SOLAR SPLASH SENIOR DESIGN PROJECT

Purely solar driven watercraft

Submitted to

Engineering Technology Department

By

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EXECUTIVE SUMMARY

The Solar Splash senior project is the first attempt at creating an entirely solar propelled watercraft. The initial project intent was to design and create a supplement meets the specifications and compete in the competition. With this in mind, a budget approach was taken in order to be able to fund the task at hand. As the project progressed toward the end of the low-level design phase it was evident that the competition would not occur. At the midpoint of the project, the goals and objectives had changed entirely. The new focus was targeted at proving the operation of the systems involved in the watercraft. Having been faced with a new series of objectives and an entirely new scope, the project began to appear doable.

The primary focus of the project at this point entirely relied on simulation data and data analysis. The idea was not reinventing the wheel but rather verifying that the wheel rolled. Using the designed propulsion, solar and sensors systems, with the help of a combination of software programs, the idea of a budget solution can be seen. The software used tell the story of the boat that would have been created had the project continued down the original proposed path. As systems were tested and analyzed, they were also adjusted and improved upon. The analysis process consumed a lot of time but acted as a highlighter for all the flaws that the system suffered from.

This document introduces the design concepts and schematics of the Solar Splash senior design project. Within are detailed drawings and diagrams for the electrical systems devised for the construction operation of the watercraft. This report is a means of displaying the layout of the final product and how all systems tie together. The report will contain detailed information on not only hardware aspects but also software and how those will bridge together. The report is meant to be in layman's terms and should be easily interpreted at all levels.

The bulk of the information found in the report will be found in the testing sections where analysis of a theoretical boat is done. The motor design, solar design, and fluid dynamic analysis of the boat hull and propeller can be found in their respective section. The innerworkings, testing processes and thoughts behind each decision can also be found in these sections.

The document begins with a table of contents identifying each main and subcategory of information. The next page is the document identification, revision history, and lesser known definitions. Following that is the introduction and scope. Specification requirements for the 'general requirements', 'electrical requirements' and 'mechanical requirements' are found on the following page. A system flowchart can be found in the high-level Design along with the design decision matrices for each system. The design portion then begins starting with the System-wide design changes and decisions. The hardware and software designs and schematics follow and cover the proposed schematics and drawings for the system. Cost breakdowns for each individual system are also found in the low-level section. Testing methodologies, results and an explanation of the testing software can be found after the low-level design. A summation of all these testing results is found near the tail of the document. Conclusions, recommendations, and appendixes can be found as the last three sections, respectively.

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REVISION HISTORY

Version	Date	Revised by	Description
0.1	8 April 2020	Matthew Sauer	Initial version
0.2	9 April 2020	Matthew Sauer	Language Revisions
0.3	12 April 2020	Matthew Sauer	Introduction Revisions & Specification requirements
0.4	14 April 2020	Matthew Sauer	Figure captions, Table of contents adjustments, Table revisions
0.5	16 April 2020	Matthew Sauer	Wording & grammatical changes
0.6	19 April 2020	Matthew Sauer	Scope revisions and Table of contents adjustments
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0.8	27 April 2020	Matthew Sauer	Addition of testing information
0.9	28 April 2020	Paul Binder	Solar Methodology
1.0	30 April 2020	Matthew Sauer	Analysis wrap up & Conclusive statements
1.1	01 May 2020	Matthew Sauer	Additions to conclusions and recommendations
1.2	02 May 2020	Khaled Almogayer	Sensor Methodology
1.1	02 May 2020	Paul Binder	Conclusion, Appendix, and Recommendation updates

INTRODUCTION

The Solar splash senior design project is intended to be a competition where-in students design entirely solar powered watercraft that are meant to compete in three trials: sprint, endurance and slalom. The crafts are required to use energy from sets of battery pairs that spin the motor and are fed from three solar panels producing up to 480 watts. Multiple sets of batteries can be used for each of the individual races. The system detailed in this document is comprised of three main systems: The solar charging system, motor control system, and the sensors used to monitor different aspects of the watercrafts current electrical state.

The initial aim for the project was to bring an abundance of assets and skills together to create a physical supplement that would be able to compete at the Solar Splash competition. The project has been altered many times over the course of its existence for an abundance of reasons. The deliverables offered in the final revision of the project primarily focus on simulation and virtual testing. The solar charge control and motor design have both been tested to ensure that the input from solar and the batteries is enough to operate the motor with competitive results. The system also includes the components necessary to make it operate in accordance with the specifications detailed by the electrical specifications found in the document.

The motor control side of the project was tested and analyzed using Multisim and MATLAB’s Simulink. Multisim gives the user the option to layout individual circuit level components and perform circuit analysis. Circuit analysis of the motor controller was the primary focus at this stage as the motor is represented simply as a resistive and inductive load. Simulink made testing the electrical to mechanical performance of the motor a possibility. Simulink created an environment where the performance aspects of the motor were able to be seen in a graph form. Metrics and characteristics of the motor analysis are drawn out in the motor testing results.

A solar boat model was created within the specifications allowed by the competition rules. Due to changes in the project, the boat is represented using simulation software. It is a simple design that meets all the requirements of the competition as going overboard with the design would be out of scope for the project. This digital representation has been used to perform a CFD analysis on the model and analyze the performance of the hull. The data given from the CFD process allows for a better understanding of what a physical representation of the virtual creation will do in water. The results that have been derived from the tests that we have created verify that the designs presented are capable and competitive.

In addition to a boat model, a propeller model was also created that was used to analyze the flow characteristics around and near the propeller and how it interacts with the water around it. This analysis includes wetting and cavitating states and considers the various high- and low-pressure zones present when the propeller is rotating. A propeller mesh creates the opportunity to also determine the amount of thrust produced as well as the capability of the propeller to move a boat of similar stature to the one used here.

With the use of OpenFOAM, flow analysis can be run against both propeller and hull. The processes involve using C++ scripts to act as solvers for the mechanical interactions that both items would experience. While the software has no immediate way of knowing that it is solving a marine CFD problem, it is still able to solve the mathematical function that each mesh represents.

SCOPE

The Solar Splash senior design project began as the creation of a physical watercraft that would have the potential to compete at the Solar Splash competition. After a series of project hurdles and challenges, the project found some stability when the scope was changed into something more achievable given the circumstances. The state of the project now takes simulations and virtual representations and uses them to illustrate the potential of the proposed systems. The broadest requirement of the project is that there be a buoyant watercraft that is powered entirely by a solar charging system and DC motor. A series of electric systems have been devised such that each control different aspects of the operation of watercraft. The current version of the project expects that tests and measurable data be taken and compared to performance metrics from previous years of competition. Comparing our digital creation to actual creations provides a measurable indication of how competitive the watercraft, if created, would be.

Specifically, the project will be completed by using various software to create a digitally characterized watercraft. The software used allows for an understanding of how the different systems interact within themselves and with the physical environment around them.

Measurably, the different tested systems will provide critical feedback that represents that singular system. The largest task will be culminating everything that is obtained and providing a big picture view of the system competing with systems from last year's competition.

Achievability wise, the project, in its current form, can be completed on time. Given the resources that have been provided and those that have come from alternate sources, the project has all the necessary equipment and materials to be successful.

Realistically, the goals that are set forth in this stage of the project are completely reachable and have been summed up in this report. The goals and objectives of the project were not easy to achieve but were entirely realistic.

Time wise, the project has had struggles getting started from the beginning but at this stage is on its feet and close to completion; for the first stage. The testing phases denoted herein are meant to be the initial stages of the project.

Ultimately, the deliverable created by this stage of the project will be testing analysis that proves the operation of the schematics created and the capabilities of a physical recreation of the systems. The capabilities of the systems are revealed in the testing results and conclusion portion of this document.

SPECIFICATION REQUIREMENTS

- **General Specifications**

1. Craft must carry >45.5 kg of lead-acid batteries
2. Bilge pump & skipper's radio powered by supplemental sources
3. Craft must not heel <15º with 10kg at the sheer line
4. Radios required while skipper is operating on water
5. USCG Type I, II, or III life preserver
6. Craft must have a sound signal device: Air Horn
7. Craft must have an orange warning flag
8. Craft must have a paddle >60cm long with a blade >13cm wide
9. Materials must not pollute

- **Electrical Engineering Specifications**

1. System voltage may not be >52 VDC or AC rms
2. Source voltage may not be >36 VDC nominal
3. Craft must have a dead man's switch
4. All capacitors at >36 v must be insulated
5. Craft must have a main fuse off the main battery
6. Craft must have a motor shut off

- **Mechanical Functional Specifications**

1. Length of the craft must be <6 meters
2. Width of the craft must be <2.4 meters
3. Height of the craft must be <1.5 meters
4. Bilge pump must be fastened to the hull (model #24-35 pump)
5. Batteries must be enclosed in battery boxes
6. Steering system must use locking nuts, double nuts, safety wire, cotter pins, etc…
7. Batteries secured with a strap thicker >1 ¼"
8. 14mm diameter towing port attached to bow

HIGH LEVEL DESIGN

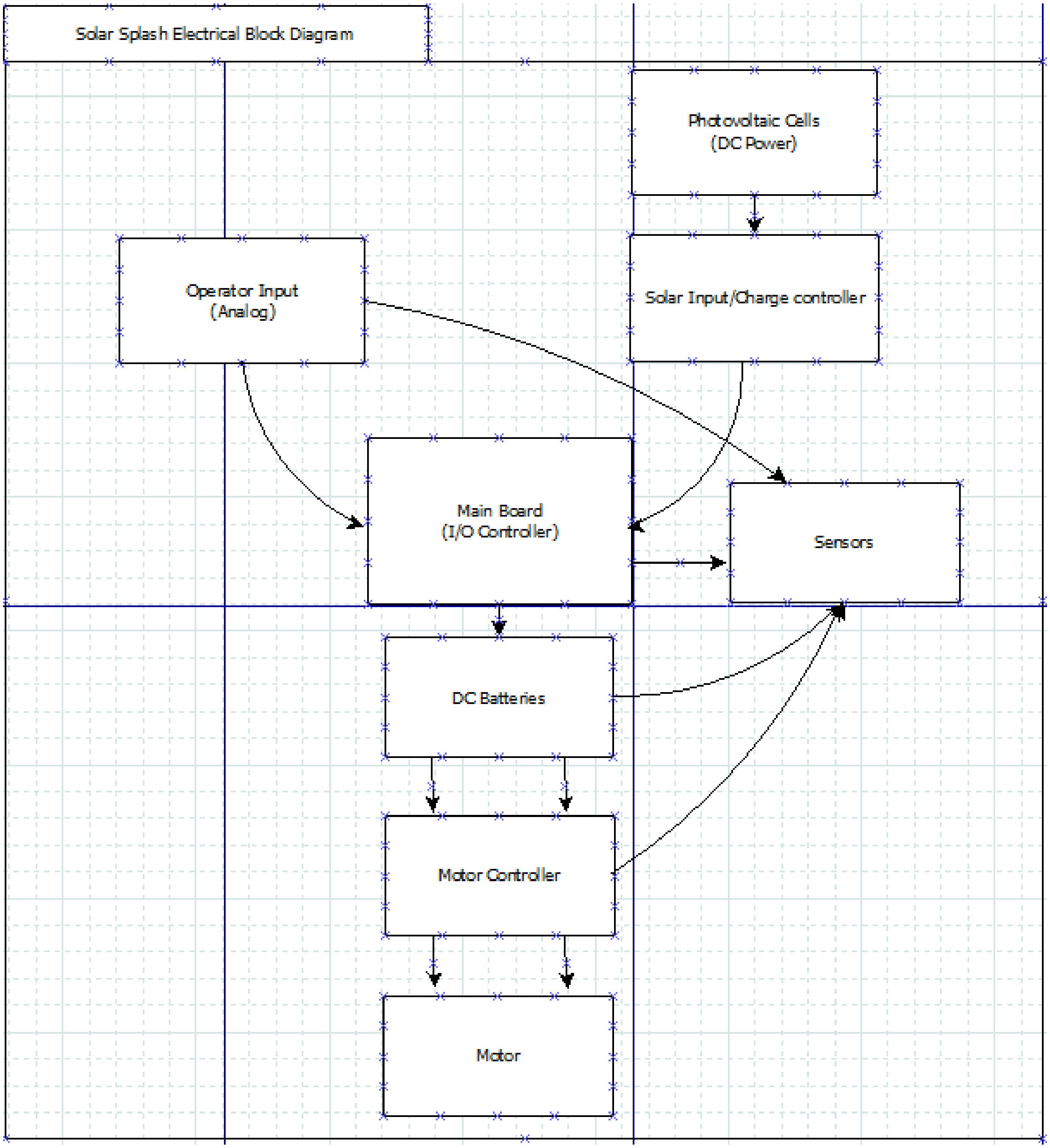


Figure 1: High Level One-Line Diagram

System Inputs	System Outputs
Operator input controls	MY1020 750w DC motor
Photovoltaic cells	Sensors

Microcontroller	efficiency	Operated Voltage	Price	Quantity of I/O S pins	Total
Arduino	4/5	5/5	3/5	5/5	17
Microcontroller chip	3/5	5/5	5/5	5/5	18

Table 1: Microcontroller Decision Matrix

1. **Arduino**
   - *Downsides*
     - Will not handle shaking of our application during performance.
     - Draw more current.
     - Not waterproof.
     - More expensive.
   - *Positives*
     - May be more efficient but will not be suitable for our application.

2. **Microcontroller chip**
   - *Downsides*
     - Will require multiple prototypes and revisions.
   - *Positives*
     - Decent efficiency.
     - Average power output.
     - Affordable price.
     - Suitable for our application.

Overview

As we kept working on this project during all the changes it went through I was finally able to get Our data collection to includes displaying all measurements needed for solar energy operation like voltage, temperature, motor speed and light intensity. Furthermore, we included a battery circuit to display the battery power capacity using LED indicator the user can access from front panel. The system can be implemented using a voltage divider to measure the voltage, and according to voltage sensor formula, I have used voltage divider in a way so that the maximum input voltage to analog to digital converter channel cannot exceed 5 volts, and I choose these resistor values to increase accuracy of measurement and to insure protection of ADC in case of greater voltage fluctuation.

Finally, temperature sensor to measure the temperature and light intensity sensor and more further details for each of the five sensors for our application.

Test Plan

We have tried a variety of software's to test the sensors section and check if we can come up with appropriate results for our data measurements. Including Multisim, Matlab and finally Proteus. Multisim is used to design and construct and test the battery test circuit and make sure it will function properly. Moreover, I used Matlab trying to simulate the motor speed and be able to get the voltage readings as well. Unfortunately. Matlab wasn't helpful in terms of displaying the data continuously instead of getting specific data for specific portion of the time and would not include the rest of the sensors data like temperature and light intensity etc. So that will affect our goal because the driver needs to see real time data during the performance. Finally, Proteus was the last software used and got us the results we want during performance including continues real time data.

Languages Used / Software

- C Language
- Proteus software
- Multisim

Motor	Efficiency	Power	Price	Quality	Total
Homemade	2/5	2/5	2/5	1/5	7/20
Commercial	5/5	5/5	0/5	5/5	15/20
Chinese-built	4/5	4/5	3/5	3/5	14/20

Table 2: Motor Decision Matrix

3. **Homemade**
    - *Downsides*
        - Involves intense manufacturing processes
        - Introduces an entirely new project all on its own
        - Will require multiple prototypes and revisions
        - Will more than likely not be able to compete with others
        - Requires an extreme level of precision
    - *Positives*
        - May be able to be produced cheap per revision

4. **Commercial**
    - *Downsides*
        - Extremely expensive for even an entry level motor
    - *Positives*
        - Extremely efficient
        - Excellent power
        - Quality is unbeatable
5. **Chinese-built**
    - *Downsides*
        - Lower quality
    - *Positives*
        - Decent efficiency
        - Average power output
        - Affordable price
        - Easily source able

Overview

The motor used in this competition will need to be efficient in order to make it through the endurance race as well as powerful to remain competitive in the sprint. Homemade and commercial motors both suffer from flaws that a Chinese-made motor does not. A homemade motor would be extremely difficult to produce with minimal tooling and experience. Unfortunately creating a motor in house is outside of the scope for this project. A commercially available motor from companies like Minn Koda, Elco, or Torqeedo would be excellent if the price tag could be overcome. The Chinese motor is an average contender here and appears to be more likely to succeed in multiple categories given its cost to performance ratio.

Test Plan

The motor can be tested after a motor controller is created and we have determined an appropriate power source. The best course of action for this is to test what the best endurance motor speed would be as well as our power output for the sprint race. With project changes, testing has become entirely virtual. The motor controller design has been tested as working in the Multisim environment. Changes to the controller have been made where necessary. Analysis of what would be expected of our small MY1020 motor has been completed in Simulink Simscape. Simscape allows for electrical translation to mechanical power. Testing in this Simscape allows for an electronic and mechanical depiction of what is occurring while the motor is operating. Ultimately, testing the motor with this software has been anything but a breeze, but the testing results from this software have allowed for a well-rounded understanding of the operation of our DC motor.

Software

- Multisim
- MATLAB Simulink & Simscape
- AutoCAD CFD
- VirtualBox 6.1
- OpenFOAM base
    - interDyMFoam
    - waveDyMFoam
    - SnappyHexMesh
    - cavitatingDyMFoam
    - sprayDyMFoam
- HullForm 1.9

LOW LEVEL DESIGN

- ***System-Wide Design Decisions***

The system contains several major design considerations in relation to cost, quality, Solar Splash requirements, and Senior Design requirements. Firstly, the system had to be developed with an extremely low budget in mind. Most of the components are the best components available within a seemingly reasonable budget. These components, while not the best quality wise, will do perfectly fine for the operations that they will perform. Our design choices also fell to the requirements of the competition and what design constraints we were required to stay in.

Sourcing a motor that worked with the system was somewhat challenging as DC motors are expensive and electric outboards are even more costly. Unfortunately, purpose designed motors for this application are all priced obnoxiously which pushed the project to a more out of the box design. Discussions also occurred considering creating a one off, but the involvement required to create a DC motor would be an endeavor all its own. These constraints lead to using an electric scooter motor with a gear to turn a shaft that turns the propeller. The motor being this way benefits the system in terms of being able to adjust propeller output speed based on gear ratio. The biggest issue with deciding to use this type of motor is creating a mounting system that allows the output shaft of the motor to interact with the shaft of the propeller. Ultimately, an all-in-one solution would have worked great, minus the abhorrent price tag.

The motor controller is a simple circuit that takes an input voltage of 36-volts DC. The overall circuitry resembles that of an off the shelf solution for similar applications. It uses an LM7812 to feed the TL494CN PWM chip that allows control over a DC motor. The motor speed is controlled through the ‘VR-VOL’ potentiometer. The LM7812 and 75N75 MOSFETs will both need heatsinked to dissipate the heat that will be produced from long periods of use.

