UNIVERSITY OF ROCHESTER | **URSS**

Solar Splash Boat #11

Edward Ruppel '17
Matthew Dombroski '17
Madeline Hermann '17
Nitish Sardana '17
John Krapf '18
Joshua Lomeo '18
Devin Marino '18
Elizabeth Stanitz '18
Ziping Liu '18
Yukun Chen '18
Enyxa Poventud '19
Elijah Mitchell '19
Christopher Dalke '19
Seth Schaffer '19
Benjamin Martell '19

Faculty Advisor:
Prof. Stephen Burns

Technical Advisors:
Robert Scott Russell
James Alkins

HAJIM
SCHOOL OF ENGINEERING & APPLIED SCIENCES
UNIVERSITY of ROCHESTER

Executive Summary

The objective of this year's University of Rochester Solar Splash (URSS) team was to increase our scores in every race by at least 75% at the International Solar Splash Competition, and to once again be competitive with the top veteran teams. This competitive spirit has driven a group of engineers at the University of Rochester to become enthusiastic about the application of their studies and solar power as an alternative source of energy. Rochester Solar Splash team members committed thousands of hours and dollars to their sixth iteration of a competitive Solar Splash boat.

Out of consideration for the sprint portion of the competition, URSS aimed to increase the efficiency and power output of the drive system. To this end, an innovative surface drive system was designed and built to utilize the full potential of our power electronics system. This system allows for full trim adjustability and electronic power steering. A smart auto-leveling system was devised to control the prop shaft to maintain a beneficial thrust vector.

The hull from 2015 has been reused, with slight modifications. Designed with the sprint and endurance portions in mind, the hull is a trimaran with a central planing hull to allow for excellent lift production at high speeds, and tapered side hulls for precise turning. This hull is made from epoxy-coated fiberglass supported by NidaCore stringers. An extension of foam and fiberglass was added to the central front to enhance angle of incidence and the hydroplaning effects of the hull.

When previously raced, the hull was completely stable on the water, although major cavitation problems prevented it from reaching its full potential and high speeds. It was hoped that the hull would be efficient in the sprint portion, as it generates less drag and essentially rides atop the water. The effectively large static surface area is best in the endurance portion of the race, as it does not require the high speeds of a pickle fork catamaran hull to operate.

To control the boat, a drive-by-wire system was created to save weight and increase efficiency in steering capabilities. A serviceable central modular console was also created to hold all the low voltage electronics in one sealed compartment. This is a benefit over previous iterations because it is an organized and centralized system, making it easier to debug, and less likely to short out. The new system was designed to incorporate a GPS to provide location information to the group on the shore, and provide the skipper with an accurate speed of the boat. The boat's telemetry is compiled by a Raspberry Pi and displayed on an LCD screen.

Over the course of upgrading the boat systems, all of the students involved in the 2015-2016 University of Rochester Solar Splash Team have vastly improved their practical engineering skills. We hope to improve our performance this year and believe our improved engineering designs and robust implementation will allow us to be very successful in the competition.

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Overall Project Objectives

The University of Rochester's major goal this year is the implementation of a new surface drive system for effective steering and optimal propeller-water surface area contact. The hull from 2015 was optimally designed for hydroplaning, but cavitation problems prevented the hull from reaching its full capabilities. A minor modification to the front of the hull was made to assist in hydroplaning. Several major improvements were made for power-electronics and telemetry systems. A new solar charger was purchased; this one being simpler, more powerful, and more compatible with the electronic systems of the boat. A new telemetry system has also been developed, allowing for real time display and data logging for efficiency analysis.

Analysis of Integral Systems

Solar System:

Previous Design

The solar panels used prior to the 2015 competition were three model SX 170Bs manufactured by BP. Each panel weighed 33.1 lbs., for a total weight of 99.3 lbs., and had an efficiency of 11%, for a total power output of 510W at 32V. In addition, a FlexMax60 MPPT charge controller by Outback Power Systems was used to interface between the solar panels and the batteries. The FlexMax60 was designed to maximize power conversion from the panels to the batteries with a conversion rate of 98.1%. To do this, the FlexMax60 utilizes a Max Power-Point Tracking Algorithm or MPPT for short.

While this system served well in past years, there were several shortcomings, specifically with respect to the solar panels. The SX 170B panels were heavy and unwieldy to work with during construction and competition. At almost 100 lbs., the panels required a strong and heavy mounting system to safely secure them to the boat. In addition, the panels were relatively inefficient, having only 11% efficiency and a power-to-weight ratio of 5.2 watts per pound. For last year's competition, a core focus was obtaining more efficient and lighter panels to both increase power output to the motor and reduce overall weight.

Current Design:

For the 2016 competition the panels used last year will be reused. The panels are manufactured by SBM solar and the specification sheet can be found in Appendix G. The solar controller this year has been updated due to variety of design considerations detailed below. In the previous year, we updated our solar panels to supply power at a higher efficiency with decreased weight. However, from this update it was discovered that our current solar charger was unable to utilize all of the improvements from the new panels. While the panels are capable of outputting over 400W of power, the FlexMax60 charge controller used during the 2015 competition is capable of only absorbing 100W of power on average. Thus a main objective for the solar system design this year was to find or modify a solar controller to increase the absorbed power from the panels.

The limitations of the FlexMax60 solar controller are due to its design as an in-house installation. Physically the controller is too large and heavy for installation in the smaller boat hall built in the previous year. Electronically the controller has two main setbacks for use in dynamic environment such as a moving boat. Because the controller is designed for use with a house mounted panel system the software of the controller has no expectation of the panels' changing orientation or motion. For this reason, the update rate of the MPPT algorithm in the FlexMax60 is quite low at about once per minute. In addition, the charging stages for the FlexMax60 are based on an entire day's sunlight. While these design decisions make the FlexMax60 a superb solar controller for a solar system for a house, they do not translate well to the dynamic environment of a boat where the panels are in constant motion. The maximum power point (MPP) of the panels needs to be recomputed constantly and a much faster recharge time is desired due to the time constraints during competition. The second setback of the FlexMax60 is the complexity of the configuration modes. While configurations themselves are useful and add to the fine tuning performance of a system, in the case of the FlexMax60, these configurations became inhibiting. Most configuration settings of the FlexMax60 are irrelevant to a system that is placed on the water and will have charging windows of a few hours at a time.

In addition, perhaps the greatest flaw of the FlexMax60 is the fact that it is a step down type charger. The FlexMax60 can take in a high voltage and then step that voltage down to the voltage required to charge the batteries. However, this presents a problem in this case, since the panels each produce a nominal 31.6V. This voltage is too low to charge a 36V battery system and thus the FlexMax60 would be unable to provide enough voltage to the batteries if the panels were connected in parallel. Connecting the panels in series however produces an open circuit voltage over 60V, which is above competition rules for maximum system voltage. While the panel voltage can be reduced by placing large power diodes in series, a large number of diodes would be required and large portion of power would be wasted through heat dissipation in the diodes. The diodes could also interfere with the operation of the MPPT algorithm tracking abilities and lead to a mismatch and more inefficiency.

Due to the reasons listed above it was decided to find a new solar controller that would perform better in the specific application of an electric boat. The most favorable controller would be that which has a fast update rate for the MPPT algorithm so as to continuously maximize power output from the panels. In addition the controller should have either relevant configuration parameters or a very simplistic interface.

The controller found that matched these desired parameters is the Genasun GV-BOOST 36V controller. This controller is designed for use in golf-carts and is designed for dynamic environments where the panel MPP is constantly changing. The update rate of the GV-BOOST is

15Hz and the interface consists only of wires to connect to the batteries and the panels and an LED to convey the state of the controller. A full spec sheet for the GV-BOOST can be found in Fig. H.

In addition, the GV-BOOST has one of the most important requirements, the ability to boost the panel voltage to the required battery charging voltage. This ability eliminates the need to implement other methods of decreasing the panel voltage, which either waste usable power output or destroys the MPPT algorithm's ability to track the MPP. With the voltage boosting ability the panels can be placed in parallel and remain under the maximum system voltage required by the competition rules, while still providing maximum power to the batteries.

New mounts were designed and built for the panels. The mounts were configured in the same way as last year, with one in front of the skipper and one behind. The mounts are attached to the hull via T-slotted tracking, 7/16" hex head bolts, and retained by quick release hitch pins. To maintain rigidity over the area of the solar panels, extruded Z-channel frames were built with machined aluminum corner clamps.

Design Alternatives:

The best addition to the design would be to add a second GV-BOOST controller so that there is one controller per solar panel. To ensure the optimal performance from the MPPT algorithm it is best to use one controller per panel as the MPP for each panel may be different. In addition using two controllers would increase the power output capabilities of the solar system. As Fig. H shows, the maximum power output of the GV-BOOST is 325W where both solar panels together can produce 480W of power. A second GV-BOOST would allow all possible output power to be utilized.

Testing and Evaluation:

Testing showed that with a single panel 150W was extracted, translating into a 10 Ah return to the batteries in approximately 2 hours. Our testing of dual panels could provide 20 Ah of power. During testing it was observed that the panels were very sensitive to shade. While the voltage does not decrease significantly due to shade, the current capability degrades greatly, dropping generally from about 4 amp output to approximately 0.5 amp or less with only one cell in the panel being covered. This was taken into account during panel mounting and the panels were placed such that all possible shadows from the boat were minimized.

	2013-2014 System	2014-2016 System
Solar Panels Model	SX 170B by BP	SBM Solar modules
# of Panels	3	2
Panel Surface Area	40.7 sq. ft.	34.6 sq. ft.
Power Output	510W	516W (2.5 sq. ft. taped off to limit to 480W)
Voltage Output	32V	30V
Efficiency	11%	20%
Weight	33.1 lbs. per panel x3 panels	15 lbs. per panel x2 panels
Resistive Power Loss During Sprint	2.3% or 304W	0.8% or 108W

***Table 1*: Tabulated comparison of previous and current solar panel specifications**

Power Electronics System

Overview

The boat utilizes a Curtis 1238 Motor Controller for its ease in programming to the current design specifications. It draws power from either the sprint or endurance batteries, which supply a set voltage of 36V and output a various range of voltages and currents depending on user input to the drive motor. Other inputs to the motor controller include the dead man switch and the throttle. In previous years, URSS used battery configurations that utilized a different set of batteries for each portion of the race – one set each for the sprint and endurance races. As in the previous years, this year's design utilizes three 42Ah batteries and three 44Ah batteries for the endurance and sprint portions of the competition, respectively. All control wires for start-up switches, throttle, and data cables are passed to the middle of the boat and to the dashboard/control console. With this configuration all high current wires and components are close together, keeping the high current wires short and resistance losses low, while all the control wires are brought to the skipper, keeping him away from the potential danger of the power electronics.

Previous Design

In last year's design, the motor and motor controller were placed in the front of the hull and in front of the skipper. The batteries were placed alongside and behind the skipper with the power wires running along the sides of the boat to the motor controller and motor. To keep the wiring system organized and the power system voltage polarities separated, two bus bars were attached to either side of the front inner panel of the boat. This setup worked well for when the motor was placed in the front of the boat. However, the power wiring was rather extended, running from the batteries in the back of the boat to the motor in the front. While the overall inefficiency introduced by this extra length of wire was minimal, shortening the main current carrying wires will always increase performance.

Analysis of Design Concepts and Design Testing

The Power electronics system currently consists of a Curtis 1236 motor controller (a 36-48V, 650 Amp controller designed for a wide range of AC electric motor applications), an AC-9 three-phase AC electric motor (capable of a peak of 18 HP, a continuous 6HP, and a maximum of 6800 RPMs), three 35Ah batteries for the endurance competition, and three Odyssey PC1100 batteries for the sprint competition. In addition, both sets will include two 7Ah SLA batteries to drive the actuator and steering, which will not be charged by the solar panels. Due to propeller specifications, the motor speed was reduced to around 3000 RPMs for greater efficiency in both motor current consumption and propeller thrust. The schematic for the power electronics system can be seen in Fig. 1.

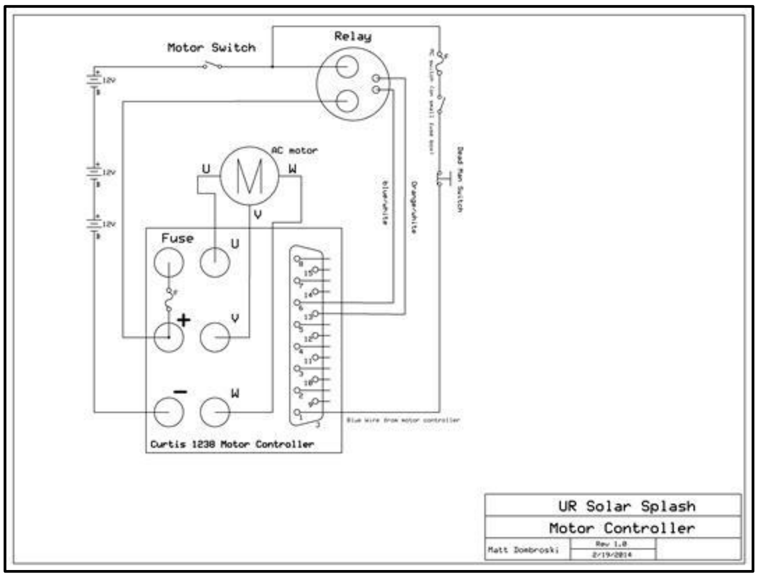

***Figure 1*: Schematic for Curtis Motor Controller**

The motor controller is fed with 36V from three batteries in series. The low current logic portion of the controller is activated by both a normally open dead man's switch and a low current toggle switch, which were connected in series with a 20 Amp fuse. The logic portion of the controller then activates a high current contactor, which energizes the rest of the power system. This setup allows for less high current wiring, lowering resistance and increase in overall efficiency, while still providing full control over the system and emergency shutoff capability.

The layouts of the power electronics subsystems – batteries, motor controller, solar charger, and motor – are concentrated towards the rear of the boat in a 2 x 4-foot compartment area. This allows for the power feeds to remain short, keeping their overall resistances low. The bus bars this year were the same as used last year, two 3 x 5 x 1.75-inch aluminum blocks used as a central connection point for all the main power subsystems: the batteries, motor controller, and solar battery charger. Each of these three subsystems are connected in parallel. The team did not take into account dissimilar material corrosion issues due to the short time that the aluminum bus bars would be attached to the copper wires. However, as part of the pre-race and post-race systems validation inspections, the team checks for any sign of oxidation on the bus bars. If oxidation is present, the team takes the necessary steps to remove the surface corrosion before the boat is to be launched again. Aluminum blocks were initially chosen because of their ease of machining and inexpensive cost compared to brass; a material of which will be utilized in future configurations.

Aside from minor adjustments the electric power system this year remains the same as last year's system. We have found that the current components work well with the current hull and there has been little incentive to update any parts.

Electrical Systems

Overview of Previous Design

Last year the electrical systems were primarily located on a foamcore dashboard, which consisted of a vertical stringer spanning across the center of the boat. This electrical system was comprised of safety switches, a throttle, and the digital readout display from the motor controller. This system interacted with the motor controller, controlling the power to the motor. The switches in this system acted as a redundant system so that the power electronics could not be accidentally activated during testing or set-up. The second electrical system, includes both a distress alarm, and a bilge pump to remove excess water from the boat.

Overview of Current Design

This year, our electronic system is divided into two separate subsystems. The low-voltage system is contained within a dashboard unit in the front of the boat, and encompasses all control and telemetry electronics. The low-voltage system communicates with the power electronics system to control the motor controllers and view sensor data. The high-voltage system is contained in the rear of the boat, and comprises of the motor, motor controller, batteries, and solar charger. Together, these two separate systems allow for efficient operation of the boat.

Low-Voltage Electronics and Dashboard

This year, control and telemetry systems are contained in a self-standing dashboard unit designed and constructed for modularity. An Arduino Mega is used to control the steering of the boat. The Arduino is connected to a potentiometer, which reads the angle of the rudder shroud and an encoder, which reads the position of the steering wheel. It converts these signals and sends them to the steering motor circuitry of the high-voltage subsystem. The Arduino also connects to an inertial measurement unit and reads tilt data from the boat. This data is used to adjust the linear actuator in order to optimize the angle of the propeller. In addition, the dashboard features a Raspberry Pi connected to a 7-inch TFT display. This runs a Java application, which collects data from sensors and displays the values on a user interface. The Pi is connected to a GPS module to obtain the current speed and heading of the boat; although, as a backup, the heading can be calculated by a digital compass in an Inertial Measurement Unit. It is also connected to the Arduino Mega and thus monitors the status of the steering control program. The UI software shows the status of each of the subsystems of the boat for debugging purposes.

The dashboard contains switches for the main power, boat horn, bilge pump, and telemetry systems. It also houses the speedometer, battery gauge, and meters to measure the current voltage output of the main batteries. The dashboard system is powered by several small auxiliary battery units, and is monitored via a multi-meter display with current and voltage measurements. The dashboard also contains a dead man's switch that trips when a clip is pulled. This clip is attached to the skipper by a cord, so that the switch will flip open and deactivate all power to the power electronics, should they fall out or another emergency warrants immediate engine cutoff.

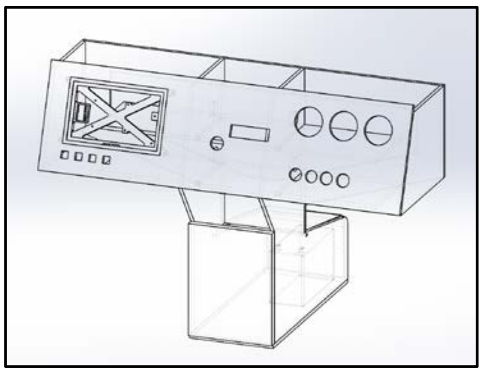

***Figure 2*: Solidworks Design of the Dashboard Console**

High Voltage Electronics

The surface drive mechanism is our most ambitious change to the boat this year. Automated-control engineering methods were used to create a system that can robotically adjust the angle of the propeller, keeping it level with the water regardless of the boat's planing angle; while at speed. A universal coupling is utilized to connect the drive system to the propeller shaft, allowing for the usage of a linear actuator as an axis control. The linear actuator can adjust within a range of 8 inches in order to change the angle of the propeller shaft.

