



*GENEVA COLLEGE*  
*DEPARTMENT OF ENGINEERING*

*Senior Capstone Design Project*  
Participating in the 2017 Solar Splash Competition  
June 7 – 11 in Springfield, Ohio



# Technical Report

## Boat # 11

08 May 2017

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## EXECUTIVE SUMMARY

The goal of Geneva's 2016-2017 Solar Splash Team is to place in the top three at the upcoming competition. To accomplish our goal, this year's team will improve sprinting capability and performance, while maintaining endurance capability and performance.

Our team consists of six mechanical engineering students, and one interdisciplinary engineering student. Each member of the team was tasked with improving different sub-systems of the boat in accordance with the main goals. The various subsystems for improvement this year included the drive system, the solar array, batteries and power supply, data acquisition, and hull design. Two faculty advisors, both mechanical engineers, oversaw the project and provided appropriate direction and consultation.

For achieving the goal of improving sprint conditions, some areas of study were weight distribution and overall weight reduction. Analysis of the current hull's center of gravity helped us determine the need for a lighter boat and a different center of gravity to improve top speeds. Hull analysis also led to the design of a small keel to improve fluid flow and planing ability. This modification allowed the opportunity to improve the overall skin friction of the hull by applying a new exterior coating.

In regards to overall weight, every member of the team was tasked to eliminate unnecessary weight in their subsystem. There was a weight reduction of 10 lbs. from replacing the top coat of the boat. A critical area for weight reduction was in the gear plate, where a 40% weight reduction was achieved. Removing unnecessary wires and connectors in the old data acquisition system also reduced the overall weight.

In removing the old data acquisition system, a new and simpler design will be implemented for the competition. The four displays visible to the skipper, which were useless last year, will now display amp readings from the three solar array segments and the overall system current. An overall voltage display will be installed where the peak power tracker display used to be housed. These various displays will greatly aid our monitoring of overall performance during testing and the competition.

The need for a new data acquisition system also resulted from this year's team goal to implement new solar panels. This new system will greatly increase charging capacity through the use of more efficient solar cells and an optimized layout. The final rated output will be just under the allowed maximum of 528 Watts with our maximum being 518 Watts. The new arrays, having easy connections, will also improve on-shore charging.

A change in the support strut for the steering reduced the drag force by at least 10 lbs. at sprint speeds. The support strut for the drive shaft was also streamlined, again reducing the overall drag the boat experiences at sprint speeds. The foils used to streamline the struts were modeled and printed with a 3D printer.

The system utilizes two Motenergy MEE-909 Brush Type permanent magnet DC motors. The motors are used in tandem in the sprint competition while only one motor is used during the endurance event. The motors are capable of sustaining up to 300A for 30 seconds and operate from 12-48V. Curtis 1205 motor controller allows for an increase in maximum system voltage up to 800 amps of current.

The Optima and CSB batteries we have used at competitions underwent various testing to determine their viability for use in the competition. The main area for testing was the discharge rate under high and low loads. Discharge testing was performed with the goal of determining a Peukert constant for the two different batteries. It was determined that the CSB batteries would perform better during endurance and the Optima batteries were better for endurance. New batteries were purchased accordingly for this year's competition.

A prioritized budget aided decisions on purchases so that each area of necessary improvement would keep designs in relative balance. A cost baseline was established in the fall to help fundraise and prioritize the use of our budget. Priority was given to the new batteries and solar panel materials.

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## I. Overall Project Objectives

The Geneva College Solar Splash team has placed an emphasis on the performance of the hull during the sprint event. To improve the team's placement in the competition, by scoring higher in all events, the team has focused primarily on the speed characteristics of the design. Although previous years had made modifications, there was still room for improvement and optimization. Any alterations to the current hull design were limited in order to keep the endurance capabilities of the design, since our hull is currently optimum for endurance runs. The main design goals for the hull would also affect the other areas of the boat.

In addition to hull optimization, improvements in the sprint event required members of the team to design and manufacture propellers, lighten the overall load of the boat, and streamline the existing drive train system. There are various parts to our drive train and motor system, and many of the parts were able to be lightened and have improved fluid dynamics.

One of our project goals includes the design and manufacture of a propeller for our sprint configuration. Geneva College has a CNC mill which has the capability to machine a propeller and the goal was to design and manufacture the propeller in house. Although other options were explored, manufacturing the propeller ourselves was chosen.

The team has modified the battery power for the different competition events by using a 36 volt system for sprint runs, and a 24 volt configuration for endurance. Through careful research and testing, we selected two different sets of batteries to use, one set for sprint and another for endurance. Each set was chosen to best fit the needs of the given race.

A final goal for this year was the fabrication of new solar panels and to elimination the need for a peak power tracker. Through the designing of a new solar panel system, our goal was to be able to create a system that could optimally charge batteries efficiently enough to eliminate the need for a peak power tracker, thus creating a simpler and more efficient system.

In summary, the team's goals are to improve the overall performance in the competition by focusing on sprint performance. This focus lead to an improvement in hull design, lighter drive system, new propeller, and new solar panels. By placing higher in the sprint and endurance events, our goal is to improve and win the competition.

## II. Solar System

### A. Solar Panels

**1) Current Design:** The current solar panel system is two years old. The system is composed of six main solar panels consisting of 36 cells connected in three parallel banks with one additional solar panel with the same number of cells that is divided into three sections. This additional panel serves to raise the voltage of the other setts to their target voltage. These panels were designed to charge a 24 volt system. Each solar cell produces approximately 0.56 Volts open circuit and approximately 4 Amps short circuit. This results in less than 2.25 Watts at maximum peak power as that value comes from the maximum voltage and current, but those conditions cannot exist simultaneously. Based on some of the voltage vs. current curves that are

available, the maximum peak power is estimated to be approximately 78% of 2.25 Watts, or 1.77 Watts.

The most prominent issue with the current solar panels is that several of them have broken cells and no longer function. In addition to this, the panel system was designed to charge and operate a 24 Volt boat system and our team wants to upgrade to a 36 Volt system. Although the panels may be able to reach 36 Volts, the cells are two years old and do not produce much power when compared to newer available solar cells.

Initially, the team wanted to know if the system should be repaired or replaced, but after seeing the power produced by newer cells, we decided that the panels should be completely replaced. In addition to upgrading to a 36 Volt system, the cells likely only produced 396.48 Watts based on the 78% of the fictional maximum power assumption made in the overview section. Because student built panels have an allowable limit of 528 Watts, the team desired to get as close to the maximum allowable value at maximum peak power as possible per Solar Splash rules.

**2) Analysis of Design Concepts:** For the new design, a similar panel lay out as the old panels will be used. There will be three solar panel banks that will be connected in parallel. Each bank will consist of two panels. Each bank will then connect to a seventh panel that will be divided into three sections. Unlike the previous design, the new panels will not have their cell columns soldered together. Instead, there will be a series of plugs that will be used to connect them. This will allow the wiring to be altered quickly and easily for both off and on shore configurations. The intended design can be seen in Fig. 1 and Fig. 2 respectively below. With the new cells the panels should produce approximately 518.4 Watts at maximum peak power for a 36 Volt system based on the manufacturer's data sheet that can be seen in Appendix E.

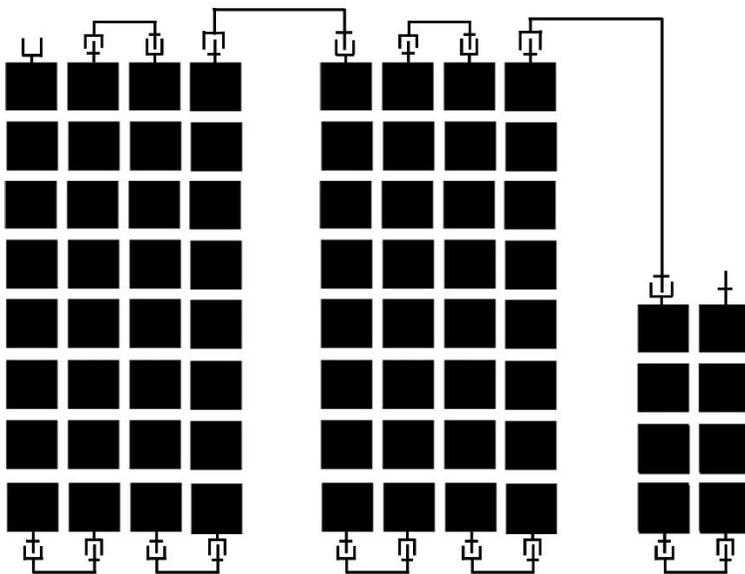


Figure 1, Off Shore Configuration

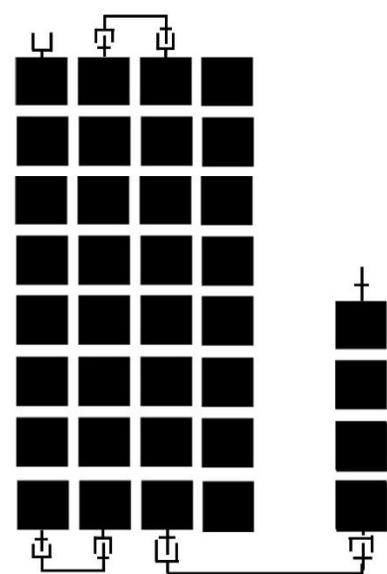


Figure 2, On Shore Configuration

There were several different solar cells that were considered, however, none of them allowed us to get close to the desired power production limit of 528 Watts. The three other solar cells produced 6 to 8 Amps at maximum peak power, which would produce too much or too little.

There was one other design considered for these cells that would have worked just as well as the design depicted in the previous section that only required six panels instead of seven. However, this design adds an additional row of cells to the main panel design and would have required that our aluminum frame be widened to accommodate this. Therefore, to avoid unnecessary modifications, the design in the previous section was selected.

Because the team intended to use a 36 Volt system to power our boat, and the limit for solar power production is 528 Watts, the maximum limit for current output can be calculated for the solar panels, and by extension the solar cells.

Because the cells within the panels and the panels within the solar panel banks are connected in series, then the maximum allowable current for each cell can be found by dividing the total allowable current for the system by the number of solar banks.

$$\text{Equation I: } P = VI_{total} \rightarrow 528W = (36V)I_{total} \rightarrow I_{total} = \frac{528W}{36V} = 14.67A$$

$$\text{Equation II: } I_{total} = I_{cell} \cdot n_{parallel} \rightarrow I_{cell} = \frac{I_{total}}{n_{parallel}} = \frac{14.67A}{3} = 4.89A$$

Because the other solar cells produced more current than this they could not come close enough to the desired output. The cells that we are using however, produce 4.8 Amps at maximum peak power and come closer to the limit than any other cells that I could find.

**3) Design Testing and Evaluation:** When the panels are built, we plan to construct the main panels by using a thermoplastic honeycomb core material for the backing material. The cells will be connected by soldering together four sets of eight cells for each panel. The ends of each cell column will have insulated wire soldered on instead of tabbing wire to connect the plugs to. After the cells are arranged on the backing material, they will be held on by heat shrinking EVA film around the panel. The plugs will be epoxy glued to the bottom of the panel to avoid catching on something and ripping off.

Before construction, each cell will be tested in direct sunlight to ensure that it meets the advertised specifications. This will be done by checking their open circuit voltage and carefully checking the short circuit current, being careful not to burn it out. To test the operating output, they will be connected to an appropriate resistor to try to produce the advertised peak power. When the panels are constructed, they will again be placed in direct sun light and tested a second time using the same method. This will also serve to indicate if there are any broken connections within each panel.

### III. Electrical System

#### A. Wiring Configurations

**1) Current Design:** We run two main electrical configurations, one for the sprint competition and one for the endurance competition. The cables utilized in the electrical system are 00 gauge welding wire; with  $0.261 \Omega/\text{km}$  resistance and are rated up to 600 Amps. Current placement of the batteries has been in the near the bow of the hull. Since the boat is over 16' long and two harnesses are needed, there is a considerable amount of wire in the bottom of the boat. The second crucial part of the system was the battery charging system which was comprised of our solar panel configuration and the associated wire harness that connects to the batteries. Our solar panels are split into six individual panels that fit into the fabricated aluminum frame which sits on the deck of our boat. The solar panels are only used for the endurance race. The wire harness for our solar panels currently have leads that go to our battery terminals, but will need to change with the new solar panels. The final critical system that falls into the overall electrical layout in our boat is the peak power tracker. The purpose of the PPT is to read the incoming power from the solar panels (input) and then determine the optimal power to send to the batteries so they can maintain a healthy charge. The PPT also has a CAT5 port to run a data cable to the display panel that is housed in the dash. This allows the skipper to clearly see the power supply and output running through the system.

#### 2) Analysis of Design Components:

While each of these systems had benefits, they also needed much improvement for this year's competition. In the power supply system, our main area of concern was reducing the amount of wire by either 1) reconfiguring the existing wire harnesses or 2) creating new wire harnesses from scratch. Excess cables in the bottom of the boat creates an obvious tripping and entanglement hazard to the skipper in case of cap sizing or another emergency. Another issue that had presented itself comes out of the charging system. This year we fabricated new solar panels and along with these new solar panels we needed to create new wiring harnesses since we no longer are using the peak power tracker.

The first area that needed improvement was the wiring harness for connecting the batteries to the motors and motor controllers. As previously mentioned, the existing harnesses used  $\frac{1}{2}$ " welding cable. We determined to continue to use the welding cable because the  $\frac{1}{2}$ " diameter wire provided sufficient current capacity and it was readily available. Also, budget constraints were an important factor, as much of the budget was dedicated to new batteries and panels. The new harness will be constructed in nearly the same

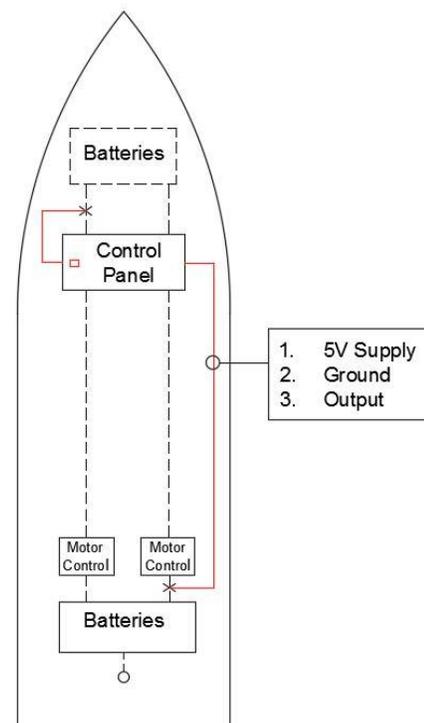


Figure 3, Main Configurations

fashion as the old but with reduces amount of wire in the boat for safety. This task includes measuring and dry fitting all the cable to length for both sprint and endurance battery configurations and then crimping on custom made copper fittings to connect to battery terminals and motor controller terminals. Along with redesigned wiring harnesses for the power supply system arose the need for new wire harnesses in the charging system. Since we are fabricating new solar panels we needed to create new wire harnesses for the solar panels. The harnesses will be fitted with quick connect connectors like the Molex connector (see Appendix N) so that panels can be inserted in series or parallel depending on the situation they are needed for. The wire used for the harness will be 4-gauge copper wire. The harness will have connections to hook into the battery terminals on the opposite end of the solar panel quick connects. The current design can be seen in fig. 3.

**3) Design Testing and Evaluation** Before implementing the designs to the electrical system, some testing was necessary. When it came to testing for the wire harnesses, there was not much that could be tested except for the basic system mockups. Most of the information for determining the harnesses came from past experiences of our teams and advisors.

### **B. Motor Controllers**

No changes were made to the motor controllers for this year's design. Since 2015, two Curtis 1205 24V/36V 400A motor controllers have been used to run the motors, with a throttle control accessible to the skipper. Both motor controllers are used during the sprint event. Only one is used during endurance event. A picture of the motor controller is shown in Fig 4.



Figure 4, Curtis 1205 Motor Controller

## **IV. Power Electronics System**

### **A. Batteries**

**1) Current Design:** Previous teams have used several different types of batteries for the Solar Splash competition. Many teams have used Optima REDTOP batteries. These are large 12-volt batteries with a high cold cranking amps rating. They are also durable. A previous team did research and testing on a CSB EVH12240 battery. They are much smaller and weigh approximately half as much as the Optimas. They used four of these 12-volt batteries to reach the desired nominal voltage of 24 volts for the endurance competition. Two batteries were connected in parallel, and two sets were connected in series. Another set of two was added for the sprint competition to accommodate the 36-volt configuration. The total weight of six CSB batteries is 99.84 lb (45.29 kg). Using six smaller 12-volt batteries was beneficial for the previous team for two reasons. They could get closer to the 100 lb (45.5 kg) limit, and they could switch between a 24-volt and 36-volt system. This year's team wanted to determine which type of batteries to use for each competition, and purchase new ones if necessary. The budget for the project was also a concern, so it was crucial to use an inexpensive design.

**2) Analysis of Design Concepts:** This year's team set out to develop a new solar panel system. The new system would not require a peak power tracker to be incorporated into the design. This removed the 24-volt restriction on the previous team's system in the endurance setup. This year's team inherited 12 Optima batteries and six CSB batteries from previous teams. The new system would be a 36-volt system for both the endurance and sprint competitions which would require at least three Optima batteries or six CSB batteries. Each Optima battery was tested to determine its viability for competition. A resistor bank was used to drain the batteries to 11 volts, which is approximately 50% discharged. The Optima batteries are closest to the C/3 curve. C is the rated capacity in amp-hours, and the C/3 curve represents a battery that is discharged at a current that is 1/3 of the rated amp-hour capacity [1]. The rated capacity of the Optima batteries is 44 A-h. The resistor bank creates a current of between 17 and 19 amps. That is approximately equal to the current that the motors will draw from the batteries in the endurance competition. Previous testing from when the batteries were new showed that the test should have lasted about 90-100 minutes. The results of the tests revealed that only one of the 12 batteries would be acceptable for competition.

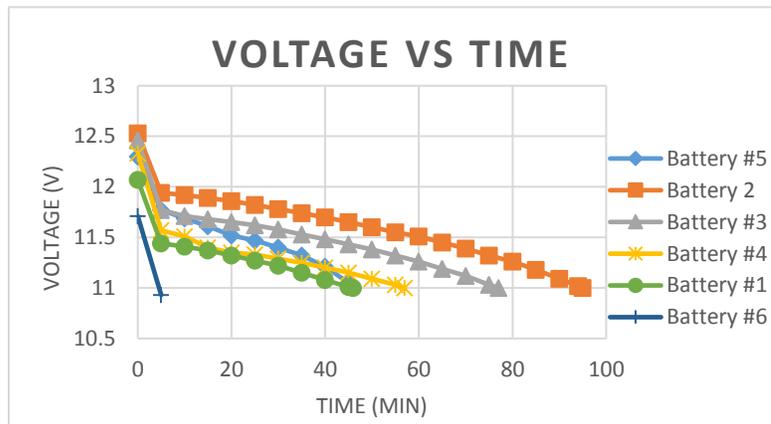


Figure 5: Optima Voltage vs. Time Graph 1

Only three others lasted more than 50 minutes. A graph of terminal voltage over time for six of the Optima batteries is shown in Fig. 5. Only six curves are shown in the figure to preserve clarity, but the rest can be found in Appendix F.

The six CSB batteries were used for the endurance and sprint competitions by the previous team. These smaller batteries are not as durable as the Optima batteries. The rapid discharge of sprint events in addition to the deep discharge of endurance events caused the CSB batteries to be less than adequate for this year's team. The batteries had also been left sitting in a deeply discharged state, which caused more damage. Even after a substantial amount of time on the charger, the CSB batteries began self-discharging at a much higher rate than is acceptable. The most promising CSB battery had a starting voltage of 12.2 volts, and previous data shows them starting closer to 13 volts. The CSB battery was tested in the same manner that the Optima batteries were tested. The test lasted only 19 minutes. Therefore, it was concluded that none of the CSB batteries would be suitable for competition either.

**3) Design Testing and Evaluation:** The selection of batteries for each event was made by using Peukert's Law. Peukert's Law is described in more detail in Appendix F. Peukert's constant is found using this equation  $t = H(\frac{C}{I})^k$ . This constant, k, is a property based on the type of battery, and it relates the time to discharge for the same battery at different currents. A low Peukert's constant means that the battery's behavior will be closer to that of an ideal battery.

An ideal battery would discharge in half the time if the current was doubled. The previous team determined the Peukert's constant for the CSB batteries to be 1.06 as shown in Appendix F. An Optima battery was tested to determine its Peukert's constant, found to be 1.19. The Peukert's Law equation can be rearranged to find the discharge current of a given time period, like 2 hours to simulate the endurance competition. The optimum discharge current for the Optima battery is 15.3 amps, and the CSB's is 21.1 amps. These currents along with the average voltage values were used to calculate the total power that each battery could produce in a 90% discharge over a 2 hour period. A 90% discharge is about 10 volts for these batteries. The power data can be seen in Fig. 6 below. The CSB batteries produce just over 70 more watts than the Optima batteries.

			P=V*I	Units		E=P*t	Units
Optima	V=V_Avg=12.8+10/2	P=	174.648	W	E=	1257466	J
CSB	V=V_Avg=13.1+10/2	P=	245.4375	W	E=	1767150	J
% Difference		%=	33.70242			33.70242	

Figure 6, Comparison of CSB and Optima Power Outputs

The CSB batteries were selected to be implemented in the endurance setup for the Solar Splash Competition because of their lower Peukert's constant and greater power output. In an attempt to minimize costs for future teams, the Optima batteries have been selected for the sprint competition. After observing the abuse that the CSB batteries took from the sprint events, it was determined that they were not well suited for more than one competition when used that vigorously. The Optima batteries are designed for starting applications in automobiles. This will be beneficial for the high load required when starting the sprint competition.

## V. Hull Design

### A. Hull Modification

**1) Current Design:** The hull design at the beginning of the academic year was a modified design of our 2008-2009 cedar strip hybrid mono-hull. The 2014-2015 team designed and implemented step chines spanning the stern to the midship with the goal achieving planing abilities during sprint races. However, although the hull's top speed was slightly improved, no planing was observed during the 2015 competition or any testing since.

The goal of this year's team was to determine why the hull has not planed and to explore what modifications can be made to continue to improve the current hull. The hull must achieve a higher speed in order to place well in the sprint race. Since modifications had been made to try to achieve planing, the first objective was to analyze this modified hull, of which we had little data on performance. Once the hull was analyzed, the next objective would be to see how we could optimize the hull. If planing could be achieved, we needed to know what needed to be done to achieve it and thus improve top speed. If the hull could not plane, then we needed to explore what could be done to improve the capabilities of the current hull.

**2) Analysis of Current Design:** There were four main areas of study and design pinpointed for this year's work. These areas were 1) major hull and related drive train modifications, 2) center of gravity, 3) key characteristics of the hull, and 4) the smoothness of the hull. Each of these will be addressed separately with the various alternatives, analyses, and rational for final choices.

The first area of study was to determine the capabilities of the hull as they relate to overall design. In the fall, we looked into some major alternatives for changing the hull to try to achieve better speed while still maintaining our high capabilities in endurance. Dr. Savitsky lists various characteristics of the displacement, semi-displacement, and planing hulls. The displacement hull is designed for low speeds, the planing hull for high speeds, and the semi-displacement hull is a mix of the two. After comparing key characteristics of our hull to Savitsky's descriptions, and performing theoretical calculations, we found our hull is classified as a semi-displacement hull (See Appendix G1). This means that our hull should not be able to plane. Semi-displacement hulls perform better at high and low speeds based on center of gravity and overall weight. To improve semi-displacement hull performance, you must modify both center of gravity and lighten loads as much as possible. Through this understanding, three main models were studied for possible hull modifications. The first design included only minor hull modifications, but keeping the same configurations of drivetrain, motor, and motor housing. The second design included an outboard motor designed for the hull, drastically changing the weight and center of gravity of the hull. A final option was performing a major modification to the hull to convert it to a planing hull by flattening the midship-to-stern submerged area with hard chines to match characteristics of a planing hull. Various tests were run on these three main models using FREEShip, a software made for hull design determining many factors, such as displacement, weight distribution, center of gravity, and various resistance curves. To decide on one of these three main designs, we created a decision matrix to aid in the decision (see Appendix G2), and the matrix showed that the best design solution was the first design option, with minor modifications possible and a similar overall configuration for motor, drive train and motor housing.