System Components

Split into the three main categories the entirety of the system is comprised of a combination of components:

Solar Components:

Count	*Item*	*Category*	*Price*	*Quantity*
1	Renogy 160W 12V	Solar Panels	$231.00	3
2	Genesis 13EP	Batteries	$134.95	9
3	Genesis 42EP	Batteries	$249.95	3
4	Genesun GV-Boost GVB-8-PB48V	MPPT	$160.00	3

Table 3: Solar Component Breakdown

Total Cost: $3137.40

Motor Components:

Count	*Item*	*Category*	*Price*	*Quantity*
1	MY1020 Motor	Motor	$119.95	1
2	Express PCB	Controller	$65.00	1
3	LM317T	Controller	$0.58	1
4	TL494CN	Controller	$0.61	1
5	75N75	Controller	$1.19	2
6	10 Ω resistor	Controller	$0.57	4
7	47 Ω resistor	Controller	$0.57	1
8	220 Ω resistor	Controller	$0.59	1
9	2200 Ω resistor	Controller	$0.60	1
10	4700 Ω resistor	Controller	$0.73	2
11	10000 Ω resistor	Controller	$0.76	1
12	22000 Ω resistor	Controller	$0.64	1
13	Propeller	Motor	$29.70	1

Table 4: Motor Component Price Breakdown

Total Cost: $226.31

Sensors Components:

Count	*Item*	*Category*	*Price*	*Quantity*
1	AT90S2313	Microcontroller	$2	1
1	PIC 16F877A	Microcontroller	$2	1
1	Temperature Sensor	Sensors	$8	1
1	Light Sensor	Sensors	$8	1
1	Voltage Sensor	Sensors	$7.79	1
4	16x2 LCD	Display	$9.99	1

Table 4: Sensor Component Price Breakdown

Total Cost: $37.78

Total System Cost: $3435.24

Concept of Execution

When implementing our systems, we plan to use an Arduino to handle the entirety of the software and logic-based functions. The code will be based on the C language and primarily be used to operate the sensors. The Arduino will link into the photovoltaic and motor systems in order to be able to read various important stats that are changing constantly based on load conditions and user inputs. The Arduino may also be an easy way to implement safety features that would not normally be present in a system without a microcontroller.

Interface Design

The interface will be presented to the user in the same way the cockpit of an automobile presents itself to its driver. There will be a method of maneuvering the flow of water coming from the motor in order to be able to steer the craft. The sensors will face the user and allow for easy reading. A throttle control will allow the skipper to adjust the motor output speed. Cutoff switches for the batteries and the motor will both be within reach and labeled appropriately. The competition required items will be within reach of the operator, including the fire extinguisher, emergency flag and air horn.

➢ *Detailed Hardware Design*

Solar Design Schematics / Diagrams

The solar design portion of the project consists of the three (3) Renogy 160W solar panels each connecting to a corresponding Genesun GV Boost Maximum Power Point Tracker (MPPT). The purpose of the MPPT is to take the smaller voltage values from the Solar panels and DC/DC step up to meet the voltage of the batteries to charge them.

The solar design portion of the project consists of the three (3) Renogy 160W solar panels each connecting to a corresponding Genesun GV Boost Maximum Power Point Tracker (MPPT). The purpose of the MPPT is to take the smaller voltage values from the Solar panels and DC/DC step up to meet the voltage of the batteries to charge them. Even if the sun is barely visible, as long as there is some sunlight, the MPPTs will provide the 14.7-15VDC to the batteries to charge them.

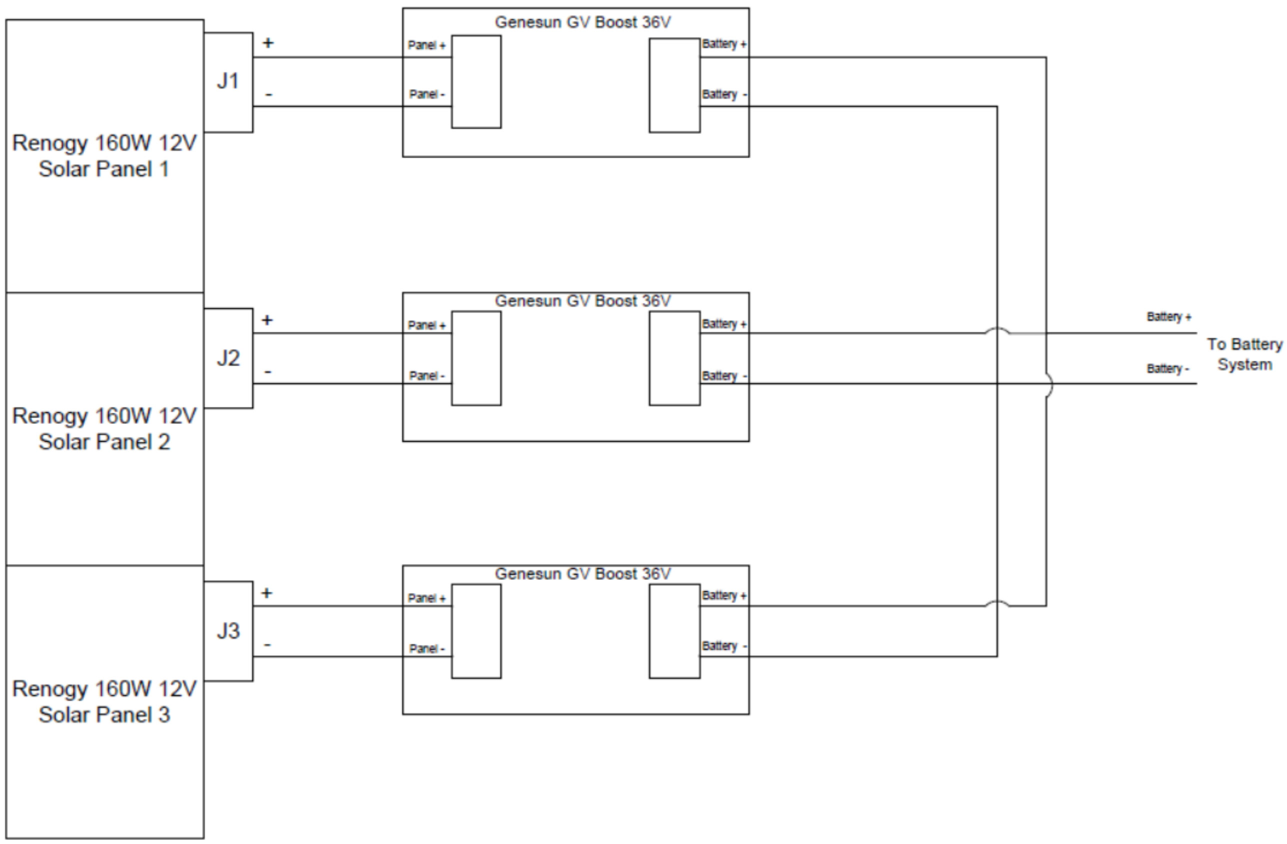


Figure 2: Solar Panel System Output to Batteries

Depending on the type of race, different batteries were chosen:

For Sprint and Shalom, nine (9) Genesis 13EP batteries will be wired in a 3x3 configuration in order to produce 39Ah of 36V efficiently for maximum power throughout the race while still keeping the total internal resistance and low as well as keeping the voltage at 36VDC output to the motor.

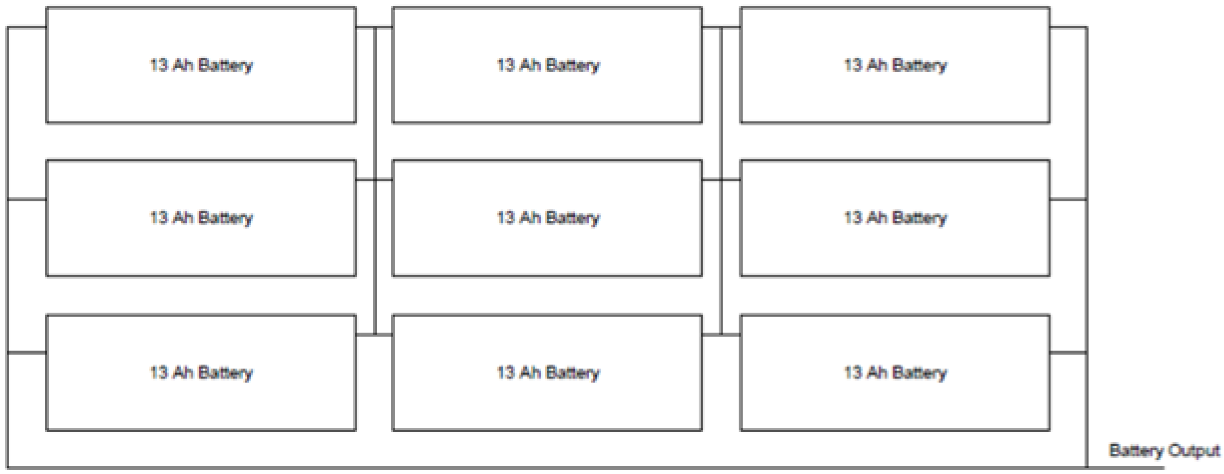


Figure 3: Genesis 13EP batteries laid out in a 3x3 configuration

For the Endurance race, three (3) Genesis 42EP batteries will be used in a 3x1 configuration in order to produce 42Ah of 36V efficiently for a longer lasting output, once again still while keeping total resistance low and output voltage to the motor at 36 VDC.

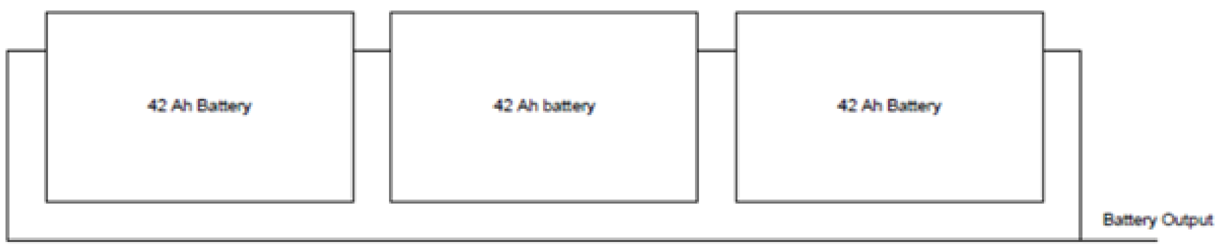


Figure 4: Genesis 42EP batteries laid out in a 3x1 configuration

Motor Design Schematics / Diagrams

The first portion of the motor design is the motor controller schematic:

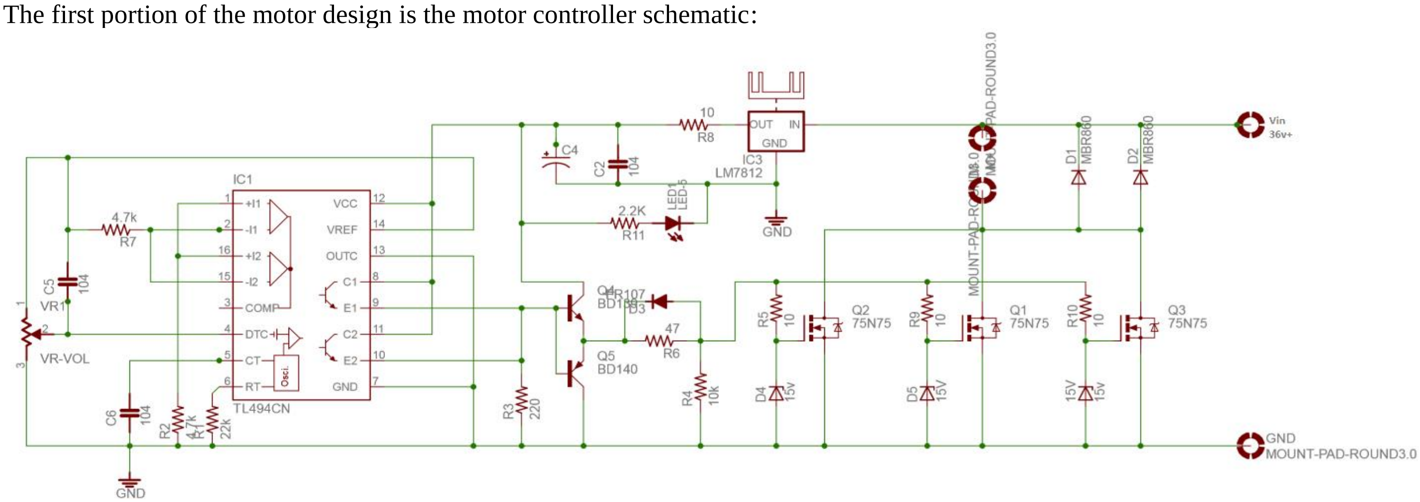


Figure 5: Motor Controller circuit layout using a TL494CN PWM chip and a LM7812 regulator

Included with the motor is a PCBExpress layout that is ready to be printed and have components installed:

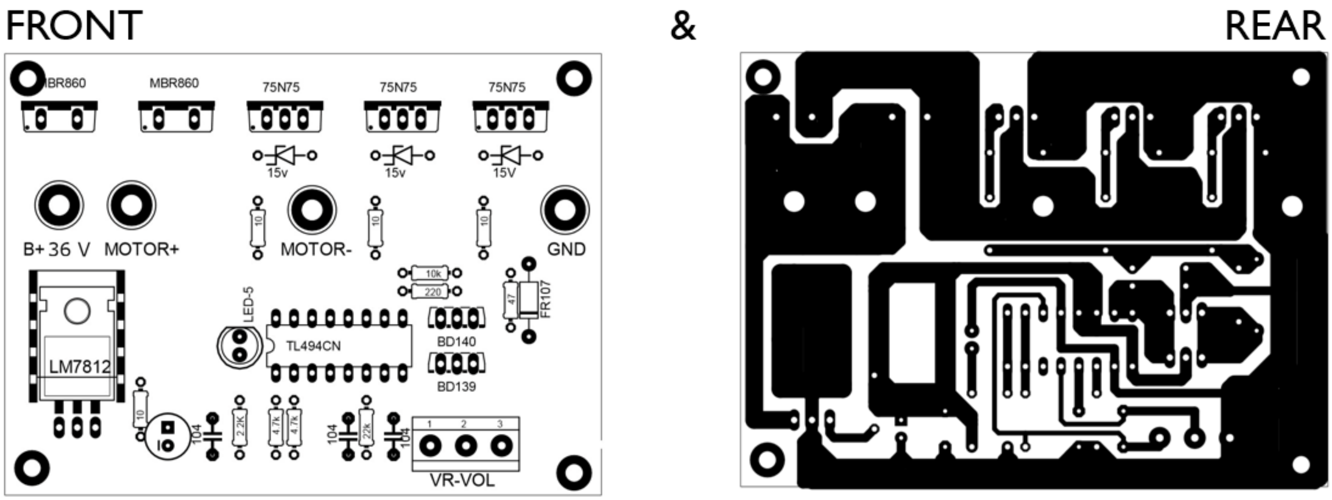


Figure 6: PCB sketch for MC

The circuitry is made around an ideal input voltage of 36 volts DC. The ideal power draw for the motor is 750w, which was taken into consideration when testing this controller. Many components were initially found during testing to be insufficient for running the MY1020 motor. This included changing the resistors, transistors, and potentiometer used in the design. The MY1020 motor speed is controlled using the VR-VOL potentiometer illustrated in the left side of the schematic. The circuits main component is the TL494CN PWM chip. This was used instead of an NE555 timer simply due to the TL494CN chip being under half the cost of the 555-timer. The LM7812, or LM317 equivalent, chip will need some sort of passive cooling to maintain decent thermals. The 75N75 MOSFETs located at Q1, Q2, and Q3 would also need some form of passive cooling. Power draws for each of these components put them within manufacturer specifications by a wide margin. The remainder of the components can simply be insulated and left to cool without heatsink.

Specification	MY1020		
Rated output Power	350W	500W	750W
Rated Voltage	24/36V DC	24/36/48V DC	36/48/60V DC
Rated speed	2250 RPM	2500RPM	2800RPM
No load speed	2700RPM	3150RPM	3500RPM
Full load Current	≤18.70A/12.50A	≤26.7/17.8/13.4A	≤26.7/20/0/16.0A
No load Current	≤2.5/2.0A	≤2.5/2.2/2.0A	≤2.5/2.2/2.0A
Rated Torque	1.5 N.m	1.9N.m	2.8N.m
Efficiency	≥78%	≥78%	≥78%

Figure 7: MY1020 Motor & Manufacturer Specification sheet

The MY1020 motor is the second element used in the motor controller design. The motor chosen is a Chinese-made 36-volt motor made as a drop-in replacement for electric scooters. The motor's output shaft makes use of an 11 tooth #25H gear. This allows for the advantage of changing the gear ratios from the motor shaft to the prop shaft. We have chosen to spin the final output shaft at a ratio of 2:1. The final loaded speed of this motor falls in the 5400-5500 revolutions per minute range. The biggest advantage to this motor setup is cost to performance. The MY1020 can reach a peak of 1000 watts with efficiency peaking around 750 watts.

Sensors Design Schematics /Diagrams

The first portion of the sensors system include sensing the solar panel to measure Voltage, Temperature and Light intensity and display the reading in LCD display screen. Then speed sensor using hall affect and microcontroller chip to display speed in separate LCD display screen. Third portion, four LEDs represent the battery capacity when all on full capacity and more off LEDs represent less capacity and so on. All in all, in the monitor and display box as the user interface that will be accessible by the user and will be mounted in front panel box for the driver to have all the readings displaying in front for him/her. Finally, the box will have a push switch for the driver to check battery capacity whenever is pushed, and two LCD display screen for the rest portion of the sensor system.

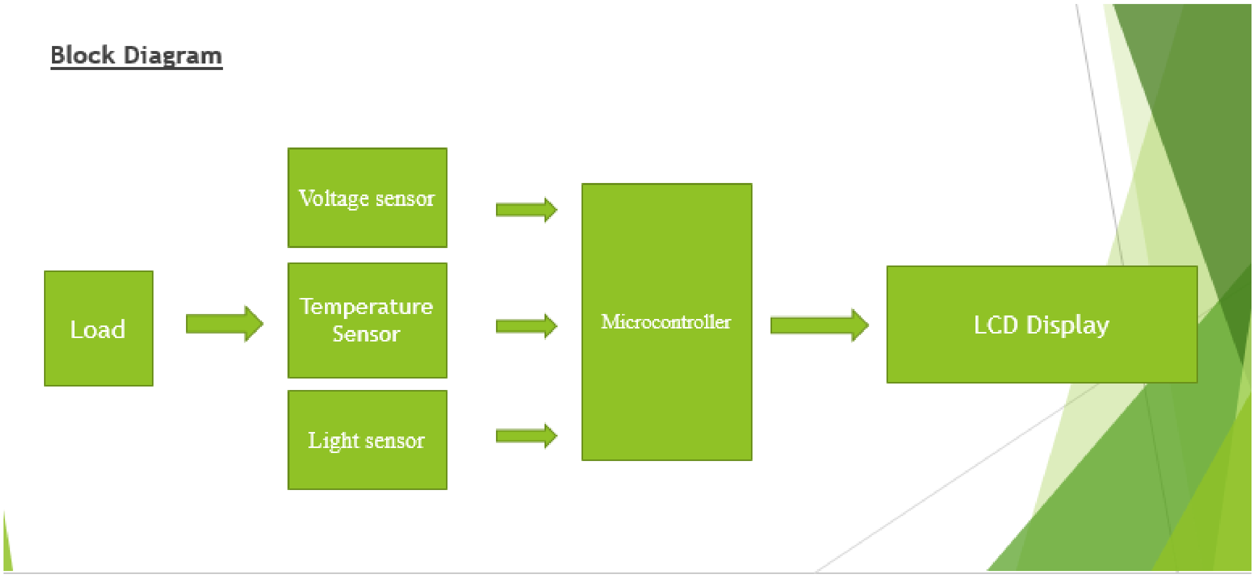


Figure 8: Block diagram for the sensors system including sensing the motor speed.

