals (Figure 3). These batteries provide 45 amps/hour for a maximum of 20 hours, and a weight of 27.5 lbs per battery. For these reasons, the PC1100s have definitely set the standards high for other batteries we were to consider this year.

Compared to the Odyssey PC950 and Optima Yellowtop D51, the Odyssey PC1100s are clearly superior batteries. Along with performance in amperage per hour, the total weight of this year's pair of batteries was also a deciding factor, considering the weight limit of the boat is 451 lbs as specified in the rules (Technical Manual, 2019, p.12). With a year's worth of data to back these batteries up, we decided to use the Odyssey PC1100 once again.

Battery	**Capacity @ 20 hrs**	**Weight (lbs/kg)**	**Price**
Optima Yellowtop D51	38 Ampere-hours	25 lbs (11.3 kg)	$237.99
Odyssey PC950	34 Ampere-hours	20 lbs (9kg)	$234.43
Odyssey PC1100	45 Ampere-hours	27.5 lbs (12.5kg)	$247.03

Figure 2: Battery Specifications and comparison

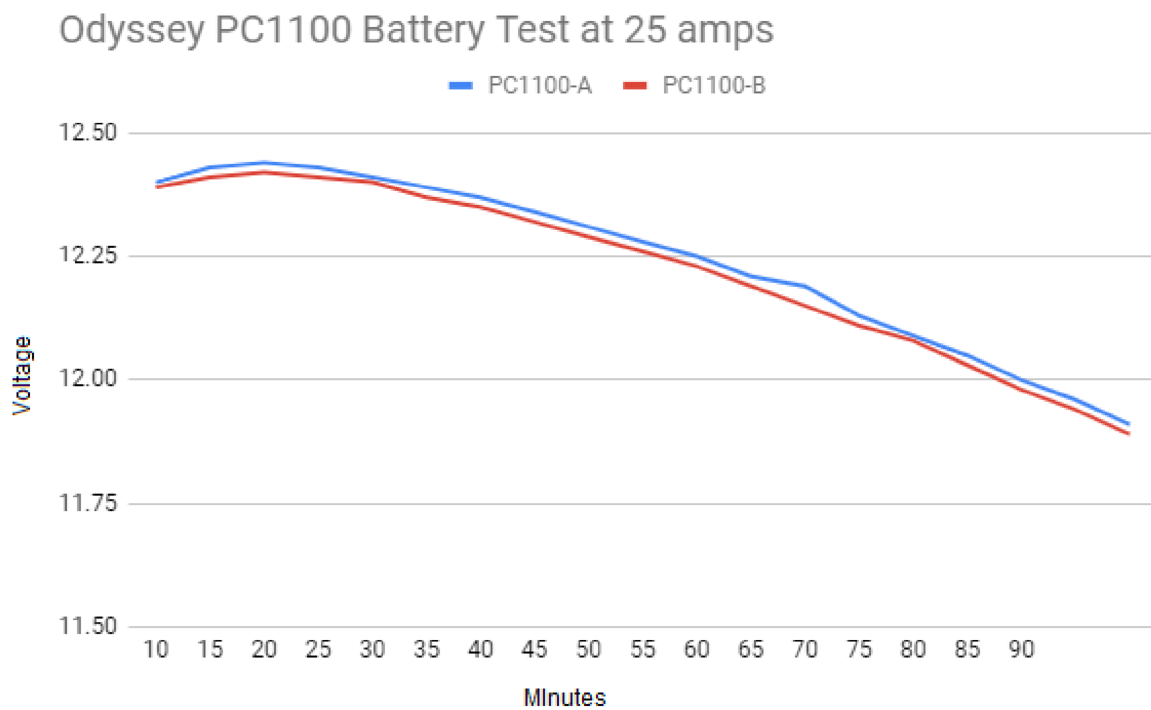


Figure 3: Data gathered on a PC1100 battery pair's voltage at constant 25 amps. Both batteries have a starting voltage of 12.45, after 90 minutes both have 11.90 volts. The PC1100 batteries where ran at 90 minutes to simulate Solar Cup's endurance event time.

A/B Switch

The A/B switch completes the circuit and allows control over specific components of the electrical system. As specified on the Solar Cup schematics, we decided to use a Cole Hersee model M-750 Serie Switch rated at 310 amps continuous and 6-36 volts (Technical Manual, 2019, p.14). We selected this model due to its flawless performance from last year, the compatible ratings, and availability in our shop.

The main motor and batteries system will be connected to the "1" of the switch while the solar array will be connected to the "2" of the switch. The "Both" option will allow both systems to run simultaneously, consuming power provided from both the live solar array and the batteries. This will be the option preferred for the competition because, as it draws power from two sources, it has the greatest stability.

Considering the rules and availability, we will be using the Cole Hersee M-750 Switch in our system for our upcoming competition.

High Current Fuse

To ensure the safety of the boat's electrical system, a fuse is used to prevent sudden surges of power from affecting the electrical system. When a current is stronger than intended, an internal conductor melts, rendering the circuit incomplete.

We purchased our fuse from the supplier McMaster-Carr but the name of the manufacturer was not specified. In our previous competition, our systems for the endurance heats pulled a constant 33 amps while our sprint heats pulled 200 amps at most. We decided to use a 250 amp fuse because our contactor relay can handle 200 amps continuously and our Alltrax motor control can handle up to 300 amps continuously. Our system will ideally run at most 200 amps meaning a 250 amp fuse is ideal and respecting the limit of a 350 amp fuse (Technical Manual, 2019, p.14).

Though it is more than needed, we use a 250 amp fuse for both the sprint and endurance heats to keep the boat and its systems safe and ensure that our boat does not fail during the competition.

Throttle

The throttle uses a potentiometer inside to allow control of the amperage entering into the system. In this manner, we will be able to control the amount of amperage supplied to the motor. The more amps entering the motor, the faster the boat will drive. In contrast, the less amps entering the motor, the slower the boat will go.