Now that an overall design had been selected, and this design eliminated any major hull modifications, we then turned to determine the optimum centers of gravity for the different races. To do this, we created an excel sheet to determine the center of gravity on the boat's long axis using basic statics,  $\Sigma M=0$  (see Appendix G3). This value on the single axis could be inputted into FREEShip and the program determined the 3-D center of gravity and water lines. After various possible configurations were created by shifting movable components within the boat, these were all run through FREEShip to produce resistance curves. A summary of the resistance curves can be seen in Fig

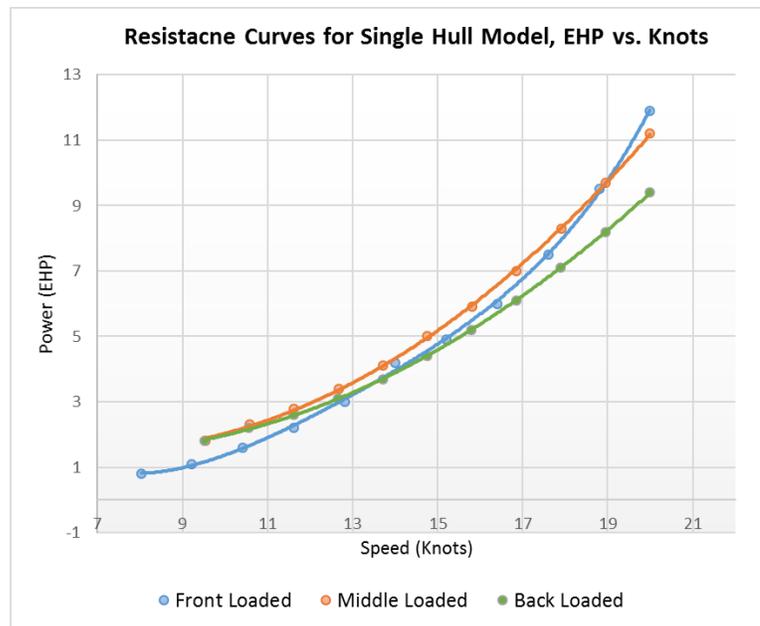


Figure 7, Resistance Curves for Center of Gravity Analysis

7, where we see the three main distributions of weight and their corresponding power vs. speed curves where the power is calculated from the overall hull resistance as it travels through the water. As can be seen from the resistance curves, the conclusions were that the front loaded hull

is more efficient in the water at low speeds, while the back loaded hull is more efficient for higher speeds. Since the target speed for our endurance runs is more than 15 knots, but less than 20 knots, this data is fully applicable to our designs. Once this observable trend was found to hold true throughout various models and configurations, we ran more specific tests to determine the optimum centers of gravity for use during the endurance and sprint races.

The third area for design related to the hull was the hull's key characteristics. As stated previously, there are key characteristics for different types of hulls. Since our hull had proven to be a semi-displacement hull, we looked into the possibility of incorporating characteristics found in planing hulls to help the hull at higher speeds, as our 2015 team did with the implementation of hard chines behind the midship. However, much of the submerged area of the hull near the stern was still curved, like a displacement hull. Three main designs were forms, each attempting to improve the curvature of the hull near the stern and provide a design more similar to a planing hull. The three designs, seen in Figs 8-11, were a fully flattened chine, an increased step chine on the sides, and a small bottom chine, all designs spanning 7 ft down the hull and fading into the hull. The fully flattened chine and the increased step chine would add significant weight to the hull, but was the most match planing hull characteristics. The bottom chine would be a small 45 degree keel installed across the bottom with the intent of slightly increasing buoyancy, displacement distribution near the stern, and improved fluid flow.

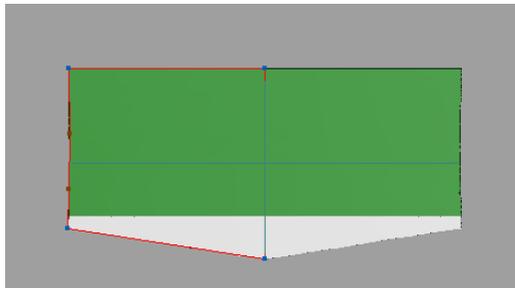


Figure 8, Flattened Chine

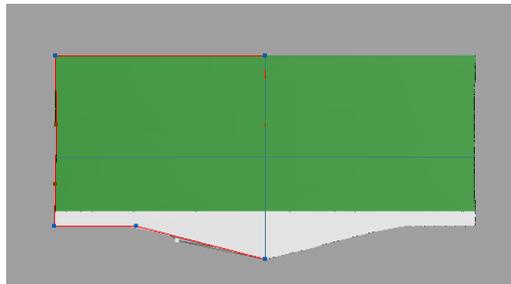


Figure 9, Original Step Chines

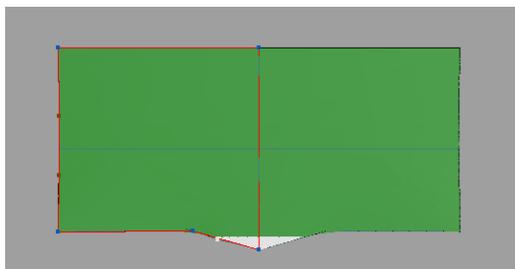


Figure 10, Increased Step Chines

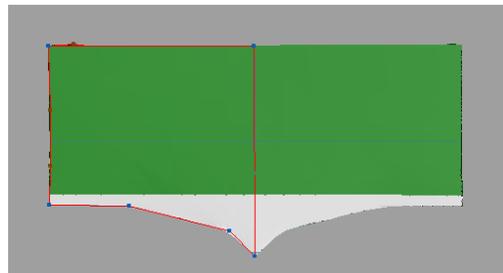


Figure 11, Bottom Chine/Keel

After testing, the bottom chine was the only design that had a positive impact on the hull, according to data gathered from FREEShip. The keel would slightly increase buoyancy in the back of the boat by 3 lbs, improve fluid flow, minimally increase weight by 1 lb, slightly improve high-speed performance based on resistance curves, and take minimum time to implement (see Appendix G4). None of the other designs showed improvements in all these areas together, thus, the bottom chine was the design of choice.

The final area of design for the hull saw the condition of the exterior surface. The hull was made from a cedar frame, coated in fiberglass adhered with hypoxy, and topped with a thick layer of varnish. However, the varnish had been on for three years and was applied too quickly and without sanding, leaving the exterior rough and bumpy. Fig. 12 shows a close up of the exterior of the hull at the beginning of the year. From basic fluid mechanics, we know that as the roughness of a surface increases so does the skin friction and overall drag of the surface.



Figure 12, Rough Exterior

Thus, a solution to this roughness had to be explored. To reduce roughness, the varnish first had to be removed by sanding and replaced with an alternative. Various alternatives were considered, including re-application of the varnish, Teflon based marine paint, hypoxy marine paint, gel coats, and waxes. After researching the alternatives, there were some primary factors to be considered, such as longevity, capability of being a topcoat, price, and impact on skin friction. After weighing out the various factors, it was found that the gel coat would be our best option. The gel coat we found, Sea Slide, also claims to be a hydrophilic product. This claims valuable because if it proves true, the gel coat will not only decrease overall skin drag resulting from roughness, but also improve the flow of the turbulent layer across the surface. The improvement would result because a hydrophilic product will create a smaller contact angle with the surface, allowing the turbulent layer to be thinner. Between the improvement of roughness and the application of the gel coat, we are hoping to easily see a 5% improvement in efficiency of the hull. See Appendix G for data regarding the gel coat.

### 3) Design Testing and Evaluation

Each of the final designs have reached the stage of implementation, although not yet fully tested.

The bottom chine design was fully implemented. See Fig. 13 for a comparison of the hull before the keel and after implementation. The chine was built from cedar strips and foam, later covered with a two coats of varnish to seal from water. Again, this improvement has yet to be tested, but overall improvement should not be too measurable as the improvement was meant to be minor.



Figure 13, Keel Implementation

In regards to the alterations in center of gravity, we plan to change the weight distribution from front loaded to back loaded by shifting the location of our batteries. Figure 14 shows the placement of our batteries for both sprint and endurance configurations. The wiring for the panels and motors will be adjusted accordingly to allow for this change in location of the 100 lb battery sets. As of yet, on water testing of these configurations has not been performed, but planned testing will record speeds and times to compare with results from previous years.

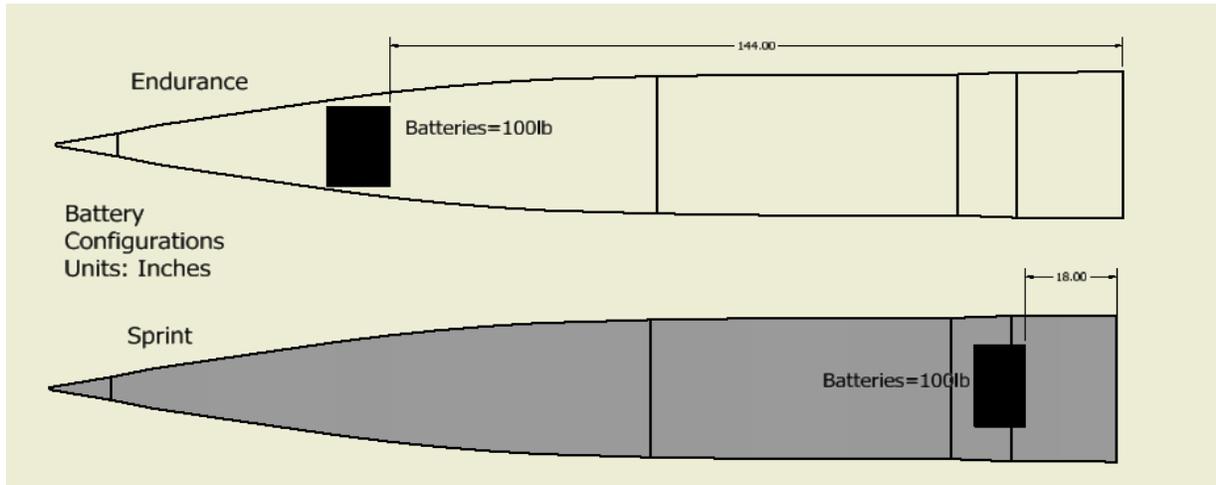


Figure 14, Battery Configurations for Sprint and Endurance

Finally, the exterior of the hull was fully redone. After a full sanding to remove most of the old varnish, we found that the sub-layer of hypox and fiberglass was still in good condition, but stained by the varnish as it had improperly dried. After trying some things to improve aesthetics, we resolved to leave the white stains on the hull since the only way to remove the stains would be to remove the hypox, and that was deemed unnecessary.

## VI. Drive Train and Steering

### A. Motor

The motor system was not changed. The system utilizes two Motenergy MEE-909 Brush Type permanent magnet DC motors. The motors are used in tandem in the sprint competition while only one motor is used during the endurance event. The motors are capable of sustaining up to 300A for 30 seconds and operate from 12-48V. The motors weight 24.1 lbs. each and are mounted to a motor plate inside the vessel. Motors data sheets can be found in Appendix O.



Figure 15, ME0909 Motor

### B. Gearing & Chains

Gear selection for the drive train is based on the desired boat speed, the angular velocity of the input shaft from the motor, and the angular velocity required of the propeller to achieve the desired speed. The desired speed of the boat for Sprint is 22 Knots, or 25 mph. The angular velocity of the input shaft from the motor is 2155 rpm based on the ME909 motor curve data. The angular velocity required of the propeller is 2500 rpm based on the nominal propeller selected using Crouch's Method.

The gear ratio is calculated by dividing the angular velocity required of the propeller by the angular velocity of the input shaft from the motor. The theoretical desired gear ratio is determined to be 1.16:1. The available drive shaft teeth numbers are 12, 18, and 20, and the available motor shaft teeth numbers are 18, 21, 22, and 24 shown in Appendix II. In order to achieve the calculated gear ratio the selected gears were 18-teeth on the drive shaft, and 22-teeth on the motor's input shaft shown in Figure 6.1. Based on previous reports the 1.22:1 ratio was chosen, because it was evident there was a lack of overdrive with the 1.16:1 ratio. During the sprint testing in the Fall of 2014 the new gearing was used, and a max speed of 17.4 mph was reached.

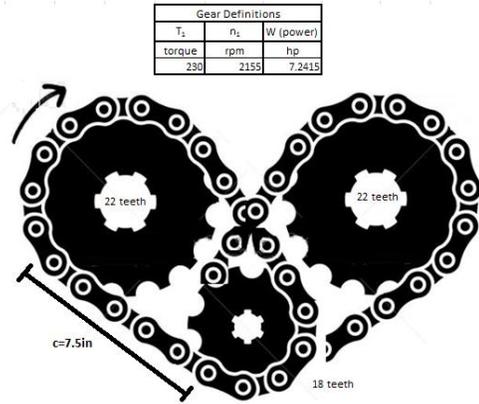


Figure 16, Gear and chain orientation

### C. Gear Plate

**1) Current Design:** The current gear plate was manufactured by the 2012 team. It is constructed from a 1/4" plate of 6061 aluminum plate. The motors are able to bolt to it, and the shaft is aligned by the bearings mounted in the tube. There is not a major issue with the current design but its weight could be reduced.

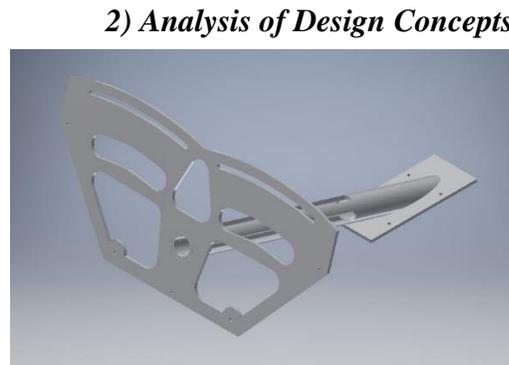


Figure 17, Gear plate with weight reduction

**2) Analysis of Design Concepts:** The weight of the gear plate could be reduced by cutting pieces of the plate out that were non-structural. There were some parts that had no stress under loading. To reduce weight, parts were cut out of the center of the plate. Material to be eliminated was found in the bottom left and right of the plate, in addition to the center of the plate and the shaft tubing, shown in Fig 17. Before weight reduction the plate weighted 10.9 lbs., after weight reduction it weighs 6.9 lbs. An analysis was done to determine that too much material was not removed from the plate. This analysis was done in inventor by applying loads at the worst condition of both motor exerting all possible torque. Failure of this component would be due to deformation because of the alignment to the shaft that it provides. The results of the analysis showed a max deformation of .002 in. in a non-critical area, showing it does not fail.

**3) Design Testing and Evaluation:** This component has yet to be optimized in this capacity. When the weight is reduced from it, it will be mounted and the motors will be mounted to it. Once this is complete, a visual inspection will be conducted to look for signs of deformation.

### D. Driveshaft

The driveshaft of the Solar Splash vessel drivetrain was fabricated from nitride coated 1045 steel bar stock. The 1045 steel has a yield strength of 45,000 psi. The driveshaft is half inch in

diameter. The driveshaft is connected to two collars (gear collars) at the top end by a key way and retaining nut. The driveshaft is supported in three places. The first two locations are roller bearings located inside the gear/motor housing mounting plate. The last support is the driveshaft strut attached to the underside of the hull. The driveshaft is connected with the constant velocity joint at the lower end. A clearance hole at the lower end is the connection for the constant velocity joint by a pin.

### ***E. Driveshaft Strut***

The current shaft support strut was created using 3/16" thick 1061-T6 aluminum, Fig. 19. The previous year's team created the strut to be fixed to the bottom of the hull, near the back. The issue with this design is that it is not the most streamlined shape, thus causing more drag than it should. By streamlining this strut, the overall drag on the boat will be reduced. After much research, the first and final design for the strut was



Figure 19, Shaft Support Strut

an airfoil shape. It was designed using Autodesk Inventor software. After an initial design was created, the drag produced was compared to the current shaft support strut to see if it actually reduced the drag in any way.

The current strut and the design for the new strut were both tested at 17 mph. The old strut produced a drag force of 1.23 lb-force, while the new design produced a drag force of 0.334 lb-force. This reduction in drag finalized the decision to manufacture the foils, seen in Fig 18.

This foil shape, which can be seen below, was 3D printed in two parts using PETG plastic. To smooth out the rough surface, the foil was sanded down and coated in a layer of epoxy. A groove that matched the shape of the current strut was cut into the new strut design so that it would fit over the existing strut.



Figure 18, 3-D Printed Foil

### ***F. Bearing***

1) ***Current Design:*** The current bearing in the shaft support strut is an oil-impregnated bronze bearing. The issue with this is that the coefficient of friction between the bearing and the steel shaft is high and could be lowered. It currently has a coefficient of friction of 0.16. The overall goal of replacing the bearing is to reduce the power loss from the bearing.

2) ***Analysis of Design Concepts:*** From the beginning, Teflon was the choice to replace the bronze bearing. The coefficient of friction between the Teflon and steel is 0.04. This would significantly reduce the power loss through this bearing. The power loss due to the current bearing is about 0.001923 hp. By using the Teflon bearing, the power loss would drop to 0.00048 hp. While the power loss through the bronze bearing was not large to begin with, any way that the power loss could be reduced further will increase the efficiency and speed of the boat.

3) ***Design Testing and Evaluation:*** The Teflon bearing will be ordered within the next few days and boat testing will occur in the weeks to follow.

## G. Universal Joint

**1) Current Design:** The 2011 team implemented the universal joint (u-joint) design that is currently on the boat. The u-joint is located outside of the hull. It connects the main drive shaft that is driven by the motors to the shaft that the propeller is fixed to. The current double u-joint is two u-joints that have been welded together. They are connected to the shafts of either side by a clevis pin. The problem with the design is that the clevis pins are warping when they are put under full load. To fix this problem more area needs to be added to where the shafts connect to the u-joint

**2) Analysis of Design Concepts:** The solution to this problem was to weld an extension onto the rear yoke of the universal joint. This allows for a second clevis pin to be used, shown in Fig. 20. Before the modification, the clevis pin had 840lbs. of force exerted on it resulting in a shear stress of 30.4 ksi when it is in single shear. The yielding point of the pin was found from the manufacturer to be 26 ksi. Adding a second pin made the shear stress 15.2ksi. The extension to the driven yoke of the universal joint was not able to be implemented due to space restrictions given by the driveshaft strut. This side was welded onto the shaft. Estimating the weld throat to be .14in., the stress on the weld, if it goes around the complete diameter, is 5.34 ksi well under the 19.34ksi yield point. Further calculations are shown in Appendix J.



Figure 20, Implementation of the double clevis pin and welded u-joint

**3) Design Testing and Evaluation:** There was an on-the-water test after this solution was implemented. It was originally hard getting the clevis pins into the new hole but that was to be expected. The boat was ran during this test in a 48V configuration, and after the test there was no noticeable deformation to the pins and the weld did not show fatigue cracks. A new u-joint should be purchased because of the looseness of the joint. In addition there is a trade off to the joint being welded to the shaft in that the shaft needs to be removed from the bottom of the boat.

## H. Bearing Housing

The 2015 team designed the current bearing housing, shown in Fig. 21. It was manufacture out of a single piece of aluminum. The team selected the current design out of three potential designs because it had a low amount of drag while also being easily made. The team calculated drag forces in Autodesk Simulation CFD 2015. At 8 m/s, (17.9 mph), the drag acting on the housing is 32.28 N, (7.25 lbs.). The design implements a tapered thrust bearing that sits in the front of the housing and a sealed ball bearing that also acts to seal the housing. Both of these bearings are shown in Appendix K. The shaft transmits the thrust from the propeller using a wider portion of the shaft that sits against the thrust bearing.

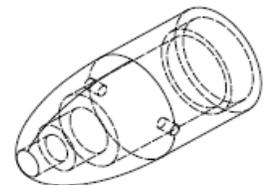


Figure 21, Model of the one-piece elliptical bearing housing

## ***I. Steering Strut***

**1) Current Design:** The 2015 solar splash team manufactured the current steering strut. They made it in a rush to get to competition after their previous steering strut had a major failure during testing right before competition. Because of the abrupt manufacturing, analysis of the strut was done by this year's team. The strut is made from 6061 aluminum stock pieces milled into shape. The design is strong, but it is not efficient in the water. Because of this, this years team sought to improve the hydrodynamic efficiency of the strut.



Figure 22, Fins attached to rear strut

**2) Analysis of Design Concepts:** Fins that fit around the existing strut were used to decrease the amount of drag. These fins increased the cross sectional area of the strut but greatly decreased the coefficient of drag. Flow models were done in Autodesk Simulation CFD 2017. The drag force acting on the main portion of the strut was found to be 12.45 lbs. before the fins were added. After the fins were added it dropped to 3.8 lbs. This was done by reducing the CD from .49 to .12. The drag acting on the lower portion of the strut was also reduced by cutting a chamfer into the leading edge. A foil was not designed for this portion because it would be hard to secure it and if it were to come off it would damage the propeller. The fins, shown in Fig 22, are 3D printed using PETG material. This material has a bhn of 110. It is also ductile enough to take a considerable impact. A good quality of this material is that upon printing, it has similar qualities of an extruded plastic part. Once printed the parts were sanded and coated with epoxy to finish the surface. The fins were printed because of their non-structural nature and the ease of manufacturing.

**3) Design Testing and Evaluation:** The fins are yet to be used in an on water test. However some tests were able to be done on pieces that were not printed correctly. Some qualitative tests were done to insure their strength and ductility. They pieces were dropped on their edge to make sure they could resist a hit. The pieces proved to be quit ductile. In addition to this, the pieces edges were sanded to make sure that they would not delaminate. Through these tests they have been proven to be a durable material.

## ***J. Propellers***

**1) Current Design:** Geneva College Solar Splash teams have been attempting to optimize propeller performance for years. Primarily, teams have focused on obtaining propellers for both sprint and endurance configurations. This has been accomplished in the past by both custom manufacturing at Geneva College and purchasing prefabricated propellers. The 2014-2015 Geneva Solar Splash Team manufacturing an optimized endurance propeller. Using a CNC Supra Mill and other campus tools available to students, a two-bladed wooden propeller was manufactured. After manufacturing was complete, the wooden propeller was coated in fiberglass to increase strength. This propeller has not been modified by the 2016-2017 Solar Splash Team. It will be used for the 2017 Solar Splash Competition.

The 2014-2015 Geneva Solar Splash Team also manufactured an optimized propeller for sprint configuration. The team used the CNC Supra Mill to machine a three-bladed propeller from

6061 aluminum. The propeller design was generated from a MATLAB-based program called OpenProp. OpenProp is a graphical user interface that allows users to input values such as power, rotations per minute, diameter, desired speed, and more. The program uses these input values to generate a three-dimensional model of the optimal propeller. The 2014-2015 Geneva Solar Splash Team finished manufacturing the OpenProp propeller design. Due to spatial limitations on the CNC Supra Mill, the three blades had to be manufactured as separate pieces. TIG (tungsten inert gas) welding was used to assemble the pieces into the final propeller. Unfortunately, the temperature of the welding considerably reduced the yield strength of the 6061 aluminum. The propeller failed during its first water trials due to deformation. Welding was determined to be the cause of the failure. The 2016-2017 Geneva Solar Splash Team determined a new propeller for the sprint configuration was required.

**2) Analysis of Design Concepts:** The 2016-2017 Geneva Solar Splash Team determined that the 2015 OpenProp sprint propeller had an optimal design. The manufacturing process required adjustments to avoid an identical deformation failure. After researching potential heat treatment options, the team chose to repeat the manufacturing process but to have the propeller heat treated after welding has been finished. The temper of the material was increased from the original 6061 aluminum (120MPa 18,000 psi) to 6061 T6 aluminum (240 MPa or 35,000 psi).

The OpenProp files were transformed into machining code using several different free educational programs. OpenProp files can be imported to a program called JavaProp as text file. JavaProp is a program similar to OpenProp. JavaProp's main function is to generate two-dimensional and three-dimensional models of airfoils for airplanes. Since propellers for boats and planes function identically, the program can be utilized to modify our OpenProp designs. JavaProp allows users to save .iges files that can be imported into AutoDesk Inventor. Once the three-dimensional model has been imported into AutoDesk Inventor, an Inventor plugin called Inventor HSM allows users to generate machining code. The Geneva Solar Splash Team's new sprint propeller model utilized this designing process.