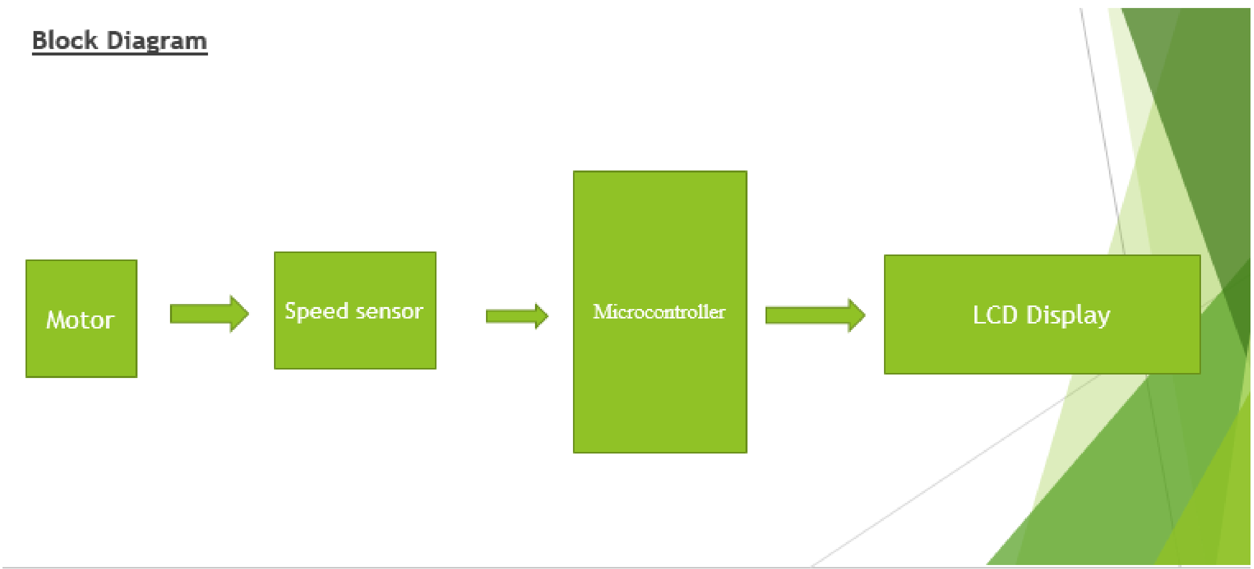


Figure 9: Motor speed calculating block diagram

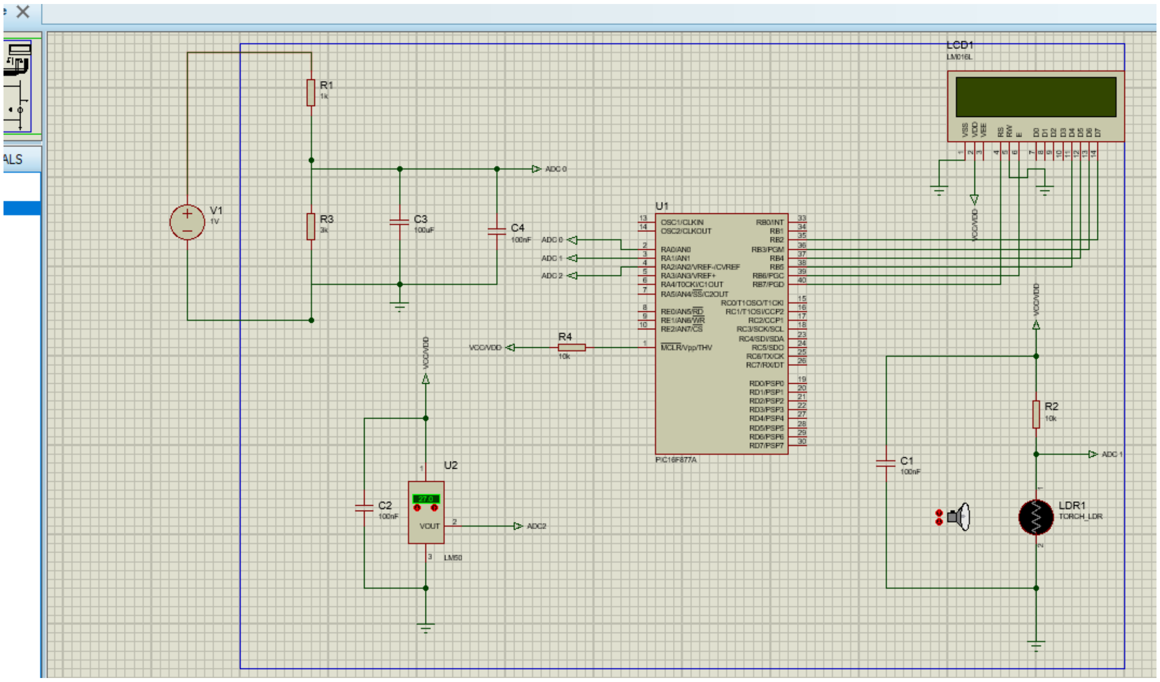


Figure 10: Microcontroller used for temperature, voltage, light intensity

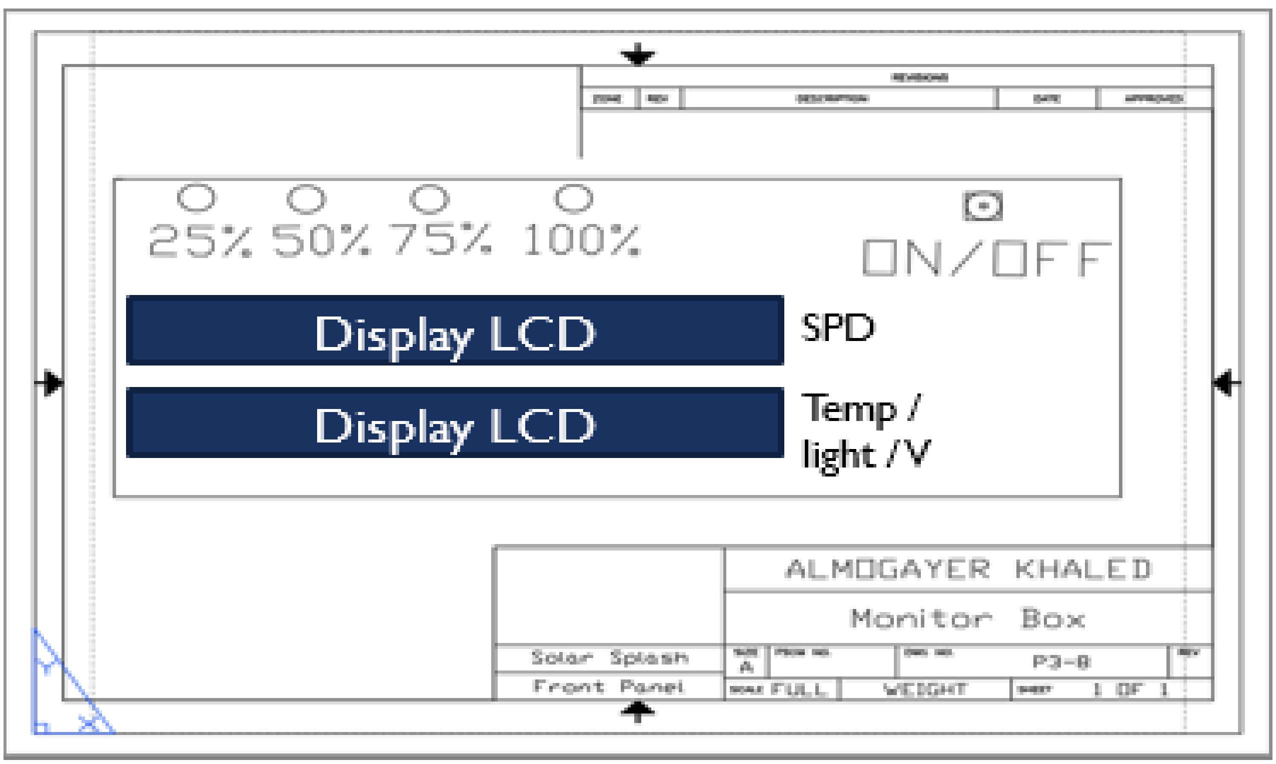


Figure 11: Monitor/Skipper's HUD

TEST METHODOLOGY & TEST RESULTS

Motor Testing Methodology

Motor testing started first by verifying operation of the motor controller. This was done by creating the motor controller circuit in Multisim and running a load across the motor terminals. Testing using Multisim created a circuit-level view of the operation of the controller while running full bore. This stage checked for integrity and component reliability when observing worst-case scenario conditions. Multisim created an opportunity to check for component weaknesses before using inferior or underrated components. Components that did not meet the specification needed were replaced with components that meet the bar.

The second stage of motor testing looked more into the electrical energy translation to mechanical energy. Simulink's Simscape allowed for this to happen using virtual blocks specialized for DC motors. Two representations of our MY1020 motor have been created: one loaded, and one unloaded. The loaded representation uses a wheel and axle as a load to represent the water that the propeller will be spinning through. For some of the calculations, a spring was attached to the wheel and axle and connected to a virtual point in space to simulate propeller drag or water resistance. This simulation allows a visualization of the motors torque, peak horsepower, maximum power draw, and simulated load efficiencies. The unloaded representation is an ideal spinning DC motor under perfect conditions. This simulation allows for a better representation of the different aspects of the motor that control the characteristics. The unloaded simulation was also created to be able to connect directly to the Solar and Sensors portions of the system in Simulink. The unloaded simulation creates an environment to test the motors reaction to different conditions can be modified easily without interrupting the operation of the simulation. The sole purpose of this reproduction is to test 'What Ifs' and potential changes to the system for improvement.

The third stage of motor testing is realized in the 'CFD Testing Results' section as the motors drive capabilities are related to moving a digitally represented hull. The fourth stage of the CFD testing results explains the motors ability to move the watercraft through water.

Motor Testing Results

The motor and motor controller were both selected and design with several items in mind. The motor was selected as the cost is within the original budget decided upon for the project. As the scope was redirected, the motor remained as the question was no longer one of how the craft was to be built but would the craft work. Motor testing is the first step in determining the operation of the watercraft.

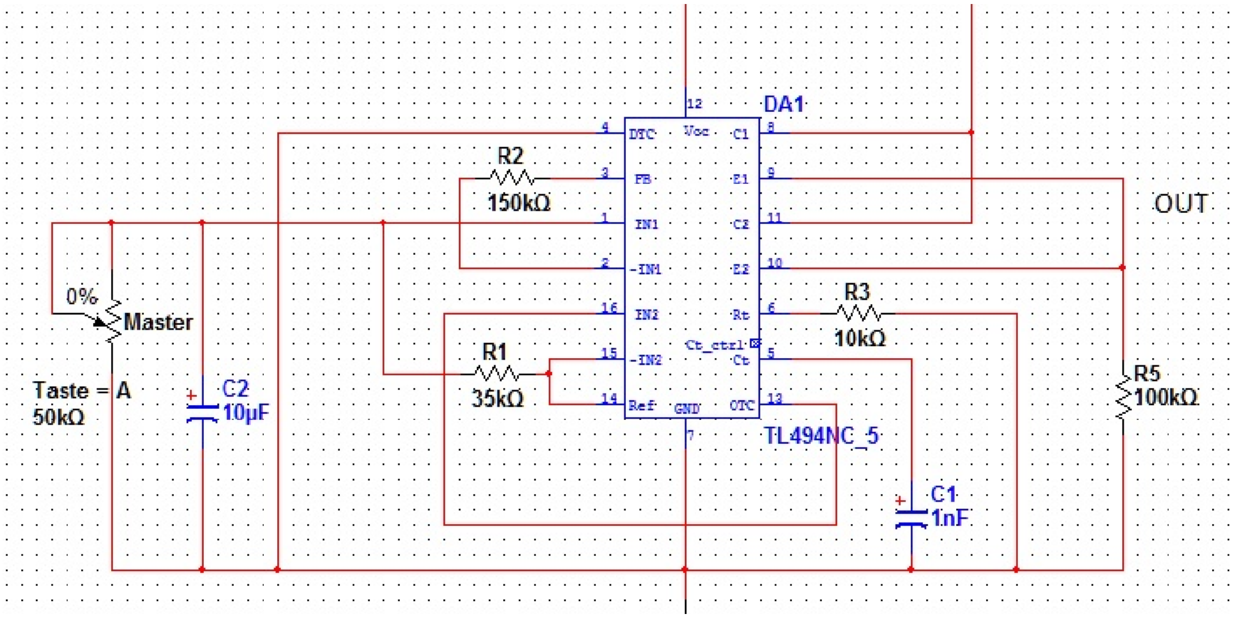


Figure 12: Multisim motor controller reaction with TL494NC addon chip

Operation of the motor controller circuit was first seen in Multisim using a recreated motor controller schematic displayed in Figure 4. Multisim highlighted several flaws in the operation of the motor controller and created and opportunity to improve on the design. Most notably, the LM7812 chip replaced a previously used LM317 purely due to its ability to handle the input voltage that is being used in this scenario. All resistors were switched with 5-watt replacements as the power draw was greater than the capabilities of the originals. This stage also allowed for experimentation with the operation of the PWM chip. Although the TL494 is a fine chip, alternatives were considered to ensure that it is capable of all that is needed from it.

This phase of testing also highlighted all the high current areas that will need cooling including the voltage regulator and the 75N75 MOSFET chips. The current draws through these components was found to be within the range suggested in their respective specification sheets. Passive cooling still provides an additional degree of reliability and safety when the potential of each component is stretched.

At this stage I was able to get a specification sheet for the MY1020 motor and determine what the internal resistance and inductance is for the motor without having one present. Assuming that the motor is capable of drawing 26.7 amps of peak armature current, the motors resistance falls somewhere in the 1.34 Ω range. The inductance listed by the manufacturer is 9 millihenries. All these values are critical in determining the operation of the motor in future stages. Exact motor performance of the actual unit is impossible to determine without a physical motor present. These are rough values in order to be able to get a relative idea of how this motor will perform. In the simulation drawn up by Simulink, the motor is operating at best-case-scenario conditions using characteristics given to the simulation software. Using these simulation results a general motor operation graph was created below.

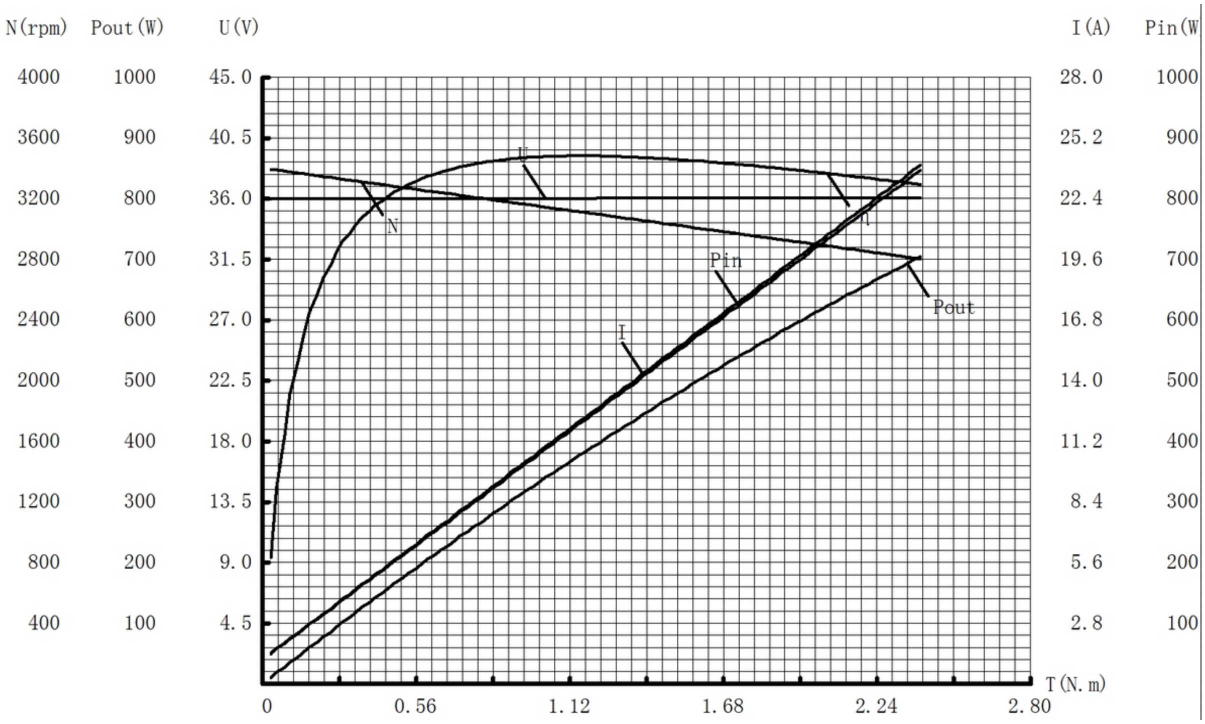


Figure 13: Simulated motor characteristics derived from Simulink data

The simulated motor characteristics are nearly a mirror image of the characteristics determined by the manufacturer's testing. The simulation observed a peak torque of 2.408 Nm, though in the efficient range of the motor, it peaked at 2.129 Nm. The low torque of the motor will primarily affect the acceleration of the motor on startup. The motor however allows for input voltages greater than 36 volts and can be ran at elevated levels if necessary.

In order to be able to add the simulation of the motor to the other systems and create a system picture, the motor was simulated in the Simulink Simscape workspace. Both simulations created operate on the same principle of a simple DC motor with a resistive and inductive load. The first simulation was created to be connected directly to the solar inputs.

