UNIVERSITY OF SOUTHERN INDIANA

University of Southern Indiana 2016 Solar Splash Team

Technical Report

Boat #6

4 May 2016

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EXECUTIVE SUMMARY

The main goal of The University of Southern Indiana's 2016 Solar Splash Team is to place in the top seven in the 2016 Solar Splash Competition. To achieve this goal, the team will need to improve on every aspect of the boat.

The team for this year's competition includes two electrical engineering students and five mechanical engineering students. By creating a responsibility matrix, each sub system of the boat has been assigned a primary and a secondary leader. The two leaders design and bring their considerations and data to the entire team. These sub systems include the out drive, steering, energy management, solar system, instrumentation, and motor and controller.

With a goal of placing in the top seven teams, the speed of the boat needed to be altered. To change this, the team decided to design a surface drive for the boat. A surface drive is seen a lot in shallow water applications like swamps. The propeller used for this application is a surface-piercing propeller. These propellers will perform the best when it is operated half out of the water.

New this year is an instrumentation panel designed by a group of seniors who graduated in the fall of 2016. This instrumentation will monitor the battery voltage and the propeller rpm. The program is also written for a sensor to determine the amount of ambient light. The ambient light sensor will not be used in this year's competition.

As far as the batteries go, the team will be using two different sets of three batteries to use the maximum voltage of 36VDC and stay under the 100lb weight limit. The first set is three Optima Red-Top deep cycle batteries rated for 132 amp-hours. The other set of three batteries are UPG batteries and are rated for 150 amp-hours.

As a second year team, The University of Southern Indiana's team will be one to not be taken lightly. With many improvements made to the boat from last year, USI plans to place in the top seven teams or better.

Table of Contents

I. Overall Project Objective

The driving force behind USI's goal to place in the top seven teams is to perform better in each event. Last year, the boat never went faster than about 3.5 knots which is roughly 4 miles per hour. The speed of the boat is the main focus for the team this year. This will in turn put the team in a higher place than the previous year.

There have been no changes to the solar system design or the hull design. The hull was donated to USI from Carnegie Melon University. This hull once competed in the Solar Splash known as the "Hydra." As for the solar system design, the design from the 2015 competition won an award. Due to the success of the design, it will not be changed for the 2016 competition.

The old out drive system, which was an out board style motor, has been scrapped and the team will be using a straight shaft surface drive. Pulleys are also being used to increase the RPM of the propeller compared to the motor shaft. A new motor was also purchased for the 2016 competition. A permanent magnet DC brushed motor will be used instead of the three-phase AC motor that was used last year.

Not only is the team looking to improve the boat, but are also trying to improve the technical report and the poster. The team did not perform well in either of the two categories in the 2015 competition. The change this many of the top technical reports have been analyzed and the team will try to create a report worth looking at.

In conclusion, by redesigning the out drive and purchasing a new motor and controller, the team looks to be a top contender on the water for this year's Solar Splash Competition.

II. Solar System Design

A. Current Design/Analysis

Since the solar design from 2015 did well, the team decided that no changed should be made to the solar system design. The solar panels are a unique monocrystalline high efficiency style panel and each are 100W each with a rated open circuit voltage of 17.7V. Figure 1 shows frame that the panels are mounted to.

Fig 1: Solar Panel Frame

Two other types of panels were researched thin film and crystalline. Crystalline panels have been around longer than the thin film technology, the efficiency is higher and they also have a lower installation cost. Since cost and efficiency are two important items on the agenda, the crystalline panels were reused. The panels are mounted on PVC pipes and suspended above the driver. This helps eliminate any shade that the driver may cast on the panels during the competition, and also acts as a shade for the driver during the two-hour endurance race.

As stated, each panel is rated at 100 watts giving the entire solar system design a total of 400 watts staying within the 480W requirement. These panels are durable, lightweight and can be configured in many ways. In the future, other teams may want to configure the panels in a different fashion. The current panels give that opportunity to any of the following solar splash teams.

III. Electrical System

A. Current Design

The electrical system design from the 2015 season did not work well for the Solar Splash Team. A few major changes have been made to the system for the 2016 competition to improve the performance of the boat.

Last year, the team created a decision matrix to determine what motor they were going to use. From this, a Permanent magnet DC brushless motor was chosen. Due to the demand of this motor, every company was on back order and had at least a six month waiting period. The team turned to an alternative and decided to purchase a 3-phase AC motor with a controller. The batteries produce a DC voltage and the motor controller had an inverter to convert the DC power supply to an AC power supply. The motor chosen was the Motenergy ME 1115 PMAC with a compatible Sevcon Gen4 AC motor controller. Unfortunately, the motor was rated for 96 volts and 12hp. With the 36V limit, the motor and controller did not perform well and only generated roughly 2hp. To conclude, the team wants to achieve a higher RPM and more horsepower from a new motor.

B. Analysis of Design Concepts

Perhaps the most vital component to the Current Cutter's success in each of the three competitions is a reliable source of power. While the solar panels and batteries provide a power source, the electric motor and motor controller allow this power to be used in mechanical means. The electric motor draws current from the battery bank and transfers this in the form of torque on an output shaft. The Montenergy ME1115 was very underpowered with the limit of 36V allowed by the Solar Splash competition rules. In order to utilize all of the power stored in the batteries, a more suitable motor, and consequently a controller, had to be selected.

Analysis of selecting a new motor began by recognizing where the old selection was lacking. Testing was performed on the motor-controller setup, and a max RPM of 2100 at 3.6 Nm was achieved. Research was performed on that particular model, and torque curves were analyzed. While the ME1115 is listed as having 12 horsepower continuous, this is at a supply voltage of 96V. When at 36V, the power is less than 2 horsepower.

Various models of motors, both AC and DC, were analyzed for the Solar Splash application. Torque curves were analyzed for each motor to conclude which would provide the most rpm and torque while still being as efficient as possible. Weight was also considered, but most motors analyzed were relatively close in weight. A conclusion was made on the ME0909 DC motor.

At 36V, the ME0909 is capable of a max rpm of 3300 and max torque of 143 lbin. Power can also be observed, and at 162 amps of current, the ME0909 makes 4800 Watts, or 6.43 horsepower.

Since the ME0909 was a DC, permanent magnet motor, the previous Sevcon Gen4 AC motor controller was not compatible. When selecting a new controller, one of the most important aspects was programmability. The Sevcon, while an efficient and expensive piece of equipment, takes much skill to program. In addition to purchasing the controller, a separate program must also be purchased. A controller with a more user-friendly programming system was sought after in order to ensure multiple tests at different settings could be performed on the ME0909 and controller. This controller also had to be efficient and compatible with a DC permanent magnet motor. The max current of the controller also had to be greater than the motor, allowing the Current Cutter to utilize all of the ME0909's power.

C. Design Testing and Evaluation

At this point in time only one short test was done using the new equipment. The red top optima batteries were connected in series and to the motor and controller. A pre-charge resistor and solid-state relay were used to help power the motor. By using a tachometer, the team measured the speed of the motor at 100% and 50% throttle with no load.

By utilizing data from the drag test, the team was able to construct strategies for the competition. The endurance curve is in **Figure 2** while the sprint is in **Figure 3**. Since the force required to propel the Current Cutter at different velocities was known, the power required from the batteries could be calculated. For these calculations, a 75% propeller efficiency and a 90% motor efficiency was assumed. As seen in the tables below, the optimum speed for the endurance race to avoid premature battery depletion was 9 mph. For the sprint race, a maximum battery depletion of approximately 3.5%. Last year, the team had reported no loss of voltage from the batteries during the competition. After reviewing this information, the estimated speed of the boat last year was only about 5mph. This would result in using less than 400W of energy. The four solar panels each produced 100W therefore there was no drain from the batteries.