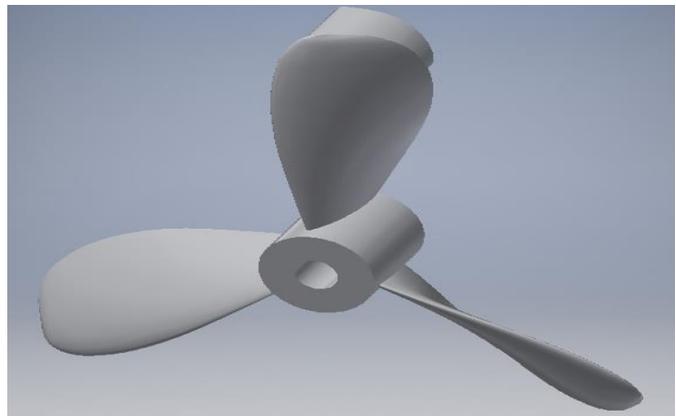


Figure 23, Sprint Propeller Design

A company located in New Castle, Pennsylvania named Flowline/E-Z Flow will provide heat treatment for our propeller. Heat treatment is effective at increasing or restoring yield strength of 6061 aluminum, even for tempers T4 and T6.

**3) Design, Testing, and Evaluation:** Before the aluminum machining began, the Solar Splash Team ran various tests on the CNC Supra Mill to ensure the material would not be wasted due to mistakes or accidents. First, the machining code was run on the machine without any material on the table to make sure the code did not have any blatant errors or problems. Second,

prototype cuts were run using hard foam material that Geneva's technical center has in stock. These prototype test runs were completed without any significant errors or setbacks.

The aluminum is planned to be milled within the month of May 2017, and is expected to be completed before the Solar Splash competition. The team is also seeking a commercial propeller that will be machined to fit our drive shaft system in the scenario a backup sprint propeller may be necessary. Test runs will be conducted on the water using both of the new sprint propellers prior to the competition.

## VII. Data Acquisition

### A. Electrical Sensors

1) **Current Design:** The final critical system that is a part of our boat is the data acquisition system. A key component of this data acquisition system has been the peak power tracker (PPT). The peak power tracker input is the output from the solar panels, the output then goes to the batteries. The purpose of the PPT is to read the incoming power from the solar panels (input) and then determine the optimal power to send to the batteries so the batteries can maintain a healthy charge. The PPT also has a CAT5 port to run a data cable to the display panel that is housed in the dash so the skipper can clearly see the power supply and output running through the system. The data acquisition system also utilizes four alternate displays on the dash board that were used at one point for readouts of certain key data values. These displays are not working under the current data acquisition system.

2) **Analysis of Design Components** As stated earlier, the construction of new solar panels this year eliminated the need for a PPT. With the removal of the PPT, we still needed a way to gather critical data. The new system needed to have two components, the first was something to read data. The Hall effect current transducers were selected for this purpose. These sensors read the current passing through a wire between two points. A total of four transducers will be used. The first will be placed on the wire harness between the battery bank and motor controllers to read amperage so we can calculate power using the formula  $P=VI$ . This current transducer is a Tamura L01Z600S05 transducer that is rated to 600 amps. The other three transducer sensors will be placed on the new solar panel harness located at the end of each lead for all three solar panel banks. These transducer sensors are made by Device Craft and are rated to 140 amps. These sensors will be used to find the power that is coming out of the charging system and going to charge the power supply system. Each current sensor has three leads on the sensor for the source voltage (5V), ground (GND) and output. The output signal is critical to the second



Figure 24, Tamura Sensor

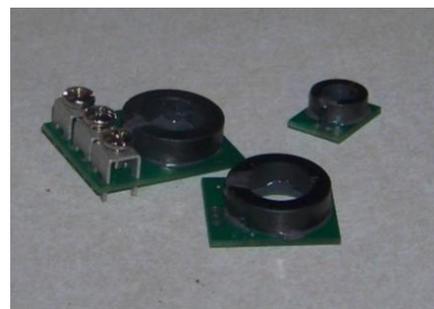


Figure 25, Device Craft Sensors

component of the new data system. We chose these two brands of current sensors because one of the previous year's team had begun to implement this system but never finished it. Therefore, we had multiples of these sensors lying around in the shop. The second component of the new data acquisition system is the display of the data being measured by the current sensors. Currently there are four unused displays on the dash of our boat. These will be used as an output for the data system. All four sensors will have their own dedicated display that will be clearly marked as to which sensor they correspond. See Appendix N for Data sheets for the sensors.

**3) Design Testing and Evaluation** Before implementing the designs for the data acquisition system, testing was done on the current sensors to ensure they functioned properly. To test the sensors, a current sensor was attached to a wire and connected between a battery and a motor. Next, wires were soldered to the 5V source voltage supply, ground, and output on the current sensor circuit board. Output wire was run to one display and connected a 5V power supply to the other wire and grounded the sensor, knowing the CSB battery being tested was supposed to be providing no more than 100 Amps. The sensor was reading 99.6 Amps which proved it worked. The process was repeated and confirmed for all four sensors.

## VIII. Project Management

### **A. Team Members and Leadership Roles**

There are currently six mechanical engineering students and one interdisciplinary student who make up the Geneva College Solar Splash team. This competition serves as the capstone project for these engineers in their Senior Design Project (EGR 481 and 482) to be accomplished starting two semester before graduation.

The various tasks of the project were divided between the individual group members. Each of the seven primary team members for this year had a section that was their responsibility.

- Hull Optimization
- Batteries
- Solar Array
- Propeller Manufacturing and Design
- Drive Train
- Data Acquisition
- Motors and Steering

Weekly meetings ensured progress and helped individuals receive assistance with issues. Most work was done collaboratively depending on the volume of the work to be done but individuals were responsible leading the efforts in their areas.

The team was advised by two faculty members: a mechanical engineering professor and an engineering technician. The guidance and assistance of these two individuals aided in the design process, as well as technical skills required in the fabrication and manufacturing involved in the project.

### ***B. Project Planning and Schedule***

The team was organized in September and responsibilities were assigned based on the project bid that was placed by each team member for selection into the senior design team. A baseline schedule was created during the fall semester to help monitor overall progress. Deadlines were made for individuals' work as to maintain steady progress on overall systems throughout the semester. Any critical changes in schedule were recorded in the weekly reports. Difficulties and set backs on larger aspects of the project have caused the need for the most significant testing and evaluation of the designs implemented to occur after this report was submitted and before the competition.

### ***C. Financial and Fundraising***

In working with the Institutional Advancement Office, a fundraising thank-you letter was drafted and sent to engineering alumni and previous benefactors in order to express the gratitude and solicit support. The letter informed the receiver about the competition, the opportunity provided through it to help the team put their education to practice, and the chance for professional development and experience. Alumni and benefactors were thanked and welcomed to join the team by investing in the team's future.

A prioritized budget aided decisions on purchases so that each area of necessary improvement would keep designs in relative balance. We created a cost baseline in the fall for the fundraising letters, and monitored costs with respect to this baseline and available funds. Apart from fixed costs (entry fee and travel expenses), batteries and solar panels were given the highest priority. This decision was based on the team's goals at the beginning of the academic year.

### ***D. Team Continuity and Sustainability***

A weekly report template was utilized through both semesters for consistent, structured communication between all project areas. The weekly meetings lasted roughly from one hour to one and a half hours. Team members communicated when they would be available to each other for consultation and collaboration on the project. Prior to the meetings, every member had to submit a weekly progress report. During weekly meetings, all work accomplished was shared and reviewed by the entire team, as well as any requests for changes in schedule or budget.

### ***E. Discussion and Self-Evaluation***

The approach taken to divide the responsibilities of the project and work collaboratively on those aspects was effective for the majority of the work accomplished. However, this led to an imbalance in the work load for the individuals in the project that allowed difficulties to delay the completion of certain systems that did not allow for the self-installed deadlines to be met. Better care could have been taken to assure the proper balance of work.

## **IX. Conclusions and Recommendations**

The following addresses project strengths and weaknesses for the past year

### ***A. Strengths***

- Created new solar panel and wiring configuration to produce more power and eliminate peak power tracker.

- Manufactured optimized propellers using calculated values and CNC machining.
- Lightened and streamlined drive train system.
- Made various improvements to hull performance.

### ***B. Weaknesses***

- Inability to fully test new designs to evaluate performance because of malfunctioning equipment and belated materials.
- Insufficient funding till late in the school year, leading to belated material ordering.

### ***C. Did we meet our overall and sub-system objectives?***

- Hull modifications and analysis complete.
- Sprint propeller will be complete for competition.
- New batteries have been purchased for use in the endurance and sprint event.
- All materials are ready for assembly of new solar panels

In general, objectives have been met but still require testing and evaluation under competition conditions as well as final fabrication and implementation.

### ***D. Where we go from here?***

Significant testing is required for the completed projects. The solar panels must be assembled, tested, and then used in on-water testing prior to competition. The modified hull must be tested for improvement, as well as the lightened and streamlined drive train. The final assembly of the data acquisition system will be required as well.

### ***E. Recommendations/Lessons Learned***

- Future teams should carefully document all tests and modifications made, including wiring diagrams for test setups for equipment battery testing and any in house manufacturing.
- Set realistic goals and deadlines early on in the year and stick to them as closely as possible.
- Enlist the help of other seniors and underclassmen who are not assigned to the project as their senior design capstone. They can help in administrative and marketing roles as well as technical roles, particularly in regards to electrical aspects.
- Do not expect funds to come in early, but rather plan all major purchases for the mid-late spring semester. However, we do recommend a team member in future years to search for more private funding.

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## Appendix A: Battery Documentation

### **Endurance Competition Batteries- (6 12-volt batteries)**

CSB EVH 12240 12V 24Ah

Specifications and MSDS attached – nominal weight of 16.64 lbs.

### **Sprint Competition Batteries- (3 12-volt batteries)**

Optima REDTOP 75/25 12V 44Ah

Specifications and MSDS attached – nominal weight of 31.4 lbs.

### **Back-up Competition Batteries- (3 12-volt batteries)**

Optima REDTOP 75/25 12V 44Ah

Specifications and MSDS attached – nominal weight of 31.4 lbs.

### **Auxiliary Battery – (1 12-volt battery)**

CSB GP 1272 F2 12V 7.2Ah

Specifications and MSDS attached – nominal weight of 5.5 lb.



## Material Safety Data Sheet

### SECTION 1: PRODUCT IDENTIFICATION

Chemical/Trade Name (as used on label)	Chemical Family/Classification
Sealed Lead Acid Battery Valve Regulated Lead Acid Battery (VRLA Battery)	Electric Storage Battery

Manufacturer's Name:	Address:
CSB Battery Co., Ltd.	10Fl. No. 301, Sec. 2, Ti-Ding Blvd, Nai Hn, Taipei 114, Taiwan

### SECTION 2: CONTACT

CSB Safety Department	+886-2-8751-5000
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### SECTION 3: HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

(Note: Product contains 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).

Exposure Limits Material	% by Wt.	(Air Exposure Limits: (ppm))			
		CAS Number	OSHA	AGGIH	NIOSH
Lead	57	7439-92-1	50	150	100
Lead Oxide	22	1309-60-0	50	150	100
Electrolyte (Sulfuric Acid)	14	7664-93-9	1	1	1

### SECTION 4: PHYSICAL/CHEMICAL CHARACTERISTIC DATA

Material is solid at normal temperatures.

#### Electrolyte:

Boiling Point:	230° F/110°C	Melting Point	Lead 327.4° C
Specific Gravity:	1.215 – 1.350	Vapor Density	Not determined
% Volatiles By Weight:	Not Applicable	Vapor Pressure	Not determined
Solubility in Water:	100% (electrolyte)	Evaporation Rate	Not determined

#### Appearance and Odor:

Electrolyte is a clear liquid with an acidic odor.

### SECTION 5: HEALTH HAZARD INFORMATION

Under normal operating conditions, the internal material will not be hazardous to your health. Only internally exposed material during production or case breakage or extreme heat (fire) may be hazardous to your health.

#### Routes of Entry:

- Inhalation: Acid mist from formation process may cause respiratory irritation.
- Skin Contact: Acid may cause irritation, burns and/or ulceration.
- Skin Absorption: Not a significant route of entry.
- Eye Contact: Acid may cause severe irritation, burns, cornea damage and/or blindness.
- Ingestion: Acid may cause irritation of mouth, throat, esophagus and stomach.

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Figure A.1, CSB Seal Lead Acid Battery Data Sheet (1 of 4)



## Material Safety Data Sheet

### Sign and Symptoms of Over Exposure:

**Acute Effects:** Over exposure to lead may lead to loss of appetite, constipation, sleeplessness and fatigue. Over exposure to acid may lead to skin irritation, corneal damage of the eyes and upper respiratory system.

**Chronic Effects:** Lead and its components may cause damage to kidneys and nervous system. Acid and its components may cause lung damage and pulmonary conditions.

**Potential to Cause Cancer:** The International Agency for Research on Cancer has classified "strong inorganic acid mist containing sulfuric acid" as a Category 1 carcinogen, a substance that is carcinogenic to humans. This classification does not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist is not generated under normal use of this product. Misuse of the product, such as overcharging, may however result in the generation of sulfuric acid mist.

### Emergency and First Aid Procedures:

- **Inhalation:** Remove from exposure and apply oxygen if breathing is difficult.
- **Skin:** Wash with plenty of soap and water. Remove any contaminated clothing.
- **Eyes:** Flush with plenty of water immediately for at least 15 minutes. Consult a physician.
- **Ingestion:** Consult a physician immediately.

### California Proposition 65:

The State of California has determined that certain battery terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. **Warning:** Wash hands thoroughly after handling batteries.

### **SECTION 6: FIRE AND EXPLOSION HAZARD DATA:**

**Flash Point:** Hydrogen = 259°C

**Auto ignition Temperature:** Hydrogen = 580°C

**Extinguishing Media:** Dry chemical, foam, CO<sub>2</sub>

**Flamability Limits:** LEL 4.1% (Hydrogen gas)

**Unusual Fire and Explosion Hazards:** Hydrogen and oxygen gases are produced in the cells during normal battery operation (hydrogen is flammable and oxygen supports combustion). These gases enter the air through the vent caps. To avoid the chance of a fire or explosion, keep sparks and other sources of ignition away from the battery.

### **SECTION 7: REACTIVITY DATA:**

**Stability:** Stable

**Conditions to Avoid:** Sparks and other sources of ignition.

### **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, and sulfur trioxide.

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Figure A.1, Cont. CSB Seal Lead Acid Battery Data Sheet (2 of 4)



## Material Safety Data Sheet

### Conditions to Avoid:

High temperature. Battery electrolyte (acid) will react with water to produce heat. Can react with oxidizing or reducing agents.

### SECTION 8: CONTROL MEASURES:

#### Engineering Controls:

Store lead/acid batteries with adequate ventilation. Room ventilation is required for batteries utilized for standby power generation. Never recharge batteries in an unventilated, enclosed space.

#### Work Practices:

Do not remove vent caps. Follow shipping and handling instructions that are applicable to the battery type. To avoid damage to terminals and seals, do not double-stack industrial batteries.

### SECTION 9: PERSONAL PROTECTIVE EQUIPMENT:

#### Respiratory Protection:

None required under normal handling conditions. During battery formation (high-rate charge condition), acid mist can be generated which may cause respiratory irritation. Also, if acid spillage occurs in a confined space, exposure may occur. If irritation occurs, wear a respirator suitable for protection against acid mist.

#### Eyes and Face:

Chemical splash goggles are preferred. Also acceptable are "visor-gogs" or a chemical face shield worn over safety glasses.

#### Hands, Arms, Body:

Vinyl coated, VC, gauntlet type gloves with rough finish are preferred.

#### Other Special Clothing and Equipment:

Safety shoes are recommended when handling batteries. All footwear must meet requirements of ANSI Z41.1 - Rev. 1972.

### SECTION 10: PRECAUTIONS FOR SAFE HANDLING AND USE:

#### Hygiene Practices:

Following contact with internal battery components, wash hand thoroughly before eating, drinking, or smoking.

#### Respiratory Protection:

Wear safety glasses. Do not permit flames or sparks in the vicinity of battery(s). If battery electrolyte (acid) comes in contact with clothing, discard clothing.

#### Protective Measures:

Remove combustible materials and all sources of ignition. Cover sills with soda ash (sodium carbonate) or quicklime (calcium oxide). Mix well. Make certain mixture is neutral then collect residue and place in a drum or other suitable container. Dispose of a hazardous waste.

Wear acid-resistant boots, chemical splash goggles, and acid-resistant gloves. Do not release un-neutralized acid.

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Figure A.1, Cont. CSB Seal Lead Acid Battery Data Sheet (3 of 4)



## Material Safety Data Sheet

### 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 hazardous waste. Do not flush lead contaminated acid to sewer.

Batteries: Send to lead smelter for reclamation following applicable Federal, state and local regulations. Product can be recycled along with automotive (SLI) lead acid batteries, or use CSB Recycling Program number (800) 3CSB/USA.

### Other Handling and Storage Precautions:

None Required.

### SECTION 11: NFPA HAZARD RATING:

#### Sulfuric Acid:

Flammability (Red) =	0
Health (Blue) =	3
Reactivity (Yellow) =	2

### SECTION 12: DEPARTMENT OF TRANSPORTATION AND INTERNATIONAL SHIPPING REGULATIONS:

Proper Shipping Name	Batteries - Non-Spillable, Electric Storage
U.S. DOT (U.S. Department of Transportation)	Classified as non-spillable, meets non-spillable criteria listed at 49 CFR 173.159 (d). See comments.
IATA (International Air Transportation Association) ICAO (International Civil Aviation Administration)	Classified as non-spillable, meets the requirements of Special Provisions A67, Non-spillable batteries should be packed according to IATA packaging instruction 806. See comments.
IMO (International Maritime Organization) IMDG (International Maritime Dangerous Goods)	Classified as non-spillable, meets the criteria listed in special Provision 238. See comments.

#### Comments:

CSB seal lead-acid batteries are classified as "non-spillable" for the purpose of transportation by DOT, and IATA/ICAO as result of passing the Vibration and Pressure Differential Test described in DOT [49 CFR 173.159 (d)] and IATA/ICAO [Special Provision A67].

CSB seal lead-acid batteries can be safely transported on deck, or under deck stored on either a passenger or cargo vessel as result of passing the Vibration and Pressure Differential Tests as described in the IMDG regulations.

To transport these batteries as "non-spillable" they must be shipped in a condition that would protect them from short-circuits and be securely packaged so as to withstand conditions normal to transportation by a consumer, in or out of a device, they are unregulated thus requiring no additional special handling or packaging.

For all modes of transportation, each battery and outer package is labeled "NON-SPILLABLE" per 49 CFR 173.159 (d). If you repackage our batteries either as batteries or as a component of another product you must label the outer package "NON-SPILLABLE" per 49 CFR 173.159 (d).

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Figure A.1, Cont. CSB Seal Lead Acid Battery Data Sheet (4 of 4)

	Title:	Date:	Rev:	Page:	File Name:
	Material Safety Data Sheet for All Optima Batteries	10/17/11	M	1 of 5	MSDS battery

MSDS No. L BA
Date Issued Feb. 20, 1990
Date Revised Oct. 17, 2011

Chemical/Trade Name (Identify used on label) <b>Sealed Lead Acid Battery/ OPTIMA BATTERY™</b>	Chemical Family/Classification <b>Electric Storage Battery</b>	HMIS Rating for Sealed, Lead Acid Battery 0 0 0; For sulfuric acid 3 0 2
Synonyms/Common Name <b>Sealed Lead Acid Battery</b>	DOT, IATA and IMDG Description <b>Non-Spillable Battery, Exempt from UN2800 Classification</b>	
Company Name <b>OPTIMA Batteries, Inc.</b>	Address <b>5757 N. Green Bay Avenue Milwaukee, WI 53209</b>	
Division or Department <b>Wholly-owned subsidiary of Johnson Controls Inc.</b>	<b>CONTACT</b>	
Questions Concerning MSDS <b>OPTIMA Batteries, Environmental, Health &amp; Safety Department</b>	<b>TELEPHONE NUMBER</b>	
Transportation Emergencies <b>CHEMTREC</b>	Day: <b>(800) 333-2222, Ext. 3138</b>	
	24 Hours: <b>(800) 424-9300</b> International: <b>(703) 527-3887 (Collect)</b>	

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 WL	CAS Number	Eight Hour Exposure Limits		
			OSHA PEL	ACGIH TLV	NIOSH REL
Specific Chemical Identity <b>Lead &amp; lead compounds</b>	65-81	7439-02-1	50 µg/m <sup>3</sup>	150 µg/m <sup>3</sup>	100 µg/m <sup>3</sup>
Specific Chemical Identity <b>Sulfuric Acid (35%)</b>	17 - 25	7664-03-0	1 mg/m <sup>3</sup>	0.2 mg/m <sup>3</sup> (respirable thoracic fraction)	1 mg/m <sup>3</sup>
Common Name <b>Battery Electrolyte (Acid)</b>					
Common Name <b>Case Material Polypropylene</b>	2-6	9010-79-1	—	—	—
Common Name <b>Separator/Paster Paper Fibrous Glass</b>	1-4	85997-17-3	—	—	—

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) <input checked="" type="checkbox"/> Solid <input type="checkbox"/> Liquid	Appearance and Odor <b>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.</b>
Boiling Point (at 760 mm Hg) <b>Lead 1766°C Batt. Electrolyte (Acid) 110-112°C</b>	Melting Point <b>Lead 327.4°C</b>
Specific Gravity (H <sub>2</sub> O = 1) <b>Battery Electrolyte (Acid) 1.210 - 1.300</b>	Vapor Pressure (kPa/mm Hg at 20°C) $\Sigma$ (PSIG) <b>Battery Electrolyte (Acid) 11.7</b>
Vapor Density (Air = 1) <b>Battery Electrolyte (Acid) 3.4</b>	Solubility in H <sub>2</sub> O <b>Lead and Lead Dioxide are not soluble. Battery Electrolyte (acid) is 100% soluble in water.</b>
% Volatile by Weight <b>Not Determined</b>	Evaporation rate (Butyl Acetate = 1) <b>Not Determined</b>

Figure A.2, MSDS for All Optima Batteries (1 of 5)

	<b>Title:</b>	<b>Date:</b>	<b>Rev:</b>	<b>Page:</b>	<b>File Name:</b>
	Material Safety Data Sheet for All Optima Batteries	10/17/11	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 soaming 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. MSDS for All Optima Batteries (2 of 5)

	Title:	Date:	Rev:	Page:	File Name:
	Material Safety Data Sheet for All Optima Batteries	10/17/11	M	3 of 5	MSDS battery

**V. Fire and Explosion Data**

Flash Point (test method) Hydrogen - 259°C	Autoignition Temperature Hydrogen 580°C	Flammable Limits in Air, % by Vol Hydrogen LEL - 4.1 UEL - 74.2
Extinguishing Media Dry chemical, foam, or CO <sub>2</sub>		
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 <input type="checkbox"/> Unstable <input checked="" type="checkbox"/> Stable	Conditions to Avoid 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 <input type="checkbox"/> May Occur <input checked="" type="checkbox"/> Will Not Occur	Conditions to Avoid 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.
<b>PERSONAL PROTECTIVE EQUIPMENT</b>
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 is 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. MSDS for All Optima Batteries (3 of 5)

	<b>Title:</b>	<b>Date:</b>	<b>Rev:</b>	<b>Page:</b>	<b>File Name:</b>
	Material Safety Data Sheet for All Optima Batteries	10/17/11	M	4 of 5	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..



**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	PIN	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	
85D/6 - 1050 SLI	8010-044	6140-01-475-9414
DS46B24R	8171-767	
85D/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. MSDS for All Optima Batteries (4 of 5)

	Title:		Date:	Rev:	Page:	File Name:
	Material Safety Data Sheet for All Optima Batteries		10/17/11	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	8005-006	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. MSDS for All Optima Batteries (5 of 5)

Powered by



# EVH 12240 ▶ 12V 24Ah

EVH 12240 (2<sup>nd</sup> generation) is designed specially with increase cycle performance and reliability from previous generations in electric vehicles application. It has high cycling life, high efficiency and long service life.