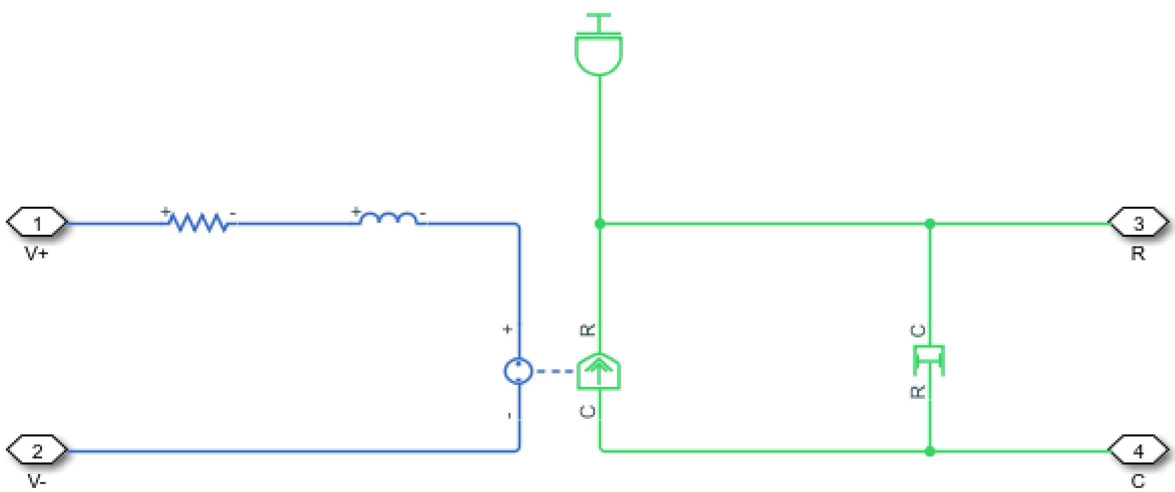


Figure 2: Base level unloaded DC motor

This simple DC motor representation contains very few components. Starting from the left, the electrical side of the motor accepts a positive voltage running through a resistor and inductor representing the inductive and resistive loads of the motor. The mechanical right side of the motor runs into an inertia block and has a damper 'across' the rotation of the motor. Moving back a block, more innerworkings of the tested DC motor become apparent:

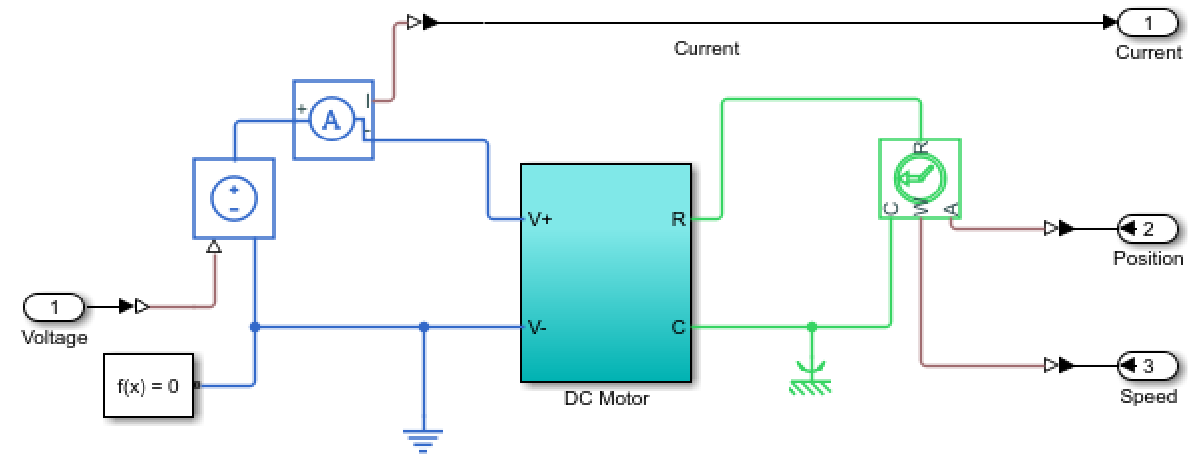
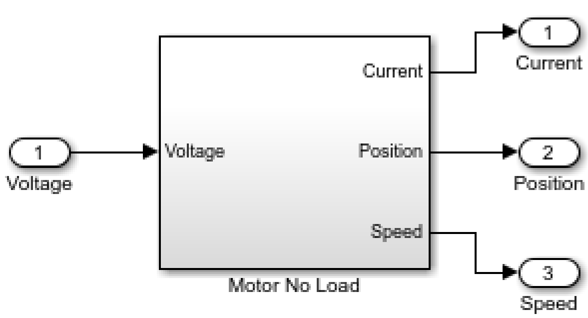


Figure 15: Second Level DC motor solver & sensor blocks

The 'DC Motor' in the center of figure 14 represents the inputs and outputs found in figure 13. Starting on the left side, or blue lines, a voltage signal enters and goes directly into a controlled voltage source block that assumes an ideal constant 36-volt source. That voltage source runs into a current sensor that runs a lead to a physical sensor that can be seen by the skipper. On the mechanical side of the motor, green, an ideal rotational sensor is used to determine the current position and current speed. This sensor is the simulations stand in for the microcontroller identified for speed in the sensors section of this report. The mechanical rotational reference found near the C port of the motor is a 'ground' or frame reference where the motor is mounted. The entire unloaded motor simulation can be represented by a single block as seen here:



These simulations use blocks that translate the electrical side into a mechanical equivalent. Several equations were used to test, analyze, and confirm different results seen throughout the examination process. The first equation used describes the electrical side of figure 14:

$$E_a(t) = i(t)R + L\frac{di}{dt} + K_e\omega_m(t)$$

Figure 16: Symbol representing the unloaded DC motor

Where $E_a(t)$ is the input voltage, $i(t)$ is the current, R is the motor resistance, L is the motor inductance, K_e is the EMF constant and $\omega_m(t)$ is the rotor speed.

The mechanical side of the DC motor simulation is defined as:

$$T_m(t) = T_L(t) + J\frac{d\omega m(t)}{dt} + B\omega_m(t)$$

Where $T_m(t)$ is the torque of the motor, $T_L(t)$ is the loaded torque, J is the inertia, and $B\omega_m(t)$ is the viscous friction coefficient.

The shaft torque of the motor can be found by:

$$T_m(t) = i(t)K_T$$

Where K_T is the torque constant.

The Loaded torque of the motor is defined as:

$$T_{Lg}(t) = T_L(t)N_g$$

Where $T_L(t)$ is the torque applied to the gear ratio and N_g is the final drive gear ratio.

Each equation is used sporadically throughout the motor analysis process. The electrical equation was used primarily when analyzing the basic function of the DC motor and determining the current at different speeds of the motors power curve. The mechanical equation was used in conjunction with Simulink to determine the motor's loaded torque using a viscous friction predicted by Simulink. A viscous friction was also confirmed using the manufacturer's provided specifications. The shaft torque was used to get the torque constant as a torque value for the motor is already known. The fourth and final equation gives some insight into the amount of power that is transferred to the final output shaft and thus transferred to the propeller.

Various retrieved motor values can be found in the chart below.

MY1020 Motor Values	
Characteristic	***Value***
Input Voltage	36.0 volts
Peak Armature Current	26.7 amps
Operating Armature Current	20.7 amps
Armature Resistance	1.34 ohms
Armature Inductance	9.00 millihenries
Motor Constant	0.1
Peak Torque	2.408 Nm
Operating Torque	1.880 Nm
Loaded Torque	1.655 Nm
Propeller Torque	3.310 Nm
Peak Input Power	962 watts
Peak Output Power	782 watts
Operating Input Power	750 watts
Operating Output Power	609 watts
Unloaded Rotational Speed	2820 rpm
Loaded Rotational Speed	2710 rpm

Table 4: MY1020 Motor Values

The second simulation uses the same principles as the first except it consists of the only load that Simscape allows for: a spring. A spring is not the ideal load for this use case, but the spring gave a good indication of what quantity of resistance would stall the motor.

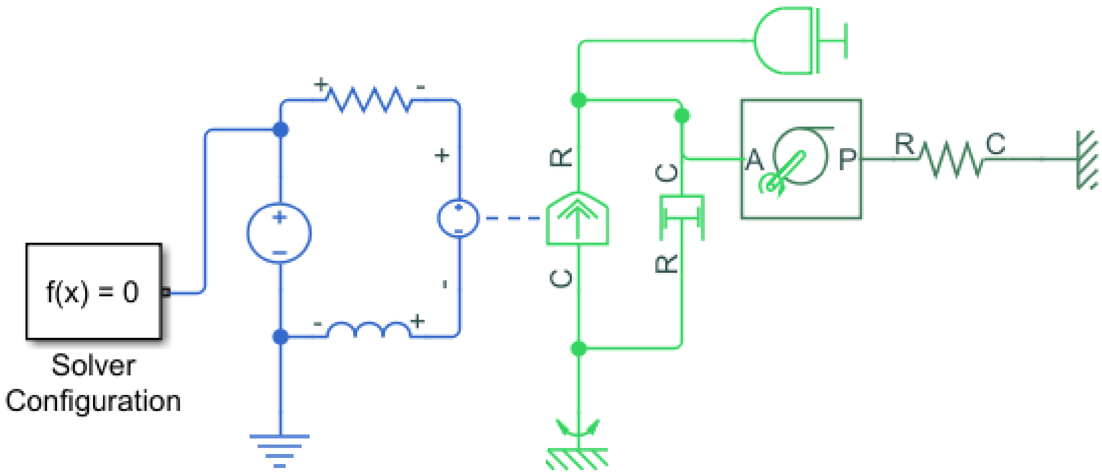


Figure 17: Loaded DC motor simulation using wheel & axle connected to a spring

The loaded motor simulation is near identical to the unloaded motor simulation bar a few changes. In this simulation, the voltage source is assumed inside the simulation rather than having connections to be fed by the solar simulation. The left electrical symbols still consist of a resistive and inductive load running into the electromagnetic converting block. The motor is directly mounted to a frame or hardpoint and uses a damper. It uses the same inertia block as the first simulation. The primary addition is seen in the wheel and axle block connected to the spring that is mount on one side to a frame. The idea here being that the wheel and axle acts as the propeller of the boat and the spring acts as the resistance that the water would have on the propeller. The damper attached to the motor is simply acting as a shock absorber between the motor and the wheel and axle.

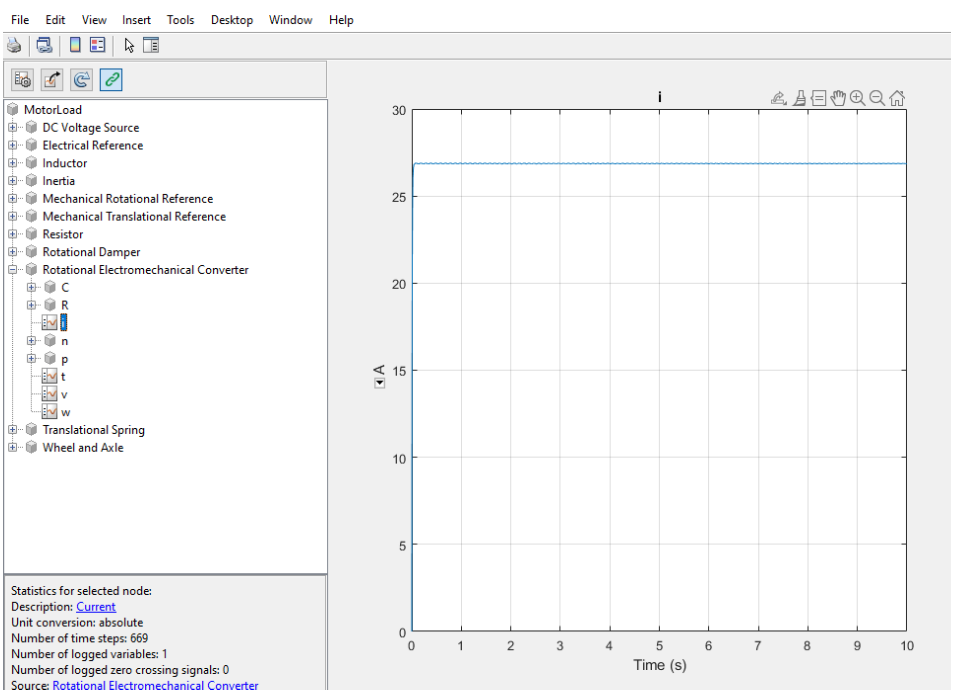


Figure 18: Maximum motor armature current observed in Simulink

Using the calculated resistance and inductance values the motor acts as intended with roughly 26.7 amps of current as the peak. The motor in this graph is trying to overpower the resistance of the spring and is simulating the maximum potential of the motor. The peak motor torque can be seen in figure 18. This is the torque that is applied to the axle and thus the wheel of the simulation setup.

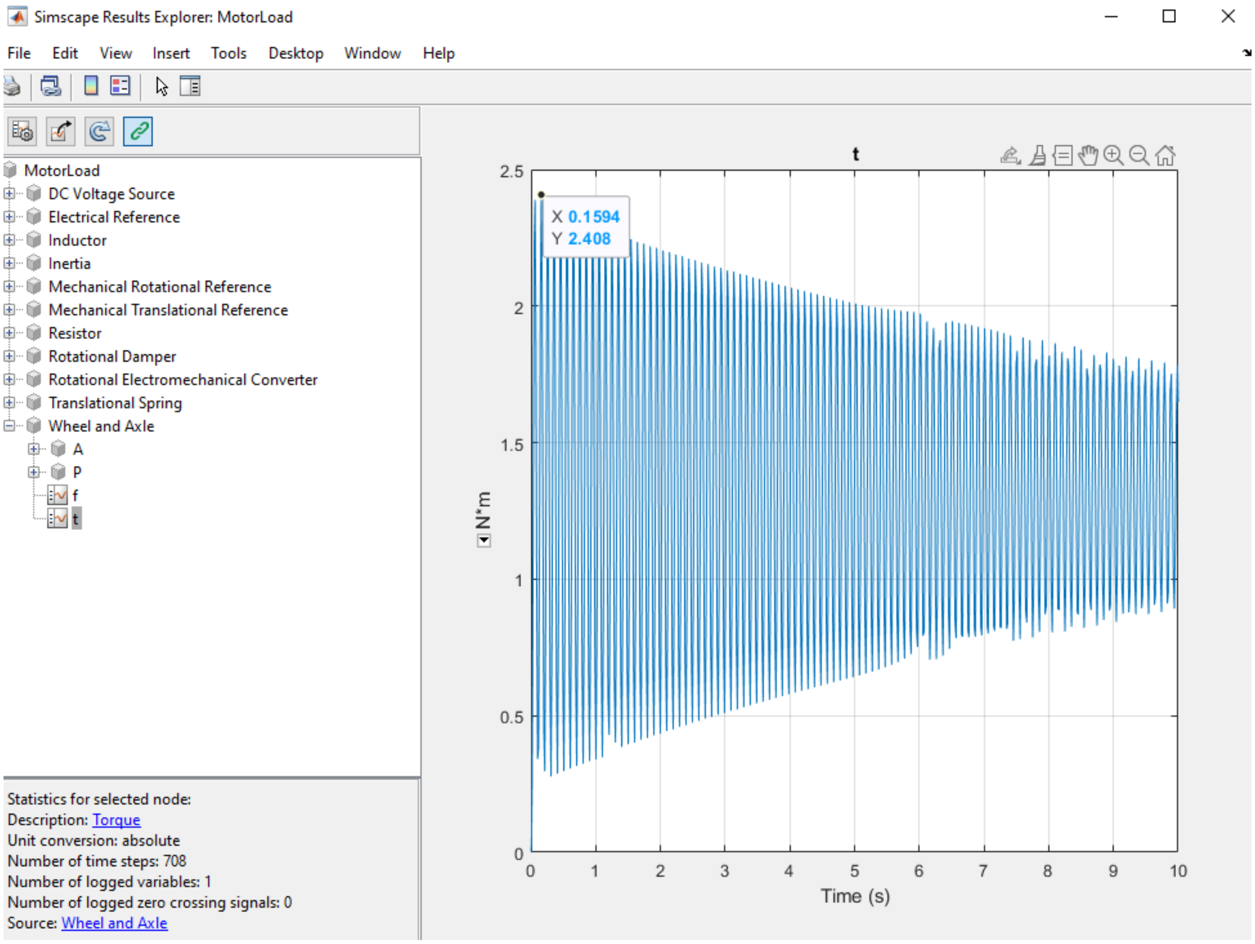


Figure 19: Peak Motor torque observed at peak motor current

The peak torque observed in this simulation would be applied to the output shaft of the motor where it would then transfer to the propeller's drive shaft. In these simulations, the motor is operating at an absolute maximum. The motor can run in these conditions although it is consuming 962 watts of power and the efficiency has fallen off. The rotational speed and torque of the motor remain low at 2790 unloaded and 2.408 Nm and aside from a decent increase in torque, there is no added benefit to pouring more energy into the motor. Under normal operating conditions and an input voltage of 36 volts, the motor will see a peak current around 20.7 amps. This results in a peak torque that looks more like:

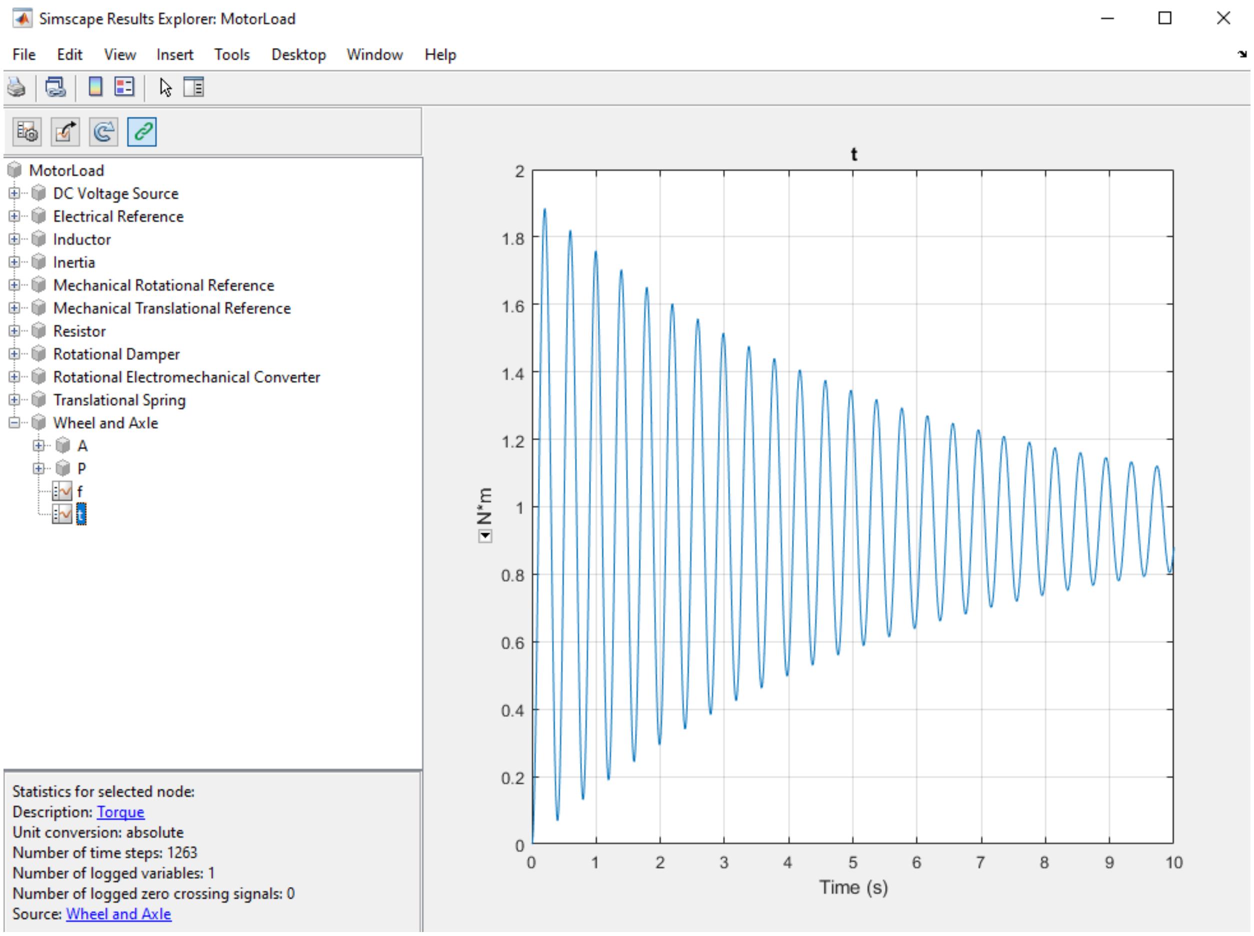


Figure 20: Peak torque observed as motor is operating under a normal condition

When simulating these normal operating conditions, the motor sees a peak wattage of 752 watts, an unloaded rotational speed of 2820 rpm and a peak torque of 1.88 Nm. The motor can be analyzed throughout its accepted power range. The torque/speed/power graph shown below is the resultant of that.