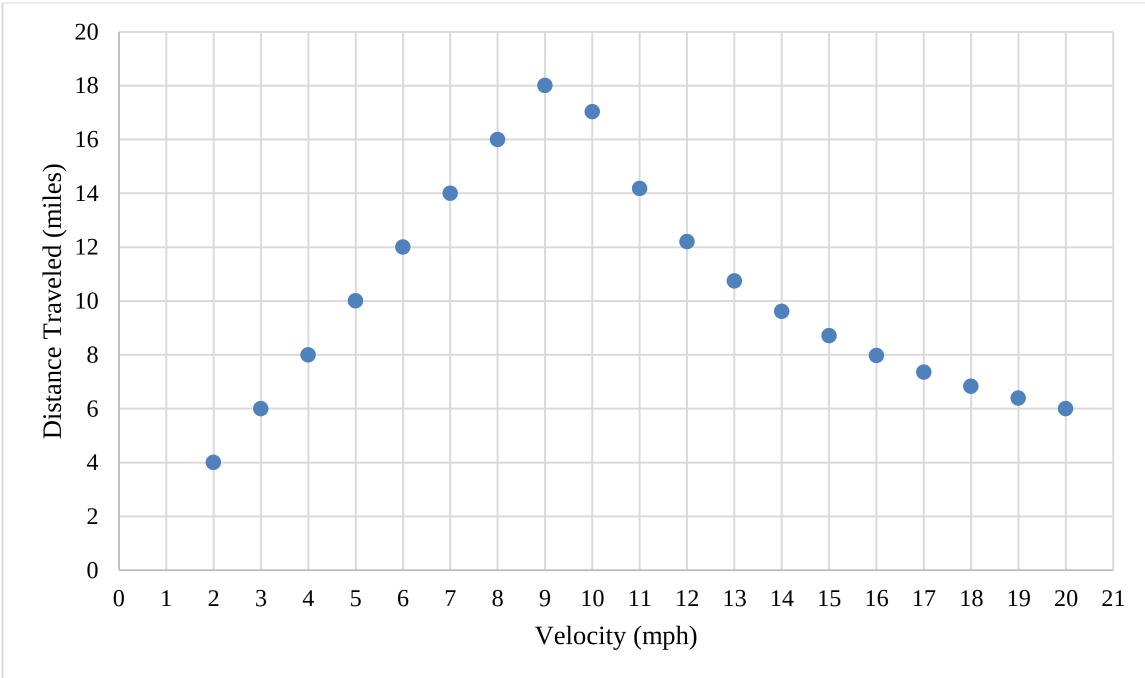


Fig 2: Endurance Race Strategy

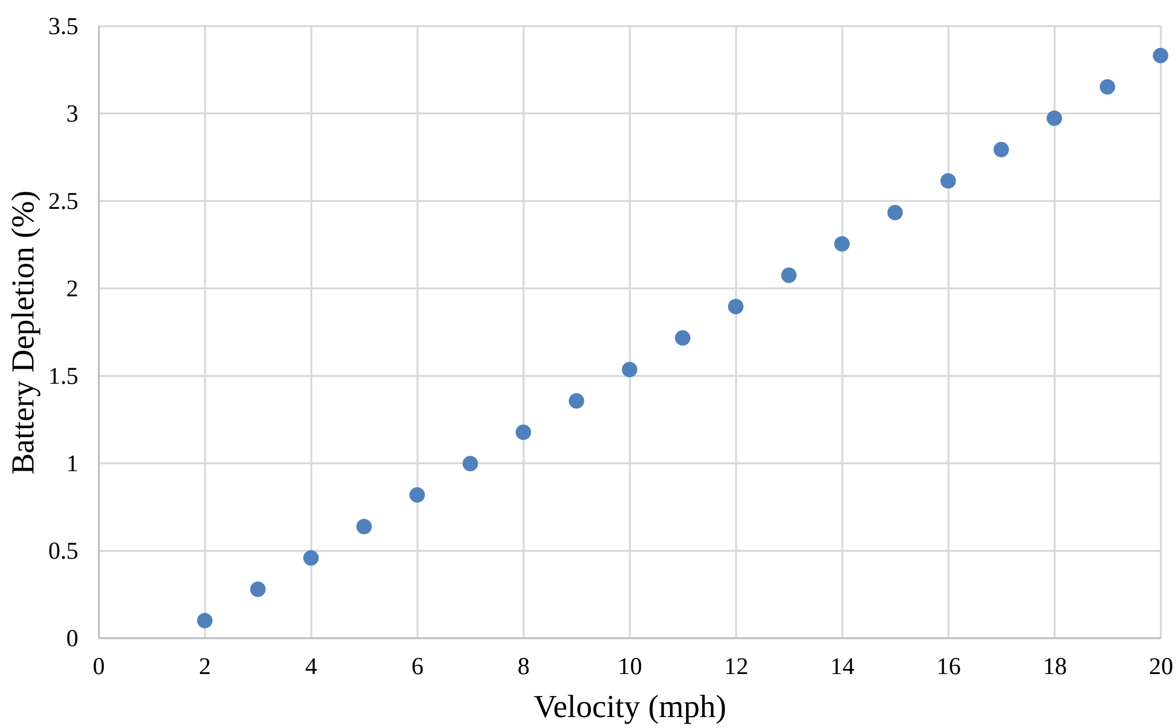


Fig 3: Sprint Battery Depletion

IV. Power Electronics System

A. Current Design/Analysis

The original design includes three 12V Optima Red-Top batteries and three 12V UPG batteries. The team will be using the same batteries that were used in the competition last year. Due to last year's design, the batteries were never fully depleted of electricity and have all been on trickle chargers since the previous competition. Batteries are one of the most expensive parts of the boat. By cutting the cost of the batteries out of the budget, more money can be spent on enhancing the performance of the boat.

The three batteries will be connected in series to produce a maximum operating voltage of 36V. Also connected to the batteries is the charge controller from the solar panels. The charge controller for the competition this year is the same charge controller from the year before, Morningstar TS-45. This charge controller has operation ratings from 12-48 volts and can handle up to 45 amps. The TS-45 is a pulse width modulation charger which improves the ability of the charger to effectively charge the batteries without overcharging. This will improve battery charge capacity and overall life of the batteries. The Morningstar controller has a four stage charging cycle which includes a bulk charge stage, in which the controller will allow approximately 14.6 volts to enter the battery until it reaches 75%-85% capacity. The next stage of the charging cycle is the pulse width modulation regulation. Once this occurs, the charge controller delivers pulses of approximately 13.9 volts until the battery reaches 95% capacity. The float charge is the next phase of the charging process. This float charge will match the discharging rate of the battery to keep the battery fully charged. The TS-45 has circuitry to prevent the batteries from being overcharged in this state.

V. Hull Design

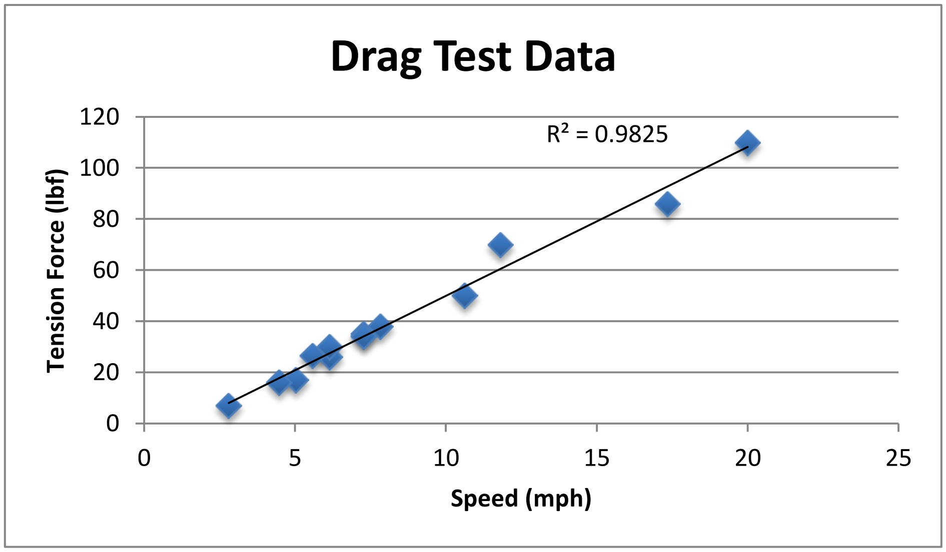
A. Current Design

The hull design has not been changed from the previous year. The hull was donated to the team from Carnegie Mellon University in Pittsburgh, PA. The dimensions of the hull are unchanged at 17 feet long by 22 inches deep by 40 inches wide. The hull alone weighs about 120 lbs. The bottom of the stern has a flat bottom, much like a johnboat would have. Moving forward on the boat, the hull has an aggressive V shape that is designed to help reduce surface area when the boat is on plane.

B. Design Testing and Evaluation

To perform testing on the hull, the team traveled an hour and a half to Patoka Lake. In order to test the hull as well as the driveshaft components, a drag test was performed. This process is explained below in the drivetrain and steering section. Results are also seen below in **Table 1**.

