2015 Solar Splash Technical Report

MIDDLE TENNESSEE STATE UNIVERSITY

Boat # 5

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EXECUTIVE SUMMARY

The Solar Splash is an International competition which challenges teams, from both the university and high school level, to construct a solar/electric boat capable of competing in both high-speed sprint races and low-speed endurance races. There are unique challenges in designing a boat that is efficient at both high and low-speed operation. The Solar Splash competition offers the chance for each design team to put forth their best effort to overcome these challenges. In doing so, each team member gains a deeper understanding of the problems they are trying to solve.

One of the most challenging aspects of this competition is in the hull design. Boats that are efficient at low-speed operation typically feature a displacement-type hull which is efficient at plowing through the water. The most recognizable hull of this type is that of a canoe. On the other end of the spectrum, a boat that is designed for high-speed operation will feature a planing hull which is designed to ride on top of the water. For the Solar Splash competition, it is desirable to have features that are conducive with both planing and displacement operation. Because of the difficulty in designing a hybrid hull, the ideal solution is to design a hull suitable for displacement operation and utilize a retractable hydrofoil to lift the boat's hull completely out of the water during the high-speed sprint runs.

However, in order to increase the efficiency of our existing hull, it was decided to implement a hydrofoil at the rear of the boat for the 2015 Solar Splash. Our current hull design is most efficient during high-speed operation when the hull is on plane. During displacement operation the shape of our transom creates eddies at the stern which prevent the hull from being hydrodynamically efficient when not on plane. In order to overcome this issue, a retractable hydrofoil will be implemented to raise the transom during the endurance runs so as to increase the hydrodynamic efficiency of the hull when not on plane.

Our current hull features a strong and lightweight carbon fiber construction with a Lantor® Soric XF3 core that serves as an inter-laminar breather material while providing the benefit of adding buoyancy to the construction. The durable nature of the hull's construction eliminates the need for internal bracing.

Our current drivetrain features an Arneson-type surface drive. This drive offers versatility in propeller selection and it can be trimmed using an attached electric actuator. Being able to trim the drive allows for the angle at which the power is being transferred to the hull to be changed, thus providing the ability to reduce downward force on the bow when planing is desired, and the ability to add downward force on the bow when displacement operation is desired.

The Arneson-type surface drive is powered by dual Motenergy® ME1003 brushed DC motors. These motors feature an efficiency rating of 90% and have an adjustable dual-brush design that allows adjustment of their efficiency and current handling capacity. A chain drive is used to connect both motors to the out-drive during the sprint run. However, for the endurance run, one of the motors will be taken offline and the chain configuration will be changed so that only one motor is connected to the out-drive.

Motor speed and power utilization will be controlled through dual Altrax® AXE 4865 motor controllers. These controllers are fully programmable through their integrated RS232 port and have a maximum current limit of 650 Amps. Their internal components are fully encapsulated in epoxy making them a resistant and well suited to the harshness of the marine environment. As with the

motors, both controllers will be utilized during the sprint run with one being taken offline during the endurance run. All offline components will remain in place in the boat during the endurance run in order to remain in compliance with Solar Splash Rule 4.2.3.

Remote telemetry will be used to provide onshore real-time monitoring and adjustment of the configuration settings of both onboard motor controllers. In addition to being able remotely monitor and update the controller configuration, the telemetry system will allow for onshore monitoring of system voltage, current draw, throttle position, speed, distance traveled, and GPS position.

The 2015 telemetry system is vastly improved over last years. Remote connectivity of the 2015 telemetry system is achieved through the implementation of a long-range Wi-Fi system that features a maximum range of 20 miles. The system consists of a 1-Watt wireless access point on shore and a 0.5-Watt wireless access point onboard the boat. An onshore laptop is connected to the system through a wireless onshore router. The boat's motor controllers, along with a GPS antenna, are connected to the boat's access point through a Lantronix RS232 to Ethernet converter. This system is extremely robust and easily expandable. The built-in error correcting of the IP connectivity scheme eliminates the connectivity errors associated with the RS232 radio modems incorporated into last year's telemetry system.

Battery power for the boat during sprint events will be provided by three Optima® Red Top Group 25 automotive-type cranking batteries. These batteries offer a Cold Cranking Amp (CCA) rating of 720 Amps, a manufactured stated weight of 31.7 lbs, and a scale weight of 33.2 lbs. Given the weight restrictions for the batteries, as imposed by the rule 7.4.1, these batteries proved to be a good choice as they offer one of the highest CCA ratings available while remaining just under the imposed weight restriction. Three batteries will be used in series for the sprint run, providing a nominal pack voltage of 36 VDC for this event.

Battery power for the boat during endurance events will be provided by two Trojan® SCS150 Group 24 marine-type deep cycle batteries. These batteries are rated at 150 Ah (20 hour rating), which give them a higher power density than the Optima® batteries chosen for the sprint configuration, and they have a manufactured stated weight of 50 lbs and an actual scale weight of 50 lbs. Though the nominal pack voltage will only be 24 VDC, the overall power output will exceed that of the three Optima® Red Top batteries by 44% as the Red Top batteries are only rated at 44 Ah (20 hour rating). The result is that we have batteries that can discharge quickly for our sprint configuration and batteries with higher charge density for the endurance configuration.

To meet the maximum of 480 watts of solar panels allowed by rule 4.2.4, two 240 watt Renogy® polycrystalline solar panels are being utilized with one being mounted to the front of the boat and one at the rear using RAM® ball mounts to help ease in taking the panels on and off of the boat. To further increase the ease in which the panels are taken on and off, two water-resistant through-hull connectors will be utilized to facilitate the connection of the panels to the boat's electrical system. The output of the panels will initially be directed through dual charge controllers to prevent sulfation of the attached battery pack. Once the sprint heat is underway, the pilot will switch the controllers out of the circuit allowing the full output of the panels to be delivered to the motor controller. At this point the applied load of the motor will prevent the batteries from becoming overcharged and sulfating.

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I. OVERALL PROJECT OBJECTIVES

A. Current Design

1) Overview of Current Design: Our current hull features a strong carbon fiber construction. Our current drivetrain features an Arneson-type surface drive that is powered by dual brushed DC motors. A drive chain is used to transfer power from the motors to the outdrive. A retractable hydrofoil is used to improve hydrodynamic efficiency during displacement operation.

Motor speed and power utilization is controlled through dual Altrax® AXE 4865 motor controllers with a remote long-range Wi-Fi telemetry system being used to provide onshore real-time monitoring and adjustment of the configuration settings of both onboard motor controllers.

Battery power for the boat during sprint events will be provided by three Optima® Red Top Group 25 automotive-type cranking batteries. Battery power for the boat during endurance events will be provided by two Trojan® SCS150 Group 24 marine-type deep cycle batteries.

Two 240 watt Renogy® polycrystalline solar panels are used for solar charging. These panels are mounted to the top surface of the boat using RAM® ball mounts with connectivity for the panels being provided by integrated through-hull electrical connectors.

Switching is provided at the helm for charge controller bypass and motor controller bypass. Additionally, the helm features instrumentation for trim position, charge status, main and auxiliary battery charge level, speed, and GPS position.

2) What Are the Problems or Issues: Issues with our previous design included a lack of hull efficiency during displacement operation. This issue resulted from the square shape of the hull's transom. Additionally, the previous telemetry system was plagued by connectivity issues that were associated with the RS232 radio modems that provided the connectivity. Any data loss would result in the motor controller's completely disconnecting from the motor controller software on the remote laptop. While onshore GPS mapping software was not as sensitive to lost data, consistent connectivity to the motor controllers was critical.

3) What Are We Trying to Improve: We are attempting to improve the efficiency of the hull during displacement operation and we are attempting to achieve a more reliable data link between the boat and our onshore telemetry station.

B. Analysis of Design Concept

1) Design Description: The boat's hull is constructed of carbon fiber with a Lantor® Soric XF3 core. Our drivetrain features an Arneson-type outdrive with an electric actuator for trimming. Power to the drivetrain is provided by dual Motenergy® ME1003 brushed DC motors. A chain drive is used to connect both motors to the outdrive during the sprint run. For the endurance run one of the motors is taken offline and the chain configuration is changed so that only one motor is connected to the outdrive.

Motor speed and power utilization is controlled through dual Altrax® AXE 4865 motor controllers. A Wi-Fi based remote telemetry system is used to provide onshore real-time monitoring and adjustment of the configuration settings of both onboard motor controllers. The telemetry system also receives GPS speed and position data from the boat. Additionally, the helm features an instrumentation packages that allows the driver to know the status of all onboard systems along with GPS speed, position, and location.

Battery power for the boat during sprint events is provided by three Optima® Red Top Group 25 automotive-type cranking batteries. Battery power for the boat during endurance events will be provided by two Trojan® SCS150 Group 24 marine-type deep cycle batteries. Two 240 watt Renogy® polycrystalline solar panels are utilized for solar charging. Mounting for the panels is facilitated by RAM® ball mounts. Electrical connectivity for the panels is facilitated through integrated water-resistant through-hull connectors.

The output of the panels will initially be directed through dual charge controllers to prevent sulfation of the attached battery pack. Once the sprint heat is underway, the pilot will switch the controllers out of the circuit allowing the full output of the panels to be delivered to the motor controller. At this point the applied load of the motor will prevent the batteries from becoming over charged and sulfating. The primary function of the charge controller bypass switch is to prevent the motor controller from shutting down due to a low-voltage condition.

Switching is provided at the helm for charge controller bypass and motor controller bypass. Additionally, the helm features instrumentation for trim position, charge status, main and auxiliary battery charge level, speed, and GPS position.

A retractable hydrofoil, attached to the transom, is used to lift the transom out of the water in order to prevent hydrodynamic drag during displacement operation. During planning operation the foil is retracted in order to prevent drag.

2) Design Alternatives/Tradeoffs: Many alternatives exist for every aspect of the design. The exploration of every alternative for every system is simply not possible given the limited amount of time available the team. However, a limited number of alternatives will be discussed in subsequent sub-sections of this report.

3) Rationale for Choice: We wanted our hull to be lightweight and strong enough so that it would not need any additional reinforcement. As such, we decided carbon fiber would be appropriate. We added a Lantor® Soric XF3 core to the layup to serve as an inter-laminar breather material and to add additional buoyancy to the construction.

The implementation of a hydrofoil for the purposes of improving hydrodynamic efficiency during displacement operation came out of recognition that our current hull shape, while efficient for planning operation, is not as efficient during displacement operation. Preliminary testing on the foil is currently underway.

We chose to design and construct an Arneson-type surface drive to provide versatility in propeller selection. We also wanted a drive that would provide trimming ability as this allows for the angle at which the power is being transferred to the hull to be changed. This is beneficial for reducing the downward force on the bow when planing is desired, and increasing downward force on the bow when displacement operation is desired.

It was decided to power the Arneson-type surface drive by dual Motenergy® ME1003 brushed DC motors because of their 90% efficiency rating. These motors also feature an adjustable dual-brush design that allows for adjustment of their efficiency and current handling capacity.

The choice of a chain drive for connecting the boat's motors to the outdrive came out of recognition that this is a simple, effective, and efficient way to transfer the mechanical energy down to the driveshaft. Also, the chain drive and sprocket system allows for multiple sprocket ratios to be tested with relative ease in order to determine the optimal configuration.

Motor speed and power utilization is controlled through dual Altrax® AXE 4865 motor controllers. These controllers offer the benefit of being fully programmable through their integrated RS232 port and offer a maximum current limit of 650 Amps. They are also waterproof and suitable for marine use due to their internal components being fully encapsulated in epoxy.

Remote telemetry was desired in order to provide onshore real-time monitoring and adjustment of the configuration settings of both onboard motor controllers. In addition to being able to remotely monitor and update the controller configuration, the telemetry system will allow for onshore monitoring of system voltage, current draw, throttle position, speed, distance traveled, and GPS position. The benefit is being able to achieve optimal power management given that the results of all controller configuration changes can be instantly monitored during testing.

It was also desired that our telemetry system be extremely robust and feature error correcting for the data transfer. In order to achieve this, remote connectivity of the 2015 telemetry system is achieved through the implementation of a long-range Wi-Fi system that features a maximum range of 20 miles. The system consists of a 1-Watt wireless access point on shore and a 0.5-Watt wireless access point onboard the boat. An onshore laptop is connected to the system through a wireless onshore router. The boat's motor controllers, along with a GPS antenna, are connected to the boat's access point through a Lantronix RS232 to Ethernet converter. This system is extremely robust and easily expandable. The built-in error correcting of the IP connectivity scheme eliminates the connectivity errors associated with the RS232 radio modems incorporated into last year's telemetry system.

Battery power for the boat during sprint events will be provided by three Optima® Red Top Group 25 automotive-type cranking batteries. These batteries offer a Cold Cranking Amp (CCA) rating of 720 Amps and have a manufactured stated weight of 31.7 lbs (though actual scale weight is 33.2 lbs). Given the weight restrictions for the batteries, as imposed by the rules for the Solar Splash event, these batteries proved to be a good choice as they offer one of the highest CCA ratings available while remaining just under the imposed weight restriction. Three batteries will be used in series for the sprint run providing a nominal pack voltage of 36 VDC for this event.

Battery power for the boat during endurance events will be provided by two Trojan® SCS150 Group 24 marine-type deep cycle batteries. These batteries are rated at 100 Ah (20 hour rating), which give them a higher power density than the Optima® batteries chosen for the sprint configuration, and they have a manufactured stated weight of 50 lbs (actual scale weight is 50 lbs). Though the nominal pack voltage will only be 24 VDC, the overall power output will exceed that of the three Optima® Red Top batteries by 44% as the Red Top batteries are only rated at 44

Ah (20 hour rating). The result is that we have batteries that can discharge quickly for our sprint configuration and batteries with higher charge density for the endurance configuration.

Given that a maximum of 480 watts of solar panels are allowed for the endurance run, two 240 watt Renogy® polycrystalline solar panels will be utilized with one being mounted to the front of the boat and one at the rear. The panels will be mounted to the top surface of the boat using RAM® ball mounts to help ease in taking the panels on and off of the boat. To further increase the ease in which the panels are taken on and off, two water-resistant through-hull connectors will be utilized to facilitate the connection of the panels to the boat's electrical system. The output of the panels will initially be directed through dual charge controllers to prevent sulfation of the attached battery pack. Once the sprint heat is underway, the pilot will switch the controllers out of the circuit allowing the full output of the panels to be delivered to the motor controller. At this point the applied load of the motor will prevent the batteries from becoming overcharged and sulfating.