We chose to use an Electric 90-94 Potentiometer with Microswitch for EZGO Marathon as a hand throttle. A hand throttle seemed most effective as its handling position is familiar to the skipper, removing chance of error. For this reason, we did not opt for other types of throttles such as a foot throttle.

According to the way we programmed the throttle in the motor controller, the output is zero at the disengaged position. However, as the skipper pushes the throttle forward, the current allowed into the motor increases and so will the boats speed. To help the skipper, our mechanical team constructed a rotating, lightweight, and comfortable handle out of aluminum (Figure 4). This handle will attach with the throttle for maximum convenience and efficiency.

With the endurance and sprint events in mind, a hand throttle with a handle will be convenient, and keep our amperage constant and to have a relaxed feel to the skipper.

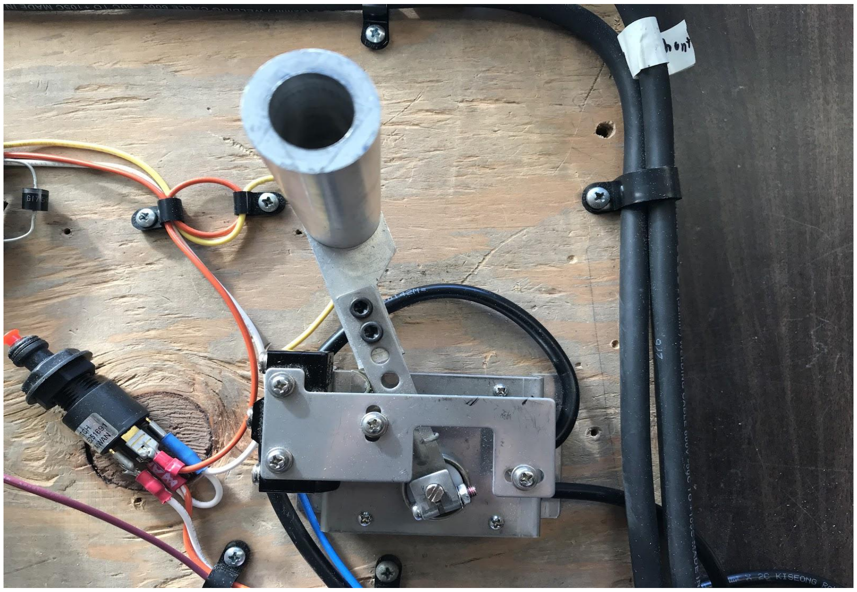


Figure 4: The throttle shown with the aluminum made handle attached to our simulation table.

Kill Switch

The kill switch, or deadman's switch, is one of the most vital parts on the boat, as this switch closes the circuit to the motor control, the throttle, and the contactor relay. In order for the circuit to close, the kill switch must be pressed down, resulting in a functional electrical system. However, if this switch is released, the circuit will continue to be open, and the current will not flow.

The kill switch that we are currently using on our simulation table is the Sierra MP40970-1, which is remarkably similar to the one shown in the Technical Workshop. We had a new kill switch from last year's purchases which will go into our simulation table. Our boat's official kill switch, however, will be the one provided in the Solar Cup technical workshop. This is because they are pre-sealed and made waterproof.

This kill switch will be kept pressed down by a proper red clip while the system is running. Our switch will be fixed to the side of the boat and the clip will be attached to the skipper's life vest. This ensures the safety of the skipper and of other boats in the event our skipper was to fall out of the boat.

Holding such a pivotal role in the maintenance of our system, the kill switch regulation of our mechanism is an overall a positive addition to safety and an adherence to the rules mandated by the technical manual.

Contactor Relay

A contactor relay, an electromagnetic switch often referred as a solenoid, is used as a safety provision to quickly open and close the current in a system. It shuts off the power to the load with a de-energized coil. A solenoid is powered by a precharged resistor which energizes the coil in the contactor relay if the circuit was closed by the killswitch (Technical Manual, 2019, p.14). It is extremely pivotal to our system and allocates current for other equipment on our boat such as the kill switch and motor controller. As recommended by the technical manual (Technical Manual, 2019, p.14), we chose the MZJ-200D solenoid manufactured by Altrax which allows for the flow of 200 amps at a continuous rate, and an 800 amps in surge into the system. The sprint pulls, at most, 200 amps, while the motor is rated for 100 amps. This, along with its 48 volt rating for our 24 volt battery, are both threshold that provide flexibility for our system.

Motor Controller

We are utilizing the Alltrax SR 48300 motor controller for this year's electrical system. Fortunately for our team, we have developed a relationship with the manufacturer, Alltrax, resulting in a generous donation of two SR 48300s.

The selection of Alltrax motor controllers embodied various shapes, sizes, voltages, and amperage choices. The SR 48300 is rated for a maximum of 300 amps and is able to run a system of 24-48 volts. It is safer around water and the terminals are separated to allow for better organization. This model also had a familiar structure when compared to last year's motor controller, which made wiring and programming the motor control fairly easily. For the competition, our team will set the SR 48300 at 200 amps and run it on two 12 volt batteries as the rules specify.

Motor

A DC motor is an electric motor that requires direct current power, such as batteries, to operate. In a DC electric motor, the rotation is dependent upon electromagnetism or an electric field. This, overall transforms electrical energy into mechanical energy. This works as a current conductor placed into a magnetic field which then experiences a force with the internal brushes resulting in the rotation on the axle. This process takes place as the “motor”.

This year, we considered the Etek 24 Volt Electric Motor and the ME0909 Brush Motor. The Etek 24 Volt Electric Motor is a DC motor that weighs 21 lbs at most with a torque of 32 ft-lbs. This motor was used by our team in the previous year but has now been discontinued, meaning that we will be using an old motor from our previous years.