CSB-manufactured VRLA (Absorbent Glass Mat type) batteries are UL-recognized components under UL1989.

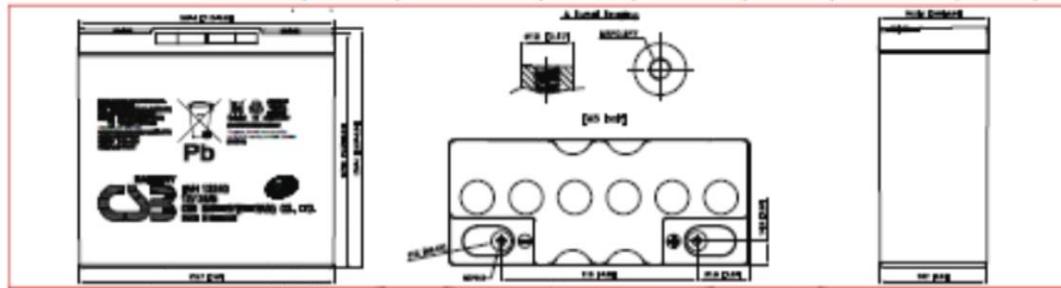
CSB is also certified by ISO 9001 and ISO 14001.

### ► Specification

Cells Per Unit	6
Voltage Per Unit	12
Capacity	24Ah @ 20hr-rate to 1.75V per cell @25°C (77°F)
Weight	Approx. 7.55 kg (16.64 lbs)
Maximum Discharge Current	320A(5sec)
Internal Resistance	Approx. 9 mΩ
Operating Temperature Range	Discharge: -15°C~50°C ( 5°F~122°F) Charge: -15°C~40°C ( 5°F~104°F) Storage: -15°C~40°C ( 5°F~104°F)
Nominal Operating Temperature Range	25°C±3°C (77°F±5°F)
Float Charging Voltage	13.5 to 13.8 VDC/unit Average at 25°C (77°F)
Recommended Maximum Charging Current Limit	7.2A
Equalization and Cycle Service	14.4 to 15.0 VDC/unit Average at 25°C (77°F)
Self Discharge	CSB Batteries can be stored for more than 6 months at 25°C (77°F). Please charge batteries before using. For higher temperatures the time interval will be shorter.
Terminal	M5-Thread lead alloy recessed terminal to accept M5 bolt
Container Material	ABS(UL 94-HB) & Flammability resistance of (UL 94-V0) can be available upon request.

### ► Dimensions :

Unit: mm (Inch)	Overall Height (H) 170±1 (6.69±0.04)	Container height (h) 170±1 (6.69±0.04)	Length (L) 181±2 (7.13±0.08)	Width (W) 76.2±1 (3.0±0.04)
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### Constant Current Discharge Characteristics Unit:A (25°C, 77°F)

F.V/T/Time	30MIN	60MIN	90MIN	2HR	3HR	4HR	5HR	8HR	10HR	20HR
1.60V	29.9	17.7	13.0	10.3	7.50	5.84	4.84	3.16	2.57	1.31
1.67V	29.6	17.5	12.9	10.2	7.44	5.83	4.78	3.15	2.56	1.30
1.70V	29.4	17.4	12.8	10.1	7.41	5.82	4.77	3.14	2.55	1.29
1.75V	29.0	17.2	12.7	10.0	7.32	5.74	4.73	3.09	2.52	1.28
1.80V	28.4	17.0	12.5	9.98	7.16	5.65	4.64	3.06	2.49	1.27
1.85V	27.0	16.2	11.9	9.56	6.85	5.44	4.47	2.91	2.34	1.17

### Constant Power Discharge Characteristics Unit:W (25°C, 77°F)

F.V/T/Time	30MIN	60MIN	90MIN	2HR	3HR	4HR	5HR	8HR	10HR	20HR
1.60V	346	208	154	123	88.9	69.9	58.6	38.3	31.4	16.2
1.67V	343	207	153	122	88.7	69.8	57.6	38.1	31.2	16.1
1.70V	340	206	152	121	87.9	69.1	57.4	38.0	31.0	16.0
1.75V	338	205	151	120	87.3	68.4	56.9	37.8	30.7	15.9
1.80V	331	199	147	118	85.1	67.1	55.9	37.2	30.3	15.7
1.85V	313	193	142	115	82.9	65.3	54.4	36.1	29.6	15.4

Ratings presented herein are subject to revision without notice. Please refer to [www.csb-battery.com](http://www.csb-battery.com) to confirm the latest version.

RA1410

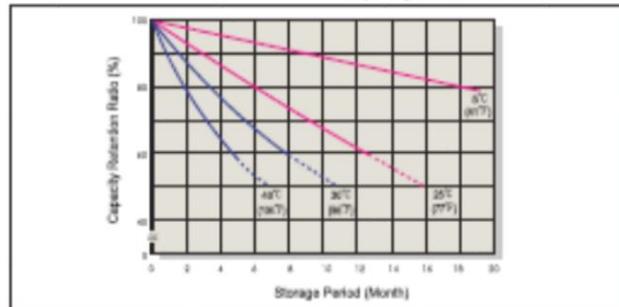
Figure A.3, CSB EVH 12240 Specification Sheet (1 of 2)

**EVH12240**

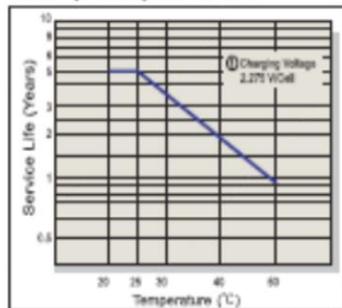
**12V 24Ah**



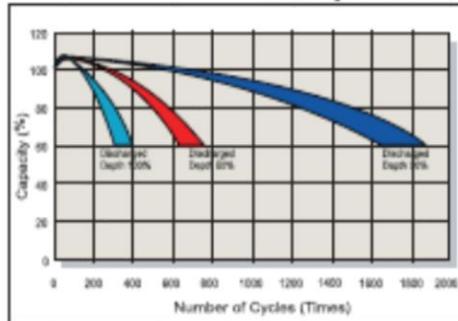
**Capacity Retention Characteristic**



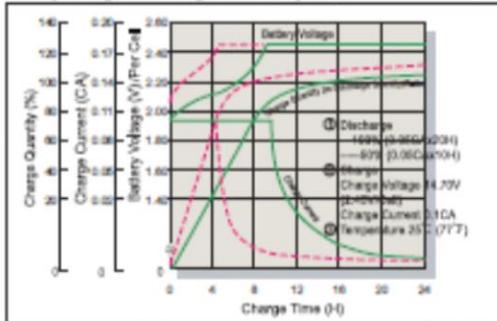
**Trickle (or Float) Service Life**



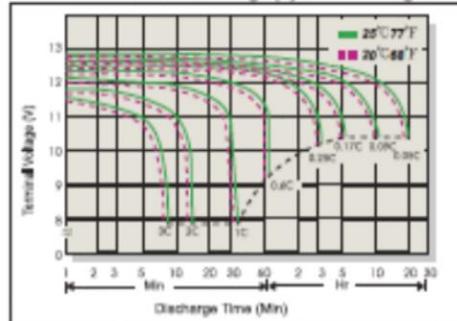
**Series Cycle Service Life**



**Battery Voltage and Charge Time for Cycle Use**



**Terminal Voltage (V) and Discharge Time**



**Charging Procedures**

Application	Charge Voltage (V/Cell)			Max. Charge Current
	Temperature	Set Point	Allowable Range	
Cycle Use	25° (77°)	2.45	2.40~2.50	0.3C
Standby	25° (77°)	2.275	2.25~2.30	

**Discharge Current VS. Discharge Voltage**

Final Discharge Voltage (V/Cell)	1.75	1.70	1.60	1.30
Discharge Current (A)	0.20 <math>(I)</math>	0.20 <math>(I)</math> <math>< 0.5C</math>	0.50 <math>(I)</math> <math>< 1.0C</math>	<math>(I)> 1.0C</math>

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Figure A.3, Cont. CSB EVH 12240 Specification Sheet (2 of 2)



# GP 1272 ▶ 12V 7.2Ah

GP 1272 is a general purpose battery up to 5 years in standby service or more than 260 cycles at 100% discharge in cycle service. As with all CSB batteries, all are rechargeable, highly efficient, leak proof and maintenance free.



## ► Specification

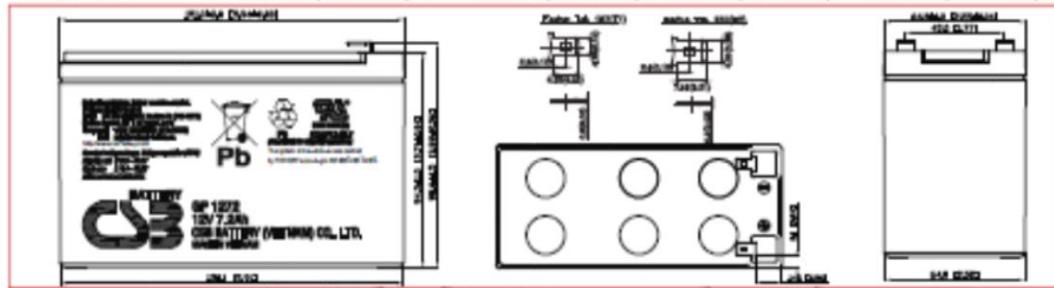
Cells Per Unit	6
Voltage Per Unit	12
Capacity	7.2Ah @ 20hr-rate to 1.75V per cell @25°C (77°F)
Weight	Approx. 2.4 kg(5.29 lbs)
Maximum Discharge Current	100A/130A(5sec)
Internal Resistance	Approx. 23 mΩ
Operating Temperature Range	Discharge: -15°C~50°C ( 5°F~122°F) Charge: -15°C~40°C ( 5°F~104°F) Storage: -15°C~40°C ( 5°F~104°F)
Nominal Operating Temperature Range	25°C±3°C (77°F±5°F)
Float Charging Voltage	13.5 to 13.8 VDC/unit Average at 25°C (77°F)
Recommended Maximum Charging Current Limit	2.15A
Equalization and Cycle Service	14.4 to 15.0 VDC/unit Average at 25°C (77°F)
Self Discharge	CSB Batteries can be stored for more than 6 months at 25°C (77°F). Please charge batteries before using. For higher temperatures the time interval will be shorter.
Terminal	F1/F2-Faston Tab187/250
Container Material	ABS(UL 94-HB) & Flammability resistance of (UL 94-V0) can be available upon request.



CSB-manufactured VRLA (Absorbent Glass Mat type) batteries are UL-recognized components under UL1989.

CSB is also certified by ISO 9001 and ISO 14001.

Dimensions :	Overall Height (H)	Container height (h)	Length (L)	Width (W)
Unit: mm (Inch)	98.6±1.5 (3.88±0.06)	94.3±1 (3.71±0.04)	151±2 (5.94±0.08)	64.8±1 (2.55±0.04)



### Constant Current Discharge Characteristics Unit:A (25°C,77°F)

F.V/Time	5MIN	10MIN	15MIN	30MIN	60MIN	90MIN	2HR	3HR	6HR	8HR	10HR	20HR
1.80V	35.6	22.0	16.5	9.61	5.51	3.92	3.08	2.13	1.34	0.92	0.77	0.45
1.87V	33.1	21.0	15.9	9.36	5.41	3.85	3.02	2.08	1.31	0.90	0.76	0.44
1.70V	31.9	20.5	15.6	9.24	5.37	3.82	3.00	2.06	1.30	0.89	0.75	0.43
1.76V	29.6	19.6	15.1	9.03	5.30	3.77	2.96	2.02	1.27	0.88	0.74	0.42
1.80V	27.2	18.6	14.4	8.77	5.23	3.71	2.91	1.98	1.25	0.87	0.73	0.42
1.86V	24.5	17.4	13.7	8.44	5.14	3.66	2.87	1.95	1.22	0.86	0.71	0.40

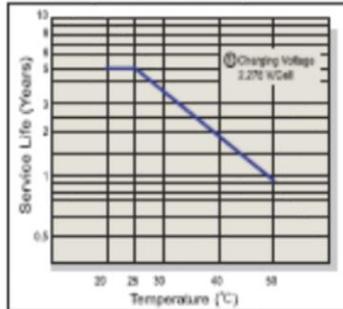
### Constant Power Discharge Characteristics Unit:W (25°C,77°F)

F.V/Time	5MIN	10MIN	15MIN	30MIN	60MIN	90MIN	2HR	3HR	5HR	8HR	10HR	20HR
1.60V	360	245	183	108	64.4	47.1	37.7	26.6	17.3	11.8	9.80	5.37
1.67V	340	235	177	106	63.6	46.4	37.1	26.3	17.0	11.6	9.68	5.27
1.70V	331	231	174	105	63.1	46.1	36.9	26.2	16.9	11.5	9.54	5.23
1.75V	313	222	170	103	62.4	45.5	36.4	25.9	16.7	11.4	9.47	5.15
1.80V	295	213	165	101	61.7	45.0	35.9	25.6	16.5	11.3	9.40	5.07
1.85V	276	202	158	99	60.8	44.3	35.4	25.2	16.3	11.2	9.29	4.99

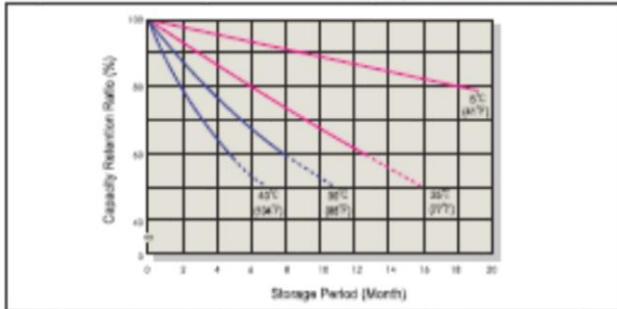
Ratings presented herein are subject to revision without notice. Please refer to [www.csb-battery.com](http://www.csb-battery.com) to confirm the latest version.

Figure A.4, CSB GP 1272 12V 7.2Ah Specification Sheet (1 of 2)

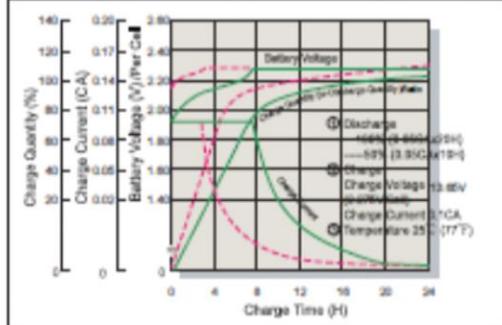
**Trickle (or Float) Service Life**



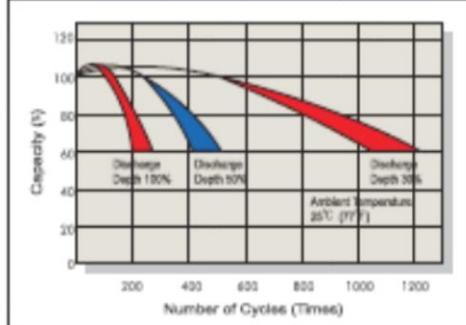
**Capacity Retention Characteristic**



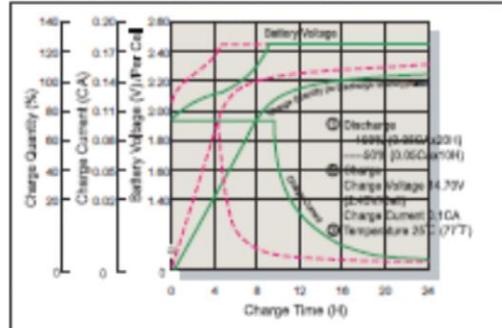
**Battery Voltage and Charge Time for Standby Use**



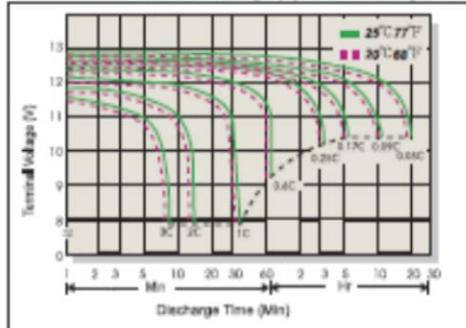
**Cycle Service Life**



**Battery Voltage and Charge Time for Cycle Use**



**Terminal Voltage (V) and Discharge Time**



**Charging Procedures**

Application	Charge Voltage(V/Cell)			Max.Charge Current
	Temperature	Set Point	Allowable Range	
Cycle Use	25°C(77°F)	2.45	2.40-2.50	0.3C
Standby	25°C(77°F)	2.275	2.25-2.30	

**Discharge Current VS. Discharge Voltage**

Final Discharge Voltage V/Cell	1.75	1.70	1.60	1.50
Discharge Current(A)	0.20(A)	0.20(A)+0.30	0.50(A)+1.00	(A)+1.00

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Figure A.4, Cont. CSB GP 1272 12V 7.2Ah Specification Sheet (2 of 2)



**Battery Model:** 75/25  
**Part Number:** 8022-091  
**Nominal Voltage:** 12 volts  
**NSN:** 6140 01 475 9361  
**Description:** High power, sealed lead acid, engine starting battery

**Physical Characteristics:**

**Plate Design:** High purity lead- $\text{Sn}$  alloy. Wound cell configuration utilizing proprietary SPIRALCELL<sup>®</sup> technology.  
**Electrolyte:** Sulfuric acid,  $\text{H}_2\text{SO}_4$   
**Case:** Polypropylene  
**Color:** Case: Dark Gray  
 Cover: "OPTIMA" Red  
**Group Size:** BCI: 75/25

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

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

**Performance Data:**

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

**Power:**

**CCA (BCI 0°F):** 720 amps  
**MCA (BCI 32°F):** 910 amps

**Recommended Charging:**

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

**Model: 75/25**  
 These batteries are designed for engine starting applications. They are not recommended or warranted for use in deep cycle applications.

Figure A.5, Optima REDTOP 75/25 Specification Sheet (1 of 2)

**Recommended Charging Information:**

**Alternator:** 13.3 to 15.0 volts  
**Battery Charger (Constant Voltage):** 13.8 to 15.0 volts; 10 amps maximum; 6-12 hours approximate  
**Float Charge:** 13.2 to 13.8 volts; 1 amp maximum; (indefinite time at lower voltages)  
**Rapid Recharge:** 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.  
**(Constant voltage charger)** 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 75/25  
December 2008

Figure A.5, Cont. Optima REDTOP 75/25 Specification Sheet (2 of 2)

## Appendix B: Flotation Calculations

Solar Splash 2017 Rule 7.14.2 Buoyancy of Craft - Sufficient flotation must be provided on board so that the craft cannot sink, even when filled with water. A 20% safety factor must be included in the calculations. Verification calculations must be included in the Technical Report. Failure to do so will result in a 5-point penalty. Revised calculations must be presented at Inspection if significant changes have been made since submission of the Technical Report.

Per the stated rule, our team has performed the following calculations, submitted below for official review.

Density of water (lbf/ft <sup>3</sup> ) =	62.4	<b>W = Fb = mg = rho*g*V = density*V</b> <b>Fnet = (Volume object) * (density water - density object)</b>
Density of styrofoam (lbf/ft <sup>3</sup> )	2.18	

### ***Sprint Mode***

Components	Weight (lbf)	Volume (ft <sup>3</sup> )	Average Density (lbf/ft <sup>3</sup> )	Force Net (lbf)
Batteries	99.3	0.846	117.38	-46.510
Mounting Plate	6.91	0.041	169.36	-4.364
Drive System	1.79	0.010	179.00	-1.166
Auxiliary Batteries (x2)	5	0.035	142.86	-2.816
Boat Hull	98.6	2.15	45.86	35.560
ME909 Motors (x2)	48	0.289	166.09	-29.966
Curtis Motor Controllers (x2)	12	0.063	190.48	-8.069
Steering System	11.22	0.057	196.84	-7.663
Gears and Chain	5	0.010	500.00	-4.376
Misc. Items (no volume)	30	-	-	-30
<b>Total</b>	<b>317.82</b>	<b>3.501</b>	Sum of forces (lbf) =	<b>-99.370</b>
<b>20% Safety Factor</b>				<b>-19.874016</b>
Total Negative Force (lbf) =				<b>-119.244</b>
<b>Volume of styrofoam needed for safe flotation (ft<sup>3</sup>) =</b>				<b>1.980</b>

### ***Endurance Mode***

Components	Weight (lbf)	Volume (ft <sup>3</sup> )	Average Density (lbf/ft <sup>3</sup> )	Force Net (lbf)
Batteries(x6)	99.84	0.497	200.97	-68.840
Mounting Plate	6.91	0.041	169.36	-4.364
Drive System	1.79	0.010	180.81	-1.172
Auxiliary Batteries (x2)	5	0.035	142.86	-2.816
Boat Hull	98.6	2.15	45.86	35.560
ME909 Motors (x2)	48	0.289	166.09	-29.966
Curtis Motor Controllers (x2)	12	0.063	190.48	-8.069
Steering System	11.22	0.057	196.32	-7.654
Gears and Chain	5	0.010	500.00	-4.376
Solar Panels (x7)*	21			
Solar Panel Mounts	20	0.098	204.19	-13.888
Misc. items - no volume**	30	-	-	-30
<b>Total</b>	<b>359.36</b>	<b>2.753</b>	Sum of forces (lbf)	<b>-135.585</b>
<b>20% Safety Factor</b>				<b>-27.11697952</b>
Total Negative Force (lbf) =				<b>-162.702</b>
<b>Volume of styrofoam needed for safe flotation (ft<sup>3</sup>) =</b>				<b>2.702</b>

*Misc. Items (assume vol=0)
Wires/Cables
Switches/Fuses
Solenoids
Digital Panel Meters
Bilge Pump

\*\*Solar panel latches to frame are not reliable enough to include buoyancy force in calculation. If latches hold, buoyancy will more than counteract the weight.

Weights and volumes for battery calculations were taken from the MSDS sheets for the different batteries found in Appendix A. Below is a sample calculation for the Optima batteries used in sprint mode.

$$F_{Buoyancy} = \rho_W V - W = \left(62.4 \frac{lb}{ft^3}\right) (0.0282 ft^3) * 3 - (33.1 lb) * 3 = -46.51 lb$$

For the calculation of the hull, data used was gathered from inventor models, FREEShip models, and hand calculations. Below is an outline of the data and process for the hull buoyancy calculations.

**Physical Properties for Inventor boat - solid model**

General Properties:

- Material: {Water}
- Density: 0.998 g/cm<sup>3</sup>
- Mass: 2346.815 lb<sub>mass</sub> (Relative Error = 0.000000%)
- Area: 14952.495 in<sup>2</sup> (Relative Error = 0.000004%)
- Volume: 65070.225 in<sup>3</sup> (Relative Error = 0.000000%)

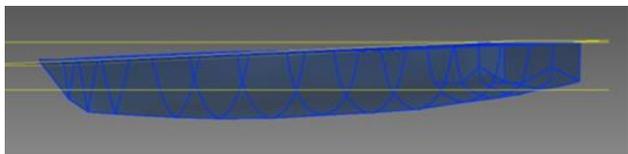


Figure B.1, Model of boat in FREEShip.