Table 1: Drag Test Data	
Speed (mph)	Force (lbs)
2.8	7
6.15	26
7.27	35
5.59	26.5
7.83	38
11.8	70
20	110
5.03	17
6.15	30
7.27	34
10.63	50
17.34	86
4.47	16



VI. Drive Train and Steering

A. Steering

1). Current Design/Analysis

The existing steering system, shown in **Figure 4**, is a rack and pinion design. The utilization of this existing system was highly desired as to minimize cost, so an addition to the steering system compatible with the proposed surface drive outdrive was designed. The rack and pinion steering system thrusts in either direction as the steering wheel is turned. The thrust rod is located directly above the stern. This was the obstacle that had to be overcome by the new design, as the new design had to thrust in either direction two feet behind the stern attached to the surface drive outer housing.

Fig 4: Steering Cable

As seen in **Figure 5**, two pulleys are mounted to the sides of the boat. A tab was created on the outdrive outer housing. A rope runs from this tab around both pulleys. The existing rack and pinion steering system grabs the rope and pulls in either direction as the driver turns the steering wheel. Due to the fact that the outdrive has trimming abilities, the necessary length of the rope varies slightly. A tensioner spring was inserted into the rope loop to solve this problem as it applies a tensioning force to the rope which reduces slack. A minimum tension force of 10lbf was desired, so a spring was selected with a constant of 5.82 lbs/in. The spring is to be inserted into the rope loop while the outdrive is at its lowest possible trim. The spring will be stretched four inches and inserted into the rope loop, in order to allow tension to be applied even at the highest trim setting.

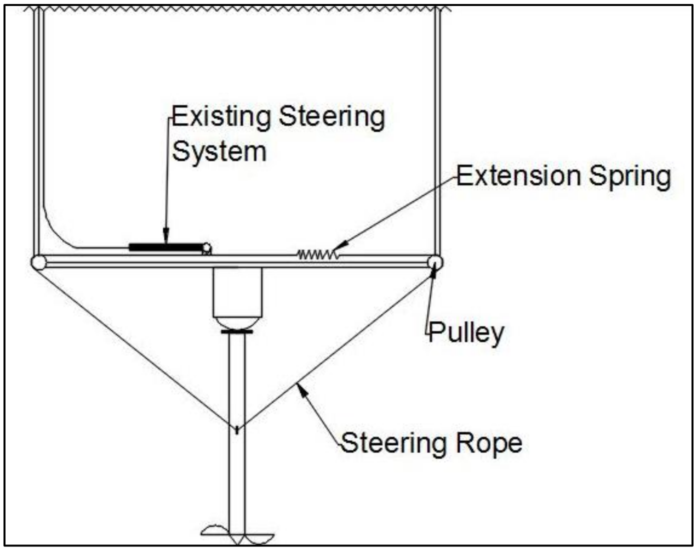


Fig 5: New Steering System

B. Drive Train Design

1). Existing Design

The 2015 USI Solar Splash, team designed, assembled, and raced their solar powered boat in Dayton, Ohio. This was the first year that USI entered the competition. In order to cut costs and manage tasks to meet the deadlines, the 2015 team used a donated hull from Carnegie Mellon University. This hull is a planing style hull constructed of wood and fiberglass. The hull measures 17 ft and weighs 120 lbs. A Montenergy ME 1115 AC electric motor, coupled with a Sevcon Gen4 controller was chosen by the 2015 team to power the boat. The Gen4 controller and ME 1115 were connected to a powertrain system shown in **Figure 6**. This shows the Montenergy electric motor (shown in grey) mounted vertically. The output shaft is facing downwards, and is coupled to the main driveshaft by a mechanical coupling and setscrew. The driveshaft travels through the driveshaft housing (shown in orange), and into the lower unit of the outboard, shown in **Figure 6**. The propeller for the boat attaches to the propeller shaft, shown as the horizontal shaft in **Figure 7**. This shaft has 8 splines on it to secure the propeller. Last year's team won the best solar system design, but had one of the slowest boats in the competition at a top speed of 7 miles per hour. The boat was so slow, in fact, that even after the 2 hours of continuous run time of the endurance challenge, the batteries still read fully charged (Wargel, 2015). Due to the fact that speed is an essential component of the drag race, endurance challenge, and slalom challenge, the need to increase the boat's speed is one of the most vital issues to address this year.

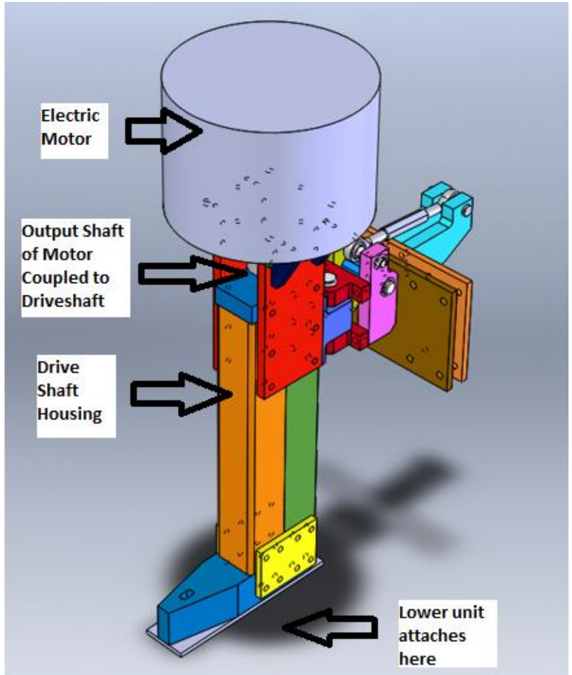


Fig 6: Current design for Solar Splash boat

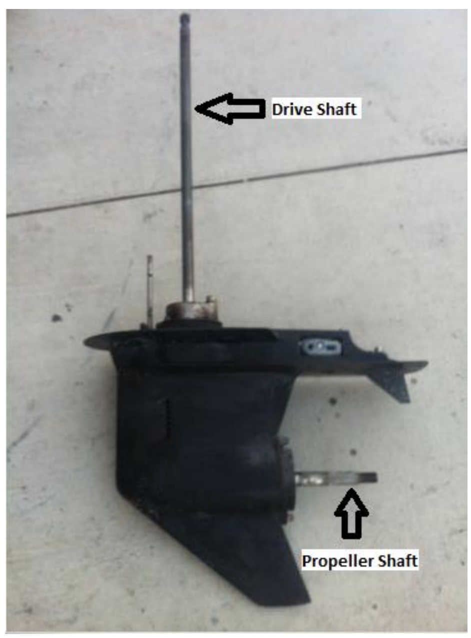


Fig 7: Lower unit of outboard

The existing design was analyzed and causes for a slow acceleration and low top speed were identified. These issues began with the ME1115 motor and Sevcon Controller. The ME1115, while very efficient at voltages between 0-96 volts, is designed for greatest performance at 96 volts. The 2015 team purchased a complete kit with throttle, controller, motor, and all wiring from for the ME1115 motor. This kit was designed to replace the large diesel engines in sailboats to provide a clean and quiet alternative drive system. These boats are able to have large banks of batteries, or utilize newer lithium ion batteries to power the motor. Lithium ion batteries are not allowed for the Solar Splash boat, as the only type of battery accepted at the competition is the traditional lead acid battery. When connected to a lower voltage such as the Solar Splash limit of 36 volts DC, the motor draws a very low amount of current resulting in a low RPM and small amount of output torque. The rpm of the output shaft of the ME1115 motor was measured to be 2150. At full speed, current draw was measured at 24 amps, and with a torque constant of 0.15 Nm/amp, the torque produced was calculated to be 3.6 Nm. This results in a total horsepower of less than 2.0. After travelling through the lower unit of the outboard to the propeller shaft, this number would shrink even more. From previous boating experience as well as calculations based on drag forces, it was determined that 2 horsepower would not be enough to power the Solar Splash boat to the desired speed of 20 mph. Programming the controller to different parameters could slightly improve performance, but the program used to modify the Gen4 costs more than $700 and requires extensive knowledge of the software.

2). Analysis of Design Concepts

The drive system chosen for the 2016 Current Cutter was a surface drive. These unique designs are used on a variety of applications. One variation is shown in **Figure 8**. Like the term "surface drive" suggests, these outdrives are meant to be operated on the surface of the water. The propeller of a surface drive is specifically designed to operate in such a way as well. As it rotates, the three to four bladed surface piercing propeller only has half of its blades submerged in the water. As a blade re-enters the water, it transmits an impact force to the water, propelling the boat in a forward direction. Surface drives were discovered by accident, when Donald Campbell discovered that at high speeds, the stern of his craft would lift and create a "roostertail" of water behind it. This "roostertail" was caused by the propeller lifting out of the water and becoming a surface piercing propeller. Due to the fact that the vessel looked to be "riding" on the propeller, this design was nicknamed "prop rider" (Smith 2010).

