UNIVERSITY OF ROCHESTER | URSS

SOLAR SPLASH #9

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Executive Summary

The objective of this year's University of Rochester Solar Splash (URSS) team was to increase our scores in every race, place in the top three overall, and once again be competitive with the top veteran teams. This competitive spirit has driven a group of multidisciplinary students 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 seventh 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, a modular outboard drive system was built with a 1.78:1 pulley ratio to spin the propeller at a maximum of 5,500 rpm. In consideration of weight, a three bar linkage-linear actuator system was implemented to control the outboard angle; a system significantly lighter than the previous gear motor controlled Levi drive.

A new hull for the 2017 competition was designed and optimized using a practical flume based model. Focusing on ease of construction and minimizing training requirements, the decision was made to construct the hull from lightweight cedar strips; a major departure from the fiberglass hulls used in the 2010-2016 competitions. Construction of the new hull provided immediate engagement for new members of the club.

In addition to the hull and the drive train system, nearly all electronics components were redesigned. Additions include a new solar charger, RPM sensors, and current sensors to monitor motor power consumption. A new battery management system was integrated into a fully custom in-house designed PCB, dubbed the System Control Board (SCB), which will monitor voltage levels, battery temperatures, and current output of the battery pack. The SCB utilizes a programmable microcontroller to interface with the GPS, RPM sensor, motor temperature sensor, steering wheel encoder, throttle position sensor, and drive motor speed controller to allow for peak efficiency operation during endurance and maximum power output during sprint. A custom built H-Bridge controls and powers the steering, and the SCB can read the position of the steering actuator for precise control and error correction. The SCB is also connected to a Raspberry Pi and a 7-inch LCD panel display, which utilizes a custom made application to display all telemetry gathered by the SCB.

The process of upgrading our Solar Splash boat system has improved the engineering skills of all students involved in the 2016-2017 University of Rochester Solar Splash Team. We hope to improve our performance this year and believe our improved engineering will allow us to be very successful in the competition.

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Overall Project Objectives

The University of Rochester's goal this year was to design all systems of the boat in house, and build them to performance specification. Using experience gained from up to three years of competition, Rochester's team aims to win the Solar Splash competition with the 2017 entry. The new boat is comprised of a cedar strip hull with stringers precision cut by CNC, improved ship to shore telemetry and communication systems, and updated drive and steering systems. In designing these components, the team analyzed the previous year's performance to design a fully encompassing system that performs efficiently at plane, while maintaining a low drag profile at low speeds. The hydroplaning effect expected for the trimaran hull used in the 2015 and 2016 competitions was limited, and issues of speed due to drag and an inefficient drive system prevented the design from achieving its full potential. Due to the thin nature of the new hull, an actuator based three-bar linkage steering system was implemented in place of the heavy linear actuator and electronic drive-by-wire system previously used. Significant improvements to telemetry and communication systems were made to ensure constant on-shore monitoring of position and battery status during the endurance portions. Weight and power consumption for the steering system and drive motor were greatly reduced, while overall efficiency was significantly increased.

Analysis of Integral Systems

I. Solar System

A. Current Design

Previously, the solar system consisted of two SBM Solar 250W solar panels connected in parallel to a Genasun GVB-8-WP waterproof solar charger. This solar controller is rated for 350W of input power, with a voltage boost so that any panel voltage 43V down to 9V will be converted to the necessary nominal 36V to charge a 36V battery system. While this design put the solar panels in parallel, decreasing the overall panel voltage below the 52V competition spec, it did not have the required maximum power tolerance to be adequately used with our panel specifications. During the competition, the fuse in-line with the solar controller on the battery side blew several times, and the solar controller had to be exchanged with a controller from previous years to continue racing in the competition. Before this had occurred, it was known that a second solar controller would solve this issue, such that each panel would have a controller. However, a second controller could not be afforded at the time. The specification sheet for the SBM solar panels can be found in Appendix K.

B. Analysis of Design Concepts

For the new design, a second Genasun GVB-8-WP controller was purchased so that each panel had its own solar controller (specification sheet can be found in Appendix L). There are several benefits of this configuration over the previous year's singular controller used for both panels. First, the power requirement for both panels combined is met. With a maximum competition power limit of 470W, the 700W combined power capability of both solar controllers is more than ample, and leaves a healthy headroom so that neither controller is overworked or brought too close to its maximum operating specifications. Secondly, this configuration causes a boost in solar charging efficiency. These controllers use the MPPT algorithm, which identifies the ideal voltage and amperage draw from the panels to maximize power production. To do this the controllers constantly modify the input panel voltage and observe the current to calculate power, selecting the voltage which produces the maximum power. The MPPT algorithm can compensate for panel dynamics such as partial sun exposure and temperature of the panel. However, these dynamics are best compensated if the MPPT algorithm has only one panel to monitor, as each panel may have different dynamics and require a different voltage to be selected to maximize power. If a single controller is connected to two panels it will at best, select a compromise voltage which is non-ideal for either panel and at worst be confused and select a very non-ideal voltage for both panels. Having two solar controllers ensures that the ideal power-maximizing voltage is selected for each panel, increasing overall power production during competition.

C. Design Testing and Evaluation

Evaluation will be conducted by dual current sensors and output voltage monitors placed on the output terminals of each solar controller. These parameters will be monitored by the SCB discussed in the Electrical System Design section. The voltages and currents will be digitized and sent via UART to both a Raspberry Pi for display on an on-board screen and through a 433MHz radio which will transmit the data to an on-shore computer for monitoring by the team on land. With this setup, the power production of each panel can be monitored and assessed in real-time.

This will be very useful during competition, as the weather dependent average power output for the panels can be calculated during the race, and the team can plan on an ideal power consumption required for best performance during the endurance portion.

II. Electrical System

A. Current Design

For the previous boat, control and telemetry systems were contained in a dashboard unit designed and constructed as a self-standing unit. An Arduino Mega was used to control the steering of the boat, being connected to a potentiometer which reads the angle of the rudder and an encoder which reads the position of the steering wheel. The Arduino was utilized to obtain tilt data and optimize the angle of the propeller through adjustment of a linear actuator. The dashboard featured a Raspberry Pi connected to a 7” TFT display, and was connected to a GPS module to obtain the current speed and heading of the boat. The dashboard contained switches for the main power, boat horn, bilge pump, and telemetry systems. It also housed the speedometer, battery gauge, meters to measure the current voltage output of the main batteries, and a dead man’s switch.

Figure 1: Central console wiring top view

B. Analysis of Design Concepts

The electronic systems, including the power system, solar charging system, and general electronics, have been previously operated in isolation to each other. While this is appropriate for general operation, it does make it difficult to control the boat in more complex configurations or to record data and analyze overall performance. Last year, progress was made in developing such a system by integrating a Raspberry Pi into a dashboard and controlling steering via an Arduino Mega and RC motor controller. While a great start, there were many improvements left to be made to further develop a centralized control system and include more telemetry systems for monitoring the boat's performance.

This year, an advanced centralized control design was implemented in the form of a system control board. The board relays throttle commands, steering control, audible feedback of critical system states, along with many sensor inputs for monitoring various aspects of the system state such as temperatures, voltages, electrical currents, and RPM. The main circuit schematic that encompasses all of the electronic subsystems is shown in Appendix X.

The goal of this system control board is to consolidate the control and monitoring of the boat through a single node, which can then communicate with a Raspberry Pi and other systems in the front console of the boat by the pilot. This approach reduces complexity, as there can be a single system in the rear of the boat for control and monitoring of boat operations, such as motor control, steering, and charging, while a separate system in the console can be used for user input and display of or analysis of data (by the pilot or computationally). These systems can then be linked through a single communication channel, giving the pilot full control of boat operations while reducing wiring and overall complexity. There is an additional benefit of better isolation of the power systems from the pilot. All high voltage and high current systems are strictly kept to the rear of the boat, and all control is performed by low voltage communication protocols.

The system control board consists of a 6x7 inch PCB mounted inside the battery box. It was designed in EagleCAD and is a standard two layer FR4 board with 1oz copper tracing. The focus in designing the board was versatility in operational capability, reliability, and absolute certainty that the main power system cannot turn on without the system control board being powered and operational. There are no high demands from the system control board itself, as it only sources control signals or receives low voltage sensor inputs. Thus, no large traces, special power isolation, or high cost power electronics are needed for the board, reducing cost and design complexity.

The microcontroller selected was the ATMEGA2560, a 100-pin 8-bit microcontroller made by Microchip and used in the popular Arduino Mega. The ATMEGA was selected for its high I/O count and good capability, as well simple programing without the more complex structures of 32-bit ARM microcontrollers. The ATMEGA also has many online resources, both in official documentation and in online forums, so debugging and programming guidance is plentiful.

Figure 2: Central and side consoles of 2017 entry

To meet versatility, many input and output capabilities are included on the board. First, an RJ-45 port is mounted on the board and an Ethernet cable is used to connect the system control board to the Raspberry Pi in the front. This cable runs a UART port to receive command data from the Pi, encoder phases for reading steering wheel input, a master system enabled 12V signal connected in series through a deadman switch and a dash panel switch dash, and a common ground, and two extra wires for future capabilities. The UART port runs telemetry data from the system control board such as temperatures, battery voltages, and current draw to the Pi for display to the pilot on a screen. It also carries throttle commands and other system configuration data from the Pi to the system control board. The encoder phases are read by the SCB, where an angle deflection is calculated from the integrated encoder pulses and mapped into a required position for the linear actuator controlling the outboard motor drive deflection. Finally, the 12V master enable line controls the power-up of the system control board. Without setting this line to 12V the system control board will not power on, and by extension the main power system will not be able to power on. The deadman switch, which controls the power of the system control board, thus still guarantees shutdown of the entire power electronics system. Further details of how the 12V master enable line ensures system shutdown can be seen in Appendix I.

The system control board has two throttle outputs, a raw PWM signal and a low-pass filtered PWM which becomes a 0-5V analog voltage signal. Our current motor controllers take a 0-5V signal, however the raw PWM was included for potential future hardware changes.

A steering control output utilizes a PWM signal to connect to an RC motor controller of the linear actuator. This will provide both direction and speed control of the actuator movement. For positional feedback, another port accepts the signal from a potentiometer built into the actuator. The board can read the analog signal from the potentiometer and then calculate current position of the actuator and thus deflection of the drive motor.

For sensory inputs, there are many voltage inputs, each for a different voltage range in multiples of 12V. There are two 48V inputs for monitoring panel voltages, then five each of 36V, 24V, and 12V inputs. The large number of inputs arises from uncertainty at the time of design, with the number of batteries being unknown, it was contemplated using many small lead acids arranged in series parallel configuration. Thus, by including a range of voltage inputs, any potential configuration would be accommodated. Additionally, there are three Hall Effect current sensor inputs, designed for sensors made by Amploc, for 5V power, ground, and an analog voltage current level output. Connected to these will be one 300A current sensor on the main motor controller power feed wire, and two 50A current sensors each on a solar panel output wire. Having both voltage and current sensing will enable total power draw monitoring and total power input monitoring per panel.

Additionally, there are 8 temperature inputs, several for different battery banks inside the battery box, one for the motor, and one for the motor controller. The temperature sensors are 1% NTC thermistors clad in a copper casing that is easily mounted to various surfaces. These sensors will allow for general overview of how hard the system is working and will provide a warning if any component begins to go over its rated temperature specification.

An additional 4 strain gage inputs are included on the board. These can be connected to strain gages placed around the hull of the boat, recording forces applied to the hull. These are being used for analysis of potential hull design changes for future builds.

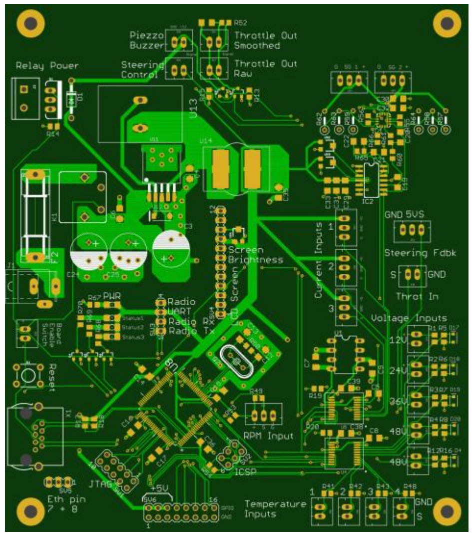

Figure 3: URSS' custom system control board (SCB), render

Finally, there are seven GPIO outputs for miscellaneous uses. No design is foolproof and there is always one last oversight or required feature that was not accommodated for, so the GPIOs act to fill in any gaps left in the overall system design and to provide some additional features if desired or required. The design view of the board can be seen in Figure 3, and schematics and further explanations of operation can be found in Appendix G.

The most important drawback of a centralized control board is that it interfaces with the high voltage and high current systems, putting it at risk of being destroyed by either human error or system faults. As the system functionality depends extremely heavily on the control board working, the possibility of destruction presents a great concern. While there are protection measures on the voltage inputs and the entire board has fuse protection, more precautions could be taken. An EagleCAD render of the boards' traces is additionally shown in Appendix H.

C. Design Testing and Evaluation

The PCB was spun by the board house EasyEDA and the components were hand soldered. 150 SMD components were solder reflowed using an electric hot-plate method, which consists of applying solder paste to all required pads, placing the components and then placing the board onto a hot plate and bringing it to the required temperature for the solder to reflow. An additional 80 through-hole components were soldered by hand. No major soldering mistakes were made during assembly aside from some minor solder bridges across the microcontroller pins, which were easily removed.

Initial testing showed that the analog to digital converter circuit had a design flaw which caused a large amount of current to be drawn. This caused a power regulator to go outside maximum specifications and induced a large ripple on the 5V power rail of the board. Unsoldering the regulator removed the excess current draw and the ripple on the power rails. The usage of the ADCs was also removed, and with it usage of voltage, temperature, and current inputs. Despite the issues with the ADCs, the microcontroller was still functional and programmable. Key functionality required to operate the boat was still functional, namely steering control and throttle control.

III. Power Electronics System

A. Current Design

In the past year, the motor powering the drive system was a 50-pound AC-9 which used a bulky DC-AC motor controller and, while having massive peak power output, required large minimum power input to get even 50% efficiency. The old design also involved a heavy stainless steel motor mount and long drive shaft for an inboard system with adjustable propeller angle, which was mechanically complex and difficult to build. This involved creating a watertight seal around a universal joint and properly sealing a hole through the back of the hull. We also added an industrial strength linear actuator to raise and lower the propeller along with the weight of the whole steering system.

The old system was over 90 pounds, including the 20-pound motor mount, the 50-pound motor, a heavier motor controller, stainless steel drive shaft, 12-pound actuator, and aluminum hardware to protect the drive shaft and support the steering system.

B. Analysis of Design Concepts

Instead of the 50-pound AC-9, the new drive system implemented runs on a Lynch brushed DC motor, which sacrifices peak power output in exchange for a far smaller and lighter package. The Lynch LEM 170-95 has a peak power output of around 20 horsepower, which is 30% less than the AC-9, but it is over 80% efficient at almost any power input level and weighs only 19 pounds. While the Lynch motor has less raw output power than the AC-9, due to its lighter weight and greater efficiency it will perform much better in the endurance and slalom portions of the competition. In addition, while the AC-9 had a large power output, the current demand was tremendous and the battery systems could only for a short time provide the necessary current for the motor to actually perform at peak power. Thus overall, the Lynch motor is a much better match for this year's new lightweight hull and the team's competition goals. The specification sheet of the Lynch LEM 170-95 is shown in Appendix E. The motor is controlled by an Alltrax AXE motor controller originally built for EZ-GO golf carts. This motor controller was used due to its simplicity of programming and ease of application. The specification sheet for the Alltrax AXE controller is shown in Appendix W.

An outboard boat motor was purchased and converted to an electrical system, the gas engine removed and the motor assembly installed on top. The motor assembly was coupled to the outboard shaft with a belt drive, replacing the previous year's large, complex inboard system.

These changes eliminate the heavy motor mount and large linear actuator for changing the vertical angle of the propeller, while allowing the propeller to pivot for optimal steering efficiency. The previous design involved pivoting a shroud over the propeller to vector the thrust, requiring less torque but ultimately being less efficient. The new system weighs under 60 pounds including the outboard, motor, controller, and mounting hardware.

In addition, a new set of batteries were purchased for this year's competition. The EnerSys G13EP was chosen for its smaller size and respectable capacity of 13Ah. In previous years the team has typically chosen a 42Ah EnerSys battery, putting three in series for the main battery bank. While this works, using only three batteries means each is physically larger and heavier, making adding and removing the batteries from the boat more difficult. In addition, putting only three batteries in series means the internal resistance is higher and more energy is lost during high current draw.

With the smaller G13EP batteries a total of nine batteries are used. In order to get a similar capacity as the past, the batteries are configured such that there are three battery banks placed in series, with three batteries in parallel in each series. With three 13Ah in parallel a total of 39Ah capacity is obtained. Once these three banks in are connected in series, 36V for the motor control is obtained. Several benefits are realized by using this configuration of nine smaller batteries. First, each battery is much smaller and the batteries can be grouped in three inside of their own boxes with and built-in handle for easy placement into the boat. Secondly, by putting batteries in series, the internal impedance of each battery bank is reduced and more current draw is allowed. The overall result is that the battery bank is physically smaller while weighing the same, and provides the same capacitance, but is able to provide more current than in past years

C. Design Testing and Evaluation

Current testing has been done using a Mars ME0708 in place of the Lynch motor, since the Lynch has not yet been received from the UK. The ME0708 has about half the power of the Lynch at a peak power of 8 horsepower, weighing 35 pounds and being 82% efficient at peak. The Lynch motor has a rated peak power of 16kW or around 20 horsepower, weighs 19 pounds, and has 88% peak efficiency.

Preliminary testing of the battery bank has shown that it has a much higher capacity than we have had previously and is able to provide more than enough current for the motor system to operate at peak performance. With the past AC-9 motor, peak current draw was upwards of 600 amps. Even the most powerful of starting batteries have trouble providing such a current for any amount of time. With the new Lynch motor and motor controller the absolute peak amperage draw is 300 amps, and paired with the lower internal impedance of the new battery bank, providing this current will pose no issue. Energy loss due to impedance will be low, as will battery temperature rise. The MSDS of the batteries are in Appendix A and the Sprint system electrical loss calculations are in Appendix J.

Figure 4: Aerial view of 2017 entry testing on-the-water

IV. Hull Design and Construction

Hull Design

A. Current Design

The University of Rochester Solar Splash team redesigned the shape of the hull for the 2015 competition year, marking the team's fourth attempt at designing and building a custom hull. The previous hull was inefficient in both the sprint and endurance portions of the competition, presenting the team with a significant opportunity for improvement. Inspired by the pickle-fork racing catamarans of the 1970's, the team aimed to design this hybrid hull with the high-speed elements of a lift-inducing airfoil and the low-speed efficiency of a displacement hull with a large surface area. This concept was achieved by creating core specifications which were continuously developed through prototyping and flume analysis. This hull design was innovative, and garnered the Outstanding Hull Design Award, however it was never able to attain the needed speed. This was partially caused by extensive drag forces at low speeds, limiting the hulls effectiveness at competition.

B. Analysis of Design Concepts

Using experience from previous years, the Rochester team developed multiple iterations of a canoe-skiff hybrid at a length of 14 feet. During the evaluation stage of the design process, the team developed a testing protocol to experimentally isolate the drag coefficients of each model and mitigate the effects of drag. Consequently, before any construction of the boat itself, the team 3D printed several small-scale models (1:10) of the hull and created a testing apparatus to measure the drag force on each design. The testing instrument consisted of a gear motor rotating an instrumented beam which held the model at a specific radius. The bending beam data was then used to create a matrix of relative drag coefficients vs boat design parameters. The data found was implemented to optimize the hull design, with the wake generated by the design minimized to its utmost extent. Schematics of the hull design are shown in Appendix M with the boat model experimental testing apparatus shown in Appendix P.

Figure 5: URSS' 2017 entry after completion of cedar strip, fiberglass, inner-deck, center console, and lid

C. Design Testing and Evaluation

The hull design was tested in water multiple times to experimentally isolate the waterline, confirming it displaced the correct amount. Upon testing completion, each component of the drive, steering, and electronic systems were placed optimally in the boat to yield a 10-degree center of mass angle towards the bow. Along placing components for stability, this angle aids in efficient planing. The boat was installed with four strain gages; on the bow, stern, keel, and the starboard bulkhead. The data was collected in real time to calculate the effects of various performance testing, including the dynamics for the endurance, sprint, and slalom portions. The strain is calibrated to the material substrate to isolate the peak stresses found in each part of the boat during each specific event (material properties isolated in uniaxial tension testing on MTS). All instrumented locations in the boat were found to have a safety factor of at least 2.4; therefore, it can be assumed that further strengthening of the hull is not necessary to prevent failure during normal loading experienced at competition. After testing the hull extensively under power, the hull was found to be unstable with the Solar Panels cantilevered off the edges. Therefore, to solve this issue, outriggers were designed and built to maintain stability and provide a superstructure for the solar panels to be effectively mounted to.

Hull Construction

A. Current Processes

The pickle-fork hull, used in the 2015 and 2016 competitions, was constructed with fiberglass using a negative polystyrene mold. The mold was cut with a CNC router by a company in Sunnyvale, Ca, using the original design file created in Solidworks. To preserve the mold and lay initial layers of fiberglass, the mold was covered with Styropoxy, a hardening polymer. After sanding the Styropoxy layer, carnauba release wax was applied to the complete surface to allow separation of the initial layers from the mold. Several layers of fiberglass were applied to this surface with epoxy, ensuring even layering with drying and sanding before additional application. The fiberglass hull was removed from the mold using multi-axial pressure and airbags. Upon removal, additional layers of fiberglass were applied to the interior of the hull, using fiberglass weaves of higher density for locations with higher applied loads. Hull flexibility was stabilized with stringers of fiberglassed Corecell foam, using a 12-oz 45-degree weave. The hull was constructed with a layer of 9-oz 45-degree weave, three layers of 6-oz 45-degree weave, and a 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.

B. Analysis of Process Concepts

The previous hull was constructed using a Styrofoam mold and several layers of fiberglass. This construction process was very time consuming, with each layer requiring a drying, sanding, and cleaning cycle before addition of the subsequent layer. Internal layers of fiberglass were also carefully layered to conform to the interior of the hull and provide support for central internal components. Although a necessary process, this quickly increases the weight of the assembly. To this end, it was decided to implement a cedar strip hull, which is easily built by layering strips on a wooden buck using the classical stitching glue method.

C. Process Testing and Evaluation

The hull for the 2017 competition is constructed from cedar strips, which reduced the weight from 75 pounds in the previous design to 25 pounds, a 67% decrease. The hull is based on a 3D model designed to reduce drag and meet certain specifications.

Figure 6: Cedar strip glue and staple application mid-process, note that the birch plywood stringers are permanent, while particle board stringers are temporary

Using a CNC router in the University of Rochester machine shop, a frame of stringers for the hull was cut based on this 3D model. The DXF's used to cut the infrastructure of the hull are shown in Appendix N. The cuts were made from cross sections of the 3D model, and were spaced one foot apart on a leveled strongback table so that the hull could be assembled upside-down. Cedar strips were layered, fitted around, and stapled to each stringer, and subsequently attached together with wood glue. Once cedar planks formed the entirety of the hull, the staples holding the strips to the frame were removed, and non-essential stringers were removed. Staple holes were filled, and the cedar hull was sanded until smooth. Once the exterior was sanded, 8-oz 45-degree fiberglass weave was applied to strengthen and waterproof the hull. For extra support, an interior deck was installed. Before placing the deck, supports were glued down for extra stabilization. Foam was placed between the supports to provide buoyancy. The outriggers were manufactured from cardboard tubing coated in 12 oz. weave fiberglass with an interlocking structure cut on the CNC.

The cedar strip hull has performed well during testing in development. Since the hull is significantly lighter than the previous fiberglass hull, it is more easily displaced. Development on interior components of the hull was significantly faster than with a fiberglass hull, cedar and plywood being very easy materials to work with. This hull design was also cost-effective, with very little material going to waste and an exact amount of cedar strip and wood glue purchased. All concealed portions of the boat were filled with flotation foam to ensure sufficient buoyancy would be provided by the hull. Further photos of the hull construction are shown in Appendix N, and the flotation foam MSDS is shown in Appendix Y.

V. Drive Train and Steering

Drive Train Design

A. Current Design

Using a different motor, the previous drive train system used a timing belt for a 1:1 ratio from the motor shaft to the propeller. This was an inboard motor system which required a shaft with a universal coupling to extend through the back of the hull. An AC-9 induction motor was used, which weighed 70 pounds including the motor mount, and had a peak power output of over 27 horsepower. Despite its high peak power, at low power outputs it was very inefficient (<60%), which proved problematic for all portions but the sprint event.

B. Analysis of Design Concepts

The drive train system has been completely redesigned, using an outboard motor rather than the inboard motor system of previous years. The motor system is much smaller and lighter, and can be swapped between two different motor configurations: with a Mars ME0708 or a Lynch LEM 170-95 motor. The Mars motor weighs 28 pounds, with a peak power output of about 12 horsepower, while the Lynch is only 19 pounds and peaks at 21 horsepower. Both motors easily achieve over 80% efficiency even at low speeds, and can peak at 83% and 88% respectively. As shown in Figure 7, the outboard system utilized a prebuilt donor lower unit from a 1965 9.5hp Johnson-Evinrude. Schematics of the donor outboard mechanics are shown in Appendix V.

The belt drive system connecting the outboard drive shaft to the motor output shaft now includes an idler and a new ratio closer to 2:1 *(1.78:1)*, increasing the RPM of the propeller. The drivetrain concept analysis is shown in Appendix Q. The outboard uses a smaller diameter propeller than used previously, limited by the ⅜" spline drive, but has a higher pitch. The addition of the idler increases the tension in the timing belt and assists in the reduction of undesirable vibrations in the system. The new gear ratio allows the system to increase use of the torque supplied by the motor for higher speed operation, which is necessary for the relatively small propeller to achieve high speeds.

Figure 7: Modified 1965 Johnson-Evinrude 5.5 hp with 1.78:1 belt drive system

Main considerations for designing the drive train system were maximizing efficiency with a new propeller, using efficient and lightweight motors, and the capability to change configurations for each event. Two propellers are available for use, one for sprint and slalom events (a three blade, 8 ¼" diameter, 8 ½" pitch propeller) and another for the endurance event (a two blade 8 ¼" diameter, 7 ¼" pitch propeller), thus allowing varying speeds while maintaining near-peak efficiency RPM for the motor. The purchased components for the drive system are documented in Appendix R with the machined components documented in Appendix S.

C. Design Testing and Evaluation

Lynch Motors operates in the UK, so to compensate for time lost in waiting for the shipment, the system was also designed to use the Mars motor. To date, all testing has been done using the Mars motor, but the Lynch will be swapped in and tested separately upon arrival.

The initial design of the pulley mounting in the gearbox included spacing, which would provide optimal tension in the timing belt during a dry stationary water test. This did not account for the weight of the boat, which placed extra torque on the system. The first iteration of the new system consisted of only the timing belt and two pulleys, and during preliminary testing tensioning of the timing belt was inadequate, resulting in slippage at higher RPM. To resolve this issue and increase the stability, an idler was added to the drive train, greatly reducing unwanted vibrations and increasing the maximum rotational speed of the propeller. With this addition, the system can now accommodate non-slip rotation at full throttle.

Steering Design

A. Current Design

In 2016, the steering system was composed of a shroud which rotated about the propeller to change the direction of thrust. This system utilized a drive-by-wire control mechanism which incorporated a heavy actuator and universal joint to allow the steering assembly to be held 3 feet off the back of the boat. This system allowed movement of the vertical angle with the water and the horizontal angle of thrust without the use of a rudder. This system weighed about 40 pounds, and involved an electric geared motor shielded from water by a 3D printed cover and water-tight sealant. The steering motor consumed at peak about 500 Watts, or 40 Amps at 12 volts, but averaged about 200 Watts when in motion.

B. Analysis of Design Concepts

The new steering system uses the range of motion naturally provided by the outboard motor, removing the need for additional components which would increase weight on the transom. In place of a power consuming steering motor is a small positional feedback actuator with a maximum load easily capable of rotating the outboard, the actuator weighing only 3.1 pounds; the specification sheet for the actuator can be found in Appendix F. It has a maximum current rating of 5 Amps at 12 Volts, the maximum power consumption thus less than 12% of the steering motor, and with a constant operation current under 50 Watts. The actuator shaft is attached to a hinged lever arm (sourced from a parallel arm door closer) which provides a larger range of motion. Thus, it can rotate the outboard motor in an arc despite the limited linear motion of the actuator shaft. Very little additional hardware was necessary to attach the actuator to the boat and the hinge arm. Due to built-in tolerance within the hinge, angular misalignment is accounted for between the

Figure 8: Actuator- hinge arm steering system

outboard trim and the rear of the boat (plane where distal end of hinge arm is attached). The hinge arm has enough range to allow for operation with the outboard at a range of vertical angles, removing the need for an additional ball and socket joint. The outboard steering system attached to the boat is shown in Figure 8.