The actuator is powered by 12 Volts and draws up to 20 Amps of current while in operation. By using a custom double SPDT Relay H-Bridge it can be reversed immediately by a microcontroller, an Arduino Mega 2560. A built in position sensor provides feedback to the Arduino so that it stops when necessary and extends or retracts the actuator as required. As a safety precaution, the linear actuator can be controlled in a manual mode as well. The boat's positional data is fed to the Arduino using a 9-degree of freedom inertial measurement unit.

***Figure 3*: Linear Actuator for Surface Drive System**

This inertial measurement unit tracks the boat's heading, bearing, absolute position, and angle relative to gravity by using accelerometers, gyroscopes, and a digital compass. Each of these tracks within three degrees of freedom. With gravity being perpendicular to the water, the boat's angle relative to the waterline is easily obtained and used to manipulate the length of the actuator with 8-bit resolution. The actuator is capable of moving over 1000 pounds and extends and retracts at 0.67 in/s.

Figure 4: Inertial Measurement Unit

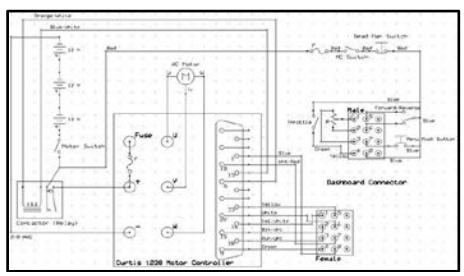

***Figure 5*: Schematic of Circuit used in Electrical System**

Hull Design and Construction Processes

Hull Design: Overall Hull Design Process

Hull Design Testing and Evaluation

It was decided for the 2016 competition that the same hull as the 2015 competition would be used, allowing the team to focus on new electronic and surface-drive systems. Some minor modifications to the front of the hull and internal components were made.

Previous Hull Design

The 2013-2014 academic year marked the second year that the University of Rochester team manufactured a hull from an Orca3D design. The previous hull design had several issues that limited its success in the competition. The hybrid planing-displacement design worked well in CFD analysis, but in use, the height and weight of the hull was extremely difficult to maneuver in wind. That said, the goal of the 2014-2015 hull design was to create a hull which would both perform in CFD analysis and in competition conditions.

Analysis of Design Concepts

In an effort to improve the standing in the competition, the University of Rochester's Solar Splash team decided to completely redesign the shape of the hull for the 2015 competition year. The original hull shape was hugely inefficient both in the sprint and endurance portions of the competition, and thus presented the team with a significant opportunity for improvement. Inspired by the pickle-fork racing catamarans of the 1970's, the team aimed to create a hybrid hull shape that would combine both the high-speed performance of a lift-inducing airfoil with the low-speed efficiency of a displacement hull with a large surface area. This concept was achieved by creating core specifications to continuously develop through prototyping and flume analysis.

Using COMSOL fluids modeling program, multiple revisions of our pickle fork trimaran were created and tested which helped streamline the overall design. In drawing the hull, multiple 3D sketched cross-sections were stitched together to make one solid surface. From our previous experience with a motor placement and shaft angle, it became apparent that a central planing hull was necessary to provide optimal lift conditions. The side hull is gently tapered upward towards the stern to give an ideal surface to ride on when the center hull is on plane; all lending towards the lift created from the U-channels between the catamaran hulls.

However, after reviewing our 2015 competition performance, we found a gross need for a revision of the front surface of the hull. During competition, the bow of the boat dipped into the water in choppy conditions, causing water to enter the boat. To remedy this, the bow and nose shape was reformed to direct water down and under the boat more aggressively. Venting grills featured on the 2015 boat were also removed and sealed. A new design for shaft and motor placement that featured a surface drive system was proposed. This system would allow varying shaft and prop angle, controlled by electric actuator. The motor was re-mounted at a rear position to allow proper function of the new drive system. A full schematic of the boat assembly can be seen in Figure 6 and Appendix J.

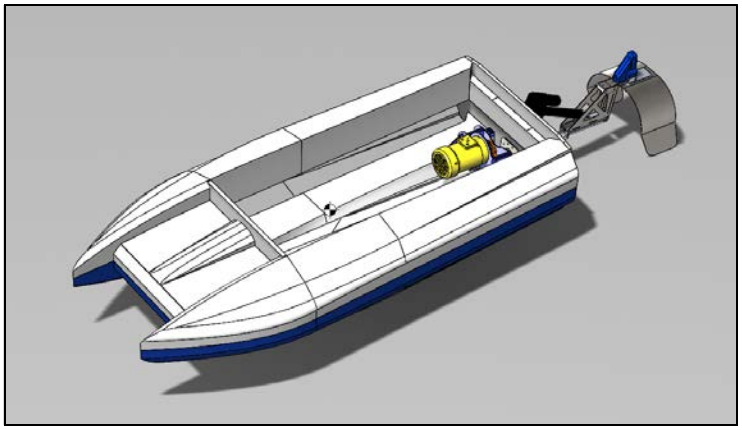

***Figure 6*: 3D CAD Drawing of Hull Design**

Hull Construction: Mold-Making Process

Previous Mold-Making Process

The previous hull was made by printing cross-sections of the model onto 2-inch-thick slabs of foam. The foam cross-sections were then sandwiched together and used as a mold to lay fiberglass atop. A reciprocating saw was used to carve out large chunks of foam, and acetone was used to dissolve any remaining foam in order to make room for internal components. The end result was a thin fiberglass shell, which required additional reinforcement from a core material and internal bracing. Although this system was accurate and relatively easy, the time that it took to accomplish this task was exponentially longer than the mold making process should be.

***Figure 7*: Cross Sections used in Manufacture of 2013 Hull**

Analysis of Mold-Making Concepts

Under consideration for the team's significant time constraints, it became apparent that the best and most accurate way to create the hull mold would be to use a CNC router to cut a negative foam mold. Fortunately, the University of Rochester found a vendor in Sunnyvale, CA with a CNC router large enough to cut the design out of expanded polystyrene blocks.

Once the mold arrived, the team took multiple steps to prepare the mold for fiberglass layers. The process first required applying multiple layers of a polymer called Styropoxy, which adhered to the foam surface to create a solid non-permeable surface. This new surface was then finely sanded smooth. Afterwards, multiple layers of carnauba mold release wax were applied to the Styropoxy surface to allow for easy fiberglass removal. After a smooth layer of wax, fiberglass layers infused with epoxy were finally applied to the mold to create the hull. Once the epoxy dried and the fiberglass layers summed to a sufficient thickness, the shell was removed by applying multi-axial pressure, employing the use of airbags between the fiberglass and mold.

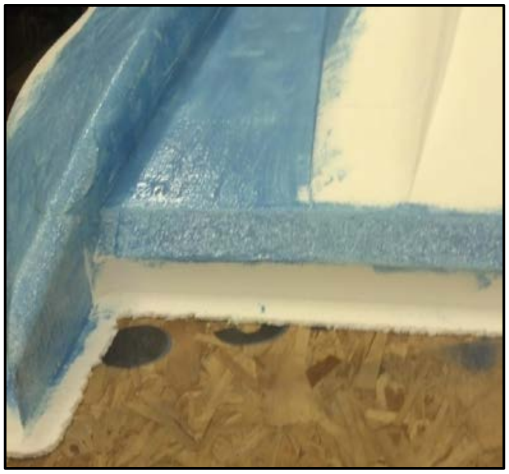

***Figure 8*: Styropoxy Application to the Foam Mold**

Mold-Making Testing and Evaluation

Although the foam mold was expensive, having a 1:1 perfect reusable mold (pictured in Figure 9) was worth the expense. Both top and bottom sections were molded from the same foam buck, which simplified the hull-building process and cut the expense of having to order a top mold. After molding both portions of the boat, it became clear that future designs must be drafted at least 10^{o} to allow for easy shell removal and effective vacuum bagging, thus keeping the mold-making time expenditures to a minimum. A CNC-cut mold is definitely the best option to create an advanced design that would otherwise be too time consuming to put together by classical means. The University of Rochester team has built a 12’x12’ CNC router to aid in future onsite mold-making capabilities. As of this year, the CNC has solely been used for the construction of the console.

***Figure 9*: Negative Foam Mold of Hull Design**

Hull Construction: Composite Structure of Hull Material Cross-Section

Previous Composite Structure

The previous hull was made from multiple layers of fiberglass sandwiching Corecell foam with wood flour epoxy as filler at joints. Although this combination of composites creates an outstandingly strong hull, the large amounts of epoxy required makes it extremely heavy.

Analysis of Composite Structure Concepts

This year's hull was constructed without an internal core material. Instead, the team used composite stringers, which were strategically placed throughout the cross-section of the hull material to provide flexural rigidity and shear strength. The construction process was derived from "stitch and glue" boat building and airplane wing construction techniques. After testing different composite thicknesses with MTS machines, the optimal shell combination was created. The composite fiberglass combination was chosen for the boat with consideration for shear strength, weight, and thickness. This composite consists of a layer of 9-oz 45-degree weave, three layers of 6-oz 45-degree weave, and one layer of 4.5-oz weave. The composite also consisted of a 12-oz 45-degree weave with 8-oz matt for all angled and corner sections to lend excellent rigidity in form. All of the stringers are made from Corecell foam and NidaCore Panel, backed with 12-oz 45-degree weave, that have been attached to the hull with 8" strips of 12-oz 45-degree weave with 8-oz mat.

Composite Design Testing and Evaluation

To account for the shear stresses on the composites caused by the concentrated loads from the batteries and electronics, expandable foam, a hot wire foam cutter, and vacuum molded plastic compartments were employed. First, expandable polyurethane foam was poured into each compartment to provide a buffer to distribute the weight of the heavy components. The team built a custom hot wire foam cutter from a Variac controlled 1000-Watt power supply and a spring-tensioned nichrome wire harness. Before each cut, the nichrome wire is formed in the shape of the object to create 1:1 embedded compartments. The carved foam compartments were then press fit with plastic compartments created by vacuum molding. This process provides a custom waterproof compartment that is vibration dampening and composite preserving. The internal weight of the boat will be mostly concentrated in its center, approximately four feet from the transom. This concentration is accounted for by additional stringers, dampening foam, ¼" thick rubber gaskets, and thick weave fiberglass for rigidity. With most of the weight towards the stern, the boat has a high ability to inefficiently plane at greater than 20-degrees when there is no weight (skipper) in the front to counter the boat's fixed load. This problem is accounted for by setting the location of the seat forward to act as a counterweight and shift the boat's effective center of mass forward from the initial neutral axis.

After extensive on-the-water evaluation at top speeds of approximately ~25 mph, the lab tests have proven to be correct; as a core material was not necessary when in usage with a thick matt backing, stringers, and buoyancy foam compartments. At less than half the weight of the previous configuration, it was determined that using stenciled composite stringers coupled with expandable foam dampeners is an excellent way to provide rigidity without excessive weight.

For the 2016 competition, an extension of foam and fiberglass was added to the bow to enhance hydroplaning effects of the hull. The extension also acts as a sealed double wall in case of collision, as was present at the 2015 competition. The stringer between the driver and the motor was removed, and a new stringer was fiber glassed in the back of the boat to account for change of motor location.

Drive Train and Steering Systems

Overall Drive System

Previous Drive System Design

The drive shaft and prop shaft system worked well in the previous year in regards to robustness of design. There were no mechanical issues experienced at competition other than the major cavitation issue that strictly limited the thrust capabilities of the drive system.

Analysis of Drive System Concepts

The motor mount-timing belt system was maintained in the current design. However, the setup was moved to the aft section of the hull in order to coordinate with a new variable surface drive system. When drafting designs for a surface drive system, it became apparent that the combination of a Levi drive and biaxial control system would be optimal for utilizing the hull's hydroplane design. The Levi drive controls angular rotation of a shroud that vectors the thrust of the propeller, giving effective steering feedback while maintaining perpendicular water-propeller contact. A linear actuator is used to control this contact area to optimal conditions, depending on water conditions, angle of planing, and race specifications. Use of a linear actuator allows flexibility in any water conditions encountered.

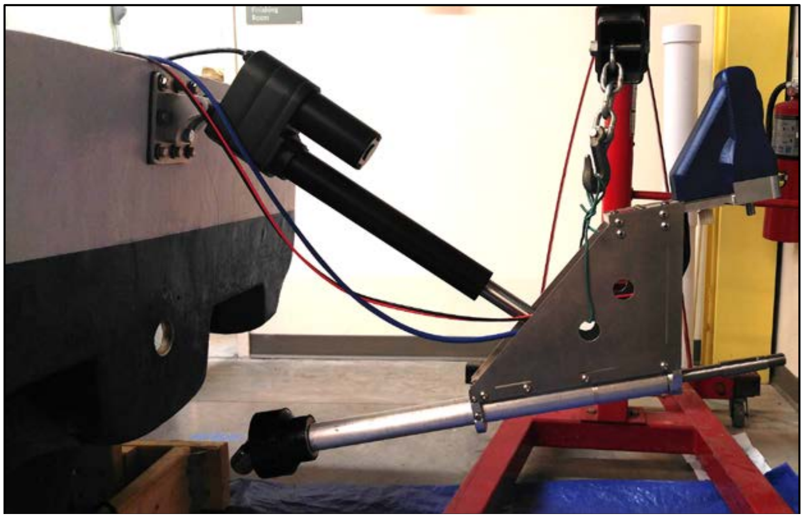

Figure 10: **Surface-Levi Drive in Assembly Process**

The same timing belt pulleys as previous are used, but new timing belts were installed for extended running life. The timing belt ratio is 1:1, making the ratio of the power of the motor to the rotation of the propeller also 1:1. A new drive shaft and propeller shaft were designed and implemented to interface with the surface drive system as shown under assembly in *Figure 10.*

Drive System Testing and Evaluation

Utilizing many of last year's parts, a much stronger motor mount (discussed below), and the addition of a mid-shaft bearing improves the robustness of the drive system. Vibrations caused by the motor's rotation are minimal, and the overall system is extremely sturdy. Potential improvements for the following year include changing the timing belt ratio and designing a magnetic-clutch gearbox system to enhance sprint capabilities.

Drive System: Motor Mount

Previous Motor Mount Design

While the motor mount for the previous design worked well, it was square, bulky, heavy, and did not enhance the modularity of design within the boat. Another major problem with the mount was that the frame twisted after extended on-water usage, due to relatively few retaining bolts.

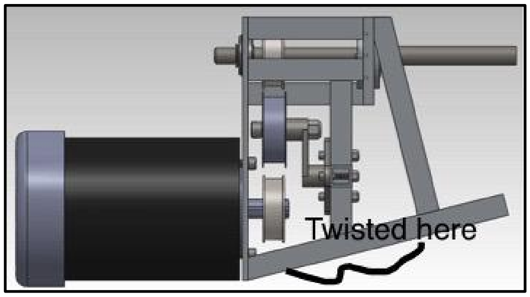

***Figure 11*: Schematic of Previous Motor Mount and Deformation Point**

Analysis of Motor Mount Concepts

The current motor mount was designed using SolidWorks to specifically fit the shape of the boat. The mount is composed of rounded plates to parallel the center curves of the boat, and these plates are welded to rectangular tubing, which sit on the interior design struts of the boat. The mount includes 7 holes on each side to ensure that it is securely attached to the boat, which is done using weld nuts, Corecell foam, rubber dampers, and stainless 3/8”-16 bolts. The motor mount sits on a line of fiberglassed Corecell cubes that have the weld nuts embedded within them. The motor mount system is shown in Figure 12**.** The location of the motor has changed since last year, and it now sits at the back of the boat as shown.

***Figure 12*: Motor Mount with Motor Embedded in Central Planing Hull**

Motor Mount Testing and Evaluation

The motor mount has more than enough strength to handle the torque of the motor (up to 4500 ft-lb) and its vibrations. It is a solid design (factor of safety of 6.5) that can likely be used for several years, unless future boats have a hull design with which it does not pair well. However, the current design is over-engineered for the load it is supporting, which prompts room for improvement next year.

Steering System

Previous Design

Last year, the team used a Teleflex NFB Safe T II Mechanical Steering System. This system worked by converting rotational motion of the steering wheel into linear motion of a flexible rod surrounded by a jacket. The rod was positioned at the back of the boat. Turning the steering wheel pushed and pulled the rod contained within the Teleflex jacket. Connected by a pin joint to end of the rod was a plastic arm. The plastic arm was connected to the rudder so that extension and contraction of the Teleflex pushed the rudder to left and right. The arm was set at a 90° angle to change the direction of the motion from parallel to the boat to perpendicular to the rudder, as the Teleflex terminated parallel to the transom.

Analysis of Design Concepts

The 2016 steering system was changed entirely from last year. The manual system used previously was replaced with a new electrical drive-by-wire steering system. This was done primarily for compatibility with the surface drive mechanism. The connections between the hull and the surface drive needed to be flexible, and the weight of the system minimized. Both of these goals could be easily accomplished with a compact brushed DC motor and planetary gearbox. The motor is bidirectional, and can be driven by an electronic speed controller, which comes waterproofed and has a variety of battery compatibilities. A gearbox was required for the Levi drive design, because the DC motor spins with no load in excess of 16,000 RPM. Therefore, a 672:1 ratio four-stage planetary gearbox is utilized to provide more torque while maintaining a reasonable steering speed. The rudder can sweep through its full 80 degree turning range in under two seconds, even with resistance of the water.

Steering System Testing and Evaluation

The steering assembly was successfully built and has been tested, utilizing a properly adjusted PID control algorithm to reach the angle defined by the steering wheel encoder. It quickly and accurately rotates to any angle within a specified range without oscillation or overshoot.

Data Acquisition and Communication

Overview

The overarching purpose of the data acquisition system this year was to record throttle, current draw, and speed of the boat over time to find the most efficient throttle setting for optimal speed. From experience last year and the fact that two-thirds through the race battery reserves were depleted, knowing the most efficient throttle position will be key for performance during the endurance section of the competition. In addition, a data acquisition system that can provide the skipper accurate and instantaneous data on the systems in the boat will assist them in making informed decisions on driving the boat in real time.