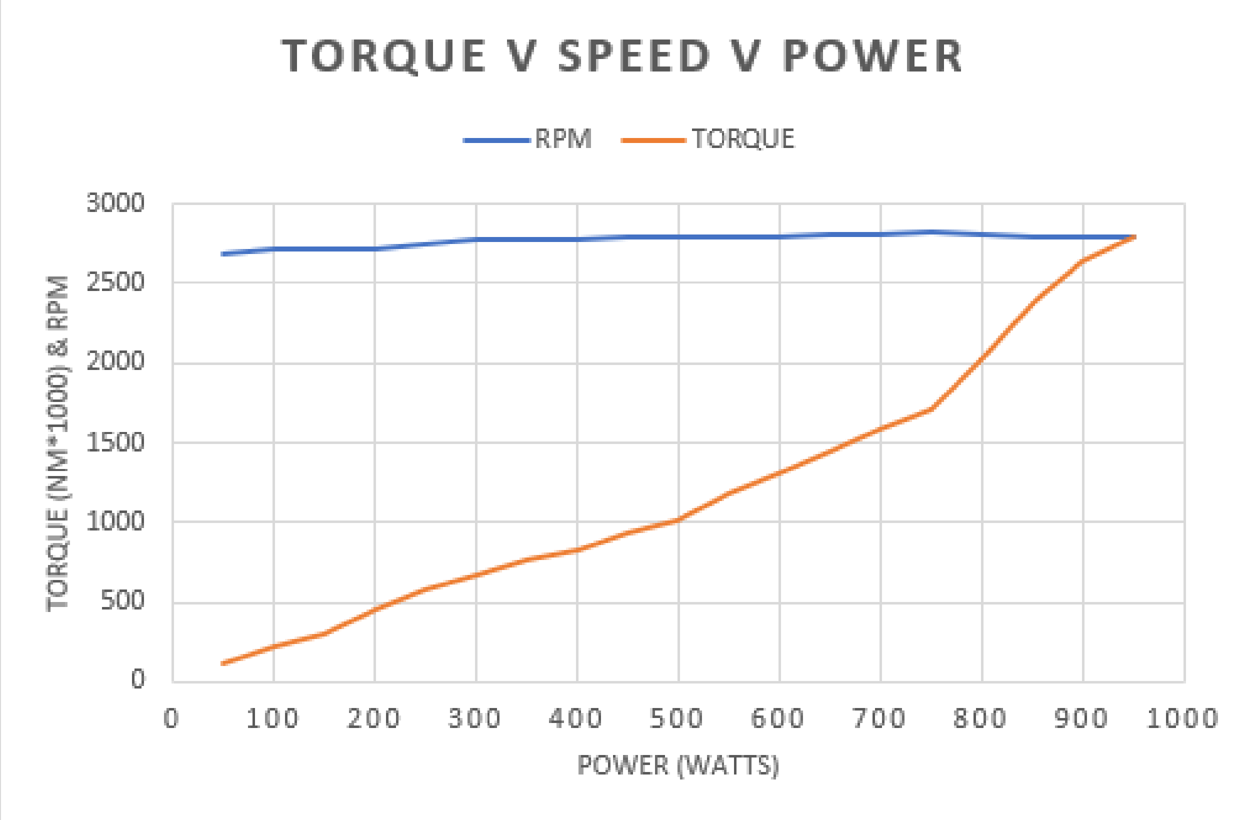


Figure 21: Torque v Speed v Power curve

It is important to note that the torque observed in this graph is a factor of 1000 when compared to the rpm and power. From the torque curve, the motor appears have a linear torque curve up until the point the power consumption reaches 750 watts. Beyond 750 watts, the curve increases slightly though it is important to identify that the efficiency of the motor falls off at this point. The motor speed across this tested power range remains stable in the 2700-2820 rpm range. The peak revolution speed can be seen in the graph at approximately 763 watts as well.

Solar Testing Methodology

The testing of the Solar Power system starts with testing the output voltage of the solar panels. This was accomplished by creating a SIMULINK simulation via MATLAB R2020a. Three solar panels were selected, and the values input from the specifications sheet. The input to the solar panel is a signal builder that simulates the irradiation levels increasing from 0 to 1200 W/m^2 then falling back down to 0. This will provide the power output for the different levels of sunlight that could be provided on a typical day. From there, each solar panel goes to it's own MPPT to step up or maintain the output voltage at 15VDC. The outputs from the MPPTs are combined and sent to the batteries to charge them.

The next portion of testing is the charging and discharging of the batteries to make sure they are outputting power to the motor. The batteries are configured in a 3 x 3 series parallel configuration to provide the needed 36VDC to the motor as well as providing 39Ah of current output. This configuration provides about 1.4kW to the motor which only requires total about 900W of power at full load. This configuration proved to be most efficient and reliable due to maintaining the required specifications needed.

Solar Testing Results

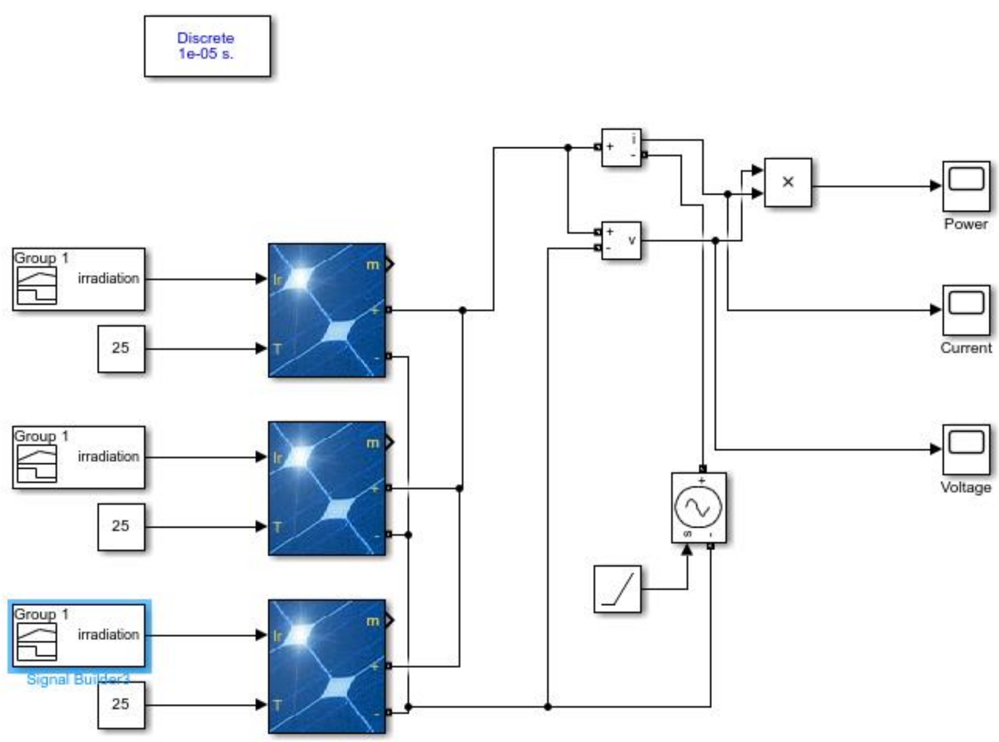


Figure 22: Solar panel configuration with irradiation input wave

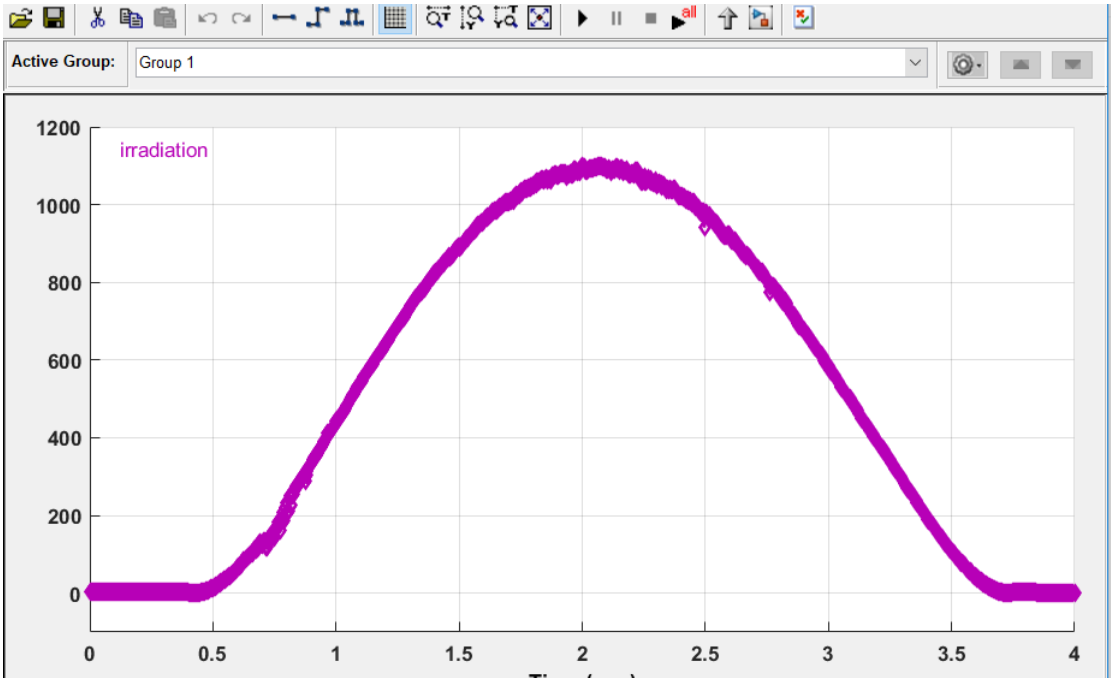


Figure 23: Irradiation wave input for solar panels

In this figure, the simulated irradiation ranges from 0 to approximately 1150W/m^2. This range covers majority of the irradiation values of a typical day in June.

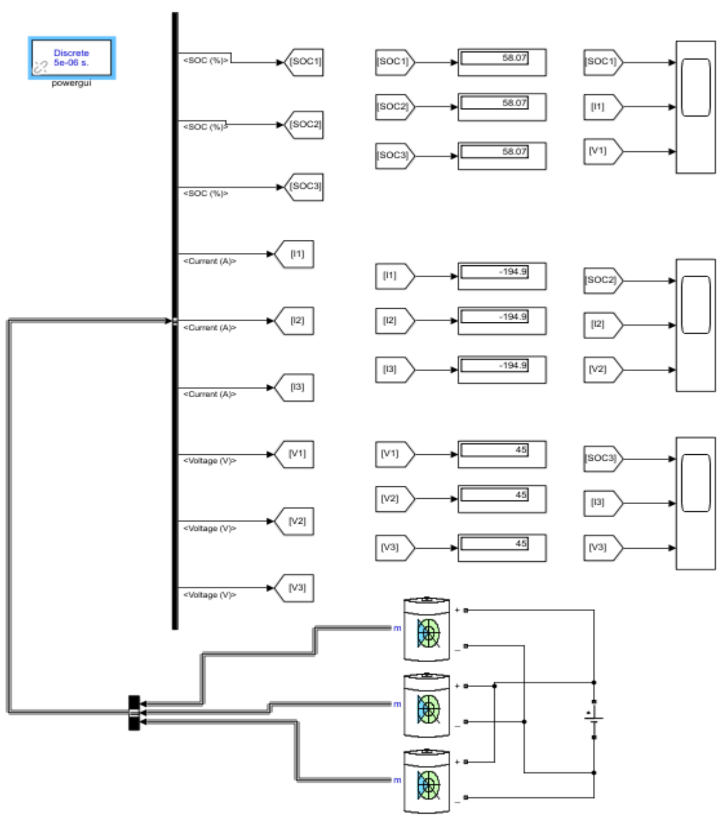


Figure 24: Charging battery configuration in SIMULINK

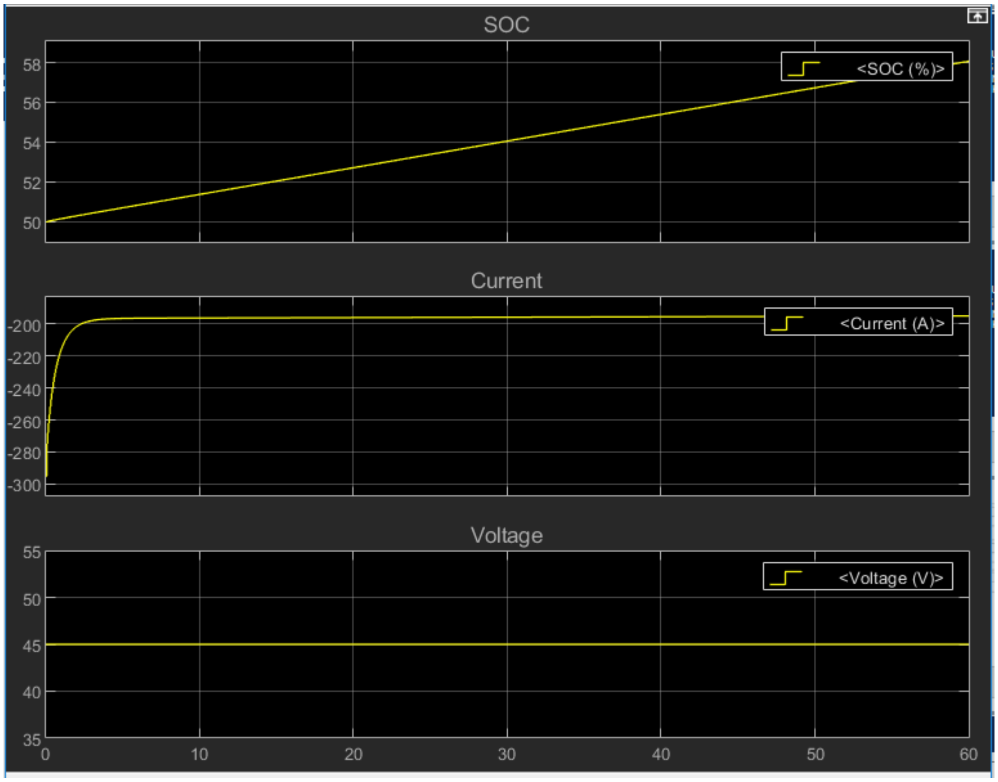


Figure 25: Charging battery values

The batteries are grouped into 3 groups of 3 to simulate the 3 x 3 series parallel configuration. They are all outputting approximately 12VDC and 13Ah. We chose to start the state of charge at 50% to simulate never allowing the batteries to drop below this percentage. If the batteries drop below 50%, they will begin to become more and more unreliable.

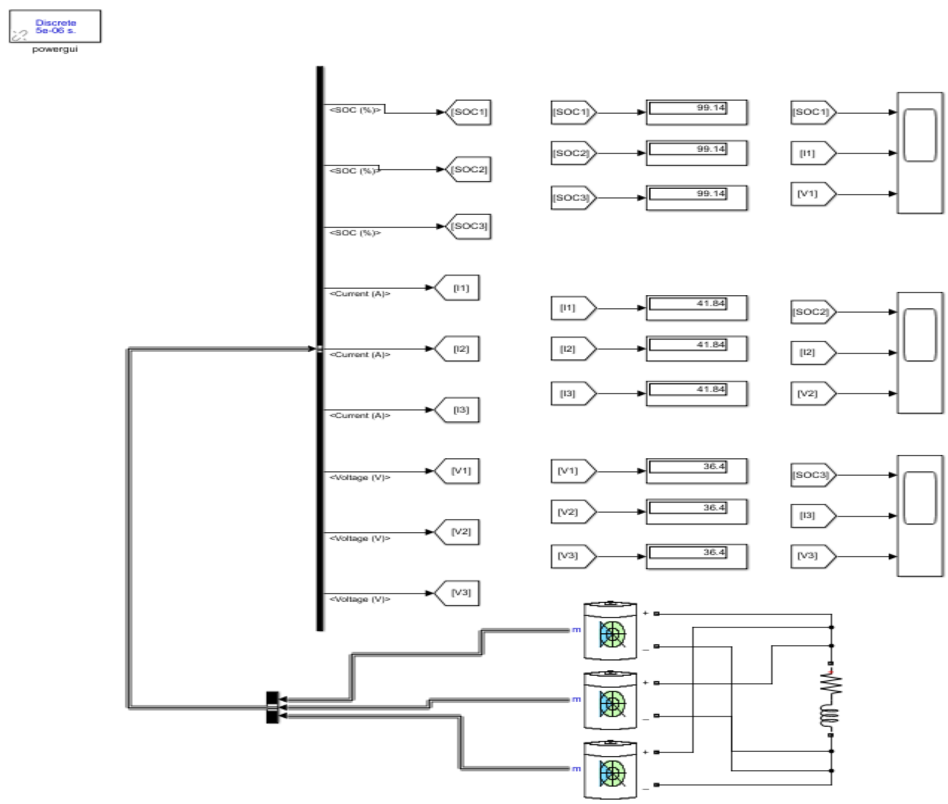


Figure 26: Discharging battery configuration in SIMULINK

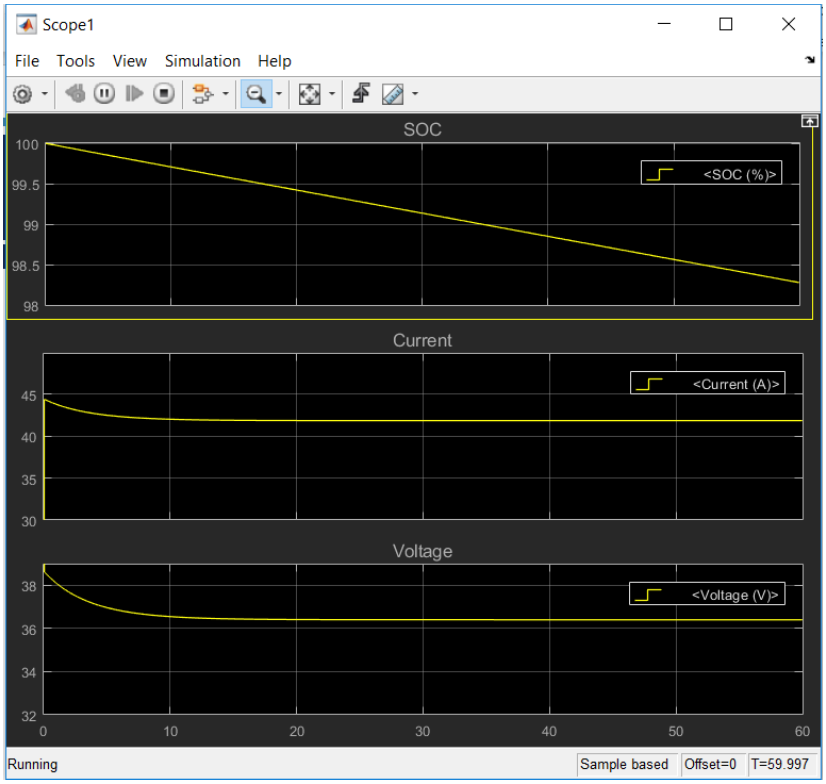


Figure 27: Discharging battery values

The batteries for the discharging portion will be in the same configuration only the output load is the impedance values of the motor. The internal resistance is approximately .209 ohms and the inductance impedance is approximately 15mH.

CFD Testing Methodology

The first stage of simulating the watercraft hull started by creating the physical dimensions of the craft. The original watercraft setup was created in Hullform and changed gradually to improve performance for the use case. Hullform is a simplistic graphical creation tool that is primarily targeted towards marine applications. Hullform gives valuable feedback regarding altering the way that the watercraft interacts with the water, the watercraft contents, and the ability of the motor to move the watercraft through the water. The original Hullform model is not the same model that is used in the stage four simulation.

The third stage of CFD testing involved AutoCAD CFD to visualize the flow of fluid around the hull of the boat. The plan was to perform all the analysis in AutoCAD as this was the software on hand. The simulation process did not go as planned and the software is either not capable of what is needed or would take a large amount of time to accomplish. OpenFOAM appealed as a viable solution to the problems that were had with AutoCAD. Using the model created in AutoCAD, the OpenFOAM counterpart was created. At this stage, the goal was to get a moving and water scaling watercraft. After Assembly and squeezing out the imperfections using community sourced addons, the hull was prepared to be slung across a virtual ocean.

The third stage primarily used OpenFOAM to simulate the propeller of the craft. The propeller is an important aspect of how the watercraft will move through the water. OpenFOAM allowed for a better representation of how the interacts with the water when compared with AutoCAD. The biggest gain from this stage is the correlation between number of rotations and horizontal movement. This simulation purely describes how the propeller moves through the water by itself.