C. Design Testing and Evaluation

After extensive testing, the system remains reliable and efficient. Despite a 25% duty cycle rating the actuator had no problem with normal use as expected for the slalom event, as it does not operate at full power while turning, only while changing the angle of the outboard (going into or out of a curve). Air flow during movement of the boat is sufficient to keep it cool, but an auxiliary fan may be added to ensure it remains cool during extended use periods, such as the endurance race.

VI. Data Acquisition and Communication

A. Current Design

The previous design contained several subsystems which collected data from the boat and motor. Within a front console, a Raspberry Pi was used to collect and log data from a GPS module, accelerometer, and gyroscope, which collected position, acceleration, and orientation data. Collected data was displayed on an LCD screen, the observation of telemetry allowing the skipper to monitor systems.

To monitor the power statistics for the high-voltage systems in the boat, a current meter was integrated into the boat. By directing the high-voltage circuit through the current meter shunt, the amperage drawn by the boat's motor was measured. Additionally, the Curtis motor controller used by the HV system collected statistics for power input and consumption that could be accessed using a data pad connected to the motor controller. This design contained no method for communicating logged data directly to the shore, instead relying on radio communication with the skipper.

B. Analysis of Design Concepts

The primary issue of the previous design was the difficulty in relaying information from the ship to the on shore team during the endurance race. The data collection systems were disjointed and difficult to use, making the skipper observe system conditions, relay them to the shore, and drive the boat at the same time.

The independent dashboard console used in the previous system was a useful design element, but time constraints resulted in inefficient and disorganized wiring configuration and component placement. For the new design, the front console and dashboard were integrated into the hull of the boat, the organization of the low voltage components was carefully planned to be well organized and easily accessed and maintained.

C. Design Testing and Evaluation

To resolve issues experienced with the previous system, the team designed an efficient ship-to-shore system. The central aspect of the system is a pair of radio emitter / receiver units designed for RC airplanes. Each unit is capable of two-way communication, and the unit on the shore can be connected to a computer via a USB cable. Using this system, the microcontroller on the boat can send packets containing all telemetry data to a computer on the shore, which plots and records the data in a Java application. This system allows the team on shore to continuously monitor the boat without distracting the skipper from driving.

Additionally, the previous design lacked the ability to measure other data about the system, such as the RPM of the motor or the temperature of different pieces of the system. Such sensors were integrated into the design of our main system board, which has several inputs for sensors. Several temperature, current, and Hall Effect sensors were purchased, all of which can be plugged into the main system board for data collection, which is then sent to shore over the ship-to-shore system.

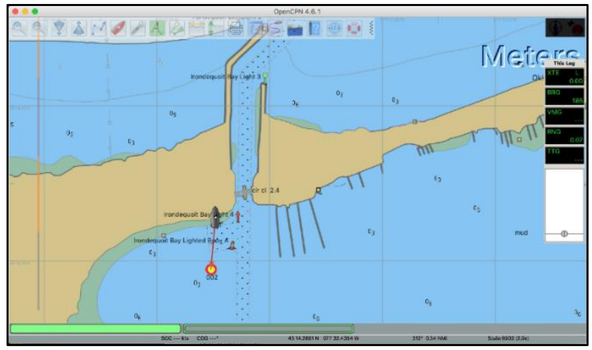

Figure 9: Screenshot of the OpenCPN Framework during testing at Irondequoit Bay

In the front dashboard, a Raspberry Pi is used to display the marine navigation software. The Pi uses the GPS input to plot the boat's position and heading on a marine map displayed using the open-source mapping software OpenCPN. Cached copies of marine maps available from the NOAA government website were downloaded, providing access of detailed maps of any likely location the boat will be driven, removing need of an available internet connection. Existing software was used for telemetry in the boat, focusing instead on software development for the on-shore communication and telemetry analysis. The GPS module specification sheet is shown in Appendix U and the radio transmitter used for the ship to shore communications is shown in Appendix T.

Project Management

A. Team Organization and Leadership

The University of Rochester team is comprised solely of undergraduate students, with students from all years and a variety of disciplines, including mechanical, biomedical, electrical and computer engineering, computer science, chemistry, and statistics. An executive board comprised of previous members guides the team in all aspects of the project. Two team meetings a week and weekly executive board meetings provide regular communication, scheduling, and design planning.

The team's co-Presidents are Edward Ruppel '17 and Christopher Dalke '19. The co-presidents' roles include recruitment, oversight on all major projects, and designating tasks. Matt Dombroski '17 is the Vice President and is responsible for maintaining the team relations with the University of Rochester Electrical and Mechanical Engineering Departments, Student Association, and other engineering clubs. Seth Schaffer '19 is the Chief Electrical Engineer and is responsible for leading projects for configuring electrical systems on the boat. Benjamin Martell '19 is the Chief Mechanical Engineer and is responsible for overseeing all engineering projects involving motor, steering, and drive systems. As the co-Business Managers, John Krapf '18 and Nitish Sardana '17 are responsible for managing all transactions incurred by the club and securing funding from sponsors. Madeline Herman ‘17 is the Secretary and Communications Chair, and is responsible for coordinating schedules and campus outreach. Joshua Lomeo ‘18 is the Chief Technical Writer and is responsible for assisting and managing writing for all components of the technical report. Devin Marino ‘18 is the Fundraising Chair and is responsible for outreach to local Rochester companies for sponsorship and for managing the USEED crowdfunding campaign.

B. Project Planning

Three meetings were conducted weekly during both semesters; one focusing on component design and analysis, another for construction, and the last for team logistics and management. In addition to the team meetings, the senior members of the club had weekly meetings with the team's faculty advisor to provide progress updates.

C. Funding and Finances

The Hajim School at the University of Rochester funded a majority of the fixed costs of the project, with an annual budget of $3,900. The University of Rochester Student Association provided a budget of $2,100 with the addition of $4,700 attained through USEED crowdfunding efforts. Approximately $2,000 was spent on new componentry to advance the capabilities of the mechanical and electrical systems, including a new motor which has been sourced from Lynch UK for a total of $1,200. Miscellaneous expenses, tools, and safety equipment cost approximately $700. Our expected expenses for the competition will approach $3,000, accounting for travel costs, food, and lodging. The allotted funds from the UR Student Association will be covering a large portion of our traveling expenses.

D. Team Sustainability

University of Rochester Solar Splash is an undergraduate club sponsored by the Student Association and the Hajim School of Engineering. For the 2016-2017 school year, University of Rochester Solar Splash sought to greatly increase membership, bringing together veteran members to instruct new members in CAD, mechanical and electrical design, and programming. The club was successful in recruiting new members from a variety of disciplines, which allowed for immediate involvement and integration into roles of their interest.

The first meetings of each semester were focused on attracting and integrating new members towards the goals of the club, and subsequent meetings engaged members in assigned design and construction tasks. With the implementation of a new hull, new members were immediately engaged in design testing in the first semester and hull construction in the second semester.

During team build and design meetings, team members gained knowledge and experience working with components outside of their disciplines. Interdisciplinary communication and design strengthened organization of the club towards completing the project for June, as well as preparing team members for maintenance work during competition.

With the experienced perspective of the team's co-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.

During the fall of the 2016-2017 school year, a crowdfunding program was run using the USEED platform, raising funds to provide financial stability and monetary sources for material and supply purchases. The money from last year's crowdfunding secured purchases of componentry for this year's entry.

Significant changes were made to the team's shop 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 significant shop experience by machining all metal components of the boat.

Specific links to the University of Rochester Solar Splash teams' web presence are shown in Appendix Z.

E. Self-evaluation

With a plethora of experience and knowledge gained from previous years, the team has developed a proven model for project management to effectively complete the boat and its requirements for the Solar Splash competition. This now seasoned but young team is well positioned for future development and contribution to Solar Splash.

Conclusions and Recommendations

A. Hull

From our experience in the previous two competitions, the short and wide trimaran hull was found to be an ineffective design. Despite stability and sufficient room for components, the increased drag gained from width was detrimental. Additionally, hull speed was never reached. For our new hull, we have designed a more conventional craft that is a hybrid of a canoe body and a skiff backend, providing similar stability and a more streamlined design compared to the previous hull. For construction materials, we decided to build our hull out of cedar strip and plywood, moving away from the fiberglass and foam technique used previously. Using the stitch-and-glue method of wooden boat construction provided a significant benefit to our team, with less training required for proficiency of the technique as compared to fiberglass layering. Building a wooden hull allows members of the club who are not significantly experienced in construction techniques or working with fiberglass to make a significant contribution. Although a full fiberglass hull can be strong and lightweight, it takes extensive practice and tooling to create a boat hull that meets the performance specifications. With cedar strip, the end product is extremely lightweight, visually attractive, and requires no specific training for construction.

In summary, we are confident that our new hull will perform better in the water than in previous years. We have constructed a lightweight, streamlined hull that has a finished appearance while not requiring excessive work from the team to develop. We plan to continue using wooden construction techniques in the future after our positive experiences this year.

B. Drive Train and Motors

Based on our previous experience and research, we believe that using an outboard motor will be the best option in the future for several reasons. An outboard motor is inherently simpler to use than an inboard design, and can be transferred between boats seamlessly for testing and revision. By using an outboard motor, there are many existing techniques available for the development of motor systems, providing many avenues for considerations in redesign. We have created a lightweight, modular system that can be easily modified, allowing easy development by future members for implementation in new hulls.

C. Electrical Systems

One of the disadvantages of our previous electronic control system was the independent design of different system components. With less attention paid to the overall system design, several inefficiencies were apparent during communications between telemetry systems.

This year, we approached the design process from a top-down method, designing the systems to be both modular and working within a larger system that obeyed weight, power, and complexity constraints. Additionally, we have chosen to move away from an AC motor system towards a DC motor system. Although AC systems are theoretically more efficient, the increased efficiencies compared to a DC system are only tangible at higher amperages than will be encountered under normal operating conditions. By switching to DC, we also simplify our power electronics system, since a bulky AC motor controller is no longer needed to drive our motor. In summary, we believe the new system will be lightweight, flexible, and robust, and sets our team up for success in the future by keeping the electrical components simple.

Acknowledgements

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Chris Pratt
Jill Morris
Sara Klinkbeil
Sarah Ansini
Jim Alkins

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

University of Rochester Machine Shop
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University of Rochester Student Association
Stacey Fisher
Appropriations Committee

Appendices

Appendix A. Battery Documentation

Construction

- 12V pure lead-tin Valve Regulated Lead Acid (VRLA) Absorbent Glass Mat (AGM) battery
- UL 94V0 flame retardant case and cover
- M6 no-maintenance terminals
- Can be installed in any orientation except inverted
- Rugged construction (optional metal jacket - G200EP excluded)
- Approved for shipping as non-hazardous, non spillable (refer to SDS sheet)

Installation and Operation

- -40°F (-40°C) to 176°F (80°C) with optional metal jacket (G200EP excluded)
- 2 year shelf life at 77°F (25°C)
- Cycle life up to 400 cycles at 80% depth of discharge

Standards

- Non-spillable classification
- Recognized by UL File no. MH12544 (excludes G200EP); G200EP recognized by UL File no. MH18697
- The management systems governing the manufacture of this product are ISO 9001:2008 and ISO 140001:2004 certified

General Specifications

Battery Type	Nominal Voltage (V)	Nominal Capacity (Ah) 10 Hr Rate-Ah	Nominal Dimensions Length in	Length mm	Width in	Width mm	Height in	Height mm	Typical Weight lbs	Typical Weight kg	Torque in-lbs	Torque Nm	Internal Resistance (mΩ)	Short Circuit Current (A)
G13EP	12	13	6.89	175.0	3.27	83.1	5.08	129.0	10.8	4.9	50	5.6	8.1	600
G16EP	12	16	7.12	180.8	2.99	75.9	6.57	166.9	13.5	6.1	50	5.6	6.9	1000
G26EP	12	28	6.54	166.1	6.89	175.0	4.92	125.0	22.3	10.1	60	6.8	4.3	1140
G42EP	12	42	7.74	196.6	6.50	165.1	6.69	169.9	32.9	14.9	60	6.8	3.8	1430
G70EP	12	72	12.94	328.7	6.54	166.1	6.85	174.0	53.5	24.3	60	6.8	2.8	2100
G200EP	12	200	22.87	580.9	4.92	125.0	12.46	316.5	132.3	59.9	44	5.0	3.3	3800

Constant Current Discharge Performance

Constant current discharge rate, amps to 10.02V at 77°F (25°C)

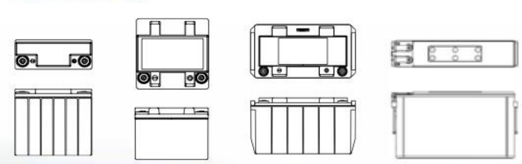
	Minutes			Hours				
Battery Type	10	15	30	1	5	8	10	20
G13EP	41.4	30.8	17.9	10.3	2.5	1.6	1.3	0.7
G16EP	49.3	36.6	21.5	12.6	3.1	2.1	1.7	0.9
G26EP	87.6	65.4	38.3	22.1	5.3	3.5	2.9	1.5
G42EP	118.9	90.3	54.4	32.1	8.0	5.4	4.4	2.3
G70EP	218.5	165.7	98.5	57.0	13.6	9.0	7.3	3.9
G200EP	475.6	380.4	241.9	150.8	36.9	24.3	19.8	10.4

Constant Power Discharge Performance

Constant power discharge rate, watts per battery to 10.02V at 77°F (25°C)

	Minutes			Hours				
Battery Type	10	15	30	1	5	8	10	20
G13EP	467.0	348.0	206.0	120.0	30.0	20.0	16.0	9.0
G16EP	560.0	421.0	251.0	149.0	38.0	25.0	20.0	11.0
G26EP	990.0	749.0	446.0	260.0	63.0	42.0	34.0	18.0
G42EP	1333.0	1026.0	629.0	376.0	96.0	64.0	52.0	28.0
G70EP	2443.0	1879.0	1139.0	669.0	162.0	107.0	87.0	46.0
G200EP	5148.0	4189.0	2736.0	1746.0	442.0	293.0	238.0	125.0

Outline Drawings



Charge Voltage

Cyclic use: 14.4V to 15.0V at 77°F (25°C) No current limit
Float use: 13.5V to 13.8V at 77°F (25°C) No current limit

Drawing sizes are for terminal position reference only;
Diagrams are not proportionate to each other

EnerSys Power/Full Solutions

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www.enersys.com

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EnerSys

MATERIAL SAFETY DATA SHEET

Form # 853024
Revised: 8/10/05
Supersedes: 12/22/04

I. PRODUCT IDENTIFICATION

Chemical Trade Name (as used on label):
Nonspillable Lead-Acid Battery

Chemical Family/Classification:
Electric Storage Battery

Manufacturer's Name/Address:
EnerSys
P.O. Box 14145
2366 Bernville Road
Reading, PA 19612-4145

Telephone:
For information and emergencies, contact EnerSys' Environmental, Health & Safety Dept. at 610-208-1996

24-Hour Emergency Response Contact:
CHEMTREC DOMESTIC: 800-424-9300 CHEMTREC INT'L: 703-527-3887

II. HAZARDOUS INGREDIENTS/IDENTIFY INFORMATION

Components	CAS Number	Approximate % by Wt. Or Vol.	Air Exposure Limits (ug/m^3) OSHA	ACGIH	NIOSH
Inorganic Lead Compound:					
Lead	7439-92-1	45 - 60	50	150	100
* Lead Dioxide	1309-60-0	15 - 25	50	150	100
* Antimony	7440-36-0	2	500	500	--
* Arsenic	7440-38-2	0.2	10	200	--
* Calcium	7440-70-2	0.2	--	--	--
* Tin	7440-31-5	0.2	2000	2000	--
Electrolyte (Sulfuric Acid)	7664-93-9	10-30	1000	1000	1000
Case Material:		5-10	N/A	N/A	N/A
Polypropylene	9003-07-0				
Polystyrene	9003-53-6				
Styrene Acrylonitrile	9003-54-7				
Acrylonitrile Butadiene Styrene	9003-56-9				
Styrene Butadiene	9003-55-8				
Polyvinylchloride	9002-86-2				
Polycarbonate, Hard Rubber, Polyethylene	--				
Other:					
Silicon Dioxide (Gel batteries only)	7631-86-9	20-40	N/A	N/A	N/A
Sheet Molding Compound (Glass reinforced polyester)	--		N/A	N/A	N/A

Inorganic lead and electrolyte (sulfuric acid) are the primary components of every battery manufactured by EnerSys.
Other ingredients may be present dependent upon battery type. Contact your EnerSys representative for additional information.

III. PHYSICAL DATA

Electrolyte:

Boiling Point:	203 - 240° F	**Specific Gravity (H_2O = 1):**	1.215 to 1.350
Melting Point:	N/A	**Vapor Pressure (mm Hg):**	10
Solubility in Water:	100%	**Vapor Density (AIR = 1):**	Greater than 1
Evaporation Rate: (Butyl Acetate = 1)	Less than 1	**% Volatile by Weight:**	N/A
Appearance and Odor:	Manufactured article; no apparent odor. Electrolyte is a clear liquid with a sharp, penetrating, pungent odor.		

IV. FIRE AND EXPLOSION HAZARD DATA

Flash Point: N/A
Flammable Limits: LEL = 4.1% (Hydrogen Gas) UEL = 74.2%

Extinguishing Media: CO_2; foam; dry chemical

Special Fire Fighting Procedures:
If batteries are on charge, shut off power. Use positive pressure, self-contained breathing apparatus. Water applied to electrolyte generates heat and causes it to spatter. Wear acid-resistant clothing.

Unusual Fire and Explosion Hazards:
Highly flammable hydrogen gas is generated during charging and operation of batteries. To avoid risk of fire or explosion, keep sparks or other sources of ignition away from batteries. Do not allow metallic materials to simultaneously contact negative and positive terminals of cells and batteries. Follow manufacturer's instructions for installation and service.

V. REACTIVITY DATA

Stability: Stable

Conditions To Avoid: Prolonged overcharge; sources of ignition

Incompatibility: (Materials to avoid)
Sulfuric Acid: Contact with combustibles and organic materials may cause fire and explosion. Also reacts violently with strong reducing agents, metals, sulfur trioxide gas, strong oxidizers and water. Contact with metals may produce toxic sulfur dioxide fumes and may release flammable hydrogen gas.
Lead Compounds: Avoid contact with strong acids, bases, halides, halogenates, potassium nitrate, permanganate, peroxides, nascent hydrogen and reducing agents.

Hazardous Decomposition Products:
Sulfuric Acid: Sulfur trioxide, carbon monoxide, sulfuric acid mist, sulfur dioxide, and hydrogen.
Lead Compounds: High temperatures likely to produce toxic metal fume, vapor, or dust; contact with strong acid or base or presence of nascent hydrogen may generate highly toxic arsine gas.

EnerSys

MATERIAL SAFETY DATA SHEET

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VI. HEALTH HAZARD DATA

Routes of Entry:
Sulfuric Acid: Harmful by all routes of entry.
Lead Compounds: Hazardous exposure can occur only when product is heated, oxidized or otherwise processed or damaged to create dust, vapor or fume.

Inhalation:
Sulfuric Acid: Breathing of sulfuric acid vapors or mists may cause severe respiratory irritation.
Lead Compounds: Inhalation of lead dust or fumes may cause irritation of upper respiratory tract and lungs.

Ingestion:
Sulfuric Acid: May cause severe irritation of mouth, throat, esophagus and stomach.
Lead Compounds: Acute ingestion may cause abdominal pain, nausea, vomiting, diarrhea and severe cramping. This may lead rapidly to systemic toxicity and must be treated by a physician.

Skin Contact:
Sulfuric Acid: Severe irritation, burns and ulceration.
Lead Compounds: Not absorbed through the skin.

Eye Contact:
Sulfuric Acid: Severe irritation , burns, cornea damage, and blindness.
Lead Components: May cause eye irritation.

Effects of Overexposure - Acute:
Sulfuric Acid: Severe skin irritation, damage to cornea, upper respiratory irritation.
Lead Compounds: Symptoms of toxicity include headache, fatigue, abdominal pain, loss of appetite, muscular aches and weakness, sleep disturbances and irritability.

Effects of Overexposure - Chronic:
Sulfuric Acid: Possible erosion of tooth enamel, inflammation of nose, throat and bronchial tubes.
Lead Compounds: Anemia; neuropathy, particularly of the motor nerves, with wrist drop; kidney damage; reproductive changes in males and females.

Carcinogenicity:
Sulfuric Acid: The International Agency for Research on Cancer (IARC) has classified "strong inorganic acid mist containing sulfuric acid" as a Category I carcinogen, a substance that is carcinogenic to humans. This classification does not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist (sulfuric acid mist) is not generated under normal use of this product. Misuse of the product, such as overcharging, may result in the generation of sulfuric acid mist.
Lead Compounds: Lead is listed as a 2B carcinogen, likely in animals at extreme doses. Proof of carcinogenicity in humans is lacking at present.
Arsenic: Listed by National Toxicology Program (NTP), International Agency for Research on Cancer (IARC), OSHA and NIOSH as a carcinogen only after prolonged exposure at high levels.

Medical Conditions Generally Aggravated by Exposure:
Overexposure to sulfuric acid mist may cause lung damage and aggravate pulmonary conditions. Contact of sulfuric acid with skin may aggravate diseases such as eczema and contact dermatitis. Lead and its compounds can aggravate some forms of kidney, liver and neurologic diseases.

EMERGENCY AND FIRST AID PROCEDURES:

Inhalation:
Sulfuric Acid: Remove to fresh air immediately. If breathing is difficult, give oxygen.
Lead: Remove from exposure, gargle, wash nose and lips; consult physician.

Ingestion:
Sulfuric Acid: Give large quantities of water; do not induce vomiting; consult physician.
Lead: Consult physician immediately.

Skin:
Sulfuric Acid: Flush with large amounts of water for at least 15 minutes; remove contaminated clothing completely, including shoes.
Lead: Wash immediately with soap and water.

Eyes:
Sulfuric Acid and Lead: Flush immediately with large amounts of water for a least 15 minutes; consult physician.

Proposition 65:
Warning: Battery posts, terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

VII. PRECAUTIONS FOR SAFE HANDLING AND USE

Spill or Leak Procedures:
Stop flow of material, contain/absorb small spills with dry sand, earth, and vermiculite. Do not use combustible materials. If possible, carefully neutralize spilled electrolyte with soda ash, sodium bicarbonate, lime, etc. Wear acid-resistant clothing, boots, gloves, and face shield. Do not allow discharge of unneutralized acid to sewer.

Waste Disposal Methods:
Spent batteries: Send to secondary lead smelter for recycling.
Place neutralized slurry into sealed containers and handle as applicable with state and federal regulations. Large water-diluted spills, after neutralization and testing, should be managed in accordance with approved local, state and federal requirements. Consult state environmental agency and/or federal EPA.

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MATERIAL SAFETY DATA SHEET

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VII. PRECAUTIONS FOR SAFE HANDLING AND USE (Cont.)

Handling and Storage:

Store batteries in cool, dry, well-ventilated areas with impervious surfaces and adequate containment in the event of spills. Batteries should also be stored under roof for protection against adverse weather conditions. Separate from incompatible materials. Store and handle only in areas with adequate water supply and spill control. Avoid damage to containers. Keep away from fire, sparks and heat.

Precautionary Labeling:

POISON - CAUSES SEVERE BURNS DANGER - CONTAINS SULFURIC ACID

VIII. CONTROL MEASURES

Engineering Controls:

Store and handle in well-ventilated area. If mechanical ventilation is used, components must be acid-resistant.

Work Practices:

Handle batteries cautiously to avoid spills. Make certain vent caps are on securely. Avoid contact with internal components. Wear protective clothing when filling or handling batteries.

Respiratory Protection:

None required under normal conditions. When concentrations of sulfuric acid mist are known to exceed the PEL, use NIOSH or MSHA-approved respiratory protection.

Protective Gloves:

Rubber or plastic acid-resistant gloves with elbow-length gauntlet.

Eye Protection:

Chemical goggles or face shield.

Other Protection:

Acid-resistant apron. Under severe exposure emergency conditions, wear acid-resistant clothing and boots.

Emergency Flushing:

In areas where sulfuric acid is handled in concentrations greater then 1%, emergency eyewash stations and showers should be provided, with unlimited water supply.

IX. OTHER REGULATORY INFORMATION

NFPA Hazard Rating for Sulfuric Acid:

Flammability (Red) = 0	Reactivity (Yellow) = 2
Health (Blue) = 3	Sulfuric acid is water-reactive if concentrated.

U.S. DOT:

EnerSys batteries that are classified as Nonspillable have been tested and meet the nonspillable criteria listed in CFR 49, 173.159 (d) (3) (i) and (ii).

Nonspillable batteries are excepted from CFR 49, Subchapter C requirements, provided that the following criteria are met:

1. The batteries must be protected against short circuits and securely packaged.
2. Each battery and their outer packaging must be plainly and durably marked "NONSPILLABLE" or "NONSPILLABLE BATTERY".

The exception from CFR 49, Subchapter C translates to no proper shipping name, no hazardous class, no UN number, no packing group and no hazardous labels when transporting a nonspillable battery.

Contact your EnerSys representative for additional information regarding the classification of batteries.

IATA:

EnerSys batteries that are classified as Nonspillable have been tested and meet the nonspillable criteria listed in IATA Packing Instruction 806 and Special Provision A67. Nonspillable batteries must be packed according to IATA Packing Instruction 806.

These batteries are excepted from all IATA regulations provided that the batteries' terminals are protected against short circuits.

Contact your EnerSys representative for additional information regarding the classification of batteries.

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MATERIAL SAFETY DATA SHEET

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IX. OTHER REGULATORY INFORMATION (Cont.)

IMDG:

EnerSys batteries that are classified as Nonspillable have been tested and meet the nonspillable criteria listed in Special Provision 238. Non-spillable batteries must be packed according to IMDG Packing Instruction P003.

These batteries are excepted from all IMDG code provided that the batteries' terminals are protected against short circuits per PP16.

Contact your EnerSys representative for additional information regarding the classification of batteries.

RCRA:

Spent lead-acid batteries are not regulated as hazardous waste by the EPA when recycled, however state and international regulations may vary.

CERCLA (Superfund) and EPCRA:

(a) Reportable Quantity (RQ) for spilled 100% sulfuric acid under CERCLA (Superfund) and EPCRA (Emergency Planning Community Right to Know Act) is 1,000 lbs. State and local reportable quantities for spilled sulfuric acid may vary.

(b) Sulfuric acid is a listed "Extremely Hazardous Substance" under EPCRA, with a Threshold Planning Quantity (TPQ) of 1,000 lbs.

(c) EPCRA Section 302 notification is required if 1,000 lbs. or more of sulfuric acid is present at one site. The quantity of sulfuric acid will vary by battery type. Contact your EnerSys representative for additional information.

(d) EPCRA Section 312 Tier 2 reporting is required for batteries if sulfuric acid is present in quantities of 500 lbs. or more and/or if lead is present in quantities of 10,000 lbs. or more.

(e) Supplier Notification: This product contains toxic chemicals, which may be reportable under EPCRA Section 313 Toxic Chemical Release Inventory (Form R) requirements.

If you are a manufacturing facility under SIC codes 20 through 39, the following information is provided to enable you to complete the required reports:

Toxic Chemical	CAS Number	Approximate % by Wt.
Lead	7439-92-1	60
Sulfuric Acid	7664-93-9	10 - 30
* Antimony	7440-36-0	2
* Arsenic	7440-38-2	0.2

If you distribute this product to other manufacturers in SIC Codes 20 through 39, this information must be provided with the first shipment of each calendar year.

The Section 313 supplier notification requirement does not apply to batteries, which are "consumer products".

* Not present in all battery types. Contact your EnerSys representative for additional information.

TSCA:

Ingredients in EnerSys' batteries are listed in the TSCA Registry as follows:

	Components	CAS Number	TSCA Status
Electrolyte:	Sulfuric Acid (H_2SO_4)	7664-93-9	Listed
Inorganic Lead Compound:			
	Lead (Pb)	7439-92-1	Listed
	Lead Oxide (PbO)	1317-36-8	Listed
	Lead Sulfate ($PbSO_4$)	7446-14-2	Listed
	Antimony (Sb)	7440-36-0	Listed
	Arsenic (As)	7440-38-2	Listed
	Calcium (Ca)	7440-70-2	Listed
	Tin (Sn)	7440-31-5	Listed

CAA:

EnerSys supports preventative actions concerning ozone depletion in the atmosphere due to emissions of CFC's and other ozone depleting chemicals (ODC's), defined by the USEPA as Class I substances. Pursuant to Section 611of the Clean Air Act Amendments (CAAA) of 1990, finalized on January 19, 1993, EnerSys established a policy to eliminate the use of Class I ODC's prior to the May 15, 1993 deadline.