Previous Design

In 2015, the data acquisition system was composed of an OBDII scanning tool which connected to the CAN bus of the motor controller. The OBDII connected over Bluetooth to an Amazon Kindle Fire. The Android app Torque was used on the Kindle to interpret and display the data. Through Torque, the voltage of the batteries, RPMs and amperage draw of the motor, temperature of the batteries and motor, and the remaining battery capacity could be monitored in real time simultaneously from the 7” display screen of the Kindle.

Analysis of Design Concepts

For 2016, a similar system to the Kindle data acquisition system was developed. A Raspberry Pi was used to retrieve and log data and output it to a LCD display mounted in the console. A Raspberry Pi was used because it has a GPIO header, which could connect the computer directly to the electronics system without the use of a scanning tool as in previous years. A Java application that runs on the Raspberry Pi was developed to display boat telemetry on the LCD display. By using a combination of GPS, accelerometer data, and measurements from various sensors on the boat, the system is able to calculate the most efficient thrust level. This allows the system to operate at high efficiency in endurance mode. The Java program also displays a list of all the subsystems of the boat and their status. This allows for easy troubleshooting in the case of malfunctioning systems.

The Raspberry Pi is contained in the center console along with other electronics. As mentioned before, having all computers and microcontrollers in a sealed console offers an advantage for multiple fronts. It was more convenient to interconnect the Raspberry Pi and other devices, and it kept electronic systems isolated, decreasing the likelihood of malfunction due to water or foreign objects. The Raspberry Pi is wired to be Internet linked, so when it connects to an open network it uploads logs of all data collected.

Project Management

Team Sustainability

University of Rochester Solar Splash is an undergraduate club sponsored by the Student Association and the Hajim School of Engineering. For 2015-2016, University of Rochester Solar Splash sought to greatly increase membership, bringing together veteran members to instruct new members in CAD, mechanical and electrical design, manufacturing methods, and programming. The club was successful in recruiting several new members from different years and disciplines, including: mechanical engineering, electrical engineering, computer science, statistics, chemistry, and chemical engineering. This variety of disciplines allowed new members to integrate easily into the club and into their own roles. Students also gained experience and knowledge working outside of their disciplines. As a whole, this strengthened the organization and compatibility of the club towards completing the project for June. With the perspective of the current team's President, Edward Ruppel '17, this team has performed analysis on its previous strengths and weaknesses to design optimum electrical and mechanical systems. The core leaders of this team, which also includes Vice President Matt Dombroski '17, have been aggressive in reaching out to previous student members and faculty for guidance in order to complete the project within a tight self-prescribed timeline.

Last competition season a crowd funding program was run using the USEED platform, raising funds for financial stability and liquid sources for material and supply purchases. The money from last years' crowd funding secured purchases of componentry for this year's entry.

Significant changes were made to the team's shop in order to maximize workspace, promote cleanliness, and ensure that all available resources were utilized. In addition, we have created a school-certified machining program with instruction from our technical advisor Jim Alkins. Members gained experience by machining surface drive components, mounts, and plates that were used on the boat.

This now seasoned but young team is well set up for future development and continued expansion, given the variety of disciplines of current members and years they have ahead.

Team Organization
The current team's President is Edward Ruppel '17, a biomedical engineering student at the University. The President's' duties involve recruitment, technical oversight of the project, and task designation. Matt Dombroski '17 is the current Vice President and is responsible for maintaining the team relations with the UR Electrical and Mechanical Engineering Departments, Student Association, and other engineering clubs. As the current business manager, Nitish Sardana '17 is responsible for managing all transactions incurred by the club and securing funding from various sponsors. Seth Schaffer '19 and Chris Dalke '19 are the current co-Chief Electrical Engineers and are responsible for leading a group of members in configuring all electrical systems on the boat. Joshua Lomeo '18 is the current Chief Mechanical Engineer and is responsible for the committee on the creation of the tech report and overseeing all engineering projects. Madeline Hermann '17, is the current Secretary and Social Chair; her responsibilities include coordinating schedules and campus outreach. Devin Marino '18, is the current Safety Manager and is responsible for ensuring the entry adheres to all rules and ensuring proper safety precautions are taken during the construction phases of the boats creation.

This year, the construction phase of the new boat was split into three major sections: the mechanical drive systems, power electronic systems, and console-telemetry design. During the previous academic year, the first semester was dedicated primarily to planning the project, while the second semester was dedicated to constructing the boat's design. The university machine shop was employed to produce the drive train components to military specifications. Multiple weekly team meetings and weekly executive board meetings allowed regular communication.

Project Planning

Weekly meetings were scheduled throughout the year to organize efforts. The first meetings of each semester were geared towards attracting and integrating new members towards the goals of the club. This included several side projects, such as the construction of an electric powered riding mower that would be used for transporting the boat across campus. Subsequent meetings focused on assigning tasks and responsibilities to individuals and groups of club members.

This year our goals were focused on the construction of the surface drive system. This included major projects for both mechanical and electrical teams. The same hull built for the 2014-2015 season was used, with some minor modifications. Mechanical improvements made this year include the redesign of the console and steering systems. New solar panel mounts were designed in order to coordinate with the repositioning of the skipper and the drive train.

Funding and Finances

The Hajim School at the University of Rochester funded the majority of the project. We received a budget of $1,000. The Student Association provided a budget of $1,300 with the addition of $1,600 attained through crowd funding efforts. Approximately $2,000 was spent on new componentry to advance the capabilities of the mechanical and electrical systems. Miscellaneous expenses, tools, and other shop equipment cost approximately $700. This includes sanders, Tyvek suits, and respirators. Our expected expenses for the competition will approach about $3,500 dollars, accounting for traveling costs, food and lodging. The allotted funds from the UR Student Association, will be covering a large amount of our traveling expenses.

Sponsorship

In order to generate the largest and most relevant list of potential partners, team members in charge of each project (electrical, steering, motor, hull, etc.) were responsible for creating an initial list of potential partners per system. The engineers relayed this information to the business manager, who researched and contacted each company to see if a mutual agreement could be arranged. If mutual benefits were found, the business manager contacted each company and managed all aspects of transactions; with the assistance of the engineers to confirm purchased products. Sponsorship agreements have been arranged with ServoCity. CADimensions, Klein Steel, SBM Solar, Genesee Brewery, Logitech, The Ideaboxx LLC, and Buffalo Bearings. Sponsors are recognized in all URSS documentation, and a logo of the company is placed on the boat if so desired.

Conclusions and Recommendations

Hull

Rochester Solar Splash successfully created a competitive hull after experimentation with the previous four iterations. With a pickle fork trimaran, we believe that it will be competitive with other submissions. Although the design is solid, the release from the mold proved to be somewhat of a challenge due to the many design features; i.e. the more surface areas for static adhesion, the more static pressure to release the mold from shell without cracking. Additionally, now that we have three years of familiarity with Dassault Systemes' Solidworks, we are comfortable designing advanced composite mono-hulls. With upperclassmen and their knowledge of finite element analysis we will be able to minimize weight and maximize hydrodynamic efficiency next year. In terms of construction, using a CNC foam cutter, "stitch and glue" stringers, and vacuum bagging turned out to be successful and not time consuming. In the future, we will definitely utilize the process we have experimented with these past two years, taking note that future designs must have no vertical surface for mold release adhesion.

Drive Train and Motors

Using the previous configurations as previous years, we have optimized our drive train system to the motor specifications. Using information from Appendix E, we have determined the optimal rpm of 3000 for our motor and have calibrated it to maintain that level throughout the race. Other improvements include the implementation of an innovative surface-Levi drive that allows for extensive modular control over the boats drive capabilities under a multitude of conditions

Electrical Systems

The electronic systems were greatly improved this year. All wires were standardized with 1/0 wire for all power systems, 12 AWG for the solar power system and steering/actuator systems, and 18 AWG for all other lower power and/or logic systems. This updated wiring system keeps power loss, due to resistance, low and also improves the maintainability and safety of the system. Additionally, the solar charger has been upgraded to provide higher efficiency from the panels at a drastically lighter weight, providing more electric power for the motor while keeping the weight of the boat low. We succeeded in reprogramming our motors to allow us to draw maximal power from them in the sprint and the appropriate power to maximize efficiency during the endurance races. Advanced telemetry systems have also been instituted to a high level of success, utilizing microcontrollers coupled with optimized control algorithms.

Acknowledgements

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Dean Robert Clark

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Professor Chris Muir
Robert Scott Russell
James Alkins
Chris Pratt
Jill Morris
Ruth Eberlin
Sarah Ansini
Sara Klinkbeil

Hajim School of Engineering: Department of Electrical Engineering
Professor Mark Bocko
Professor Victor Derefinko
Paul Osborne

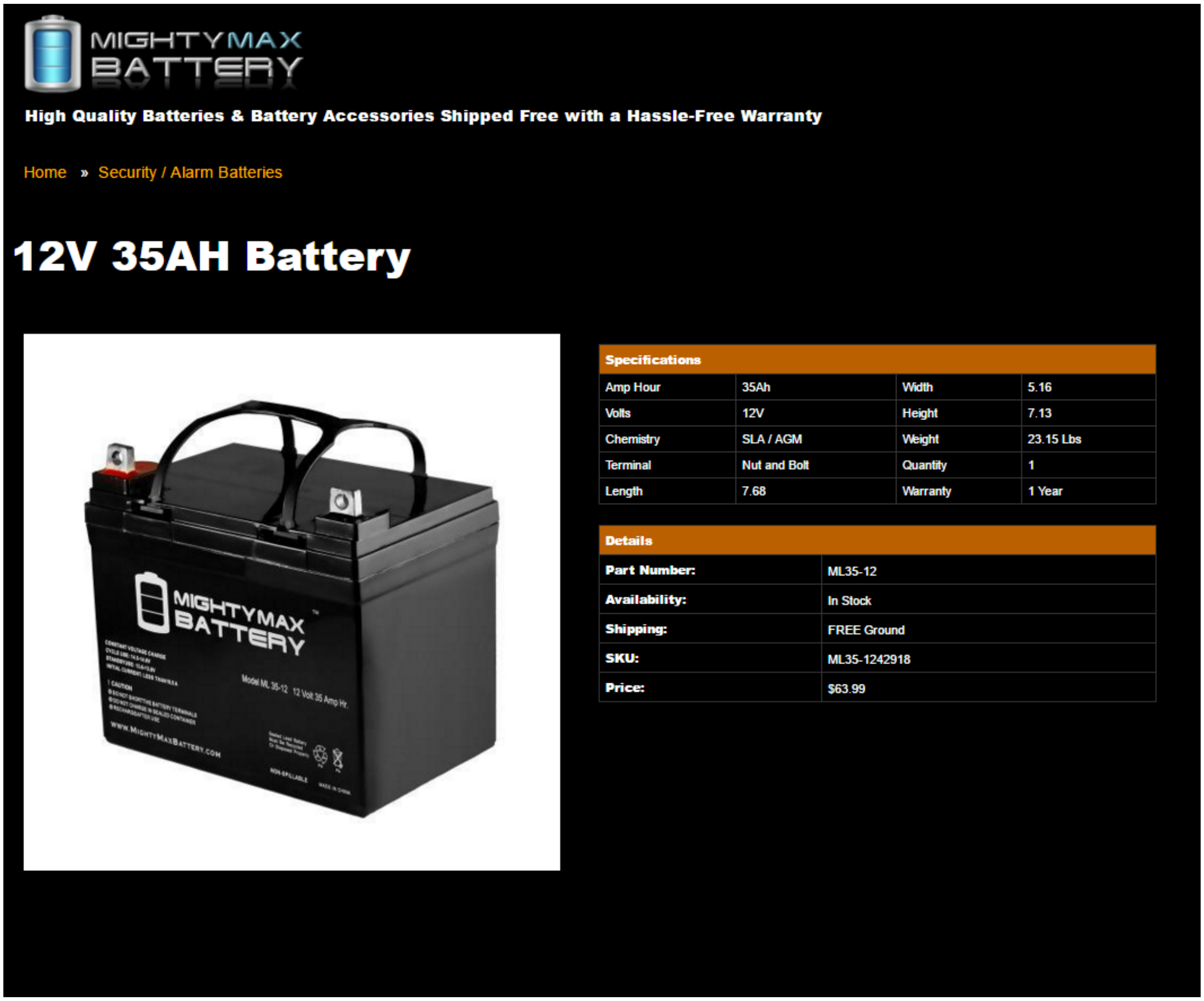
University of Rochester Machine Shop
John Miller

Corporate Sponsors
CAD Dimensions
Klein Steel Service
The Boat Locker
Buffalo Bearing Inc
SBM Solar
The Ideaboxx LLC
Logitech
Thunderstruck Motors
Servocity

University of Rochester Student Association
Stacey Fisher
Appropriations Committee

Appendices

Appendix A: Battery Documentation



MIGHTYMAX BATTERY

High Quality Batteries & Battery Accessories Shipped Free with a Hassle-Free Warranty

Home » Security / Alarm Batteries

12V 35AH Battery

Specifications			
Amp Hour	35Ah	Width	5.16
Volts	12V	Height	7.13
Chemistry	SLA / AGM	Weight	23.15 Lbs
Terminal	Nut and Bolt	Quantity	1
Length	7.68	Warranty	1 Year

Details	
Part Number:	ML35-12
Availability:	In Stock
Shipping:	FREE Ground
SKU:	ML35-1242918
Price:	$63.99

Figure A1: **Endurance Battery Documentation**

Product Details

Description

12V 35AH Battery for Apollo BA12

The ML35-12 by Mighty Max Battery offers the highest level of reliability, strength in performance, and long lasting duration at an incredible price. This gives you the peace of mind about having the power you need for your work or home security system and alarm panel. Your purchases come with the following valuable additions:

Each item is backed by a **1 year hassle-free warranty**

Super easy return options

Carefully delivered to you via **free ground shipping** within a few days

Safe and secure packaging

Processing typically within 24 business hours

All At No Extra Cost

This heavy duty ML35-12 by Mighty Max Battery, with its calcium-alloy grid, is the perfect replacement AGM battery for your wired or wireless home security system, alarm system, and fire alert system. Being pre-charged, factory sealed, and maintenance free makes it immediately ready to power your security systems. And with a deep cycle battery, you get longer usage between charges with the same number of lifetime charge cycles. Feeling safe and secure from threats of danger in your home or work shouldn't be a challange. Mighty Max Battery is here to help.

Many security and alarm panels are designed to alert you if the batteries are low, but it might not be obvious that your batteries might need to be replaced. The best way to confirm is by testing the security systems battery or batteries. Each battery in your system should be tested individually and, in case the system uses multiple batteries, together or serially. Furthermore, the batteries should be tested two ways. The first is while they are disconnected from the alarm or security system. The next is while being connected and in use by the system, which is called load testing. The goal of the tests are to see if the batteries display and maintain the correct voltage levels, which can be found in your security system manual, in both scenarios. This requires the right tools and knowledge of the security system. To ensure proper testing and maintenance, refer to your user manual or contact the system manufacturer for assistance.

Please note that you should keep any cables that come with your home security system and alarm system panels as they may be required when you replace your old batteries with Mighty Max Battery.

SLA AGM Alarm & Security System Battery

Absorbed Glass Mat (AGM) Batteries:

Made with highly absorbent polyester or fiberglass mat separators, these sealed lead acid batteries, with valve regulated design, take advantage of the way that the electrolyte (sulfuric acid) can't stream freely and is equally spread over the charged plate surfaces. AGM works by utilizing recombinant science, where oxygen recombines through the separators which live between the negative and positive plates. Moreover, the plates and separators are held inside of their cells under pressure, bringing about up to 20 times better imperviousness to vibration. Another AGM point of preference is that they discharge substantially slower than a flooded battery when not in use. AGM is more secure in light of the fact that there is no free electrolyte, AGM batteries wipe out the spill risk that exists with lead-acid batteries, bringing about an expanded level of wellbeing for the user.

We strive to make your Mighty Max Battery experience a pleasant one from your visit to our website all the way to your use of your purchase. Therefore, in addition to offering the best prices, all of our products come with a hassle-free 1 year warranty, free ground shipping, and your orders are generally processed within 24 business hours.

Many of our batteries are offered as multi-packs, which are reduced in price the more there are in the pack. Take advantage of these savings and add a multi-pack to your cart before checking out.

12V 35AH Battery

Figure A2: **Endurance Battery Documentation**

PC1100

ODYSSEY Extreme Series Battery Model PC1100
(M6 SS studs)

Powersport vehicles need a powerful battery that's built to take the constant pounding that comes with the territory, whether it's is on land, sea, or snow.

The ODYSSEY battery can handle it. Featuring rugged construction and packed tightly with pure lead plates, the non-spillable AGM design ODYSSEY battery protects against the shock and vibration that can quickly destroy other batteries. And the pure lead plates mean more power—twice the overall power and three times the life of conventional batteries—up to 400 cycles at 80% depth of discharge!

Similar batteries:
PC 370 - PC 950

SPECIFICATIONS	
Pulse (5-second) Hot Cranking Amps (PHCA)	1100
Cold Cranking Amps (CCA)	500
20Hr Nominal Capacity (Ah)	45
Reserve Capacity Minutes	87
Dimensions L x W x H (in)	9.8 x 3.8 x 8.1
Metric Dimensions L x W x H (mm)	250.0 x 97.0 x 206.0
Weight (lbs)	27.5
Weight (kg)	12.5

***Figure A3*: Sprint Battery Documentation**

Recommended Charging Information:

Alternator:	13.3 to 15.0 volts
Battery Charger (Constant Voltage):	13.8 to 15.0 volts; 10 amps maximum; 6-12 hours approximate
Float Charge:	13.2 to 13.8 volts; 1 amp maximum; (indefinite time at lower voltages)
Rapid Recharge: **(Constant voltage charger)**	Maximum voltage 15.6 volts. No current limit as long as battery temperature remains below 125°F (51.7°C). Charge until current drops below 1 amp. **All limits must be strictly adhered to.**

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

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

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

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

Always wear safety glasses when working with batteries.