Calculating for the material surface area: Surface Area = 68.79 ft<sup>2</sup>

*Area from the Inventor Model: 14952.495 in<sup>2</sup>*

*Approximate Area for Calculation: 14,953 in<sup>2</sup>*

*Top Surface Area Calculated from Inventor Model: 5,046.797 in<sup>2</sup>*

*Approximate Area for Calculation: 5,047 in<sup>2</sup>*

$$14,953 in^2 - 5,047 in^2 (\text{neglect top surface area of the model}) = 9,906 in^2$$

$$9,906 in^2 \times \frac{1 ft^2}{144 in^2} = 68.79 ft^2$$

Calculating for the material volume of the Hull: Volume of Cedar = 1.43 ft<sup>3</sup>

*Measured thickness of cedar: 0.25 in*

*Approximate thickness of epoxy coat: 0.125 in*

$$68.79 ft^2 * \left( (0.25 in + 0.125 in) * \frac{1ft}{12in} \right) = 2.150 ft^3.$$

### Physical Properties for Gear Plate

#### General Properties:

Material:	{Aluminum 6061, Welded}
Density:	2.71 g/cm <sup>3</sup>
Mass:	6.91 lb <sub>mass</sub> (Relative Error = 0.315481%)
Area:	628.47 in <sup>2</sup> (Relative Error = 0.000056%)
Volume:	70.64 in <sup>3</sup> (Relative Error = 0.315481%)

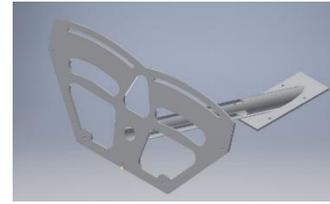


Figure B.2, Gear Plate

### Physical Properties for 18 Teeth Gear (x2)

#### General Properties:

Material:	{Steel, High Strength Low Alloy}
Density:	7.84 g/cm <sup>3</sup>
Mass:	1.05 lb <sub>mass</sub> (Relative Error = 0.486784%)
Area:	23.33 in <sup>2</sup> (Relative Error = 0.000000%)
Volume:	3.71 in <sup>3</sup> (Relative Error = 0.486784%)



Figure B.3, 18 Teeth Gear

### Physical Properties for 22 Teeth Gear (x2)

#### General Properties:

Material:	{Steel, High Strength Low Alloy}
Density:	7.84 g/cm <sup>3</sup>
Mass:	1.87 lb <sub>mass</sub> (Relative Error = 0.449698%)
Area:	31.71 in <sup>2</sup> (Relative Error = 0.000000%)
Volume:	6.63 in <sup>3</sup> (Relative Error = 0.449698%)

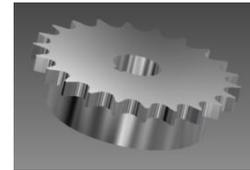


Figure B.4, 22 Teeth Gear

### Physical Properties for Drive Shaft

#### General Properties:

Material:	{Steel, High Strength Low Alloy}
Density:	7.84 g/cm <sup>3</sup>
Mass:	3.20 lb <sub>mass</sub> (Relative Error = 0.120466%)
Area:	92.38 in <sup>2</sup> (Relative Error = 0.026252%)
Volume:	11.31 in <sup>3</sup> (Relative Error = 0.120466%)

### Physical Properties for Steering Swivel

#### General Properties:

Material:	{Steel}
Density:	7.85 g/cm <sup>3</sup>
Mass:	1.63 lb <sub>mass</sub> (Relative Error = 0.039274%)
Area:	39.66 in <sup>2</sup> (Relative Error = 0.000000%)
Volume:	5.77 in <sup>3</sup> (Relative Error = 0.039274%)

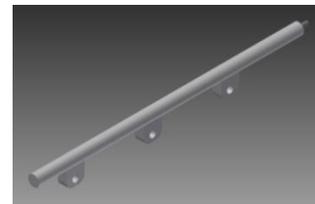


Figure B.5, Steering Swivel

### Physical Properties for Transverse Arm (x6)

#### General Properties:

Material:	{Aluminum 6061}
Density:	2.71 g/cm <sup>3</sup>
Mass:	0.32 lb <sub>mass</sub> (Relative Error = 0.000149%)
Area:	27.46 in <sup>2</sup> (Relative Error = 0.000000%)
Volume:	3.30 in <sup>3</sup> (Relative Error = 0.000149%)

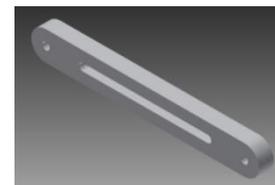


Figure B.6, Transverse Arm

### Physical Properties for Steering Strut

General Properties:

Material: {Aluminum 6061, Welded}  
Density: 2.71 g/cm<sup>3</sup>  
Mass: 3.95 lb<sub>mass</sub> (Relative Error = 0.001178%)  
Area: 198.13 in<sup>2</sup> (Relative Error = 0.00000%)  
Volume: 40.55 in<sup>3</sup> (Relative Error = 0.001178%)

### Physical Properties for ACME screw

General Properties:

Material: {Steel}  
Density: 7.850 g/cm<sup>3</sup>  
Mass: 0.407 lb<sub>mass</sub> (Relative Error = 0.053793%)  
Area: 15.536 in<sup>2</sup> (Relative Error = 0.000000%)  
Volume: 1.436 in<sup>3</sup> (Relative Error = 0.053793%)

### Physical Properties for Propeller

General Properties:

Material: {Aluminum 6061}  
Density: 2.710 g/cm<sup>3</sup>  
Mass: 1.181 lb<sub>mass</sub> (Relative Error = 0.887189%)  
Area: 154.660 in<sup>2</sup> (Relative Error = 0.281014%)  
Volume: 12.061 in<sup>3</sup> (Relative Error = 0.887189%)

### Physical Properties for the Foil

General Properties:

Material: {PETG plastic}  
Density: 1.541 g/cm<sup>3</sup>  
Mass: .927 lb<sub>mass</sub> (Relative Error = 0.329278%)  
Area: 207.83 in<sup>2</sup> (Relative Error = 0.147807%)  
Volume: 16.646 in<sup>3</sup> (Relative Error = 0.329278%)

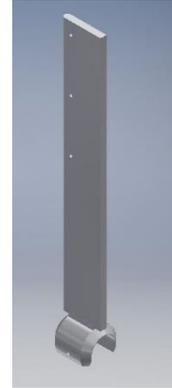


Figure B.7, Steering Strut

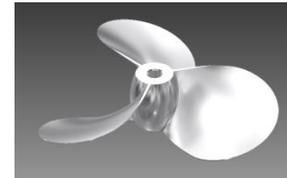


Figure B.8, Sprint Propeller

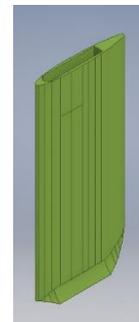


Figure B.9, Foil

## Appendix C: Proof of Insurance

Solar Splash 2017 Rule 2.7 Insurance - Each participating Team is required to provide proof of general liability insurance from their educational institution or written proof that, as a state institution, they are self-insured. Proof of insurance must be supplied with the Technical Report. Failure to do so will result in a 10 point penalty applied to the Technical Report score.

\*\*The current insurance policy from Geneva College expires on June 1, 2017. Our team will obtain a paper copy, after June 1, 2017, and provide competition officials, upon arrival, proof of insurance from Geneva College. Below is a copy of an expired form for example of insurance only. \*\*

Client#: 4234		GENECO		DATE (MM/DD/YYYY)
<b>ACORD</b>		<b>CERTIFICATE OF LIABILITY INSURANCE</b>		5/04/2015
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 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	CONTACT NAME	PHONE (A/C, No., Ext.)	FAX (A/C, No.)	
HDH Pittsburgh P&C 210 Sixth Avenue, 30th Floor Pittsburgh, PA 15222 412 391-7300		412 391-7300	412 391-7322	
	E-MAIL ADDRESS			
	INSURER(S) AFFORDING COVERAGE		NAIC #	
INSURED	INSURER A - Travelers Indemnity Company		25658	
Geneva College Trustees 3200 College Avenue Beaver Falls, PA 15010	INSURER B			
	INSURER C			
	INSURER D			
	INSURER E			
	INSURER F			

COVERAGES		CERTIFICATE NUMBER:		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 SUBR INSR	INSR WVD	POLICY NUMBER	POLICY EFF. (MM/DD/YYYY)	POLICY EXP. (MM/DD/YYYY)	LIMITS
A	GENERAL LIABILITY <input checked="" type="checkbox"/> COMMERCIAL GENERAL LIABILITY <input type="checkbox"/> CLAIMS-MADE <input checked="" type="checkbox"/> OCCUR			Y6302920M248TIA14	05/31/2014	05/31/2015	EACH OCCURRENCE \$1,000,000 DAMAGE TO RENTED PREMISES (Ea. Occurrence) \$100,000 MED EXP (Any one person) \$5,000 PERSONAL & ADV INJURY \$1,000,000 GENERAL AGGREGATE \$3,000,000 PRODUCTS - COM/PROP AGG \$2,000,000
	GEN'L AGGREGATE LIMIT APPLIES PER: POLICY <input type="checkbox"/> PRO-JECT <input type="checkbox"/> LOC <input type="checkbox"/>						\$
	AUTOMOBILE LIABILITY ANY AUTO <input type="checkbox"/> SCHEDULED AUTOS <input type="checkbox"/> ALL OWNED AUTOS <input type="checkbox"/> NON-OWNED AUTOS <input type="checkbox"/> HIRED AUTOS <input type="checkbox"/>						COMBINED SINGLE LIMIT (Ea. Accident) \$ BODILY INJURY (Per person) \$ BODILY INJURY (Per accident) \$ PROPERTY DAMAGE (Per accident) \$
	UMBRELLA LIAB EXCESS LIAB <input type="checkbox"/> OCCUR <input type="checkbox"/> CLAIMS-MADE <input type="checkbox"/>						EACH OCCURRENCE \$ AGGREGATE \$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY ANY PROPRIETOR/PARTNER/EXECUTIVE/OFFICER/EMBER EXCLUDED? <input type="checkbox"/> Y/N If yes, describe and describe operations below			N/A			WC STATU-TORY LIMITS <input type="checkbox"/> OTH-ER \$ E.L. EACH ACCIDENT \$ E.L. DISEASE - EA EMPLOYEE \$ E.L. DISEASE - POLICY LIMIT \$
DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (Attach ACORD 101, Additional Remarks Schedule, if more space is required)							

CERTIFICATE HOLDER	CANCELLATION
Evidence of Coverage	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 <i>Andrew H. Nelson</i>

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Figure C.1, Expired Proof of insurance.

## Appendix D: Team Roster

Name (Left to Right)	Degree Program	Year	Team Role
Joey Beichy	Mechanical Engineering	Senior	Batteries and electrical configurations
Ryan Carrig	Mechanical Engineering	Senior	Propeller design and manufacturing
Byron Childs	Mechanical Engineering	Senior	Drive System, gears, and propeller housing
Thomas J Acosta	Interdisciplinary Engineering	Senior	Team Representative, Hull Optimization
Kirk Musselman	Mechanical Engineering	Senior	Steering and Motors
Jonathan Dawley	Mechanical Engineering	Senior	Solar panels and electrical configurations
Aaron DeSantis	Mechanical Engineering	Senior	Data acquisition system, drive shaft
Jordan Bonenberger (Not Shown)	Mechanical Engineering	Senior (December 2017 graduate)	Propeller design

Table D.1 Team Roster



Figure D.2 Team picture

Name	Program	Role
Dr. David Shaw	Mechanical Engineering	Advisor
Dave Clark	Technical Engineering	Advisor

Table D.3, Team Advisers

## Appendix E: Solar System Data

YTH TECHNOLOGY CO., LTD



### YTH Solar Cell Quotation

**125mm 2BB Monocrystalline solar cell**

**Physical Characteristics:**

**Dimension:** 125mm\*125mm±0.5mm

**Thickness:** 180µm±20µm

**Diagonal:** 160mm±1.0mm(round chamfers)

**Front:** 1.6mm Silver bus bars; Blue/others silicon nitride antireflection coating

**Back:** 2.8mm Silver bus bars; Full-surface aluminum BSF

**Electrical Characteristics:**

Efficiency	Pmax(W)	Impp(A)	Vmpp(V)	Isc(A)	Voc(V)	Price	Quality
>15.5	>2.50	5.378	0.526	5.711	0.628	USD1.0	A
15.30-15.50	2.40-2.50	4.826	0.498	4.909	0.517	USD0.9	A



www.ythsolar.com

**Note:**

- \*Data under standard testing condition (STC): 1,000W/m<sup>2</sup>,AM1.5,25°C.
- \*All figures bear±3% of tolerance.
- \*MOQ:1000PCS Above is EXW Price.

Figure E.1, Data Sheet for Solar Cells

Equation I

$$P = VI_{total} \rightarrow 528W = (36V)I_{total} \rightarrow I_{total} = \frac{528W}{36V} = 14.67A$$

Equation II

$$I_{total} = I_{cell} \cdot n_{parallel} \rightarrow I_{cell} = \frac{I_{total}}{n_{parallel}} = \frac{14.67A}{3} = 4.89$$

Sources for Materials:

- Solar cells:
  - 125mm 2BB Monocrystalline Solar Cell
  - YTH Technology Co., LTD, 5F 21 Building, Tongfuyu Industrial Area, Dalang Street, Longhua New District, Shenzhen, China
  - Purchased through Alibaba.com
- Honeycomb core backing:
  - PP Polypropylene Honeycomb
  - Plascore Incorporated, 615 N. Fairview St., Zeeland, MI 49464-0170

## Appendix F: Battery Testing

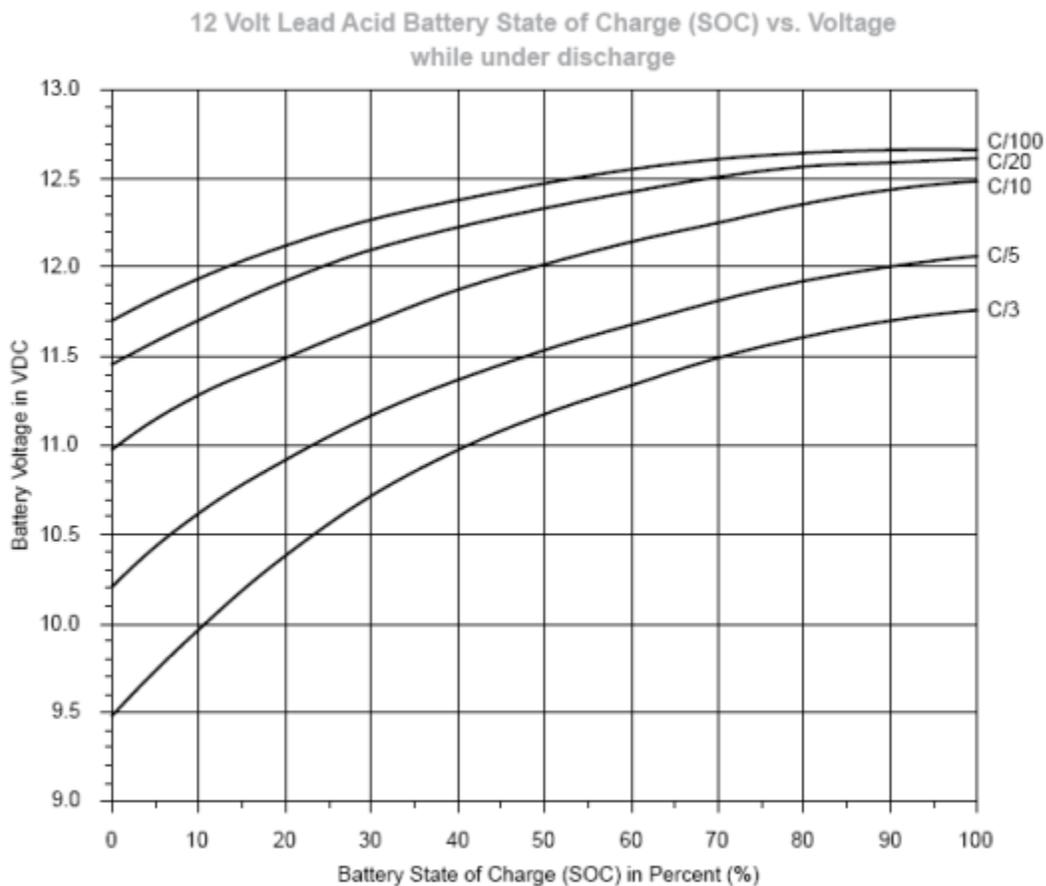


Figure F.1, Battery Voltage vs. State of Charge

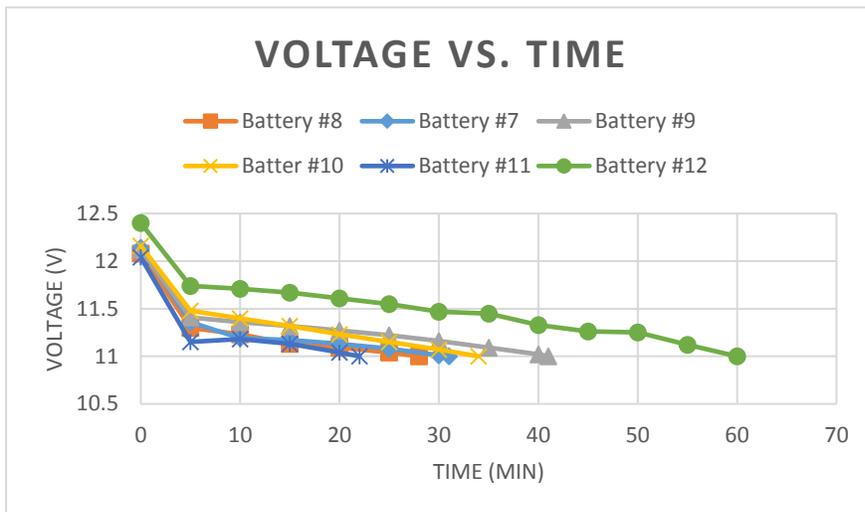


Figure F.2, Optima Voltage vs. Time Graph 2

*Peukert's Law:* The equation for Peukert's Law is  $t = H\left(\frac{C}{IH}\right)^k$ . Where t is the time to discharge, H is the rated discharge time from the manufacturer, C is the rated capacity in amp-hours at H, I is the actual discharge current, and k is the Peukert's constant. The basic principle of the law is that as discharge current increases, the time to discharge decreases at a nonlinear rate. This is due to chemical processes between the electrolyte and the surface of the plates inside the battery. Sulphuric acid, a good conductor, is changed to lead sulphate, a poor conductor, in the reaction that produces energy. This increases the internal resistance and provides less surface area for the reaction to take place. The available capacity is therefore decreased as the battery is discharged. The previous team used a simplified version of the equation for Peukert's Law. The equation returns the same absolute value of Peukert's equation, but the slope is negative.

$$T = \frac{1}{C} I^2$$

$$\ln(T) = \ln\left(\frac{1}{C}\right) + n \ln(I)$$

Time	LN(TIME)	Current	LN(Current)
141	4.9	5.32	1.671473303
105	4.7	8.18	2.101692151
54	4.0	15.1	2.714694744

Table F.1, CSB Peukert's Constant Calculation Data. The Slope of the Trend line is 'n.'

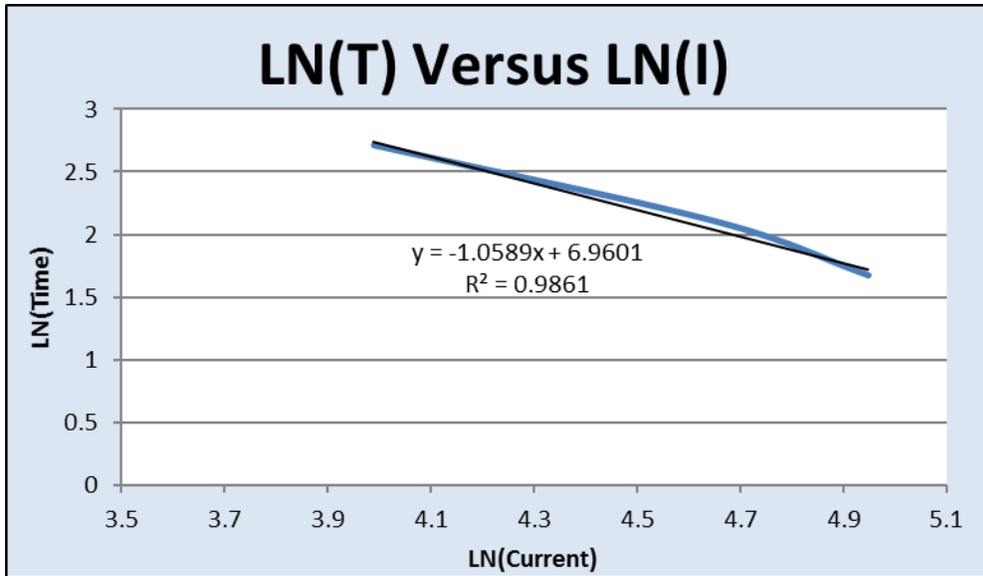


Figure F.3, Graph Showing CSB Peukert's Constant

$$t = H(C/IH)^k$$

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

t/H	$\ln(t/H)$	C/IH	$\ln(C/IH)$
0.2375	-1.43759	0.312992	-1.16158
0.075	-2.59027	0.118481	-2.133

Table F.2, Optima Peukert's Constant Calculation Data

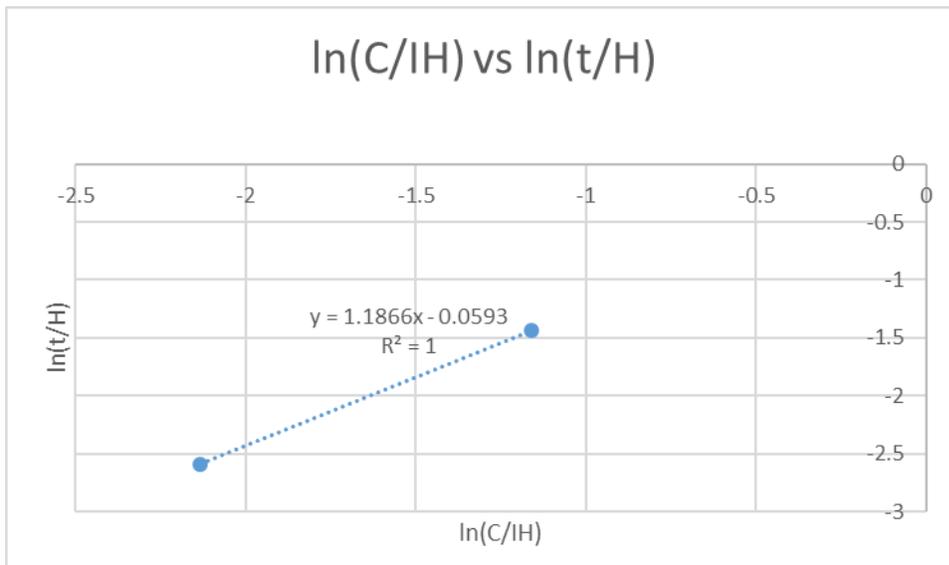


Figure F.4, Graph Showing Optima Peukert's Constant. The Slope of the Trend line is "k."

## Appendix G: Hull Design and Optimization

### A. Hull Characterization

The following is a compilation of characteristics of Hulls according to Dr. Daniel Savitsky, taken from his writing titled, "ON THE SUBJECT OF HIGH-SPEED MONOHULLS".

#### Characteristics of Semi-Displacement Hulls:

- *Water entry lines that are fine, and straight buttock lines in the afterbody with a slight steady rise aft. These terminate at a sharp wide transom that is partially submerged.*
- *Round bilges along the entire hull -although some designers may prefer a combination of sharp chine aft with round chine forward or vice-versa.*
- *Straight, Vee-formed cross-sections in the forebody.*

#### Characteristics of Planing Hulls:

- *Complete avoidance of convex surfaces (except for the bow area which is out of the water at planing speeds) to avoid the development of bottom suction pressures.*
- *Sharp edge chines at the intersection of the bottom and sides to insure complete separation of the transverse flow component from the bottom.*
- *A deeply submerged wide transom with a sharp trailing edge to insure complete separation of the longitudinal flow from the bottom- thus insuring that the entire transom is ventilated to the atmosphere.*
- *Vee-bottom transverse sections with the deadrise increasing towards the bow. The deadrise is required to reduce the wave impact loads in a seaway and to provide lateral wetted surface required for course-keeping stability and maneuvering.*

$$SLR = \frac{Wk}{\sqrt{LWL}}$$

$W_s$  = weight of hull and super-structure.

$W_p$  = weight of propulsion system.

$W_{o+a}$  = weight of outfit and auxiliary systems

$W_l$  = light-ship weight

$W_{ul}$  = useful load

$\Delta$  = Displacement

Hull Type	$\frac{Wk}{\sqrt{LWL}}$	$\frac{W_s}{\Delta}$	$\frac{W_p}{\Delta}$	$\frac{W(o+a)}{\Delta}$	$\frac{W_l}{\Delta}$	$\frac{W_{ul}}{\Delta}$
Displacement	1.2	0.23	0.01	0.12	0.36	0.64
Semi-Displacement	2.8	0.25	0.10	0.12	0.52	0.53
Planing	6.0	0.30	0.36	0.12	0.78	0.22

Our hull fell into Semi-Displacement for most of these characteristics, including the graphs on the next pages.