Page 4

MODEL	Voltage	PHCA** (5 sec.)	CCA*	HCA	MCA	Nominal Capacity (20 Hr Rate-Ah)	(10 Hr Rate-Ah)	Reserve Capacity Minutes	Length inches (mm)	Width inches (mm)	Height inches (mm)	Weight lbs (kg)	Terminal	Torque Specs in-lbs (Nm max)	Internal Resistance (mΩ)	Short Circuit Current
 PC310	12	310	100	200	155	8	7	9	5.43 (138.0)	3.90 (99.0)	3.98 (101.0)	5.9 (2.7)	M4 Receptacle	8.9 (1.0)	27.1	455A

ODYSSEY®

THE EXTREME BATTERY

MSDS

Section I - Product and Manufacturer Identity

Product identity:

Sealed Lead Battery

Cyclon®, Genesis®, SBS, SBS J, Hawker XE™ Odyssey® or Trolling Thunder™

Manufacturer's Name and Address:
EnerSys Energy Products Inc. (formerly Hawker Energy Products Inc.)
617 North Ridgeview Drive
Warrensburg, MO 64093-9301
Emergency Telephone Number: (660) 429-2165
Customer Service Telephone Number: 800-964-2837

Section II - Ingredients

Hazardous Components	CAS #	OSHA PEL-TWA	% (By weight)
Lead	7439-92-1	50µg/m3	45 - 60 %
Lead Dioxide	1309-60-0	50µg/m3	15 - 25 %
Sulfuric Acid Electrolyte	7664-93-9	1.0 mg/m3	15 - 20 %
Non-Hazardous Materials	N/A	N/A	5 - 10 %

Section III - Physical/Chemical Characteristics

Boiling Point - N/A Specific Gravity ($H2O=1$) - NA
Vapor Pressure (mm Hg.) - N/A Melting Point - N/A
Solubility in Water - N/A Appearance & Color - N/A

Section IV - Fire & Explosion Hazard Data

Flash Point (Method Used): N/A **Flammable Limits**: N/A **LEL**: N/A **UEL**: N/A

Extinguishing Media:
Multipurpose Dry chemical, CO2 or water spray.

Special Fire Fighting Procedures:
Cool Battery exterior to prevent rupture. Acid mists and vapors in a fire are toxic and corrosive. Unusual Fire and Explosion Hazards: Hydrogen gas may be produced and may explode if ignited. Remove all sources of ignition.

Section V - Reactivity Data and Shipping/Handling Electrical Safety

Conditions to Avoid: Avoid shorting, high levels of short circuit current can be developed across the battery terminals. Do not rest tools or cables on the battery. Avoid over-charging. Use only approved charging methods. Do not charge in gas tight containers.

Requirements for Safe Shipping and Handling of Cyclon® Cells: Warning – Electrical Fire Hazard – Protect Against Shorting

- Terminals can short and cause a fire if not insulated during shipping.
- Cyclon® product must be labeled "NONSPILLABLE" during shipping. Follow all federal shipping regulations. See section IX of this sheet and CFR 49 Parts 171 through 180, available anytime online at wwww.gpoaccess.gov.

Requirements for Shipping Cyclon® Product as Single Cells

- Protective caps or other durable inert material must be used to insulate each terminal of each cell unless cells are shipping in the original packaging from EnerSys, in full box quantities.
- Protective caps are available for all cell sizes by contacting EnerSys Customer Service at 1-800-964-2837.

Requirements for Shipping Cyclon® Product Assembled Into Multicell Batteries

- Assembled batteries must have short circuit protection during shipping.
- Exposed terminals, connectors, or lead wires must be insulated with a durable inert material to prevent exposure during shipping.

Section VI - Health Hazard Data

Routes of Entry: N/A

Health Hazards (Acute & Chronic): N/A

Emergency & First Aid Procedures:
Battery contains acid electrolyte which is absorbed in the separator material. If battery case is punctured, completely flush any released material from skin or eyes with water.

Proposition 65:
Warning: Battery posts, terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

Section VII - Product and Manufacturer Identity

Steps to be taken in case material is released or spilled:
Avoid contact with acid materials. Use soda ash or lime to neutralize. Flush with water.

Waste Disposal Method:
Dispose of in accordance with Federal, State, & Local Regulations. Do not incinerate. Batteries should be shipped to a reclamation facility for recovery of the metal and plastic components as the proper method of waste management. Contact distributor for appropriate product return procedures.

Section VIII - Control Measures - Not Applicable

Section IX - Transportation, Shipping and Handling

EnerSys Energy Products Inc. batteries are starved electrolyte batteries which means the electrolyte is absorbed in the separator material. The batteries are also sealed. As of September 30, 1995, EnerSys Energy Products Inc. batteries were classified as "nonspillable batteries", and as such are not subject to the full requirements of 49 CFR § 173.159. The previous exempt classification, "Dry Batteries, Not Restricted" was discontinued effective September 30, 1995. "Nonspillable" batteries are excepted from the regulation's comprehensive packaging requirements if the following conditions are satisfied: (1) The battery is protected against short circuits and is securely packaged. (2) For batteries manufactured after September 30, 1995, the battery and outer packaging must be plainly and durably marked "NONSPILLABLE" or "NONSPILLABLE BATTERY". (3) The battery is capable of withstanding vibration and pressure differential tests specified in 49 CFR § 173.159(d). (4) At a temperature of 55 ºC (131ºF), the battery must not contain any unabsorbed free-flowing liquids, and is designed so that electrolyte will not flow from a ruptured or cracked case.

EnerSys Energy Products Inc. batteries have been tested by WYLE Scientific Services & Systems Laboratories Group and determined to be in compliance with the vibration and pressure differential tests contained in 49 CFR § 173.159(d), and therefore as of September 30, 1995, excepted from the DOT requirements set forth in 49 CFR § 173.159, other than paragraph (d).

Battery shipments from EnerSys Energy Products Inc. Warrensburg location, will be properly labeled in accordance with applicable DOT regulations.

Packaging changes performed at other locations may require additional labeling, since in addition to the battery itself containing the required marking, the outer packaging of the battery must also contain the required marking: "NONSPILLABLE" OR "NONSPILLABLE BATTERY". Because the batteries are classified as "Nonspillable" and meet the three conditions above, [from § 173.159(d)] they do not have an assigned UN number nor do they require additional DOT hazard labeling.

The regulation change effective September, 1995, was to clarify and distinguish to shippers and transporters, all batteries that have been tested and determined to be in compliance with the DOT Hazardous Material Regulations, the International Civil Aeronautics Organization (ICAO), and the International Air Transport Association (IATA) Packing Instruction 806 and Special Provision A67, and therefore excepted from all other requirements of the regulations and classified as a "nonspillable battery".

Per 42 USC Section 14322 (US Code Title 42 – The Public Health and Welfare), packaging must be marked with the following: "Contains Sealed Lead Battery" and "Battery Must Be Recycled".

Section X - Additional Information

The EnerSys Energy Products Inc. sealed lead acid battery is determined to be an "article" according to the OSHA Hazard Communication Standard and is thereby excluded from any requirements of the standard. The Material Safety Data Sheet is therefore supplied for informational purposes only.

The information and recommendations contained herein have been compiled from sources believed to be reliable and represent current opinion on the subject. No warranty, guarantee, or representation is made by EnerSys Energy Products Inc., as to the absolute correctness or sufficiency of any representation contained herein and EnerSys Energy Products Inc. assumes no responsibility in connection therewith, nor can it be assumed that all acceptable safety measures are contained herein, or that additional measures may not be required under particular or exceptional conditions or circumstances.

N/A or Not Applicable - Not applicable for finished product used in normal conditions.
Informational MSDS Part Number 2602-0043 Rev. 2 (09/07/06)

Appendix B. Flotation Calculation

Description	Sprint (lbs.)	Endurance (lbs.)
Batteries	99	99
Motor	20	20
Hull	35	35
Motor Controller	2	2
Solar Arrays	0	25
Cables	20	20
Steering	15	15
Passenger	150	150
Miscellaneous (Chair, Safety, etc)	30	30
Outboard Unit & Propeller	40	40
TOTAL (x1.2)	**411 (493.2)**	**436 (523.2)**

The displacement due to the wall thickness of our cedarstrip, plywood, and fiberglass composite will account for part of the flotation. The buoyant force,F_B, is calculated as follows, the outriggers are factored into this calculation as well as the full sheet of flotation foam used:

$$F_B = A_{boat} t \rho_{water} + 2\pi r_{outrigger}{}^2 L_{outrigger} \rho_{water} + A_{foam} t_{foam} \rho_{water}$$

$$F_B = 22\ ft^2 \times \frac{0.15\ in}{12\ in/ft} \times 62.2 \frac{lb}{ft^3} + 2\pi \times 5\ in^2 \times 55\ in\ \times 62.2 \frac{lb}{ft^3} \times \frac{1\ ft^3}{1728\ in^3} + 8\ ft \times 4\ ft\ \times 2\ in\ \times 62.2 \frac{lb}{ft^3} = \mathbf{701.125\ lb}$$

$$Bouyancy\ Surplus = 701.125 - 532.2 = \mathbf{168.9\ lb}$$

Therefore, the buoyancy force provided by the hull design is sufficient to sustain the weight of the boat and its componentry if it were to fill with water.

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

IMPORTANT

If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must be endorsed. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

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).

DISCLAIMER

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)

Appendix D. Team Roster

Edward Ruppel '17 is pursuing a Biomedical Engineering degree. He is the co-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.

Christopher Dalke '19 is pursuing a Computer Science degree. He is the co-President and is responsible for designing and constructing the dashboard-telemetry system, as well as overseeing the construction of the low-voltage electronics systems for the boat. He has done extensive work in developing Rochester's custom telemetry and throttle control system.

Matthew Dombroski '17 is pursuing a degree in Electrical and Computer Engineering. He is the 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.

Seth Schaffer '19 is pursuing a Mechanical Engineering degree. He is the Chief Electrical Systems Engineer, and is responsible for designing the electronic systems of the drive motor and drive-by-wire steering, plus the low power console systems and sensors.

Benjamin Martell '19 is pursuing a Mechanical Engineering degree. He is the Chief Mechanical Engineer, and is responsible for designing, testing, and machining parts for the boat.

Joshua Lomeo '18 is pursuing a degree in Chemistry. He is the Chief Technical Writer and is responsible for the report in all aspects.

Madeline Hermann '17 is pursuing a degree in Statistics. She is the Secretary and 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 pursuing a Biomedical Engineering degree. He is the co-Business Manager and is responsible for managing the budget, purchases, and searching for sponsorships.

Nitish Sardana '17 is pursuing a Biomedical Engineering degree. He is the co-Business Manager and is responsible for managing the budget, purchases, and searching for sponsorships.

Devin Marino '18 is pursuing a Mechanical Engineering degree. He is responsible for fundraising for the team, including management of the successful USEED campaign.

Andrew Gutierrez '19 is pursuing a Mechanical Engineering degree. He is responsible for the steering system and assisting in hull construction.

Ryan Green '20 is pursuing a Mechanical Engineering degree. He is responsible for helping the team on various sub-projects and controlling the team's web presence as the social chair.

Maxwell Kearns '20 is pursuing a Chemical Engineering degree. He is responsible for helping the team on various sub-projects.

Martin Barocas '19 is pursuing a Mechanical Engineering degree. He works with the team on various sub-projects and performs a multitude of tasks.

Appendix E. Specifications of Lynch Motor Company's LEM-170

LMC GENERATING MOVEMENT EFFICIENTLY

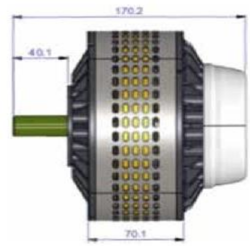
MOTORS LEM-170

Overview

The LEM-170 is an axial gap DC brushed motor suitable for traction and industrial applications.

Example applications include compressors, sweepers, mopeds, golf carts and pumps.

The LEM-170 is available in 95, 126 and 127 strip armatures with magnet grade selection dependant on application.

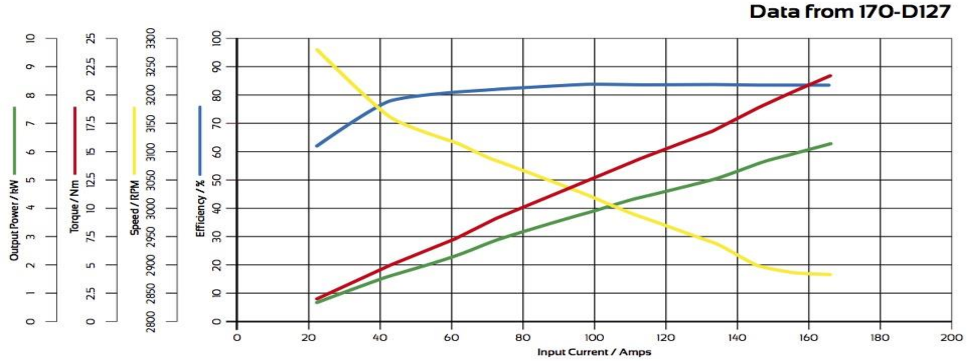


Features

- High efficiency (up to 90%)
- Lightweight design (8.5kg)
- Simple electronic control
- Long brush Life
- Interchangeable Shaft
- Rugged Construction
- CE Marked
- Ip20 rating
- Available from 12 to 60v
- Speed proportional to voltage

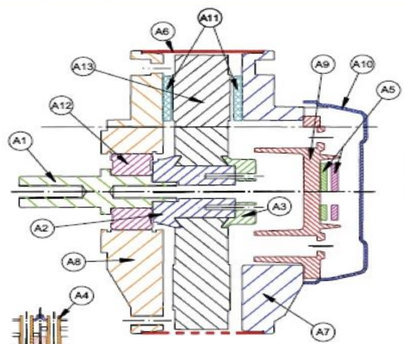
Typical Technical Data Curve

Data from 170-D127

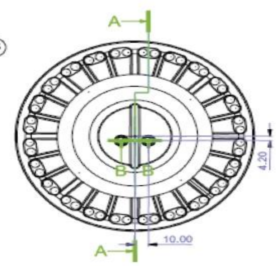


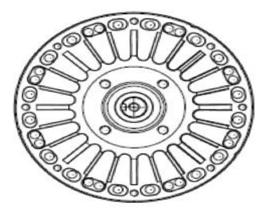
Technical Data

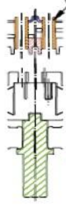
Motor	No Load Current	Torque Constant	Speed Constant	Armature Resistance DC	Armature Inductance @ 15kHz	Armature Inertia	Peak Power	Peak Efficiency	Peak Current	Rated Power	Rated Speed	Rated Voltage	Rated Current	Rated Torque
	A	Nm/A	Rpm/V	mΩ	μH	Kgm^2	kW	%	A	kW	Rpm	V	A	Nm
D127	4	0.134	62	21	15	0.0236	21	90	400	7.10	3720	60	140	18.2
126	18	0.055	140	185	8	0.0234	7	76	400	4.30	3360	24	240	12.2
127	5	0.12	68	24	23	0.0236	16	89	400	5.54	3264	48	140	16.2
95	8	0.101	95	21	18	0.0238	16	88	400	7.2	3420	36	200	16.5



SECTION A-A
Scale 0.75

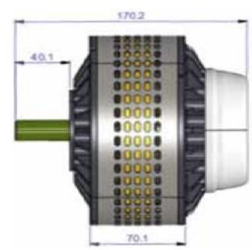






SECTION B-B

Label	QTY	PartNo.	Description
A1	1	LEM 00010 P	Shaft
A2	1	LEM 00008 P	Hub
A3	1	LEM 00009 P	Cap
A4	2	LEM 00012 P	Terminal post
A5	2	LEM 00011 P	Terminal plate
A6	1	LEM 00004 P	Band cover
A7	1	LEM 00006 P	Commutator casting
A8	1	LEM 00007 P	Drive casting
A9	1	LEM 00003 S	Brush holder & Extrustions Sub-Assy
A10	1	LEM 00035 P	Brush Cover
A11	16	LEM 00038 P	Drive magnets
A12	1	LEM 00037 P	Bearing
A13	1	LEM 00039 S	Armature
Dimensions: MM			



LMC | GENERATING MOVEMENT EFFICIENTLY

ACS REGISTRARS ISO 14001
ACS REGISTRARS ISO 9001

LCM Limited, Lynch Motor Company Ltd, Unit 27,
Flightway Business Park, Dunkeswell, Honiton, Devon EX14 4RJ
Tel: +44 (0) 1404 892940 **Fax:**+44 (0) 1404 891990
email: sales@lmcltd.net **www.lmcltd.net**

Appendix F. Specifications and Load Capacity of Steering System Actuator

PROGRESSIVE AUTOMATIONS
FORWARD THINKING

PA-14P LINEAR ACTUATOR
WITH POTENTIOMETER

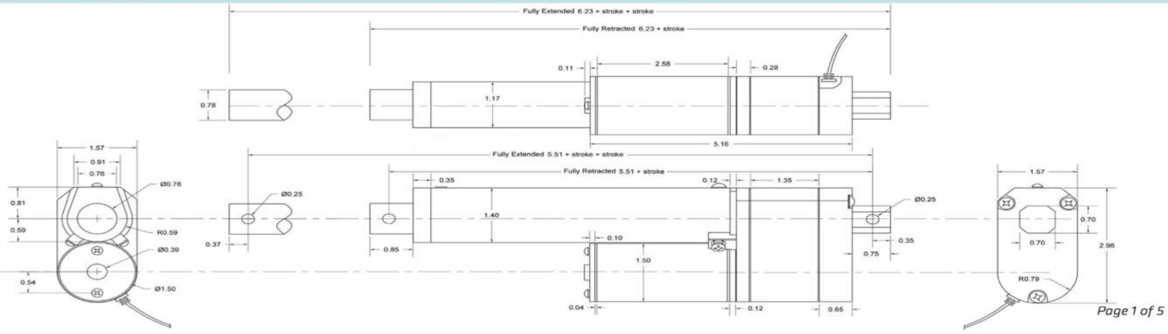
HOW TO ORDER
1.800.676.6123
sales@progressiveautomations.com
www.progressiveautomations.com

SPECIFICATIONS

- Input Voltage: 12 VDC
- Current: 5A at full load
- Load Capacity: 35 lbs, 50 lbs, 150 lbs
- Static Load: 2 x Load
- Speed: 0.59"/sec - 2.00"/sec
- Stroke length: 2" to 40"
- Mounting holes: 0.25" diameter
- Potentiometer: 10K ohm
- Screw: ACME Screw
- Duty Cycle 25%
- Operational Temperature: -26°C~65°C (-15°F~150°F)
- Limit Switch: built-in non adjustable
- IP Grade: IP54
- Certification: CE and RoHS
- Housing: Aluminum Alloy
- Gears: Powder Metallurgy
- Wire Length: 40"
- Gear Ratio: 20:1

For Custom Options See Page 5

DIMENSIONS IN INCHES



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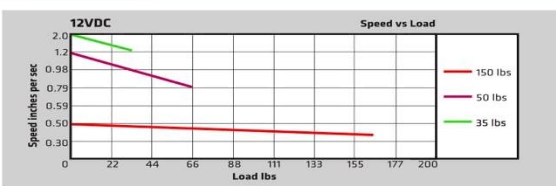
PROGRESSIVE AUTOMATIONS
FORWARD THINKING

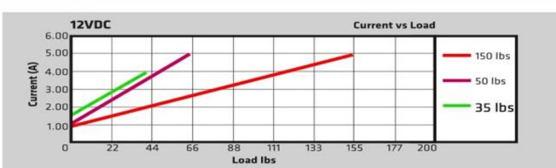
PA-14P LINEAR ACTUATOR
WITH POTENTIOMETER

HOW TO ORDER
1.800.676.6123
sales@progressiveautomations.com
www.progressiveautomations.com

12 VDC SPEED VS LOAD



12 VDC CURRENT VS LOAD



SPEED IN INCHES PER SECOND

Forces (lbs)	No Load	Full Load
35	2.00	1.20
50	1.18	0.94
150	0.59	0.51

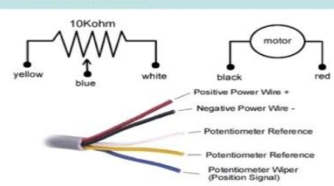
HOLE TO HOLE DIMENSIONS

Stroke Sizes (in inches)	PA-14P Model Actuator Fully Retracted (in inches)	PA-14P Model Actuator Fully Extended (in inches)
0	5.51	5.51
1	6.51	7.51
2	7.51	9.51
3	8.51	11.51
4	9.51	13.51
6	11.51	17.51
8	13.51	21.51
9	14.51	23.51
10	15.51	25.51
12	17.51	29.51
14	19.51	33.51
16	21.51	37.51
18	23.51	41.51
20	25.51	45.51
22	27.51	49.51
24	29.51	53.51
30	35.51	65.51
40	45.51	85.51

PRODUCT ACCESSORIES

- Will work with any PA's AC & DC controls boxes
- Mounting Brackets: BRK-14 (for each end); BRK-03
- Rocker Switches: any PA's Rocker Switches
- Foot Controls: PDL-01, PDL-02 and PDL-03
- Rubber Boot: AC-20

POTENTIONMETER



Red + 12 vdc
Black gnd

(Actuator extends, reverse polarity to retract)

Page 2 of 5

Appendix G. Schematic Diagrams of System Control Board

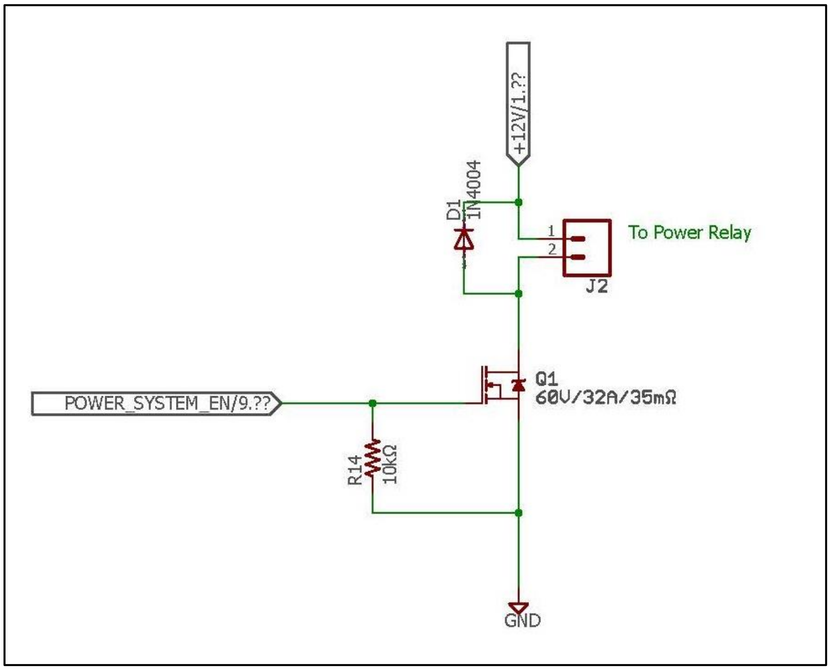


Figure 10: Power system relay enable circuit

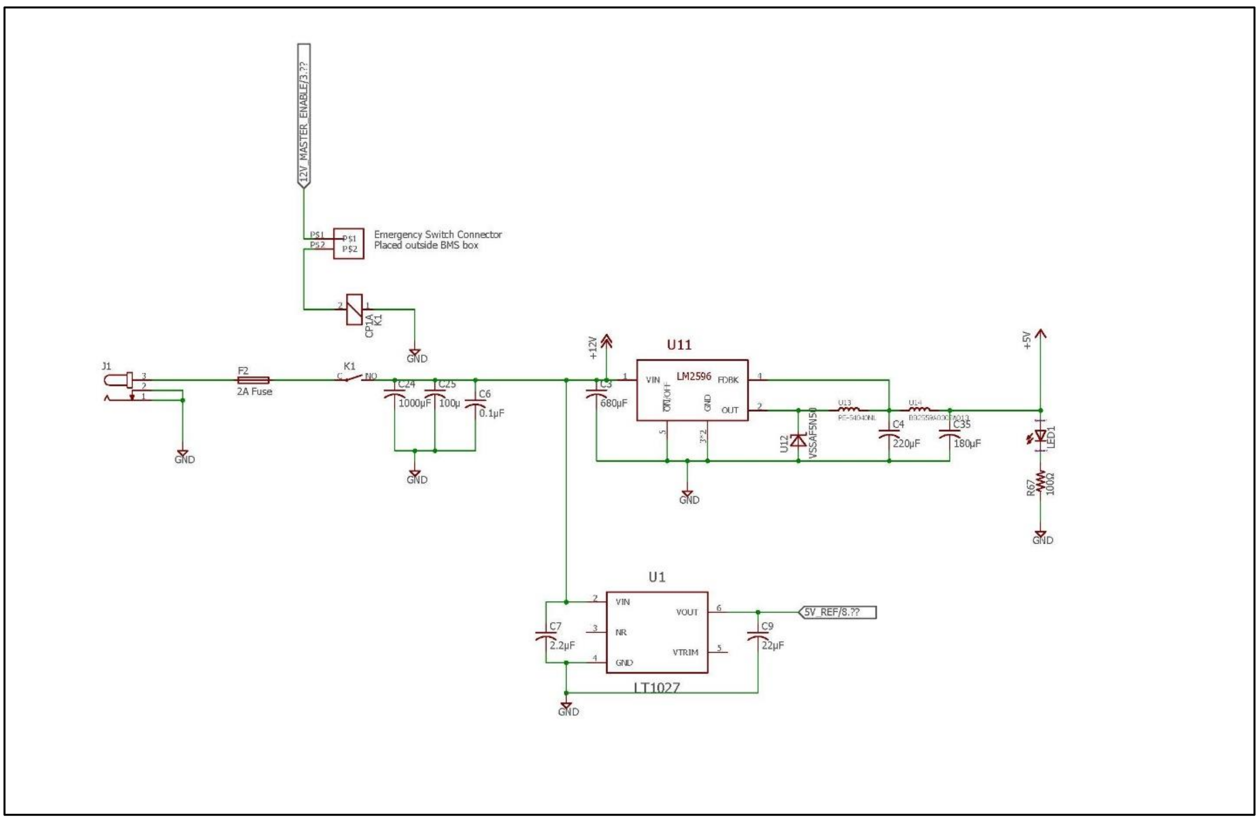


Figure 11: Power Supply Schematic. A 12V input is regulated and conditioned to the required system voltage of 5V.