C. Design Testing and Evaluation

1) Test Procedures: Our major changes come in the form of our implementation of a hydrofoil for improved displacement operation and the implementation of an improved telemetry system for remote system configuration and data acquisition. The telemetry system was tested outside of the boat over a two-mile distance and tested in the boat, on the water, over a distance of one mile. The benefits of the implementation of the hydrofoil will be determined by additional on-water testing.

2) Test Results: Preliminary testing of the benefits of the hydrofoil are currently underway. To date only one on-water test has been performed with promising results. The foil was able to provide some lift to the transom and provide an overall increase in both speed and range. However, the foil will require more testing in order to ensure optimum design and attachment. Due to unseasonably cool weather and excessively low water levels at the lake where we test our boat, opportunities for additional on-water testing have yet to present themselves. Testing of the telemetry system has been exceptionally positive. The new telemetry system has actually exceeded expectations and is considered to be fully operational and race-ready.

3) Evaluation of Performance: Overall the team is satisfied with the appearance and performance of the boat to date. A lot of work went into designing a hydrofoil that would improve the performance of our existing hull, and the team looks forward to additional testing and any necessary redesigns. Also, a lot of work went into designing a telemetry system that would not only be able to maintain connectivity over a long range, but also be expandable and able to meet any future connectivity requirements. In respect to the telemetry system, the team's expectations have been exceeded.

4) Discussion: Having over a month to continue working before the 2015 Solar Splash, the team's confidence is high that enough time remains in which to complete the final testing and design of the hydrofoil. Given that the boat is currently in perfect running condition with all systems functioning perfectly, the team's moral is exceptionally high.

II. SOLAR SYSTEM DESIGN

A. Current Design

1) Overview of Current Design: Two 240 watt Renogy® polycrystalline solar panels are being utilized to provide the 480 watts maximum allowable solar power. One panel will be mounted to the front of the boat and one at the rear. RAM® ball mounts will be used to mount the panels to the boat. Two marine-type through-hull connectors are utilized to facilitate the connection of the panels to the boat's electrical system. Dual dash-mounted charge controllers will regulate battery charging from the solar panels. A charge controller bypass switch will allow for the full output of the panels to be passed to the single motor controller that will be in use during the endurance run.

2) What Are the Problems or Issues:

- Must provide the maximum power allowable.
- Must be easy to mount and dismount.
- They must charge the batteries in a regulated fashion in order to avoid battery over-charge and subsequent sulfation.
- Easy method for electrical connectivity is desired.
- Easy method for converting boat's electrical system over to solar configuration.

3) What Are We Trying to Improve: Our current system resolves all problems and issues, therefore no additional improvement is required.

B. Analysis of Design Concept

1) Design Description:

- Two 240 watt Renogy® polycrystalline solar panels will be utilized.
- RAM® ball mounts function as both mounting points and supports
- Dual C4860 Solar Charge Controllers provide charge regulation.
- Dual thru-hull electrical connectors allow the solar panels to simply be plugged in.
- Electrical reconfiguration from sprint to endurance mode is switch controlled at the helm.
- A charge controller bypass switch allows for the full output of the panels to be passed to the single motor controller that will be in use during the endurance run.

2) Design Alternatives/Tradeoffs: A design alternative would be to avoid commercially available panels in favor of the team constructing their own panel. Doing so would allow the team to take advantage of the additional 10% of solar power allowed by the rules for team-constructed panels. Additionally, the cells could be integrated into the boat's top deck surface, increasing the overall aesthetics of the boat.

3) Rationale for Choice:

- The two 240 watt Renogy® polycrystalline solar panels were selected due to their ability to provide the maximum 480 watts of solar power allowed.
- RAM® ball mounts were selected to function as both mounting points and supports in order to simply the mounting and dismounting process as they eliminate the need for tools or hardware when placing or removing the panels.
- Dual C4860 Solar Charge Controllers were selected to provide charge regulation due to their

being relatively inexpensive, easy to mount in or dash, programmable for the required charging voltages, and they feature displays that allow the driver to monitor both the charge status and the battery level.

- Dual thru-hull electrical connectors were chosen to allow the solar panels to simply be plugged in instead of physically wired in when they were placed on the boat.
- Electrical reconfiguration is switch controlled at the helm in order to further reduce the time required to switch over between sprint and endurance run configurations.
- A charge controller bypass switch was added to the dash to allow for the full output of the panels to be passed to the single motor controller that will be in use during the endurance run. This prevents the motor controller from experiencing a “low voltage” situation which could possible cause the controller to shut down while the boat is in operation. Despite the output from the panels being bypassed to the motor controller, the charge controllers will continue to provide battery health information to the driver.

C. Design Testing and Evaluation

1) Test Procedures: With the panels connected, the endurance batteries installed and the electrical system switched into the endurance mode configuration, the boat was placed in the sun to verify charging. To verify the operation and functionality of the charge bypass switch, the bypass was put into operation during on-water testing.

2) Test Results: With the panel’s output passing through the charge controller, the batteries were charged to 13.5 volts each, at which time the charging process was stopped automatically by the charge controllers. During on-water testing, when the charge bypass switch was tuned on, the charge controllers continued to provide battery health information and the charge controllers remained in operation after two-hours of continuous operation.

3) Evaluation of Performance: The solar system meets the team’s expectations as it operates as designed and intended.

III. ELECTRICAL SYSTEM

A. Current Design

1) Overview of Current Design:

- Two 240 watt Renogy® polycrystalline solar panels are utilized for solar charging, providing a total of 480 watts of solar power.
- Dual C4860 Solar Charge Controllers provide charge regulation.
- Dual thru-hull electrical connectors allow the solar panels to simply be plugged in.
- A charge controller bypass switch allows for the full output of the panels to be passed to the single motor controller that will be in use during the endurance run.
- Battery power for the boat during sprint events will be provided by three Optima® Red Top Group 25 automotive-type cranking batteries.
- Battery power for the boat during endurance events will be provided by two Trojan® SCS150 Group 24 marine-type deep cycle batteries.
- Motor speed and power utilization is controlled through dual Altrax® AXE 4865 motor

controllers.

- A long-range Wi-Fi based telemetry system is used for motor controller configuration and GPS data logging. The system consists of a 1-Watt wireless access point on shore and a 0.5-Watt wireless access point onboard the boat. An onshore laptop is connected to the system through a wireless onshore router. The boat's motor controllers, along with a GPS antenna, are connected to the boat's access point through a Lantronix RS232 to Ethernet converter.
- Auxillary power for the onboard telemetry system, trim position indicator and electric horn is supplied by a 10Ah sealed lead acid battery.
- 3/0 copper welding cable supplies all high-current power throughout the electric drive system.
- Throttling is controlled by an in-dash potentiometer.
- An electric horn is used for signaling (a backup air horn is also onboard).
- Appropriate fusing is implemented throughout, to include one 500 amp fuse for each motor controller.
- An electric actuator is used to facilitate trimming of the outdrive. The actuator's direction is controlled by a toggle switch on the dash and a relay bank that changes the current direction as required.
- A string-potentiometer is mounted to the actuator to provide trim position feedback to the dash-mounted trim gauge.
- A voltmeter is integrated into the dash with a selector switch for choosing between main battery, aux battery, and off.
- A master switch and dead-man's switch are wired in series, as required by rule 3.7.
- Dual motor controller bypass switches are integrated into the dash to allow the pilot to bypass the motor controllers in the event of a controller failure.
- A dash-mounted tachometer provides the pilot with driveshaft speed information (primarily for testing purposes).
- A dash-mounted GPS device allows provides the pilot with speed, distance, and positional information.

2) What Are the Problems or Issues: Our current electrical system operates as designed and desired with no significant problems or issues having been identified to date.

3) What Are We Trying to Improve: Currently, there are no identified areas that the team deems to be in need of improvement.

B. Analysis of Design Concept

1) Design Description: An accurate description of the current design is provided under the *Current Design* sub-section above.

2) Design Alternatives/Tradeoffs: The team has discussed a desire to implement brushless motors into next year's design. The brushed motors were selected as a result of their efficiency and their being relatively inexpensive. In fact, they have proved to be extremely reliable with the 2015 Solar Splash being the fourth Solar Splash in which the current motors have been used.

3) Rationale for Choice:

- The two 240 watt Renogy® polycrystalline solar panels were chosen because they are able to provide the allowed 480 watts of solar power.
- Dual C4860 Solar Charge Controllers were selected to provide charge regulation due to their being relatively inexpensive, easy to mount, programmable for the required charging voltages, and they feature displays that allow the driver to monitor both the charge status and the battery level.
- Dual thru-hull electrical connectors were chosen to allow the solar panels to simply be plugged in instead of physically wired in when they were placed on the boat. This increased the speed at which the solar panels can be placed and removed.
- A charge controller bypass switch was added to the dash to allow for the full output of the panels to be passed to the single motor controller that will be in use during the endurance run. This prevents the motor controller from experiencing a "low voltage" situation which could possible cause the controller to shut down while the boat is in operation. Despite the output from the panels being bypassed to the motor controller, the charge controllers will continue to provide battery health information to the driver.
- Optima® Red Top Group 25 automotive-type cranking batteries were chosen for the sprint run because these batteries offer a Cold Cranking Amp (CCA) rating of 720 Amps and have a scale weight of 33.2 lbs, allowing three of them to meet the weight restrictions for the batteries as imposed by the rules for the Solar Splash event. These batteries also offer one of the highest CCA ratings available for their size.
- The decision to use Trojan® SCS150 Group 24 marine-type deep cycle batteries for the endurance runs was due to their 50 lb weight and their 100Ah rating.
- The Altrax® AXE 4865 motor controllers were chosen because these controllers offer the benefit of being fully programmable through their integrated RS232 port and offer a maximum current limit of 650 Amps. They are also waterproof due to their internal components being fully encapsulated in epoxy.
- The implementation of a long-range Wi-Fi based telemetry system for motor controller configuration and GPS data logging arose from the need for a system that provided built-in error correcting against data loss. The Wi-Fi based telemetry system's IP connectivity scheme eliminates the connectivity errors associated with the RS232 radio modems incorporated into last year's telemetry system.
- The decision to use a sealed lead acid battery to power the auxiliary systems was based on the fact that such batteries are commonly available, easily charged from automotive-type wall chargers, provide the required amount of power, are recyclable, and are relatively inexpensive.
- 3/0 copper welding cable supplies is used for all high-current power throughout the electric drive system in order to minimize the I^2R losses. Due to the weight of the cable, and the increase in resistance over distance, care was taken to ensure that all cable runs were as short as possible. The cable ends were all terminated using high-quality crimp lugs with heat shrink tubing applied for strain relief and dressing purposes. The result is a high-current, low-loss system capable of delivering the necessary power when needed.
- Throttling is controlled by an in-dash potentiometer in order to maintain maximum cockpit ergonomics. A side-mounted marine-type throttle, in addition to encroaching into the available cockpit space, could potentially hamper the pilot's egress should there be an emergency.

- Though seemingly insignificant, an electric horn is used as the primary method for emergency signaling. This feature solves the problem of air-horn storage, and simplifies signaling for the pilot (a backup whistle is also onboard).
- The use of appropriate fusing throughout the electrical system is a necessity in order to prevent electrical fires, component damage, and battery explosions.
- The outdrive required a method for trimming. To achieve this, an electric actuator is used. The electric actuator solution was chosen because it is lighter and simpler than a hydraulic solution.
- Because the pilot needs to know the trim position of the outdrive, a string-potentiometer is mounted to the actuator to provide trim position feedback to the dash-mounted trim gauge.
- To help with power management, a voltmeter is integrated into the dash with a selector switch for choosing between main battery, aux battery, and off. However, main battery levels are also monitored from the shore through the telemetry system
- In order to be compliant with the rules, a master switch and dead-man's switch are wired in series. When either of these switches are opened, power will not pass to the drive system.
- Dual motor controller bypass switches are integrated into the dash to allow the pilot to bypass the motor controllers in the event of a controller failure. While applying the full potential of the batteries to the motors is less than ideal, this system allows the pilot an option for continuing the race should the motor controllers fail. The bypass switch does not bypass the deadman switch.
- A dash-mounted tachometer provides the pilot with driveshaft speed information (primarily for testing purposes). Knowing the shaft speed allows for theoretical speed calculations based on propeller pitch and diameter. Additionally, it provides the pilot with visual input that the motors are turning should the speed of the craft reach a point where this may be in question.
- A dash-mounted GPS device provides the pilot with speed, distance, and positional information. Though GPS speed and position are logged through the telemetry system, this feature allows for the boat to have an integrated speedometer and a redundant method for recording distance traveled.

C. Design Testing and Evaluation

1) Test Procedures*:* All systems were designed and installed to professional standards. Testing consisted of power-up tests in the lab and on-water testing.

2) Test Results: All systems contained within the boat's electrical system have been tested and determined to be operational. The wiring harness contained within the boat has remained consistent for three years with the only modifications made being those to the telemetry system. As such, the current electrical system has proved to be consistently reliable.

3) Evaluation of Performance: The electrical system performs as designed and desired. No operational anomalies have been observed. As such, it can be concluded that the performance of the electrical system meets all expectations for operational performance and robustness.

IV. POWER ELECTRONICS SYSTEM

A. Current Design

1) Overview of Current Design:

- Motor speed and power utilization is controlled through dual Altrax® AXE 4865 motor controllers.
- Throttling is controlled by an in-dash potentiometer.
- Dual C4860 Solar Charge Controllers provide charge regulation.

2) What Are the Problems or Issues: The current motor and charge controller function as desired. There are no known problems or issues with electronic power management systems

3) What Are We Trying to Improve: The charge controllers are capable of passing the maximum power produced by the solar cells, and the motor controllers are capable of passing the desired 500 amps of current to the motors. Additionally, the implementation of a potentiometer for throttle control is well suited for our team's design. At this point, no improvements have been attempted or desired in regards to the power management electronics. However, a Morningstar TS-45 charge controller was ordered for testing and will be implemented into next year's design. Given that our IP based telemetry system will be ported to next year's build, the primary reason for desiring the Morningstar controller is its ability to connect to our telemetry system through its integrated Ethernet connection.