Fig 8: Surface drive outdrive design

One large advantage of the surface drive design lies in the significant decrease in drag forces acting on the mechanical parts of the outdrive. With a surface drive, only a small section of the rudder and half of the propeller is in contact with the water at one time. When compared to the surface area that is submerged with an outboard or inboard design, this significant drop in drag force is not surprising. Another advantage is related to the torque required to spin the propeller. Since the propeller is only halfway submerged, less torque is required to spin it when compared to a completely submerged propeller (Smith 2010). Also related to this is the rpm of the propeller shaft. A higher rpm is achieved due to the smaller amount of torque required. Another advantage, although one that may not play a large role with the Current Cutter, is that surface drives are able to run in a very small water depth. For this reason, variations of the surface drive are used for hunting waterfowl and other shallow-water applications.

Momentum theory proves larger propellers exhibit higher efficiencies than smaller ones at a given thrust and speed (Peterson, 2005). Traditional, fully submerged propeller selection is almost always maximizing the propeller diameter while balancing performance limiting factors such as blade clearance from hull, maximum vessel draft, shaft angle, and engine location. Designers choose the propeller with the largest diameter that meets these criteria, and this choice often comes with a loss of efficiency (Peterson, 2005). All of these limitations are applicable to both outboard and inboard outdrive applications, but a surface drive liberates the design from these restrictions.

The most notable advantage of surface drive applications over conventional submerged outdrives is the elimination of cavitation. A propeller works by creating a low-pressure area on the forward face of the propeller, which creates a forward thrust. Problems arise when this pressure reaches the vapor pressure of the water (Casciani, 2015). The water vapor bubbles collapse and exert a large force often exceeding 7 kg/cm^2. This force causes propeller damage as well as loss of speed (Casciani, 2015). Surface piercing propellers eliminate cavitation by bringing air pockets next to the propeller with every stroke of propeller rotation. When the pressure drops, these air pockets compress instead of vaporizing the water. There is only a slight performance loss by allowing air into cavities adjacent to the propeller, due to the atmospheric pressure pushing against the blades, but this pressure is negligible compared to the thrust pressure of the propeller (Casciani, 2015).

Surface drives also have distinct disadvantages when compared to other outdrives. Because of the “rooster tail” of water that is created by the propeller, these applications are not used often on pleasure boating applications. While this might affect the Current Cutter if the team planned to pull any water-skiers, there are no rules about the wake that can be produced by the outdrive. Another slight disadvantage is that the propeller creates a larger amount of noise impacting the surface of the water when compared to submerged propellers. Again, while this disadvantage may play into other applications, noise is not a factor with the Solar Splash competition. Perhaps the only disadvantage applicable to the Current Cutter application is the availability of parts. When compared to a more common outdrive system such as the outboard, surface drive propellers and accessories are hard to find.

In order to determine which of the three outdrives discussed prior was the best option for the current cutter, a decision matrix was used. Although some designs combine two of the three categories, most designs can be placed in one of these three categories. Requirements and criteria were formed and placed into the decision matrix. Two requirements of a chosen outdrive design were identified to be a maximum cost of $2,500 and compliance with all Solar Splash regulations. Five criteria were identified as crucial to our application: estimated cost, frictional drag, cutting of hull, steering modification, and trim options.

Estimated cost is a necessary criterion because a lower cost outdrive allows the team to allocate funds to other areas of the boat that are in need of improvement. This was given a 5% weight in the decision matrix because the outdrive is the largest modification planned for the boat this year, and a higher performing outdrive with a possible higher initial cost is acceptable in order to use for future competitions. An outboard outdrive would be the cheapest of the three choices due to the fact that an outboard outdrive is already assembled. Changes would still need to be made however, so it was estimated to cost $500 to optimize the existing outboard design. Using an inboard type outdrive was estimated to cost $1,000 due to the necessity of a complete new outdrive and rudder assembly. Using a surface drive outdrive was estimated to cost $900 in order to cover materials for the outdrive design, a new surface piercing propeller, and the steering modification.

Drag is an extremely important criterion due to the fact that frictional losses must be minimized in a high performing Solar Splash boat. Higher drag will decrease the boat's performance in all three areas of competition. Due to this fact, drag was given a weight of 40% in the decision matrix. Surface drives provide up to a 50% reduction in drag coefficient over traditional outboard and inboard designs (Surface Drives, 2015). This fact is illustrated in **Figure 9**. Due to this 50% reduction in drag, the surface drive was awarded the top score of 1 in the drag category of the decision matrix. Inboards present the second least amount of drag, and therefore were awarded a 0.65. Outboards and sterndrives present a significantly higher amount of drag, so an outboard was awarded a 0.5.

Fig 9: Drag force illustration between inboard, outboard, and surface drive

Estimated hull cutting is important in order to minimize fiberglass patching of the hull. Fiberglass patches can be unreliable at times, and a leak in the hull could prove to be problematic on competition day. Therefore, hull cutting was awarded a weight of 10%. The outboard outdrive type would not require any cutting of the hull; therefore, it was awarded the highest score of 1. The surface drive was awarded a 0.5 since cutting would be required but it would only be through the stern part of the boat that is reinforced with plywood. The inboard outdrive type was awarded a 0.1 since a large amount of cutting would be required in the center section of the vessel's fiberglass hull.

Necessary steering modification was chosen as a criterion because a large amount of steering modifications would complicate the design process and potentially cause the project to exceed the budget. This criterion was given a 5% weight because alterations could be made, but they would take time. An outboard style outdrive would not require any steering modifications, so it was awarded the highest score of 1 in the decision matrix. The inboard type outdrive was awarded a 0 since a completely new steering system would likely be needed due to the location of the inboard and the incorporation of a rudder system. The surface drive type outdrive was awarded a 0.85 since only some steering modification would be needed due to the location of the outdrive being on the stern.

Efficiency was chosen as a criterion because a high efficiency is one of the main goals of the Solar Splash boat. Due to this large importance, efficiency was given a weight of 75% in the decision matrix. Surface drive type outdrives provide the advantage of being 15-30% more fuel efficient (Surface Drives, 2015). The advantage was assumed to be 30%, so the inboard and outboard type outdrives were awarded scores of 0.75. The surface drive was awarded a score that was 130% of the outboard score, the perfect score of 1.

Trim ability was also a desired capability because the line of propulsion should be directly in line with the center of mass of the boat and its cargo. The term "trimming" a boat refers to the angle at which the motor propels water with respect to the hull. Trimming an outdrive down will result in a larger upward force on the hull, while trimming up will result in thrust force parallel with the surface of the water. The ability to move the center of gravity as needed was desired, so the ability to trim is a large benefit. The existing center of gravity was calculated to be 163" behind the bow, 0.15" starboard of centerline, and 20" above the boat floor. Trimming is also important to helping the boat plane. Getting the Current Cutter to plane is another one of our main goals. The boat will plane when most of the boat's weight is supported by hydrodynamic forces, not buoyant forces. When on plane, less of the boat's hull is in contact with the water, resulting in a lower drag force. Because trimming significantly aids planning, trim ability was given a 15% weight in the decision matrix. Both outboard type outdrives and surface drive outdrives are capable of trim while inboards are not. Therefore, outboards and surface drives were awarded scores of 1, the highest score in the decision matrix, and the inboard type was awarded a 0.

The totals for each outdrive can be seen in the rightmost column of the table located in the appendix. As can be seen in the table, the surface drive, obtaining a score of 0.9, proved to be the best choice while outboard was second with a score of 0.78 and inboard was third with a score of 0.48. Due to these promising results, a surface drive type outdrive was chosen to begin the design process.

2.) Design Evaluation

Once an acceptable source of power was selected, a method of transferring this rotational energy into the drive shaft of the outdrive had to be designed. Several options were considered. The first and simplest is a direct drive system. In this style, the output shaft of the motor is coupled directly to the driveshaft. Benefits of this are simplicity and cost, however, no manipulation of rpm or torque is achieved. Output rpm and torque of the motor is precisely what is delivered to the driveshaft. For the Current Cutter outdrive, a higher rpm was desired. Since a surface drive requires less torque to operate than a conventional submerged propeller design, a higher operating rpm is achievable. In order to increase the drive shaft rpm, a system involving sprockets, gears, or pulleys was determined to be preferable.

When considering a gear increaser, the key criteria were weight, cost, efficiency, and ease of installation. A design in which the gear ratio could be adjusted for testing was also favorable. Due to this, a pulley system was concluded upon. Out of the three, a belt and pulley system was the least cost, easiest to install, lightest, and easiest to modify. Efficiency was an issue, but was addressed in the design of the pulleys and selection of the belt(s).