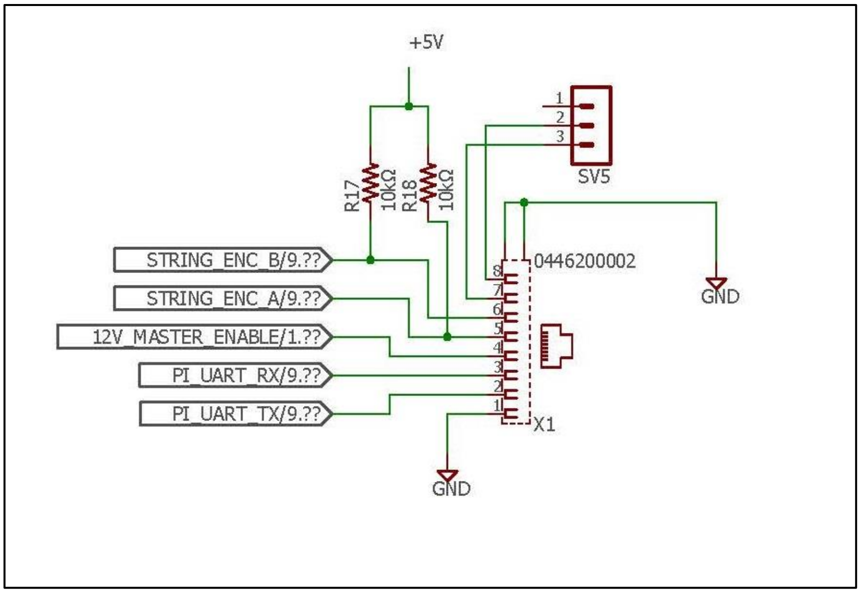


Figure 12: RJ-45 Raspberry Pi pinout schematic

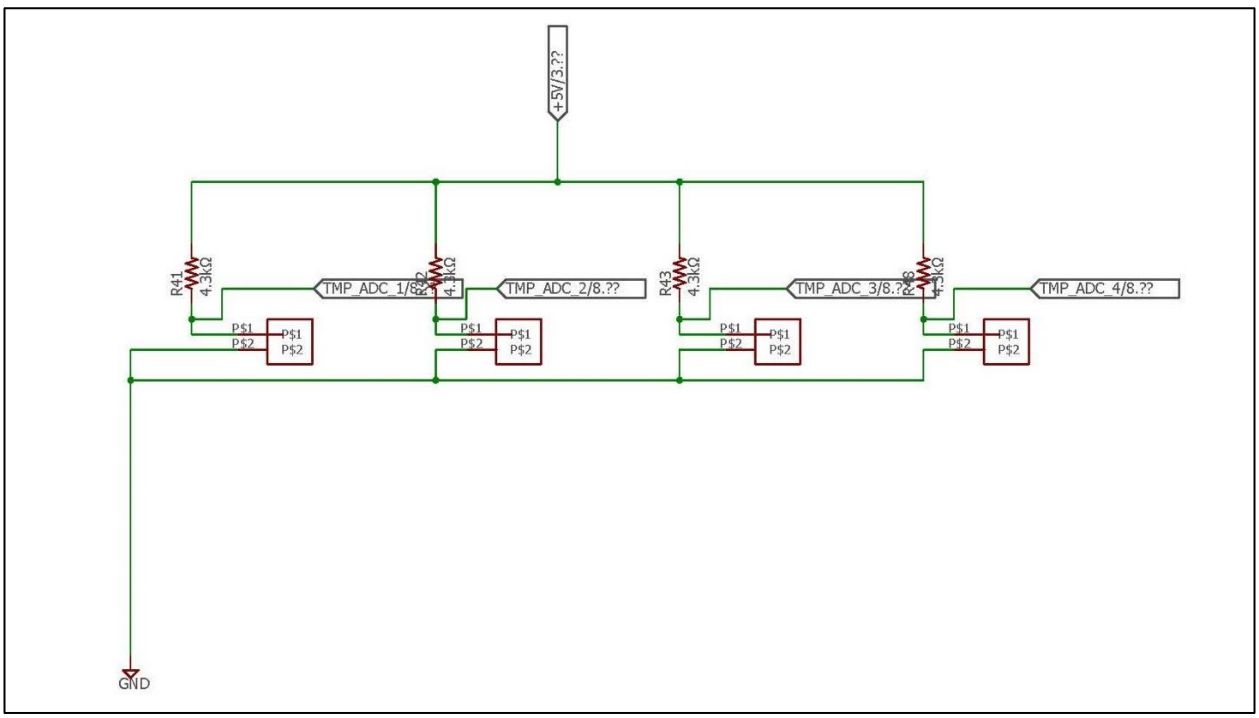


Figure 13: Temperature sensing circuitry schematic

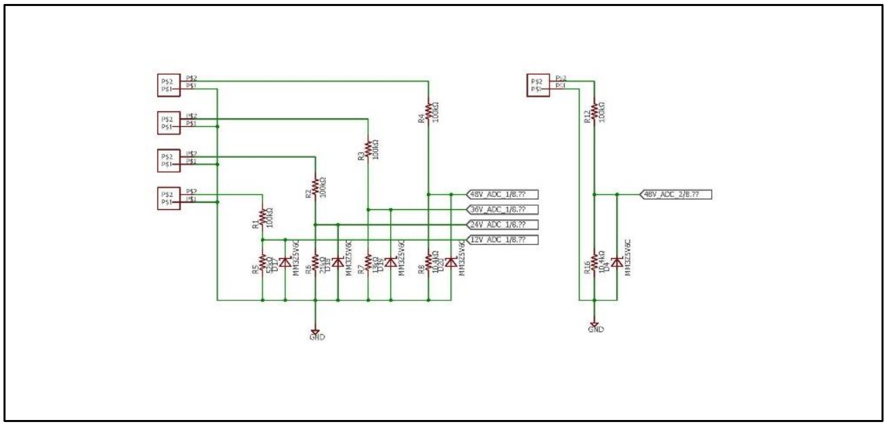


Figure 14: Voltage sensing circuitry schematic

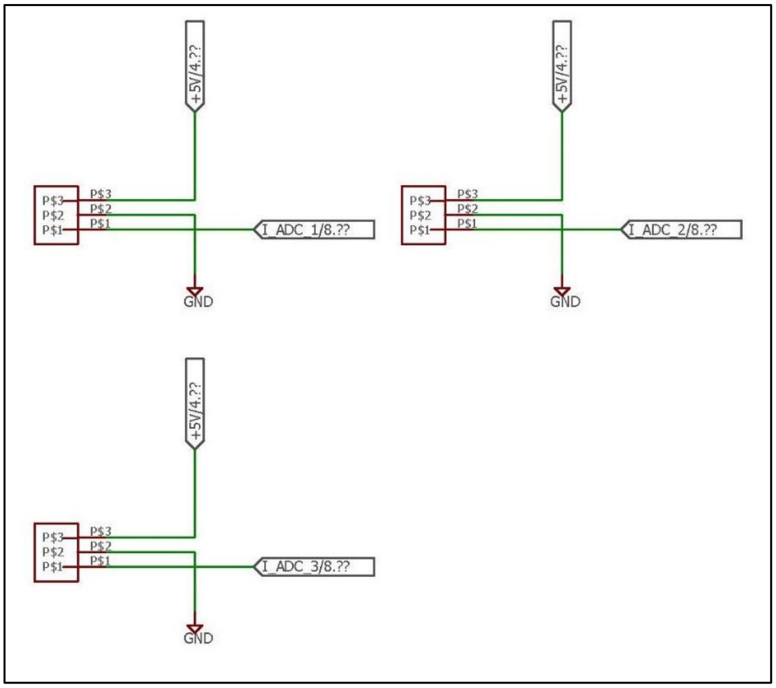


Figure 15: Current sensing circuitry schematic

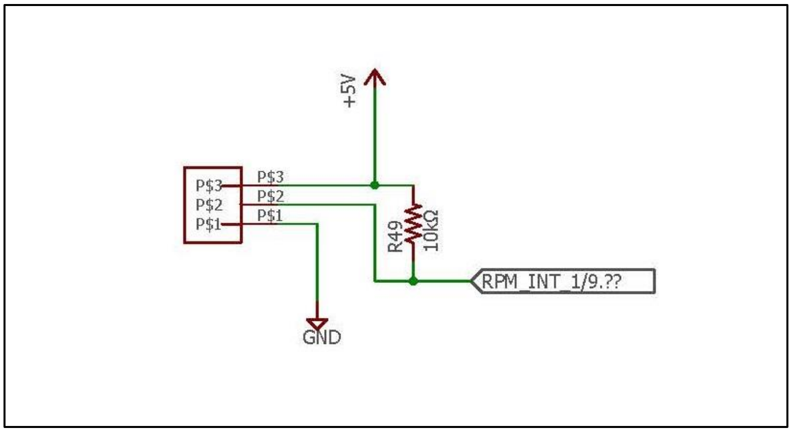


Figure 16: RPM sensing circuit

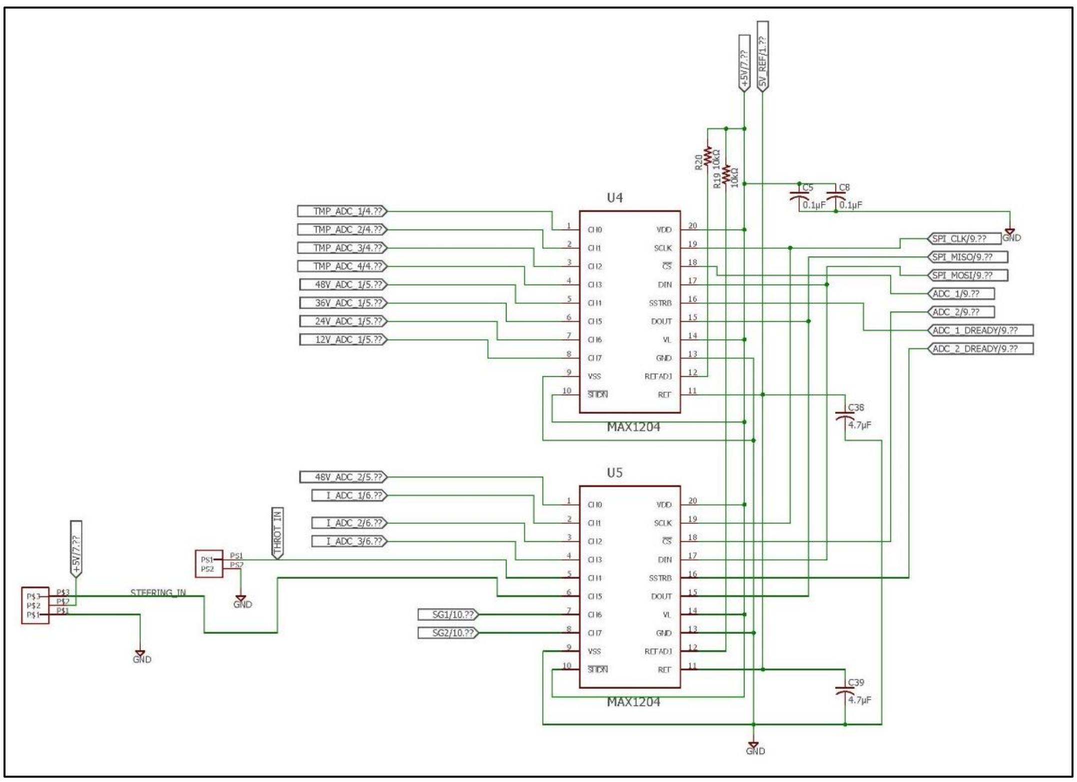


Figure 17: ADC connection schematic

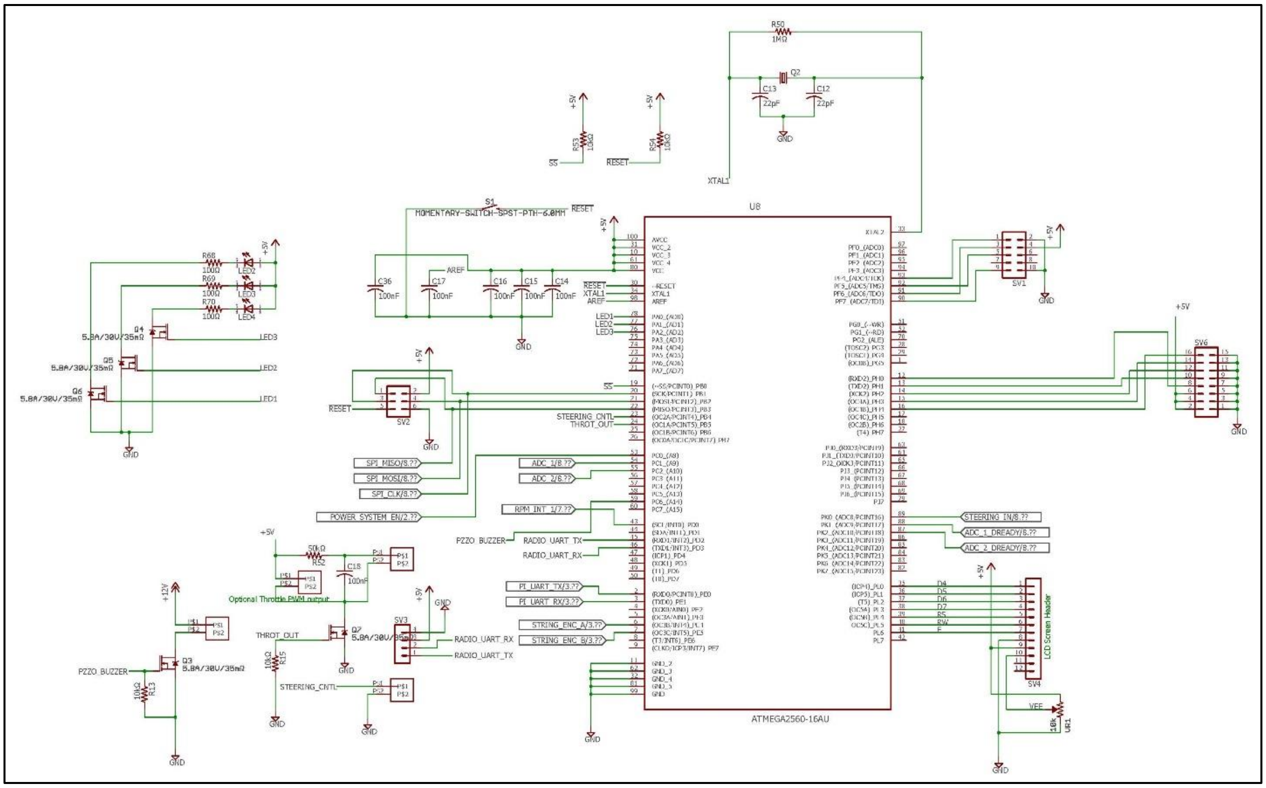


Figure 18: Microcontroller schematic

Appendix H. EagleCAD Render of the System Control Board PCB

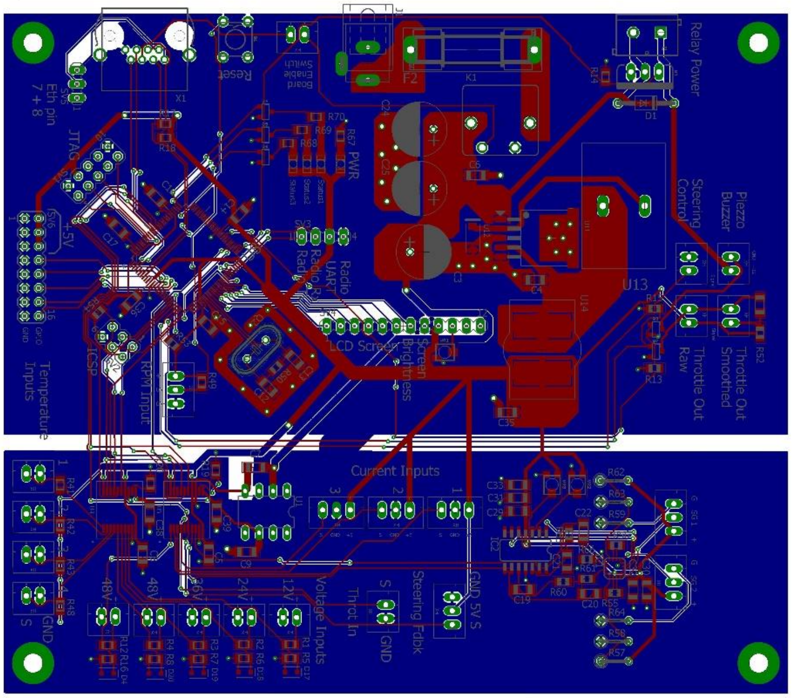


Figure 19: PCB layout render of the final design

Appendix I. 12V Master Enable Line

As seen in Figure 10 the main power relay for the power electronics system is enabled by the system control board via a sending a logic HIGH signal to a MOSFET to drive current through the solenoid. Without the microcontroller and the system control board overall being powered, the main power relay has no way to remain closed. Referencing Figure 11 the system control board is enabled by the 12_MASTER_ENABLE line, which is a 12V signal that comes over the Ethernet cable which goes to the front of the boat. Without 12V applied to the 12V_MASTER_ENABLE line the relay on the system control board cannot be closed and thus power is shut off, and by extension shutting off and deactivating power to the main power electronics relay. By putting the deadman switch in series with the 12V_MASTER_ENABLE line it is ensured that the deadman switch will always completely shut down the power electronics system during any emergency.

Appendix J. Sprint Electrical Losses and Power Consumption

The sprint motor configuration has a peak of 15 HP, which is equivalent to 11.2 kW:

$$15\ Hp \times \frac{745\ W}{1\ HP} = 11175\ W$$

At a peak voltage of 36 V

$$P = IV = 11175 = (36)(I) \rightarrow I = 310.4\ A$$

The current will therefore be on the order of 280-340 A flowing from the batteries depending on the internal impedances.

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. Approximately 15 feet of 1/0 wire was used to wire the power electronics systems of the boat. The voltage drop across the wire is approximately 0.29 V and the power loss is about 6% of our original.

$$R = 15ft \times \frac{.09827\Omega}{1000ft} = 1.47 \times 10^{-3}\Omega$$

$$P = I^2R = 310.4^2(1.47 \times 10^{-3}) = 141.6\ \text{W}$$

$$\%\ Power\ Loss = 100 \times \frac{141\ W}{11175\ W} \approx 1.3\ \%$$

This power loss of course only occurs at peak power consumption during the sprint competition, and only for a short period of time. During the endurance component of the race the current consumption is much lower and thus energy loss due to resistive heating is much lower.

Appendix K. 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.

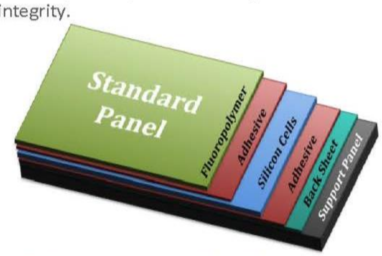
HIGH TRANSPARENCY / LOW GLARE

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!

HAJIM SCHOOL OF ENGINEERING & APPLIED SCIENCES
UNIVERSITY of ROCHESTER

Appendix L. Specifications of Genasun GVB-8-WP

Reliability & efficiency down to a science.

Marine | RV | Industrial | Military | Street Lighting | Off-Grid

Get your money's worth with Genasun. A true problem-solver, the unique GVB charge controller with MPPT allows a lower-voltage solar panel to charge higher-voltage batteries. Want to charge a 24V battery with a 48-cell solar panel? No problem. A 48V battery from a 12V panel? We've got you covered. With 99% peak efficiency, they are the industry's most efficient voltage-boosting controllers. True MPPT delivers consistent performance, unlike the "Nominal MPPT" of competitors. The advanced electronics inside the controller are encased in a proprietary potting compound making them ideal for golf-cart, marine, and vehicle applications.

GVB-8-WP (BOOST) | 8A MPPT @ 12-48V

- Waterproof
- 99% peak efficiency
- Built-in fuse
- Ultra-fast true MPP Tracking
- Excellent low-light performance
- Wire leads for easy installation

Take advantage of Genasun's advanced MPPT technology and enjoy more reliable power from smaller panels.

+10% additional power in the summer. No panel is too hot to handle.

+30% more power on those shorter, colder winter days.

+50% increase in energy harvest from partially shaded panels.

Typical power gains from Genasun MPPT controllers vs the best PWM controllers available.

GENASUN | www.genasun.com (760) 597-1642 | Sold through Blue Sky Energy sales@blueskyenergyinc.com

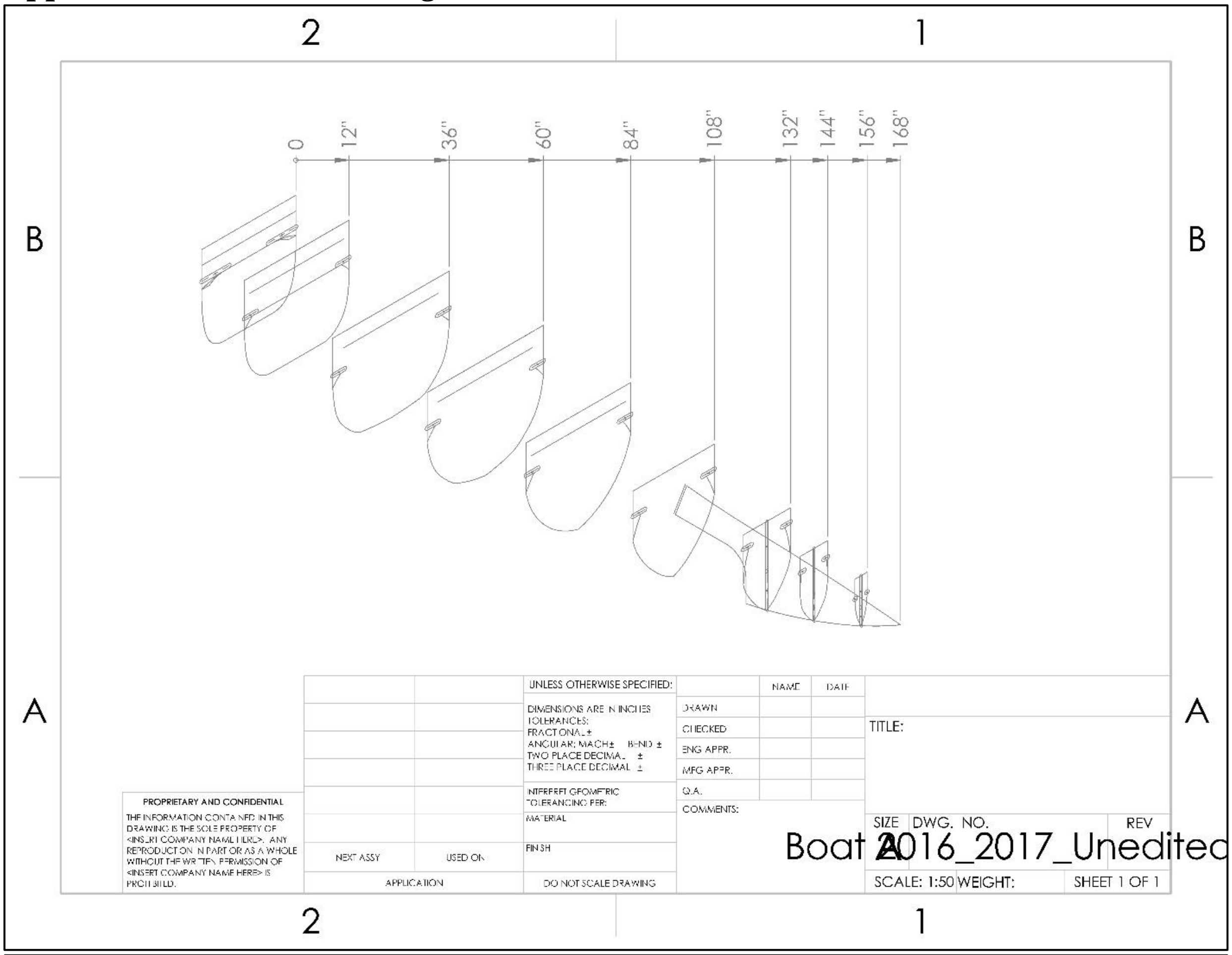
Specifications:

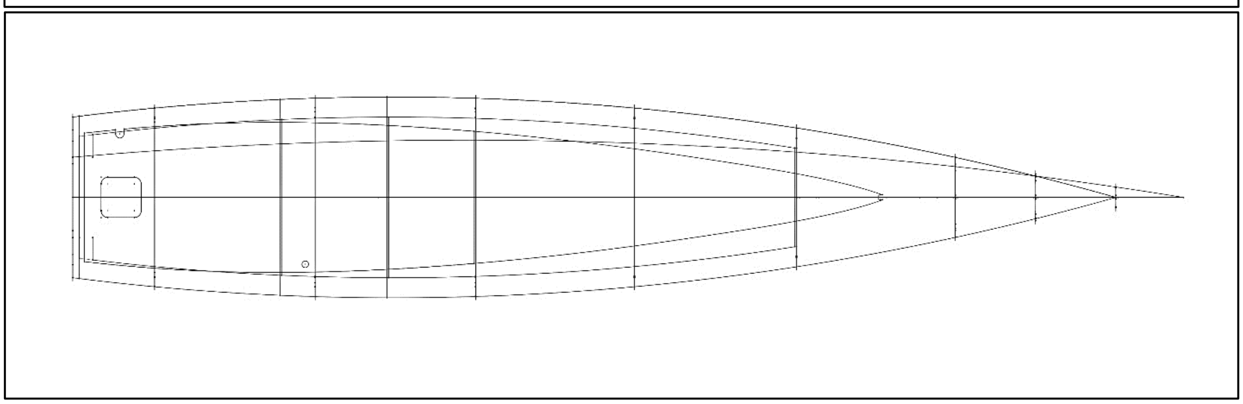
	GVB-8-Pb-12V	GVB-8-Pb-24V	GVB-8-Pb-36V	GVB-8-Pb-48V	GVB-8-Li-**.*V
Rated Panel (Input) Current:	8A*				8A*
Minimum Panel Voltage for Charging:	5V				5V
Minimum Battery Voltage for Operation:	9.5V				9.5V
Absolute Maximum Panel Open-Circuit Voltage (Voc):	60V				60V
Charge Profile:	Multi-Stage with Temperature Compensation				CC-CV
Nominal Battery Voltage:	12V	24V	36V	48V	(See specs for closest -Pb equivalent.)
Maximum Recommended Panel Vmp:	13V	26V	41V	43V	
Maximum Recommended Panel Power (8A Panel w/~155mm cells):	105W	210W	325W	350W	
Bulk Voltage:	14.4V	28.8V	43.2V	57.6V	-
Absorption Voltage:	14.2V	28.4V	42.6V	56.8V	-
Absorption Time:	2 Hours				-
Float Voltage (Pb models) or CV Voltage (Li models):	13.8V	27.6V	41.4V	55.2V	**.*V as specified in part number
Battery Temperature Compensation:	-28mV/°C	-56mV/°C	-84mV/°C	-112mV/°C	-
Electrical Efficiency:	95% - 97% typical	96% - 98% typical	96% - 98% typical	96% - 99% typical	(See specs for closest -Pb equivalent.)
Night Consumption:	7mA	6mA	6mA	5mA	
Tracking Efficiency:	99+% typical				
MPPT Tracking Speed:	15Hz				
Operating Temperature:	-40°C - 85°C				
Enviromental Protection:	IP68, Waterproof (indoor use)				
Connection:	Flying Leads, 16 AWG tinned wire, pre-stripped				
Weight:	10.3oz (290g)				
Dimensions:	5.5x3.2x2.2", (14x8.1x5.5cm)				
Warranty:	5 years				

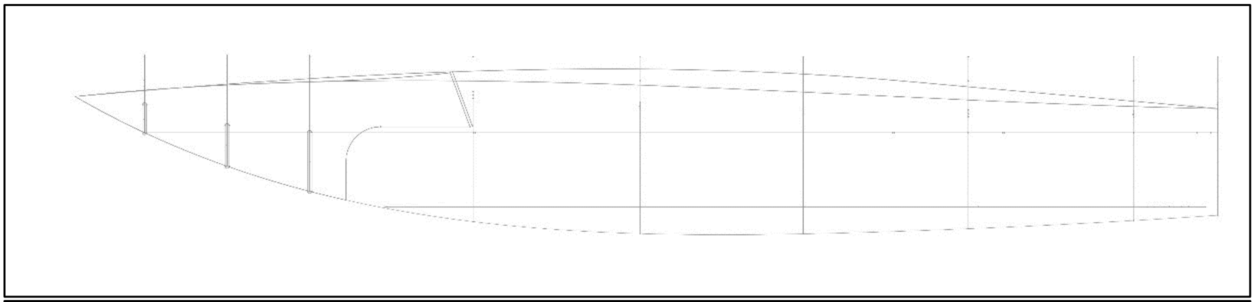
*Panel ratings have increased since we designed the GVB. Although we don't believe in changing specifications without a corresponding engineering change, based on both our customers' experiences over the years as well as the headroom we designed into the GVB, we feel comfortable recommending the GVB for panels with Imp up to 8A.