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

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

Shipping and Transportation Information:

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

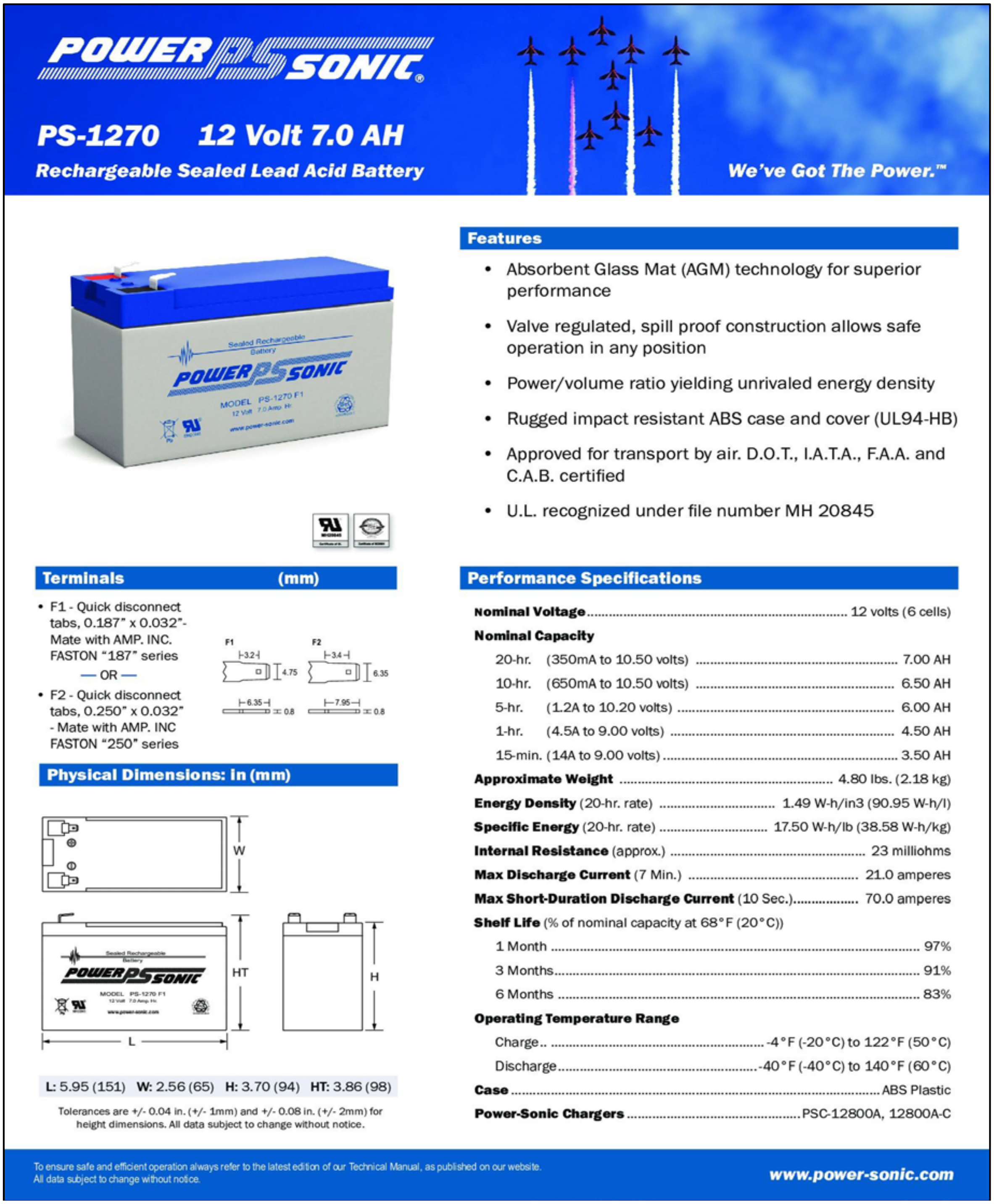
Manufacturing Location:

Enertec Exports S. de R.L. de C.V.
RFC: EEX020516KU2
Avenida. del Parque No. 2155
Monterrey Technology Park
Cienega de Flores, N.L. 65550
MEXICO
Phone: 52 (81) 81542300
Fax: 52 (81) 81542301

BCI = Battery Council International

OPTIMA Batteries
Product Specifications: Model 75/25
December 2008

***Figure A4*: Sprint Battery Documentation**



POWER SONIC

PS-1270 12 Volt 7.0 AH

Rechargeable Sealed Lead Acid Battery

We've Got The Power.™

Features

- Absorbent Glass Mat (AGM) technology for superior performance
- Valve regulated, spill proof construction allows safe operation in any position
- Power/volume ratio yielding unrivaled energy density
- Rugged impact resistant ABS case and cover (UL94-HB)
- Approved for transport by air. D.O.T., I.A.T.A., F.A.A. and C.A.B. certified
- U.L. recognized under file number MH 20845

Terminals (mm)

- F1 - Quick disconnect tabs, 0.187" x 0.032"- Mate with AMP. INC. FASTON "187" series

— OR —

- F2 - Quick disconnect tabs, 0.250" x 0.032" - Mate with AMP. INC FASTON "250" series

Physical Dimensions: in (mm)

L: 5.95 (151) W: 2.56 (65) H: 3.70 (94) HT: 3.86 (98)

Tolerances are +/- 0.04 in. (+/- 1mm) and +/- 0.08 in. (+/- 2mm) for height dimensions. All data subject to change without notice.

Performance Specifications

Nominal Voltage .... 12 volts (6 cells)

Nominal Capacity

- 20-hr. (350mA to 10.50 volts) .... 7.00 AH
- 10-hr. (650mA to 10.50 volts) .... 6.50 AH
- 5-hr. (1.2A to 10.20 volts) .... 6.00 AH
- 1-hr. (4.5A to 9.00 volts) .... 4.50 AH
- 15-min. (14A to 9.00 volts) .... 3.50 AH

Approximate Weight .... 4.80 lbs. (2.18 kg)

Energy Density (20-hr. rate) .... 1.49 W-h/in3 (90.95 W-h/l)

Specific Energy (20-hr. rate) .... 17.50 W-h/lb (38.58 W-h/kg)

Internal Resistance (approx.) .... 23 milliohms

Max Discharge Current (7 Min.) .... 21.0 amperes

Max Short-Duration Discharge Current (10 Sec.)........ 70.0 amperes

Shelf Life (% of nominal capacity at 68°F (20°C))

- 1 Month 97%
- 3 Months........ 91%
- 6 Months 83%

Operating Temperature Range

- Charge.. .... -4°F (-20°C) to 122°F (50°C)
- Discharge........ -40°F (-40°C) to 140°F (60°C)

Case .... ABS Plastic

Power-Sonic Chargers PSC-12800A, 12800A-C

To ensure safe and efficient operation always refer to the latest edition of our Technical Manual, as published on our website.
All data subject to change without notice.

www.power-sonic.com

***Figure A5*: Supplementary Battery Documentation**

Appendix B: Flotation Calculations

Description	Sprint (lbs.)	Endurance (lbs.)
Batteries	99	99
Engine	50	50
Hull	45	45
Motor Controller	15	15
Solar Arrays	0	20
Cables	20	20
Steering	25	25
Passenger	150	150
Miscellaneous (Chair, Safety, etc)	30	30
Shaft and Propeller	25	25
TOTAL (x1.2)	**360 (432)**	**380 (456)**

The displacement due to the wall thickness of our foam and fiberglass composite will account for part of the flotation. The buoyant force,F_B, is calculated as follows, where A_b is the surface area of the hull, t is the thickness of the boat and ρ_{water} is the density of water

$$F_b = A_b t \rho_{water} = 22\ ft^2 \times \frac{0.15\ in}{12\ in/ft} \times 62.2 \frac{lb}{ft^3} = \mathbf{17.105\ lb}$$

The remaining buoyant force must be created in another way. 440 lbs. of buoyant force must still be accounted for in order to avoid sinking when capsized.

$$456 - 17.105 = 438.9\ lb$$

$$V_D = \frac{438.9\ lb}{62.2\ lb/ft^3} = \mathbf{7.056\ ft^3}$$

Therefore approximately 7 cubic feet must be displaced. 4 Optimist sailboat airbags from The Boat Locker, which each hold approximately 2 cubic feet of air, will be distributed strategically along the bottom of the hull (one in the front and one by each gunwale). Buoyancy foam distributed in the front and along the sides of the hull also sums to roughly 4.5 cubic feet in volume. The airbags and buoyancy foam add a total of roughly 12.5 cubic feet of buoyancy, which covers the remaining buoyancy force V_D.

Appendix C: Proof of Insurance

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY) 05/10/2013

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
MARSH USA INC.
70 LINDEN OAKS
STE 310
ROCHESTER, NY 14625
Attn: UniversityofRochester.certrequest@marsh.com
30008 -MAIN-MAST-12-13

CONTACT NAME:
PHONE (A/C, No, Ext): FAX (A/C, No):
E-MAIL ADDRESS:

INSURER(S) AFFORDING COVERAGE		NAIC #
INSURER A :	United Educators Ins Risk Ret. Grp.	10020
INSURER B :	N/A	N/A
INSURER C :	N/A	N/A
INSURER D :	N/A	N/A
INSURER E :		
INSURER F :		

INSURED
UNIVERSITY OF ROCHESTER
ATTN: MARY GOLDENBERG
OFFICE OF COUNSEL
P. O. BOX 278979
ROCHESTER, NY 14627-8979

COVERAGES CERTIFICATE NUMBER: NYC-005691214-11 REVISION NUMBER: 7

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 X COMMERCIAL GENERAL LIABILITY CLAIMS-MADE X OCCUR X Retention: $500,000 occurrence Liquor Liability - Included GEN'L AGGREGATE LIMIT APPLIES PER: X POLICY PRO-JECT LOC			BLX201200037000	07/01/2012	07/01/2013	EACH OCCURRENCE DAMAGE TO RENTED PREMISES (Ea occurrence) MED EXP (Any one person) PERSONAL & ADV INJURY GENERAL AGGREGATE PRODUCTS - COMP/OP AGG	\$ 500,000 \$ INCLUDED \$ EXCLUDED \$ INCLUDED \$ 2,000,000 \$ INCLUDED \$
	AUTOMOBILE LIABILITY ANY AUTO ALL OWNED AUTOS SCHEDULED AUTOS HIRED AUTOS NON-OWNED AUTOS						COMBINED SINGLE LIMIT (Ea accident) BODILY INJURY (Per person) BODILY INJURY (Per accident) PROPERTY DAMAGE (Per accident)	\$ \$ \$ \$ \$
	UMBRELLA LIAB OCCUR EXCESS LIAB CLAIMS-MADE DED RETENTION \$						EACH OCCURRENCE AGGREGATE	\$ \$ \$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y / N ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) If yes, describe under DESCRIPTION OF OPERATIONS below	N / A					WC STATU-TORY LIMITS 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)
EVIDENCE OF COVERAGE FOR SOLAR SPLASH 2013

CERTIFICATE HOLDER
AMERICAN SOCIETY OF MECHANICAL ENGINEERS
UNIVERSITY OF SOUTH CAROLINA
MECHANICAL ENGINEERING DEPARTMENT
COLUMBIA, SC 29208

CANCELLATION
SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.

AUTHORIZED REPRESENTATIVE
of Marsh USA Inc.
Annette M. Smith

Annette M. Smith

ACORD 25 (2010/05) The ACORD name and logo are registered marks of ACORD

***Figure C1*: Proof of Insurance**

IMPORTANT

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This Certificate of Insurance does not constitute a contract between the issuing insurer(s), authorized representative or producer, and the certificate holder, nor does it affirmatively or negatively amend, extend or alter the coverage afforded by the policies listed thereon.

Acord 25 (2009/01)

***Figure C2*: Proof of Insurance**

Appendix D: Team Roster

Edward Ruppel '17 is currently pursuing a Biomedical Engineering degree. He is the current President and is responsible for establishing a timeline, designating tasks to other members, overseeing the project, organizing all aspects of the clubs processes, and communicating with faculty. He is also responsible for all aspects of the mechanical drive systems, the hull design, modernization of the UR Solar Splash shops, and competition logistics.

Matthew Dombroski '17 is currently pursuing a degree in Electrical and Computer Engineering. He is the current Vice President and is responsible for maintaining the equipment and work environment. He is also responsible for all electrical systems of the boat; including the solar system, power electronics system, and telemetry system.

Joshua Lomeo '18 is currently pursuing a degree in Chemistry. He is the Chief Mechanical engineer and is responsible for designing and testing mechanical systems of the boat. He also leads the team in workshops on technical writing.

Madeline Hermann '17 is currently pursuing a degree in Statistics. She is the current Communications Chair and is responsible for organizing campus outreach. She is also responsible for assisting in the construction of the boat, leading fiberglass application, and machining parts.

John Krapf '18 is currently pursuing a Biomedical Engineering degree. He is the Chief Engineer and is responsible for supervising the Chief Electrical and Chief Mechanical Engineers.

Nitish Sardana '17 is currently pursuing a Biomedical Engineering degree. He is the current Business Manager, and is responsible for communicating and establishing relationships with potential sponsors.

Devin Marino '18 is currently pursuing a Mechanical Engineering degree. He is responsible for maintaining safety components of the boat.

Christopher Dalke '19 is currently pursuing a Computer Science degree. He is the current co-Chief Electrical engineer, and is responsible for designing and constructing the dashboard-telemetry system.

Seth Schaffer '19 is currently pursuing a Mechanical Engineering degree. He is the current co-Chief Electrical engineer, and is responsible for designing the electronic systems of the surface-drive and drive-by-wire steering systems.

University Of Rochester Solar Splash

Benjamin Martell ‘19 is currently pursuing a Mechanical Engineering degree.

Enyxa Poventud ‘19 is currently pursuing a degree in Electrical and Computer Engineering.

Elizabeth Stanitz ‘18 is currently pursuing a Mechanical Engineering degree.

Ziping Liu ‘18 is currently pursuing a Biomedical Engineering degree. He is responsible for designing and constructing the hull, and is also responsible for fiberglass application and machining parts.

Yukun Chen ‘18 is currently pursuing an Electrical and Computer Engineering degree. He is responsible for assisting in the construction of the boat, including fiberglass application and machining parts.

Elijah Mitchell ‘19 is currently pursuing a Mechanical Engineering degree.

Appendix E: ThunderStruck AC-9 Motor Torque Performance

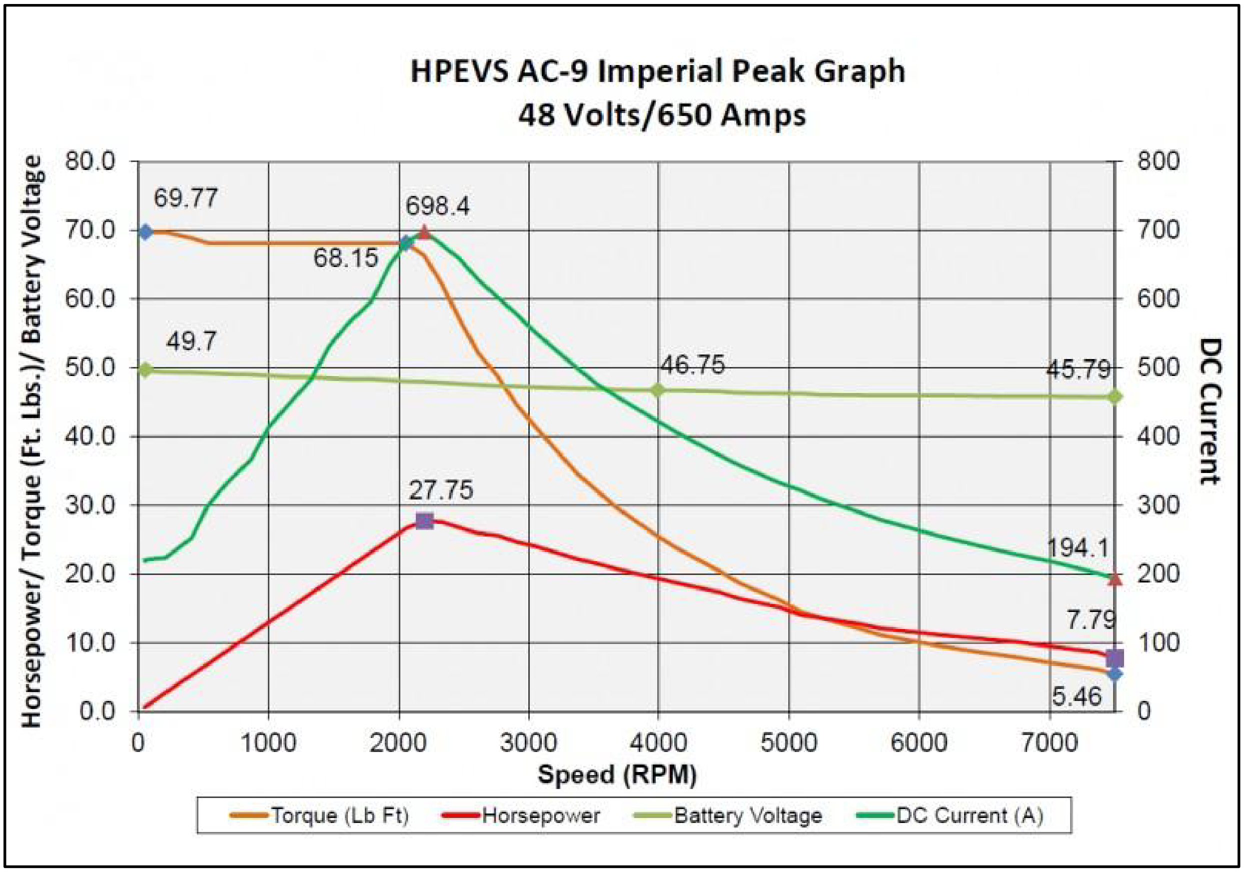


***Figure E1*: ThunderStruck AC-9 Motor Torque Performance**

Appendix F: Sprint Electrical Losses and Power Consumption

The sprint motor configuration has a peak of 35 HP, which is equivalent to 26.1 kW:

$$35\ Hp \times \frac{745\ W}{1\ Hp} = 26{,}099\ W$$

At a peak voltage of 36 V,

$$P = IV = 26{,}099 = (36)(I) \rightarrow \boldsymbol{I = 725\ A}$$

Although the peak output is around 725 A, we will control the output to be on the order of 350-400 A flowing from the batteries depending on the internal impedances. Our batteries can produce 720 cold cranking amps, and therefore approximately 700 cranking amps, ample current for this application.