The ME0909 Brush Motor manufactured by Mars Electric is the one we used last year, and the one we will use for Solar Cup 2019. The size of the motor is acceptable, and its weight, torque, and phenomenal efficiency that ran unrivaled with only 5 hours of use at most. The weight being 24 pounds with a torque at 25 lb/in, it is adequate to propel efficiently in water. In addition RPM of 2200, as last year we had no issues with the motor being too weak to tread through the water resulting in it selection for this year's competition.

Motor	Weight (lb.)	Type of Motor	Rated Voltage	RPM	Torque
Etek DC Motor	21	DC	24-48V	72 per Volt	32 ft-lbs
ME0909	24	Brush, DC	24-48V	2200 at 30 amps	25 lb/in

Figure 5: The important specifications of the motors we considered

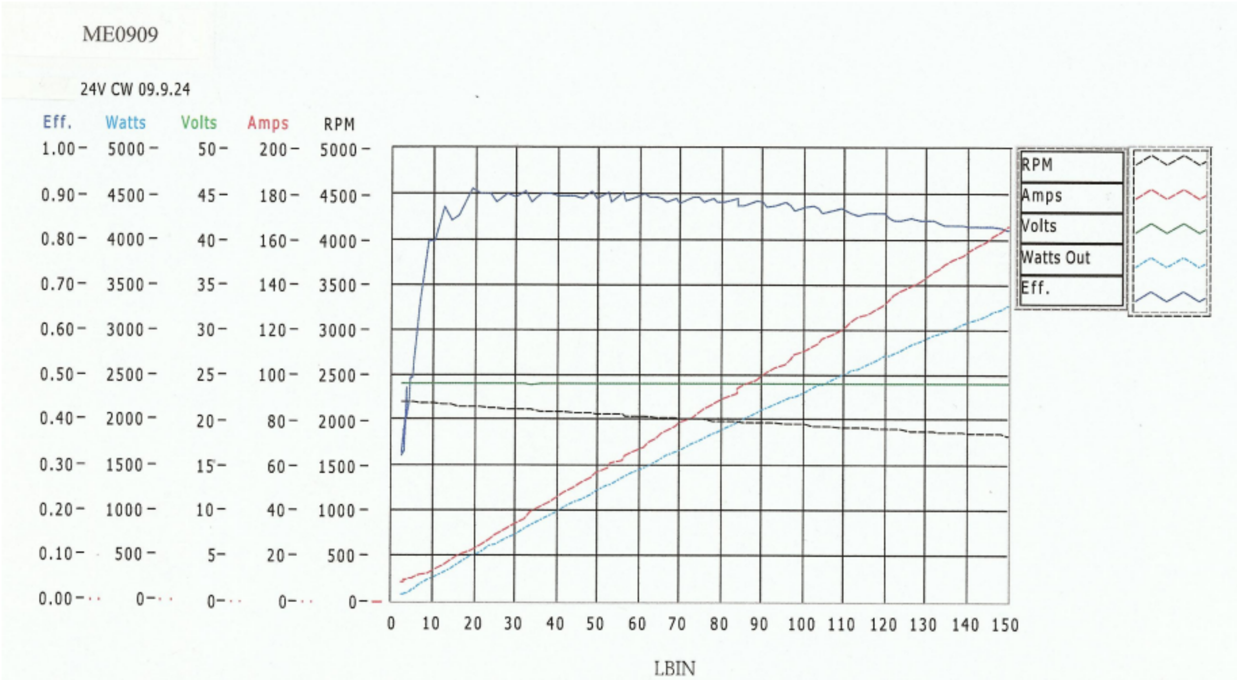


Figure 6: The performance curves of the motor we chose to use ME0909. In between 20A and 40A, the efficiency is excellent.

Shunt

A shunt is a precision resistor that is rated on a certain amperage allowed in, a property that can be measured. Our shunt operates with a 1:4 ratio in regards to millivolts and amperage. This means we will use a multimeter to read the millivolts, which is directly proportional to the amperage flowing through the system. The millivolt indication allows us to compare ratings recorded in our discharging station and maintain a constant speed throughout the endurance heats. The shunt we are going to use is rated for 350 amps, a generous approximation for the theoretical 200 amps that could be pulled.

Solar Panels

When making the decision as to which solar panels to use, we had three candidates. We considered the Photowatt International PW 750-80W, the BP Solar SX160, and the Renogy 160 Watt Flexible Monocrystalline solar panels, to maintain our 320 watt system.

The PW 750-80 panels have a maximum capacity of 80 watts, meaning that four panels would need to be purchased and fixed upon the boat to meet the required 320 watts. Since each panel weighs 17.2 lbs, the total added weight would amount to 68.8 lbs (Posharp, 2018). In addition to the physical hindrance, our team would suffer a loss of $400, since we do not yet own the panels. If we were to use these panels, we felt that the size and weight would create sluggishness. In addition, mounting them would burden our mechanics with extra work.

The BP Solar SX160 panels have a maximum capacity of 160 watts each, meaning that we would only need two units. Two units happen to be in our stock, so we would be able to spend $500 on other necessities. Each panel unit weighs 33.1 lbs, so two of these panels would add 66.2 lbs to our boat (Solar Design Tool, 2018). While we might save money, we would have to pay the price of speed during the competition. The extra cash does not outweigh the cost of racing performance.

The Renogy 160W Flexible Monocrystalline solar panels have a maximum capacity of 160 watts each panel. We purchased two of them of them for last year's competition, which means that we would not have to spend $600 this year. Each panel weighs 6.2 lbs, meaning that the total weight for two of them would amount to 12.4 lbs (Renogy, 2018). This weight is miniscule when compared to our other options. Overall, this option will bring us preferable results and will be used in our final product.