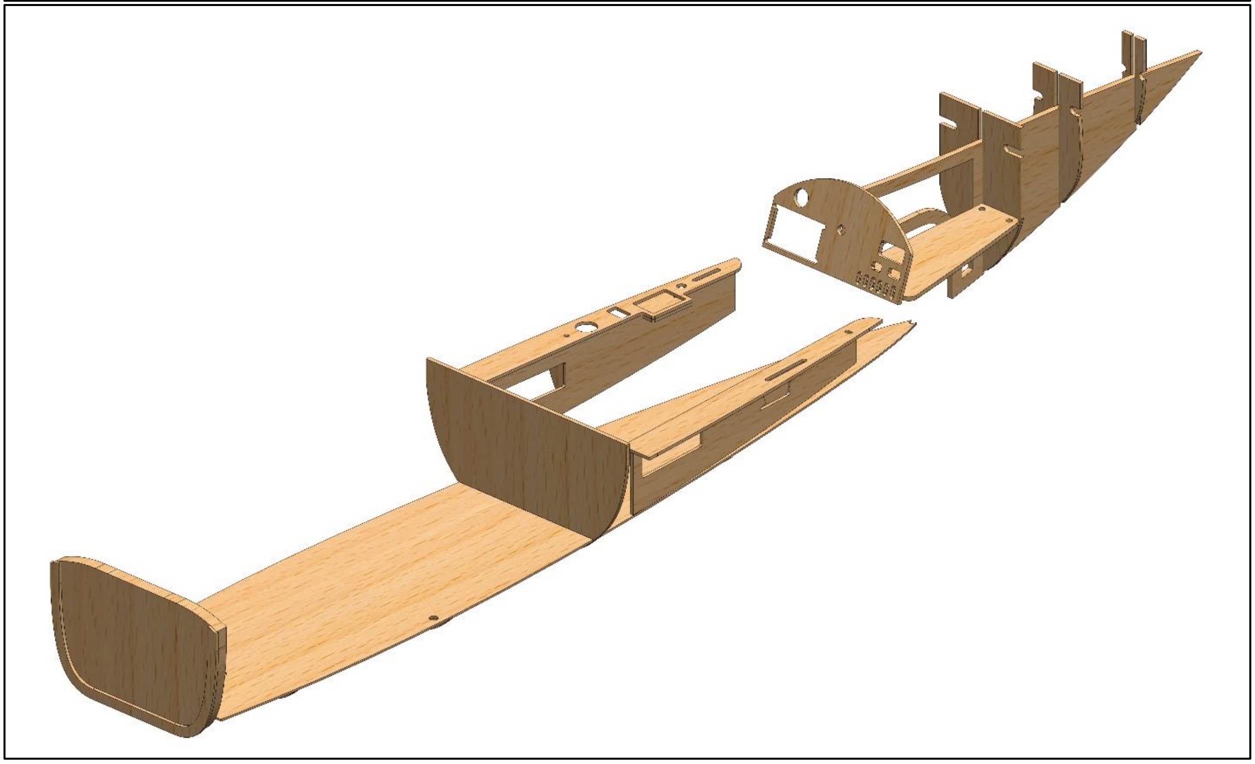
Certifications: CE FC RoHS

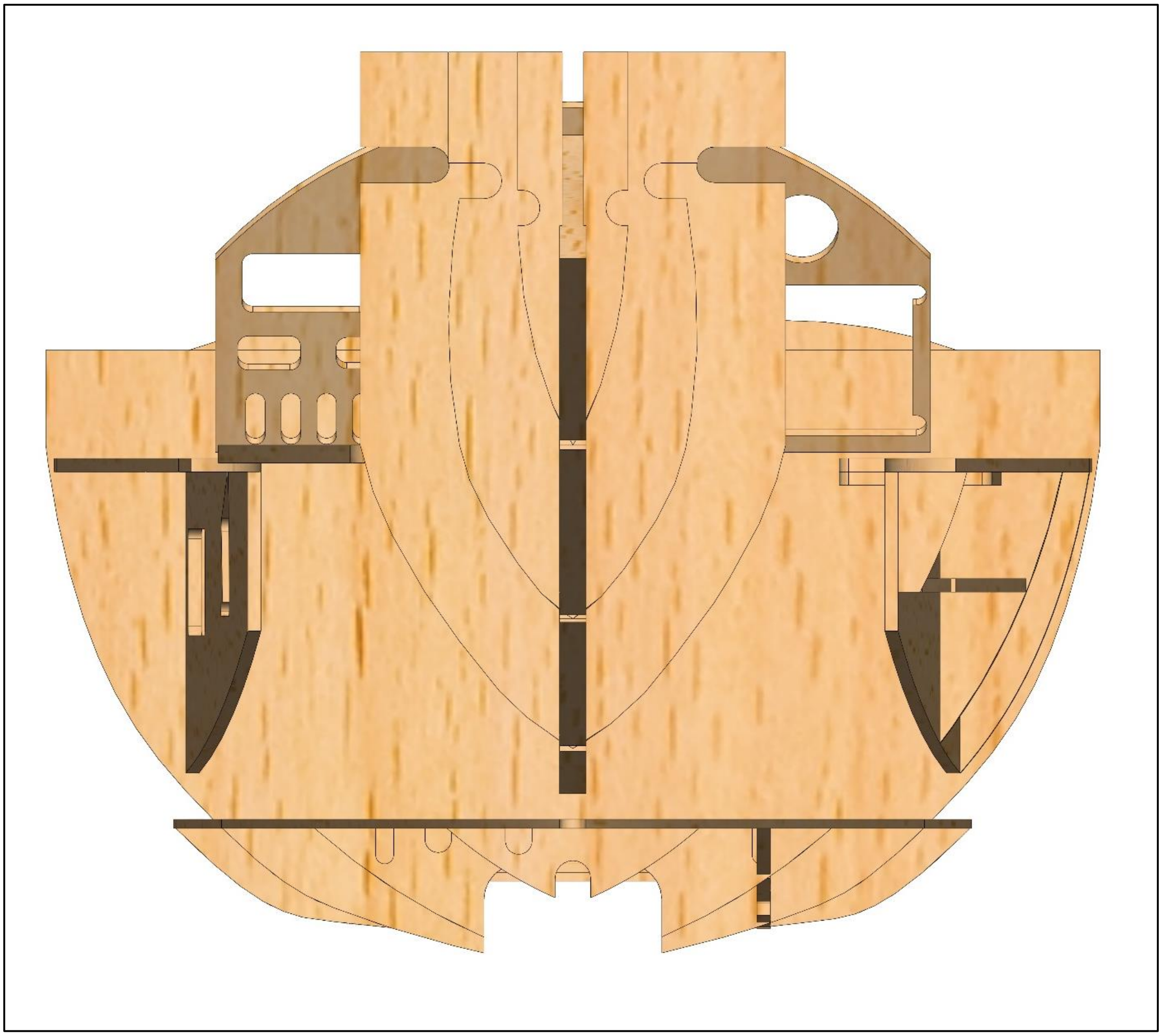
Appendix M. Hull Design Schematics

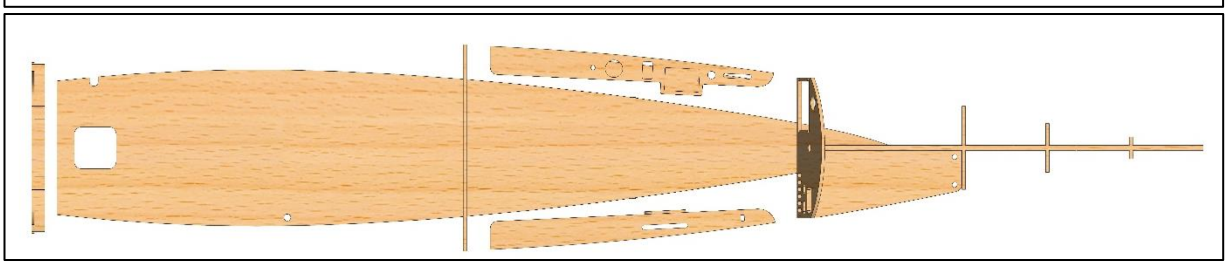




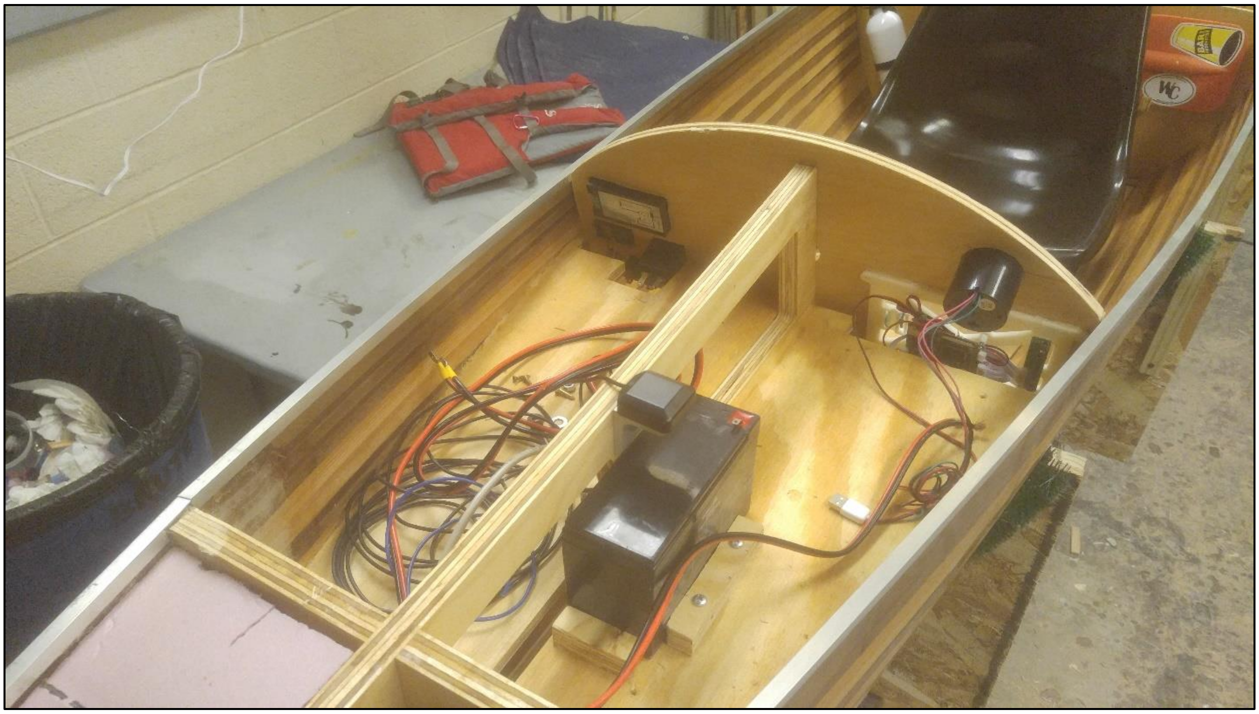


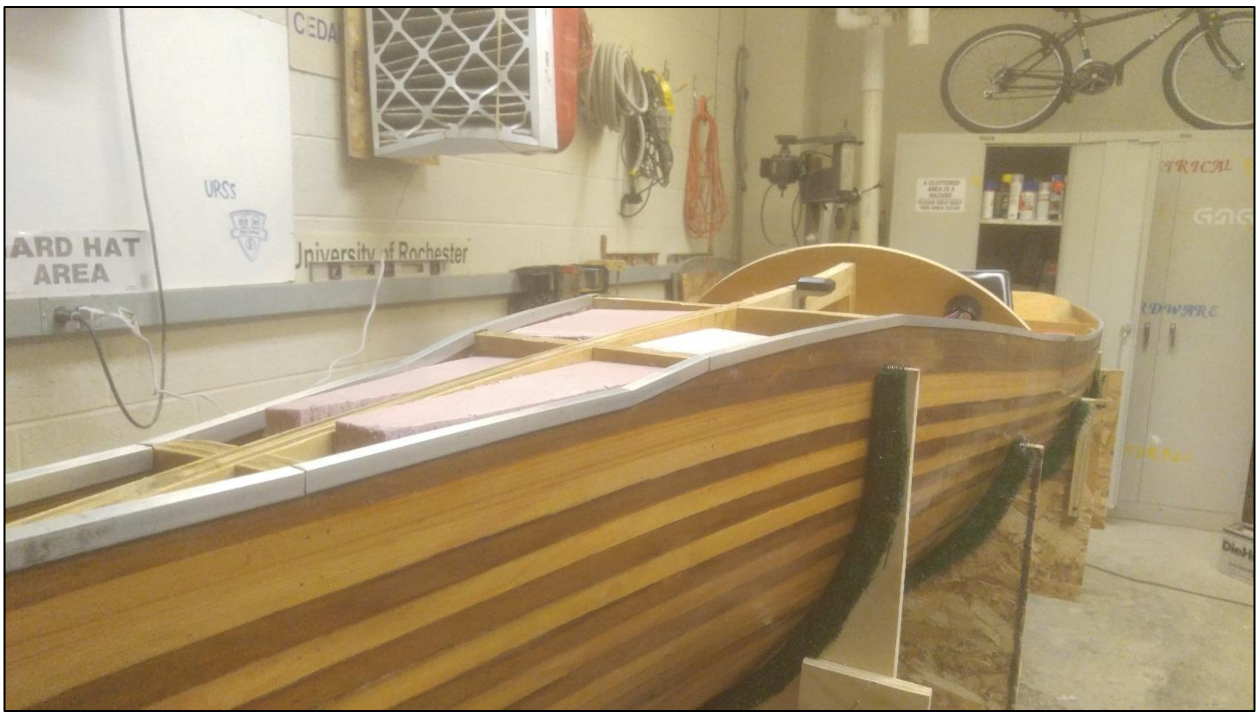






Appendix N. Hull Construction Photos

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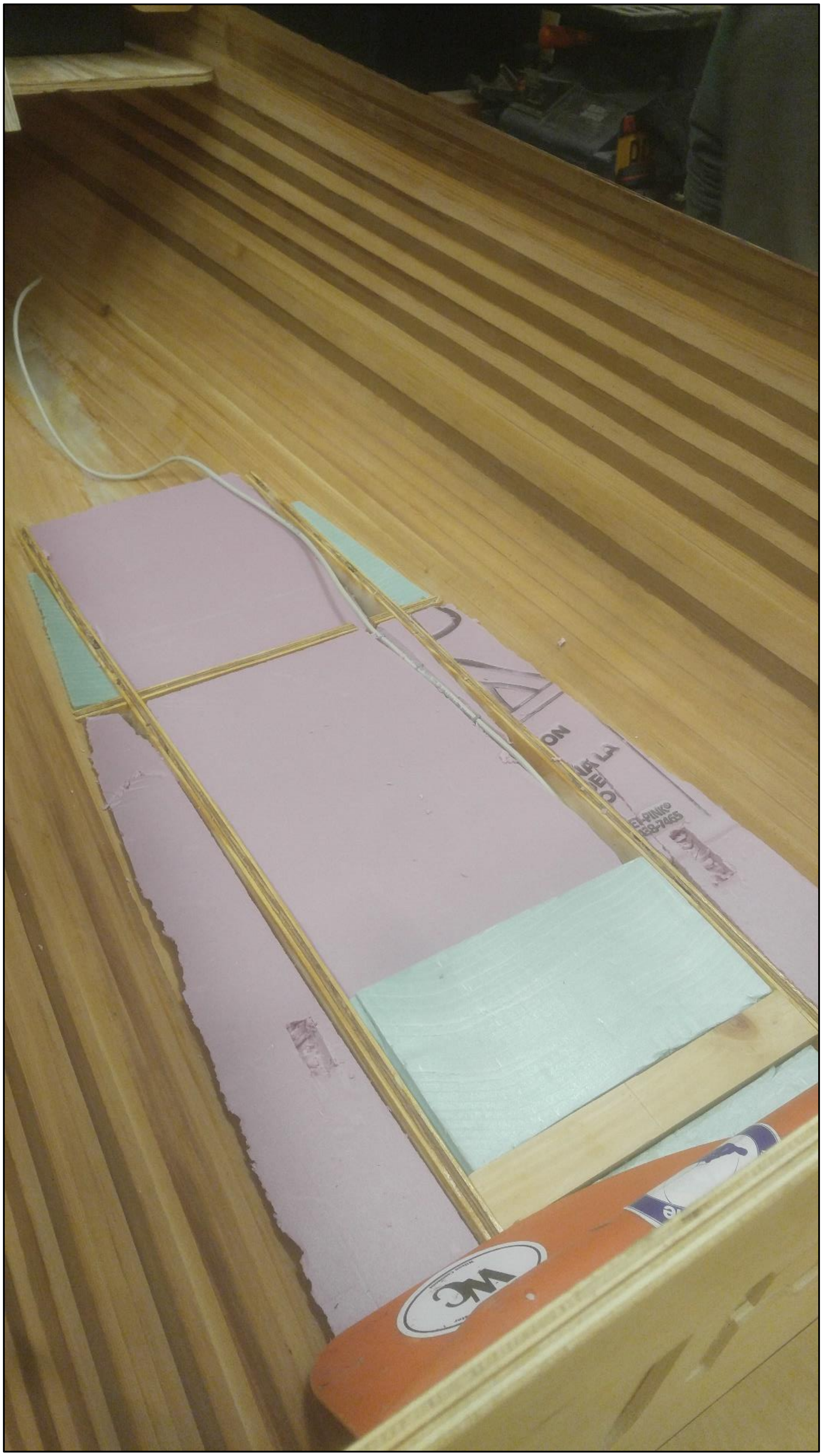

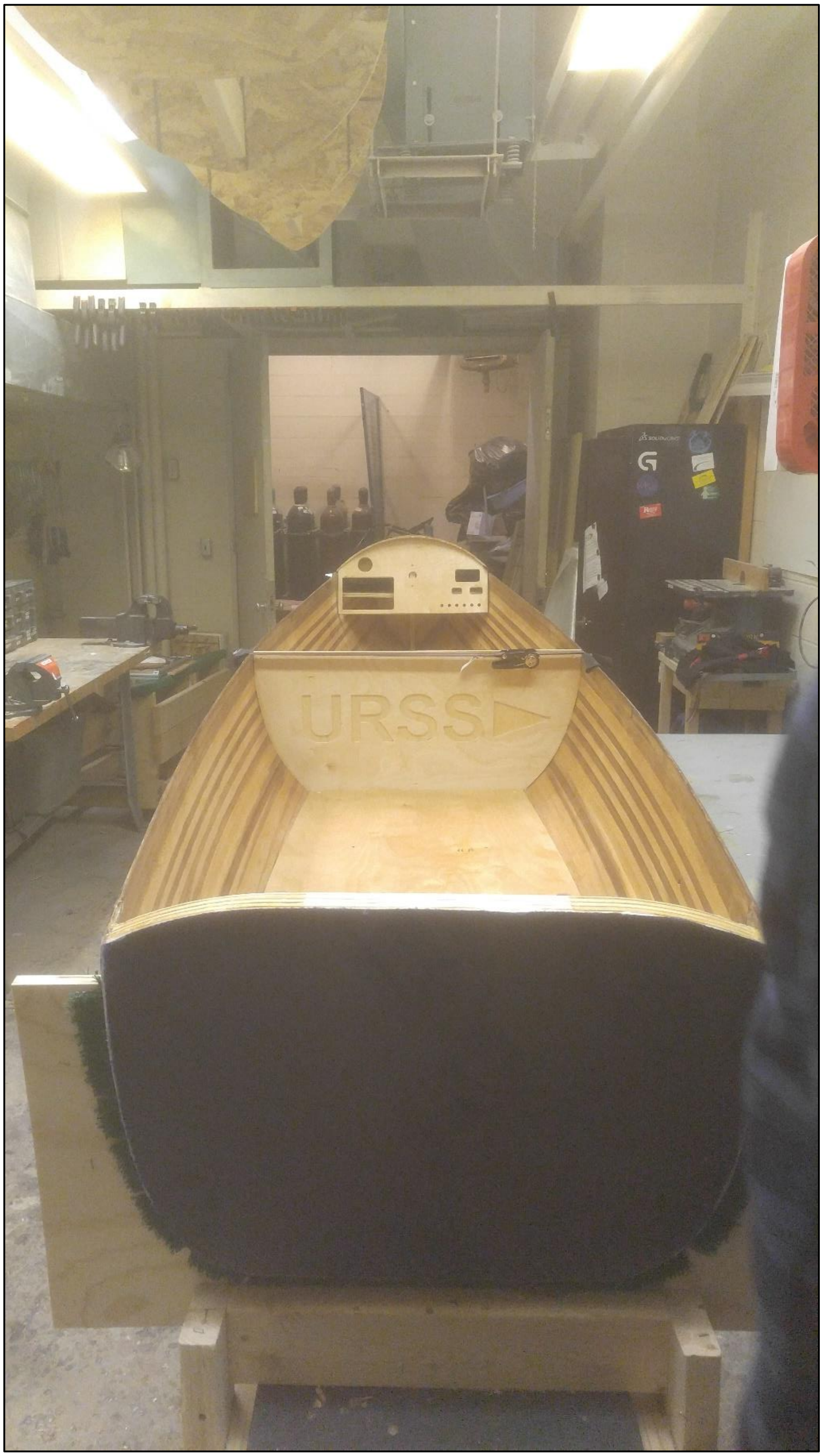
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HARDWARE
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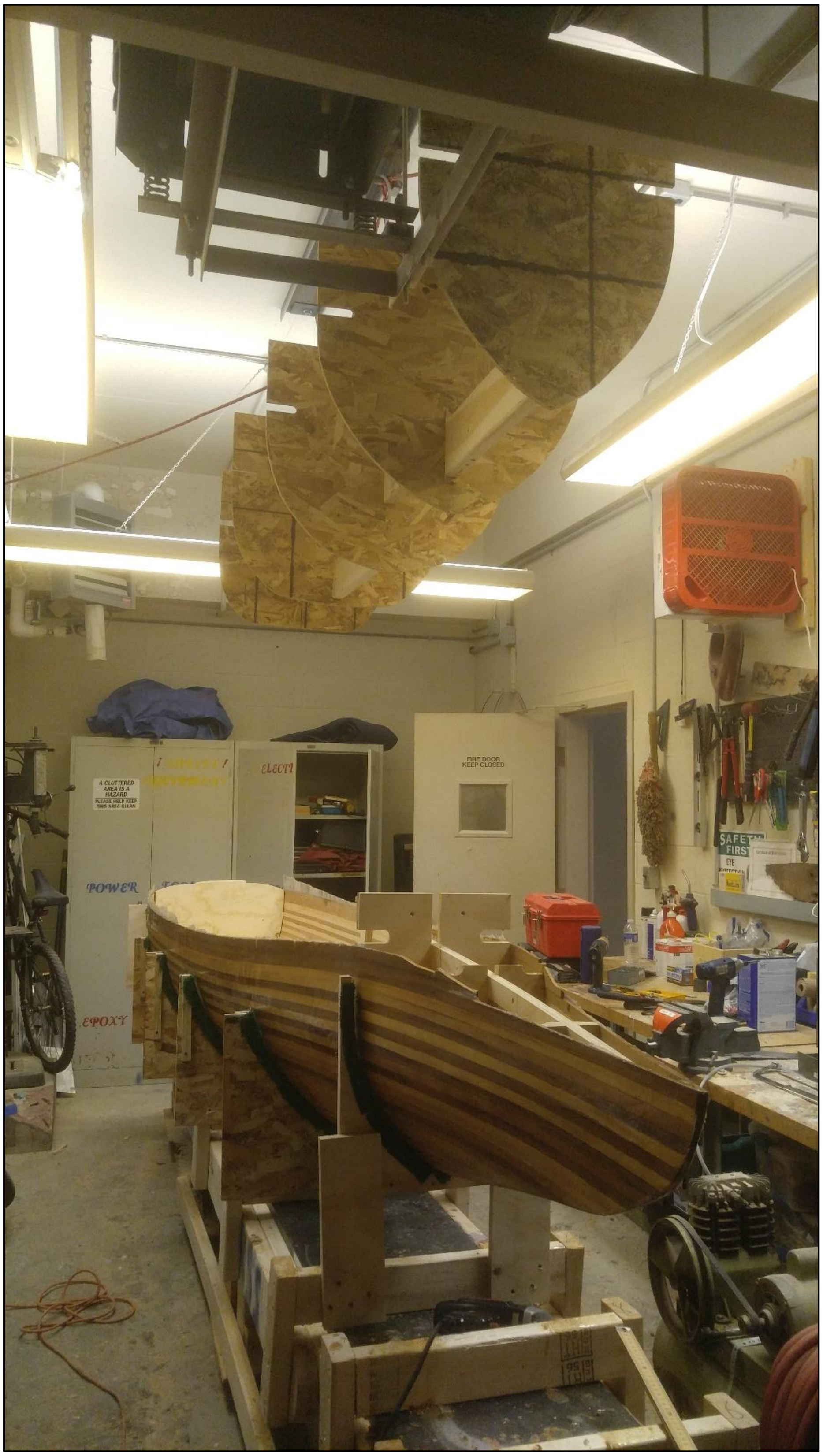
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EPOXY


ELECTRICAL


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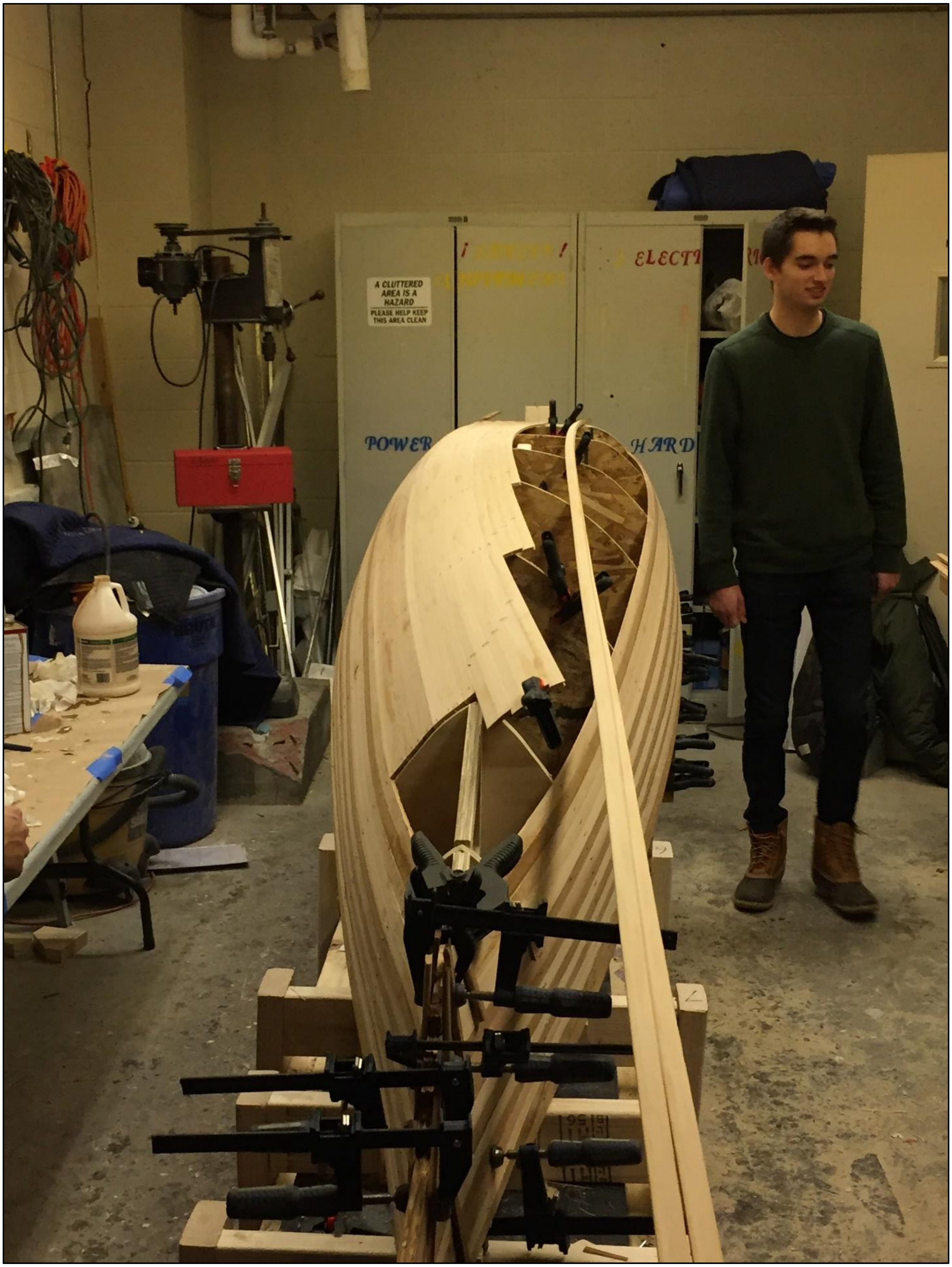
KEEP CLOSED
A CLUTTERED AREA IS A HAZARD