However at these great currents, come significant power losses in the electrical system. 1/0 Gage Copper wire has an impedance of 0.09827 Ω per 1000 ft. We used 6 feet of this wire that will carry the current of this wire, the voltage drop across the wire is approximately 0.29 V and the power loss is about 6% of our original.

$$R = 6ft \times \frac{.09827\Omega}{1000ft} = 7.86 \times 10^{-4}\Omega$$
$$V = IR = 372.5(7.86 \times 10^{-4}) = .29\ V$$
$$P = I^2R = .29 \times 372.5 = 108\ W$$
$$\%\ Power\ Loss = 100 \times \frac{108\ W}{13410\ W} \approx \mathbf{0.8}\ \%$$

This is effectively the same as the estimated loss last year.

Appendix G: Solar Panel Specifications

SBM Solar

SBM 258W Module

WHY SBM SOLAR?

- Lightweight
- Shatterproof
- Strong & Durable
- High Transparency
- Low Glare
- High Efficiency
- MADE IN USA

UL CERTIFICATION

SBM's 140W non-glass, crystalline PV, rigid modules are UL1703 certified

IEC CERTIFICATION

SBM 140W Module has been certified for Hail Impact Resistance based on the IEC61215 Testing Standards from TUV Rheinland PTL, LLC

For more information please visit us at: www.sbmsolar.com

SBM SOLAR, INC.
8000 Poplar Tent Rd
Suite C
Concord, NC 28027
Phone 704.788.2881
Fax 704.793.1909

Available with black or white back sheet behind cells
*Shown in black

Specifications

Maximum Power (Pmax)	258W
Rated Voltage (Vmp)	31.62V
Rated Current (Imp)	8.16A
Open Circuit Voltage (Voc)	37.38V
Short Circuit Current (Isc)	8.72A
Max Fuse Rating	15 A
Weight lbs (kg)	27 lbs (12.3kg)
Power to Weight Ratio: Watts Per Lb/(kg)	9.5W (21W)
Dimensions (inches)	38.67 x 65.06
Module Area ft^2 (m^2)	17.3 ft^2 (1.61 m^2)
Power Output: Watts per ft^2 (m^2)	14.9W (160.5W)
Diodes per module	4
Mono Crystalline Solar Cells	60 cells
Cell Efficiency	~19%

SBM Solar, Inc., founded 2002, is one of the first manufacturers of a UL certified, non-glass, non-EVA and crystalline PV solar module. The module's multi-layered structure provides excellent environmental and chemical protection, better moisture resistance. The encapsulating package is the combination of a Fluoropolymer film provided by *DuPont* and the adhesive encapsulating material, by *The Dow Chemical Company*, performs superior comparing to commonly used EVA. This non-glass PV module is manufactured in the USA.

LIGHTWEIGHT

SBM's solar modules are 40-50% lighter than glass panels. This makes easier for shipping, handling, and installation, and save cost.

SHATTERPROOF/DURABLE

When the glass module is shattered, its entire module will be subsequently loss of power. SBM's non glass modules are completely shatterproof. It is able to withstand the hazardous environmental conditions (hail, rain, wind, heat, cold, and humidity). They are **IEC 61215** certified for hail impact resistance.

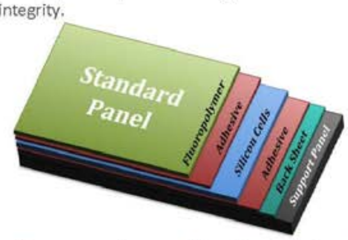
HIGH TRANSPARENCY / LOW GLARE

Blinding glare associated with glass panels can be dangerous and unsafe in certain applications. SBM's solar module utilizes its advanced material property to reduce the reflection. This makes SBM solar modules perfect for applications where glare becomes a critical safety issue such as in military, airport, and highways.

HIGH EFFICIENCY C-Si SOLAR CELLS

SBM Solar modules have over twice the wattage per square foot compared to thin film. They have over 19% cell efficiency and 14.7 watts per square foot compared to thin film's 6-8% module efficiency and 5 watts per square foot.

Besides our standard panels, SBM also develops customized and / or building integrated solar applications. This provides architects and engineers optimal architectural flexibility which preserves design and aesthetic integrity.



All components are made and manufactured in USA

GO GREEN & DEMAND THE BEST!

Figure G1: **SBM 258W, Solar Panel Specifications**

Appendix H: Solar Controller Specifications

	GVB-8-Pb-36V-WP	GVB-8-Pb-48V-WP	GVB-8-Li-56.8V-WP
Rated Panel (Input) Current:	8A*		
Minimum Panel Voltage for Charging:	5V		
Minimum Battery Voltage for Operation:	9.5V		
Maximum recommended Panel Open-Circuit Voltage (Voc) at STC	51V		
Absolute Maximum Panel Open-Circuit Voltage (Voc):	63V		
Nominal Battery Voltage:	36V	48V	48V (16-cell LiFePO4)
Maximum Recommended Panel Maximum Power Voltage (Vmp) at STC:	41V	43V	
Maximum Recommended Panel Power (8A Panel w/~155mm cells): For higher power controllers, please visit the **Blue Sky Energy Product Page**.	325W	350W	
Bulk Voltage:	43.2V	57.6V	—
Absorption Voltage:	42.6V	56.8V	—
Absorption Time:	2 Hours		—
Float Voltage (Pb models) or CV Voltage (Li model):	41.4V	55.2V	56.8V
Battery Temperature Compensation:	-84mV/°C	-112mV/°C	—
Electrical Efficiency:	96% - 98% typical	96% - 99% typical	
Night Consumption:	6mA	5mA	
Tracking Efficiency:	99+% typical		
MPPT Tracking Speed:	15Hz		
Environmental:	Waterproof		
Connection:	Flying Leads, 16 AWG tinned wire, pre-stripped		
Weight:	10.3oz (290g)		
Dimensions:	5.5x3.2x2.2", (14x8.1x5.5cm)		
Warranty:	5 years		

Figure H: **GVB-8-Pb-36V-WP Solar Controller Specifications**

Appendix I: Circuit Schematic

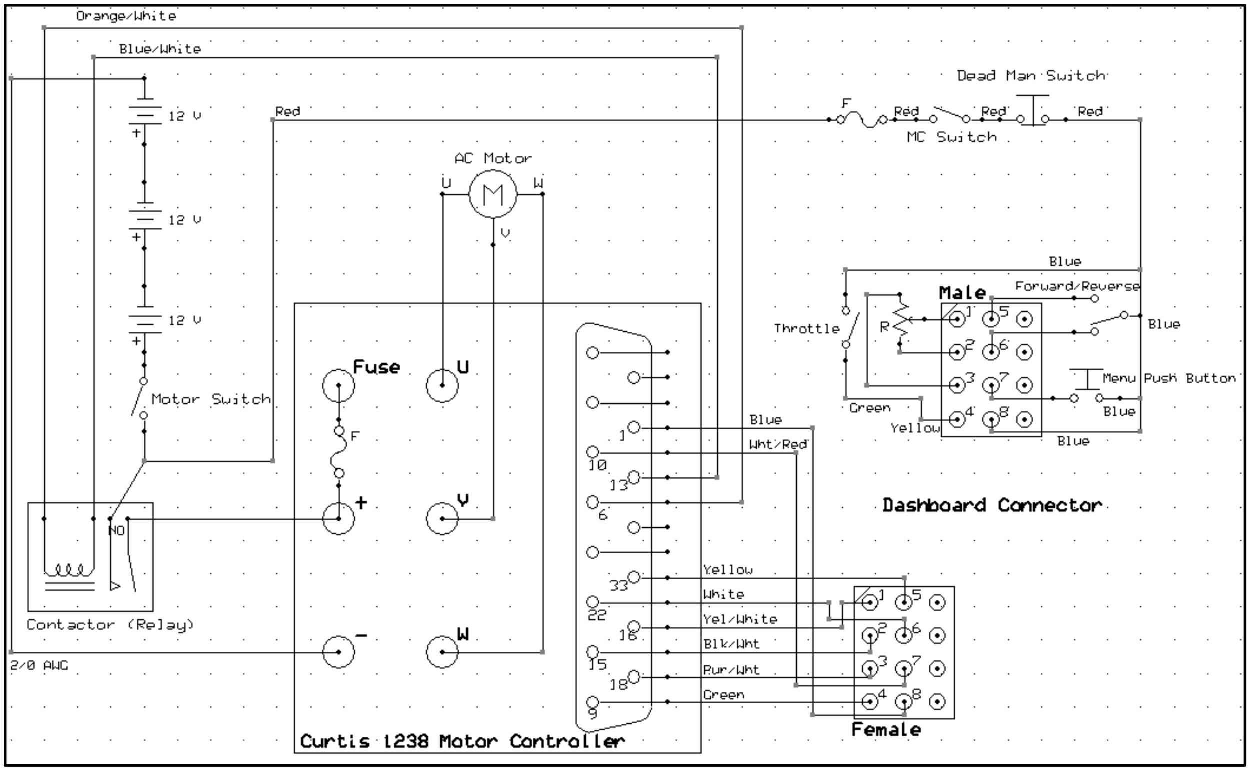


***Figure I1*: Circuit Schematic of Curtis Motor Controller**

Appendix J: Hull Design Drawings

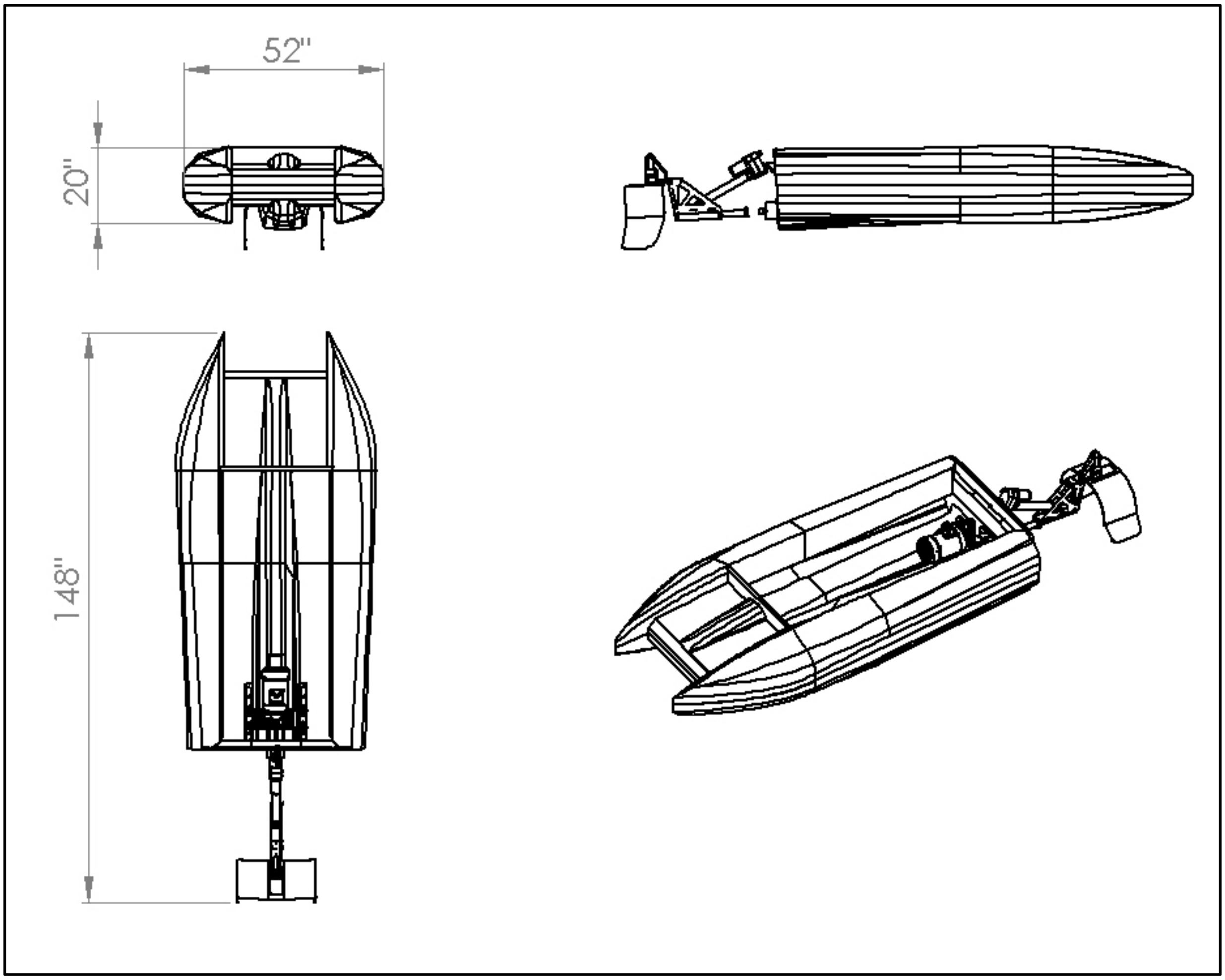


***Figure J1*: Hull Concept Design**

Appendix K: Bearings Used in Drive System

High-Speed/High-Load Steel Ball Bearing with Shaft Collar
for 3/4" Shaft Diameter, 1-3/4" OD with Retaining Ring

Each
ADD TO ORDER

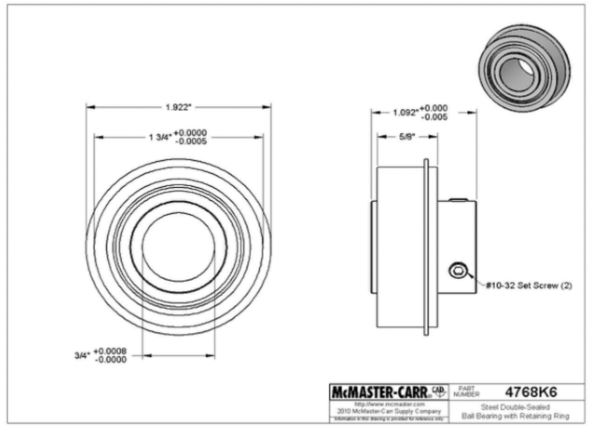
In stock
$34.80 Each
4768K6

You ordered 1 each on 04/16/15.

Bearing Type	Ball
Ball Bearing Style	Double Sealed
Bearing Material	Steel
Seal Material	Synthetic Rubber
Temperature Range	-20° to 250° F
Bearing No.	7612
For Shaft Diameter	3/4"
For Shaft Diameter Tolerance	-0" to +0.0008"
OD	1 3/4"
OD Tolerance	-0.0005" to +0"
Bearing Width	5/8"
Overall Width	1.092"
Overall Width Tolerance	-0.005" to +0"
Dynamic Load Capacity	2,595 lbs.
Maximum rpm	6,000
Feature	Retaining Ring

Great for high speeds and high loads, these bearings have an extended inner ring that acts as a built-in shaft collar to save you time and space when mounting. All are double sealed with synthetic rubber seals that block out dirt, preserve lubricants, and reduce noise. They also have a retaining-ring groove. Temperature range is –20° to 250° F. Two set screws for secure mounting are included.

Available with and without a retaining ring, which holds the bearing in the housing.