**Data for SLR vs Rt/Displacement graph used to identify types of hulls.**

2015 Configuration, Front Loaded

Vs( kn)	Tau (degr)	Rt (lbf)	Pe (EHP)	Rt/Δ	Speed/Length ratio
8.02	0.58	31.2	0.8	0.067503	1.975645144
9.22	0.57	39.1	1.1	0.084595	2.271252897
10.42	0.57	48.4	1.6	0.104717	2.566860649
11.62	0.62	60.1	2.2	0.13003	2.862468401
12.81	0.91	75.4	3	0.163133	3.155612755
14.01	1.61	95.2	4.2	0.205971	3.451220508
15.21	0.87	103.1	4.9	0.223064	3.74682826
16.41	0.6	117	6	0.253137	4.042436012
17.6	0.57	137.6	7.5	0.297707	4.335580367
18.8	0.6	163.1	9.5	0.352878	4.631188119
20	0.53	191.7	11.9	0.414756	4.926795871

Table G.1, Results for 2015 boat front-loaded.

	LWL=	16.479 ft
	Displacement (Δ)=	462.2 lb

2015 Configuration, Back Loaded

Vs( kn)	Tau (degr)	Rt (lbf)	Pe (EHP)	Rt/Δ	Speed/Length ratio
9.51	3.54	61.9	1.8	0.133925	2.384739732
10.56	3.25	66.3	2.2	0.143444	2.648039071
11.61	3.04	72.1	2.6	0.155993	2.911338411
12.66	2.87	79	3.1	0.170922	3.17463775
13.71	2.78	87.1	3.7	0.188447	3.43793709
14.75	2.7	95.9	4.4	0.207486	3.698728816
15.8	2.62	105.5	5.2	0.228256	3.962028156
16.86	2.54	115.8	6.1	0.250541	4.227835108
17.9	2.44	126.9	7.1	0.274556	4.488626835
18.95	2.34	138.7	8.2	0.300087	4.751926174
20	2.23	151.1	9.4	0.326915	5.015225514

Table G.2, Results of 2015 boat back loaded.

	LWL=	15.903 ft
	Displacement (Δ)=	462.2 lb

Using the data above which was obtained from our hull model inputted into FREEShip, we can create the graphs in Figure G.2. The theoretical graph is displayed on the right in Figure G.1, and we can see that our front loaded hull configuration is similar to the theoretical graph of the Overdriven Displacement Hull. However, when we graph the same hull model, except with more weight towards the back of the hull, we find that the hull behaves slightly more like a planing hull, but still not well. These graphs were further proof of our conclusions for center of gravity location shifting for endurance and sprint races, and that our hull is a semi-displacement hull capable of displaying some planing hull characteristics.

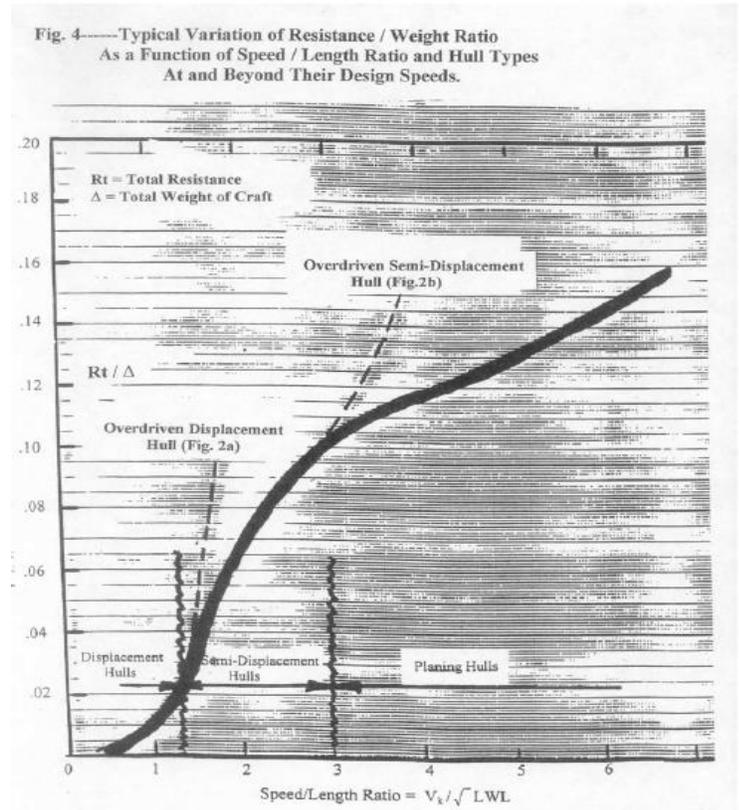


Figure G.1, Theoretical SLR vs Rt/Displacement

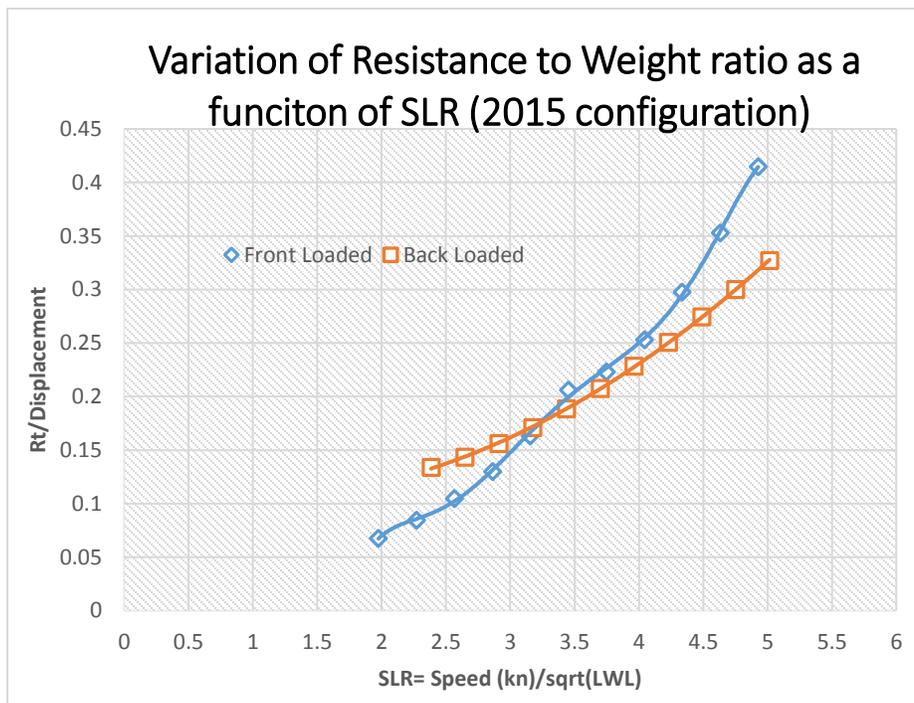


Figure G.2, SLR vs Rt/Displacement for Current Hull

## B. Decision Matrix for Hull Model/Configuration

### Design Goals for Hull Designs

Performance: Endurance (PE)

Sprint (PS)

Slalom (PSL)

Maneuverability (PM)

Costs: Material costs (CM)

Time: Implementation (TI)

Testing (TT)

Aesthetics (AS)

Ease of Use (EU)

Maintenance (Likelihood of repair) (MR)

	PE	PS	PSL	PM	CM	TI	TT	AS	EU	MR	Totals
PE		1	1	1	1	0.5	1	1	1	0.5	<b>8</b>
PS	0		1	1	1	0.5	1	1	1	0.5	<b>7</b>
PSL	0	0		0.5	1	0	0.5	1	1	0	<b>4</b>
PM	0	0	0.5		1	0	0.5	1	0.5	0	<b>3.5</b>
CM	0	0	0.5	0.5		1	0.5	1	1	0	<b>4.5</b>
TI	1	1	1	1	0.5		1	1	1	1	<b>8.5</b>
TT	0.5	0.5	1	1	0	0		1	1	0.5	<b>5.5</b>
AS	0	0	0	0	0	0	0		0.5	0	<b>0.5</b>
EU	0	0	0	0	0.5	0	0.5	1		0	<b>2</b>
MR	0.5	0.5	0.5	0.5	1	0	1	1	1		<b>6</b>

Table G.3, Rank Ordering list of design goals (1=row>column, 0=column>row, 0.5=equal value)

1	TI	<b>8.5</b>
2	PE	<b>8</b>
3	PS	<b>7</b>
4	MR	<b>6</b>
5	TT	<b>5.5</b>
6	CM	<b>4.5</b>
7	PSL	<b>4</b>
8	PM	<b>3.5</b>
9	EU	<b>2</b>
10	AS	<b>0.5</b>

Table G.4, Final Ranked Order

**Relative weighting values for design goals:**

	100	Implementation Time
<i>Critical</i>	90	Endurance Performance
	80	Sprint Performance
	70	Maintenance, possible repair
	60	Testing Time
<i>Important</i>	50	Cost of materials
	40	Performance in Slalom
	30	Performance in Maneuverability
	20	Ease of Use
<i>Optional</i>	10	Aesthetics
	0	

**Design Rating Factors:**

10 = Excellent

8 = Good

6 = Satisfactory

4 = Mediocre

2 = Unacceptable

0 = Failure

Decision Matrix	Design Goals										
	IT	PE	PS	MR	TT	CM	PSL	PM	EU	AS	
	Weighing Factors										
	100	90	80	70	60	50	40	30	20	10	
<i>Alternate Designs</i>											<b>Totals</b>
2015 configuration	9	8	6	8	9	8	7	7	8	6	<b>4310</b>
Outboard	6	9	8	6	6	5	8	8	8	6	<b>3860</b>
Increased Chine	7	7	7	6	7	7	6	6	8	4	<b>3700</b>

Table G.5, Final Design Matrix

### C. Center of Gravity Analysis

The tables on this page are some of the tables used to determine the center of gravity of our boat when all of the components are in place. Using the  $\Sigma M=0$  from statics, we can find the single axis center of gravity based on the weight and location of all the major components. Once the center of gravity is determined on the single axis, it can be inputted into the FREEShip software which will then calculate the three dimensional center of gravity and the resulting water line. Once these setups were created, we then ran the software to determine the resulting resistance curves. Examples of resulting resistance curves and raw data can be found in Fig. G.6 and Table G.8.

<b>2015 Configuration with Batteries in Middle (3)</b>		
Object	Placement, x (ft) from transom	Weight (lb)
Skipper	9	150
Batteries	6.75	100
Hull	6.59	99.6
Drive Train	-0.583	19.6
Sterring unit	10	20
Motors	4.583	48
Motor housing	4	15
Miscellaneous	5	10
<b>Total weight (lb)</b>		462.2
<b>Total weight (metric tonnes)</b>		0.206339286
$\Sigma M$ about x=0, find resultant length, d		
		d= 6.92323929

Table G.6, Center of gravity records

<b>2015 Configuration with Batteries in Front (1)</b>		
Object	Placement, x (ft) from transom	Weight (lb)
Skipper	9	150
Batteries	12	100
Hull	6.59	99.6
Drive Train	-0.583	19.6
Sterring unit	10	20
Motors	4.583	48
Motor housing	4	15
Miscellaneous	5	10
<b>Total weight (lb)</b>		462.2
<b>Total weight (metric tonnes)</b>		0.206339286
$\Sigma M$ about x=0, find resultant length, d		
		d= 8.059

<b>2015 Configuration with Batteries in Back (2)</b>		
Object	Placement, x (ft) from transom	Weight (lb)
Skipper	9	150
Batteries	1.5	100
Hull	6.59	99.6
Drive Train	-0.583	19.6
Sterring unit	10	20
Motors	4.583	48
Motor housing	4	15
Miscellaneous	5	10
<b>Total weight (lb)</b>		462.2
<b>Total weight (metric tonnes)</b>		0.206339286
$\Sigma M$ about x=0, find resultant length, d		
		d= 5.787367373

Table G.7, Center of gravity records

### D. Bottom Chine/Keel Analysis and Calculations

Dimensions- Acquired by hand measurements and FREEShip

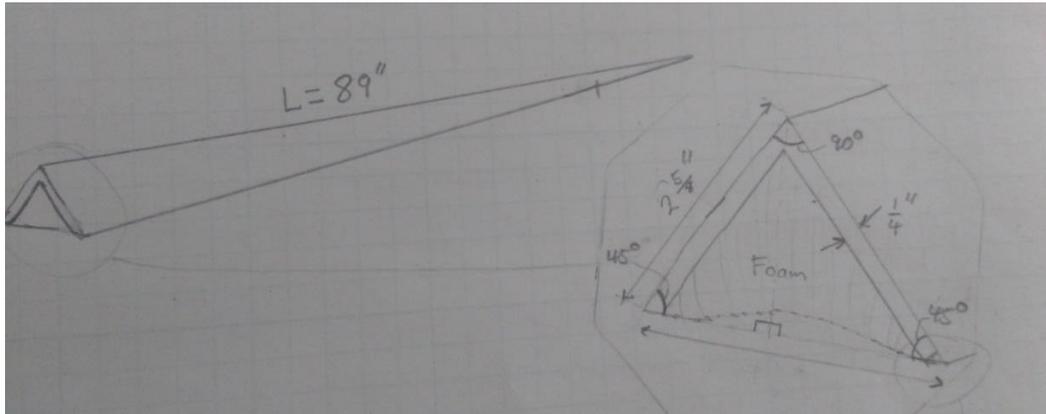


Figure G.3, Design for the Keel.

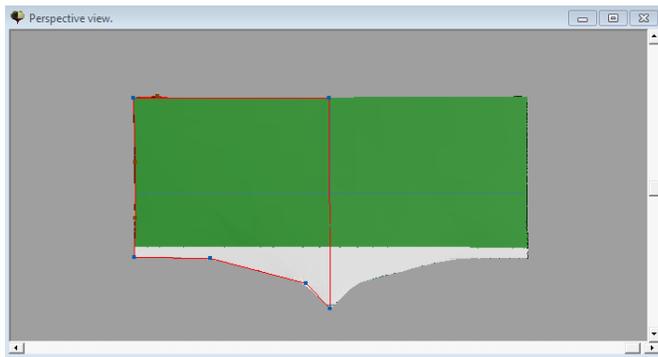


Figure G.4, Rearview of boat in FREEShip

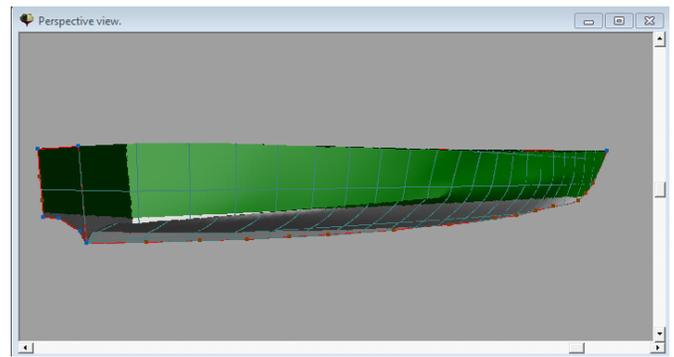


Figure G.5, Rear-iso view of boat in FREEShip

### Volumes

$$V = \frac{1}{3} A_b H$$

$$V_T = \frac{1}{3} (1.856 \text{ in})^2 (89 \text{ in}) = 102.20 \text{ in}^3 = 0.05914 \text{ ft}^3$$

$$V_{\text{Foam}} = \frac{1}{3} (1.856 \text{ in} - 0.35355 \text{ in})^2 (65 \text{ in}) = 39.1275 \text{ in}^3 = 0.02264 \text{ ft}^3$$

$$V_{\text{Cedar}} = V_T - V_{\text{Foam}} = 63.0725 \text{ in}^3 = 0.03650 \text{ ft}^3$$

## Weights

$$W = \rho V$$

$$W_{Cedar} = \rho_{Cedar} V_{Cedar} = \left( 23 \frac{lbs}{ft^3} \right) (0.03650 ft^3) = 0.8395 lbs$$

$$W_{Foam} = \rho_{Foam} V_{Foam} = \left( 6 \frac{lbs}{ft^3} \right) (0.02264 ft^3) = 0.13586 lbs$$

## Buoyancy Forces

$$F_B = F_{bottom} - F_{Top} = \rho_{Fluid} gV - W$$

$$F_{B,Cedar} = \gamma_{Water} V_{Cedar} - W_{Cedar} = \left( 62.4 \frac{lb_f}{ft^3} \right) (0.03650 ft^3) = 1.4381 lbs$$

$$F_{B,Foam} = \gamma_{Water} V_{Foam} - W_{Foam} = \left( 62.4 \frac{lb_f}{ft^3} \right) (0.02264 ft^3) = 1.2769 lbs$$

$$F_{B,Total} = 2.6896 lbs$$

## ***E. Data for Gel Coat***

### **PREPARATION**

#### **On Painted Hull Surfaces:**

Sea-Slide Formula can be used on wood, metal and fiberglass hulls that have been properly prepared and coated with vinyl or hard epoxy anti-fouling paint (vinyl provides better adhesion). Coating adhesion and durability is substantially reduced if Sea-Slide Formula is applied over soft or “self-polishing” antifouling paints. Recent anti-fouling paint applications must be completely dried in accordance with manufacturer’s instructions, preferably overnight. Compared to other types of marine paints, epoxies usually require a longer time to cure completely.

#### **On Bare Hull Surfaces:**

Bare fiberglass hulls should be pre-treated with a marine primer to improve adhesion of the Sea-Slide coating. Allow primer coat to dry according to label instructions. Where no primer is available, thorough sanding of the surface before applying the Sea-Slide coating will improve adhesion.

### **DIRECTIONS FOR USE**

Do not apply if rain is expected during the required curing period of 3 to 4 hours\*, or if relative humidity exceeds 90%. \*For best results use on dry, sunny day with relative humidity of 80 % or below, and temperature of 50°F (10°C) or warmer.

- Sea-Slide Formula may be applied with a brush, a paint roller, sponge or spray equipment.
- Coating should be spread to form an even film over the hull surface. Apply on a clean dry surface.
- For spraying, Sea-Slide Formula may be diluted up to 50% (2 parts Sea-Slide Formula to 1 part tap water).
- Allow coating to dry and cure for 4 to 5 hours, preferably in direct sunlight.
- Sea-Slide Formula will form a clear film coating when dry.
- Curing takes place after the coating dries to the touch.

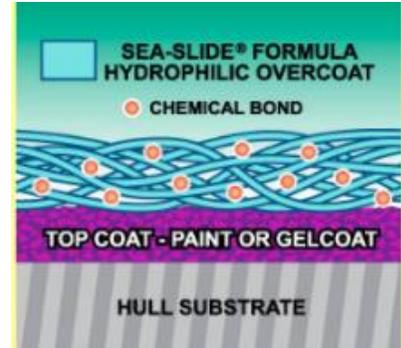
After Sea-Slide Formula has cured, boat may be launched immediately or kept from water indefinitely. The coating will not be adversely affected by repeating wetting/drying cycles. Once cured, the coating will be insoluble in water, but should not be scrubbed or sanded. Water line organic growth may be sponged off.

**COVERAGE:**

- One Gallon = Approximately 700 to 900 square feet
- One Quart = Approximately 175 to 225 square feet
- One Pint = Approximately 85 to 110 square feet

**WATERCRAFT COATING CALCULATOR:**

- Personal watercraft: Jet Ski, canoe, kayak, row and paddle boats = One Pint
- 00-00 ft. watercraft, sail and power boats = One Quart
- 00-00 ft. watercraft, large sail and commercial boats = One Gallon



**CLEAN UP**

Clean painting equipment, clothing and spills with soap and water before coating dries.

**HOW TO REMOVE SEA-SLIDE COATING**

The Sea-Slide coating may be removed from hull surfaces by power washing with high-pressure water and a nylon scrub brush. Prior to refinishing watercraft hull or reapplication of anti-fouling bottom paint, first remove the Sea-Slide coating entirely.

**CAUTION:**

Avoid spills of Sea-Slide Formula on deck surfaces or other areas of watercraft where a slippery surface would be hazardous. The cured coating is extremely slippery when wetted. Overturned or capsized watercraft may become virtually impossible to hold onto, or to handle well enough to reverse or right. Take appropriate precautions once Sea-Slide coating has been applied to your watercraft.



**Sea-Slide Formula tested on Kawasaki 1100s**

Three Kawasaki 1100s were coated with Sea-Slide Formula with results below:  
 All tests were conducted during summer months on Barnaget Bay, New Jersey.  
 All tests were for one hour in duration (and are the averaged results of the 3 Kawasaki 1100s subjects tested).

Without Sea-Slide Formula				
Test	Water Conditions	Fuel Consumption	Top Speed	Handling
1	Calm	0.50 gal.	60 mph	Excellent
2	Slight Chop	1.25 gal.	50 mph	Good
3	Choppy	2.00 gal.	45 mph	Fair

With Sea-Slide Formula				
Test	Water Conditions	Fuel Consumption	Top Speed	Handling
1	Calm	Less than 0.25 gal.	65+ mph	Excellent
2	Slight Chop	Less than 1.00 gal.	65+ mph	Very Good
3	Choppy	1.00 gal.	60 mph	Good

**Note:** 65+ means that they buried their speedometers!  
 Durability – all subjects reported that one Sea-Slide coating lasted greater than two weeks.  
 Subjects rated Ease of Application from Very Good to Excellent.  
 All subjects noted that when left in the water, their watercraft had substantial fouling when uncoated. <sup>L</sup>  
 When coated, minimum fouling was noticed, even when jet skis were left in the water for two weeks.  
 All subjects noted that they would definitely continue to use Sea-Slide Formula for their watercraft.

**F. Examples of Data from FREEShip**

The following graphs, charts, and data excerpts are to help the reader understand what kind of data is produced with the FREEShip software. After the 3-Dmodel of the hull is inputted into the software using the programs interface, various tests can be run. These tests will produce all hydrostatic variable, such as waterline, trim angles, displacement based on weight, prismatic coefficients, and deadrise angles. Once hydrostatic variables are verified, you can run hydrodynamic testing, mainly the development of resistance curves. There are several methods the program used to calculate the resistance curves, but the two most useful methods for our use were the Kaper method, for endurance conditions, and the Sedov method, for sprint conditions. Comparisons of the data were done graphically in Excel or by comparison in PowerPoint.