The goal rpm of the propeller on the Current Cutter was determined to be 5000. Technical specs for the ME0909 were consulted to acquire the predicted rpm of the output shaft at 36VDC. Given this, a gear increaser of approximately 1.5:1 was calculated to be needed. To begin the design of the pulley system, measurements were taken of the inside of the Current Cutter where the motor would be mounted. A center-to-center distance of 12" was determined to be suitable to allow enough room for installation of the bilge pump and other necessary equipment in the bottom of the boat. A V-belt system was chosen to increase the contact area between the pulley and the belt. V-belts have less slip involved in them, making for an overall more efficient design. For sheave dimensions, the horsepower rating of the ME 0909 was used. Due to the max horsepower of 12, it was determined that more than one class A belt was needed, or one class B belt.

The minimum sheave diameter for a class B belt was too large to achieve the desired output rpm, so a class A belt system was chosen. The driving sheave was chosen to have an outside diameter of 3 inches, and the driven sheave consequently had on outside diameter of 4.5 inches minimum. Using AutoCAD, the pulley layout was sketched and an overall length of the belt was measured to be 35.849 inches. For this reason, an A35 polyamide belt was chosen. The pitch length, L_p, was calculated to be 35.83 inches, so a tensioner was determined to be needed to ensure enough tension on the belt to avoid slipping. The allowable horsepower for each belt was calculated to be 8.4. Since the ME0909 is capable of exceeding this in the sprint competition given enough electrical current, a second A35 belt was added to the design. To accommodate the second belt, driven and driving sheaves were selected to be double-groove models. An AutoCAD sketch of the pulley layout is shown in **Figure 10**.

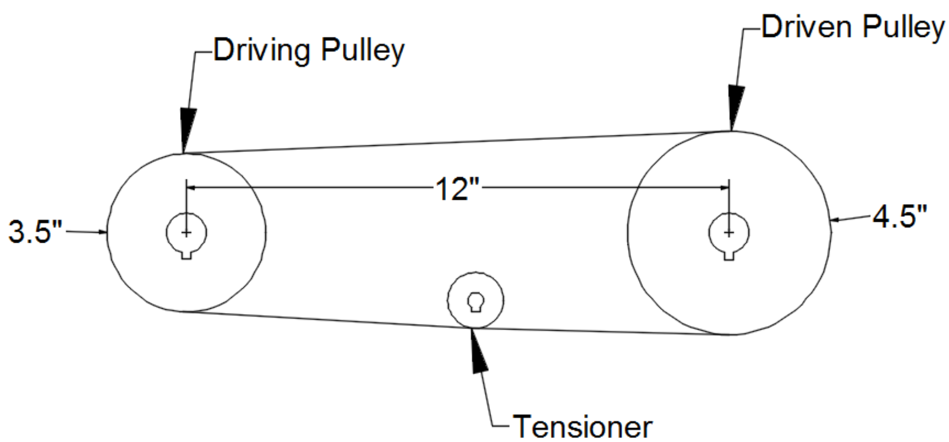


Fig 10: Pulley Design Layout

The first step in the driveshaft design was the selection of a CV joint to design the rest of the driveshaft components around. The implementation of a CV joint into the surface drive design allows for changes in steering and trim without the addition of a rudder. When searching for CV joints, four things were considered: horsepower rating, size, price, and availability. It was determined that CV joints on ATVs would be sized the closest to the needs of the Current Cutter. They are also designed for large torque and RPM due to the applications the vehicles are used for. The CV joint that was selected was the front right CV joint axle from a Honda TRX450 Foreman 4x4. This axle is designed for a 26.9hp ATV which is well over the 6hp that is expected from the Current Cutter. Once the CV joint was selected, the rest of the driveshaft was designed. A ¾" driveshaft was chosen due to the fact that most propellers fit on ¾" spline shafts. The material selected was stainless steel, and this produced a factor of safety of 19. A housing, shown in **Figure 11**, was also designed because rotating shafts in a fluid contribute to frictional drag more than stationary shafts. Two needle roller bearings were selected to encompass the driveshaft in the outer housing, and the specifications are included in the appendix. A pillow block bearing was selected to support the driveshaft on the inside of the vessel, and its specifications are also displayed in the appendix.

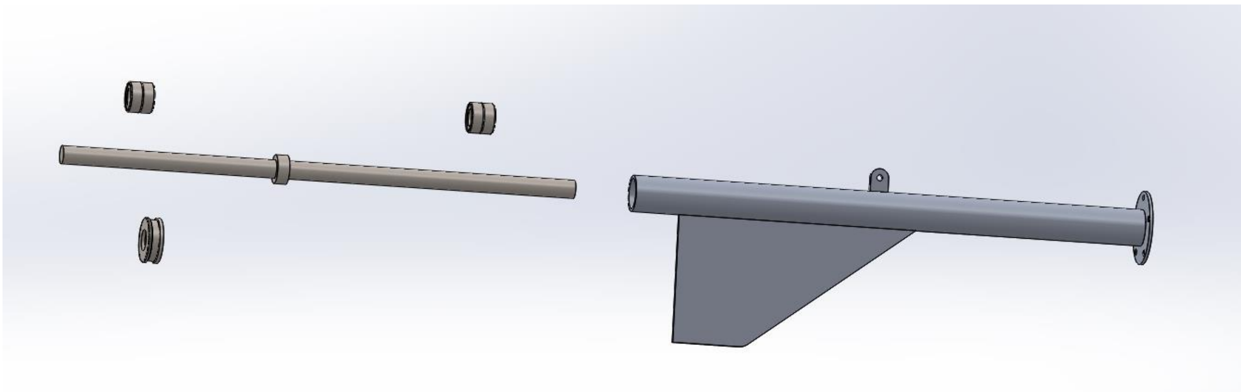


Fig 11: Exploded view of the driveshaft, housing, and three bearings it encompasses

Force Distribution

Adequate force distribution was crucial to the designed model due to the fact that the selected CV joint is not rated for axial loads. In order to quantify the amount of force exerted on the outdrive design from the propeller, a drag test was performed. Simulations were considered, but it was determined that an actual experiment would provide more accurate data for the design decisions. Two different types of drag forces exist on ships: wave making drag and frictional drag. A ship traveling through water creates a characteristic pattern of waves that originate from both the bow and stern. Creating these waves requires energy, and this energy loss is considered wave-making drag. If it were not for these wave making drag forces, speeds of boats would be significantly faster, and hull designers have only been able to improve a ships resistance to these drag forces by a small amount (Gillmer, 2016). Frictional drag is also present, and it is dependent on surface roughness, area, velocity, and density of the fluid. The drag test measures the sum of all of these different drag forces exerted on the Current Cutter's hull. The drag test consisted of towing the Current Cutter behind another vessel at different, constant speeds. The goal of the Solar Splash team was to implement a boat capable of achieving a speed of 20mph, so speeds from 0-20mph were used in this test. The tension in the towrope was measured at each speed, and this force was assumed to equal the sum of the wave making and frictional drag forces due to having no acceleration. The data from the drag test can be seen in **Figure 12**. As seen in **Figure 12**, the drag forces at speeds of 0-20mph exhibits a linear trend with a R^2 value of 0.9825. The drag force as a speed of 20mph was 110lbf, so this was the minimum force that the outdrive should be able to withstand.