The fourth stage is continued in OpenFOAM and combined the propeller and a simplification of the watercraft. The propeller in this simulation spins at a set speed. The speed used in the simulation is the geared output speed of 5100 rpm. This simulation is predicting the slip of the propeller and giving insight into top speed and acceleration. The results acquired are a good outlook of what a physical implementation could be, but still rely on optimal conditions.

CFD Testing Results

The Hullform model is a simple sailboat design that is large enough to contain all the components necessary for the electrics of the system. The original design was 15 feet long and 6 feet wide at its midsection. It serves, at this point, as nothing more than a starting point for the simulations completed in future stages.

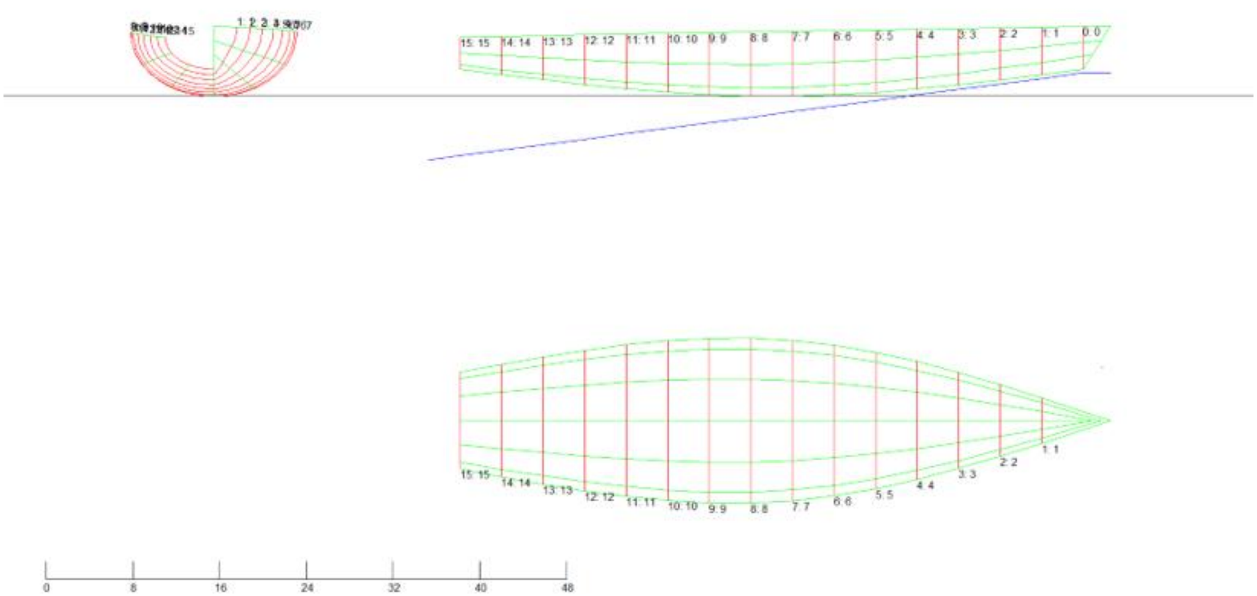


Figure 28: Hullform original hull design

Using the model in figure 21, the craft was created in AutoCAD CFD as this was initially the software that was going to be used to perform an analysis of the hull. A struggle was to be had with the operation of Autodesk's product. Ultimately, the software was lackluster in the marine CFD department and an alternative had to be found.

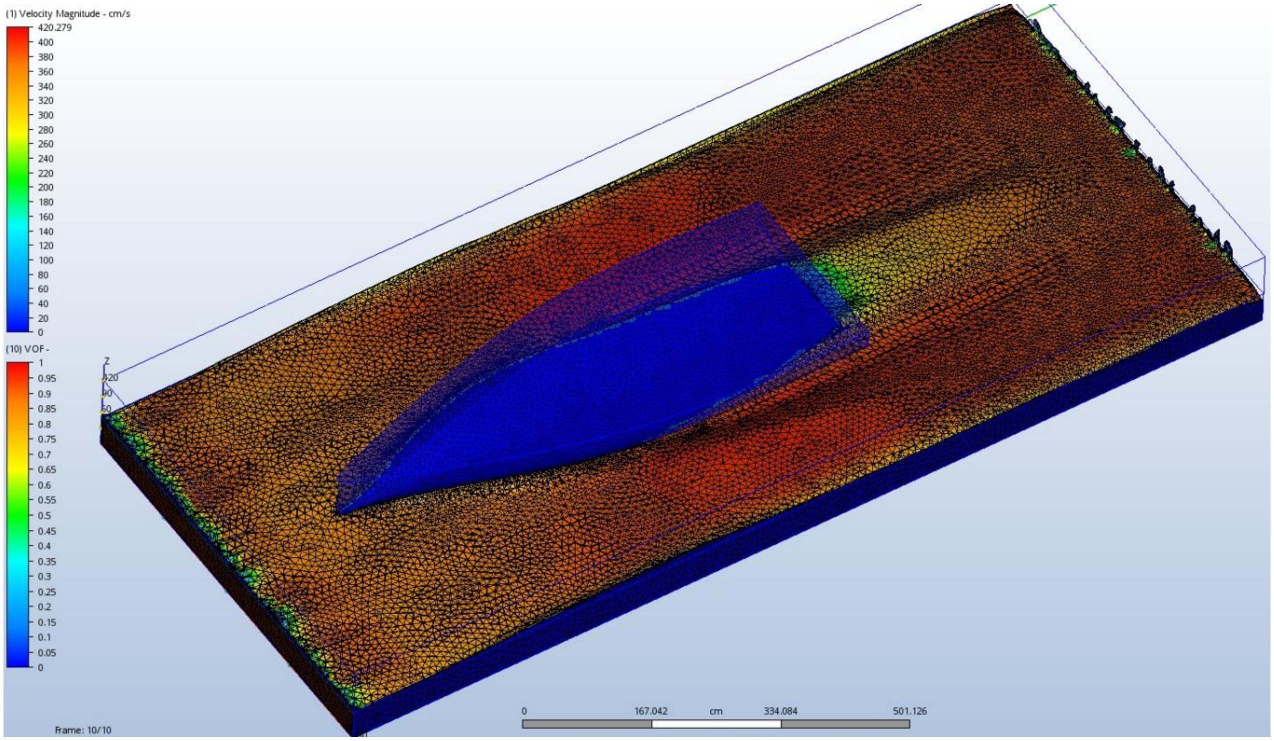


Figure 29: AutoCAD CFD initial hull

The analysis process as this point continued in OpenFOAM where the potential for movement and flow analysis is possible. OpenFOAM is a C++ toolbox for developing numerical solvers and pre-/post-processing utilities for mechanics problems, primarily computational fluid dynamics. Since it is an open source utility, it has an abundance of community made addons and tools. In these solutions and simulations many different solvers and tools were used to aid and make the simulation perform as expected. The addons and solvers not only add an entirely new degree of functionality but can be tweaked while being used. Each time an addon is used it will be mentioned in the report. The first benefit of using OpenFOAM are the overwhelming number of solvers that allow for an endless combination of simulation possibilities. The second seen benefit is found in the simulations below: model movement and flow.

The first sim created in OpenFOAM is the cutaway 'mesh' of the design that will be the final product used throughout the flow analysis process. At this stage it is a solid complex shape with a length of 12 feet, width of 2 ¾ feet and depth of 1 ¾ feet. The wave crossing the breast of the hull below was one of the first tests done using waveDyMFoam. This same solver is used in recreating the movement around the hull during the flow simulation.

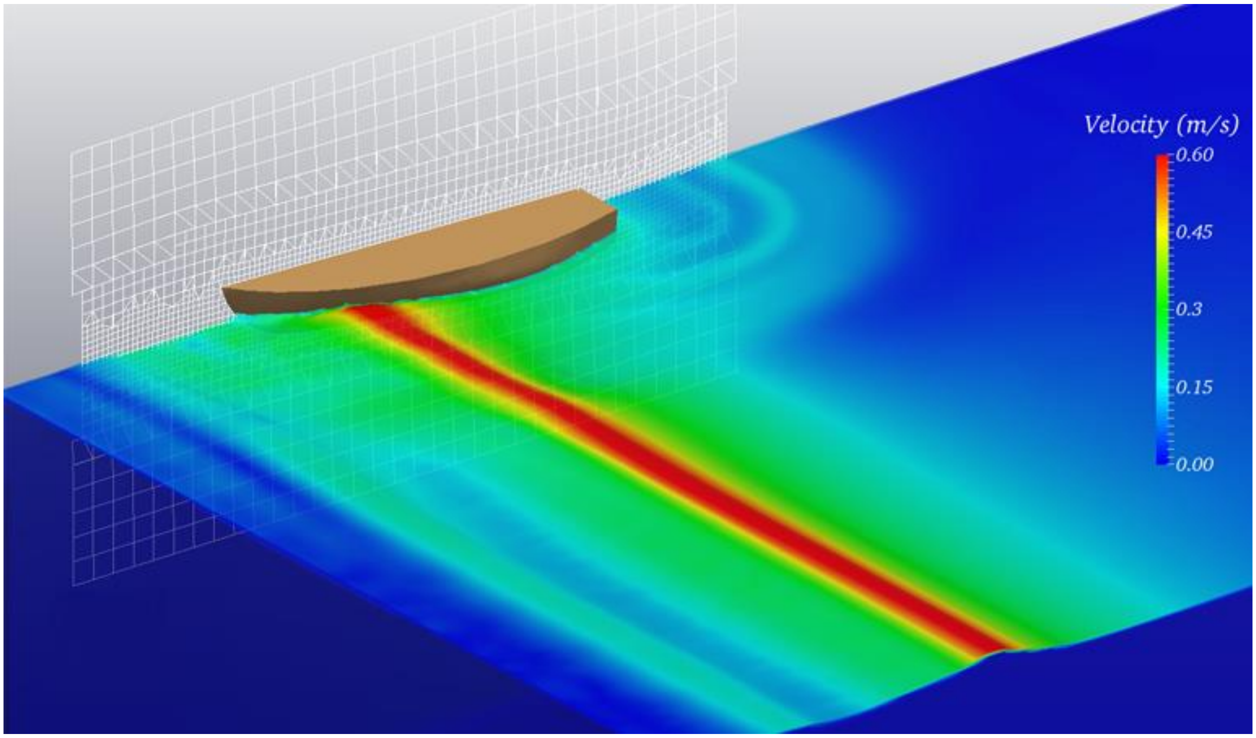


Figure 30: OpenFOAM initial mesh cutaway

To create a complete mesh, the one-sided cutaway was mirrored across the x-axis and hollowed to create a realistic hollow volume inside the hull of the ship. Minus a few operational and visual changes, a semi-final cutaway mesh can be observed here:

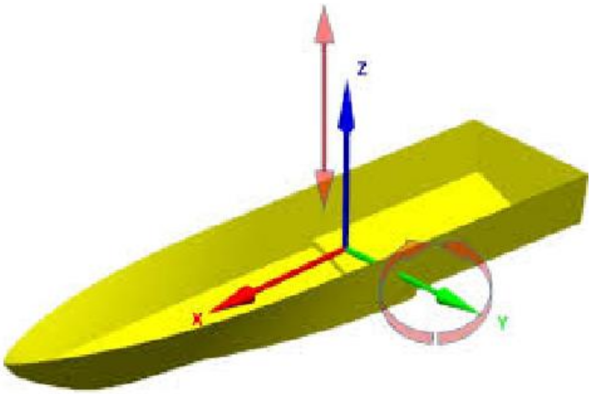


Figure 31: Hollow mirrored mesh

The second simulation created in OpenFOAM simulates the flow around the boat as it moves through the water. This is done using the addons interDyMFoam and waveDyMFoam. Both are used to aid in the simulation of the water around the hull of the boat. interDyMFoam is used to refine the mesh as it changes dynamically and makes the interface appear sharper like anti-aliasing. waveDyMFoam is for exactly what it sounds like: wave creation and water movement analysis. Both tools essentially made for a smoother simulation. After the mesh for the boat was created, the boat was thrown straight onto the water and cutting waves. This simulation in no way represents the motors ability to move the watercraft. This recreation serves as the basis used to create the final sim that uses the motors 'power' to propel the craft. The craft in this image is simply moving across the fluid it sits in by being given a predetermined speed. OpenFOAM handles the rest.

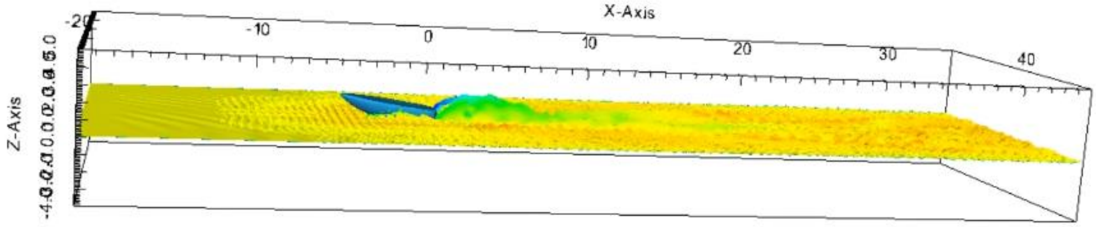


Figure 32: Smoothed mesh meets water

At this stage, the hull design is finalized and remains the same throughout the remainder of the processes. The boat setup as tested is using a 164-pound aluminum frame. The analysis takes this into account when figuring the length of the waterline surrounding the hull and craft depth when loaded.

Finalized Aluminum Hull Characteristics	
Characteristic	**Value**
Length	12 feet
Width	5 ½ feet
Depth	1 ¾ feet
Weight (Aluminum)	164 pounds
Weight (Fiberglass)	115 pounds
Volume	115 ½ feet^3
Drag Coefficient	0.54

From this point, the simulations become a bit more time consuming and intensive. The focus from this point is tying together the pieces and determining a weight for the watercraft when it contains all the components and presumably a 70-kilogram skipper. Below is a breakdown of all the parts and what their associated weight in pounds. A breakdown is listed for each configuration: sprint and endurance race. Some parts were impossible to source a weight for and some of the smaller PCB parts were measured using samples on hand. The first configuration set up for the endurance weighs in at approximately 503 pounds. A seemingly meager number when considering this weight is fully loaded with all the required items for competition.

Parts	From	Quantity	Weight	Total Weight (lbs)
Renogy Solar Panels	Solar	3	22.1	66.3
Genesis 12EP	Solar	9	10.582	95.238
Genesun GV-Boost	Solar	3	0.40625	1.21875
MY1020 Motor	Motor	1	9	9
PCB	Motor	1	0.25	0.25
Resistors	Motor	11	0.00059	0.00645073
LM317	Motor	1	0.22063	0.220625
TL494CN	Motor	1	0.2304	0.2304
75N75	Motor	3	0.1801	0.5403
Machete III	Motor	1	0.45	0.45
AT90S2313	Sensors	1	0.00498	0.004982438
PIC16F877A	Sensors	1	0.00063	0.000625
Sensors	Sensors	3	0.245	0.735
16x2 LCD	Sensors	1	0.07716	0.0771618
Aluminum boat hull	Boat	1	164	164
Skipper	Human	1	154.324	154.324
Gear assembly	Power	1	8	8
Bilge Pump	Required	1	0.79366	0.79366414
Life Preserver	Required	1	4.5	4.5
60mm paddle	Required	1	1.54	1.54
Fire Extinguisher	Required	1	5.8	5.8
Air Horn	Required	1	1.25	1.25
			TOTAL:	514.4799591

Figure 33: Sprint Configuration Part Weights

Parts	From	Quantity	Weight	Total Weight (lbs)
Renogy Solar Panels	Solar	3	22.1	66.3
Genesis 42EP	Solar	3	32.75	98.25
Genesun GV-Boost	Solar	3	0.40625	1.21875
MY1020 Motor	Motor	1	9	9
PCB	Motor	1	0.25	0.25
Resistors	Motor	11	0.00059	0.00645073
LM317	Motor	1	0.22063	0.220625
TL494CN	Motor	1	0.2304	0.2304
75N75	Motor	3	0.1801	0.5403
Machete III	Motor	1	0.45	0.45
AT90S2313	Sensors	1	0.00498	0.004982438
PIC16F877A	Sensors	1	0.00063	0.000625
Sensors	Sensors	3	0.245	0.735
16x2 LCD	Sensors	1	0.07716	0.0771618
Aluminum boat hull	Boat	1	164	164
Skipper	Human	1	154.324	154.324
Gear assembly	Power	1	8	8
Bilge Pump	Required	1	0.79366	0.79366414
Life Preserver	Required	1	4.5	4.5
60mm paddle	Required	1	1.54	1.54
Fire Extinguisher	Required	1	5.8	5.8
Air Horn	Required	1	1.25	1.25
			TOTAL:	517.4919591

Figure 34: Endurance Configuration Part Weights

Each configuration gives us the ability to determine the underwater volume of the boat while on water. Since the hull may either be in salt water or fresh water, the specific gravities of each differ. Salt water has a specific gravity of 64 lb/ft^3, while fresh water has a specific gravity of 62.4 lb/ft^3. Using the weights of both configurations we can see the underwater volumes are as follows:

Endurance		**Sprint**	
Saltwater	*Freshwater*	*Saltwater*	*Freshwater*
8.085 ft^3	8.293 ft^3	8.039 ft^3	8.245 ft^3

Table 5: Underwater Volumes

Using these underwater volumes, we can determine the drag that the hull of boat is subjected to over a 20-knot speed increase. Simulated values are figured using the submerged volumes in each case and logged using a script written for the interDyMFoam solver. This will give us the force that has to be overcome to move the boat through the water at a determined speed. The force required to move the hull and its components is factored into the simulation and graphed below as drag forces as speed increases.