B. Analysis of Design Concept

1) Design Description: The Altrax® AXE 4865 motor controllers are connected to the batteries and the motors using 3/0 copper welding cable. Throttling of the controllers is achieved through a dash-mounted potentiometer. Configuration of the motor controllers, along with monitoring of current flow, throttle response, battery health, and controller temperature, is achieved through a Wi-Fi based remote telemetry system that interfaces with the controllers through their integrated RS232 ports via a Lantronix RS232 to Ethernet adapter.

All solar charging of the batteries is facilitated through the dual dash-mounted C4860 Solar Charge Controllers. The charge controllers offer the pilot the ability to monitor charge status and battery health.

2) Rationale for Choice:

- The Altrax® AXE 4865 motor controllers were chosen because these controllers offer the benefit of being fully programmable through their integrated RS232 port and offer a maximum current limit of 650 Amps. They are also waterproof due to their internal components being fully encapsulated in epoxy.
- Throttling is controlled by an in-dash potentiometer in order to maintain maximum cockpit ergonomics. A side-mounted marine-type throttle, in addition to encroaching into the available cockpit space, could potentially hamper the pilot's egress should there be an emergency.
- Dual C4860 Solar Charge Controllers were selected to provide charge regulation due to their being relatively inexpensive, easy to mount in our dash, programmable for the required charging voltages, and they feature displays that allow the driver to monitor both the charge

status and the battery level.

C. Design Testing and Evaluation

1) Test Procedures: All systems were designed and installed to professional standards. Testing consisted of power-up tests in the lab and on-water testing.

2) Test Results: All electronic systems contained within the boat's electrical management system have been tested and determined to be operational. The current electronic systems used for electrical management have met all expectations for design and operation.

3) Evaluation of Performance: The Altrax® AXE 4865 motor controllers provide efficient power handling and their programmability and data streaming abilities allow for easy configuration and data logging from the shore through the boat's Wi-Wi based telemetry system. Additionally, the charge controllers have proven to be efficient at regulating the charge for both the 36 volt sprint battery pack and the 24 volt endurance battery pack.

V. HULL DESIGN

A. Current Design

1) Overview of Current Design:

- Strong and lightweight carbon fiber composite construction.
- A Lantor® Soric XF3 foam core for weight reduction and increased buoyancy.
- Integrated top deck surface to help reduce aerodynamic drag.
- Fully enclosed battery and motor compartments.
- A professional-grade paint job with clear coat finish.
- Foam sponsons to prevent water splash onto the pilot and into the boat.
- Low-profile tracking fins attached at the rear.
- Transom mounted hydrofoil to improve hydrodynamic efficiency during displacement operation.

2) What Are the Problems or Issues: The hull was originally designed to be efficient in both planning and displacement operation. However, the efficiency of the hull during displacement operation has been noted to suffer as a result of the square shape of the transom. In order to overcome this, a hydrofoil is currently being tested for the purposes of raising the transom during displacement operation as this will prevent the formation of eddies at the stern that rob the hull of hydrodynamic efficiency when it is not on plane.

3) What Are We Trying to Improve: Hydrodynamic efficiency during displacement operation.

B. Analysis of Design Concept

1) Design Description: When the team began the process of discussing hull designs, the need for efficient planing and displacement operation was the guiding factor. The design process began with shaving down some Styrofoam models and then moved onto a CAD representation and refinement of the chosen shape. Fig. 1 shows the hull shape as it was designed in CAD.

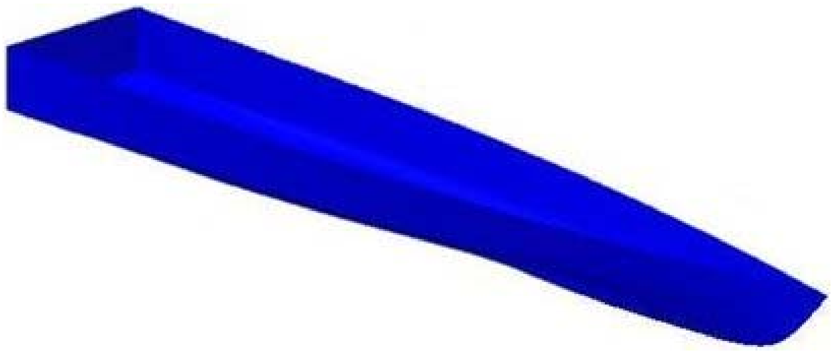

Fig. 1 – CAD rendering of hull design

Once a hull shape was determined it was decided that the hull would be constructed of carbon fiber in order to ensure that the hull was lightweight and durable. The three-part molding process that was used to create the hull was as follows:

- Construction of the positive mold was a multi-stage process, as shown in Fig. 2. It began with constructing a wooden frame that was then covered with foam board and finally with Bondo automotive body filler and sanded flush.

- Once the mold was true to form, a coat of high-build primer was applied, sanded, and buffed.

Wooden frame | Foam buildup | Foam Smoothing | Bondo Smoothing

Fig. 2

Fig. 3 – Finished negative mold

- The reinforced two-part negative mold, shown in Fig. 3, was constructed of fiberglass chopped strand fiberglass mat infused with polyester resin.

- The first step in the vacuum forming process was to select a proper composite material layup schedule. This was carefully researched to ensure that our layup schedule was optimized. The layup included six (6) layers of 5.7 oz 3k, 2x2 twill weave bidirectional carbon fiber, three (3) layers of 9.0 oz unidirectional carbon fiber to reinforce the keel and bow, and one (1) layer of Lantor® Soric XF3 as a core material.

- Based on research, the plies were arranged in the mold as follows:
  (2x) bidirectional, (1x) unidirectional, (1x) bidirectional, (1x) Soric, (2x) bidirectional, (1x) unidirectional, (1x) bidirectional, (1x) unidirectional.

- The plies were then carefully cut to size, and a plywood reinforcement panel was laid symmetrically in between the plies to ensure maximum transom strength for the surface drive unit. The layup schedule was then covered with nylon peel ply to allow the vacuum bag and infusion materials to be easily separated after curing.

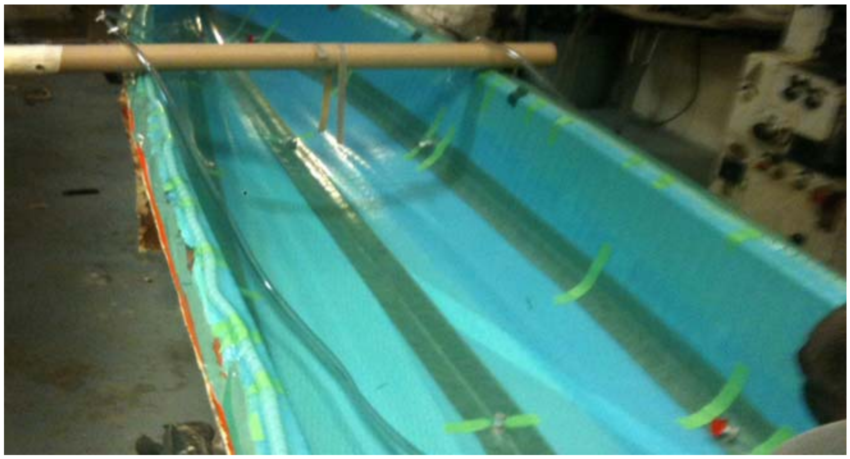

Fig. 4 – Vacuum forming of the hull

- Vacuum pressure was applied until complete epoxy infusion throughout, shown in Fig 4. After 48 hours, the hull was removed from the mold and the edges were trimmed from the part.

- The hull was then sanded, coated with a marine-grade vinyl ester primer, wet-sanded, painted with a metallic blue finish automotive paint, and then finally coated with six coats of clear coat. A final wet sanding and buffing was performed.

2) Design Alternatives/Tradeoffs: Many alternatives exist for every aspect of the hull's design, from shape to composition. Discussion for next year's hull design includes catamaran hybrid design, suitable for both low-speed displacement and high-speed planing operation. Construction material options discussed include fiberglass, thermoformed plastic, and carbon fiber.

3) Rationale for Choice: We wanted our hull to be lightweight and strong enough so that it would not need of any additional reinforcement. As such, we chose carbon fiber. The Lantor® Soric XF3 core was added to the layup to serve as an inter-laminar breather material and to add additional buoyancy to the construction.

C. Design Testing and Evaluation

1) Test Procedures: All hull testing consisted of on-water operation and observation.

2) Test Results: While the hull has consistently performed well during planning operation, it is not as efficient in displacement operation. While the team is currently satisfied with the boat's performance while on plane, more testing with our hydrofoil is required in order to increase displacement efficiency.

3) Evaluation of Performance: The hull is a great planning hull and, with additional work and testing on the team's hydrofoil implementation, it is believed that the displacement performance will be substantially increased.

VI. DRIVE TRAIN and STEERING

A. Current Design

1) Overview of Current Design:

- Dual brushed Motenergy® ME1003 DC motors
- Transom-mounted custom built Arneson-type surface drive.
- Helm-adjustable electric trim.
- Rudderless vectored-thrust steering controlled by a rotary helm and steering cable.
- Interchangeable sprockets for variable gear ratios.
- Easy propeller swapping.
- Pilot controllable trim with dash-mounted position indicator.

2) What Are the Problems or Issues: The current drivetrain and steering system function as designed and intended. There are no known problems or issues with these systems.

3) What Are We Trying to Improve: Given the lack of issues or problems with our current system, no areas for improvement have been identified.

B. Analysis of Design Concept

1) Design Description:

- The Arenson-type surface drive was designed and machined in MTSU's machine shop by team members using pictures of existing designs as a guide. The drive, shown in Fig. 5, minus the propeller, consists of four main components: an oil-filled thrust tube which carries the propeller shaft; a spherical pivot that houses the double-cardan universal joint, the ball-socket housing that contains the spherical retainer ring and the primary driveshaft, and the driveshaft itself. The housings are all constructed of 6061-T6 aluminum, the spherical retainer ring is constructed of 360 brass alloy, and the driveshaft is hardened 1018 cold-rolled steel. The fully assembled unit weighs approximately 50 pounds, including the trim and steering actuators.

  The universal joint was sourced from a Mercruiser® Stern Drive due to its ability to handle massive torque loads at several degrees from its central axis. The secondary shaft was then extended with the 1" O.D. 1018 steel stock to lengthen the propeller shaft to the necessary dimensions. The ball-and-socket joint in conjunction with the double-cardan u-joint enables omnidirectional steering and trim angles of up to 30 degrees from centerline of the drive unit. The propeller attaches at the aft section of the propeller shaft by means of a 3/16” key.

Fig. 5 – Completed surface drive with trim actuator

- Steering is achieved through rotary helm and a steering cable connected to a mechanical arm located at the transom. The steering mechanism is shown in Fig. 6 below.

Fig. 6 – View of steering mechanism

- The motor drive plate and sprockets, shown in Fig. 7, were designed using AutoCAD and fabricated using computer numerical control (CNC) milling. An eccentric chain tensioner was added to allow for chain tension adjustment. Incorporated handles assist with lift.

- The chain-and-sprocket system uses an inexpensive and readily available #40 roller chain. The sprockets currently in use are 25-tooth and 15-tooth sprockets.

- A Michigan 9.5” diameter four-bladed propeller with added cuppings, shown in Fig. 8, was tested and selected for use in the sprint runs. A high-effeciency Torqueedo® threebladed propeller, shown in Fig. 9, was tested and selected for use during the endurance runs.

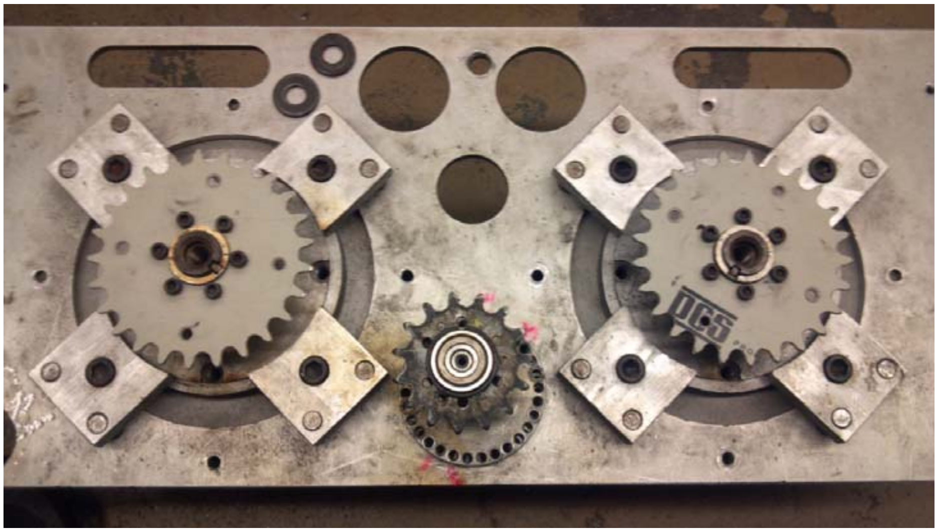

Fig. 7 – Motor drive plate, sprockets, and chain tensioner

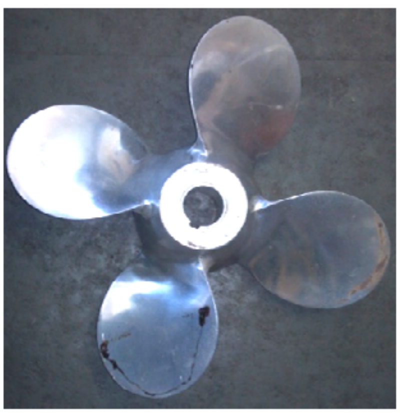

Fig. 8 – Michigan propeller

Fig. 9 – Torqueedo propeller

2) Rationale for Choice:

- The Arenson-type surface drive was designed and machined in MTSU's machine shop by team members. This type of drive unit allows for a fully adjustable trim while simultaneously eliminating the need of a steering rudder. A universal motor mount and swappable drive sprockets were adapted into the drivetrain design to allow full adjustment of torque and RPM specifications to aid in achieving the optimum drivetrain configuration through trial-and-error testing. Available on-hand parts included a commercially available rotary helm and steering cable for which the steering arm linkage was designed to accommodate.