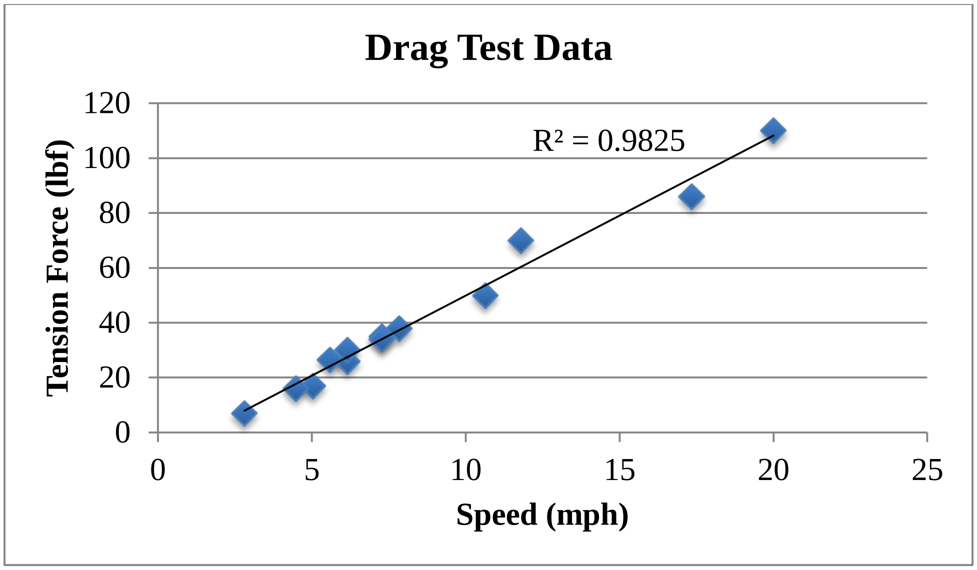


Fig 12: Drag Force Quantification Test Data

The force exerted on the driveshaft from the propeller must be transferred to the outer housing prior to the CV joint. A thrust bearing was selected in order to achieve this. The thrust bearing that was selected was a TC1220 thrust needle roller bearing. This bearing was selected due to its low cost, capability of withstanding 10,500lbf statically and 2,900lbf dynamically which is well over the requirements. The use of a thrust bearing required the use of a collared driveshaft. The collar on the driveshaft was dimensioned so that half of the rollers on the TC1220 thrust bearing were in contact with the driveshaft. This allows for adequate clearance between the outer housing and driveshaft. A collar was also added to the outer housing design for the opposite side of the thrust bearing to ride against. The same clearance dimensions were used for the housing collar as the driveshaft collar. With the addition of the thrust bearing and collars, the force will successfully be transmitted from the driveshaft to the outer housing. **Figure 11** shows the collar, thrust bearing, and roller bearings. The force must then be transmitted to the stern of the boat, while still having the ability to rotate for steering and trim. A ball and socket design was selected to achieve these requirements. The ball was designed to attach to the outer housing and encompass the CV joint, while the socket was designed to attach to the stern and surround the ball. The ball and socket were dimensioned according to the CV joint that was selected. A 40-degree steering and trim ability in each direction was desired, so the ball was dimensioned to allow these capabilities. The material was selected as to minimize weight and cost while still being capable of withstanding the thrust forces from the propeller. 6061 aluminum was selected due to its relatively low cost, high availability, low weight, and sufficient yield strength. **Figure 13** shows the three components that make up the ball and socket design.

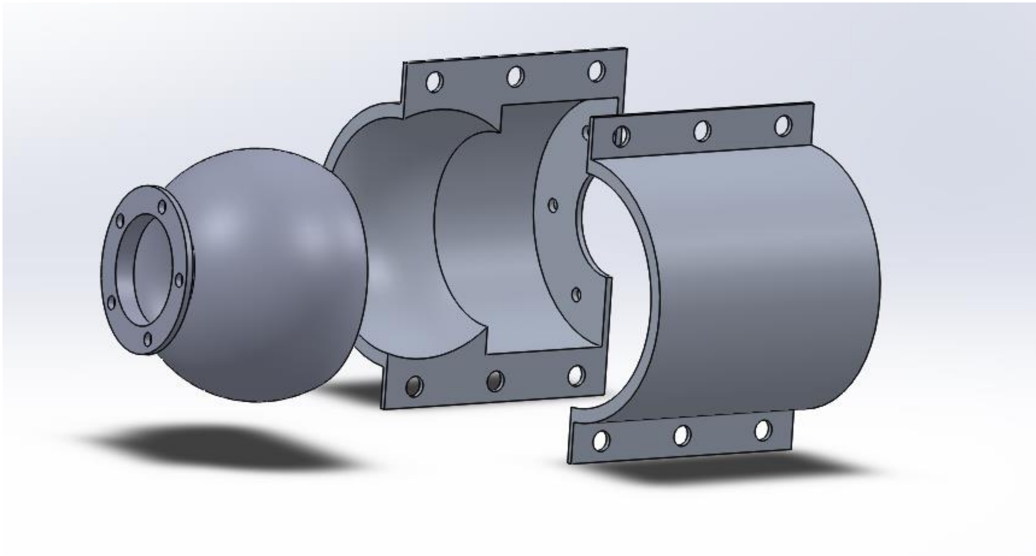


Fig 13: Three components that make up the ball and socket design

In order to determine how the ball, socket, and driveshaft housing would perform under the thrusting force from the propeller of the Current Cutter, SolidWorks was utilized. Simulations were performed on each component, first adding the measured 110 lbf, and then at 300 lbf to ensure a large factor of safety was achieved. For all bolted assemblies, bolts were torqued to 50 ftlbs.

The ability to trim was a requirement of the Current Cutter's new outdrive system. Most boat hulls are designed for optimum performance while operating parallel with their at-rest waterline (Armitage, 2016). The required angle of trim can vary with different water conditions, weight distribution, and velocities. A properly trimmed boat operates at its peak efficiency by minimizing the amount of hull in contact with the water, therefore minimizing drag forces (Armitage, 2016). This is especially important to the Solar Splash design, as efficiency is crucial. Due to the fact that the necessary trim angle can change with speed, a trim system that could by adjusted at any point during operation was needed. In order to accomplish this, an electric linear actuator was chosen and implemented. An electric linear actuator was the best option for this application due to their relative low cost, high availability, and ability to be operated using the boat's batteries. A tab was added to the outer housing of the outdrive to serve as a connection point for the actuator. This tab can be seen in **Figure 11.**

For a zero-degree trim angle, the needed length of the actuator was determined to be 24". An actuator was selected with 24" within its range of motion, while still having enough retraction and extension ability to give the outdrive trimming capabilities of 30 degrees in either direction. The linear actuator selected was shown in **Figure 14**. A three-position toggle switch was utilized to control this actuator.

Fig 14: Electric linear actuator chosen for the Current Cutter trimming design

VII. Data Acquisition and Communications

A. Current Design

From the rookie year of the team, there was no Data Acquisition or communication hardware in place. This year the team will be using an Intel Galileo which was programmed by a senior project for the Current Cutter. The Intel Galileo is a microcontroller board which contains a 32-bit Pentium class chip system (also referenced as a data sheet). This board was programed to be universal by adapting and modifying the functionality of the digital pins (ARED and GND pins, the analog inputs (ICSP and UART port inputs), and the code functionality by using an Arduino Uno R3 pinout system. With the multi-functionality the microcontroller can monitor a variety of systems but its main purpose is to monitor the voltage of the batteries and the RPM (revolutions per minute) of the propeller. Even though there will only be voltage and rpm digital outputs the Data Acquisition can be varied to read temperature, boat speed, and ambient light with modifications to the hardware in the future. All of these features will help the skipper to determine how fast to go during each event based upon RPM and battery voltage levels. Since the team has never used DAQ, this will be a good year to test the equipment and upgrade in the future.

VIII. Project Management

When working with seven different team members it can be difficult to efficiently complete tasks. A responsibility matrix was made to help hold each team member accountable for his or her job. Each student was a primary leader for at least one item and can be secondary for many other items on the list. The responsibility matrix can be seen in **Appendix E.** The team also had weekly meetings to discuss ideas and to see the progress on the boat. The team needed to work much more than just an hour a week after the meeting to ensure the boat was competition ready. The University of Southern Indiana has an Applied Engineering Center toward the back of campus. This is where the team would work on the boat and have the meetings. There were also many weekends spent working. Time management was also key to the success of the team. It is difficult to find a time when the entire team can meet so once one time was found that is when we met for the entire semester.

IX. Conclusions and Recommendations

In conclusion, the work on the boat did not necessarily start until early January. The team is excited to see how the 2016 competition will go. As a second year team, the members have a better understanding of the competition and procedures. As stated earlier in the report, the drive train was the biggest change to the boat this year. Changing from an out board style motor to a straight shaft surface drive. More testing needs to be done on the boat and the batteries before the competition. As it sits now, the boat is not ready for the water. The surface drive has not been fully machined. The team plans to have the boat in the water at least two weeks before the competition to do testing. A lake at the university will be adequate for the testing. Placing in the top seven teams for the competition should be no problem for the team this year. After doing some testing to find to optimum operation of the boat, the team will be ready for the trip to Dayton.

References

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Appendix A: Battery Documentation

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

Physical Characteristics:

Plate Design: High purity lead-tin alloy. Wound cell configuration utilizing proprietary *SPIRALCELL*® technology.
Electrolyte: Sulfuric acid, H_2SO_4
Case: Polypropylene
Color: Case: Dark Gray
Cover: "OPTIMA" Red
Group Size: BCI: 75/25

	Standard	**Metric**
Length:	9.313"	236.5 mm
Width:	6.813"	173.0 mm
Height:	7.625"	193.7 mm (height at the top of the terminals)
Weight:	33.1 lb.	15.0 kg

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

Performance Data:

Open Circuit Voltage (fully charged): 12.8 volts
Internal Resistance (fully charged): 0.0030 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.