The information in this 3-D model is provided for reference only. Details

***Figure K1*: Motor Mount Head Bearing**

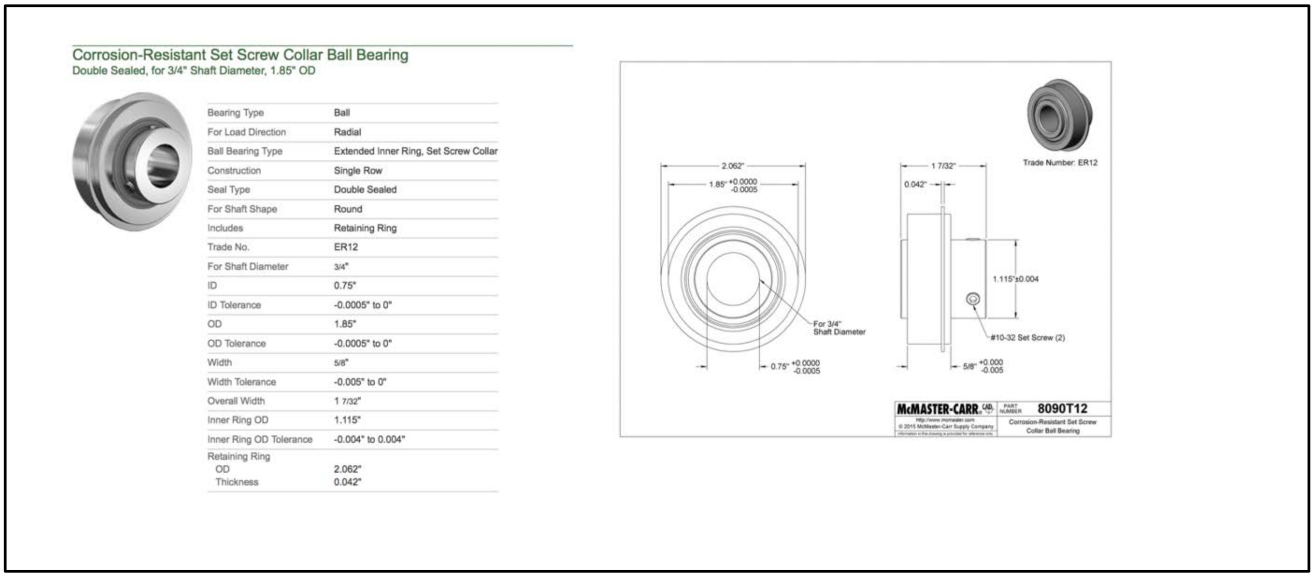


***Figure K2*: Thrust Plate Head Bearing**

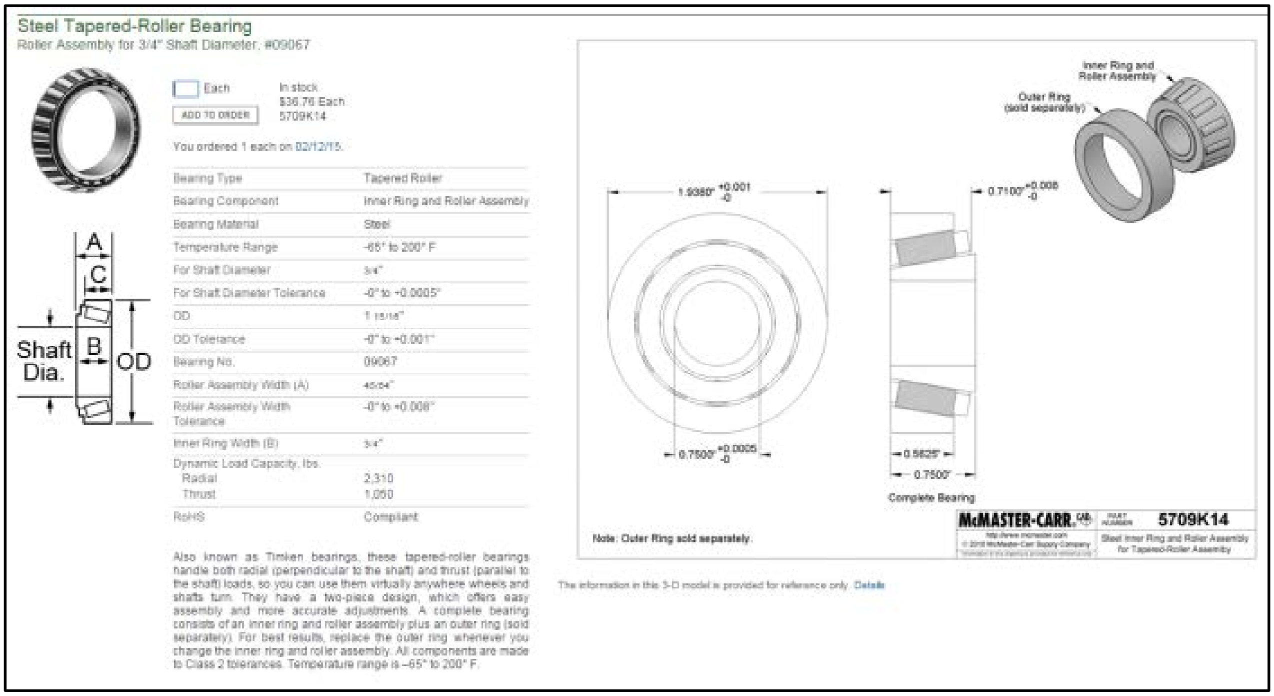


***Figure K3*: Central Drive Shaft Bearing**

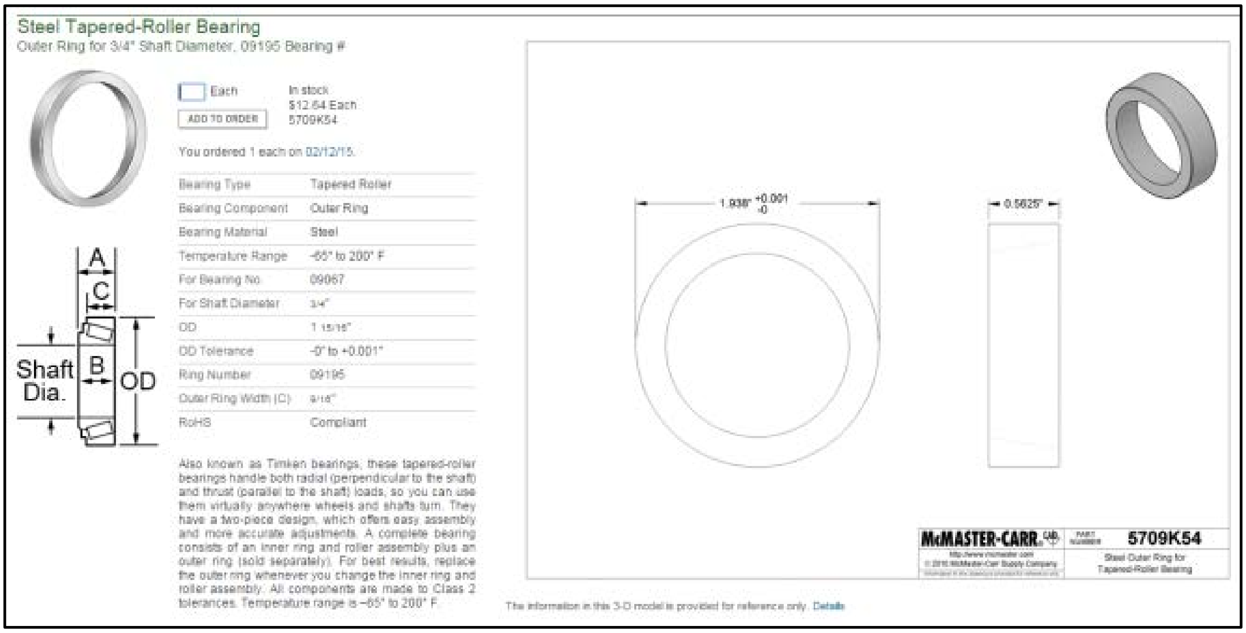
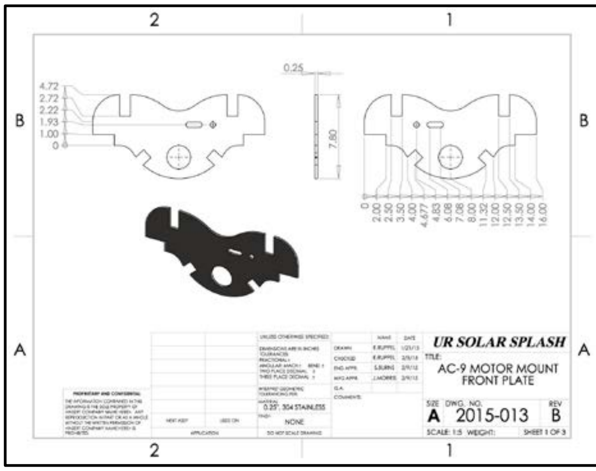
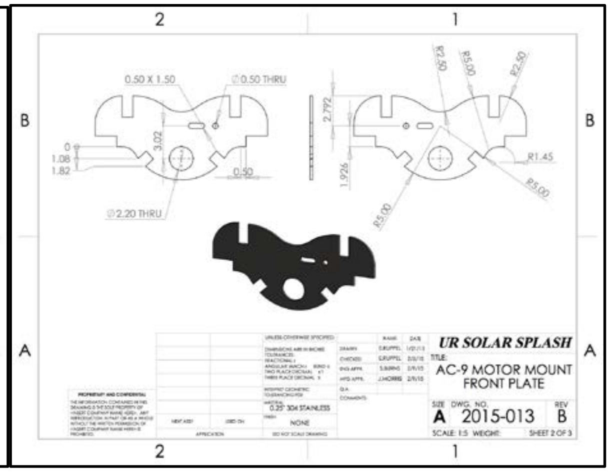


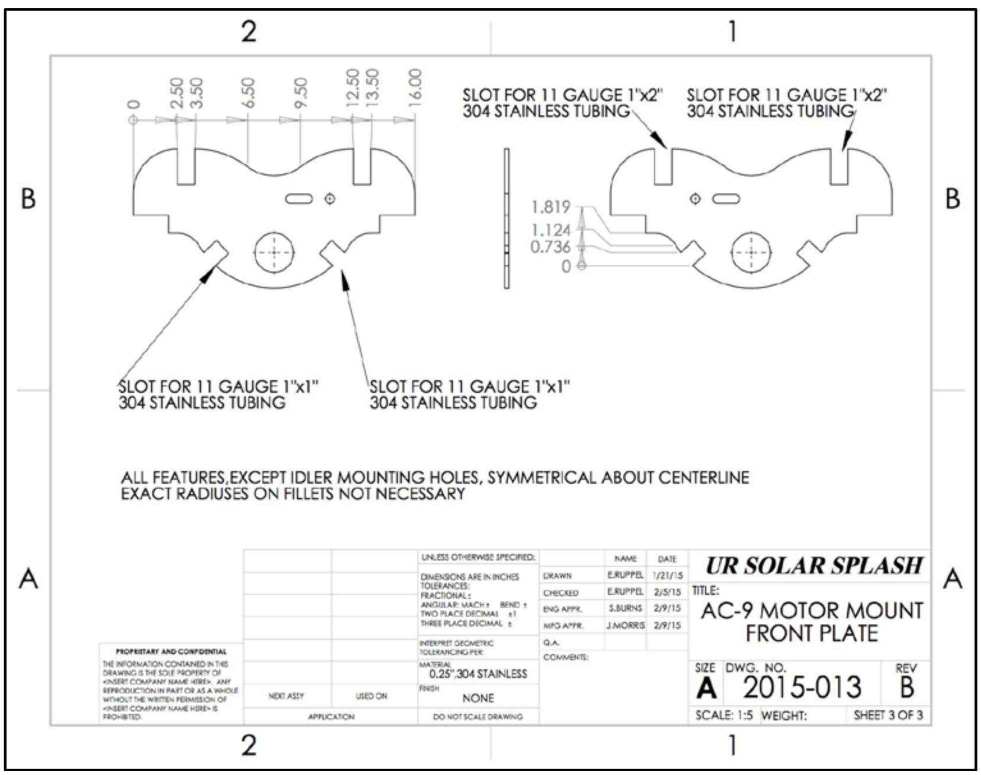
***Figure K4*: Raceway for Central Drive Shaft Bearing**

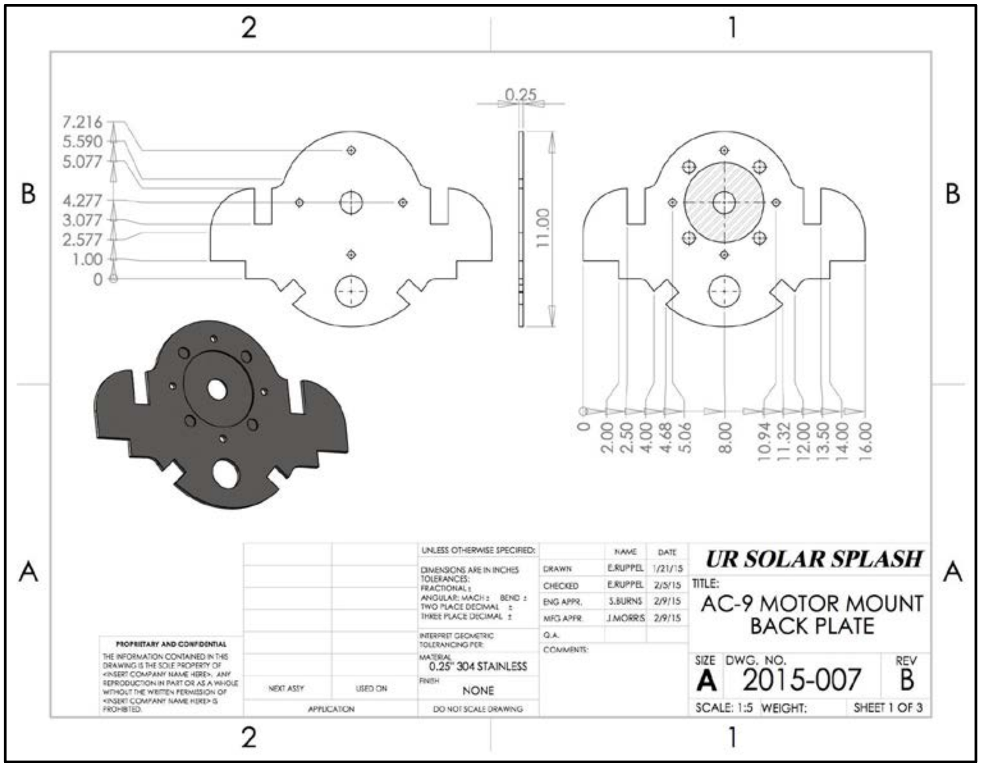
Appendix L: Motor Mount Plates, Assembly, and Placement

The motor mount design was specifically configured for compatibility in the hull. The curves of the back plate conform neatly to the cavity formed by the central planing hull. Round cuts decreased the amount of required material without sacrificing rigidity and strength in stress and strain. All cuts and welds for the motor mount plates were contracted to John Miller.

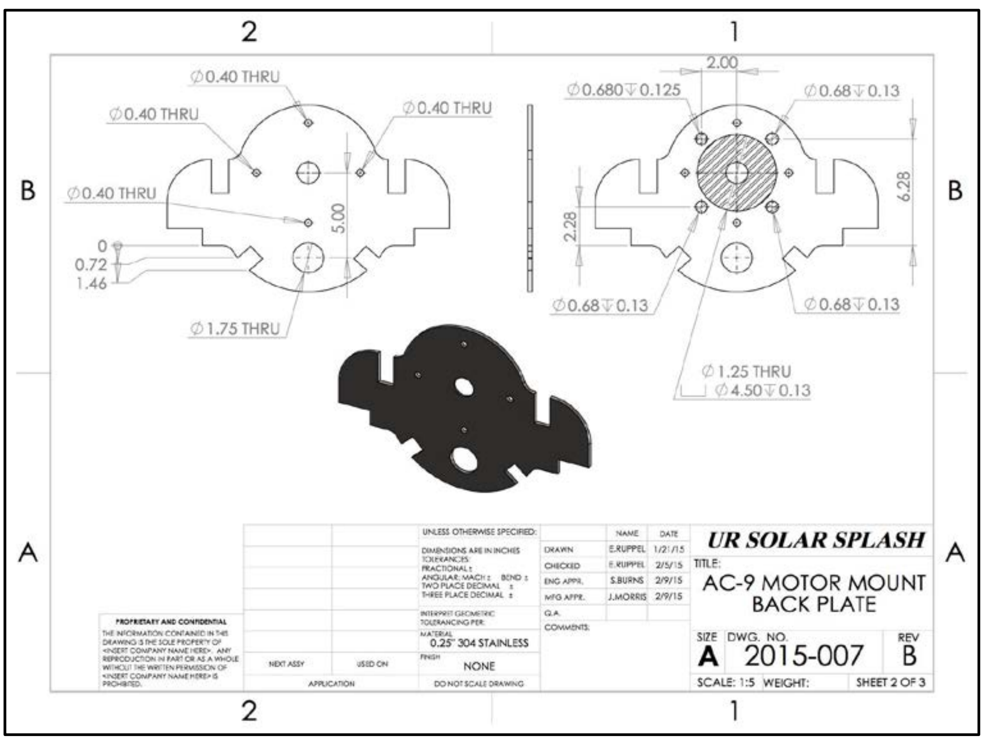




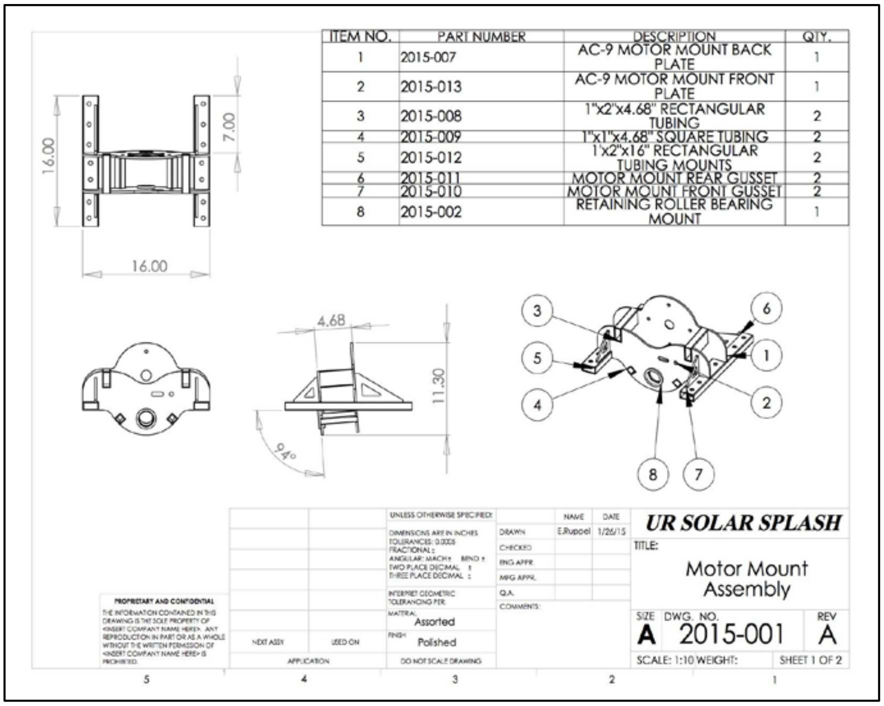




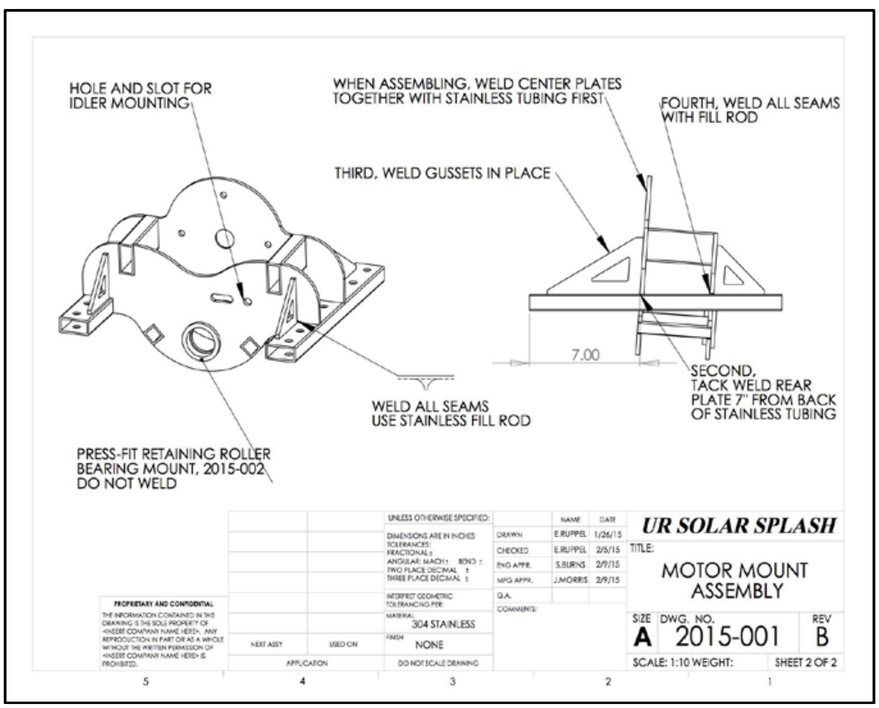
0.25
11.00
7.216
5.590
5.077
4.277
3.077
2.577
1.00
0
0 2.00 2.50 4.00 4.68 5.06 8.00 10.94 11.32 12.00 13.50 14.00 16.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 0.25" 304 STAINLESS
FINISH NONE
DO NOT SCALE DRAWING
DRAWN E.RUPPEL 1/21/15
CHECKED E.RUPPEL 2/5/15
ENG APPR. S.BURNS 2/9/15
MFG APPR. J.MORRIS 2/9/15
UR SOLAR SPLASH
TITLE: AC-9 MOTOR MOUNT BACK PLATE
SIZE A
DWG. NO. 2015-007
REV B
SCALE: 1:5 WEIGHT: SHEET 1 OF 3