Solar Panel	Power	Weight	Price
Photowatt International PW 750-80W	80 watts	17.2 lbs (7.8Kg)	$99.99/ Panel
BP Solar SX160	160 watts	33.1 lbs (15kg)	$249.99/ Panel (Already Owned)
Renogy 160W Flexible Monocrystalline Solar Panel	160 watts	6.2 lbs (2.8 kg)	$299.99/ Panel (Already Owned)

Figure 7: A comparison of the solar panel specifications we considered this year

Solar Charge Controller

The solar charge controller is a device in our system which will give us the control over the voltage going in and out of our solar array. This prevents malfunctions in the flow of electricity into the solar panels and batteries. We first thought of the Outback FLEXmax 80, but we then deemed unusable as it required power beyond the 320-watt limit and weighed too much, measuring at 12.2 lbs. We later narrowed our choices to either the Blue Sky Energy Solar Boost 3024i or a Xantrex C35 since the two met the requirements for use and are available in our shop. The Xantrex C35 was tested and gave back poor results as the power given were significantly low making the the Blue Sky Energy Solar Boost 3024i our solar charger for this year..

Bilge Pump

Our team decided to use the Seaflo Model SFBP1-G750-06 (also referred to as the Seaflo 06 Series 750 GPH Bilge Pump), as it has many advantages over the Johnson Pump Cartridge, which our team utilized last year. The Johnson Bilge Pump can pump 500 gallons per hour, but failed to remove all the water from the boat and the tubing last year, so this year our team will utilize another pump (Technical Report 2018, p. 12). The Seaflo meets all the rules specified for a bilge pump, which require it to be pump at least 500 gallons per hour, run and utilize a float switch (Technical Manual, 2019, p.13), and have its own batteries to power it for a minimum of two hours (Technical Manual, 2019, p.13). This model has a rating of 750 GPH, meaning it will pump 50% more water out of the boat compared to last year's pump (Seaflo). Because of this, our team will power the Seaflo pump with SLA-12V5-F1 batteries. This means that this year's pump will not only be more powerful, but also more efficient, pumping much more water while using the same voltage. This pump also comes with a float switch built in, which avoids many potential issues involving switch compatibility, malfunction, occupied space, and price. This built-in switch is yet another improvement upon last year's pump, which required us to purchase a separate float switch to function. The Seaflo pump meets all the contest requirements and greatly improves upon last year's pump, making it an obvious choice for our team to utilize in the competition.

Wire Size

The size of wire dictates the amount of amperage that flows through the system. The higher the gauge (AWG), a unit of measuring wire, the smaller the diameter will be. Smaller wires force resistance into the current passing by. Using thinner wires risks overheating and can potentially melt the wire. A larger diameter allows more amperage to enter the system and prevent overheating. For higher voltage systems such as ours, this results in the most effective use of our batteries allowing more amperage to flow while preventing our system to overheat. With our 24 voltage system on the boat, we will use 2 AWG, a thicker wire, allowing us to run endurance at 30 amps for 90 minutes without any issues (Figure 7). The solar panels and charge controller will use 6 AWG to allow a considerable amount of energy back into the batteries. The smaller wiring required will use 20 AWG as recommended on the schematics and usage on past boats.