ELECTRICAL
POWER TOOLS
HARDWARE
FIRE DOOR
KEEP CLOSED
A CLUTTERED AREA IS A HAZARD
PLEASE HELP KEEP THIS AREA CLEAN


POWER


A CLUTTERED AREA IS A HAZARD
PLEASE HELP KEEP THIS AREA CLEAN
POWER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HARDWARE
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FIRE DOOR
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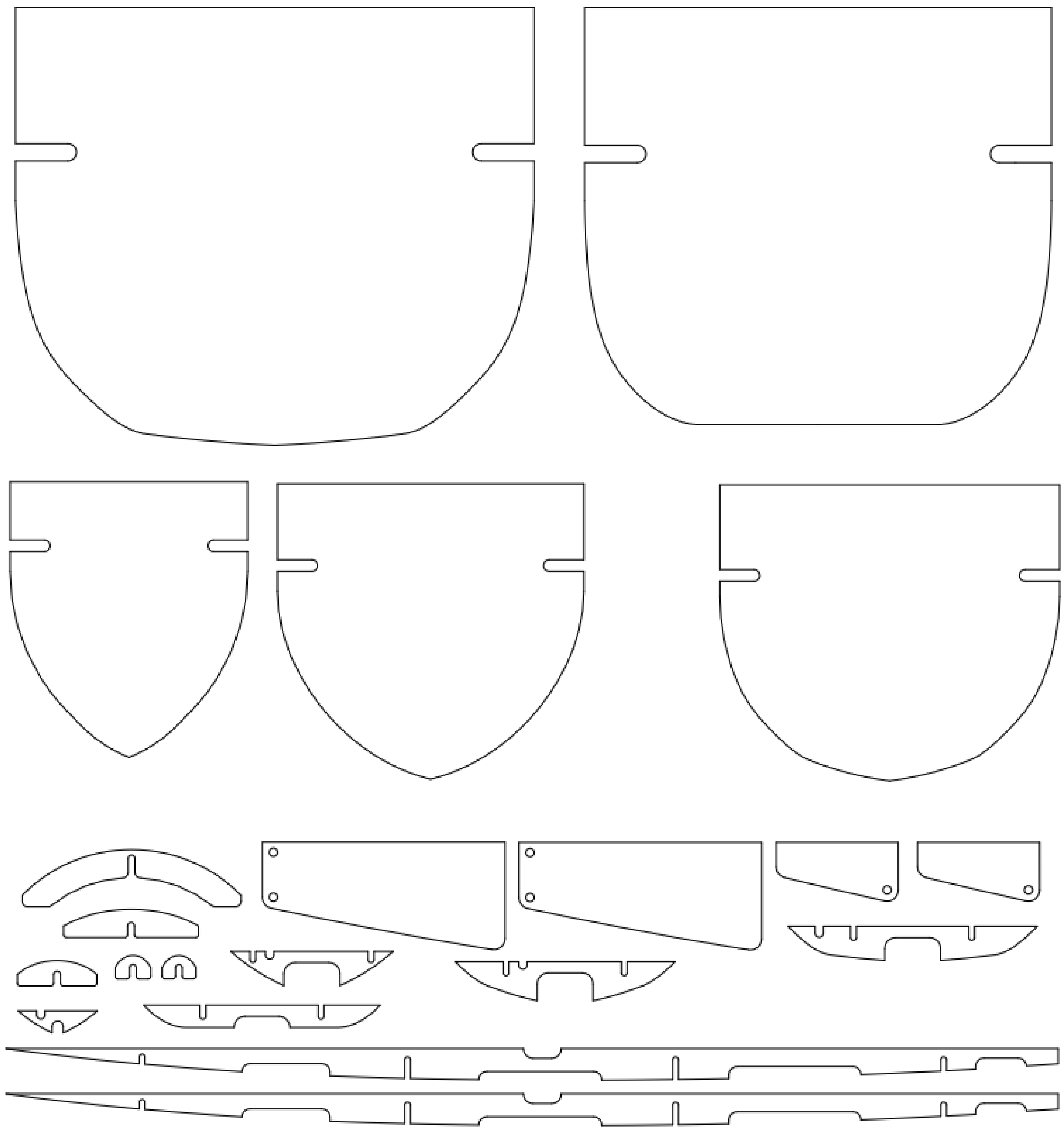
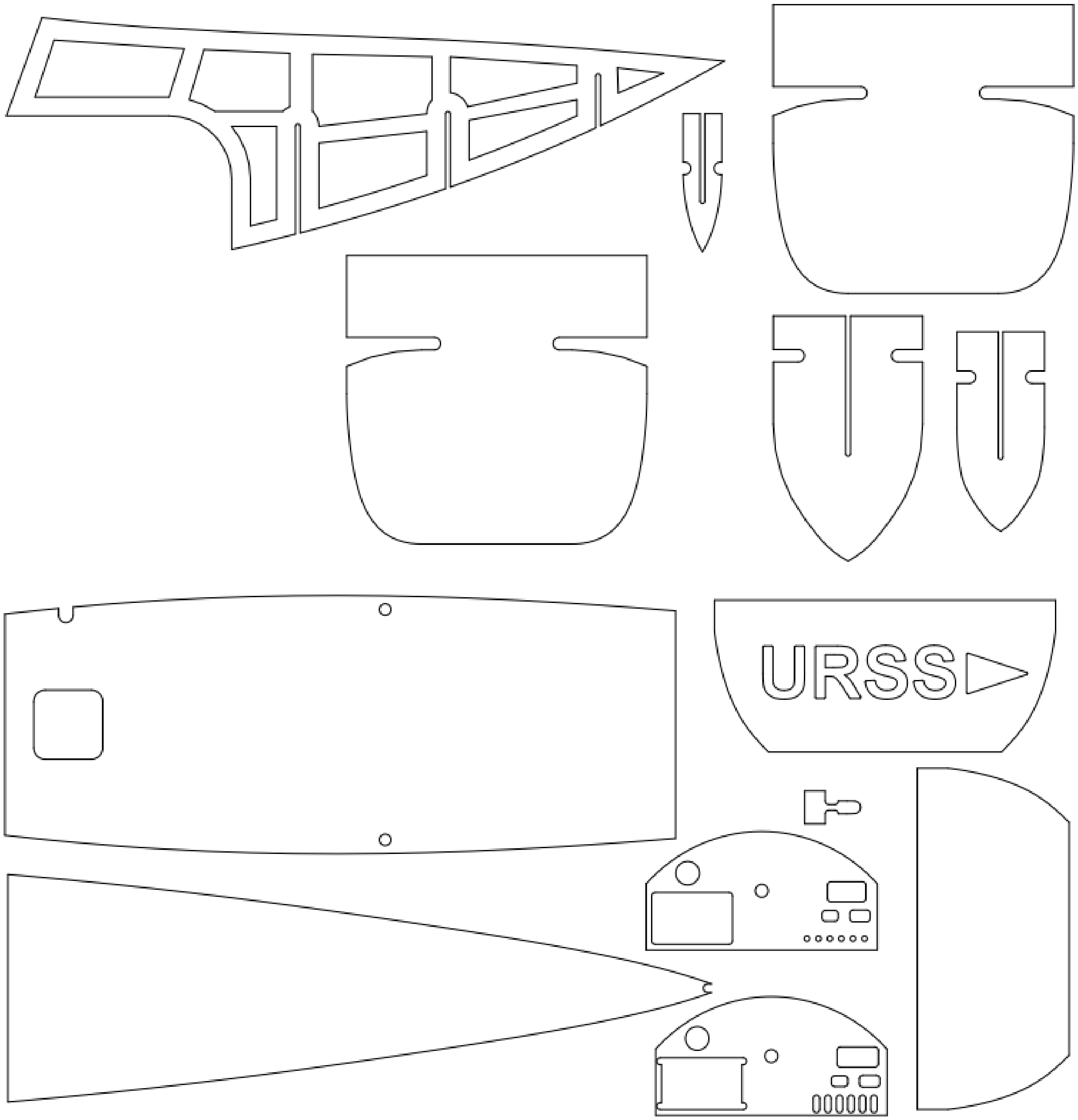
Appendix O. Hull Infrastructure CNC DXF's

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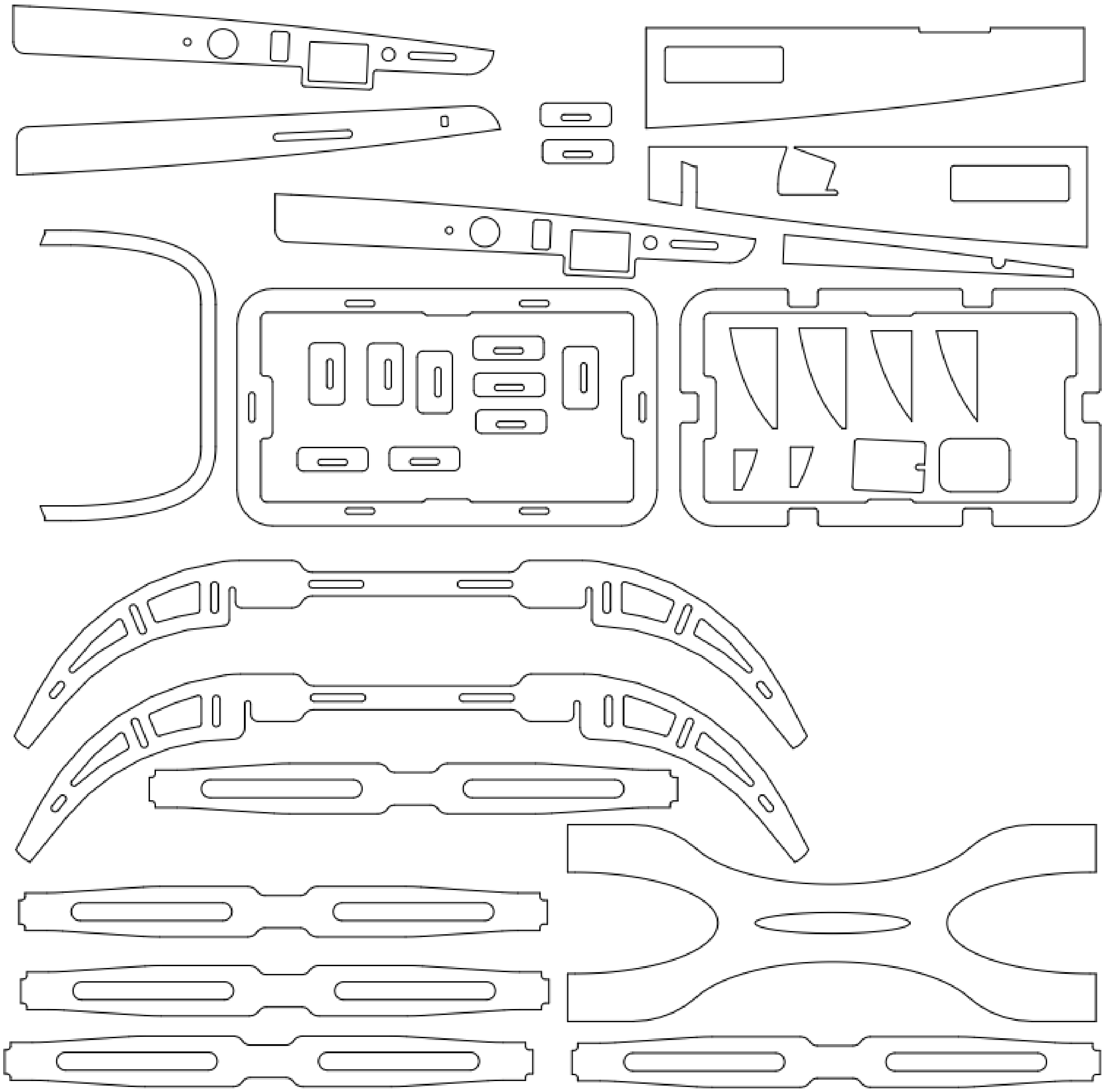


Appendix P. Boat Model Testing Apparatus

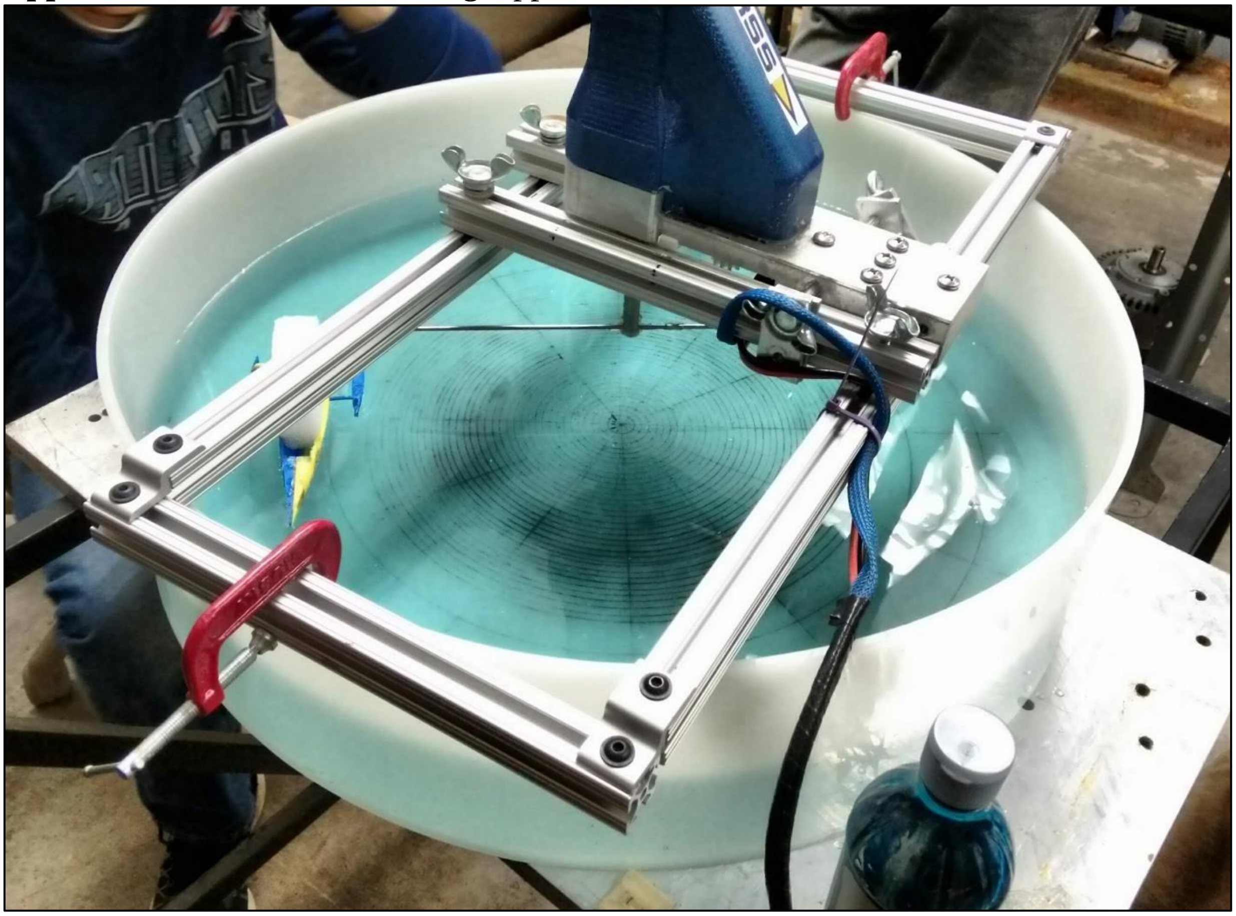


Figure 20: Boat Model testing apparatus using gear motor from 2016 Levi drive with blue dye agent

Appendix Q. Drivetrain 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° 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 R. Drivetrain Purchased Components

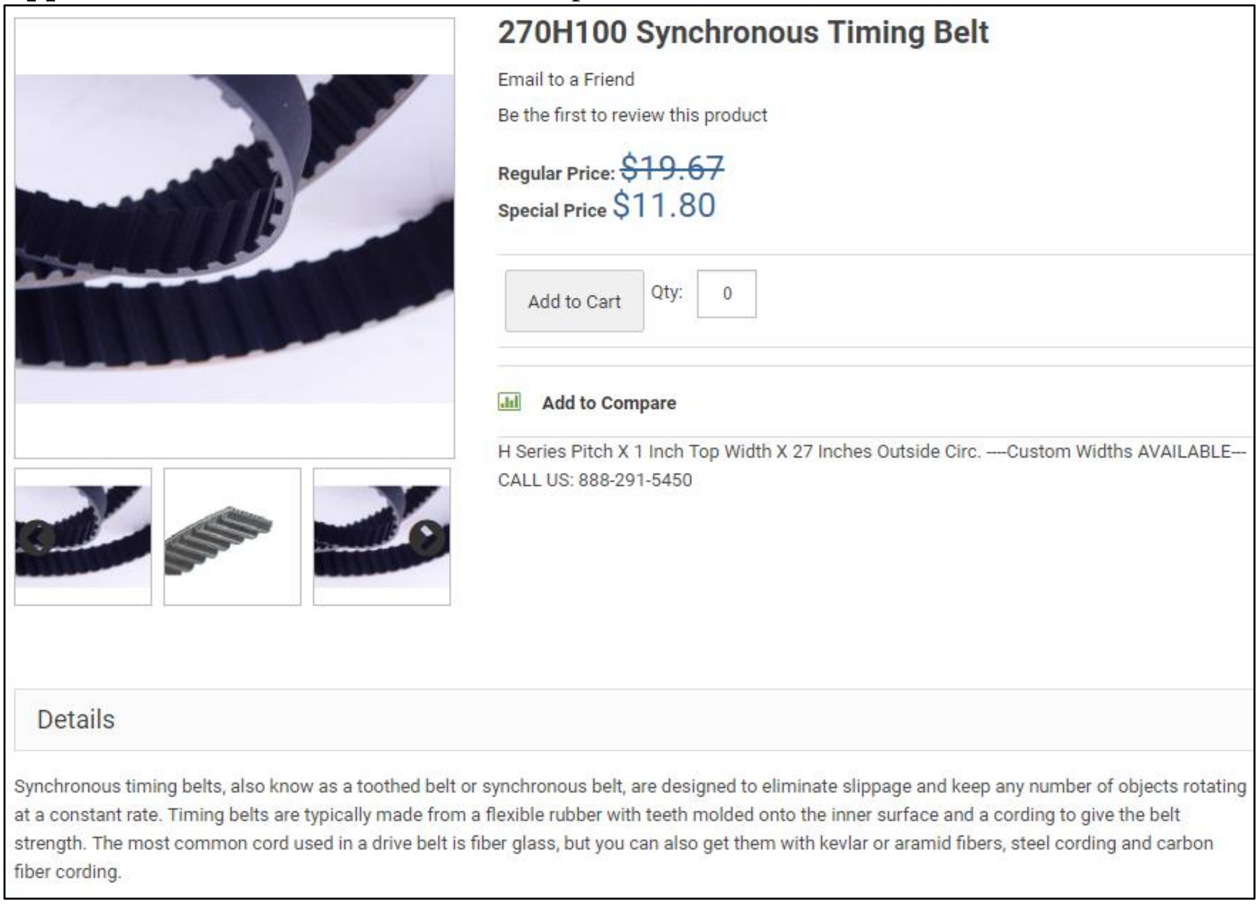


Figure 21: Synchronous timing belt used in assembly

MARTIN SPROCKET & GEAR

TB32H100

PRODUCT DETAILS

- 1/2" Pitch
- H Belt Type
- 1" Belt Width
- 32 Teeth
- 5.093" Pitch Diameter

FEATURES

- Nonslip
- No lubrication required
- Minimum backlash
- Constant speed

CAUTION

- It is necessary to use a minimum of one flanged pulley to prevent the belt from riding off
- When the drive is operated on other than horizontal shafts, or when the center distance is greater than eight times the diameter of the smaller pulley on drive ratios less than 3:1, both pulleys should be flanged
- When a drive has three pulleys, at least two should be flanged
- If the drive has more than three pulleys, every other pulley should be flanged

FOOTNOTE

- Bushings sold separately.

Figure 22: Large timing belt pulley used in assembly

MARTIN SPROCKET & GEAR
TB18H100

T.B. WOODS
TL18H100

PRODUCT DETAILS

- 1/2" Pitch
- H Belt Type
- 1" Belt Width
- 18 Teeth
- 2.865" Pitch Diameter

FEATURES

- Nonslip
- No lubrication required
- Minimum backlash
- Constant speed

CAUTION

- It is necessary to use a minimum of one flanged pulley to prevent the belt from riding off
- When the drive is operated on other than horizontal shafts, or when the center distance is greater than eight times the diameter of the smaller pulley on drive ratios less than 3:1, both pulleys should be flanged
- When a drive has three pulleys, at least two should be flanged
- If the drive has more than three pulleys, every other pulley should be flanged

FOOTNOTE

- Bushings sold separately.