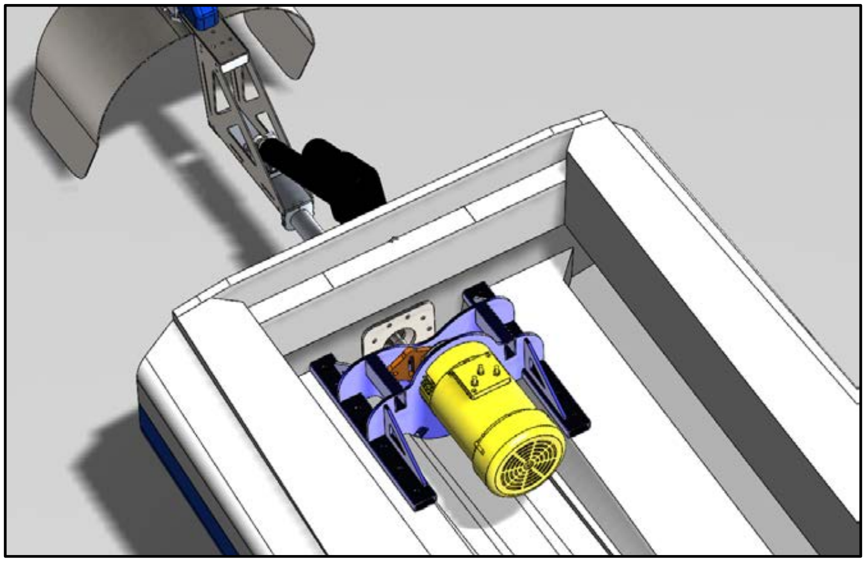
Ø0.40 THRU
Ø0.40 THRU
Ø0.40 THRU
Ø0.40 THRU
5.00
0
0.72
1.46
Ø1.75 THRU
2.00
Ø0.680↧0.125
Ø0.68↧0.13
6.28
2.28
Ø0.68↧0.13
Ø0.68↧0.13
Ø1.25 THRU
Ø4.50↧0.13
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL 0.25" 304 STAINLESS
FINISH NONE
DO NOT SCALE DRAWING
DRAWN E.RUPPEL 1/21/15
CHECKED E.RUPPEL 2/5/15
ENG APPR. S.BURNS 2/9/15
MFG APPR. J.MORRIS 2/9/15
UR SOLAR SPLASH
TITLE: AC-9 MOTOR MOUNT BACK PLATE
SIZE A
DWG. NO. 2015-007
REV B
SCALE: 1:5 WEIGHT: SHEET 2 OF 3

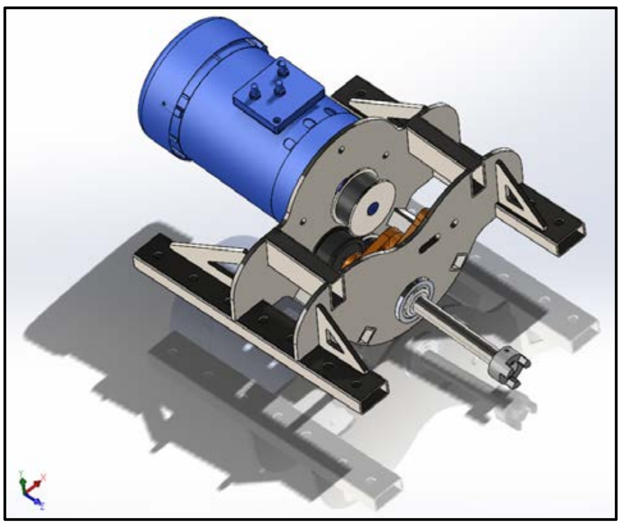


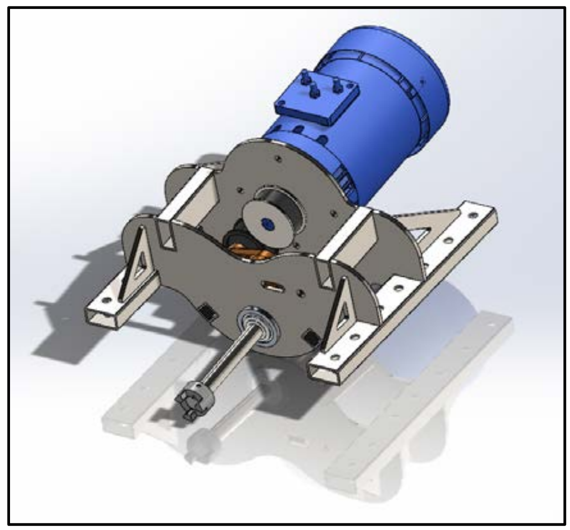
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | 2015-007 | AC-9 MOTOR MOUNT BACK PLATE | 1
2 | 2015-013 | AC-9 MOTOR MOUNT FRONT PLATE | 1
3 | 2015-008 | 1"x2"x4.68" RECTANGULAR TUBING | 2
4 | 2015-009 | 1"x1"x4.68" SQUARE TUBING | 2
5 | 2015-012 | 1"x2"x16" RECTANGULAR TUBING MOUNTS | 2
6 | 2015-011 | MOTOR MOUNT REAR GUSSET | 2
7 | 2015-010 | MOTOR MOUNT FRONT GUSSET | 2
8 | 2015-002 | RETAINING ROLLER BEARING MOUNT | 1
16.00
7.00
16.00
4.68
11.30
94°
UR SOLAR SPLASH
TITLE:
Motor Mount Assembly
DRAWN E.Ruppel 1/26/15
MATERIAL Assorted
FINISH Polished
SIZE A DWG. NO. 2015-001 REV A
SCALE: 1:10 WEIGHT: SHEET 1 OF 2



HOLE AND SLOT FOR IDLER MOUNTING
WHEN ASSEMBLING, WELD CENTER PLATES TOGETHER WITH STAINLESS TUBING FIRST
FOURTH, WELD ALL SEAMS WITH FILL ROD
THIRD, WELD GUSSETS IN PLACE
7.00
SECOND, TACK WELD REAR PLATE 7" FROM BACK OF STAINLESS TUBING
WELD ALL SEAMS USE STAINLESS FILL ROD
PRESS-FIT RETAINING ROLLER BEARING MOUNT, 2015-002 DO NOT WELD
UR SOLAR SPLASH
TITLE:
MOTOR MOUNT ASSEMBLY
DRAWN E.RUPPEL 1/26/15
CHECKED E.RUPPEL 2/5/15
ENG APPR. S.BURNS 2/9/15
MFG APPR. J.MORRIS 2/9/15
MATERIAL 304 STAINLESS
FINISH NONE
SIZE A DWG. NO. 2015-001 REV B
SCALE: 1:10 WEIGHT: SHEET 2 OF 2







Appendix M: Drive Train Concept Analysis

Concept 1 (Worm Gear) Calculations:

$$\text{Efficiency-worm} = \frac{\cos \alpha_n - \mu \tan \gamma}{\cos \alpha_n + \mu \cot\gamma}$$

α_n = Normal pressure angle = 20^o as standard
γ = Worm lead angle = $(180/\pi)\tan^{-1}(z_1/q)$(deg)
z_1 = Number of threads (starts) on worm
μ = coefficient of friction (for lubricated steel on steel)
q = diameter factor

Worm shaft made large enough to survive its own stresses		
Torque	1800	ft-lb
Shaft diameter	1.6875	in
Shaft diameter	0.140625	ft
2nd AM = pi*d^4 / 64	1.91964E-05	ft^4
Radius c	0.0703125	ft
Shear stress Tc/J	6593029.278	psf
Shear stress Tc/J	45784.92554	psi

17-4 stainless	140000	psi
Safety factor	3.057774985	(unitless)

Safety Factor Calculations for Worm Gear Teeth, with load fatigue		
Sult	140000	psi
Se	70000	psi
Kl (for 18E6 cycles)	0.9	
Kt	1	
Kr	1	
Sf	63000	psi
J(Table 12-11)	0.36	
F	0.125	in
Pd	12	
Kb	1	
Ki	1.42	
Ks	1	
Kv	0.9	
Ka	1	
Km	1.6	
Wt	11675.67568	lb
Sig	7859891.892	psi
SF	0.008015377	

Concept 2 (Spur Gear) Calculations:

Spur System After Gearing		
Incoming torque	90	ft-lb
Gear ratio	1.4	lb-lb
Outgoing torque	126	ft-lb
Shaft diameter	0.875	in
Shaft diameter	0.072916667	ft
2nd AM = pi*d^4 / 64	1.38764E-06	ft^4
Radius c	0.036458333	ft
Shear stress Tc/J	3310474.37	psf
Shear stress Tc/J	22989.40534	psi
8620 steel	87000	psi
Safety factor	3.784351909	(unitless)

Appendix N: Drivetrain Stress Analysis

Drive Shaft:

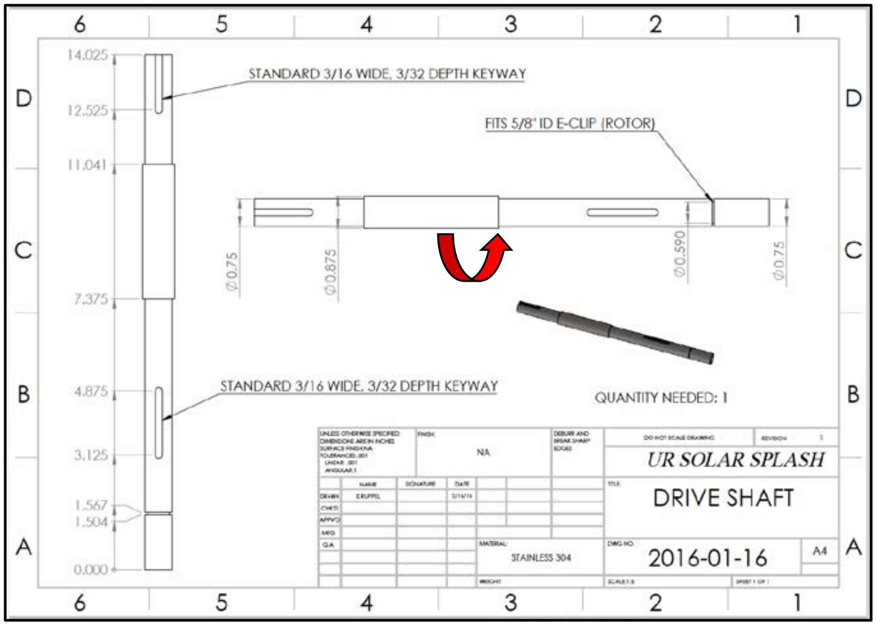


***Figure N1*: Drive Shaft Free Body Diagram**

The drive shaft was analyzed at the point where it most likely to fail, the interface between the 7/8’’ and the ¾’’ diameter which is located at the thrust roller bearing. This area creates a stress concentration which increases the chance of failure. The axial loads, 698 lbs., are well within the critical load for buckling (on the order of 15 x 10^3 psi) so the factor of safety wasn’t considered for this scenario. Using a bending moment of 19 ft.lb (mostly from the shafts own weight) and an applied torque of 90 ft.lb, we were able to calculate the factor of safety for the shaft. Other parameters considered were the stress concentration at the bearing interface, which we found to be 1.7, and the material properties of 304 stainless steel. The factor of safety for the beam using these parameters was calculated to be 4.5.

Front Thrust Plate:

The thrust load from the propeller is supported by a thrust bearing. We ensure that the loads are transferred to the bearing by tapering the propeller shaft from 1'' diameter to ¾'' at the bearing interface. The bearing itself is discussed elsewhere, but assuming a rigid, keyed, fit, the thrust forces will be transferred from the thrust bearing to the thrust plate. We initially had two options for the plate, one at 0.125'' thickness and another at 0.25'' thickness. Both designs were 4''x 7.5'' we analyzed the stresses and displacements in each option to determine if the plate would deform beyond the tolerance of our system (near 0.02 inches to ensure the roller bearing's safety).

The 0.125'' design was analyzed in Abaqus, with non-displacement conditions at the interfaces between the 1 $inch^2$ stainless support bars and the corners of the plate. The load was estimated as a 698 lb. thrust load. The load was conservatively estimated by assuming that the 100% of the motor's peak power output (~33,000 ft. lbs.) is transferred to the propeller, the thrust force is the peak power divided by the forward velocity. The maximum speed of the boat is near 28 knots/hour, thus we calculate the maximum thrust load to be 698 lbs. We divided the load in equal sections across an area 0.05 square inches around each bolt hole.

We saw that the deformation on the plate in the z-direction (thrust direction) was too small (3.23×10^{-4} inches) to disrupt the function of the roller bearing. The peak stresses within the plate were satisfactory, as 23,100 psi gave us a safety factor of 2.87. We then analyzed a 0.25'' plate in Abaqus to examine its deformations. We used similar boundary conditions as before, but since the thrust bearing is being connected with a mounting plate this time, we used a distributed force around the edge of the inner circle to model the thrust force.

The model showed that the plate held up to the forces much more robustly. Its maximum deformation was only 0.000183 inches, within our tolerance and the max stress was 2910 psi. For 304 stainless this gives the design a safety factor of 21.3. The entire drivetrain is encased within the boat so elemental factors were not taken into account. The thicker plate's improved performance and safety factor enticed our group to use the thicker plate design.

Appendix O: Motor Belt and Pulley

The motor drive system utilized the following components to transfer power.

Synchronous Belt Specifications (1 used)	
Outside Diameter	19.5”
Pitch	L (0.375”)
Material	Neoprene, Fiber reinforced
Top Width	1”
Specification	High-Torque Drive
Vendor	V-Belt Supply for, D&D Powerdrive (195L100)

Timing Belt Pulley Specifications (2 used)	
Outside Diameter	2.238”
Outside Diameter (Flange)	2.5”
Pitch	L (0.375”)
Teeth #	19
Material	Steel
Top Width	1.25”
Specification	Type 6F, Hub and Flanges, Bored Taper-Lock Bushing
Vendor	B&B Manufacturing (19L100)