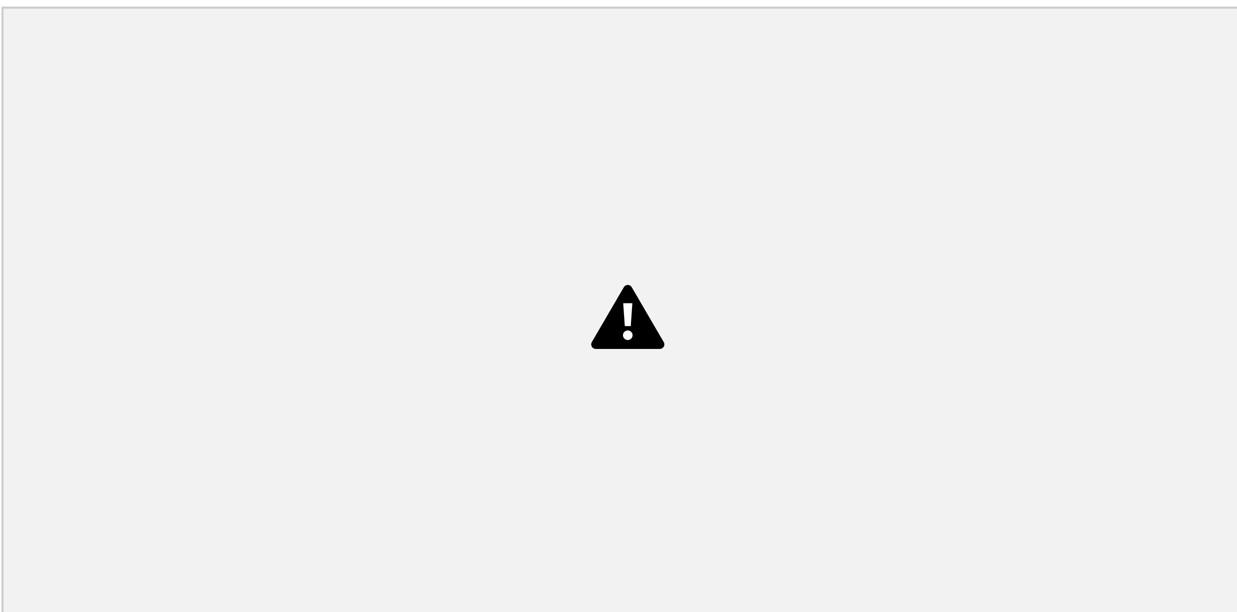
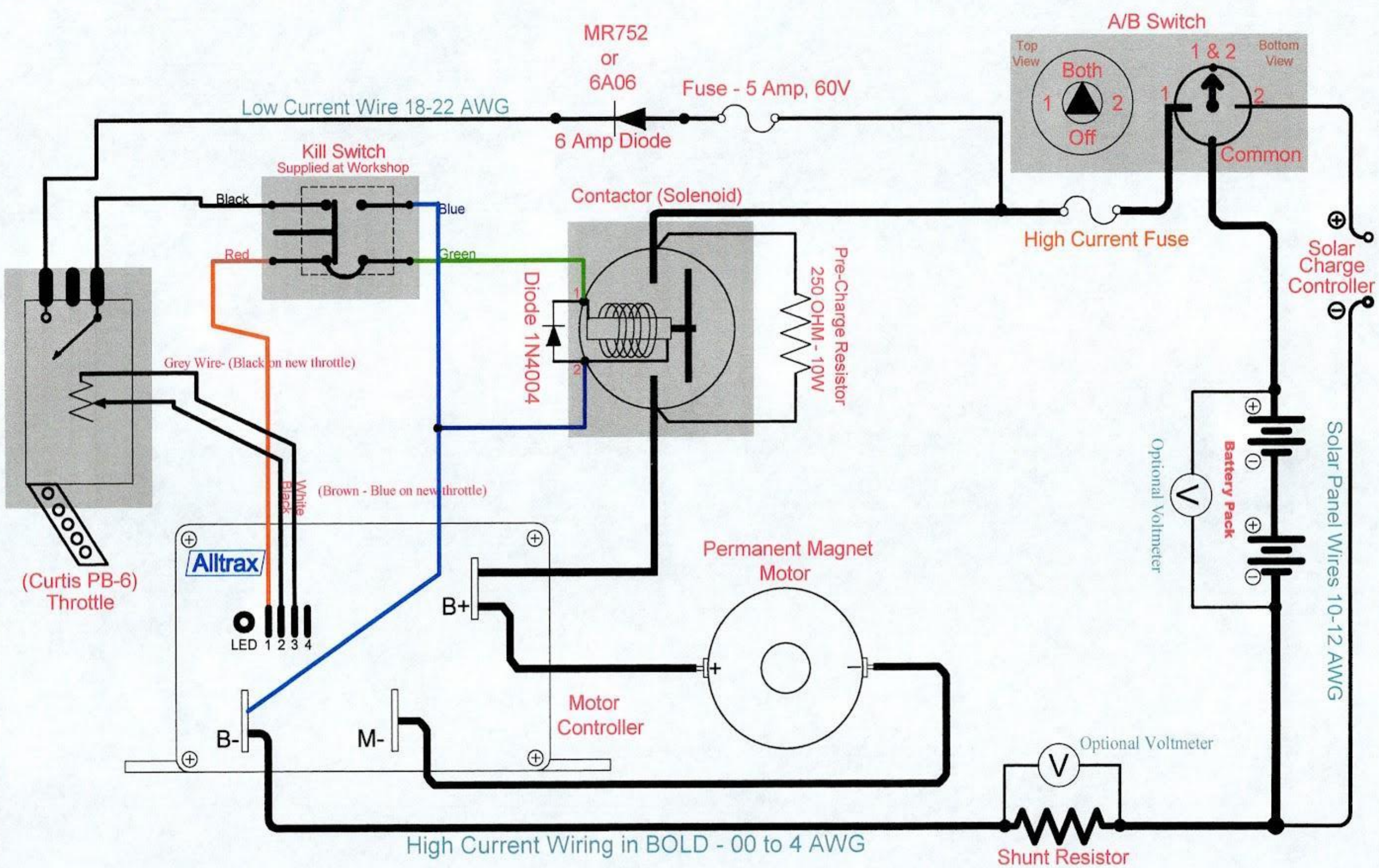


Figure 7: Wire diameter needed for a given amperage and feet chart

Electrical Schematic

The electrical system schematic is the same as the one recommended by Solar Cup because we knew this system worked well due to the success of past years. This system is easy to assemble allowing us to create our simulation table early in the year and the relatively inexpensive parts allow us to have a bigger budget.



Controller Pin Out

- Pin 1 = KSI Voltage
- Pin 2 = Throttle
- Pin 3 = Throttle
- Pin 4 = NC
- B+ = Battery Positive
- B- = Battery Negative
- M- = Motor Minus

Notes

1) Fuses required for all boats
2) Diode required across coils
3) Pre-Charge resistor required
4) Kill switch required
5) Foot switch is normally open
6) YOU MUST refer to the ALLTRAX manual for up to date information

Revision History

Rev	Date	Description

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Department: **Solar Cup - 2018**

Part Number: **Brushed PM Motor**

Drawing: Solar Cup Electrical Schematic_2018.tcw REV E

Drawn By: CO DATE 10/07/17 SHEET 1 OF 1

Solar Panel Schematics

The schematic we will be using for our solar panels is from the Blue Sky Energy Solar Boost 3024i solar charge controller. Our previous year we modified this system and we took out the ground all together because we found in our tests that too much of the current was going to the ground rather than powering the whole system. With last years performance and success in our solar charging throughout the year, we feel confident in our modified solar schematics.