MSDS No.	L 8A
Date Issued	**Feb. 20, 1990**
Date Revised	**Oct. 17, 2011**

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

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

II. Hazardous Ingredients

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

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

III. Physical Data

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

IV. Health Hazard Information

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

ROUTES AND METHODS OF ENTRY

Inhalation
Acid mist may be generated during battery overcharging and may cause respiratory irritation. Seepage of acid from broken batteries may present inhalation exposure in a confined area.

Skin Contact
Battery electrolyte (acid) can cause severe irritation, burns and ulceration.

Skin Absorption
Skin absorption is not a significant route of entry.

Eye Contact
Battery electrolyte (acid) can cause severe irritation, burns, and cornea damage upon contact.

Ingestion
Hands contaminated by contact with internal components of a battery can cause ingestion of lead/lead compounds. Hands should be washed prior to eating, drinking, or smoking.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

Acute Effects
Acute effects of overexposure to lead compounds are GI (gastrointestinal) upset, loss of appetite, diarrhea, constipation with cramping, difficulty in sleeping, and fatigue. Exposure and/or contact with battery electrolyte (acid) may lead to acute irritation of the skin, corneal damage of the eyes, and irritation of the mucous membranes of the eyes and upper respiratory system, including lungs.

Chronic Effects
Lead and its compounds may cause chronic anemia, damage to the kidneys and nervous system. Lead may also cause reproductive system damage and can affect developing fetuses in pregnant women. Battery electrolyte (acid) may lead to scarring of the cornea, chronic bronchitis, as well as erosion of tooth enamel in mouth breathers in repeated exposures.

POTENTIAL TO CAUSE CANCER

The National Toxicological Program (NTP) and The International Agency for Research on Cancer (IARC) have classified "strong inorganic acid mist containing sulfuric acid" as a Category 1 carcinogen, a substance that is carcinogenic to humans. The ACGIH has classified "strong inorganic acid mist containing sulfuric acid" as an A2 carcinogen (suspected human carcinogen). These classifications do not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist (sulfuric acid mist) is not generated under normal use of this product. Misuse of the product, such as overcharging, may result in the generation of sulfuric acid mist.

The NTP and the IARC have classified lead as an A3 carcinogen (animal carcinogen). While the agent is carcinogenic in experimental animals at relatively high doses, the agent is unlikely to cause cancer in humans except under uncommonly high levels of exposure. For further information, see the ACGIH's pamphlet, *1996 Threshold Limit Values and Biological Exposure Indices.*

EMERGENCY AND FIRST AID PROCEDURES

Inhalation
Not expected for product under normal conditions of use. However, if acid vapor is released due to overcharging or abuse of the battery, remove exposed person to fresh air. If breathing is difficult, oxygen may be administered. If breathing has stopped, artificial respiration should be started immediately. Seek medical attention immediately.

Skin
Exposure not expected for product under normal conditions of use. However, if acid contacts skin, flush with water and mild soap. If irritation develops, seek medical attention immediately.

Eyes
Exposure not expected for product under normal conditions of use. However, if acid from broken battery case enters eyes, flush with water for at least 15 minutes. Seek medical attention immediately.

Ingestion
Not expected due to physical form of finished product. However, if internal components are ingested:
Lead/Lead compounds: Consult a physician immediately for medical attention.
Battery Electrolyte (Acid): Do not induce vomiting. Refer to a physician immediately for medical attention.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Inorganic lead and its compounds can aggravate chronic forms of kidney, liver, and neurologic diseases. Contact of battery electrolyte (acid) with the skin may aggravate skin diseases such as eczema and contact dermatitis.

V. Fire and Explosion Data

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

Extinguishing Media
Dry chemical, foam, or CO_2

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

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

VI. Reactivity Data

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

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

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

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

VII. Control Measures

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

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

PERSONAL PROTECTIVE EQUIPMENT

Respiratory Protection
None required for normal handling of finished product.

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

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

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

VIII. Safe Handling Precautions

Hygiene Practices

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

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

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

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

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

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

SECTION 1: PRODUCT NAME

Valve regulated lead-acid batteries.

SECTION 2: HAZARDOUS COMPONENTS

COMPONENTS	%WEIGHT	TLV	LD50 ORAL	LC50 INHALATION	LC50 CONTACT
Lead (Pb, PbO_2, $PbSO_4$)	About 70%	N/A	(500) mg/Kg	N/A	N/A
Sulfuric Acid	About 20%	1 mg/m^3	(2.140) mg/Kg	N/A	N/A
Fiberglass Separator	About 5%	N/A	N/A	N/A	N/A
ABS or PP	About 5%	N/A	N/A	N/A	N/A

SECTION 3: PHYSICAL DATA

COMPONENTS	DENSITY	MELTING POINT	SOLLUBILITY (H2O)	ODOR	APPEARANCE
Lead	11.34	327.4°C (Boiling)	None	None	Silver-Grey Metal
Lead Sulfate	6.2	1070°C (Boiling)	40 mg/L(15°C)	None	White Powder
Lead Dioxide	9.4	290°C (Boiling)	None	None	Brown Powder
Sulfuric Acid	About 1.3	About114°C (Boiling)	100%	Acidic	Clear Colorless Liquid
Fiberglass Sep.	N/A	N/A	Slight	Toxic	White Fibrous Glass
ABS or PP	N/A	N/A	None	No Odor	Solid

SECTION 4: PROTECTION

EXPOSURE	PROTECTION	COMMENTS
SKIN	Rubber gloves, Apron, Safety shoes	Protective equipment must be worn if battery is cracked or otherwise damaged.
RESPIRATORY	Respirator (for lead)	A respirator should be worn during reclaim operations if the TLV exceeded.
EYES	Safety goggles, Face Shield	

SECTION 5: FLAMMABILITY DATA

COMPONENTS	FLASHPOINT	EXPLOSIVE LIMITS	COMMENTS
Lead	None	None	
Sulfuric Acid	None	None	
Hydrogen	259?	4% - 74.2%	Batteries can emit hydrogen only if over charged (float voltage> 2.4 VPC). The gas enters 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. Extinguishing Media: Dry chemical, foam, CO_2.
Fiberglass Sep.	N/A	N/A	Toxic vapors may be released. In case of fire: wear self-contained breathing apparatus.
478 Polystyrene	None	N/A	Temperatures over 300 °C (572°F) may release combustible gases. In case of fire: wear positive pressure self-contained breathing apparatus.

SECTION 6: REACTIVITY DATA

COMPONENT	Lead/lead compounds
STABILITY	Stable
INCOMPATIBILITY	Potassium, carbides, sulfides, peroxides, phosphorus, sulfurs.
DECOMPOSITION PRODUCTS	Oxides of lead and sulfur.
CONDITIONS TO AVOID	High temperature, Sparks and other sources of ignition
COMPONENT	Sulfuric Acid
STABILITY	Stable at all temperatures
POLYMERIZATION	Will not polymerize
INCOMPATIBILITY	Reactive metals, strong bases, most organic compounds
DECOMPOSITION PRODUCTS	Sulfuric dioxide, trioxide, hydrogen sulfide, hydrogen
CONDITIONS TO AVOID	Prohibit smoking, sparks, etc. from battery charging area. Avoid mixing acid with other chemicals.

SECTION 7: CONTROL MEASURES

1. 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.
2. 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.

STEPS TO TAKE IN CASE OF LEAKS OR SPILLS

If sulfuric acid is spilled from a battery, neutralize the acid with sodium bicarbonate (baking soda), sodium carbon (soda ash), or calcium oxide (lime).

Flush the area with water discard to the sewage systems. Do not allow unneutralized acid into the sewage system.

WASTE DISPOSAL METHOD:

Neutralized acid may be flushed down the sewer. Spent batteries must be treated as hazardous waste and disposed of according to local state, and federal regulations. A copy of this material safety data must be supplied to any scrap dealer or secondary smelter with battery.

ELECTRICAL SAFETY

Due to the battery's low internal resistance and high power density; high levels of current can be developed across the battery terminals. Do not rest tools or cables on the battery. Use insulated tools only.

Follow all installation instruction and diagrams when installing or maintaining battery systems.