Final calculations of resistance and power for planing ships

Vs [kn]	FrB -	Tau [degr]	R <sub>f</sub> [lbf]	R <sub>p</sub> [lbf]	R <sub>t</sub> [lbf]	Pe [ehp]
9.51	1.70	3.65	29.8	27.5	59.8	1.8
10.56	1.89	3.35	35.3	25.3	63.9	2.1
11.61	2.08	3.12	41.2	23.6	69.3	2.5
12.65	2.26	2.95	47.5	22.3	75.9	3.0
13.70	2.45	2.85	54.0	21.5	83.6	3.6
14.75	2.64	2.76	60.9	20.9	92.1	4.2
15.80	2.83	2.68	68.3	20.2	101.2	5.0
16.85	3.01	2.59	76.0	19.5	111.0	5.8
17.90	3.20	2.49	84.2	18.8	121.5	6.8
18.95	3.39	2.38	92.8	18.0	132.7	7.8
20.00	3.58	2.27	101.8	17.1	144.6	9.0

Table G.8, Excerpt of Data Produced by FREEShip

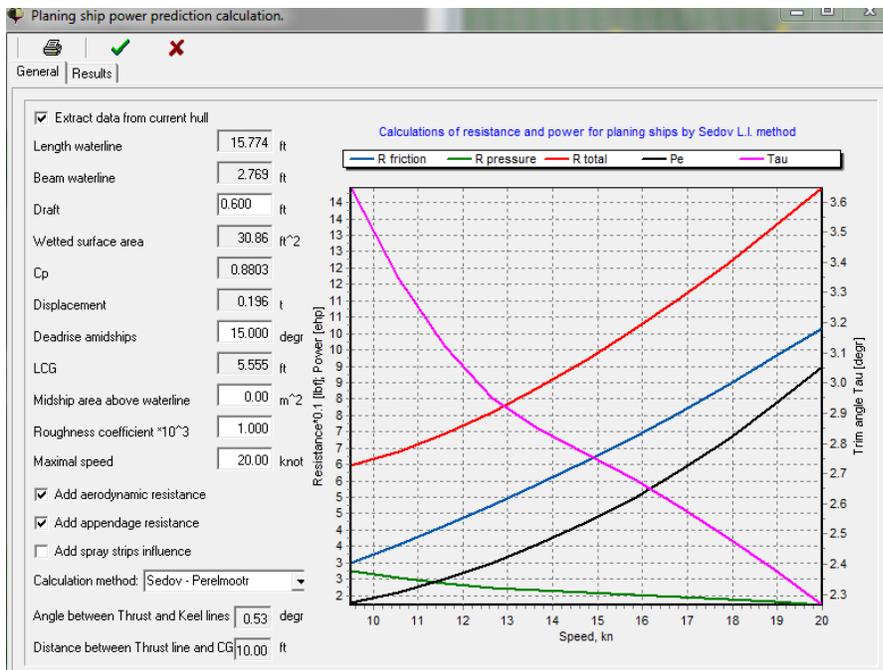


Figure G.6, Resulting Resistance Curve from FREEShip

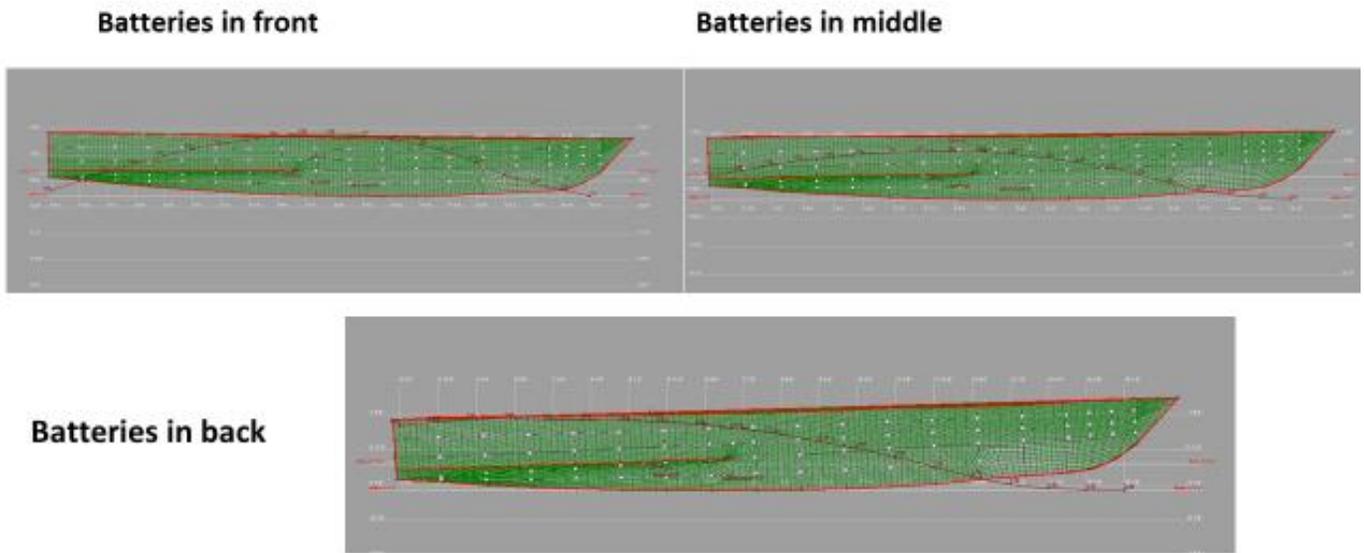


Figure G.7, Graphical Distribution of Water Displacement in Reference to Hull

```

Design length      : 17.500 ft
Design beam       : 1.370 ft
Design draft      : 0.730 ft
Midship location  : 8.750 ft
Water density     : 65.016 lbs/ft^3
Appendage coefficient : 1.0000
  
```

```

Date      : 4/11/2017
Time     : 1:28:13 PM
  
```

-----  
 Input variables

```

Hull
Effective waterline length : 16.460 ft
Beam on waterline         : 2.000 ft
Draft hull                : 0.730 ft
Wetted surface area       : 31.49 ft^2
Prismatic coefficient      : 0.6402
Displacement               : 0.22 t
Deadrise amidships        : 15.000 degr
X of CoG                  : 7.621 ft
Midship area above waterline : 0.00 ft^2
Roughness coefficient *10^3 : 1.000
Maximal speed              : 20.00 knots
Angle between Thrust and keel lines : 0.53 degr
Distance between Thrust line and CoG : 10.000 ft
  
```

Figure G.8, Example of Various Variables Produced by FREEShip

## Appendix H: Gears and Chains

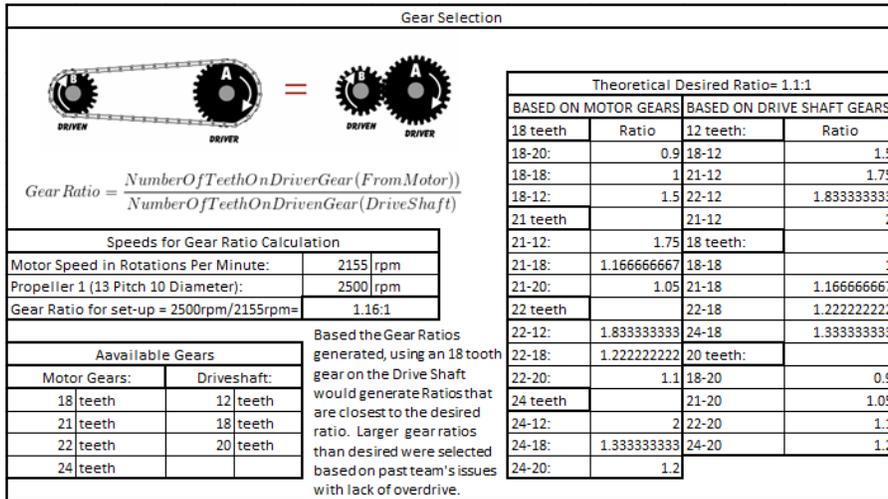


Figure H.1 – Gear Selection Table

Calculating the gearing ratio is accomplished by dividing the teeth number of the driver gear (motor gear) by the teeth number of the driven gear (drive shaft gear). The speeds for Gear Ratio Calculation show the motor speed based on the ME909 motor curve data, the propeller speed based on calculation from Crouch’s Method, and the theoretically desired gear ratio which is calculated by dividing the propeller speed by the motor speed. The list of available

gears shows the Sprint gears (chain size 40) available. Using the list all of the gear ratios were calculated for all possible arrangements.

The image to the right shows the gearing ratio chosen for Sprint. The gears in the drive train are Martin Sprockets. The pinion sprocket (22-teeth) is a Martin 40BS22 (7/8), and the driven sprocket is a Martin 40BS18HT 1. The dimensions were found on the Martin Gear Catalogue. The drive train set-up utilizes two motors spinning the larger sprockets which connect to a single drive shaft with the two smaller sprockets. The torque rotation is clockwise.

The image to the right shows the calculations for the angular velocity, torque, and pitch circle diameter for the driver and driven gears selected for Sprint.

### Chain:

The image to the right displays the chain dimensions. The chain definitions and values for the chain used is taken from the Standard Handbook of Chains. The most important

Martin 40BS22 7/8		Martin 40BS18HT 1	
Material:	steel	Material:	steel
Pitch Type:	Single	Pitch Type:	Single
Bore Type:	Finished with Keyway	Bore Type:	Finished with Keyway
Chain Number:	40	Chain Number:	40
Number of Hubs:	1	Number of Hubs:	1
Number of Strands Across:	1	Number of Strands Across:	1
Number of Teeth:	22	Number of Teeth:	18
Pitch:	0.5 in	Pitch:	0.5 in
Bore Diameter:	0.875 in	Bore Diameter:	1.125 in
Length Through Bore:	1 in	Length Through Bore:	1 in
Outside Diameter:	3.78 in	Outside Diameter:	3.14 in
Tooth Width:	0.284 in	Tooth Width:	0.284 in
Hub Diameter:	2.875 in	Hub Diameter:	2.3125 in
Keyway Size:	3/16 X 3/32	Keyway Size:	1/4 x 1/8
Pitch Diameter:	3.513	Pitch Diameter:	2.879

Gear Relationships	
Angular Velocity (Driver)	$\omega_1 = \frac{2\pi n_1}{60} = \frac{2\pi (2155 \text{ rpm})}{60} = 225.67 \text{ rad/s}$
Angular Velocity (Driven)	$\omega_2 = \omega_1 \cos\left(\frac{180^\circ}{N}\right) = \left(\frac{225.67 \text{ rad}}{s}\right) \cos\left(\frac{180^\circ}{18}\right) = 222.242 \text{ rad/s}$
	$\frac{T_1}{T_2} = \frac{d_p}{d_g}$
Torque (input)	$T_1 = \omega_1 \cos\left(\frac{180^\circ}{N}\right) = 230 \text{ lb} \cdot \text{in}$
Pitch Circle Diameter (Driver)	$d_p = \frac{p_{\text{chain}}}{\sin\left(\frac{180^\circ}{N_p}\right)} = \frac{0.5 \text{ in}}{\sin\left(\frac{180^\circ}{22}\right)} = 3.513 \text{ in}$
Pitch Circle Diameter (Driven)	$d_g = \frac{p_{\text{chain}}}{\sin\left(\frac{180^\circ}{N_g}\right)} = \frac{0.5 \text{ in}}{\sin\left(\frac{180^\circ}{18}\right)} = 2.879 \text{ in}$
Torque (output)	$T_2 = \frac{T_1 d_g}{d_p} = \frac{(230 \text{ lb} \cdot \text{in})(2.879 \text{ in})}{(3.513 \text{ in})}$
	$\text{Gear Ratio} = \frac{n_2}{n_1}$

Figure H.4, Gear Relationships

components of the chain are the Chain number (40), and the pitch (0.5in).

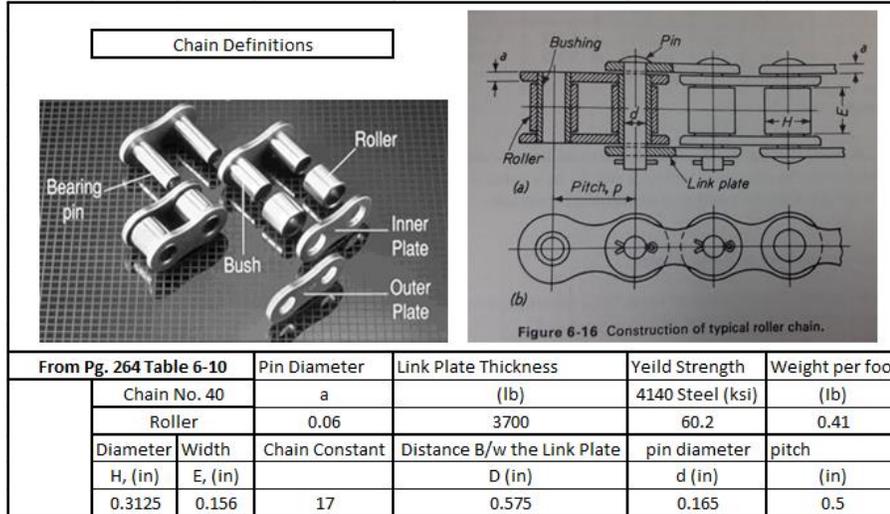


Figure H.5, Chain Schematic

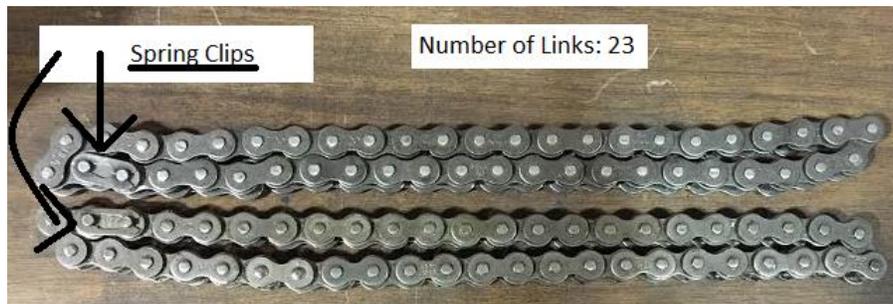


Figure H.6 - Picture of the chain used in the drive train

## Appendix I: Gear Plate

The gear plate mounts to the hull in on two different planes. The first plane is made from three pieces of wood two are mounted to the hull on the starboard and port sides. The third is mounted to the lower portion on the hull. The gear plate rests on the bottom piece in a groove (hidden in picture). The plate is also bolted to the two mounts on either side. In addition to these three mounts there is also a bottom plate on plate that bolts into a mount that has been attached to the hull with the use



Figure I.2, Gear plate in position before modification.

of epoxy. These two fixed plains ensure that the gear plate does not twist or become unaligned. This support is what also allows for the plate to be lightened. Since there is ample amount of support to keep it from twisting or bending metal can be removed from the center and top of the plate. To be sure that the plate would not deform an analysis in inventor was done. The plate was fixed in the model the same way it is in the boat. All bolt holes are fixed and the face that rests on the bottom on the first plane is fixed along with the face that mount to the rear mount. The loading was done to simulate the worst case. The torque was simulated to be 200 lb.-in this is a safety factor of about 1.5 to what the max torque is. The weight of the motors, 24.1 lbs. were also applied to the models of the motors mounted with their motor mounts. After the plate was fixed and the loads were added the deflection on the plate was shown (Fig. I.3 ). It was determined to be .002 in, shown in red. This deflection also occurred on the edges of the motors, which is non-critical. The places where the gears are and where the shaft is mounted showed negligible amount of deflection

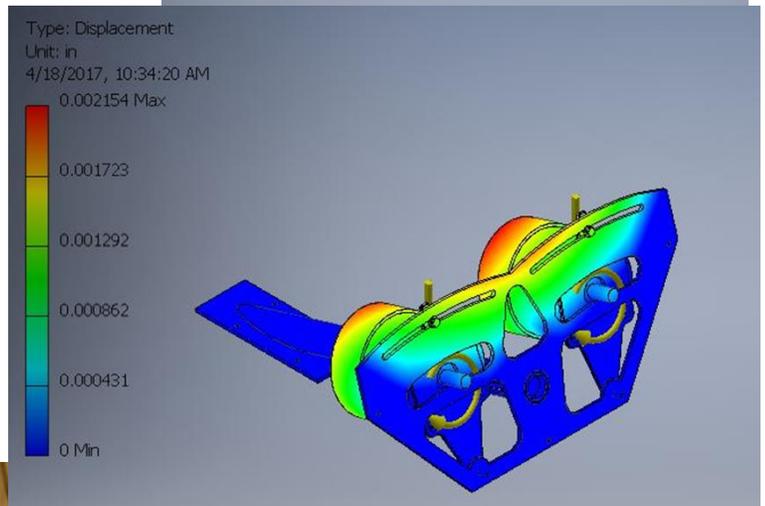


Figure I.3, Analysis of the gear plate.

of epoxy. These two fixed plains ensure that the gear plate does not twist or become unaligned. This support is what also allows for the plate to be lightened. Since there is ample amount of support to keep it from twisting or bending metal can be removed from the center and top of the plate. To be sure that the plate would not deform an analysis in inventor was done. The plate was fixed in the model the same way it is in the boat. All bolt holes are fixed and the face that rests on the bottom on the first plane is fixed along with the face that mount to the rear mount. The loading was done to simulate the worst case. The torque was

## Appendix J: Driveshaft and Universal Joint

The previous 2012-2013 team fabricated the vertical strut for the driveshaft. Three individual pieces of the strut were welded together. The base fastens to the hull and a second plate located inside the hull evenly distributes loads applied to the strut. The design minimized the area for lateral forces to act on and maximized the area for the strut to resist bending stresses. The strut was fabricated out of 1061-T6 aluminum.

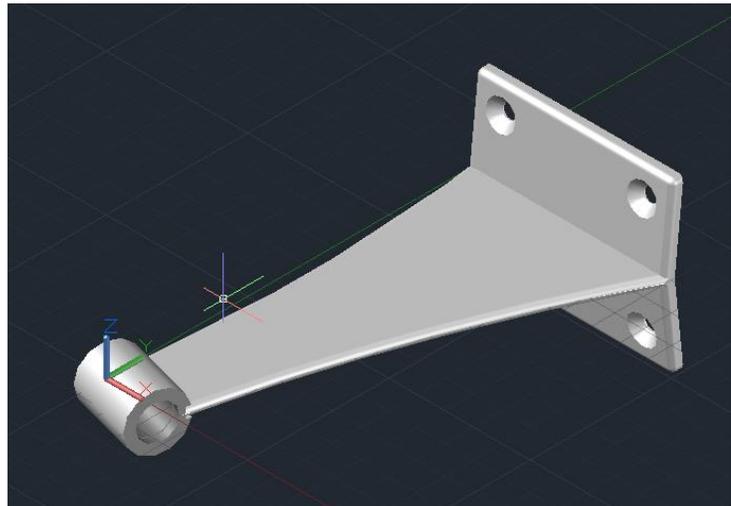


Figure J.1, Driveshaft support strut model

The worst case scenario was used in calculations; as the boat conducts hard turns at high speeds during the competition events. At top speed, the strut creates drag determined to be 89 lbs. of force. At 3/16<sup>th</sup> inch plate the bending stress was determined to be 17,020 psi for a 3/16<sup>th</sup> inch plate. The 3/16<sup>th</sup> thick aluminum afforded a safety factor of two. Of the common aluminum alloys, 1061-T6 aluminum plate was chosen since its yield strength is 40,000 psi.

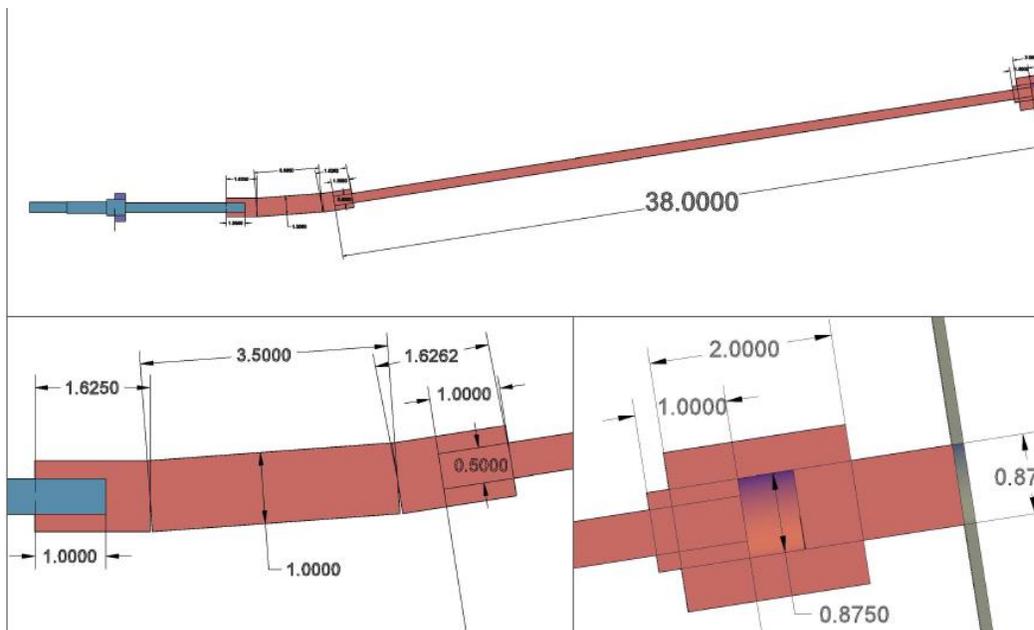


Figure J.2, Driveshaft drawing

Deformation was occurring in the pins that connected the main driveshaft to the universal joint and the u- joint to the propeller driveshaft when full torque was being applied to them. The pins are 3/16” in diameter and they are calculated to have shear strength of 26Ksi. This number is from McMaster. The max torque from the motor is 35 Ft/lb. With this torque the shear force acting on the pins is 840 lbs. with a 1/2” diameter shaft. For the purpose of ease of taking out pin, this calculation was done assuming single shear, even though when the pin deforms it goes to double shear. A single pin, with a cross sectional area or .0276 in<sup>2</sup>, has a stress of 30.4 Ksi. Adding a second pin divides this stress by two. Two pins would more than count for the force of the motor. Calculations for pin are shown in Fig. L.1. To have two pins securing the shaft an extension had to welded to the end of the universal joint. However, there was not enough room where the shaft comes out of the boat and connects to the universal joint for an expansion. The shaft was welded to the universal joint for this reason. Calculations were done to determine how much of the shaft needed to be welded. It was found that 2/3 of the shaft needed to be welded. Because of porosity in the weld, the whole shaft was welded.

$$\tau = \frac{P}{A}$$

$$30.42Ksi = \frac{840 \text{ lbs.}}{.0276 \text{ in}^2}$$

$$\text{area of weld} = \pi D \times t \text{ of weld} = .5in \times \pi \times .14in = .2198in^2$$

“t” assumed to be .14 in

$$3.8Ksi = \frac{840 \text{ lbs.}}{.2198in^2}$$

Yield point of steel in shear = 19.14Ksi

Equation J.3, Shear stress calculations on pin and weld.

## Appendix K: Bearing Housing

The elliptical bearing housing was previously chosen for the simplicity of its design and improved shape. The housing is made of aluminum and is one solid piece, milled from a piece of round stock. The housing contains a thrust bearing at the front to carry the propeller thrust and a roller bearing to keep the shaft aligned at the rear. The setup involves plastic seals in front of and

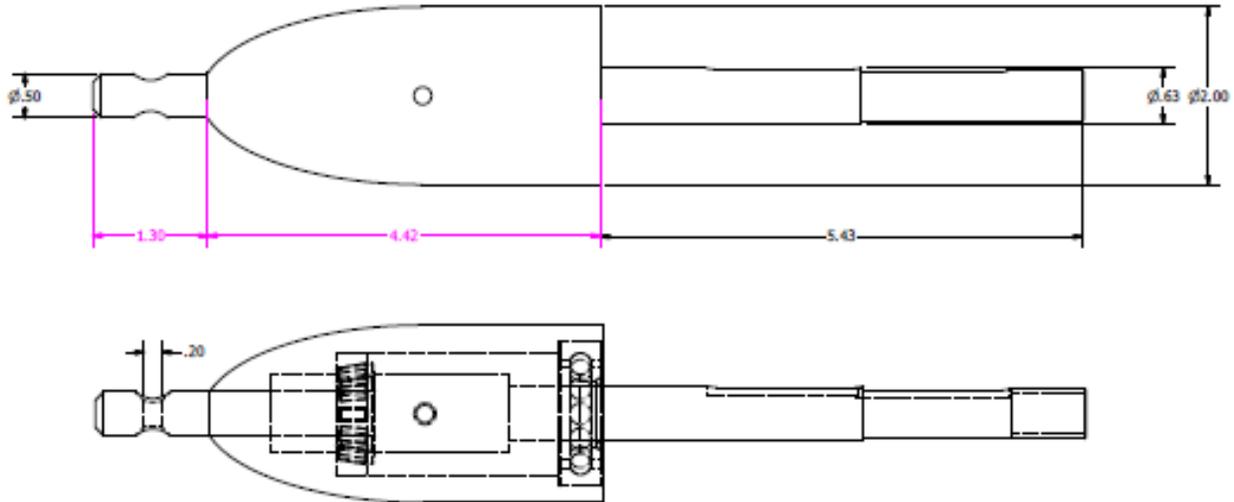


Figure K.7, Bearing housing assembly drawing

behind the thrust bearing to make it water tight. The roller bearing has double plastic seals. The shaft is held in place by the connection to the constant velocity joint at the front and the propeller hub secures the roller bearing and shaft from the back.

The design requires a new shaft to be made. The new shaft will be made of steel and manufactured on the lathe. It contains a larger diameter section to support the thrust bearing, a hole for connection to the constant velocity joint, a keyway for connection to the propeller hub, and threads to secure the propeller into position.