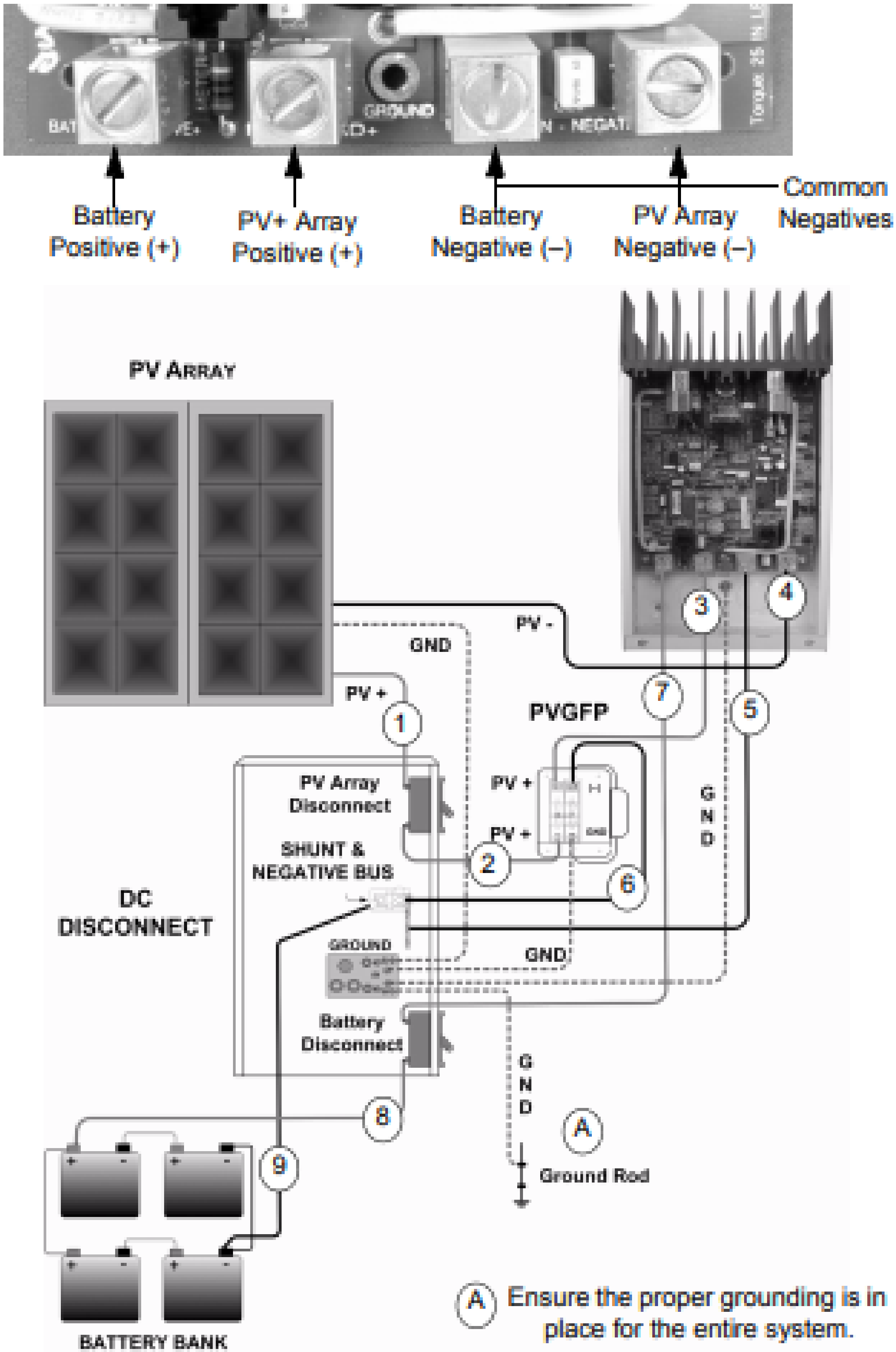
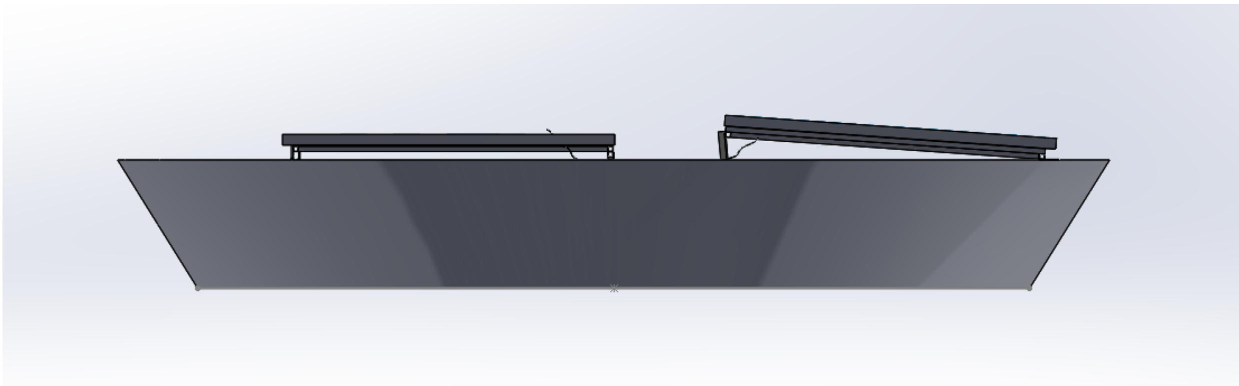


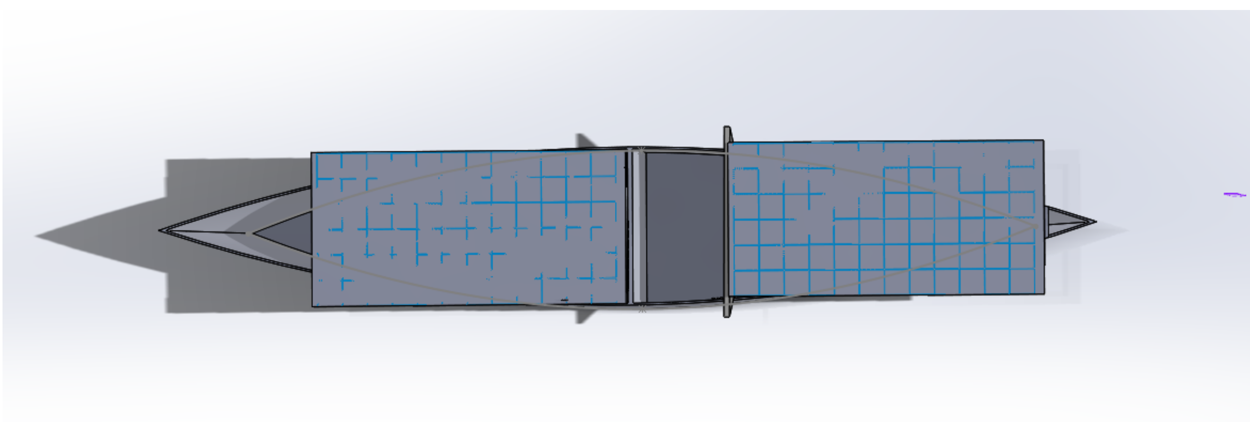
Figure 2-23 PV Charge Control Mode Wiring