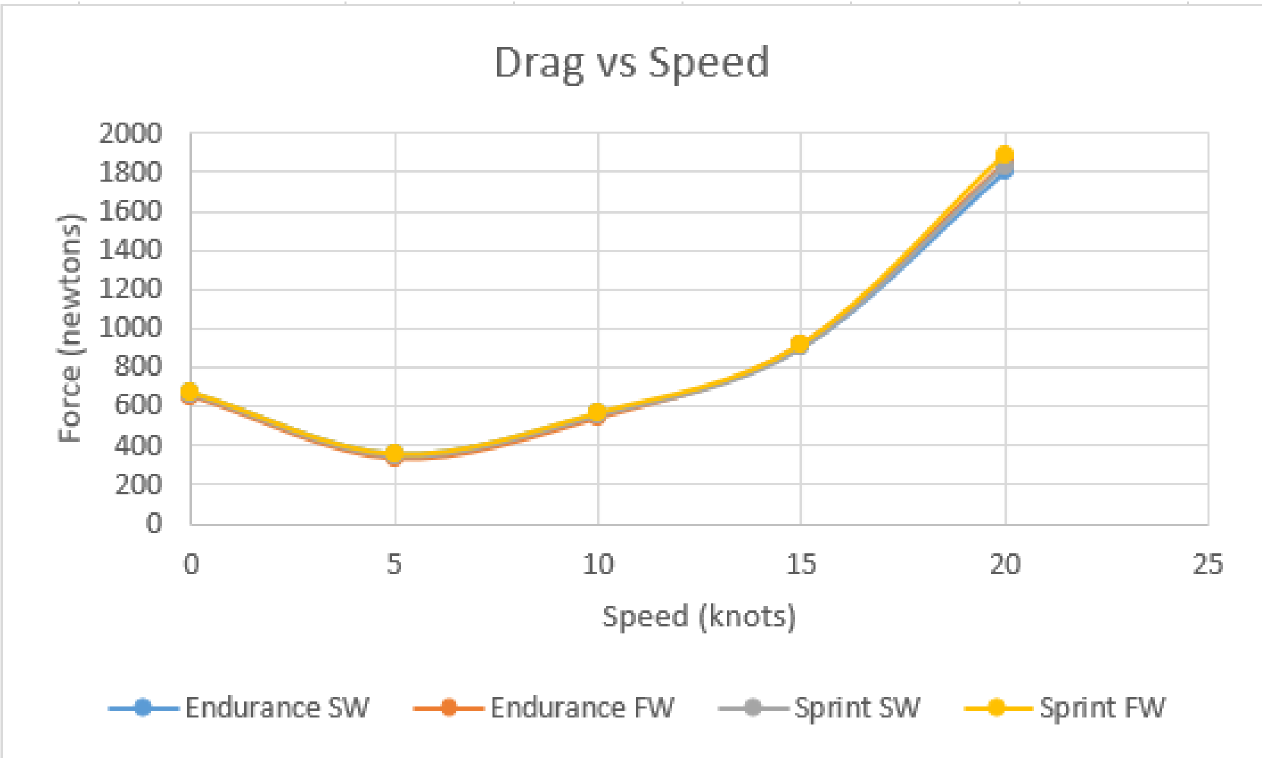
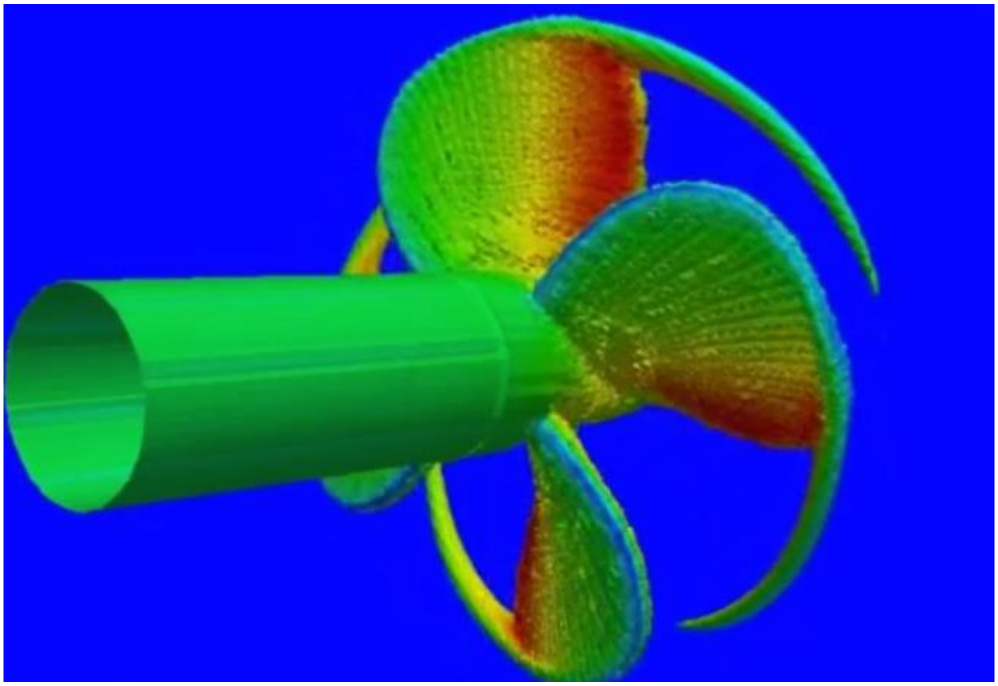


Figure 35: Drag vs Hull Speed

Based on the water-based drag on the hull, we can figure out the amount of power needed to move the craft through the water. Within the drag given for that given speed, the hull experiences a drag coefficient of 0.54. Continuing, the propeller thrust must be simulated and compared to the drag of the hull. An initial propeller mesh is visualized in OpenFOAM below. This, again, is a first revision as the software becomes more familiar. The final prop mesh shares the same appearance as figure 29. Several changes had been made to achieve this point. The fins themselves are modeled to cup and move water more accurately. The shaft the propeller extrudes from is also ½" smaller than the propeller's base diameter of 2.62". The nose cone is also much more efficient with navigating the low pressure slip stream that follows.



The mesh uses a series of complex shapes to create the 22-pitch propeller. The hub diameter is 2.62” and the overall diameter is 5.5”. The shaft pictured is not representative of the final shaft the propeller would use in a realistic scenario. The tails of the simulated propeller allow for a better visualization of how the propeller cuts through the water and the distance that each revolution represents.

Figure 36: First propeller mesh created in OpenFOAM with drag trails and high/low pressure

This first revision of the propeller mesh did not operate as intended and therefore was simplified to a finalized mesh that was used to begin testing on the cavitating and wetting nature of the propeller. The cavitating state of a propeller is important to analyze as this is the state the propeller will spend most of its time in while rotating. In this state, OpenFOAM makes the process of determining thrust easy. Drag trails on the trailing edges of the propeller’s fins give an indication of the distance that is traveled with in a singular rotation.

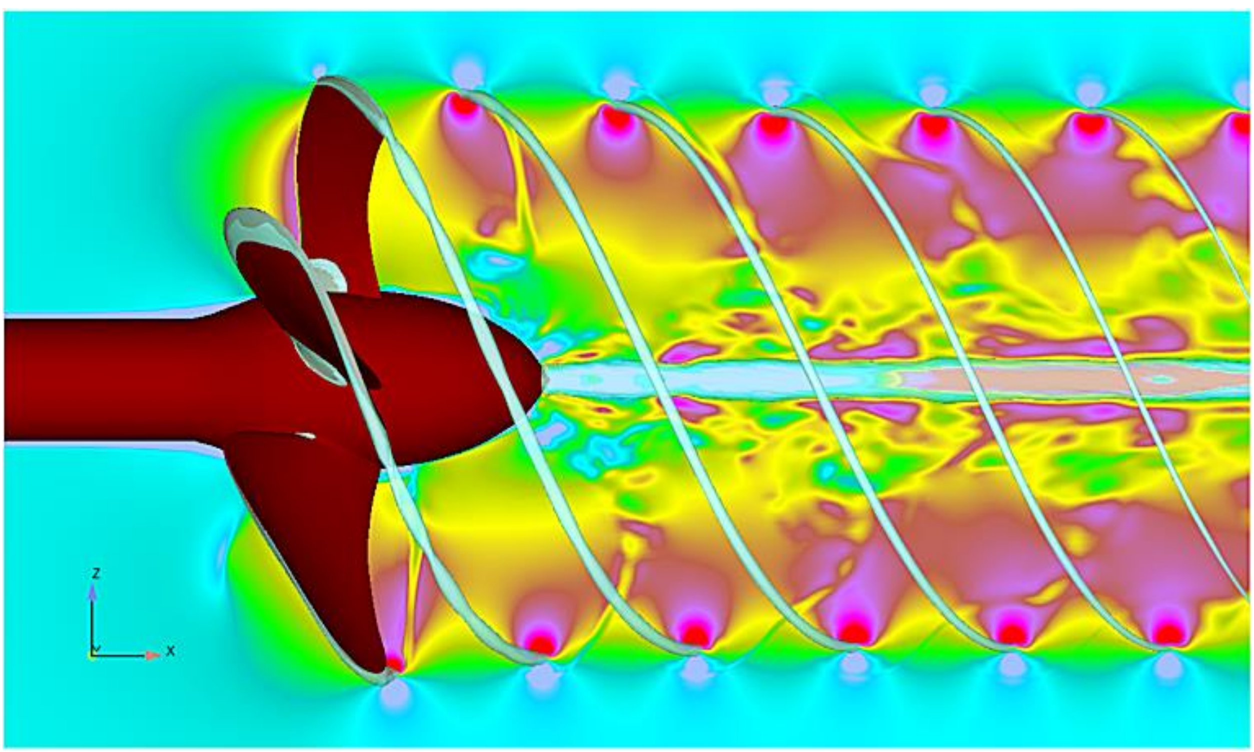


Figure 37: Cavitating state of 22-pitch propeller mesh

The red areas of the image are describing an area where higher pressure is found. The pressure is low around the tips of the fins and at the center of the prop cap. The wetting state is meant to describe the interaction between the propellers surface and the water. It identifies the low-pressure layer around the propeller. This is significant as it is an indication of how well the water will form to the propeller and allow the propeller to displace the watercraft.

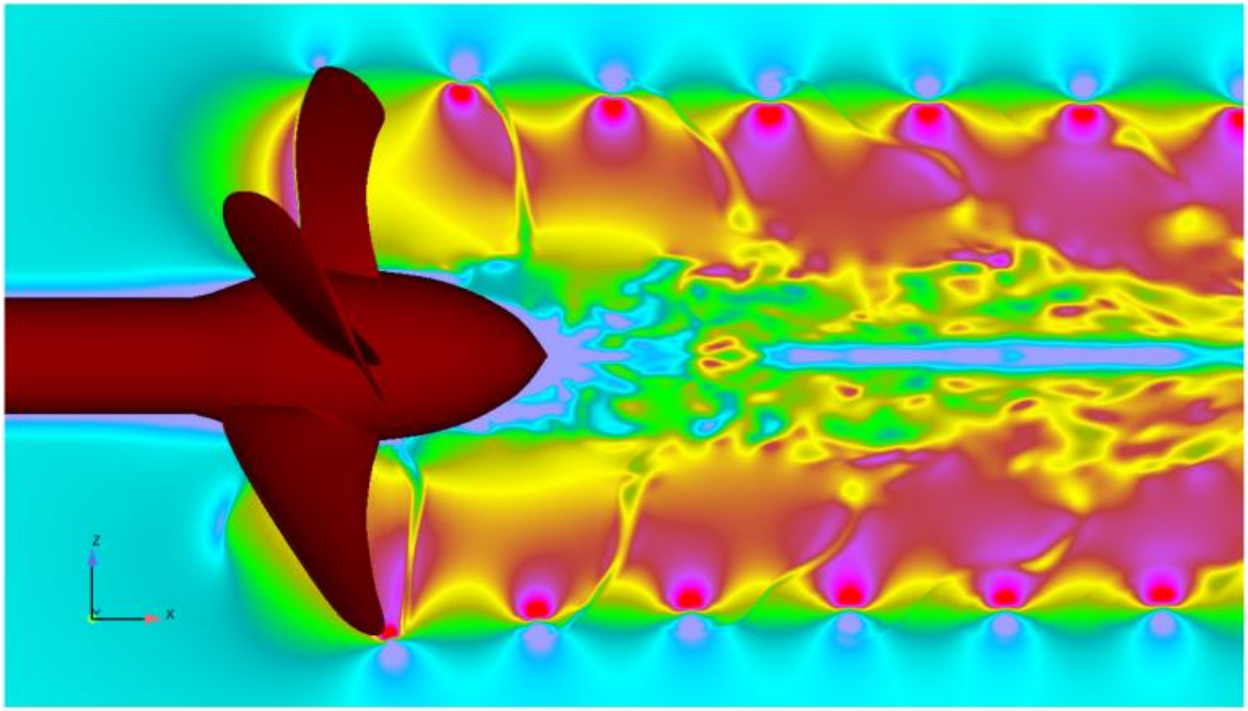


Figure 38: Wetting state of 22-pitch propeller mesh

The thrust of the propeller is gained by running a 15-second snippet of the propeller spinning through the power range of the motor. The output log from this simulation can be visualized as a graph here:

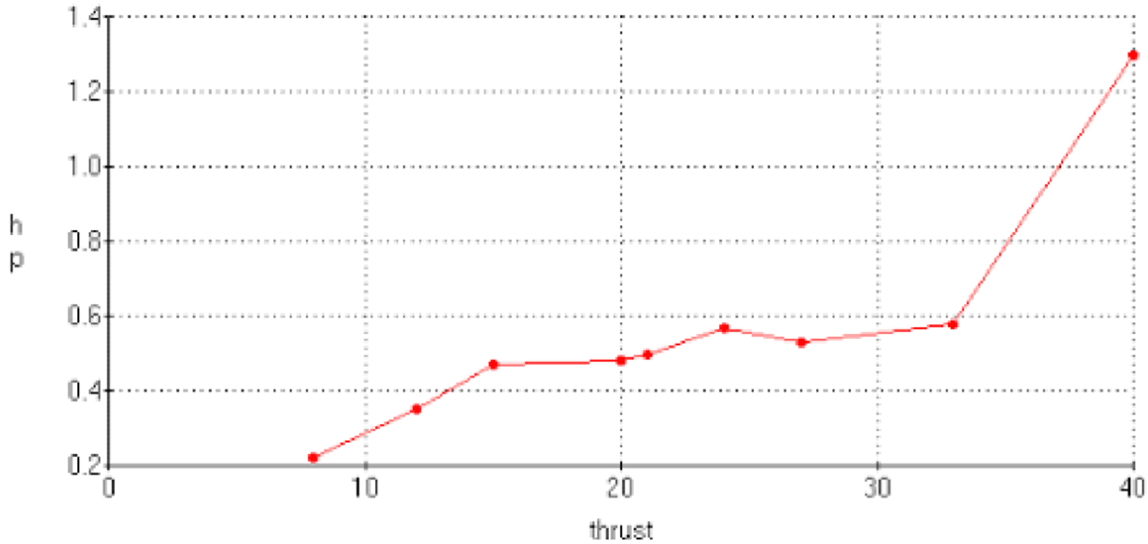


Figure 39: Thrust / Power ratio

The power of the motor is represented as horsepower in this display. The peak thrust of 44.5-pound feet of thrust is seen when the motor reaches a power of 955 watts. In the range of efficiency, the propeller creates a massive 35.2-pound feet of thrust. At this step it is becoming clear that the produced power from the motor is much less than the drag resistance that the hull is subjected to. To confirm, a 12 second simulation is created that takes the power of motor through its power range and accelerate the hull model.

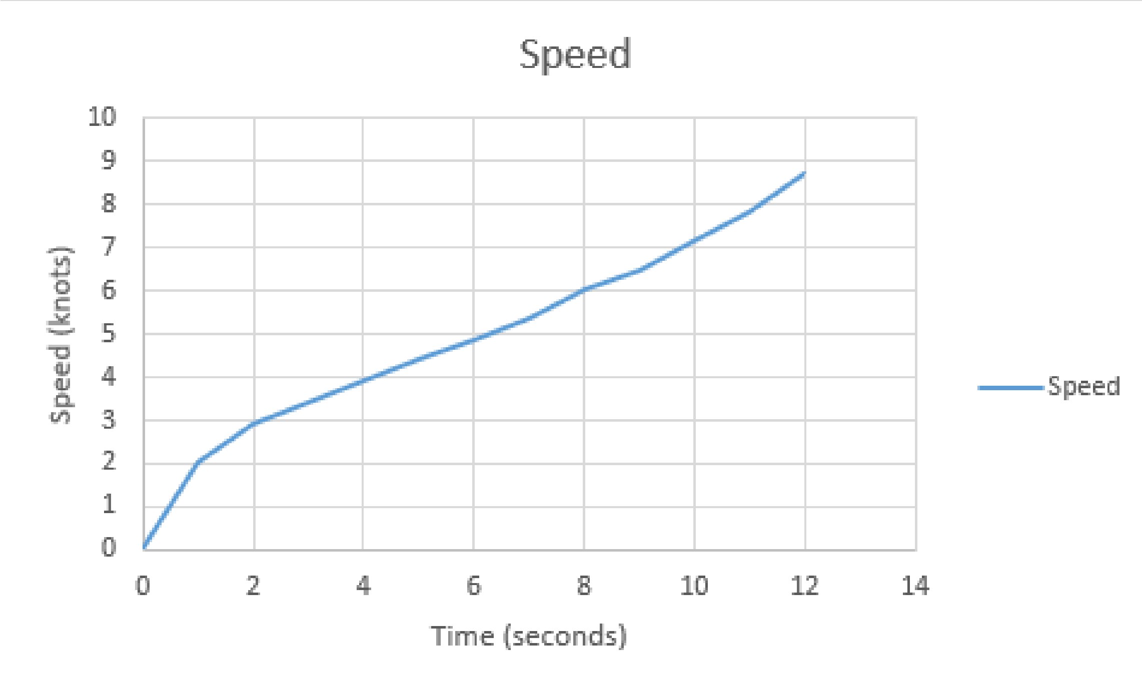


Figure 40: Speed/Time curve pulled from parsed simulation data (752 watts consumed)

The movement capabilities of the MY1020 motor are seen here in figure 32. Testing under normal circuit operating conditions, the craft reached a peak speed of 8.7 knots after a twelve second testing period. Testing further, an even greater top speed of 12.3 knots is reached after 20 seconds of runtime. The data speaks for itself and simply put, the motor and propeller combination chosen simply is not powerful enough to compete within the Solar Splash competition. When increasing the motors input power to the maximum 962 watts, the speed improves slightly over the same twelve second period as seen here:

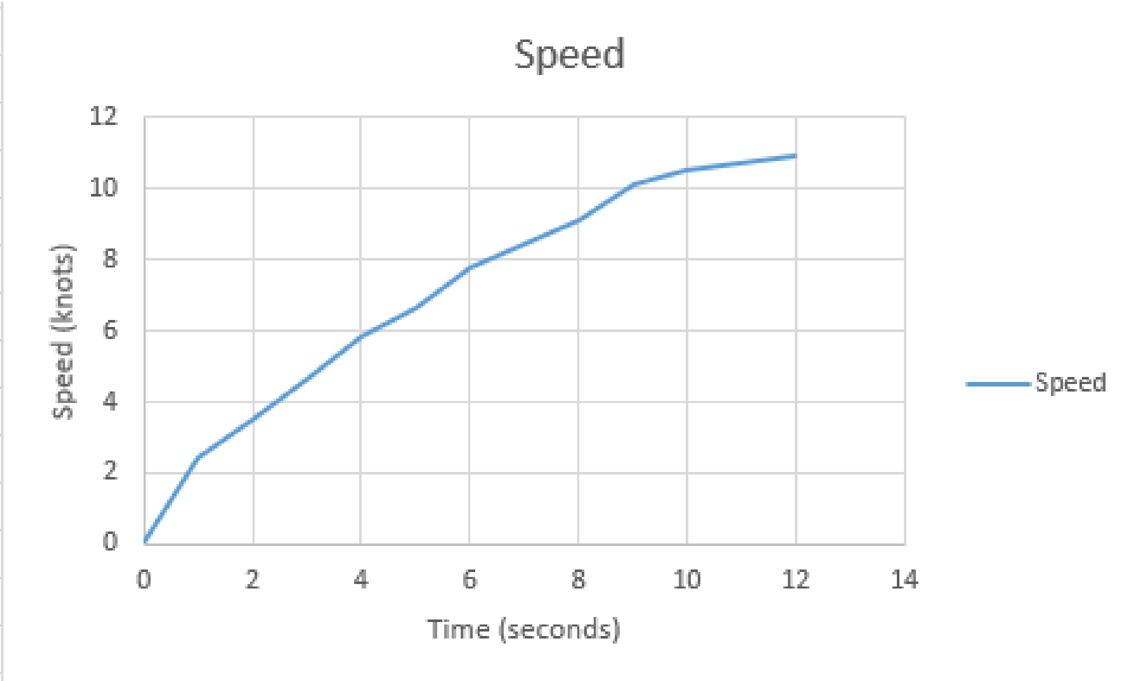


Figure 41: Speed/Time curve pulled from parsed simulation data (962 watts consumed)

As described by the second speed/time simulation, the improvement from an additional 200 watts of power is minimal. When compared with other competitors of the competition, the watercraft is still unable to accelerate to a rate that would be competitive in nature. Although this motor would be an excellent budget option, it does not have nearly enough power to be able to compete at this level.