C. Design Testing and Evaluation

2) Test Procedures: Testing of the drivetrain and steering system initially took place in the lab. Once the team was satisfied with the functionality, on-water testing was performed.

3) Test Results: Both drivetrain and the steering system functioned as designed resulting in both systems being deemed to meet the expectations of the team.

VII. DATA ACQUISITION and COMMUNICATIONS

A. Current Design

1) Overview of Current Design:

- On-shore telemetry station:
  - WL2410GM 1 watt Outdoor Wi Fi Access Point
  - Linksys R10000G Wireless-G Broadband Router, 2.4GHz
  - OM2415, 2.4 Ghz antenna, 15 Dbi gain
  - Dell laptop running Altrax motor controller configuration and GPS mapping software
- Onboard the boat:
  - ASU 500mW, 2.4 GhZ Outdoor WiFi Access Point
  - Linksys R10000G Wireless-G Broadband Router, 2.4GHz
  - Lantronix RS232 to Ethernet converter
  - Uniden BC-GPSK Serial GPS Receiver
  - 8 dBi omni-directional Wi-Fi

2) What Are the Problems or Issues: Our previous telemetry system employed three RS232 radios modems onshore and three onboard the boat in order to facilitate the data link. However, due to a lack of error correction in this system, connectivity to the motor controllers would frequently fail.

3) What Are We Trying to Improve: Connection reliability. The implementation of a long-range Wi-Fi based telemetry system for motor controller configuration and GPS data logging arose from the need for a system that provided built-in error correcting against data loss. The Wi-Fi based telemetry system's IP connectivity scheme, with built-in error correction, eliminates the connectivity errors associated with the RS232 radio modems incorporated into last year's telemetry system.

B. Analysis of Design Concept

1) Design Description: The shore station consists of a WL2410GM 1 watt outdoor Wi Fi access point connected to a Linksys R10000G wireless-G broadband 2.4GHz router. These units are housed in a Pelican case and attached to a dolly that serves as a mounting point for the OM2415, 2.4 Ghz, 15 Dbi gain antenna. A laptop is setup on a small folding table and wirelessly connected to the Linksys router located in the Pelican case. The WL2410GM 1 watt outdoor Wi Fi access point located in the Pelican case connects to the ASU 500mW, 2.4 GhZ outdoor WiFi access point

located on the boat. A second Linksys router is connected to the boat's access point, to which a Lantronix RS232 to Ethernet converter is connected.
The Lantronix RS232 to Ethernet converter features two physical RS232 serial ports. One is connected to an AB switch box at the helm, with the A and B cable connected to the motor controllers. The other RS232 port provides connectivity for the Uniden BC-GPSK serial GPS receiver.

The onshore laptop is running Lantronix virtual serial port software which allows the operating system to treat the RS232 ports located on the boat as physical ports located directly on the computer. As such, the Altrax motor controller configuration and GPS mapping software are able to seamlessly connect with the motor controller and the GPS antenna as if they were plugged directly into the laptop.

2) Rationale for Choice: The Wi-Fi based telemetry system's IP connectivity scheme, with built-in error correction, eliminates the connectivity errors associated with the RS232 radio modems incorporated into last year's telemetry system.

C. Design Testing and Evaluation

1) Test Procedures: The onshore and onboard systems were originally setup on two separate tables and located several rooms apart from each other. Once connectivity was verified, the onshore system was mounted into a Pelican® case and connectivity was again tested over a longer distance.

2) Test Results: Testing has confirmed the reliability of this system and its suitability for porting onto next year's boat.

3) Evaluation of Performance: Because this system implements an IP connectivity scheme with built-in error correcting, and because it has a maximum range of 20 miles, it offers an expandability and robustness the previous telemetry system did not.

4*) Discussion:* It is hoped that additional functionality will be added to this telemetry system in the future, to include streaming video and a private voice over IP (VOIP) communication line between the pilot and the shore station operator. While the required FRS radios will continue to provide communication between the pilot and the shore as required by the rules, a private VOIP connection would allow for full-duplex technical discussions and prevent unnecessary FRS radio chatter.

VIII. PROJECT MANAGEMENT

A. Team Members and Leadership Roles

Aside from the roles of Captain and Co-Captains, there were only a few specific roles for team members. As new tasks presented themselves, all team members collaborated together to complete the tasks at hand before moving on to the next task. A few specialized tasks were granted to certain individuals as determined by their level of expertise in that area. Aside from these specialized tasks, the majority of the tasks were completed as a collaborative effort.

The Captain was responsible for all of the project scheduling, acquisition of materials, manpower allocation, and administrative duties. In his absence, one of the Co-Captains was responsible for fulfilling these duties.

B. Project Planning and Schedule

While the overall build could be considered to have gone exceptionally smooth, some difficulties did present themselves in construction scheduling. The acquisition of team members was also slow to ramp up. However, once a solid group of individuals was finally on the project, meeting team goals became less of a problem. Ultimately, construction was completed well before the competition providing adequate time for testing. Though a rigid schedule and timeline proved impossible to adhere to, all tasks were performed in a timely manner and the end result exceeded expectation.

C. Financial and Fund-Raising

The majority of funding for our project comes from the MTSU Student Government Association which gathers and allocates funds for student projects. Additional funding came from various grants and donations that were secured by the project's faculty advisor.

IX. CONCLUSIONS/RECOMMENDATIONS

A. Did We Meet Our Overall and Sub-System Objectives?

Our primary goal was to increase the hull's efficiency during the endurance runs and to design and implement a telemetry system that was not plagued with the connectivity issues associated with our previous telemetry system.

Through the implementation of a hydrofoil and additional testing we feel that the performance of the hull will meet the expectations of the team by the time the boat goes to the competition. Additionally, our new telemetry system has far exceed our expectations and will be more than suitable for porting on to the next build.

B. Recommendations to Future Teams

A recommendation to future teams would be to start early and identify all problems that will need to be overcome up front. No matter how hard we try we accept that we'll never be able to achieve 100% optimization within our design given the time constraints within which he have to operate. However, every team hopes that the next will learn from the mistakes that are made and be able to avoid them in the next build.

Like all of the experimental vehicles that are built by students at MTSU, this boat was built by individuals that have given every second of time they had to give. The Solar Splash offers a unique opportunity to gain hands on experience, build team skills, and gain insight into how others have solved the problems we are trying to solve. Those of us who have participated in this build are proud of what we have accomplished and we look forward to the Solar Splash.

X. REFERENCES

Optima® Battery MSDS (Appendix A)

Interstate Batteries. (2011, Oct 17). *Material safety data sheet for all Optima® batteries*. Retrieved from http://corporate.interstatebatteries.com/msds/Optima®_msds_010930.pdf

Trojan® Battery MSDS (Appendix A Cont.)

Interstate Batteries. (2013, Jan 09). *Trojan® Battery Material Safety Data Sheets*. Retrieved from http://www.trojanbattery.com/pdf/MSDSPastedplate_January09_2013.pdf

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Montergy Motors (Appendix E)

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Alltrax® Controllers (Appendix F)

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Optima® Battery Specs (Appendix J)

Optima® Batteries. (2013). *Optima® batteries full specs sheet*. Retrieved from http://jci_media.s3.amazonaws.com/9613/4583/5078/REDTOP_Full_Specs_Sheet.pdf

Trojan® Battery Manufacturer Data Sheet (Appendix K)

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Appendix A: Optima® Battery Material Safety Data Sheet (MSDS)

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

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

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

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

II. Hazardous Ingredients

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

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

III. Physical Data

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

IV. Health Hazard Information

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

ROUTES AND METHODS OF ENTRY

Inhalation

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

Skin Contact

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

Skin Absorption

Skin absorption is not a significant route of entry.

Eye Contact

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

Ingestion

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

SIGNS AND SYMPTOMS OF OVEREXPOSURE

Acute Effects

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

Chronic Effects

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

POTENTIAL TO CAUSE CANCER

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

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

EMERGENCY AND FIRST AID PROCEDURES

Inhalation

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

Skin

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

Eyes

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

Ingestion

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

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

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

V. Fire and Explosion Data

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

Extinguishing Media
Dry chemical, foam, or CO_2

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

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

VI. Reactivity Data

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

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

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

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

VII. Control Measures

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

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

PERSONAL PROTECTIVE EQUIPMENT

Respiratory Protection
None required for normal handling of finished product.

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

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

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

VIII. Safe Handling Precautions

Hygiene Practices

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

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

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

	SPILL OR LEAK PROCEDURES

Protective Measures to be Taken if Material is Released or Spilled

Remove combustible materials and all sources of ignition. Avoid contact with acid materials. Use soda ash, baking soda or lime to neutralize any acid that may be released.

If battery is broken, wear chemical goggles and acid-resistant gloves for handling the parts.

DO NOT RELEASE UNNEUTRALIZED ACID!

Waste Disposal Method

Battery Electrolyte (Acid): Neutralize as above for a spill, collect residue, and place in a drum or suitable container. Dispose of as a hazardous waste.

DO NOT FLUSH LEAD-CONTAMINATED ACID INTO SEWER.

Send spent or broken batteries to a lead recycling facility or smelter that follows applicable Federal, State and Local regulations for routine disposition of spent or damaged batteries. The distributor / user is responsible for assuring that these "spent" or "damaged" batteries are disposed of in an environmentally sound way in accordance with all regulations. OPTIMA batteries are 100% recyclable by any licensed reclamation operation..

	SUPPLEMENTAL INFORMATION

Proposition 65 Warning (California) Proposition 65 Warning: The state of California has listed lead as a material known to cause cancer or cause reproductive harm (July 9, 2004 California List of Chemicals Known to Cause Cancer or Reproductive Toxicity) Battery posts, terminals and related accessories contain lead and lead compounds. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

TSCA Registry: Ingredients listed in the TSCA Registry are lead, lead compounds, and sulfuric acid.

Transportation: Sealed Lead Acid Battery is not a DOT Hazardous Material.

Other: Per DOT, IATA, ICAO and IMDG rules and regulations, these batteries are exempt from "UN2800" classification as a result of successful completion of the following tests:

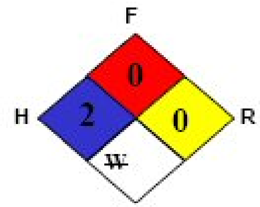
1) **Vibration Tests**
2) **Pressure Differential Tests**
3) **Case Rupturing Tests (no free liquids)**

US MILITARY NATIONAL STOCK NUMBER (NSN)

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

Trojan® Battery Material Safety Data Sheet (MSDS)

Hazard Rating



TROJAN BATTERY COMPANY
LEAD PASTED PLATES
MATERIAL SAFETY DATA SHEET

SECTION 1 – CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MANUFACTURER'S NAME: TROJAN BATTERY COMPANY	EMERGENCY TELEPHONE NO.: CHEMTREC (800) 424-9300 International (703) 527-3887
ADDRESS: 12380 CLARK ST., SANTA FE SPRINGS, CA 90670	OTHER INFORMATION CALLS: 562-236-3000 800-423-6569
PERSON RESPONSIBLE FOR PREPARATION: Ismael Pedroza, Jr. – Director of EH&S	Revised Date: January 09, 2013

SECTION 2 -- COMPOSITION/INFORMATION ON INGREDIENTS

C.A.S.	PRINCIPAL HAZARDOUS COMPONENT(S) (chemical & common name(s))	Hazard Category	% Weight	ACGIH TLV - mg/m³	OSHA PEL/TWA - mg/m³
7439-92-1	Grid Containing Lead	Acute-Chronic	40-50	0.05 mg/m³	0.05 mg/m³
7440-36-0	Antimony	Chronic	0-7.0	0.5	0.5
7440-31-5	Tin	Chronic	0-3.0	2	2
7440-70-2	Calcium (lead calcium alloy)	Reactive	0-0.5	Not Established	Not Established
7440-38-2	Arsenic (inorganic)	Acute-Chronic	0-0.2	0.01	0.05
None assigned	Paste Containing Lead Oxide (Litharge)	Acute-Chronic	50-60	0.05 (lead)	0.05 (lead)
7446-14-2	Lead Sulfate	Acute-Chronic	5-20	Not Established	0.05 mg/m³ (as lead)
1333-86-4	Carbon Black	Chronic	<0.2	3.5	3.5

Note: PEL's for Individual states may differ from OSHA's PEL's. Check with local authorities for the applicable state PEL's

COMMON NAME: (Used on label) (Trade Name & Synonyms) Pasted Plates	Chemical Family: Toxic Mixture
Chemical Name: Lead, Pasted Plates	Formula: Mixture

SECTION 3 – HAZARD IDENTIFICATION

Signs and Symptoms of Exposure	1. Acute Hazards	Direct skin or eye contact may cause local irritation. Inhalation or ingestion of lead dust or fumes may result in headache, nausea, vomiting, abdominal spasms, fatigue, sleep disturbances, weight loss, anemia and leg, arm and joint pain.	
	2. Sub-Chronic and Chronic Health Effects	Prolonged exposure may cause central nervous system damage, gastrointestinal disturbances, anemia, wrist-drop and kidney dysfunction. Pregnant women should be protected from excessive exposure to prevent lead from crossing the placental barrier and causing infant neurological disorders. **California Proposition 65 Warning: This product contains lead and lead compounds, which are chemicals known to the State of California to cause cancer and birth defects or other reproductive harm.**	
Medical Conditions Generally Aggravated by Exposure	Pulmonary edema, bronchitis, emphysema, dental erosion and tracheobronchitis.		
Routes of Entry	Inhalation- YES Ingestion – YES	Eye Contact- YES	Skin Absorption- NO

Chemical(s) Listed as Carcinogen or potential Carcinogen	Proposition 65 - YES	National Toxicology Program - YES	I.A.R.C. Monographs - YES	O.S.H.A. - NO	EPA CAG - YES	N.I.O.S.H. - YES

SECTION 4 - FIRST AID MEASURES

Emergency and First Aid Procedures	Contact with Lead/Pasted Plates
1. Inhalation	Move to ventilated area. Obtain medical attention if experiencing effects of overexposure.
2. Eyes	Flush the eyes with copious quantities of cool running water for 15 minutes. Obtain immediate medical attention.
3. Skin	Wash area thoroughly with soap and water.
4. Ingestion	Do not induce vomiting. If conscious drink large amounts of water/milk. Obtain medical attention. Never give anything by mouth to an unconscious person.
5. Lead Exposure	May cause lassitude, constipation, anemia, nausea, vomiting, paralysis, and central nervous system depression. Greatest exposure comes from dust in the air and on hands when packing/unpacking, and during lead acid battery manufacturing.