Figure 23: Small timing belt pulley used in assembly

Appendix S. Drivetrain Manufactured Components

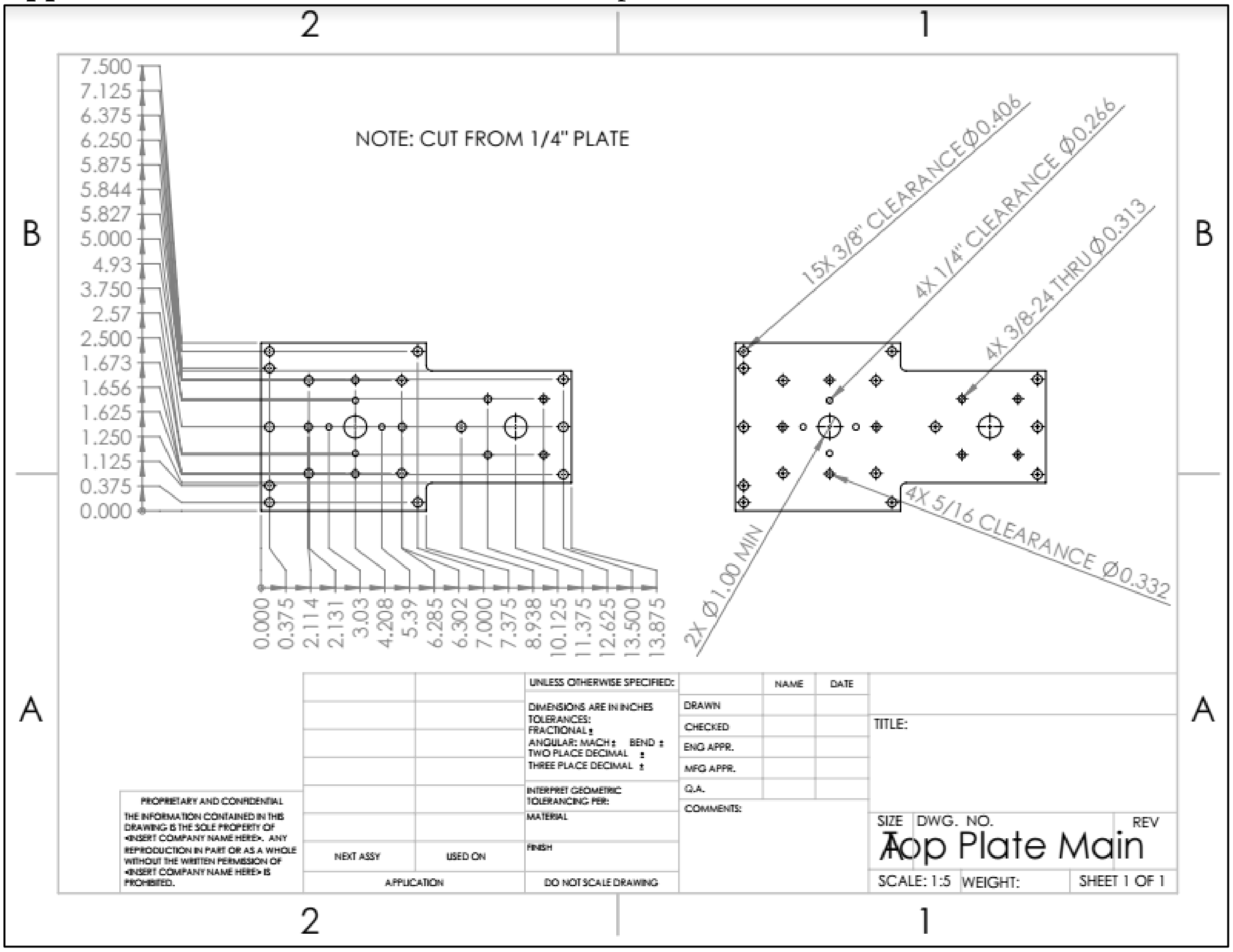


Figure 24: Top plate of outboard assembly

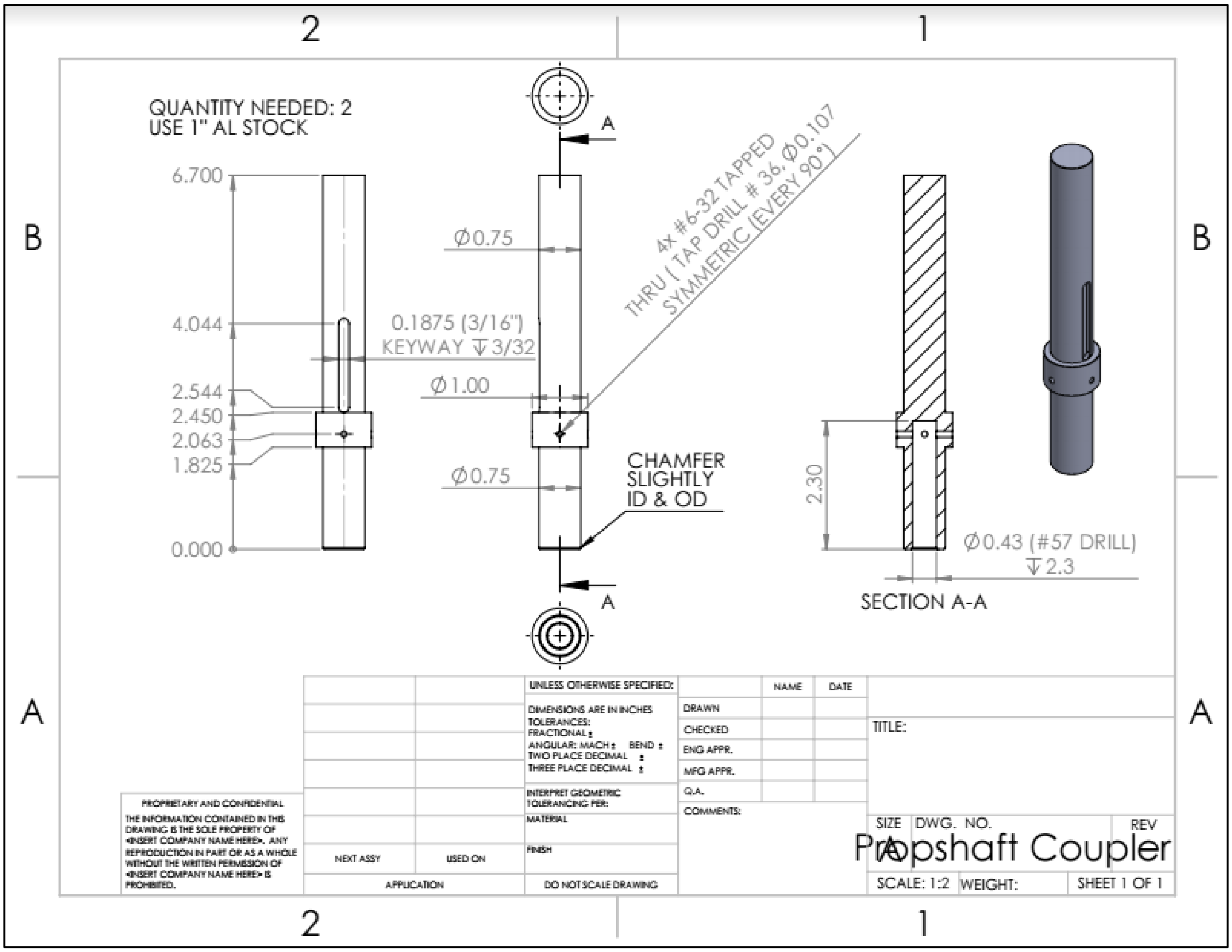


Figure 25: Propshaft coupler for drivetrain

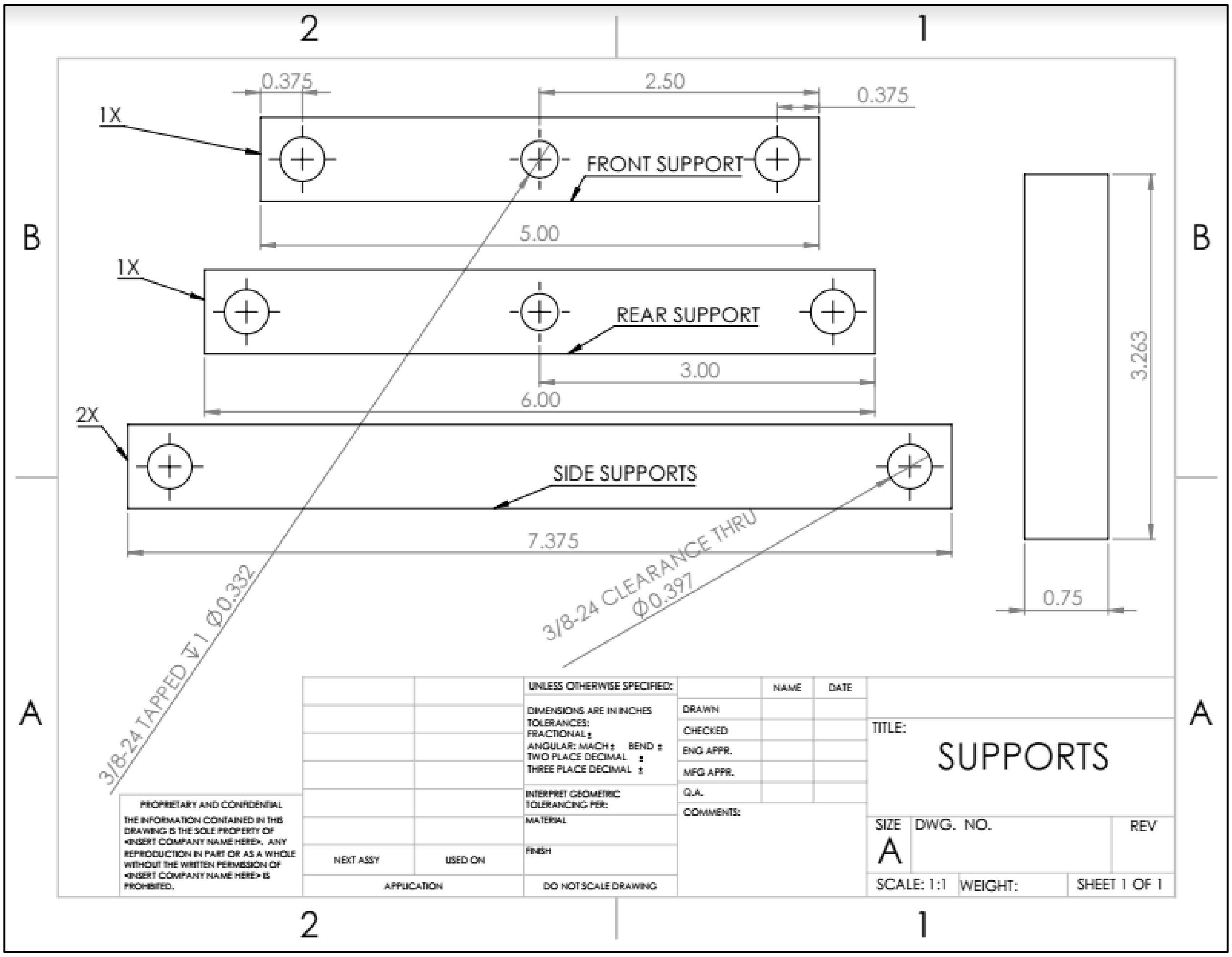


Figure 26: Vertical supports for outboard assembly

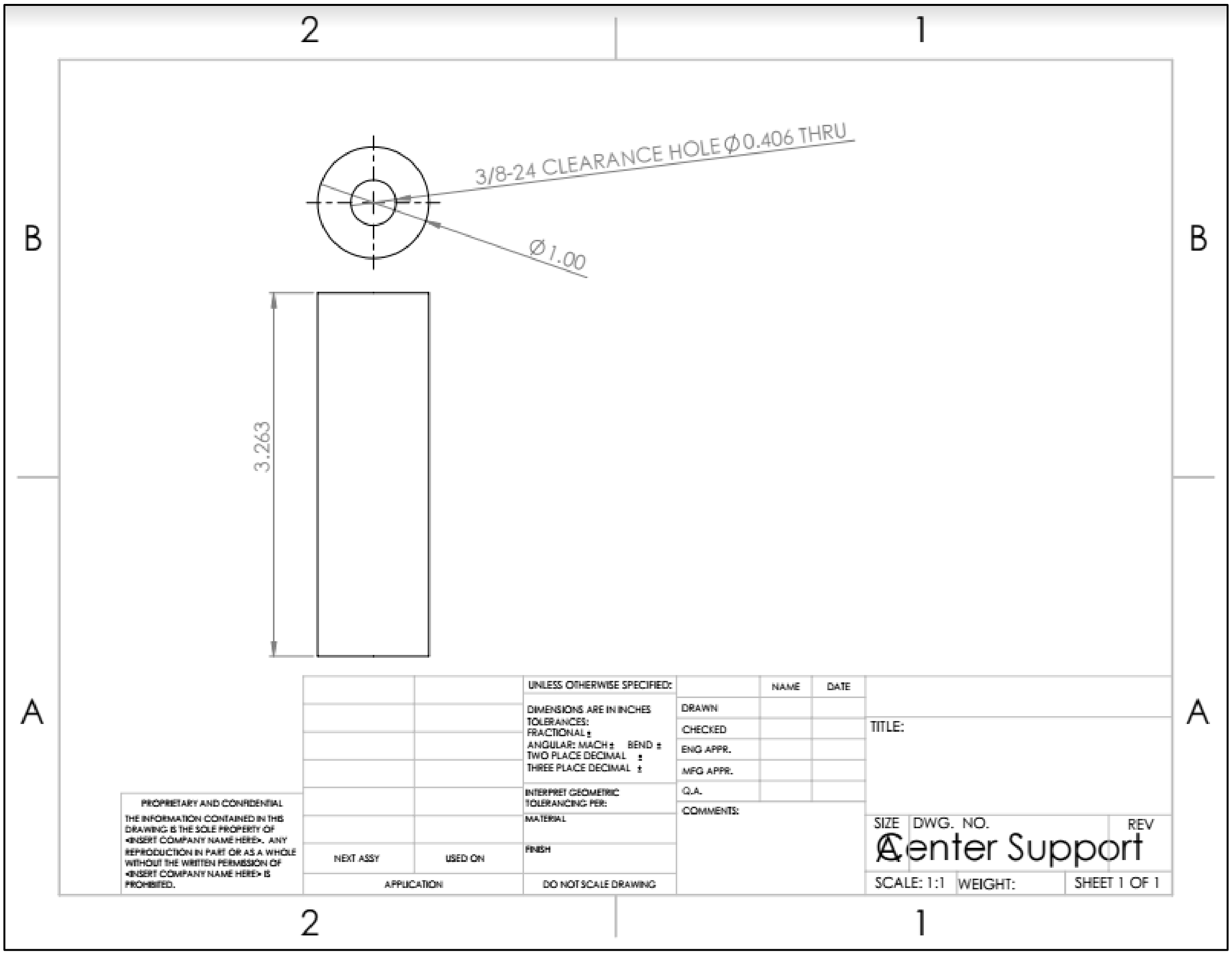


Figure 27: Center vertical support for outboard

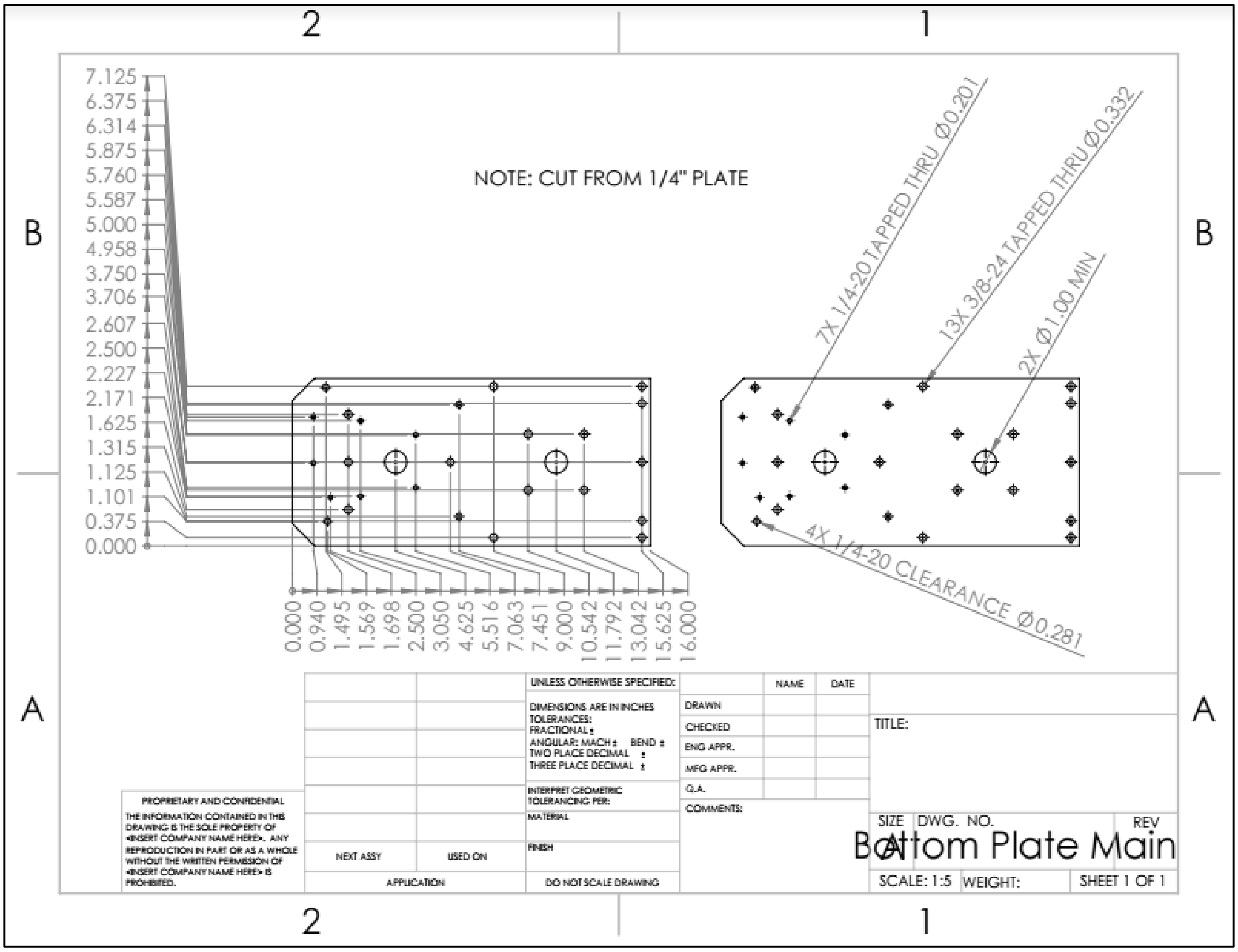


Figure 28: Bottom plate for outboard assembly

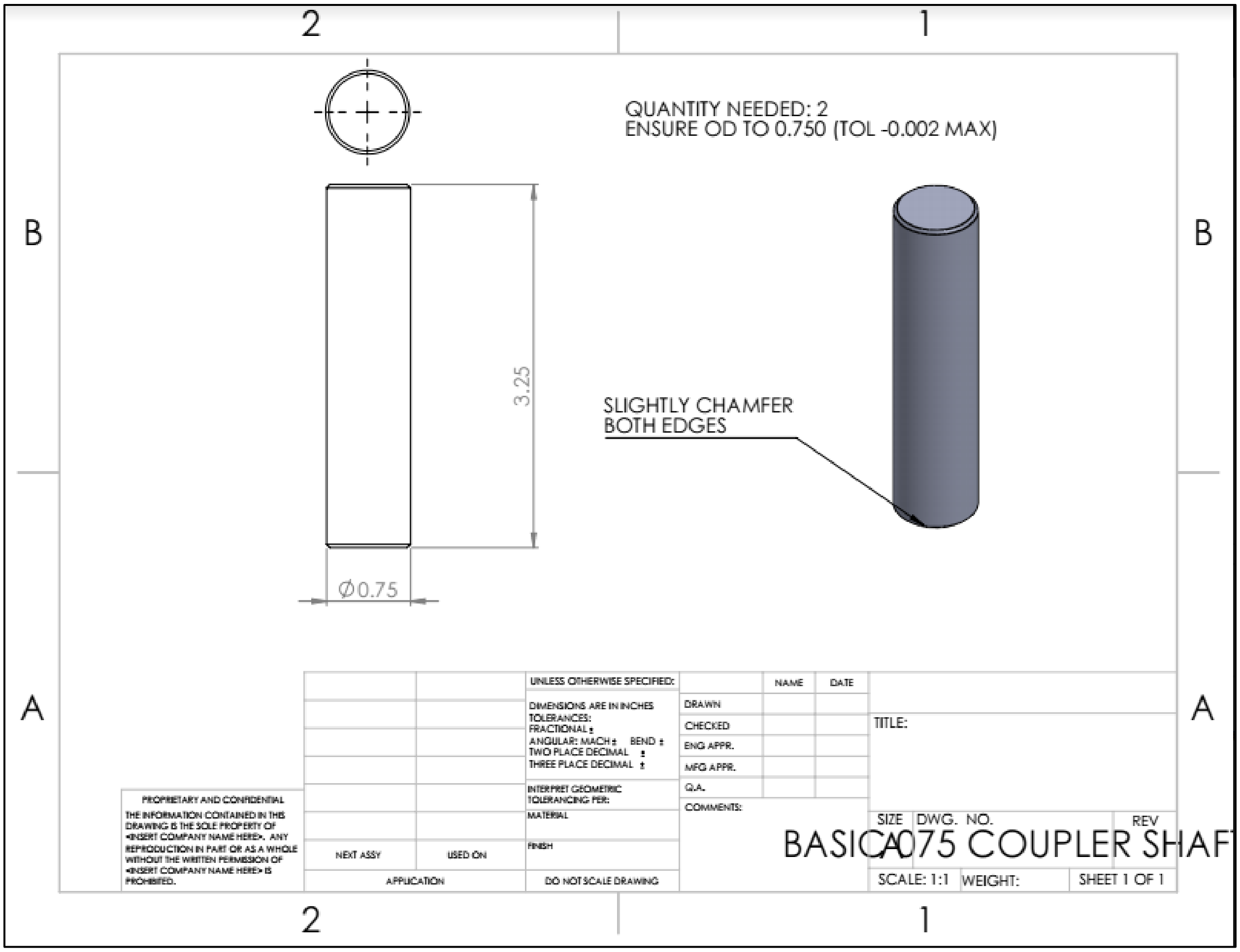


Figure 29: Coupler shaft for DC8 motor

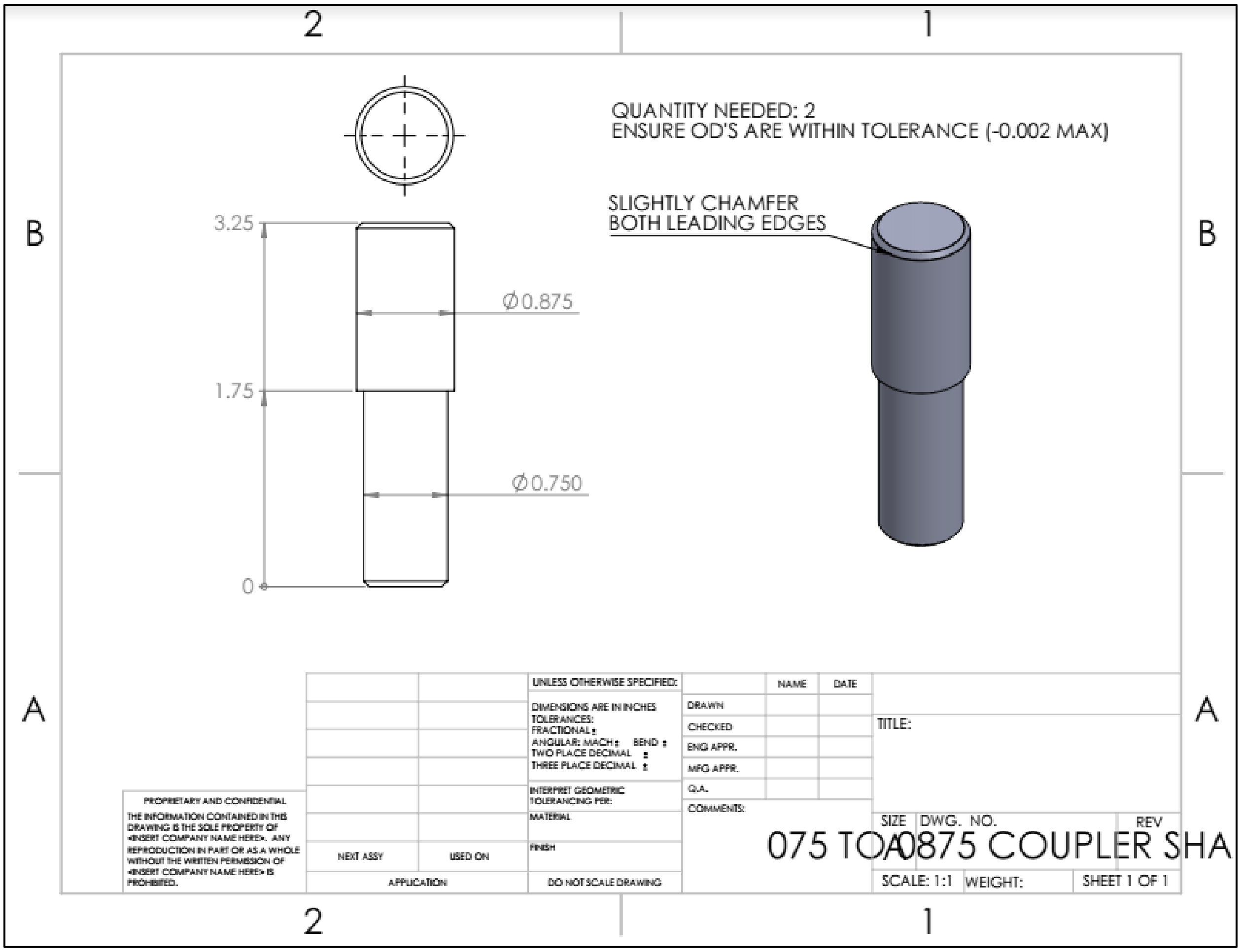


Figure 30: Lynch coupler for lynch motor

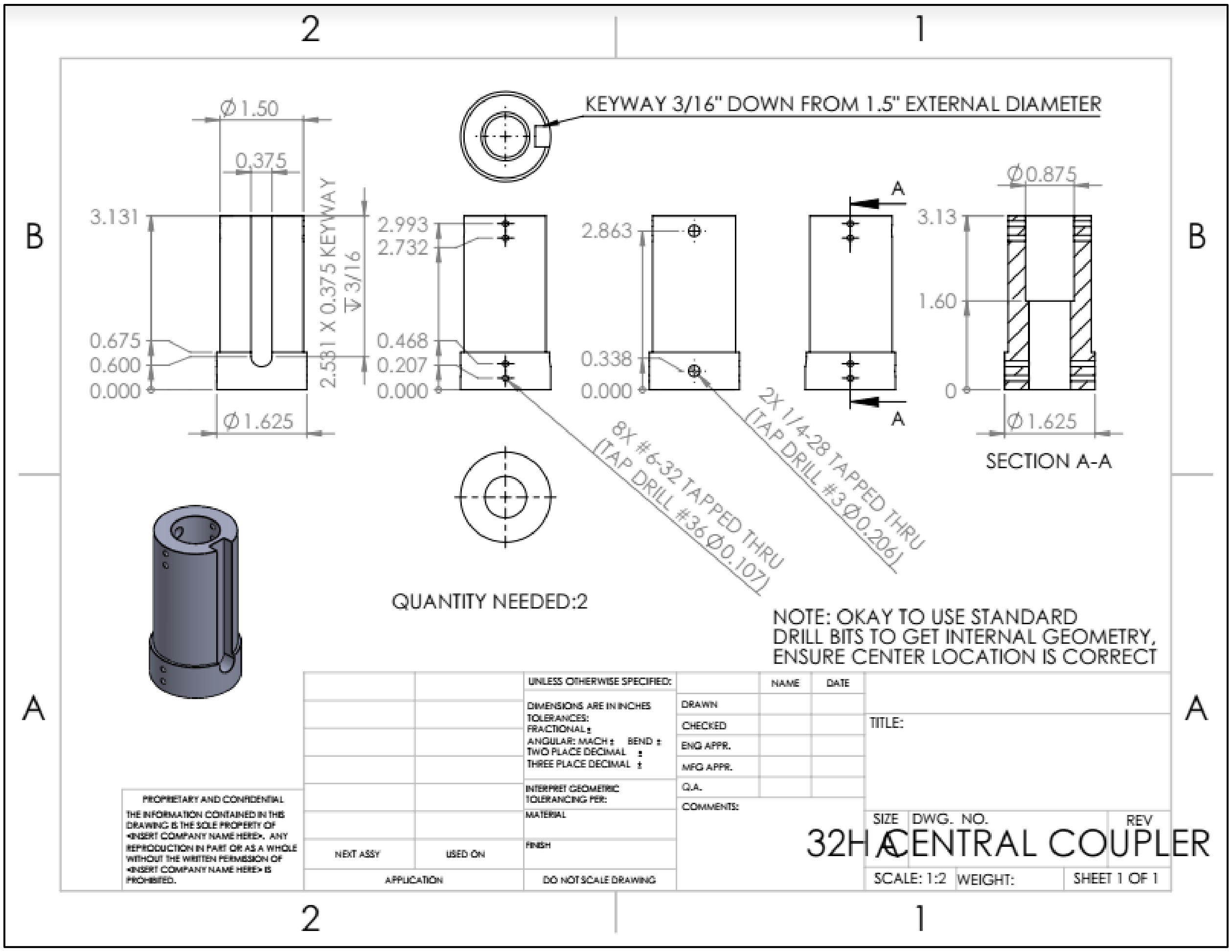


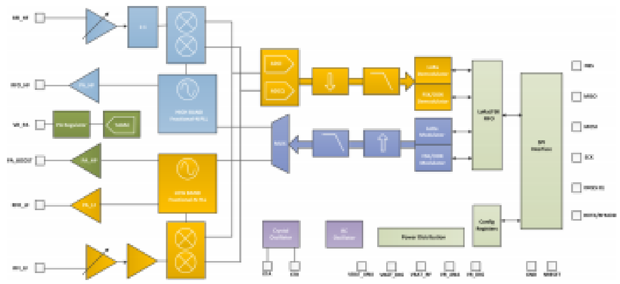
Figure 31: Central motor coupler

Appendix T. Specifications of Radio Transmitter

SEMTECH LoRa **SX1276/77/78/79**

WIRELESS, SENSING & TIMING **DATASHEET**

SX1276/77/78/79 - 137 MHz to 1020 MHz Low Power Long Range Transceiver



GENERAL DESCRIPTION

The SX1276/77/78/79 transceivers feature the LoRa™ long range modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimising current consumption.

Using Semtech's patented LoRa™ modulation technique SX1276/77/78/79 can achieve a sensitivity of over -148dBm using a low cost crystal and bill of materials. The high sensitivity combined with the integrated +20 dBm power amplifier yields industry leading link budget making it optimal for any application requiring range or robustness. LoRa™ also provides significant advantages in both blocking and selectivity over conventional modulation techniques, solving the traditional design compromise between range, interference immunity and energy consumption.

These devices also support high performance (G)FSK modes for systems including WMBus, IEEE802.15.4g. The SX1276/77/78/79 deliver exceptional phase noise, selectivity, receiver linearity and IIP3 for significantly lower current consumption than competing devices.

ORDERING INFORMATION

Part Number	Delivery	MOQ / Multiple
SX1276IMLTRT	T&R	3000 pieces
SX1277IMLTRT	T&R	3000 pieces
SX1278IMLTRT	T&R	3000 pieces
SX1279IMLTRT	T&R	3000 pieces

- QFN 28 Package - Operating Range [-40;+85°C]
- Pb-free, Halogen free, RoHS/WEEE compliant product

KEY PRODUCT FEATURES

- LoRa™ Modem
- 168 dB maximum link budget
- +20 dBm - 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -148 dBm
- Bullet-proof front end: IIP3 = -11 dBm
- Excellent blocking immunity
- Low RX current of 9.9 mA, 200 nA register retention
- Fully integrated synthesizer with a resolution of 61 Hz
- FSK, GFSK, MSK, GMSK, LoRa™ and OOK modulation
- Built-in bit synchronizer for clock recovery
- Preamble detection
- 127 dB Dynamic Range RSSI
- Automatic RF Sense and CAD with ultra-fast AFC
- Packet engine up to 256 bytes with CRC
- Built-in temperature sensor and low battery indicator

APPLICATIONS

- Automated Meter Reading.
- Home and Building Automation.
- Wireless Alarm and Security Systems.
- Industrial Monitoring and Control
- Long range Irrigation Systems

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Appendix U. Specifications of GPS Module

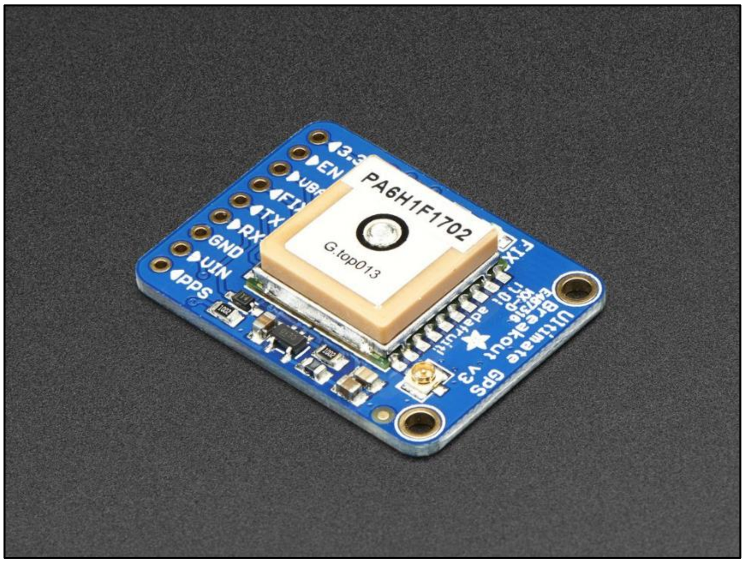


Figure 32: GPS module used in telemetry calculations

TECHNICAL DETAILS

- Satellites: 22 tracking, 66 searching
- Patch Antenna Size: 15mm x 15mm x 4mm
- Update rate: 1 to 10 Hz
- Position Accuracy: < 3 meters (all GPS technology has about 3m accuracy)
- Velocity Accuracy: 0.1 meters/s
- Warm/cold start: 34 seconds
- Acquisition sensitivity: -145 dBm
- Tracking sensitivity: -165 dBm
- Maximum Velocity: 515m/s
- Vin range: 3.0-5.5VDC
- MTK3339 Operating current: 25mA tracking, 20 mA current draw during navigation
- Output: NMEA 0183, 9600 baud default
- DGPS/WAAS/EGNOS supported
- FCC E911 compliance and AGPS support (Offline mode : EPO valid up to 14 days)
- Up to 210 PRN channels
- Jammer detection and reduction
- Multi-path detection and compensation

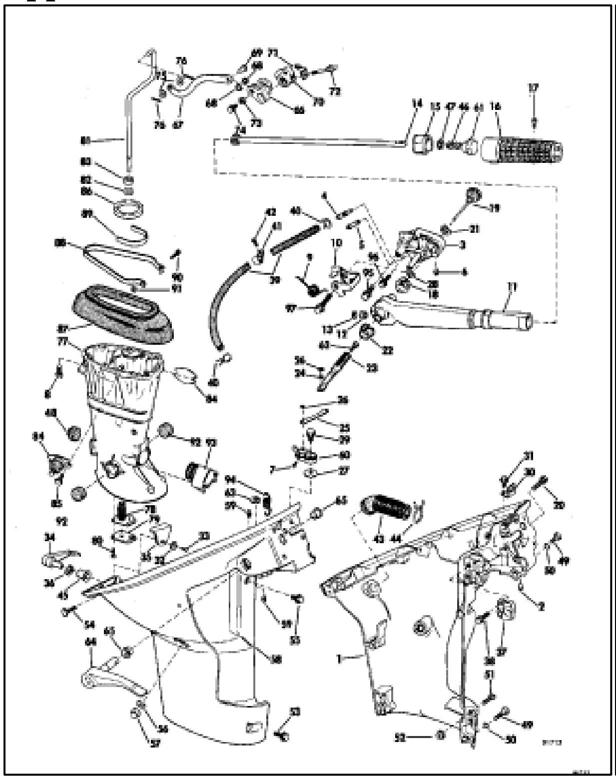
Revision History:

- As of 8/10/2014 we are shipping with firmware v. 5632 which improves altitude calculations and stability. It is equivalent in all other functionality and is a drop-in replacement.
- As of Feb 1, 2017 we have made minor silkscreen updates, improved the ground plane for better reception, increased the mounting hole diameter to 2.5mm from 2.0mm, and added a protection diode to the VBAT line. Functionality is otherwse the same.

Breakout board details:

- Weight (not including coin cell or holder): 8.5g
- Dimensions (not including coin cell or holder): 25.5mm x 35mm x 6.5mm / 1.0" x 1.35" x 0.25"

Appendix V. Donor Outboard Schematics



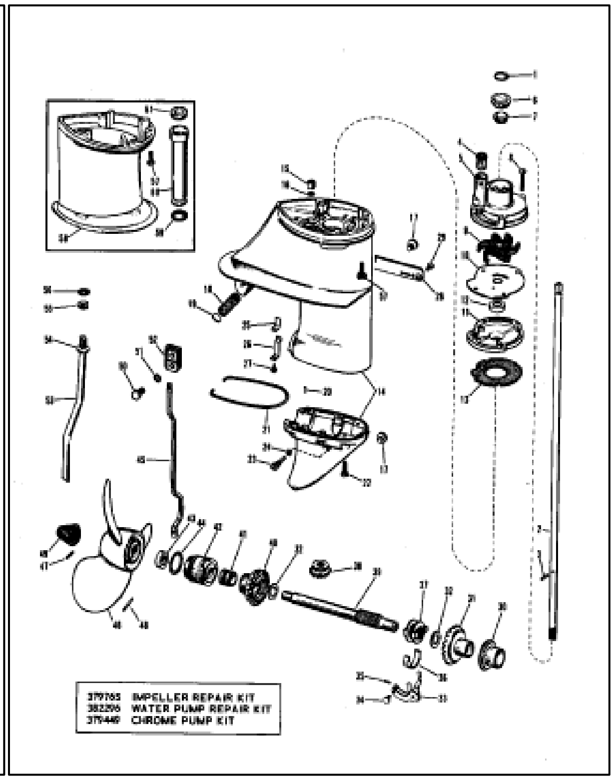


Figure 33: Donor outboard schematics from Johnson Evinrude

Appendix W. Specifications of Alltrax Motor Controller

LED Status Indicator

LED Blink Codes:

At power up, # of green blinks indicates configured throttle type:

1 Green = 0-5k-ohm
2 Green = 5k-0-ohm
3 Green = 0-5 Volt
4 Green = EZ-GO inductive (ITS)
5 Green = Yamaha 0-1K
6 Green = Taylor-Dunn 6-10.5V
7 Green = CLUBCAR 5K-3-wire

Normal display status:

Solid Green: Controller ready to run

Solid Red: Controller in programming mode
Solid Yellow: Controller throttle is wide open, controller is supplying max output, and is not in current limit.