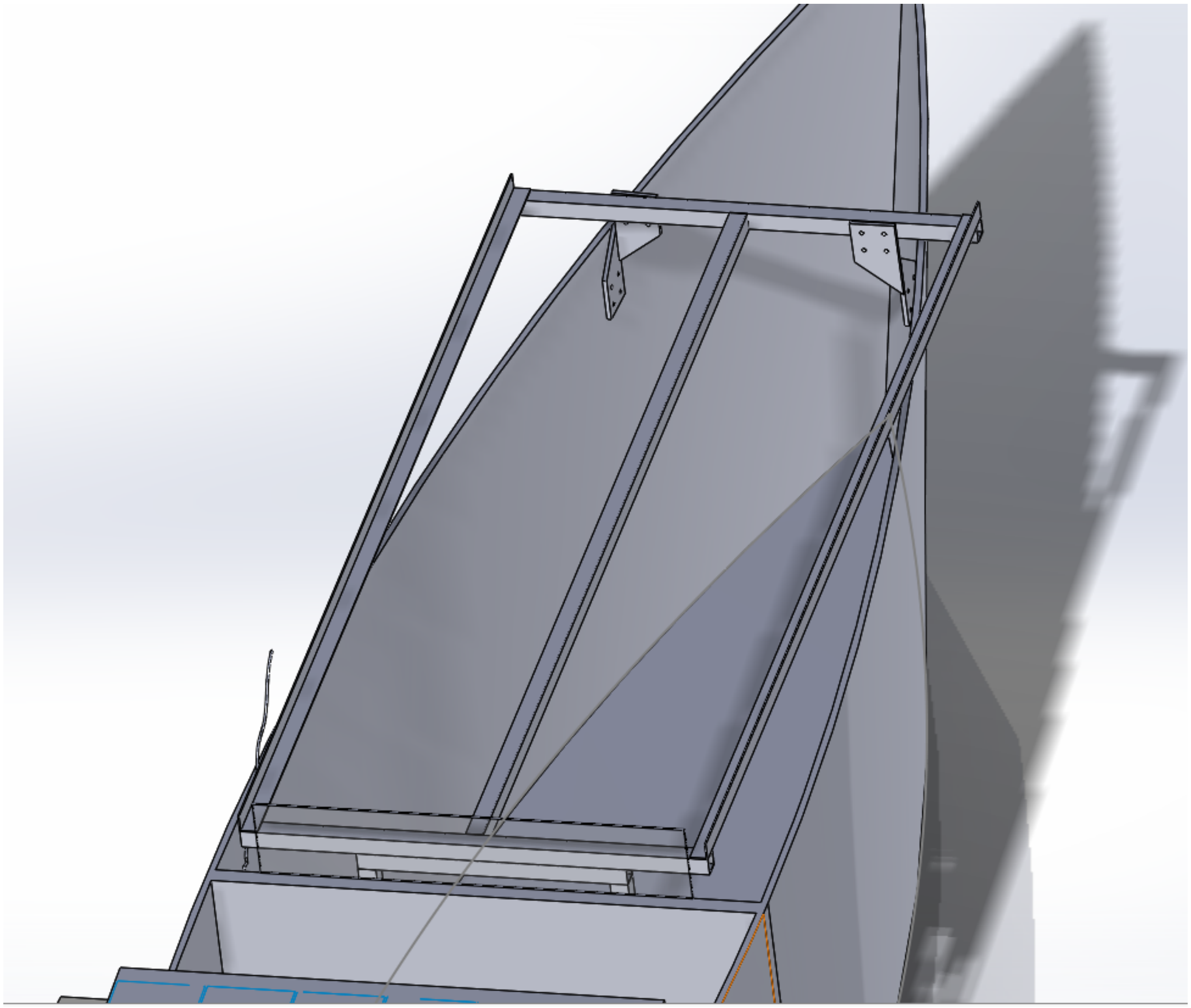
Boat Drawings

Below: side view of the solar boat with the panels on top and the lanyard attachment on the inside of the boat.