SECTION 5 – FIRE-FIGHTING MEASURES

Flash Point - Not Applicable	Flammable Limits in Air Lower Upper % by Volume N/A N/A	Extinguishing Media – Dry Chemical or CO_2	Auto-Ignition Temperature - Not Applicable
Special Fire Fighting Procedures	Do not use water on fires where molten metal is present. Use NIOSH/MSHA approved SCBA and full body protective equipment operated in positive pressure mode.		
Unusual Fire and Explosion Hazards	Molten metals produce fumes and/or vapor that may be toxic or respiratory irritants. Product can react vigorously with strong oxidizing agents.		

SECTION 6 – ACCIDENTAL RELEASE MEASURES

Procedures for Cleanup: Avoid contact with any spilled material. Contain spill, isolate hazard area, and deny entry. Limit site access to emergency responders. Material should be vacuumed with HEPA filter or wet swept and stored in dry containers for later disposal. Do not use compressed air or dry sweeping as a means of cleaning.

Personal Precautions: Wear protective clothing and appropriate NIOSH/MSHA approved respirator. ANSI approved safety glasses with side shields recommended.

Environmental Precautions: Lead and its compounds are a severe threat to the environment. Contamination of water, soil and air should be prevented.

SECTION 7 – HANDLING AND STORAGE

Precautions to be Taken in Handling and Storage	Store away from reactive materials, open flames and sources of ignition as defined in Section 10 – Stability and Reactivity.
Other Precautions	GOOD PERSONAL HYGIENE AND WORK PRACTICES ARE MANDATORY. Refrain from eating, drinking or smoking in work areas. Thoroughly wash hands, face, neck and arms before eating, drinking and smoking. Work clothes and equipment should remain in designated lead contaminated areas, and never taken home or laundered with personal clothing. Wash soiled clothing, work clothes, and equipment before reuse.

SECTION 8 – EXPOSURE CONTROLS AND PERSONAL PROTECTION

Respiratory Protection	NIOSH approved respirator is required when the PEL is exceeded or employee experiences respiratory irritation. When exposure levels are unknown or when fire-fighting, wear a self-contained breathing apparatus with a full face-piece operated in positive pressure mode.		
Ventilation	Use adequate general or local exhaust ventilation to keep airborne concentration below the PEL.		
Protective Gloves	Rubber Gloves	Eye Protection	ANSI approved safety glasses with side shields recommended.
Other Protective Clothing or Equipment	Aprons, boots and protective clothing appropriate for an industrial environment. Ventilation, as described in the Industrial Ventilation Manual produced by the American Conference of Governmental Industrial Hygienists, shall be provided in areas where exposures are above the PEL or TLV specified by OSHA or other local, state and federal regulations. Safety shower and eyewash.		

SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point: Not Applicable	Vapor Pressure Not Applicable	Specific Gravity 7.4 g/ml	Melting Point: 550°F
Percent Volatile By Volume Not Applicable	Vapor Density Not Applicable		Evaporation Rate Not applicable
Solubility in water 33 mg/l		Reactivity in Water None	
Appearance and Odor: Lead: Gray metallic, solid Lead Oxide: Orange or gray paste No apparent odor		Product manufactured by pasting lead oxide over lead frame (grid).	

SECTION 10 – STABILITY AND REACTIVITY

Stability: Stable	Conditions to Avoid: Intense Heat; avoid high concentrations of corrosives/acids.
Incompatibility (Materials to Avoid)	Strong oxidizers and this product may liberate hydrogen gas.
Hazardous Decomposition Products	Molten metals produce fumes and/or vapors that may be toxic or respiratory irritants.
Hazardous Polymerization	Hazardous Polymerization has not been reported.

SECTION 11 - TOXICOLOGICAL INFORMATION

GENERAL: The primary routes of exposure are ingestion or inhalation of dust.

ACUTE:
INHALATION/INGESTION: Exposure to lead and its compounds may cause headache, nausea, vomiting, abdominal spasms, fatigue, sleep disturbances, weight loss, anemia, and pain in the legs, arms and joints. Kidney damage, as well as anemia, can occur from acute exposure.

CHRONIC:
INHALATION/INGESTION: Prolonged exposure to lead and its compounds may produce many of the symptoms of short-term exposure and may also cause central nervous system damage, gastrointestinal disturbances, anemia, and wrist drop. Symptoms of central nervous system damage include fatigue, headaches, tremors, hypertension, hallucination, convulsions and delirium. Kidney dysfunction and possible injury has also been associated with chronic lead poisoning. Chronic overexposure to lead has been implicated as a causative agent for the impairment of male and female reproductive capacity, but there is at present, no substantiation of the implication. Pregnant women should be protected from excessive exposure. Lead can cross the placental barrier and unborn children may suffer neurological damage or developmental problems due to excessive lead exposure in pregnant women.

SECTION 12 - ECOLOGICAL INFORMATION

In most surface water and groundwater, lead forms compounds with anions such as hydroxides, carbonates, sulfates, and phosphates, and precipitates out of the water column. Lead may occur as sorbed ions or surface coatings on sediment mineral particles or may be carried in colloidal particles in surface water. Most lead is strongly retained in soil, resulting in little mobility. Lead may be immobilized by ion exchange with hydrous oxides or clays or by chelation with humic or fulvic acids in the soil. Lead (dissolved phase) is bioaccumulated by plants and animals, both aquatic and terrestrial.

SECTION 13 - DISPOSAL CONSIDERATIONS

DISPOSE IN ACCORDANCE WITH LOCAL, STATE AND FEDERAL REGULATIONS FOR LEAD AND LEAD COMPOUNDS.

SECTION 14 - TRANSPORT INFORMATION

U.S. DOT PROPER SHIPPING NAME: UN3077, (RQ) Environmentally Hazardous Substances, solid, n.o.s.
U.S. DOT HAZARD CLASS: 9
U.S. DOT ID NUMBER: UN3077
U.S. DOT PACKING GROUP: III
U.S. DOT LABEL: Class 9

SECTION 15 - REGULATORY INFORMATION

U.S. HAZARDOUS UNDER HAZARD COMMUNICATION STANDARD:

LEAD – YES
ANTIMONY – YES
ARSENIC – YES
LEAD SULFATE - YES

INGREDIENTS LISTED ON TSCA INVENTORY: YES

CERCLA SECTION 304 HAZARDOUS SUBSTANCES: (micrometer).	LEAD – YES	RQ: REPORTING NOT REQUIRED WHEN DIAMETER OF THE PIECES OF SOLID METAL RELEASED IS EQUAL TO OR EXCEEDS 100 μm
	ANTIMONY – YES	RQ: 5000 POUNDS
	ARSENIC – YES	RQ: 1 POUND
	LEAD SULFATE –YES	RQ: 10 POUNDS
EPCRA SECTION 313 TOXIC RELEASE INVENTORY:	LEAD – CAS NO: 7439-92-1 ANTIMONY – CAS NO: 7440-36-0 ARSENIC – CAS NO: 7440-38-2 LEAD SULFATE – CAS NO: 7446-14-2	

SECTION 16 - OTHER INFORMATION

THE INFORMATION ABOVE IS BELIEVED TO BE ACCURATE AND REPRESENTS THE BEST INFORMATION CURRENTLY AVAILABLE TO US. HOWEVER, TROJAN BATTERY COMPANY MAKES NO WARRANTY OF MERCHANTABILITY OR ANY OTHER WARRANTY, EXPRESSED OR IMPLIED, WITH RESPECT TO SUCH INFORMATION, AND WE ASSUME NO LIABILITY RESULTING FROM ITS USE. USERS SHOULD MAKE THEIR OWN INVESTIGATIONS TO DETERMINE THE SUITABILITY OF THE INFORMATION FOR THEIR PARTICULAR PURPOSES. ALTHOUGH REASONABLE PRECAUTIONS HAVE BEEN TAKEN IN THE PREPARATION OF THE DATA CONTAINED HEREIN, IT IS OFFERED SOLELY FOR YOUR INFORMATION, CONSIDERATION AND INVESTIGATION. THIS MATERIAL SAFETY DATA SHEET PROVIDES GUIDELINES FOR THE SAFE HANDLING AND USE OF THIS PRODUCT; IT DOES NOT AND CANNOT ADVISE ON ALL POSSIBLE SITUATIONS, THEREFORE, YOUR SPECIFIC USE OF THIS PRODUCT SHOULD BE EVALUATED TO DETERMINE IF ADDITIONAL PRECAUTIONS ARE REQUIRED.

Form MSDS Rev. January 09, 2012

Appendix B: Buoyancy Calculations

The buoyancy calculations were performed after using Inventor to determine the volume of the of the integrated AB expanding foam blocks (Fig. B-1 and B-2).

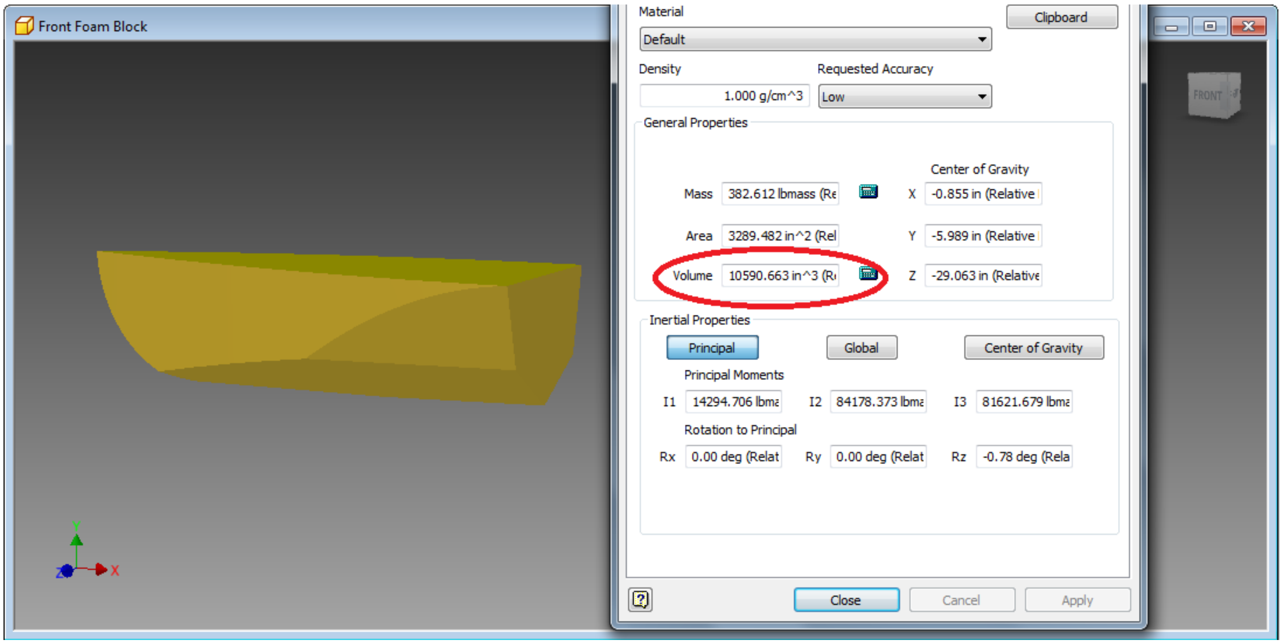


Fig. B-1

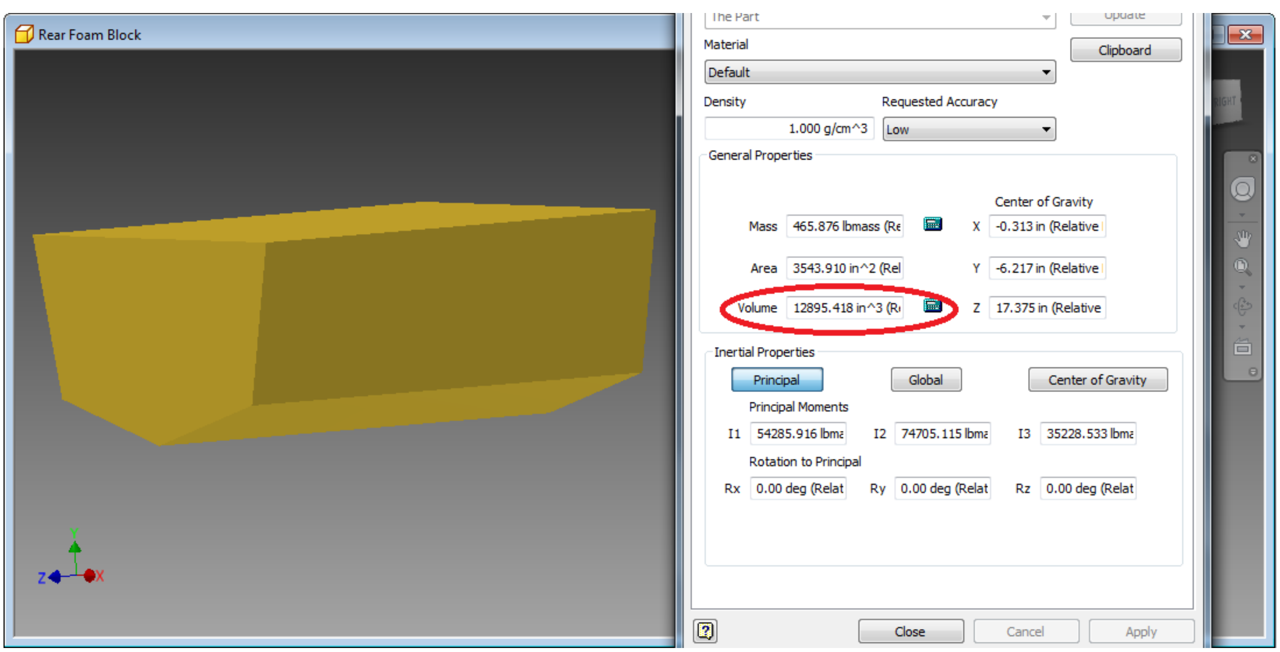


Fig. B-2

Next, the flotation value of the Ethafoam sponsons was calculated (these are the foam rails attached to the boat where the hull meets the top deck).