Appendix P: Drive Shaft Specifications

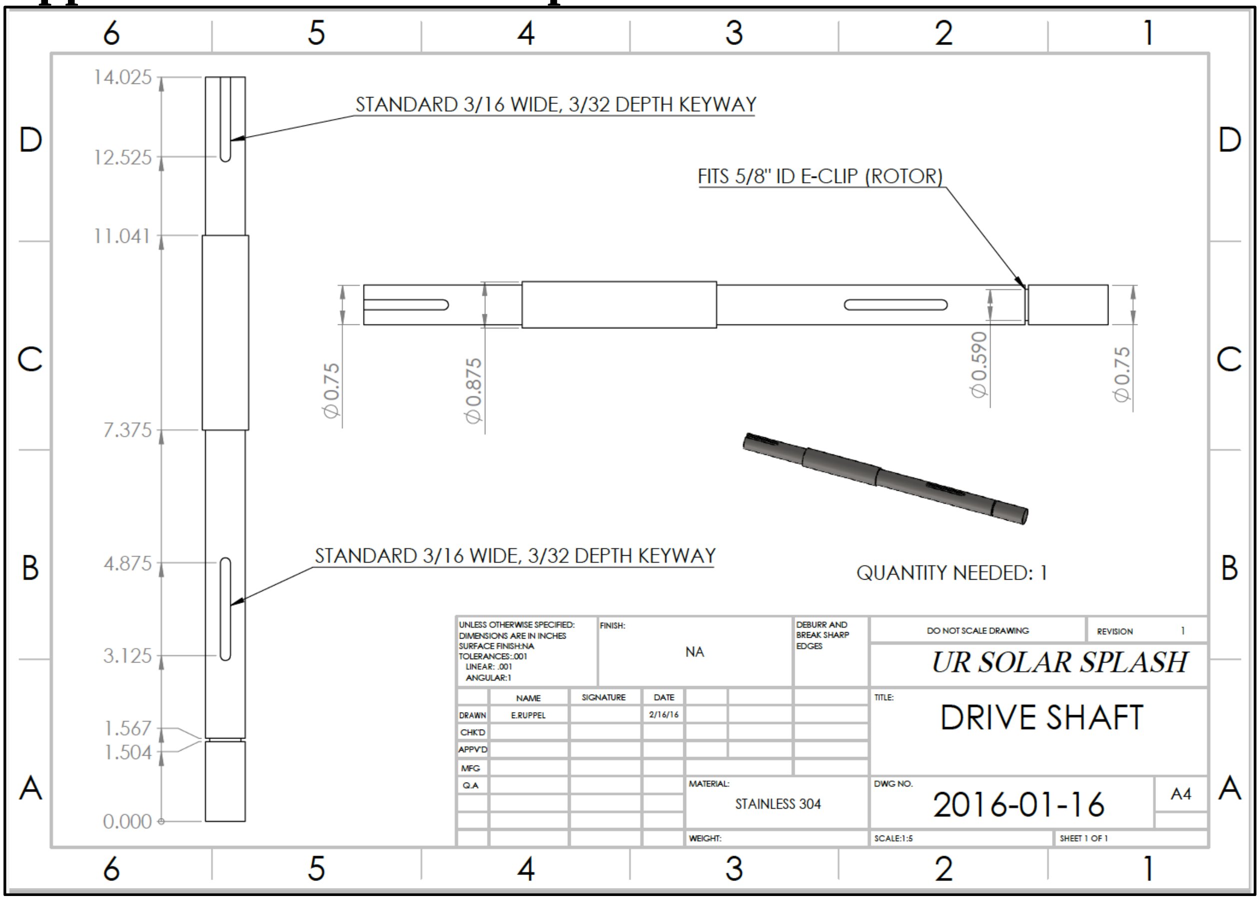


***Figure P1*: Specifications & Dimensions of Drive shafts**

Appendix Q: Steering Mechanism

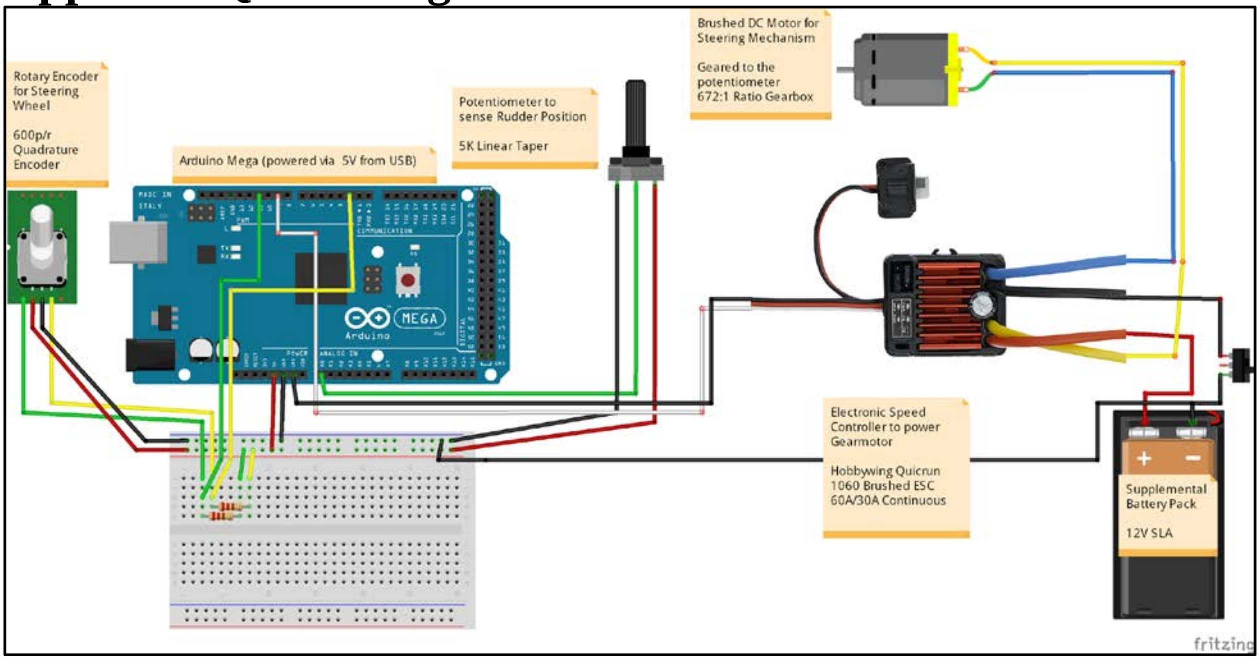


***Figure Q1*: Schematic of Steering Mechanism**

Appendix R: Corecell Technical Data

Figure R1: **Material Specifications of Corecell Foam**

Gurit

Corecell™ A-Foam

Structural Core Material

- Exceptional impact tolerance
- Suitable for dynamically-loaded structures
- Superior styrene and temperature resistance to linear PVC foam
- Highly thermoformable
- Ideal for resin infusion

Introduction

Corecell A-Foam shares the benefits of SAN chemistry common to all **Core**cell products.
Built in toughness – Very high ductility and damage tolerance
Environmental stability – High tolerance for heat and chemical exposure
Fine cell size – Resin absorbtion is very low, saving both weight and cost
Superior uniformity – Low density variation
Compatibility – Suitable for use with all polyester, vinylester and epoxy resins
Handling – Tough and easy to machine
No inhibition - **Core**cell does not inhibit epoxy curing mechanisms

Corecell A-Foam is the original **Core**cell material, developed because of frustrations with inadequate PVC core technology in marine sandwich structures. **Core**cell A-Foam is well known for it's incredible toughness and resistance to cracking, which comes from its high ductility. **Core**cell A-Foam can elongate up to 65% in shear before failure, making core shear failure in a laminate almost impossible. Tests and experience show that **Core**cell A-Foam is the most reliable core material for dynamic loading situations where PVC and balsa may fail due to poor shear elongation properties. This reliability has made **Core**cell A-Foam the preferred choice amongst offshore yachtsmen for twenty years.

For the manufacturer, **Core**cell A-Foam offers the benefit of high resistance to styrene and other chemicals and better thermal stability than linear-PVC foam. **Core**cell A-Foam is also highly thermoformable, which is useful in many applications where cutting the core material is undesirable.

Corecell A-Foam is available in every resin infusion format and is compatible with polyester, vinylester and epoxy resin systems. The low resin absorption characteristics of **Core**cell and it's unique knife-cut formats deliver higher performing infusions, low resin cost and low weight. Gurit's global technical team have 10 years experience in resin infusion and offer on-site support for **Core**cell customers. This combination makes **Core**cell a key part of a reliable package.

Approvals
- Accepted for DNV Slamming and Fatigue Applications
- Approved by the US Coast Guard for use as buoyancy foam
- Approved by the US Coast Guard for use as sandwich core material in the structures of integral diesel fuel tanks
- Type approved by: The American Bureau of Shipping, Germanischer Lloyd, Det Norske Veritas

Gurit

Type	Test Method	Units	A400	A450	A500	A550	A600	A800	A1200
Nominal Density		kg/m³	69	81	92	103	116.5	150	210
		lb/ft³	4.3	5.0	5.7	6.4	7.3	9.3	13.1
Density Range		kg/m³	64-74	75-86	87-97	98-108	109-124	140-160	200-220
		lb/ft³	4.0-4.6	4.7-5.4	5.4-6.0	6.1-6.7	6.8-7.7	8.7-10.0	12.5-13.7
Compression Strength	ASTM D1621	MPa	0.6	0.8	0.9	1.1	1.4	2.1	3.9
		psi	90	112	135	161	197	308	564
Compressive Modulus	ASTM D1621b	MPa	41	53	64	72	83	117	217
		psi	5950	7620	9290	10450	12040	16980	31490
Shear Strength	ISO 1922	MPa	0.7	0.8	1.0	1.1	1.2	1.6	2.6
		psi	102	123	144	157	176	229	373
Shear Modulus	ISO 1922	MPa	22	24	26	30	34	47	76
		psi	3190	3480	3770	4350	4930	6820	11030
Shear Elongation	ISO 1922	%	63%	63%	69%	66%	64%	50%	46%
Tensile Strength	ASTM C-297	MPa	0.9	1.1	1.3	1.6	1.8	2.5	3.9
		psi	135	165	194	225	264	364	560
Tensile Modulus	ASTM C-297	MPa	50	65	81	97	120	183	321
		psi	7260	9430	11750	14080	17410	26560	46580
Thermal Conductivity	ASTM C518	W/mK	0.03	0.03	0.04	0.04	0.04	0.04	0.05
Dimensional Stability	DIN 53424	°C	63	63	63	63	63	63	63
		°F	145	145	145	145	145	145	145

* Peak change rate under static load

Intermediate densities may be available on request, subject to minimum order quantities.

Please Note

:Data quoted is average data at each product s nominal density, and is derived from our regular testing of production materials.

Statistically derived minimum value data, satisfying the design requirements of various classification societies, is available on request.

Notice

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Gurit are continuously reviewing and updating literature. Please ensure that you have the current version, by contacting Gurit Marketing Communications or your sales contact and quoting the revision number in the bottom right-hand corner of this page.

E gurit@gurit.com
W www.gurit.com

Figure R2: **Material Specifications of Corecell Foam**

Appendix S: Stress Analysis of Rudder Shroud with 12 Gauge Stainless Steel; *Analysis performed on structure at 2x max possible thrust over total side wall surface area, as set by motor peak specifications*

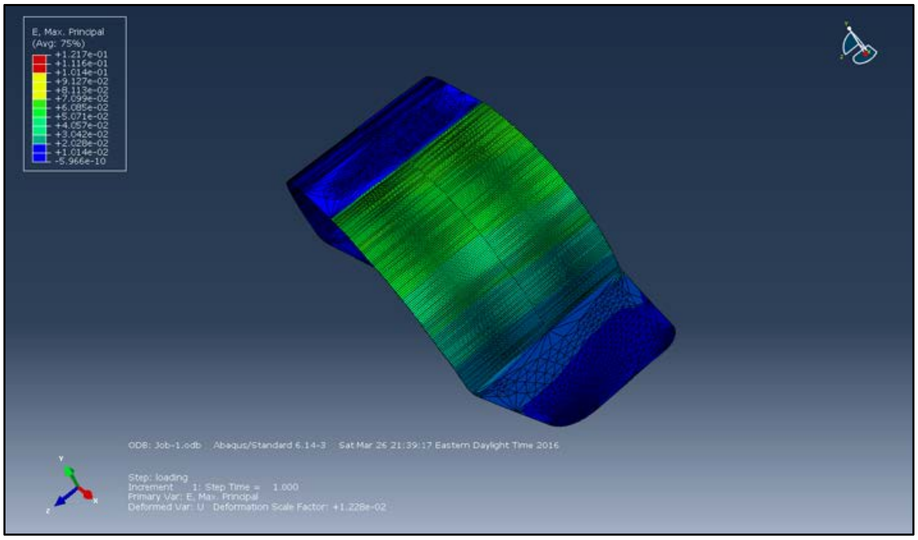

***Figure S1*: Abaqus Principal Strain Test of Rudder Shroud**

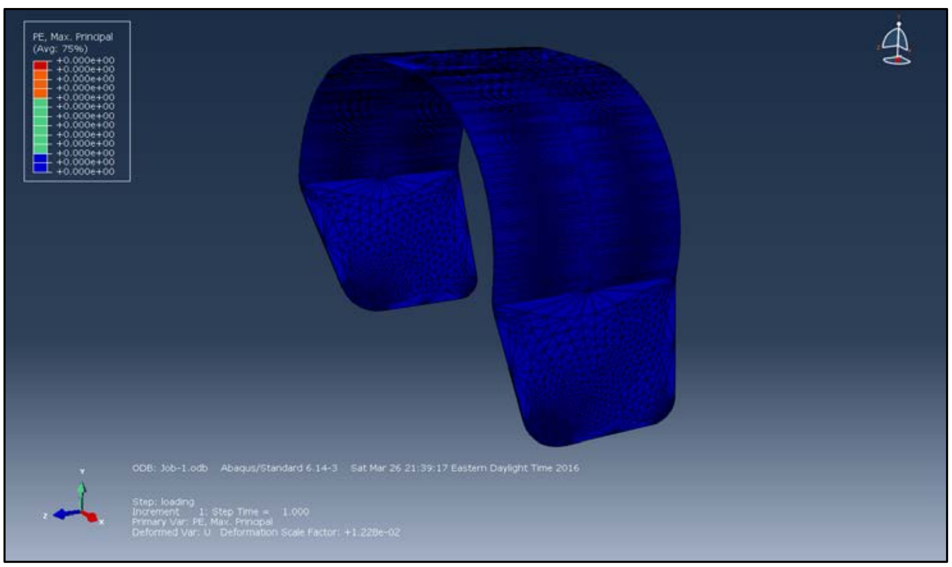

***Figure S2*: Abaqus Plastic Strain Test of Rudder Shroud, No Plastic strain, used as check to ensure accuracy of analysis**

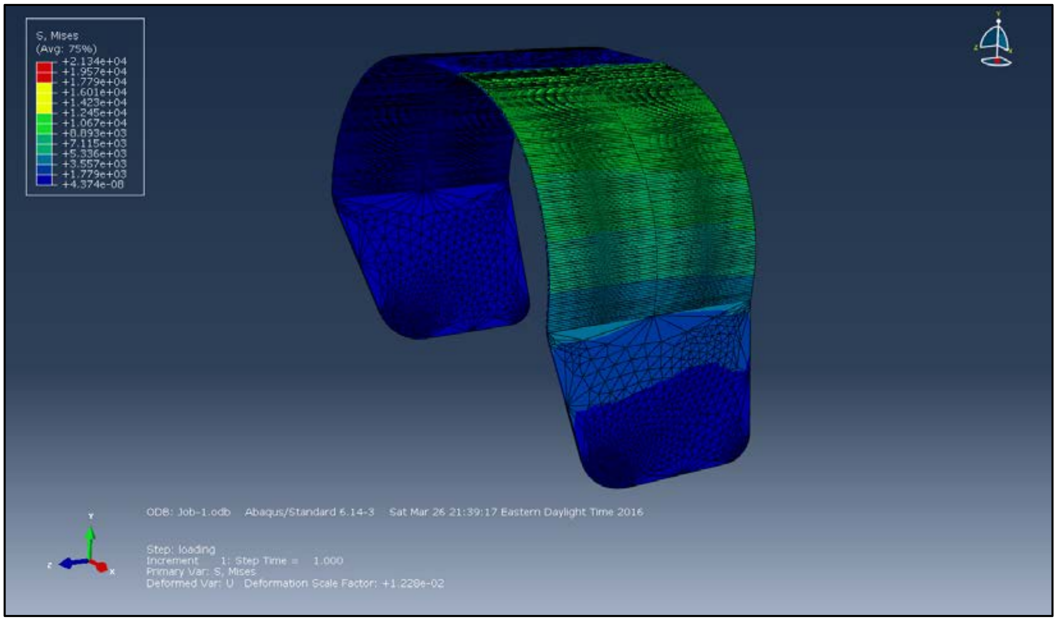

***Figure S3*: Abaqus Von Mises Stress Test of Rudder Shroud**

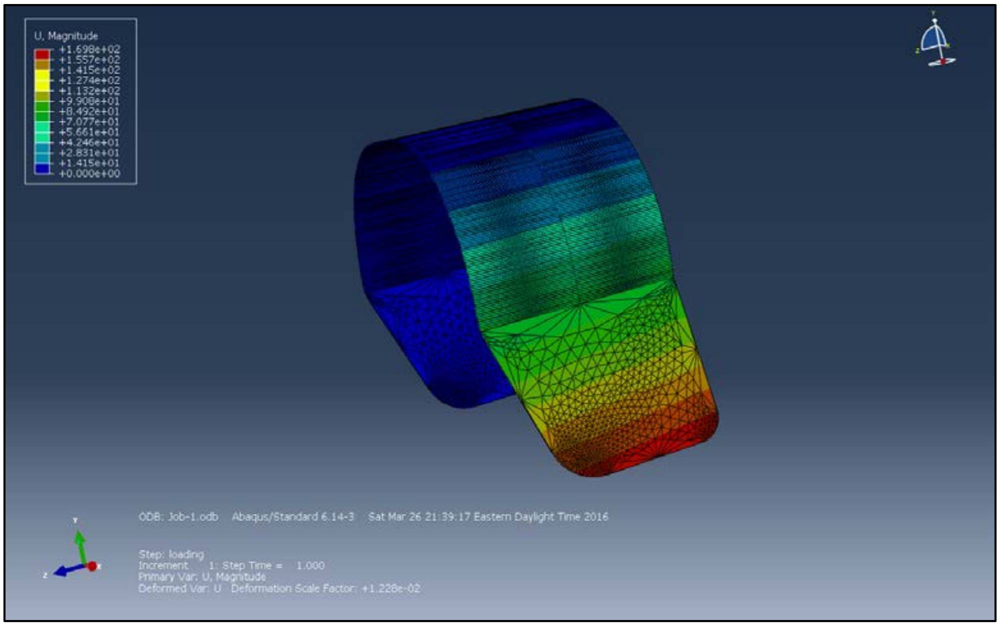

***Figure S4*: Abaqus Node Displacement Test of Rudder Shroud, displacement in µm**

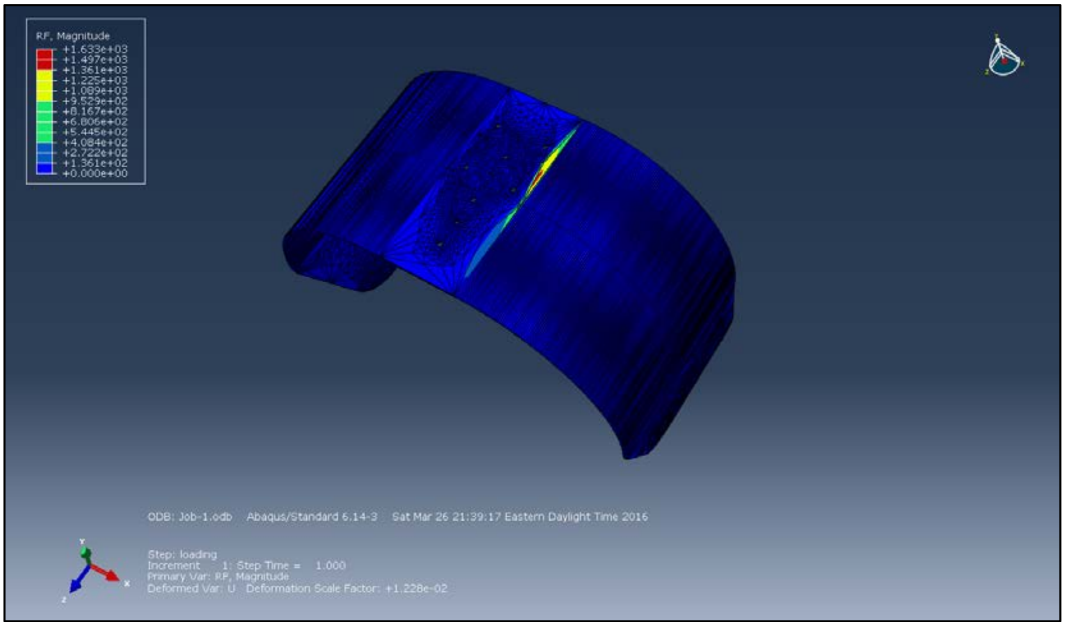

***Figure S5*: Abaqus Reaction Force Test of Rudder Shroud, to ensure stresses are withing gear motors capabilities**