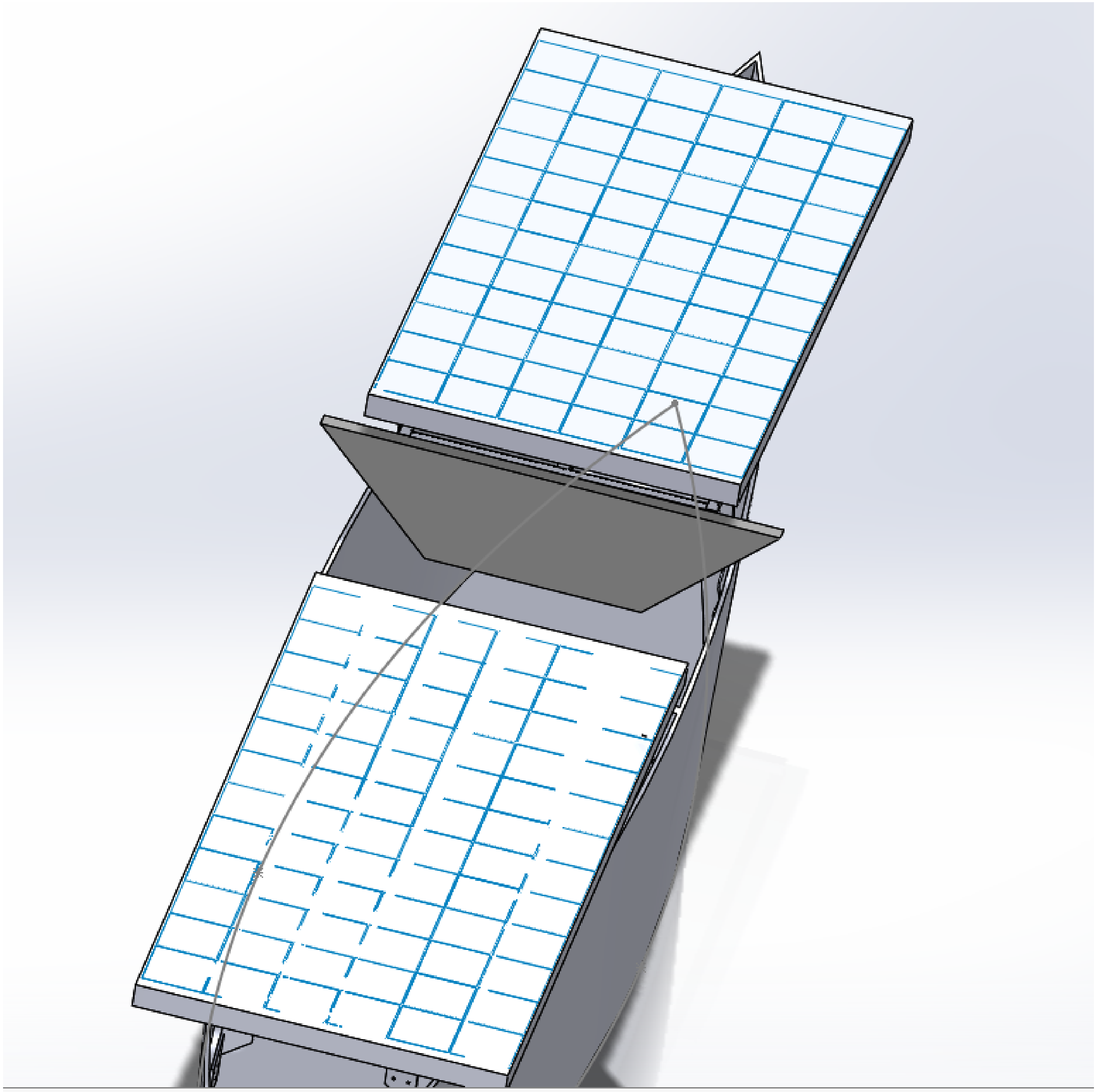


Below: Top view of the boat with panels on the aluminum bars and attachment to the inside of the boat.

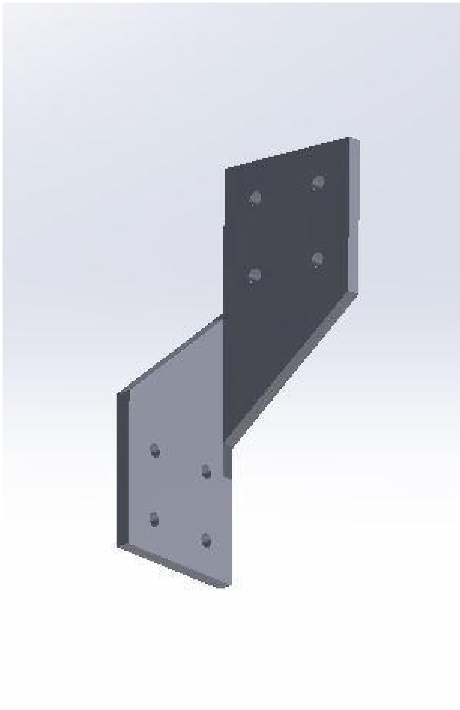
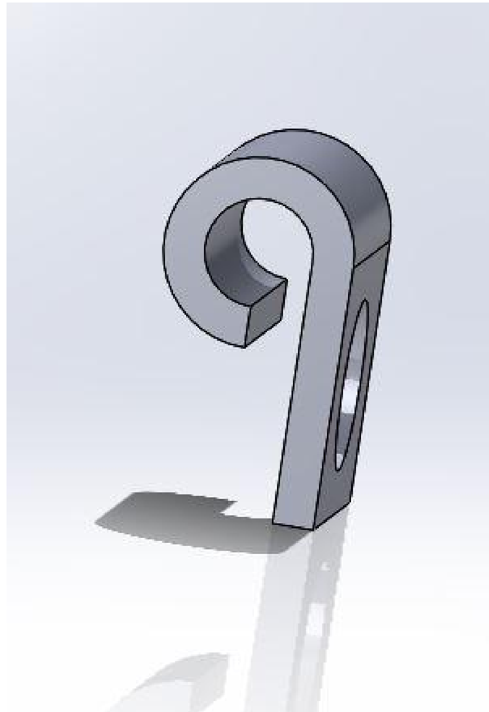




Above: view of the solar panel without the panels on. We will secure the panels with 2 aluminum bars and 4 hurricane ties on both the stern and the bow, to keep the solar panel assembly from moving around during the race. The lanyard will then attach directly to the panel in case they fall off.



Above: view of the solar panels on top of the before mentioned aluminum bars and hurricane ties.

Above Left: hurricane tie

Above Right: lanyard hook attached to the boat

Conclusion

After our performance from last year along with this year's experience, we have grown together as a team setting our expectations high and meeting them. Our new members have brought significant work into the competition demonstrating their determination with leadership keeping everyone on track. With only a year of experience after a 7-year hiatus, we are aware of what to expect and proceed with excitement and confidence. Even with confidence and growth, we have kept the saying of previous teams before us, “The success of our team will be determined not by how intelligent we are, but by how well we communicate with each other” with this in mind we will continue and grow our program’s legacy.

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