The manufactures states that a 9 foot section of the sponson material provides 45 lbs of flotation. Our installation features 15 foot of sponson material down each side, for a total of 30 linear feet.

At 45 lbs of flotation per 9 foot section, that equates to 5 lbs of flotation per linear foot.

30 feet x 5 lbs = 150 lbs of flotation attributable to the foam sponsons

Next, the weight of the boat in both the sprint and endurance configuration was calculated using Excel (figure B-3). The maximum weight allowable for the battery packs was used in the weight calculation, and all weights were rounded up to the next whole pound.

Endurance Configuration		
Hull	102	lbs.
Batteries	100	lbs.
Motors	78	lbs.
Motor Mount	10	lbs.
Motor Controllers	16	lbs.
Wire, Contactors, Components	50	lbs.
Drivetrain Assembly	50	lbs.
Solar Panels	99	lbs.
Cockpit Assembly	10	lbs.
Computer System	10	lbs.
Auxiliary Batteries	12	lbs.
Total Weight	537	lbs.

Sprint Configuration		
Hull	102	lbs.
Batteries	100	lbs.
Motors	78	lbs.
Motor Mount	10	lbs.
Motor Controllers	16	lbs.
Wire, Contactors, Components	50	lbs.
Drivetrain Assembly	50	lbs.
Cockpit Assembly	10	lbs.
Computer System	10	lbs.
Auxiliary Batteries	12	lbs.
Total Weight	438	lbs

Table B-1

Once the weights were totaled, it can be seen that the maximum weight of the boat occurs when it is in the endurance configuration, at which time it weighs 537 lbs (Table B-1). The foam has a density of 4 lbs per ft^3. Using Excel it was determined that the foam and sponsons have a total combined flotation capacity of 953.873 lbs (Table B-2). This equates to a safety factor of 75.77 %, which well exceeds the required safety factor of 20%.

Buoyancy Calculation		
Front AB Foam Block	10,590.66	in^3
Rear AB Foam Block	12,895.42	in^3
Total	23,486.08	in^4
Total Foam Volume	13.591	ft^3
Total Ethafoam Sponsons	30.00	ft
Density of Water	62.41	lbs/ft^3
Density of AB Foam	4.00	lbs/ft^4
Tota Buoyancy of Foam	793.873	lbs
Buoyancy of Sponsons at 5 lbs per linear ft	150.000	lbs
Total Buoyancy Ability	943.873	lbs
Safety Factor		
Maximum Boat Weight	537	lbs.
Max Wt. + 20% Safety Factor	644.40	lbs.
Percentage Over Required Buoyancy	31.73%	lbs.
Actual Buoyancy Safety Factor	75.77%	lbs.
<u>943.873 lbs. > 537 lbs by 75.77%</u>		

Table B-2

Appendix C: Proof of Insurance

<u>The following is a fax copy of the State of Tennessee's Certificate of Self Insurance</u>

CERTIFICATE OF SELF INSURANCE

The State of Tennessee self-insures its exposures in general liability, automobile liability, professional malpractice and workers' compensation. The limits of liability for general liability, professional malpractice and automobile liability are $300,000 per person and $1 million dollars per occurrence. The limits of liability under workers' compensation are those set forth in Tenn. Code Ann. § 50-6-101 *et seq.* The statute which authorizes actions against the State of Tennessee, establishes the State's limit of liability, and authorizes self insurance through the Claims Award Fund is set forth in Tenn. Code Ann. § 9-8-101 *et seq.*

The State's self insurance program insures all liability created under Title 9, Chapter 8 of the Tennessee Code Annotated for all State departments, agencies and institutions, including State institutions of higher education. This program is effective for any acts or omissions of the State or its employees that occur on or after January 1, 1985. Persons wishing to file a claim for damages against the State of Tennessee arising from an act or omission of the State or its employees should file such claim with the State Treasury Department, Division of Claims Administration, 9th Floor, Andrew Jackson State Office Building, Nashville, Tennessee 37243.

Paul G. Summers
Attorney General and Reporter

8/26/02
Date

Stephen Adams, State Treasurer
Chairman, Board of Claims

8/30/02
Date

Appendix D: Team Members

Students

Matthew Ham
Team Captain
Major: Electro Mechanical Engineering
Sophmore

Melissa Sanders
Team Co Captain / Pilot
Major: Mechatronics
Junior

Lindsey Blankenship
Team Co Captain / Pilot
Major: Physics
Junior

Nicholas A. Cronin
Team Member
Major: Mechatronics
Junior

David Sprouls
Team Member
Major: Mechatronics
Freshman

Frederico Martinez
Team Member
Major: Mechanical Engineering
Freshman

Cary Woodson
Major: Engineering Management
Graduate Assistant
Experimental Vehicles Program

Jeremy Posey
Major: Engineering Management
Graduate Assistant
Experimental Vehicles Lab Director

Faculty

Rick Taylor
Machine Shop Mentor
ET Labs and Machine Shop Director

Dr. Saeed Foroudastan
Faculty Advisor
Associate Dean for the College of Basic and
Applied Sciences

Appendix E: Solar Panel Data Sheet

Renogy 240 Watt Poly Solar Panel

Key Features

- Top Ranked PTC Rating
- High Modules Conversion Efficiency
- Fast and Inexpensive Mounting
- Maximize system output by reducing the mismatch loss
- 100% EL Testing on Every Renogy Modules, Guaranteed No Hotspot
- Guaranteed Positive Output Tolerance (0+3%)
- Withstand High Wind (2400 Pa) and Snow Loads (5400 Pa)
- Excellent performance in low light environments

Application

- On-grid Roof Top/Ground Mounted
- Residential/Commercial/Power Stations
- Compatible with Enphase Inverters

Electrical Characteristics

Maximum Power at STC (Pmax):	240 W
PV USA Test Conditions (PTC):	216.0
Optimum Operating Voltage (Vmp):	31.20 V
Optimum Operating Current (Imp):	7.69A
Open-Circuit Voltage (Voc):	37.20 V
Short-Circuit Current (Isc):	8.34A
Module Efficiency:	14.69 %
Cell Efficiency:	16.9 %

STC: Irradiance 1000 W/m², module temperature 25°C, AM=1.5

Temperature Characteristics

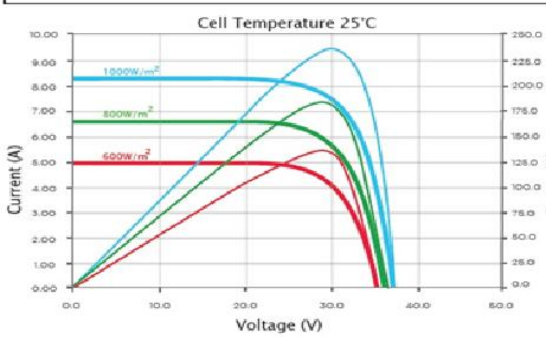
Nominal Operating Cell Temperature (NOCT):	45±2°C
Temperature Coefficient of Pmax:	-0.44%/°C
Temperature Coefficient of Voc:	-0.30%/°C
Temperature Coefficient of Isc:	0.04%/°C

Maximum Ratings

Operating Module Temperature:	-40°C to +90°C
Maximum System Voltage:	600 V DC (UL) 1000 V DC (IEC)
Maximum Series Fuse Rating:	15 A

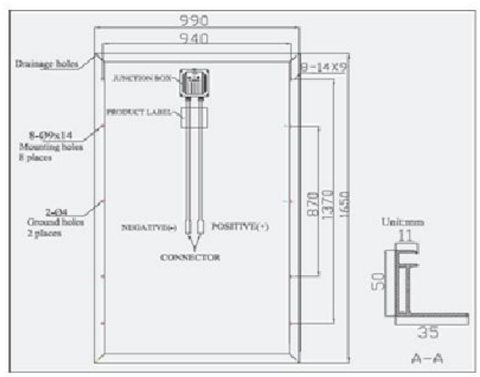
Mechanical Characteristics

Solar Cell:	Polycrystalline 156 x 156mm (6 inches)
No. of cells:	60 (6 x 10)
Dimensions:	65.0 x 39.0 x 1.57 inches
Weight:	19.0 kgs (41.9 lbs)
Front Glass:	3.2 mm (0.13 inches) tempered glass
Frame:	Anodized aluminum alloy
Junction Box:	IP65/IP67 rated
Output Cables:	4.0 mm² (0.006 inches²),1000mm (39.4 inches)
Connectors:	MC4 connectors
Fire Rating:	Classs C
UL Listed:	UL 1703



Current, Power vs. Voltage Characteristics of RNG-235P

Current vs. Voltage — Power vs. Voltage



Appendix F: Motor Data Sheet

Motenergy, Inc	Product Information ME1003	Rev:	
		Date:	05/03/11
		Check By:	JF

Features

- Permanent Magnet Brush-Type motor
- High Efficiency approaching 90%
- Brush life of 1500 hours at 200 Amps
- Open Frame, Fan Cooled design
- Adjustable Brush Timing
- Speed range 0-5000 RPM
- Easy removal of Brush Holder without disturbing the motor bearings
- Neodymium magnets rated for 150 C.

Applications

- Electric motorcycle
- Electric golf car or utility vehicle
- Electric outboard and inboard boat drive
- Micro car
- Hydraulic pumps
- Floor burnishers

Description

The ME1003 is an Open Frame, Fan Cooled version of the 8" diameter family of brush-type dc motors. The motor offers a small volume and a high power to weight ratio.

The ME1003 can be used in 96V, 72V, 60V, 48V, 36V and 24V DC application with and without a speed controller.

Some applications require variable speed and a speed control is required. For constant speed operation, a contator is all that is required to run the motor.

This motor has two brushes per holder to carry more current than the standard brush-type dc motors.

I

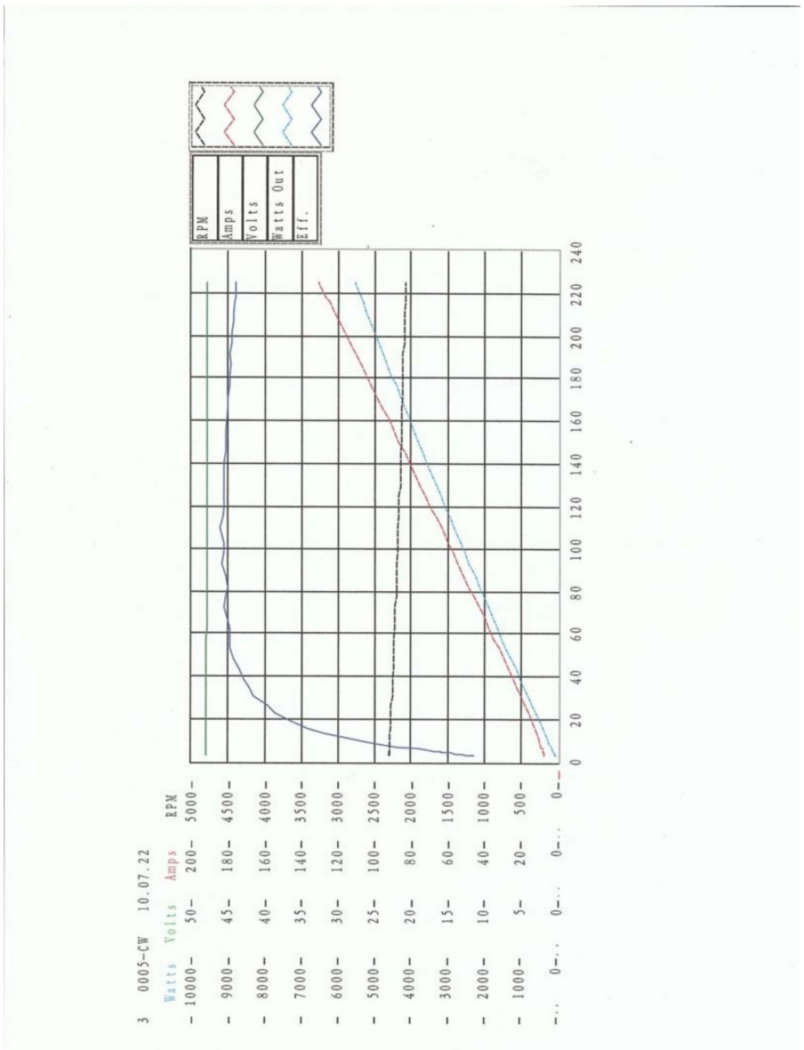
Motor Electrical Parameters

Electrical Parameter	Unit	Parameter
Operating Voltage Range	VDC	0 minimum to 96 maximum
Rated Continuous Current	ADC	200
Peak Current	ADC	500 (10 sec) 400 (30 sec), 300 (1 minute)
No Load Current (I_{NL})	ADC	6 amps typical at neutral timing
Peak Stalled Current	Arms	500
Voltage Constant	V/RPM	0.02
Armature Resistance (L-L)	Ohm	0.01
Turns	Turns	1
Inductance	uH	93 at 120 Hz
Torque Constant	Nm/A	0.2
Maximum Continuous Power	KW	16 (96V), 14.3 (84V), 12.6 (72V)
Macimum Case Temperature	F	250

Motor Mechanical Parameters

Mechanical Parameter	Unit	Parameter
Rated Speed	RPM	3000 (at 72 VDC0
Maximum Speed	RPM	5000
Rated Torque	Lb-in	39 (200 amps)
Continuous Stalled Torque	Lb-in	20 (100 amps)
Peak Torque	Nm	98 (at 500 amps)
Operating Ambient Temperature	C	-40 to 40 (for these ratings)
Armature Inertia	$kg.cm^2$	268
Motor Winding Insulation	Class	F
Max. Winding Operating Temperature	C	155
Shaft Configuration		See Drawing
Face Mounting Details		See Drawing
Tightening Torque for Terminals		See Drawing
Weight	lb	39
Direction of Rotation	l	Bi-directional fan (CCW Timed)
Storage Temperature	C	-30 to 150
Materials of Construction		Standard
Number of Brushes		16

Typical Motor Performance Data



Data taken with 48 VDC Power Supply, constant voltage.
X-Axis is Torque in Pound Inches. (1 Pound Inch equals 0.11 Nm)
Maximum speed is set by the motor control.
The speed is proportional to the applied voltage. For 24 VDC, the speed is ½. For 96 VDC, the speed is double.