SECTION 8: HEALTH HAZARD DATA

LEAD: The toxic effects of lead are cumulative and slow to appear. It affects the kidneys, reproductive, and central nervous system. The symptoms of lead overexposure are anemia, vomiting, headache, stomach pain (lead colic), dizziness, loss of appetite, and muscle and joint pain. Exposure to lead from a battery most often occurs during lead reclaim operations through the breathing or ingestion of lead dusts and fumes. THIS DATA MUST BE PASSED TO ANY SCRAP OR SMELTER WHEN A BATTERY IS RESOLD.
SULFURIC ACID: Sulfuric acid is a strong corrosive. Contact with acid can cause severe burns on the skin and in the eyes. Ingestion of sulfuric acid will cause GI tract burns. Acid can be release if the battery case is damaged or if the vents are tampered with.
FIBERGLASS SEPARATOR: Fibrous glass is an irritant of the upper respiratory tract, skin and eyes. For exposure up to 10F/CC use MSA Comfort with type H filter. Above 10F/CC up to 50F/CC use Ultra-Twin with type H filter. NTP or OSHA does not consider this product carcinogenic.

SECTION 9: SULFURIC ACID PRECAUTIONS

INHALATION: Acid mist form may cause respiratory irritation. Remove any individual from exposure, and apply oxygen if breathing is difficult.

SKIN CONTACT: Acid may cause irritation, burns or ulceration. Flush with plenty of soap and water, remove contaminated clothing, and see physician if contact area is large or if blisters form.

EYE CONTACT: Acid may cause severe irritation, burns, cornea damage and blindness. Call physician immediately and flush with water until physician arrives.

INGESTION: Acid may cause irritation of mouth, throat, esophagus and stomach. Call physician. If patient is conscious, flush mouth with water, have the patient drink milk or sodium bicarbonate solution.

DO NOT GIVE ANYTHING TO AN UNCONSCIOUS PERSON.

SECTION 10: TRANSPORTATION REGULATIONS

We hereby certify that all UPG Valve Regulated Lead-acid Rechargeable batteries conform to the UN2800 classification as " Batteries, wet, Non-Spillable, and electric storage" as a result of passing the Vibration and Pressure Differential Test described in D.O.T., 49 CFR 173.159(d), and IMO/IMDG, and ICAO/IATA packing instruction 806 and note A67.

Batteries having met the related conditions are EXEMPT from hazardous goods regulations for the purpose of transportation by DOT, and IATA/ICAO, and therefore are unrestricted for transportation by any means. For all modes of transportation, each battery outer package is labeled "NON-SPILLABLE". All our Batteries are marked non-spillable.

Updated: Feb. 18, 2010

Appendix B: Flotation Calculations

The 20% safety factor to ensure the boat stays afloat even if the boat is full of water. This was found by using the following equation.

$$F_{buoyant} = 1.2 * W_{Total}$$

$F_{buoyant}$ is found by calculating the volume of everything that will remain in the boat if it were to fill with water. The volume is then multiplied by the specific weight of water which is 62.2 $\frac{lbs}{ft^3}$. 1.2 is multiplied by the total weight of the vessel including any parts that are connected to the boat. Multiplying the specific weight of water in lb/in^3 times the total volume the buoyant force of the boat is 498.66 lbs.

$\frac{498.66}{318} = 1.568$ $\frac{498.66}{344} = 1.449$

From this data, you can see that 1.568 and 1.449 are both greater than 1.2 which is the 20% requirement.

Component	Volume (in^3)
Wood	840
Wood	168
Wood	767.25
Wood	252
Wood	63
Wood	798
Wood	-137.5
Wood	176.8125
Wood	48.375
Foam	2840.5
Wood	2819.875
Wood	21
Wood	315
Foam	3458
Batteries	1423.042381
Total	13853.35488

Components	Weight (lbs)	
	Sprint	Endurance
Hull	120	120
Batteries	100	100
Motor	24	24
Controller	4	4
Solar Array w/ Stand	0	26
Drivetrain	20	20
Misc	50	50
	318	344

Specific Weight of Water	
62.2	lb/ft^3
0.03599537	lb/in^3

Copy of 2016 Certificate of Liability Insurance has been requested from the University

Appendix C: Proof of Insurance

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 10/22/2014

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	
1-630-773-3800	CONTACT NAME: Art Pauls
Arthur J. Gallagher Risk Management Services, Inc.	PHONE (A/C, No, Ext): 630-694-5462 — FAX (A/C, No): 630-285-4062
Higher Education Division	E-MAIL ADDRESS: art pauls@ajg.com
Two Pierce Place	
Itasca, IL 60143	
Bill Powell	

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : UNITED EDUCATORS INS RRG INC	10020
INSURER B :	
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

INSURED
University of Southern Indiana
8600 University Boulevard
Evansville, IN 47712

COVERAGES CERTIFICATE NUMBER: 41894620 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 INSR	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	GENERAL LIABILITY			CGL201400100300	10/19/14	10/19/15	EACH OCCURRENCE	$ 1,000,000
	X COMMERCIAL GENERAL LIABILITY						DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 1,000,000
	CLAIMS-MADE X OCCUR						MED EXP (Any one person)	$ 5,000
							PERSONAL & ADV INJURY	$ 1,000,000
							GENERAL AGGREGATE	$ 3,000,000
	GEN'L AGGREGATE LIMIT APPLIES PER: X POLICY PRO-JECT LOC						PRODUCTS - COMP/OP AGG	$
								$
	AUTOMOBILE LIABILITY						COMBINED SINGLE LIMIT (Ea accident)	$
	ANY AUTO						BODILY INJURY (Per person)	$
	ALL OWNED AUTOS / SCHEDULED AUTOS						BODILY INJURY (Per accident)	$
	HIRED AUTOS / NON-OWNED AUTOS						PROPERTY DAMAGE (Per accident)	$
								$
	UMBRELLA LIAB / OCCUR						EACH OCCURRENCE	$
	EXCESS LIAB / CLAIMS-MADE						AGGREGATE	$
	DED RETENTION $							$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N						WC STATU-TORY LIMITS / OTH-ER	
	ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH)	N / A					E.L. EACH ACCIDENT	$
	If yes, describe under DESCRIPTION OF OPERATIONS below						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
To Whom It May Concern 8600 University Blvd. Evansville, IN 47712 USA	SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS. AUTHORIZED REPRESENTATIVE

ACORD 25 (2010/05)

Appendix D: Team Roster

2016 University of Southern Indiana Solar Splash Team:

Member	Degree Program	Year	Attending	Team Role
Dr. P. Kuban		Advisor	Yes	Advisor
Dr. B.Field		Advisor	No	Advisor
Rachel Athippozhy	Electrical Engineering	Senior	Yes	Electrical/ DAQ
Ryan Elpers	Mechanical Engineering	Senior	Yes	Electrical Assistance
Johnnie Guy	Mechanical Engineering	Senior	Yes	Drivetrain/Motor
Josh Guy	Mechanical Engineering	Senior	Yes	Drivetrain/Motor
Ryan Loehrlein	Mechanical Engineering	Sophomore	Yes	Propeller
Josh Terrell	Mechanical Engineering	Junior	Yes	Motor Assistance
Jackson Traylor	Electrical Engineering	Senior	Yes	Power Management/DAQ

Appendix E: Responsibility Matrix

The responsibility matrix was created to help manage the project. Each person was placed in a category where they would be able to learn more outside of their discipline in engineering.

Responsibility Matrix								
Item number	Work item	Rachel A.	Ryan E.	Johnnie G.	Josh G.	Ryan L.	Josh T.	Jackson T.
1	Solar Design		S				**P**	
2	Solar Panels		**P**				S	
3	Batteries					S		**P**
4	Power Management			**P**	S			
5	Propeller					P	S	
6	Drive Train			S	**P**			
7	Motor	S			**P**			
8	Motor Controller			**P**	S			
9	Hull Design		**P**			S		
10	Data Acquisition		S					**P**
11	Steering			**P**			S	
12	Poster	**P**						S
13	Technical Report					S		**P**
14	Grants/Funding	**P**						
15	Team Shirts	**P**						

Appendix F: Decision Matrix

	Cost			Drag			Cutting of Hull			Steering Modification			Efficiency			Trim			Totals
	Score	Weight	Weighted Score	Score	Weight	Weighted Score	Score	Weight	Weighted Score	Score	Weight	Weighted Score	Score	Weight	Weighted Score	Score	Weight	Weighted Score	
Outboard	1	0.1	0.1	0.5	0.3	0.15	1	0.1	0.1	1	0.05	0.05	0.75	0.3	0.225	1	0.15	0.15	0.78
Inboard	0.5	0.1	0.05	0.5	0.3	0.15	0.1	0.1	0.01	0	0.05	0	0.75	0.3	0.225	0	0.15	0	0.44
Surface Drive	0.6	0.1	0.056	1	0.3	0.3	0.5	0.1	0.05	0.85	0.05	0.0425	1	0.3	0.3	1	0.15	0.15	0.90