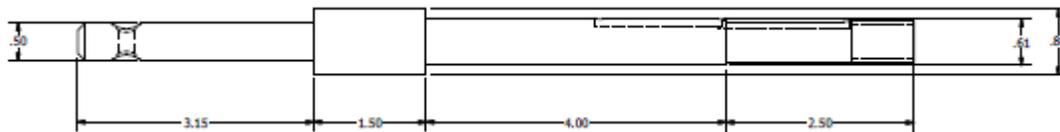


Figure K.8, New propeller shaft drawing

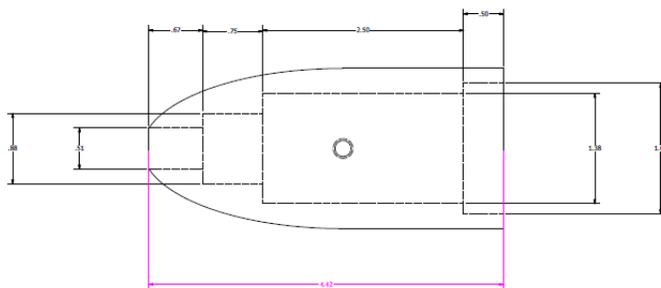


Figure K.9, Bearing housing drawing

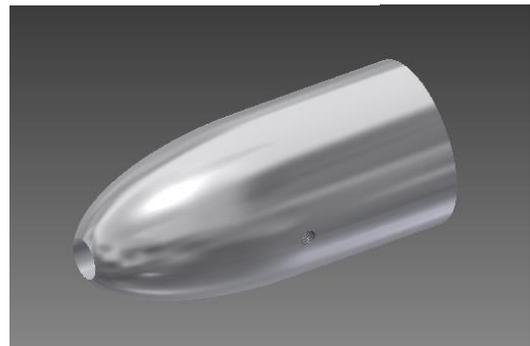


Figure K.10, Bearing housing rendering

## Appendix L: Steering System

The current steering system was designed, fabricated, and installed in 2013. The current system, shown in Fig. N.1, will be utilized during competition. The material used to fabricate all components of the system is 6061 aluminum. The previous team utilizes an aluminum pivot rod until that component failed during testing in 2014. An incident occurred with the propeller kicking back up into the steering strut, hitting the strut with enough force to shear one of the propeller blades from the main hub. Damage to the propeller, steering strut, steering pivot rod, drive shaft, and drive shaft strut was sustained. The previous team designed solutions for the damaged components. A new steel pivot rod was fabricated and was installed for the current system. The steel pivot rod is shown below in Fig. N.2. This system is operated by a push-pull cable that is manipulated by a steering wheel that is mounted in the front of the boat



Figure L.1, Steering system



Figure L.2, Steel pivot rod, which replaced previous aluminum pivot rod.

## Appendix M: Steering Strut

The 2015 team fabricated the strut in a rush to get to competition after their original design had failed catastrophically. Because of this they were rushed and unable to design an ideal strut. Their strut is strong, but lacks hydrodynamic efficiency. This is what this year's team wants to improve upon. The original strut in Fig. O.1 is a rectangular stock bar made of 1/2" thick 60601 aluminum bar. It has a 1/2" diameter half circle that was welded to the front of it



Figure M.1, Original steering strut

to reduce drag. Welded onto the bottom of this bar is a 3" diameter, 1/2" thick half tube that the bearing housing bolts to. This piece does not have any shape attached to it to reduce drag, fig In order to get a starting position of how the strut performed in the water, a fluid flow analysis was done in ANSYS Workbench using their Fluent modeling package. The original geometry was imported to the model and water was formed around that geometry. Because of complications with ANSYS the geometry was broken into two pieces. The first was the main strut body and the second was the lower portion that the bearing housing bolted to. For the main strut body I only considered the portion that was in the water during sprint conditions.

Analysis was done on these two portions at sprint like conditions. From previous groups it was found that the max speed achieved was 17 mph, so for the testing this speed was used. The main body of the strut had a drag force of 12.45 lbs. when going through the water at 17 mph. It was also determined that the coefficient of drag of this part was .49. The lower portion, when going through water at 17mph had a drag force of 5 lbs. with a CD of .4. This is not surprising considering it does not have any tapered edges.

These results can be seen in table O.1.

To reduce the drag force acting on the main body of the strut a foil was designed to go around the strut. The design of the strut was taken from NACA foil, SD8020-010-88. The website allowed for the foil to be increased till I could fit the rectangular shape inside. After I had sized the foil I exported the points into Inventor and extruded the foil. Unfortunately the foil was too long so it needed to be shortened so the propeller would not come in contact with it. In addition to the foil, the edges of it were tapered to resemble a boat rudder and a fillet was added to the bottom of it to transition into the lower unit. Both of these are to reduce the low pressure area behind. Once the foil was designed it was 3D printed with the help of a student that had a printer in his room. It is made out of PETG, Polyethylene Terephthalate Glycol. This material is as strong as ABS but is easier to print. PET is a plastic resin that is

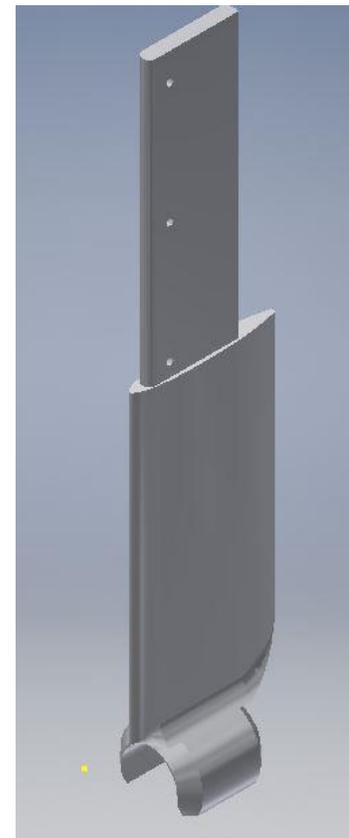


Figure M.2, Strut with foil

commonly used in plastic bottles, but glycol can be added to improve its mechanical properties. PETG has a Bhn of 110 but has the ductility needed to absorb impact without breaking. When printed it has properties similar to if it was one solid piece. Once the foil was printed it was sanded the imperfections were filled with epoxy and it was primed and painted.

The lower portion of the strut was streamlined by cutting a chamfer into the leading and trailing edge of the lower unit. The original plan was to make a foil for the lower unit as well. This was decided against because it would be difficult to mount anything to the front of it and if it fell off it would damage or destroy a propeller.

The results of the fin and chamfer were greater than expected. The drag acting on the strut was diminished to 3.8lbs. and the force on the lower unit was lowered from 5.8lbs. to 1 lb. These results were also backed up by hand calculations, Fig. O.2. The ANSYS numbers are higher because it counts for skin friction and other effects. Overall, there was a decrease in drag force of about 14 lbs. when the boat is going 17 mph.

Part	Projected Area	Characteristic L	CD	ANSYS drag	Drag from Hand
	in. <sup>2</sup>	in.		lbf.	lbf.
Shaft	5	2	0.2	4.1	4.18
Shaft Strut	1.75	3	0.5	5.04	3.66
Universal Joint	1.3	3	0.3	1.6	1.63
bottom housing	3.14	6	0.25	5	3.28
bottom section of strut	2.6	3.5	0.4	5.83	4.35
Main portion of strut	6	3.5	0.49	12.45	12.30
total				34.02	29.41

Table M.1, Drag Forces before Streamlining

Part	Projected Area	Characteristic L	CD	ANSYS drag	Drag from Hand
	in <sup>2</sup>	in		lbf.	lbf.
Shaft	5	2	0.2	4.1	4.18
Shaft Strut	1.75	3	0.5	5.04	3.66
Universal Joint	1.3	3	0.3	1.6	1.63
bottom housing	3.14	6	0.25	5	3.28
bottom section of strut	2.6	3.5	0.4	1	4.35
Main portion of strut	6	3.5	0.12	3.6	3.01
total				20.34	20.12

Table M.2 Drag Forces after Streamlining

## Appendix N: Data Acquisition Information

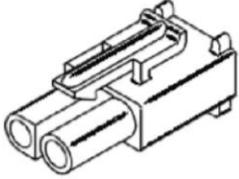
The following sheets are the data sheets for the materials to be used in the new data acquisition system. The materials include:

- Molex Pin and Socket Connectors
- Tamura L017 Current Sensors
- Device Craft Hall Current Sensors



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**PLEASE CHECK WWW.MOLEX.COM FOR LATEST PART INFORMATION**

<b>Part Number:</b>	<b>0019091029</b>	 <p style="font-size: x-small; color: red;">Series image - Reference only</p>
<b>Status:</b>	<b>Active</b>	
<b>Overview:</b>	Standard .093" Pin and Socket Connectors	
<b>Description:</b>	2.36mm Diameter Standard .093" Pin and Socket Receptacle Housing with Positive Latch, UL 94V-2, 2 Circuits	
<b>Documents:</b>		
3D Model	<a href="#">Product Specification PS-02-09 (PDF)</a>	
Drawing (PDF)	<a href="#">RoHS Certificate of Compliance (PDF)</a>	
<b>Agency Certification</b>		
CSA	LR19980	
UL	E29179	
<b>General</b>		
Product Family	Crimp Housings	
Series	3191	
Application	Power, Wire-to-Board, Wire-to-Wire	
Comments	Polarized to Mating Part, without Mounting Ears	
Overview	Standard .093" Pin and Socket Connectors	
Product Name	Standard .093"	
UPC	800753594463	
<b>Physical</b>		
Breakaway	No	
Circuits (maximum)	2	
Color - Resin	Natural	
Flammability	94V-2	
Gender	Receptacle	
Glow-Wire Compliant	No	
Keying to Mating Part	None	
Lock to Mating Part	Yes	
Material - Resin	Nylon	
Net Weight	2.117/g	
Number of Rows	1	
Packaging Type	Bag	
Panel Mount	No	
Pitch - Mating Interface	6.70mm	
Polarized to Mating Part	Yes	
Stackable	No	
Temperature Range - Operating	-40 °C to +105 °C	
<b>Electrical</b>		
Current - Maximum per Contact	12.0A	
<b>Solder Process Data</b>		
Lead-freeProcess Capability	N/A	
<b>Material Info</b>		
Engineering Number	3191-2R1	
<b>Reference - Drawing Numbers</b>		
Product Specification	PS-02-09	
Sales Drawing	SD-3191-2*	

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Not Relevant

<b>EU RoHS</b> Compliant	<b>China RoHS</b>
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**REACH SVHC**  
Not Contained Per -ED/01/2017 (12 January 2017)

**Halogen-Free Status**  
Low-Halogen

**Need more information on product environmental compliance?**

Email [productcompliance@molex.com](mailto:productcompliance@molex.com)  
Please visit the [Contact Us](#) section for any non-product compliance questions.

China ROHS	Green Image
ELV	Not Relevant
RoHS Phthalates	Not Contained

**Search Parts in this Series**  
3191 Series

**Mates With**  
19-09-2026 , 19-09-2027 , 19-09-2028 , 19-09-2029 , 521 9

**Use With**  
1189 Crimp Terminals, 1190 Crimp Terminals, 1380 Male Crimp Terminals, 1381 Female Crimp Terminals, 1433 Crimp Terminals, 1434 Male Crimp Terminals, 2605 , 2606 , 1973 , 2151 , 2273 , 2870 , Link:2871, 4272

Figure N.1, Data Sheet for Socket Connectors

## Hall Effect Current Sensors L01Z\*\*\*S05 Series



### Features:

- Open Loop type
- Printed circuit board mounting
- Unipolar power supply
- Aperture for cable or bus bar
- Insulated plastic case according to UL94V0

### Advantage:

- Excellent accuracy
- Very good linearity
- Low temperature drift
- Wide frequency bandwidth
- No insertion loss
- High Immunity To External Interference
- Optimised response time
- Current overload capability

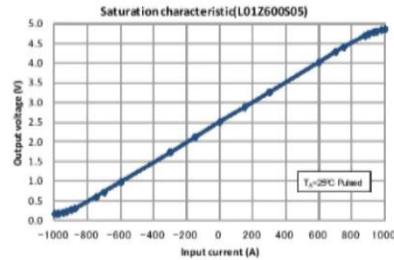
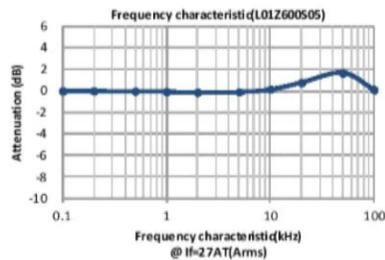
### Specifications

$T_A=25^\circ\text{C}$ ,  $V_{CC}=+5\text{V}$ ,  $R_L=10\text{k}\Omega$

Parameters	Symbol	L01Z050S05	L01Z100S05	L01Z150S05	L01Z200S05	L01Z300S05	L01Z400S05	L01Z500S05	L01Z600S05
Primary nominal current	$I_f$	50AT	100AT	150AT	200AT	300AT	400AT	500AT	600AT
Saturation current	$I_{fmax}$	$\geq \pm I_f \times 1.25$							
Rated output voltage (at $I_f$ )	$V_o$	$V_{or}+1.5\text{V} \pm 0.045\text{V}$	$V_{or}+1.5\text{V} \pm 0.035\text{V}$						
Offset voltage <sup>1</sup> (at $I_f=0\text{A}$ )	$V_{of}$	$V_{REF} \pm 0.035\text{V}$	$V_{REF} \pm 0.030\text{V}$						
Saturation output voltage	$V_{o min/max}$	$V_{o min} \leq 0.5\text{V}$ , $4.5\text{V} \leq V_{o max}$							
Output linearity <sup>2</sup> (0A~ $I_f$ )	$\epsilon_L$	$\leq \pm 1\%$ (at $I_f$ )							
Power supply voltage	$V_{CC}$	$5\text{V} \pm 2\%$							
Consumption current	$I_{CC}$	$\leq 15\text{mA}$							
Response time <sup>3</sup>	$t_r$	$\leq 10\mu\text{s}$ (at $di/dt = 100\text{A} / \mu\text{s}$ )							
Thermal drift of gain <sup>4</sup>	$TcVo$	$\leq \pm 2\text{mV}/^\circ\text{C}$	$\leq \pm 1.5\text{mV}/^\circ\text{C}$						
Thermal drift of offset	$TcVof$	$\leq \pm 2\text{mV}/^\circ\text{C}$	$\leq \pm 1.0\text{mV}/^\circ\text{C}$						
Hysteresis error (at $I_f=0\text{A} \rightarrow I_f=0\text{A}$ )	$V_{OH}$	$\leq 8\text{mV}$	$\leq 4\text{mV}$	$\leq 4\text{mV}$	$\leq 4\text{mV}$	$\leq 4\text{mV}$	$\leq 4\text{mV}$	$\leq 6\text{mV}$	$\leq 6\text{mV}$
Insulation voltage	$V_d$	AC2500V for 1minute (sensing current 0.5mA), inside of through hole $\leftrightarrow$ terminal							
Insulation resistance	$R_{is}$	$\geq 500\text{M}\Omega$ (at DC500V), inside of through hole $\leftrightarrow$ terminal							
Ambient operation temperature	$T_A$	$-10^\circ\text{C} \sim +80^\circ\text{C}$							
Ambient storage temperature	$T_s$	$-15^\circ\text{C} \sim +85^\circ\text{C}$							

<sup>1</sup>  $V_{REF} = V_{CC} / 2$  (ratio metric). After removal of core hysteresis—<sup>2</sup> Without offset —<sup>3</sup> Time between 90% input current full scale and 90% of sensor output full scale —<sup>4</sup> Without Thermal drift of offset

### Electrical Performances



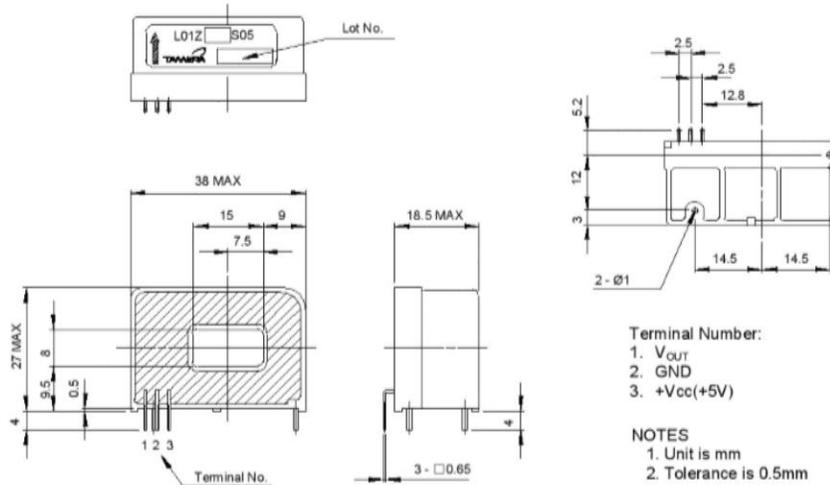
L01ZXXXS05revD, March 2012

Tamura reserve the right to modify its products in order to improve them without prior notice

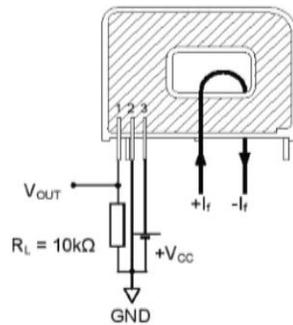
Figure N.2, Data Sheet for L017 Current Sensors (1 of 2)

## Hall Effect Current Sensors L01Z\*\*\*S05 Series

### Mechanical dimensions



### Electrical connection diagram



### Package & Weight Information

Weight	Pcs/box	Pcs/carton	Pcs/pallet
45g	50	200	4800



Figure N.2, Data Sheet for L017 Current Sensors (2 of 2)



## Factory Calibrated Hall Effect Isolated Current Sensor

P/N IS-5 1/4" aperture

P/N IS-6 1/2" aperture

P/N IS-7 1/2" aperture with screw terminals

### Features:

- Linear Sensing Bipolar DC and AC current
- Factory calibrated offset and gain
- Available from 25Amp to 140+Amps (higher available with segmented core)
- Isolated (sensing wire passes thru opening)
- Bandwidth 20khz response time 15usec
- Single supply +5volt operation (4.5v to 5.5v operating range)
- Low power consumption ~8mA
- Option Output RC filter

### Applications:

- Measuring high currents without loss
- Over Current protection
- Motor current control

Please specify sensitivity when ordering. 25,30,35,40,45,50,, 135,140Amps

Example: IS-7-50A for a +/-50Amp sensor

Contact us for higher currents.

Figure N.3, Data Sheets for Hall Current Sensors (1 of 3)

## Specifications

Parameter	IS-5,6,7	
Operating Voltage	4.5V to 5.5v	Calibrated at 5.000v
Power Supply Current	8 mA typical	
Measurement Range	+/- 150 Amps Max	Factory Calibrated
Over Current Response Time	~15us	
Bandwidth	20khz	
DC Offset (with no applied field current)	5mv typical	Factory Calibrated
Sensitivity	65mv/Amp to 15 mv/Amp	Factory Calibrated
Output Center Voltage	½ Supply	
Inductance	~30nh	
Gain Temperature Drift -10C to 70C	low	
Offset Temperature Drift -10C to 70C	low	
Hysteresis Offset (After 100Amp Pulse)	low	
Linearity	~1%	
Output Swing	Supply - 200mV	
Chopping Noise	Depends on Sensitivity	
Minimum Load	4.7k ohms	

## Input/Output Pins:

Pin	Name	Function
1(top)	Vc	DC power supply input voltage (5v)
2	Gnd	Unit ground input
4	Out	Analog output (~2.5v nominal)

Figure N.3, Data Sheets for Hall Current Sensors (2 of 3)

## Description

The devicecraft hall effect sensor is a low cost current sensor useful for many applications. The device consists of a special core, hall effect sensor, power line decoupling capacitor, and optional output filter.

The standard device is set to have a center voltage of 1 half the supply voltage. Depending on the direction of current the output voltage will rise or fall with increasing current. To reverse the polarity simply pass the wire through the in opposite direction.

The device can also be configured for increased sensitivity. The device can also be made more sensitive by passing the sense wire through the loop multiple times. The output voltage will be linear multiple with the number of turns.

## Output Filter

The devicecraft hall effect sensor has a output filter. The output filter can be seen on the schematic. The output filter consist of the R1 C2 combination. The output filter helps isolated the output of the OPAMP from transients, filters the output, and provides short circuit protection. The output filter is not installed.

The filter can be modified. The noise from the Hall Effect sensor can be reduced further by decreasing the bandwidth. The user may also desire to decrease the bandwidth to delay the response time for any over current condition. The filter bandwidth is reduce by increasing either C2 or R1.

Note: R1 should be greater than 4.7k ohms. The unit cannot source or sink much current.

When sensing 60/50Hz current, a filter will greatly reduce the hall effect sensor chopping noise. Too low a bandwidth and the current phase will be shifted.

## Sensing AC Current

The devicecraft hall effect sensor is capable of sensing both AC and DC currents. When sensing AC currents the output voltage will also be AC floating on  $\frac{1}{2}$  the power supply rail. The RMS AC current can be calculated by sampling the signal and converting to a DC value proportional to the AC RMS reading. The sensed AC voltage may also be AC coupled with a series capacitor/resistor to ground and connected to a RMS to DC converter or peak detector.

When sensing AC current the output may be phase shifted or non sinusoidal. Inductive loads, such as motors, and power supplies using peak rectification will produce a phase shifted or distorted sine wave. The sensed current waveform along with the AC voltage can be used to accurately calculated the power factor.

## Power Supply

The power supply for powering the unit must be stable. The offset is rated for  $\frac{1}{2}$  the power supply voltage. Any noise or ripple on the power supply will be reflected in the output.

The unit is calibrate with an accurate 5.000v power supply. If a 5.200 volt power supply is used the offset voltage will be 2.600v rather than 2.500 volts.

Figure N.3, Data Sheets for Hall Current Sensors (3 of 3)

## Appendix O: Motor Data

APPENDIX C

### APPENDIX C SPECIFICATIONS

NOMINAL INPUT VOLTAGE	12V, 24–36V, and 36–48V	
PWM OPERATING FREQUENCY	15 kHz	
STANDBY CURRENT	less than 20 mA	
STANDARD THROTTLE INPUT	5 kΩ ±10% (others available)	
WEIGHT	1204: 1.8 kg (4 lbs)	1205: 2.7 kg (6 lbs)
DIMENSIONS	1204: 146mm×170mm×70mm (5.75"×6.75"×2.8") 1205: 146mm×222mm×70mm (5.75"×8.75"×2.8")	

MODEL NUMBER	NOMINAL BATTERY VOLTAGE (volts)	CURRENT LIMIT (amps)	2 MIN RATING (amps)	5 MIN RATING (amps)	1 HOUR RATING (amps)	VOLTAGE DROP @ 100 AMPS (volts)	UNDER-VOLTAGE CUTBACK (volts)
1204-0XX	24–36	275	275	200	125	0.35	16
-1XX	24–36	175	175	130	75	0.50	16
-2XX†	24–36	275	275	200	125	0.35	16
-3XX†	24–36	175	175	130	75	0.50	16
-4XX	36–48	275	275	200	125	0.35	21
-5XX	36–48	175	175	130	75	0.50	21
-6XX	12	275	275	200	125	0.35	9
-7XX	12	175	175	130	75	0.50	9
1205-1XX	24–36	400	400	275	175	0.25	16
-2XX	36–48	350	350	250	150	0.30	21
-3XX	12	400	400	275	175	0.25	9

† Models for use with permanent magnet motors (no A2 bus bar provided).

Curtis PMC 1204/1205 Manual

C-1

This ME0909 is a Brush-Type, Permanent Magnet DC motor with very high efficiency. Capable of 4.8 KW continuous and 15 KW for 30 seconds. For voltages from 12 to 48 VDC input and 100 amps continuous (300 amps for 30 seconds). Designed for battery operated equipment.

Power	4.8 KW continuous 15KW for 30 seconds
Voltage	12 - 48 Volts
Speed	3,984 rpm at 48V Unloaded 83 RPM per Volt
Size	6.88" OD, 6.29" long (w/o shaft)
Shaft	7/8"x 1-5/8", 3/16" key
Weight	24.1 Lbs.