(NOTE: Page 4 of 4 of this document is blank and has been omitted from this report)

Appendix G: Controller Data Sheet

AXE *Performance* Products used for SERIES Wound or Permanent Magnet Electric Motors

[*PERFORMANCE*]

The **AXE** product line is used with SERIES Wound and Brushed Perm-Magnet Motors. These units drive golf cars, scissors lifts, boom trucks, Neighborhood electric vehicles, and a variety of other applications.
Features include:

- Programmable via RS232 comm port using PC or Laptop
- Integrated anodized heat-sink with multi bolt pattern for flexibility
- Fully encapsulated epoxy fill - environmentally rugged design
- Available in 300 through 650 amp Performance versions
- Advanced MOSFET power transistor design for excellent efficiency and power transfer
- 1/2 Speed reverse option and "Plug Brake" options available

AXE SPECIFICATIONS

Model	2434	2444	4834	4844	7234	4845	4855	4865	7245
Model Size	xxx4 6.5" Heatsink 					xxx5 8.5" Heatsink 			
Battery Voltage	12-24V		24-48V		24-72V	24-48V			24-72V
Current Limit / 30Sec Rating / 2 Min Rating	300A	400A	300A	400 A	300A	400A	500A	650A	450A
5 Min Rating	200A	350A	200A	300A	200A	300A	350A	400A	350A
1 Hour Rating	135A	200A	135A	150A	125A	175A	250A	250A	200A
Voltage Drop(*) @100Amp	<0.30V	<0.10V	<0.30V	<0.13V	<0.16V	<0.18V	<0.09V	<0.08V	<0.11V

Note: The last digit in the AXE model number denotes heat sink size. See mechanical drawings below.
>xxx4 replaces the Curtis 1204 short heat sink at 6.5" in length (165.1mm)
>xxx5 replaces the Curtis 1205 long heat sink at 8.5" in length (215.9mm)

Model Breakdown

Model number breakdown, for example the { AXE4834P } is broken down as:

- AXE - Family name
- 48 - First two digits = Battery String Voltage (two digits)
- xx3x - third digit = amperage, 3=300 Amp model
- xxx4 - fourth digit = Case size small heat-sink
- "P" model - Denotes Plug Break, "M" denotes Momentary

PRODUCT FEATURES

Type: DC "SERIES WOUND" motor controller
Undervoltage cutback: adjustable, 16-30 VDC
Overvoltage shutdown: adjustable,

- **30-60 VDC (48V models) (60VDC MAX)**
- **60-90 VDC (72V models) (90VDC MAX)**

Operating Frequency: 18kHz
Control voltage range for Key Switch (KSI), Throttle and Reverse inputs:

- **24-48 VDC Nom, 60 VDC Max**

Reverse Horn Output: 50mA sink max
Standby Current (Powered Up): < 35mA
Throttle Input:

- **ITS (inductive)**
- **Resistive 0-5K ohm (+/-10%) (2-wire and 3-Wire)**
- **Resistive 5K-0 ohm (+/-10%)**
- **0-5Volt**
- **6-10Volt**

Operating Temperature: -25C to 75C, 95C shutdown
Adjustments via Controller Pro software:

- **Throttle acceleration / deceleration rate and map profile**
- **Armature current limit**
- **Brake current limit**
- **Under / Over voltage shutdown**
- **Half Speed Reverse**
- **High Pedal Disable**
- **Plug Brake**

LED STATUS INDICATOR

Click on image to enlarge
(large file size)

LED Status Indicator:

and used for troubleshooting.

The LED Blink Codes occur at power up, the number of green blinks indicates the throttle configuration:

- 1 Green LED flash = 0-5 kohm resistive
- 2 Green LED flashes = 5K-0 ohm resisitive
- 3 Green LED flashes = 0-5 Volt
- 4 Green LED flashes = EZ-GO inductive (ITS)
- 5 Green LED flashes = Yamaha 0-1K ohm resistive
- 6 Green LED flashes = Taylor-Dunn 6-10.5 Volt
- 7 Green LED flashes = ClubCar 5k-0 ohms, 3-wire throttle

Normal display status:

- Solid Green: Controller ready to run
- Solid Red: Controller in programming mode (using Controller Pro)
- Solid Yellow: Controller throttle is wide open, controller is supplying max output, and is not in current limit.

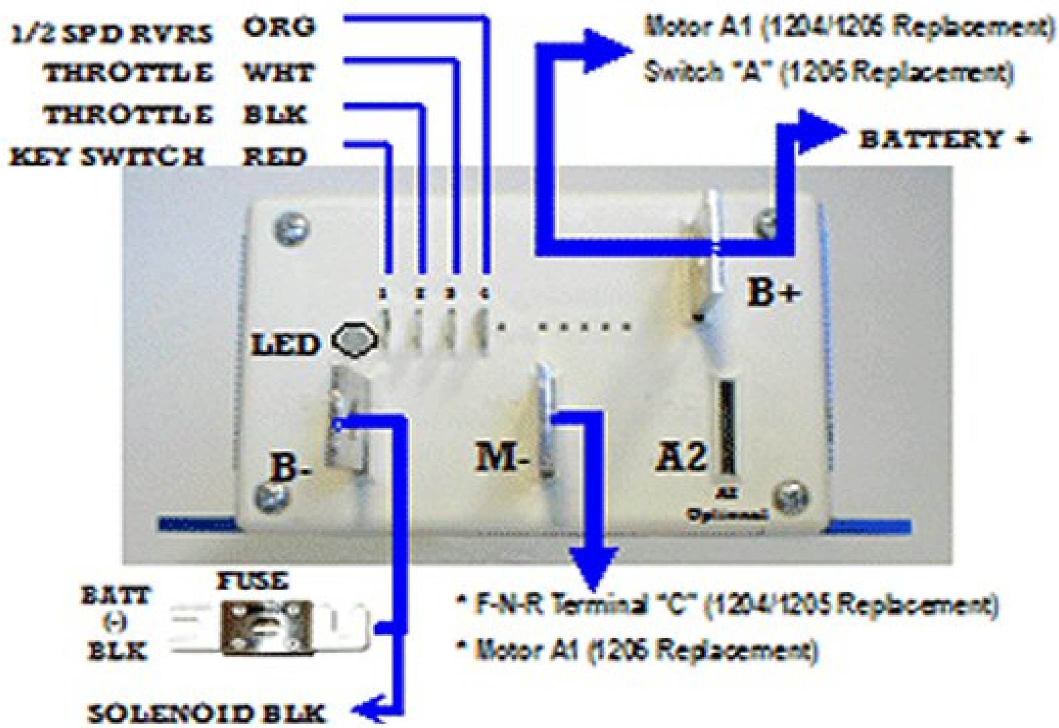
Trouble Shooting:

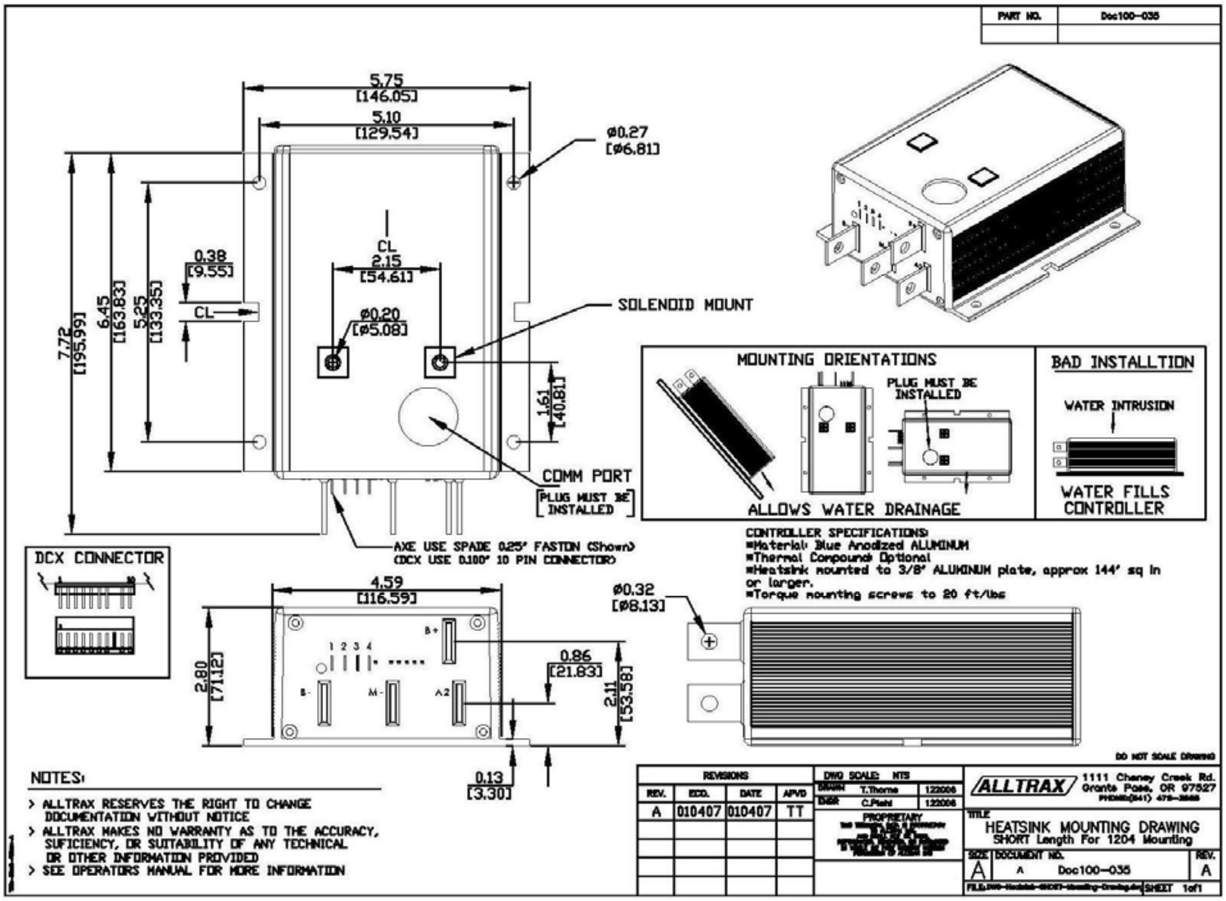
Error code display:# of RED blinks indicates any error conditions that might exist:

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 = Not used
6 Red = Battery Under Voltage detected. Battery V < under voltage slider
7 Red = Battery Over Voltage detected. Battery V > over voltage slider

PRODUCT WIRING CONNECTIONS

AXE Wiring Diagram:
An example of the inputs and outputs are shown. Click on the image to enlarge. This diagram is very generic example, pleasee see the Document Depot for the many various configurations this product can be used in.




PART NO. Doc100-035
5.75 [146.05]
5.10 [129.54]
Ø0.27 [Ø6.81]
CL
2.15 [54.61]
0.38 [9.55]
7.72 [195.99]
6.45 [163.83]
5.25 [133.35]
Ø0.20 [Ø5.08]
SOLENOID MOUNT
1.61 [40.81]
COMM PORT
PLUG MUST BE INSTALLED
AXE USE SPADE 0.25" FASTON (Shown)
(DCX USE 0.100" 10 PIN CONNECTOR)
MOUNTING ORIENTATIONS
PLUG MUST BE INSTALLED
ALLOWS WATER DRAINAGE
BAD INSTALLTION
WATER INTRUSION
WATER FILLS CONTROLLER
DCX CONNECTOR
4.59 [116.59]
2.80 [71.12]
0.86 [21.83]
2.11 [53.58]
0.13 [3.30]
B+
B-
M-
A2
CONTROLLER SPECIFICATIONS:
*Material: Blue Anodized ALUMINUM
*Thermal Compound: Optional
*Heatsink mounted to 3/8" ALUMINUM plate, approx 144" sq in or larger.
*Torque mounting screws to 20 ft/lbs
Ø0.32 [Ø8.13]
DO NOT SCALE DRAWING
NOTES:
> ALLTRAX RESERVES THE RIGHT TO CHANGE DOCUMENTATION WITHOUT NOTICE
> ALLTRAX MAKES NO WARRANTY AS TO THE ACCURACY, SUFICIENCY, OR SUITABILITY OF ANY TECHNICAL OR OTHER INFORMATION PROVIDED
> SEE OPERATORS MANUAL FOR MORE INFORMATION
REVISIONS
REV. ECO. DATE APVD
A 010407 010407 TT
DWG SCALE: NTS
DRAWN T.Thorne 122006
ENGR C.Piehl 122006
PROPRIETARY
ALLTRAX
1111 Cheney Creek Rd. Grants Pass, OR 97527
TITLE
HEATSINK MOUNTING DRAWING
SHORT Length For 1204 Mounting
SIZE A
DOCUMENT NO. Doc100-035
REV. A
SHEET 1of1

Appendix H: Optima Battery Manufacturer Specification Sheet

Battery Model: 25
Part Number: 8025-160
Nominal Voltage: 12 volts
NSN: Number applied for, product currently available
Description: High power, sealed lead acid, engine starting battery

Battery Model: 35
Part Number: 8020-164
Nominal Voltage: 12 volts
NSN: Number applied for, product currently available
Description: High power, sealed lead acid, engine starting battery

Physical Characteristics:

Plate Design:	High purity lead-tin alloy. Wound cell configuration utilizing proprietary *SPIRALCELL*® technology.
Electrolyte:	Sulfuric acid, H_2SO_4
Case:	Polypropylene
Color:	Case: Dark Gray Cover: "OPTIMA" Red
Group Size:	BCI: 25 & 35

	Standard	Metric
Length:	9.340"	237.24 mm
Width:	6.700"	170.18 mm
Height:	7.685"	195.20 mm (Height at the top of terminals)
Weight:	31.7 lb	14.4 kg

Terminal Configuration: SAE / BCI automotive.