Trouble Shooting

Error code display:# of RED blinks indicates any error conditions that might exist:

1 Red = Throttle Position Sensor Over Range. Check for open wires.
2 Red = Under Temperature. Controller below -25C
3 Red = HPD. Throttle hasn't gone to zero during this power on cycle.
4 Red = Over Temperature. Controller over 95C
5 Red = unused
6 Red = Battery Under Voltage detected. Battery V < under voltage slider
7 Red = Battery Over Voltage detected. Battery V > over-voltage slider

AXE

LIMITED WARRANTY

Alltrax, Inc., (hereafter Alltrax) warrants that the product purchased is free from defects in materials or workmanship for a period of *2 years* from the date of manufacture. This warranty does not apply to defects due directly or indirectly to misuse, abuse, negligence, accidents, repairs, improper installation, submersion, alterations or use contrary to any instructions provided by Alltrax in verbal or written form.

In the event you should need warranty repair, contact Alltrax at (541) 476-3565 to receive warranty service authorization instructions for returning the defective product to Alltrax for evaluation. Products or parts shipped by customer to Alltrax must be sent postage paid and packaged appropriately for safe shipment. Alltrax is not responsible for customer products received without warranty service authorization and may be rejected.

Alltrax reserves the right to repair or replace merchandise at its option at no cost to the customer, except for shipping costs of sending the defect item to Alltrax. Replacement shall mean furnishing the customer with a new equivalent product to the defective item. Alltrax also reserves the right to make changes to any of its products or specifications without notice.

Alltrax assumes no liability for applications assistance or customer product design. Customers shall be responsible for evaluating the appropriateness of the use of any Alltrax product in any application. Customers shall provide adequate design and operating safeguards that are in compliance with standard practices of other similar applications or any standards of any governing agency.

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NO REPRESENTATIVE EMPLOYEE, DISTRIBUTOR OR DEALER OF ALLTRAX HAS THE AUTHORITY TO MAKE OR IMPLY ANY WARRANTY, REPRESENTATION, PROMISE OR AGREEMENT, WHICH IN ANY WAY VARIES THE TERMS OF THIS LIMITED WARRANTY.

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Alltrax, Inc.
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Grants Pass, OR. 97527
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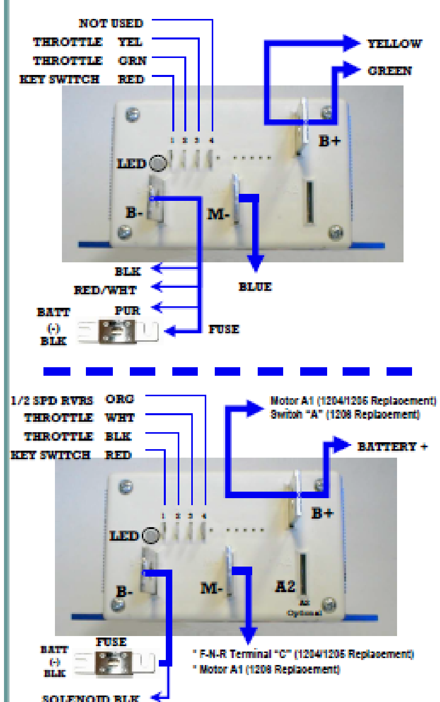
QUICK INSTALLATION GUIDE

Club Car & E-Z-GO Wiring Diagrams



For complete instructions and wiring diagrams for other configurations and vehicles, please download our AXE Manual from www.alltraxinc.com

Not all controllers use the A2 terminal. If not, bolt the two wires together, insulate with tape or heat shrink, then secure in safe location.

ControllerPRO

ControllerPRO is free user friendly software for customizing your Alltrax AXE Controllers. Download your copy of ControllerPRO from: www.alltraxinc.com

Configuration

WARNING: Disconnect all battery charging sources while programming your AXE controller. The controllers RS-232 serial port is referenced to the B- battery connection. **Beware of any possible ground loop faults between your computer and the controller which could damage both the AXE Controller and PC, or cause personal injury.**

Hardware: Use a STRAIGHT-THROUGH DB-9 pin / RS-232 serial interface cable to connect the controller to the PC. Alternatively use the preferred DB-9 pin RS-232 serial port to USB adapter.

The AXE controller must be powered before the ControllerPRO program will have any effect. Before programming the AXE, **READ THE SAFETY NOTES BELOW.** For bench programming prior to installation, a fused 18V or higher battery may be used to power the controller. Connect battery negative to the B- bus bar, battery positive to pin 1.

If you see an error **"Motor Controller is Not Responding"**, verify the controller is powered up and the connections are inserted correctly. If the error message continues, uninstall then reinstall the drivers for the communications cable. If the problem persists, contact Alltrax Technical Support.

Safety Notes:

Alltrax recommends that all motor controller applications have a fuse in the battery circuit. Many vehicles do not have a fuse, and will need to have one installed. The following fuses manufactured by Bussman or Littelfuse are acceptable: For controllers rated at 400 amps or less use ANN250. On controllers rated at 450 amps or more use ANN400. [See: Doc100-016-A_OP-Fuse-Install-Guide.doc]

Alltrax also recommends a diode across the coil of the solenoid if it is not already installed. A minimum of a 100V 1A diode (a 1N4004 is suitable) is required. See complete wiring diagrams for orientation.

Working on electric vehicles, sudden unexpected events can occur, it's recommended to:

- Place the drive axle on jack stands—wheels off the floor
- When working on wiring or batteries, always remove rings and watches
- Use the proper safety equipment, eye protection, and insulated tools
- Never connect a computer while the vehicle is being charged
- Disconnect batteries before installing or working on the controller

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1111 Cheney Creek Rd
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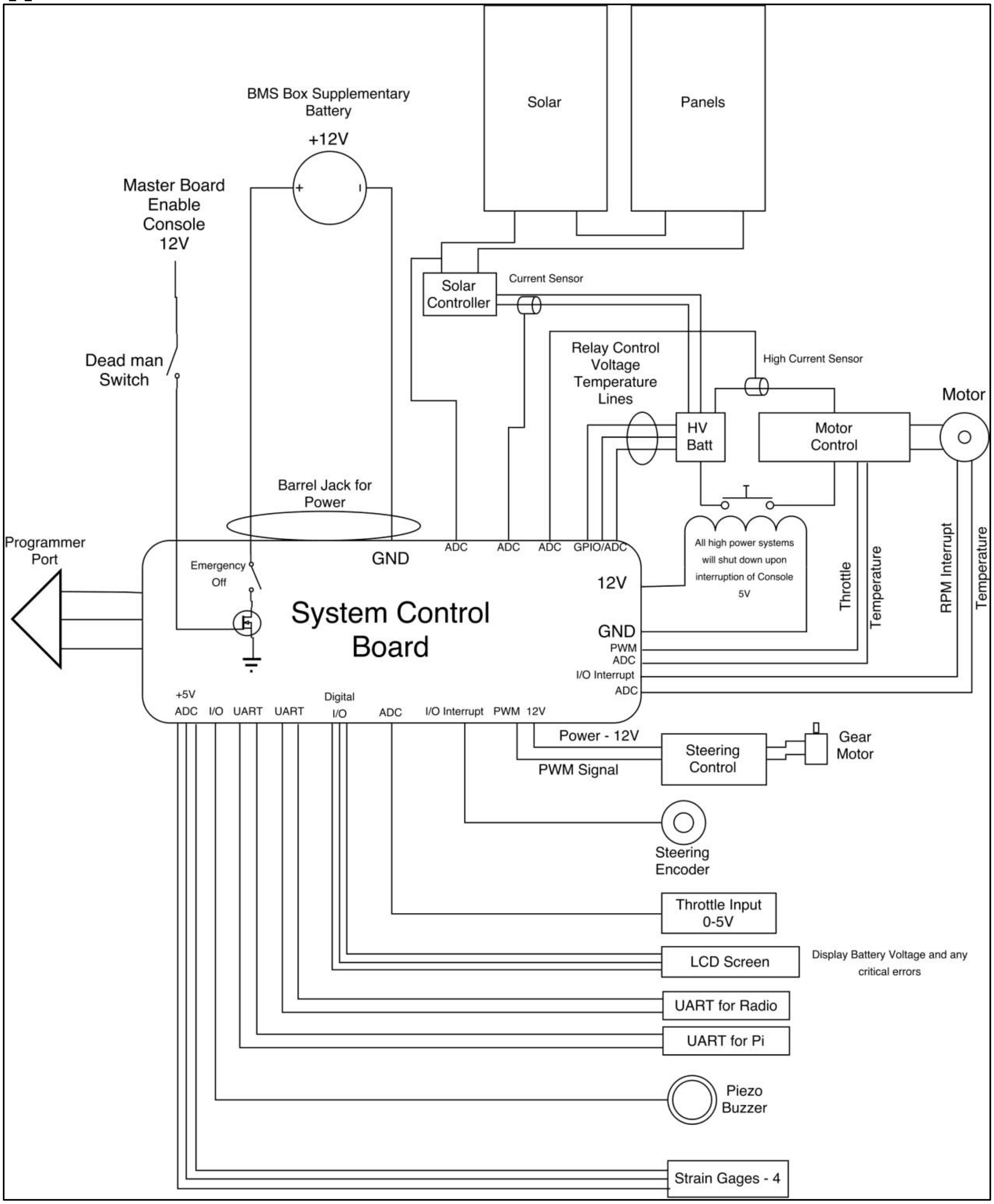
Appendix X. Main Circuit Schematic



Appendix Y. Flotation Foam MSDS

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation **MSDS No.: 15-MSD- 21528-01-C**

* * * Section 1 - Chemical Product and Company Identification * * *

Product Name(s): Foamular® 150, Foamular® 250, Foamular® 350, Foamular® 400, Foamular® 404, Foamular® 600, Foamular® 604, Foamular® 1000, Foamular® CW15, Foamular® CW25, Foamular® LT30, Foamular® LT40, Foamular® 404RB, Foamular® 604RB, Foamular® AgTek, Foamular® ProPink, Foamular® DuraPink, Foamular® PinkCore, Foamular® Half-Inch, Foamular® InsulPink, Foamular® ThermaPink, Foamular® DuraPink FA, Foamular® DuraPink Plus, Foamular® InsulPink - Z, Foamular® ThermaPink 18, Foamular® ThermaPink 25, Foamular® ThermaPink 40, Foamular® ThermaPink 60, Foamular® Extruded Polystyrene, Foamular® Insulating Sheathing, Foamular® Insuldrain, Foamular® PinkForm-Xtra ; Foamular® OC LiteForm

Owens Corning
One Owens Corning Parkway, World Headquarters
Attn. Product Stewardship
Toledo, OH 43659, USA

Emergency Contacts:
Emergencies ONLY (after 5pm ET and weekends): 1-419-248-5330,
CHEMTREC (24 hours everyday): 1-800-424-9300,
CANUTEC (Canada - 24 hours everyday): 1-613-996-6666.

Health and Technical Contacts:
Health Issues Information (8am-5pm ET): 1-800-GET-PINK,
Technical Product Information (8am-5pm ET): 1-800-GET-PINK.

* * * Section 2 - Composition / Information on Ingredients * * *

CAS #	Component	Percent by Wt.
9003-53-6	Polystyrene	80-90
75-68-3	HCFC-142b	7-12
3194-55-6	Hexabromocyclododecane	0.5-1.5
14807-96-6	Talc	0-2

Component Related Regulatory Information
This product may be regulated, have exposure limits or other information identified as the following: Nuisance particulates.

Component Information/Information on Non-Hazardous Components
No additional information available.

* * * Section 3 - Hazards Identification * * *

Appearance and Odor: Pink, white or green closed-cell foam board with no odor.

Emergency Overview

Exposure to dust may be irritating to eyes, nose, and throat. To prevent ignition, avoid smoking, keep from open flames and high temperatures. Grinding, sawing or fabrication activities can produce dust particles which may under certain conditions form explosive dust atmospheres that can be ignited.

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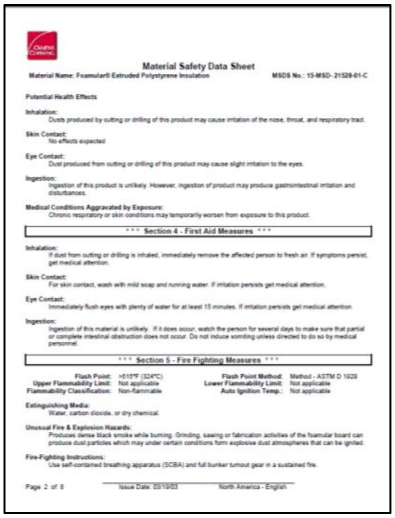

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

Potential Health Effects

Inhalation:
Dusts produced by cutting or drilling of this product may cause irritation of the nose, throat, and respiratory tract.

Skin Contact:
No effects expected

Eye Contact:
Dust produced from cutting or drilling of this product may cause slight irritation to the eyes.

Ingestion:
Ingestion of this product is unlikely. However, ingestion of product may produce gastrointestinal irritation and disturbances.

Medical Conditions Aggravated by Exposure:
Chronic respiratory or skin conditions may temporarily worsen from exposure to this product.

*** Section 4 - First Aid Measures ***

Inhalation:
If dust from cutting or drilling is inhaled, immediately remove the affected person to fresh air. If symptoms persist, get medical attention.

Skin Contact:
For skin contact, wash with mild soap and running water. If irritation persists get medical attention.

Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes. If irritation persists get medical attention.

Ingestion:
Ingestion of this material is unlikely. If it does occur, watch the person for several days to make sure that partial or complete intestinal obstruction does not occur. Do not induce vomiting unless directed to do so by medical personnel.

*** Section 5 - Fire Fighting Measures ***

Flash Point:	>615°F (324°C)	Flash Point Method:	Method - ASTM D 1929
Upper Flammability Limit:	Not applicable	Lower Flammability Limit:	Not applicable
Flammability Classification:	Non-flammable	Auto Ignition Temp.:	Not applicable

Extinguishing Media:
Water, carbon dioxide, or dry chemical.

Unusual Fire & Explosion Hazards:
Produces dense black smoke while burning. Grinding, sawing or fabrication activities of the foamular board can produce dust particles which may under certain conditions form explosive dust atmospheres that can be ignited.

Fire-Fighting Instructions:
Use self-contained breathing apparatus (SCBA) and full bunker turnout gear in a sustained fire.

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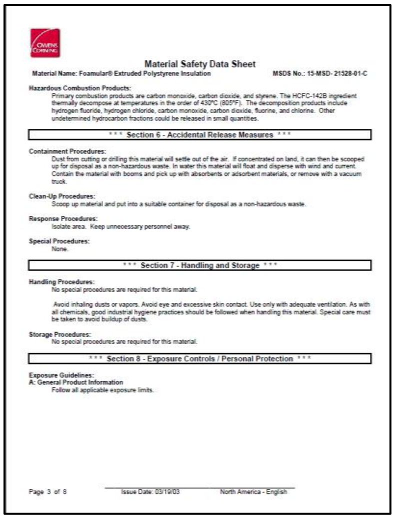

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

Hazardous Combustion Products:
Primary combustion products are carbon monoxide, carbon dioxide, and styrene. The HCFC-142B ingredient thermally decompose at temperatures in the order of 430°C (805°F). The decomposition products include hydrogen fluoride, hydrogen chloride, carbon monoxide, carbon dioxide, fluorine, and chlorine. Other undetermined hydrocarbon fractions could be released in small quantities.

*** Section 6 - Accidental Release Measures ***

Containment Procedures:
Dust from cutting or drilling this material will settle out of the air. If concentrated on land, it can then be scooped up for disposal as a non-hazardous waste. In water this material will float and disperse with wind and current. Contain the material with booms and pick up with absorbents or adsorbent materials, or remove with a vacuum truck.

Clean-Up Procedures:
Scoop up material and put into a suitable container for disposal as a non-hazardous waste.

Response Procedures:
Isolate area. Keep unnecessary personnel away.

Special Procedures:
None.

*** Section 7 - Handling and Storage ***

Handling Procedures:
No special procedures are required for this material.

Avoid inhaling dusts or vapors. Avoid eye and excessive skin contact. Use only with adequate ventilation. As with all chemicals, good industrial hygiene practices should be followed when handling this material. Special care must be taken to avoid buildup of dusts.

Storage Procedures:
No special procedures are required for this material.

*** Section 8 - Exposure Controls / Personal Protection ***

Exposure Guidelines:
A: General Product Information
Follow all applicable exposure limits.

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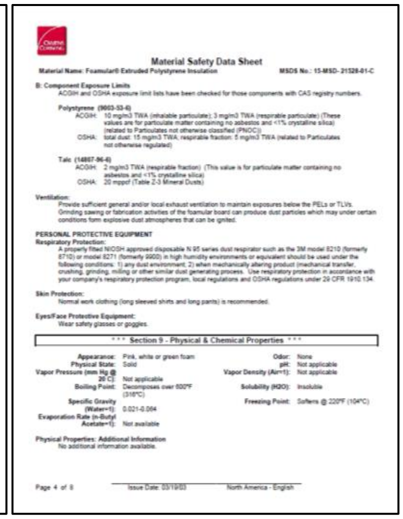

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

B: Component Exposure Limits
ACGIH and OSHA exposure limit lists have been checked for those components with CAS registry numbers.

Polystyrene (9003-53-6)
ACGIH: 10 mg/m3 TWA (inhalable particulate); 3 mg/m3 TWA (respirable particulate) (These values are for particulate matter containing no asbestos and <1% crystalline silica) (related to Particulates not otherwise classified (PNOC))
OSHA: total dust: 15 mg/m3 TWA; respirable fraction: 5 mg/m3 TWA (related to Particulates not otherwise regulated)

Talc (14807-96-6)
ACGIH: 2 mg/m3 TWA (respirable fraction) (This value is for particulate matter containing no asbestos and <1% crystalline silica)
OSHA: 20 mppcf (Table Z-3 Mineral Dusts)

Ventilation:
Provide sufficient general and/or local exhaust ventilation to maintain exposures below the PELs or TLVs. Grinding sawing or fabrication activities of the foamular board can produce dust particles which may under certain conditions form explosive dust atmospheres that can be ignited.

PERSONAL PROTECTIVE EQUIPMENT
Respiratory Protection:
A properly fitted NIOSH approved disposable N 95 series dust respirator such as the 3M model 8210 (formerly 8710) or model 8271 (formerly 9900) in high humidity environments or equivalent should be used under the following conditions: 1) any dust environment; 2) when mechanically altering product (mechanical transfer, crushing, grinding, milling or other similar dust generating process. Use respiratory protection in accordance with your company's respiratory protection program, local regulations and OSHA regulations under 29 CFR 1910.134.

Skin Protection:
Normal work clothing (long sleeved shirts and long pants) is recommended.

Eyes/Face Protective Equipment:
Wear safety glasses or goggles.

*** Section 9 - Physical & Chemical Properties ***

Appearance:	Pink, white or green foam	Odor:	None
Physical State:	Solid	pH:	Not applicable
Vapor Pressure (mm Hg @ 20 C):	Not applicable	Vapor Density (Air=1):	Not applicable
Boiling Point:	Decomposes over 600°F (316°C)	Solubility (H2O):	Insoluble
Specific Gravity (Water=1):	0.021-0.064	Freezing Point:	Softens @ 220°F (104°C)
Evaporation Rate (n-Butyl Acetate=1):	Not available		

Physical Properties: Additional Information
No additional information available.

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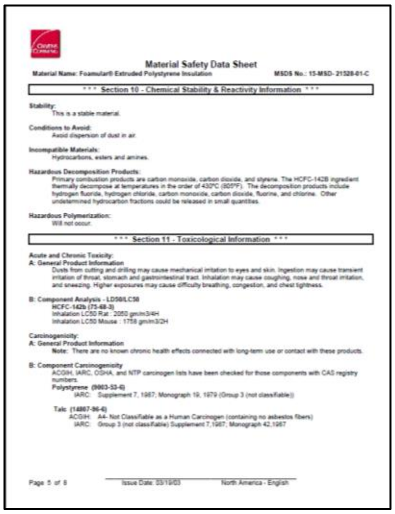

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

*** Section 10 - Chemical Stability & Reactivity Information ***

Stability:
This is a stable material.

Conditions to Avoid:
Avoid dispersion of dust in air.

Incompatible Materials:
Hydrocarbons, esters and amines.

Hazardous Decomposition Products:
Primary combustion products are carbon monoxide, carbon dioxide, and styrene. The HCFC-142B ingredient thermally decompose at temperatures in the order of 430°C (805°F). The decomposition products include hydrogen fluoride, hydrogen chloride, carbon monoxide, carbon dioxide, fluorine, and chlorine. Other undetermined hydrocarbon fractions could be released in small quantities.

Hazardous Polymerization:
Will not occur.

*** Section 11 - Toxicological Information ***

Acute and Chronic Toxicity:
A: General Product Information
Dusts from cutting and drilling may cause mechanical irritation to eyes and skin. Ingestion may cause transient irritation of throat, stomach and gastrointestinal tract. Inhalation may cause coughing, nose and throat irritation, and sneezing. Higher exposures may cause difficulty breathing, congestion, and chest tightness.

B: Component Analysis - LD50/LC50
HCFC-142b (75-68-3)
Inhalation LC50 Rat : 2050 gm/m3/4H
Inhalation LC50 Mouse : 1758 gm/m3/2H

Carcinogenicity:
A: General Product Information
Note: There are no known chronic health effects connected with long-term use or contact with these products.

B: Component Carcinogenicity
ACGIH, IARC, OSHA, and NTP carcinogen lists have been checked for those components with CAS registry numbers.
Polystyrene (9003-53-6)
IARC: Supplement 7, 1987; Monograph 19, 1979 (Group 3 (not classifiable))

Talc (14807-96-6)
ACGIH: A4- Not Classifiable as a Human Carcinogen (containing no asbestos fibers)
IARC: Group 3 (not classifiable) Supplement 7,1987; Monograph 42,1987

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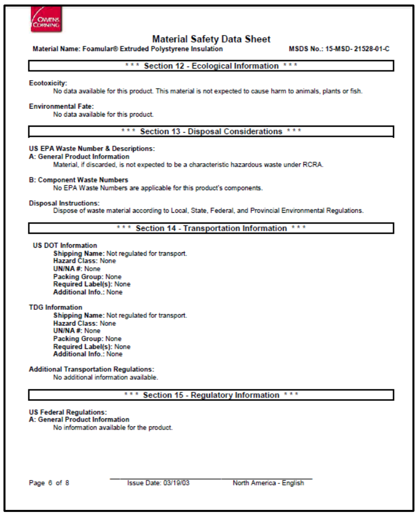

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

*** Section 12 - Ecological Information ***

Ecotoxicity:
No data available for this product. This material is not expected to cause harm to animals, plants or fish.

Environmental Fate:
No data available for this product.

*** Section 13 - Disposal Considerations ***

US EPA Waste Number & Descriptions:
A: General Product Information
Material, if discarded, is not expected to be a characteristic hazardous waste under RCRA.

B: Component Waste Numbers
No EPA Waste Numbers are applicable for this product's components.

Disposal Instructions:
Dispose of waste material according to Local, State, Federal, and Provincial Environmental Regulations.

*** Section 14 - Transportation Information ***

US DOT Information
Shipping Name: Not regulated for transport.
Hazard Class: None
UN/NA #: None
Packing Group: None
Required Label(s): None
Additional Info.: None

TDG Information
Shipping Name: Not regulated for transport.
Hazard Class: None
UN/NA #: None
Packing Group: None
Required Label(s): None
Additional Info.: None

Additional Transportation Regulations:
No additional information available.

*** Section 15 - Regulatory Information ***

US Federal Regulations:
A: General Product Information
No information available for the product.

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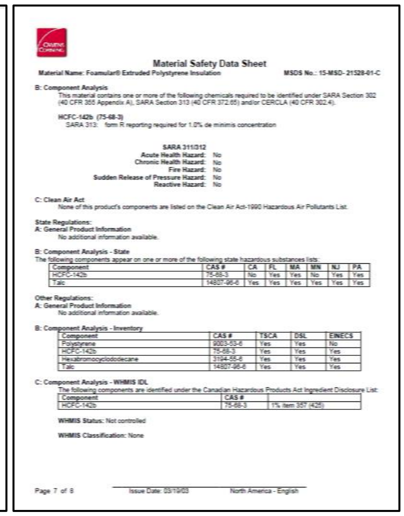

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

B: Component Analysis
This material contains one or more of the following chemicals required to be identified under SARA Section 302 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65) and/or CERCLA (40 CFR 302.4).

HCFC-142b (75-68-3)
SARA 313: form R reporting required for 1.0% de minimis concentration

SARA 311/312
Acute Health Hazard: No
Chronic Health Hazard: No
Fire Hazard: No
Sudden Release of Pressure Hazard: No
Reactive Hazard: No

C: Clean Air Act
None of this product's components are listed on the Clean Air Act-1990 Hazardous Air Pollutants List.

State Regulations:
A: General Product Information
No additional information available.

B: Component Analysis - State
The following components appear on one or more of the following state hazardous substances lists:

Component	CAS #	CA	FL	MA	MN	NJ	PA
HCFC-142b	75-68-3	No	Yes	Yes	No	Yes	Yes
Talc	14807-96-6	Yes	Yes	Yes	Yes	Yes	Yes

Other Regulations:
A: General Product Information
No additional information available.

B: Component Analysis - Inventory

Component	CAS #	TSCA	DSL	EINECS
Polystyrene	9003-53-6	Yes	Yes	No
HCFC-142b	75-68-3	Yes	Yes	Yes
Hexabromocyclododecane	3194-55-6	Yes	Yes	Yes
Talc	14807-96-6	Yes	Yes	Yes

C: Component Analysis - WHMIS IDL
The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:

Component	CAS #	
HCFC-142b	75-68-3	1% item 357 (425)

WHMIS Status: Not controlled

WHMIS Classification: None

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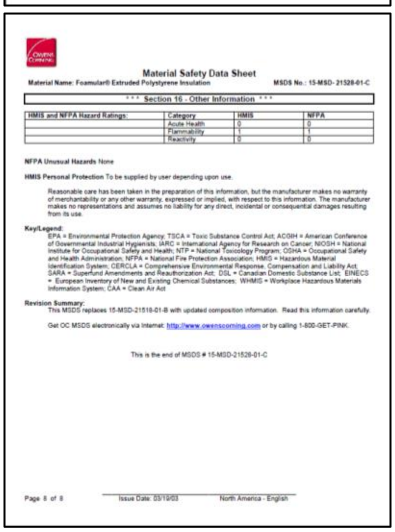

Material Safety Data Sheet

Material Name: Foamular® Extruded Polystyrene Insulation — MSDS No.: 15-MSD- 21528-01-C

*** Section 16 - Other Information ***

HMIS and NFPA Hazard Ratings:	Category	HMIS	NFPA
	Acute Health	0	0
	Flammability	1	1
	Reactivity	0	0

NFPA Unusual Hazards None

HMIS Personal Protection To be supplied by user depending upon use.

Reasonable care has been taken in the preparation of this information, but the manufacturer makes no warranty of merchantability or any other warranty, expressed or implied, with respect to this information. The manufacturer makes no representations and assumes no liability for any direct, incidental or consequential damages resulting from its use.

Key/Legend:
EPA = Environmental Protection Agency; TSCA = Toxic Substance Control Act; ACGIH = American Conference of Governmental Industrial Hygienists; IARC = International Agency for Research on Cancer; NIOSH = National Institute for Occupational Safety and Health; NTP = National Toxicology Program; OSHA = Occupational Safety and Health Administration; NFPA = National Fire Protection Association; HMIS = Hazardous Material Identification System; CERCLA = Comprehensive Environmental Response, Compensation and Liability Act; SARA = Superfund Amendments and Reauthorization Act; DSL = Canadian Domestic Substance List; EINECS = European Inventory of New and Existing Chemical Substances; WHMIS = Workplace Hazardous Materials Information System; CAA = Clean Air Act

Revision Summary:
This MSDS replaces 15-MSD-21518-01-B with updated composition information. Read this information carefully.

Get OC MSDS electronically via Internet: http://www.owenscorning.com or by calling 1-800-GET-PINK.

This is the end of MSDS # 15-MSD-21528-01-C

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Appendix Z. Web-links for URSS promotional material

USEED Page: *https://rochester.useed.net/give/609*

Youtube:

Maiden Voyage: *https://www.youtube.com/watch?v=4sQXrLurOZo*

Project Highlights:

Lawn Mower: https://www.youtube.com/watch?v=Bp61vZFk7kg&t=1s

USEED Video: https://www.youtube.com/watch?v=eglNn1_4Xf4

Boat Model Testing: https://www.youtube.com/watch?v=P-VwbPe0tUE

Facebook: *https://www.facebook.com/URSolarSplash/*

Website: *http://sa.rochester.edu/solarsplash/*