Performance Data:

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

Power:

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

Recommended Charging:

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

Model: 25 and 35
These batteries are designed for engine starting applications. They are not recommended or warranted for use in deep cycle applications.

Recommended Charging Information:

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

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

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

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

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

Always wear safety glasses when working with batteries.

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

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

Shipping and Transportation Information:

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

BCI = Battery Council International

OPTIMA Batteries
Product Specifications: Model 25 and 35
December 2008

Appendix I: Trojan Battery Manufacturer Specification Sheet

Trojan
BATTERY COMPANY

SCS150 DATA SHEET

MODEL: with Pod Vent

VOLTAGE: 12

DIMENSIONS: Inches (mm)

BATTERY: Flooded/wet lead-acid battery

COLOR: Maroon (case/cover)

MATERIAL: Polypropylene

WATERING SYSTEM: N/A

PRODUCT SPECIFICATIONS

BCI GROUP SIZE	TYPE	CAPACITY[A] Minutes		CRANKING Performance		CAPACITY[B] Amp-Hours (AH)				ENERGY (kWh)	TERMINAL Type[G]	DIMENSIONS[C] Inches (mm)			WEIGHT lbs. (kg)
		@25 Amps	@75 Amps	C.C.A.[D] @0°F	C.A.[E] @32°F	5-Hr Rate	10-Hr Rate	20-Hr Rate	100-Hr Rate	100-Hr Rate		Length	Width	Height[F]	
12 VOLT MARINE/RV DEEP-CYCLE BATTERIES - with T2 TECHNOLOGY™															
24	SCS150	150	36	530	650	80	92	100	111	1.33	10	11.30 (286)	6.73 (171)	9.80 (248)	50 (23)

A. The number of minutes a battery can deliver when discharged at a constant rate at 80°F (27°C) and maintain a voltage above 1.75 V/cell. Capacities are based on peak performance.
B. The amount of amp-hours (AH) a battery can deliver when discharged at a constant rate at 80°F (27°C) for the 20-Hour and 100-Hour rates and 86°F (30°C) for the 5-Hour rate and maintain a voltage above 1.75V/cell. Capacities are based on peak performance.
C. Dimensions are based on nominal size. Dimensions may vary depending on type of handle or terminal.
D. C.C.A. (Cold Cranking Amps) - the discharge load in amperes which a new, fully charged battery can maintain for 30 seconds at 0°F at a voltage above 1.2V/cell.
E. C.A. (Cranking Amps) - the discharge load in amperes which a new, fully charged battery can maintain for 30 seconds at 32°F at a voltage above 1.2V/cell. This is sometimes referred to as marine cranking amps @ 32°F or M.C.A. @ 32°F.
F. Dimensions taken from bottom of the battery to the highest point on the battery. Heights may vary depending on type of terminal.
G. Terminal images are representative only.
Trojan's battery testing procedures adhere to both BCI and IEC test standards.

CHARGING INSTRUCTIONS

CHARGER VOLTAGE SETTINGS (AT 77°F/25°C)				
System Voltage	12V	24V	36V	48V
Daily Charge	14.8	29.6	44.4	59.2
Float	13.2	26.4	39.6	52.8
Equalize	15.5	31.0	46.5	62.0

Do not install or charge batteries in a sealed or non-ventilated compartment. Constant under or overcharging will damage the battery and shorten its life as with any battery.

TERMINAL CONFIGURATIONS

10	DWNT	Dual Wingnut Terminal

Terminal Height Inches (mm)
1.57 (39)
Torque Values in-lb (Nm)
95–105 (10.7 – 11.9)
Bolt Size
5/16 – 18

CHARGING TEMPERATURE COMPENSATION

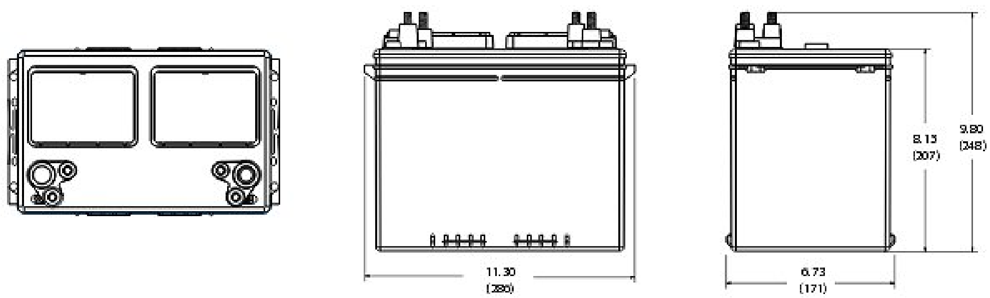
.028 VPC for every 10°F (5.55°C) above or below 77°F (25°C) (add .028 VPC for every 10°F (5.55°C) below 77°F and subtract .028 VPC for every 10°C above 77°F).

OPERATIONAL DATA

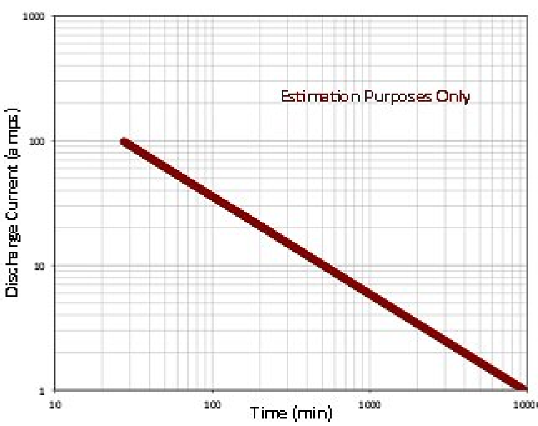
Operating Temperature	Self Discharge
-4°F to 113°F (-20°C to +45°C). At temperatures below 32°F (0°C) maintain a state of charge greater than 60%.	5 – 15% per month depending on storage temperature conditions.

TRJN_SCS150_DS_0214

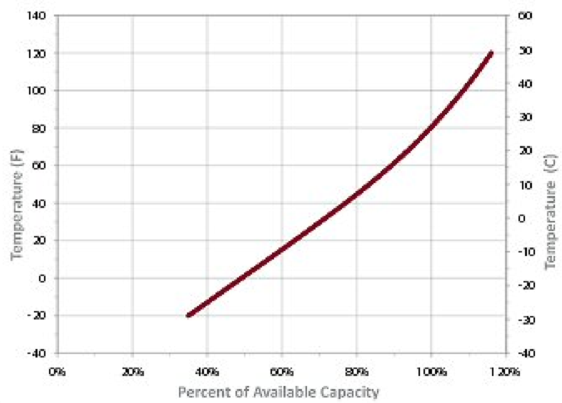
BATTERY DIMENSIONS (shown with DWNT)



TROJAN SCS150 PERFORMANCE



PERCENT CAPACITY VS. TEMPERATURE



TROJAN BATTERY COMPANY WITH QUALITY SYSTEM CERTIFIED BY DNV
= ISO 9001:2008 =

Trojan BATTERY COMPANY®
Clean energy for life.

Trojan batteries are available worldwide through Trojan's Master Distributor Network.
We offer outstanding technical support, provided by full-time application engineers.

For a Trojan Master Distributor near you,
call 800.423.6569 or + 1.562.236.3000 or visit www.trojanbattery.com

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TRJN_SCS150_DS_0214

Appendix J: Sprint Configuration Wiring Diagram

The Sprint Configuration (Fig. L-1) features a 36 V battery pack, dual Altrax® AXE 4865 motor controllers, each connected to a Motenergy® ME1003 DC motor. A wireless telemetry system interfaces with the RS232 connections on the motor controllers and allows for onshore adjustment and monitoring of the performance of the controllers.

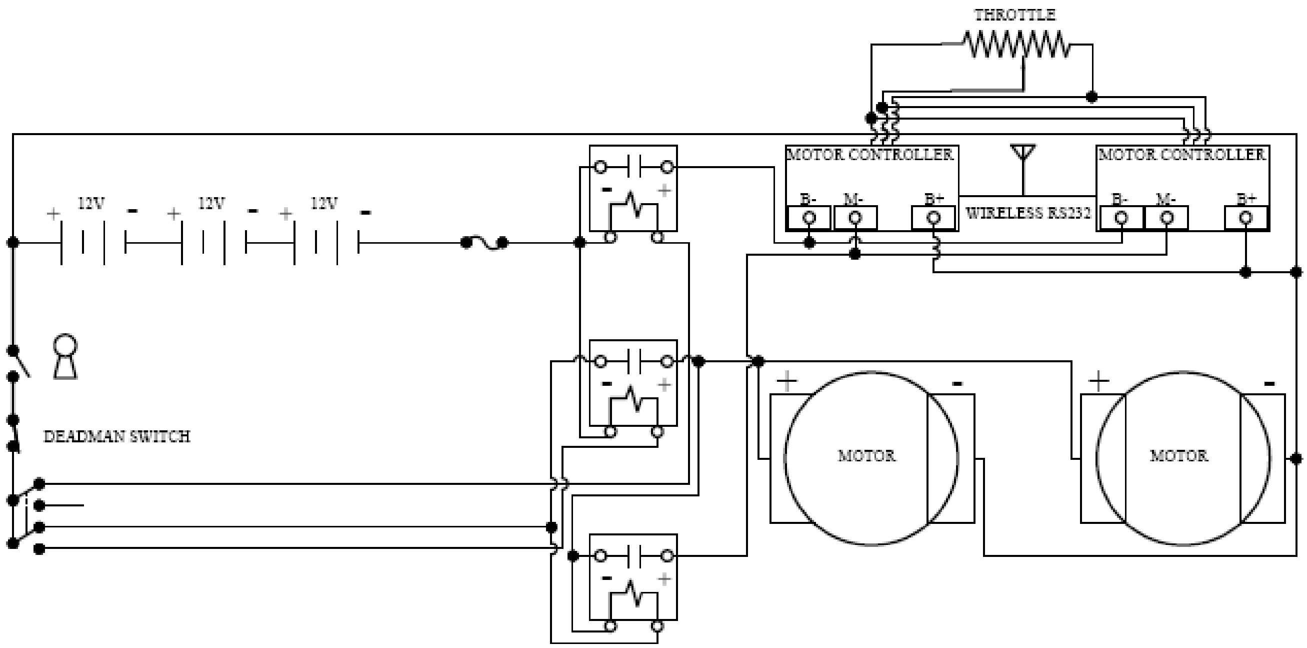

Fig. L-1 – Sprint configuration

Appendix K: Endurance Configuration Wiring Diagram

The endurance configuration (figure M-1) features a 24 V battery pack and dual 240 watt Renogy® polycrystalline solar panels. In addition to a reduction in available battery power and the addition of the solar panels, the endurance configuration differs from the sprint configuration in that one of the motor and controller sets is switched out of the electrical system in order to better manage available power.

Initially, the output from the solar panels will be regulated through series connected charge controllers in order to prevent battery sulfation. However, once the sprint heat is underway, the charge controllers will be bypassed and the output from the panels will be allowed to flow unimpeded into the electrical system. While the boat is underway the applied load will prevent the solar panels from being able to overcharge the batteries.

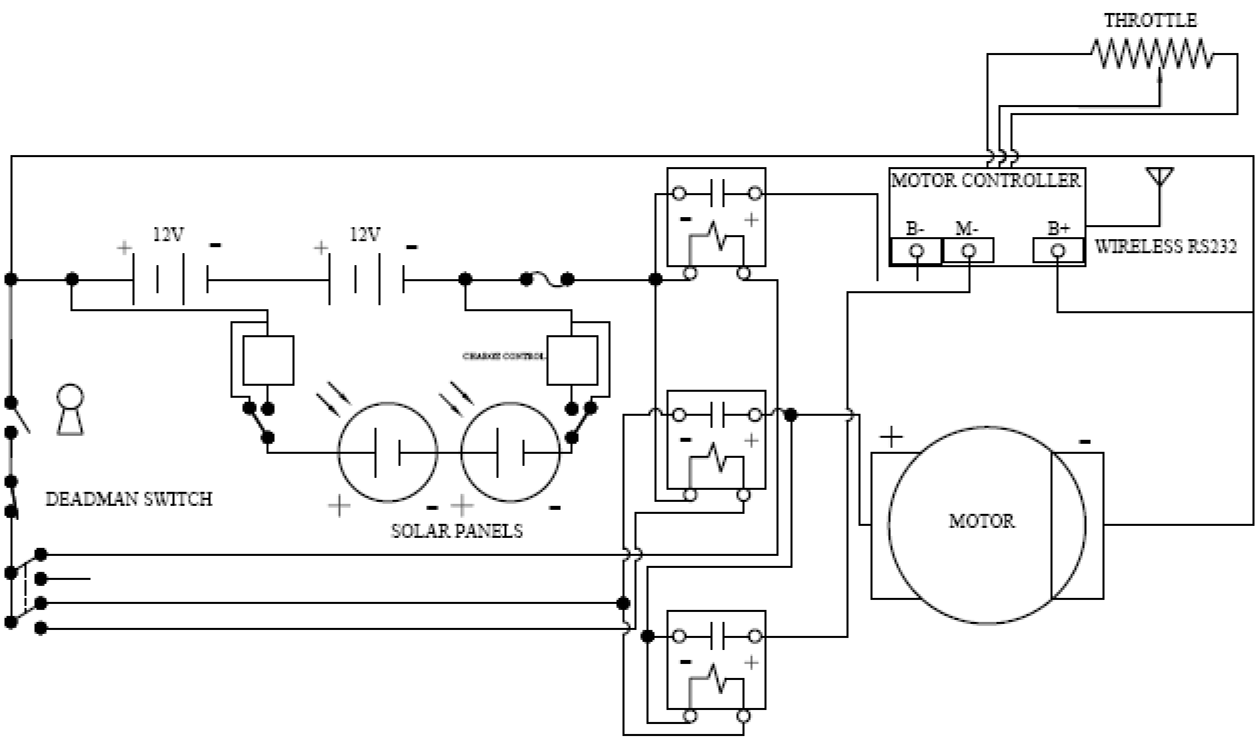

Fig. M-1 – Endurance configuration