A solid transition would be to go to an outboard motor that is dedicated for the purpose of marine watercraft. With the correct budget for the project, an adequate motor would be easy to source. A motor that is a viable option for the project would not come cheap. A couple options include those found in the commercial motor considerations in the high-level design portion of this report. An entry level Caroute N300 35-volt commercial outboard would be a remarkable improvement over the capabilities afforded by the MY1020. A solution like the N300 would produce over seven times the power that the MY1020 is capable of outputting. While this does not directly translate to seven times the ability to move the same hull, it does afford the watercraft power not found in the MY1020. Another alternative would be an offering from Elco. The EP-600 is quoted as being a six-horse capable motor. From the specification sheet the motor also provides four times the amount of thrust that the MY1020 does. A ray electric motor would be the pinnacle of electrical outboard motors. The 36-volt model is rated at 10 hp and the 48-volt model is almost double at 16 hp. With price tags of $5,865 and $5,935 respectively, it is evident that this type of performance is untouchable without a comma in the cost.

It is also important to realize that the teams that are competing in the event are using multiple thousand-dollar motors. For instance, the motors that the Steven's institute used to reach a sprint speed of 28 knots, the Elco 9.9, MSRP for $2,900.00. They were able to use two of them. Ultimately, there is no replacement for sheer power – and that power comes at a price.

Sensors Testing Methodology

Sensor testing methodology was presented in 5 different stages for each sensor we needed for our application. First one was battery testing circuit to test battery capacity and was tested in Multisim to get the voltage and current readings etc.

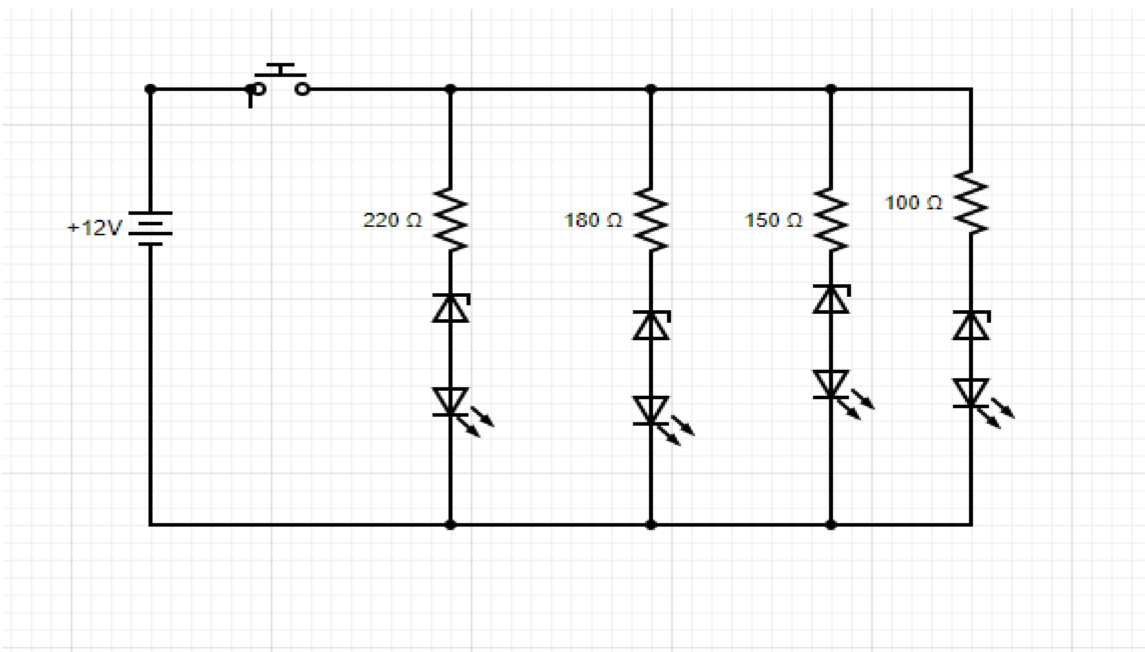


Figure 42: Battery indication wiring schematic

In details, the circuit is constant of battery source which would be our actual battery string from our application as every string in made of 12 volts. Also, the switch in the circuit is represented in the monitor box for the user interface is for the driver to check the battery capacity whenever the driver needs. Finally, four resisters to protect LEDs and four Zener diodes to allow current to flow in one direction to turn the specific LED coordinately.

Proteus was used to implement the speed sensor for the motor speed, temperature, light, and voltage sensors for the solar panel measurements and readings.

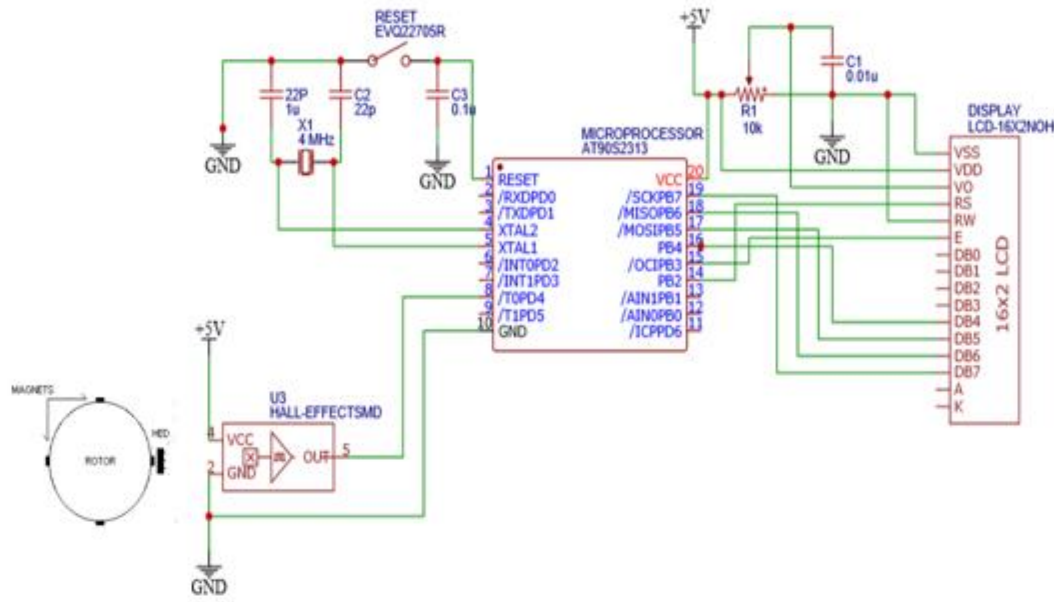


Figure 43: AT90S2313 Microcontroller used to detect motor speed

We can see that the hall affect sensor is mounted on the motor as a device to measure the magnitude of a magnetic field changes. For example, It will output a voltage that is directly proportional to the magnetic field changes through it. In other words whenever the motor shift full turn the magnetic field stretch an dchanges and that when the sensor will detect this change and record it then it will be sent from the microcontroller as alpha numric to the LCD display screen.

```
#include <LiquidCrystal.h>
int sensorPin = 2; //hall effect
int counter = 0;
int ledpin = 13;
float start, finished;
float elapsed, time;
float revs;
float revolution;
LiquidCrystal lcd(8, 9, 4, 5, 6, 7);
/*
* LCD RS pin to digital pin 8
* LCD Enable pin to digital pin 9
* LCD D4 pin to digital pin 4
* LCD D5 pin to digital pin 5
* LCD D6 pin to digital pin 6
* LCD D7 pin to digital pin 7
* LCD R/W pin to ground
* 10K resistor:
* ends to +5V and ground
* wiper to LCD VO pin (pin 3)
*/
void setup()
{
  //setup lcd
  lcd.begin(16, 2);
  lcd.print("Motor  SPEED");
  lcd.setCursor(9, 1);
  lcd.print(" RPM");

  // setup serial - diagnostics -
  Serial.begin(115200);
  // setup pins
  pinMode(sensorPin, INPUT);
  pinMode(ledpin, OUTPUT);
  // setup interript
  attachInterrupt(0, RPM, RISING);
  start=millis();

}

void RPM()
{
  int sensorValue = digitalRead(sensorPin);
  //lcd.clear();
  elapsed=millis()-start;
  start=millis();
  float revs = 60000/elapsed;
  float revolution = elapsed/1000;
  Serial.print(elapsed);
  Serial.print(" mS ");
  Serial.print(revolution);
  Serial.print(" SEC ");
  Serial.print(revs);
  Serial.print(" RPM ");
  Serial.print(millis() );
  Serial.print(" ");
  Serial.println(start);
  lcd.setCursor(3, 1);
  if (elapsed < 1200) {lcd.print(revs,0);}
    else {lcd.print(" 0     ");}
  /*
  if (sensorValue == 0) && ( >= 1000) {lcd.print("0");}
  else {lcd.print(revs);}
  */

}

void loop()
{
elapsed=millis()-start;

  //counter++;
  int sensorValue = digitalRead(sensorPin);
  //Serial.print(counter);
  //Serial.print(" ");
  //Serial.println(sensorValue);
  //delay(1000);

  if (sensorValue == 0) {digitalWrite (ledpin, HIGH);}
  else {digitalWrite(ledpin, LOW);  }
  //lcd.setCursor(3, 1);
  if (elapsed > 1200) {revs == 0;}

}
```

Figure 44: Code used to detect motor speed using AT90S2313

Nevertheless, another portion of the system is Voltage, temperature and light sensors. Starting off with the voltage sensor to measure voltage of solar panel using voltage divider. Two capacitors were used in parallel as seen below to avoid voltage fluctuation and avoid harmonics to go into ADC of PIC microcontroller. Based on the voltage sensor formula used here, for solar panel of 12 volt values of voltage divider resistors are based on the maximum input voltage to Analog to digital converter channels as they can never be more than 5 volts.

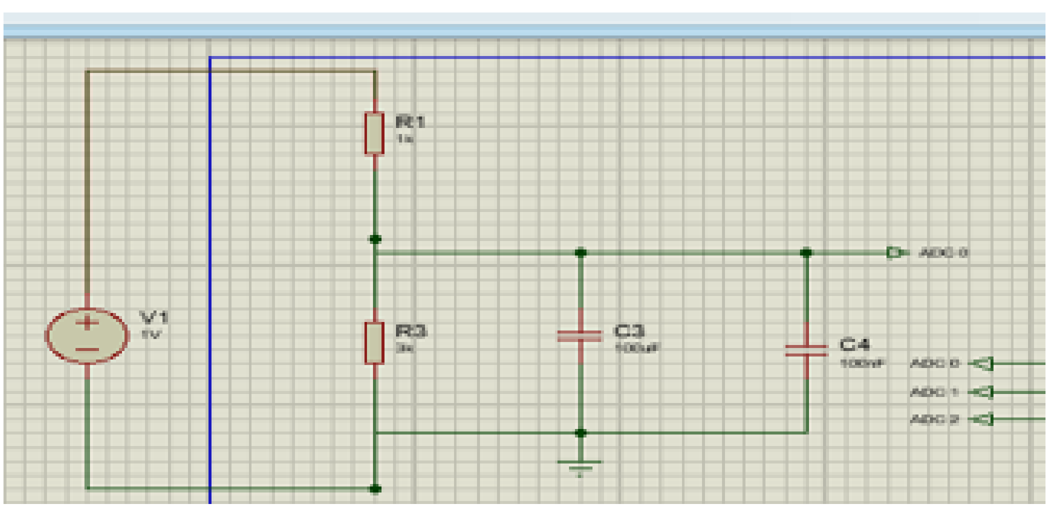


Figure 45: Voltage sensor schematic

Also, I calculated these resistor values according to increase the accuracy of our measurement and to insure protection of ADC in case of greater voltage fluctuation. Lastly, DC voltage source is used instead of solar panel in Proteus just for simulation purpose since solar panel simulation is not available in Proteus software.

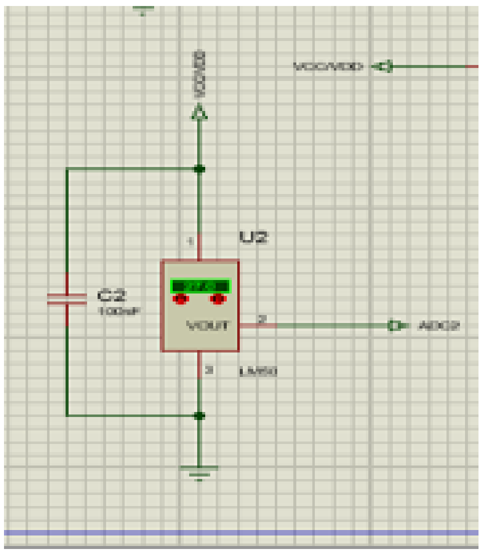


Figure 46: Temperature sensor schematic

For the tempreture sensor The LM35 is used in simulation for many reasons including the fact that it is a inexpensive but precise temperature sensor range to measure temperature lies between -50 to 150 Celsius. It operates from 4 V to 30 V and consume less than 60-µA Current and Only 5 volt power supply is required for LM35 and there is no need of extra circuitry to operate it. PIC16F877A microcontroller is used to read temperature value. 16X2 LCD is used to display temperature value on LCD.

LM35 temperature sensor converts temperature into its proportional analog voltage value. LM35 is three terminal device.Pin number one and three are for 5-volt voltage supply. Pin two is analog voltage output with respect to temperature value.Relation between measured temperature and analog output voltage is:

1oC = 10m volt

meaning for every 1 degree increase in temperature there will be a increment of 10m volt in output voltage of LM35 sensor. PIC16F877A microcontroller is used to measure analog voltage value. All these conversion has been done through programming. LCD is connected to PORTB of PIC16F877A microcontroller.

```
sbit LCD_D7 at RB2_bit;
sbit LCD_D6 at RB3_bit;
sbit LCD_D5 at RB4_bit;
sbit LCD_D4 at RB5_bit;
sbit LCD_EN at RB6_bit;
sbit LCD_RS at RB7_bit;

sbit LCD_D7_Direction at TRISB2_bit;
sbit LCD_D6_Direction at TRISB3_bit;
sbit LCD_D5_Direction at TRISB4_bit;
sbit LCD_D4_Direction at TRISB5_bit;
sbit LCD_EN_Direction at TRISB6_bit;
sbit LCD_RS_Direction at TRISB7_bit;
//*********************temperature variables***************
int temp;
char temper[7];
//*************************************************************

void READ_temp(void)
{
temp = ADC_Read(0);
temp = temp *
5/1023;
        temp = temp * 100;


}
void data_converstion(void)
{

inttostr(temp,temper);
}
void display1(void)
{
lcd_out(1,1,"TEMPERATURE=");
lcd_out(1,13, Ltrim(temper));
Lcd_Chr_Cp(0xdf);
Lcd_Chr_Cp('C');
Lcd_Chr_Cp(' ');


}
void main()
{
ADC_Init();
Lcd_Init(); // Initialize LCD
Lcd_Cmd(_LCD_CLEAR); // Clear display
lcd_cmd(_LCD_CURSOR_OFF);
lcd_out(1,4,"DIGITAL TEMPERATURE");
lcd_out(2,6,"SENSOR");
delay_ms(1000);
Lcd_Cmd(_LCD_CLEAR); // Clear display

while(1)
{

READ_temp();
data_converstion();
display1();
}
}
```

Figure 47: Code to detect the temperature using the PIC

Final portion of the sensor system is the light dependent resistor that is used to measured intensity of light. LDR is a light controlled variable resistor. The resistance of LDR changes based on the changes in intensity of the light. For example, greater the intensity of light, lower will be the resistance and lower the intensity of light, greater will be the resistance. Change in resistance can be easily measured by converting it into voltage form as shown in circuit diagram below.

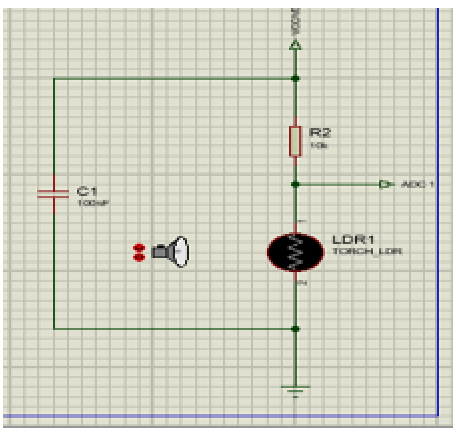


Figure 48: Light Intensity Sensor

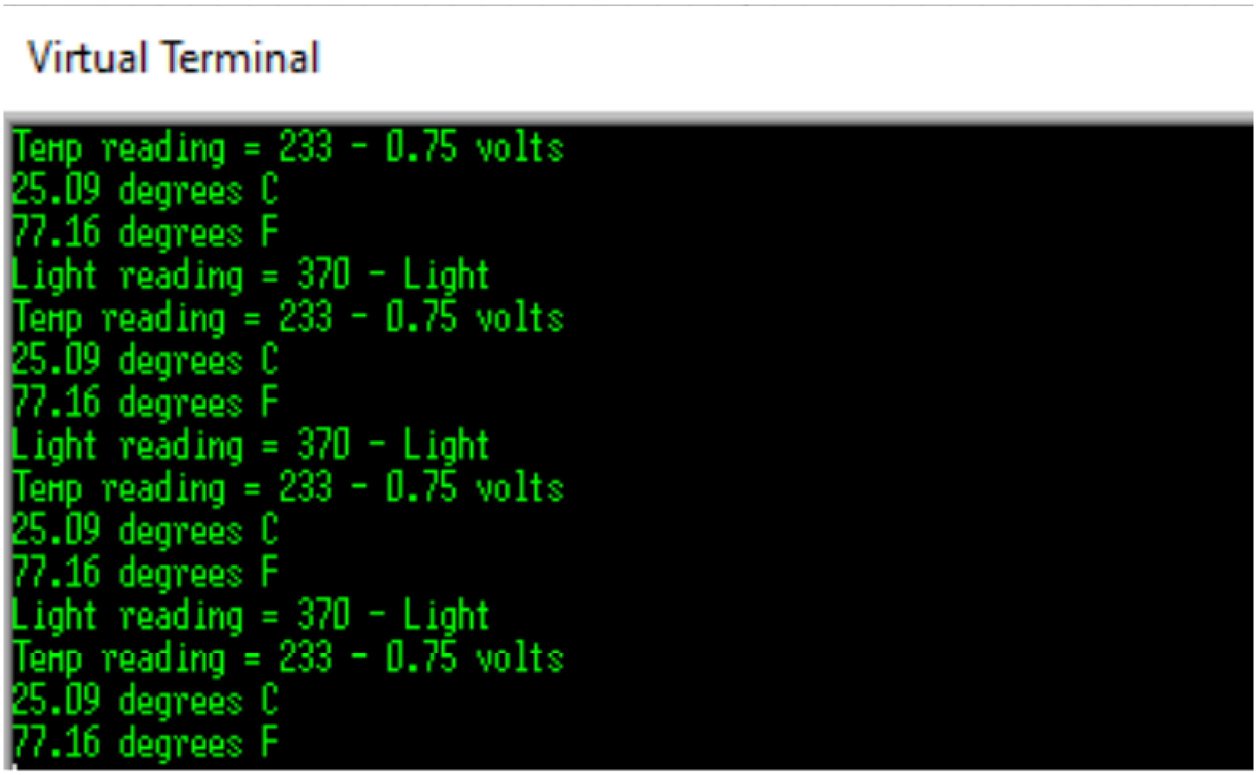


Figure 49: Virtual readout for information the skipper would receive

CONCLUSIONS

Over the course of the Solar Splash senior design project it has shifted directions many times. The path to this point has not always been straight and challenges were encountered along the way. As the simulation revision of the project began, the mindset of "will it work" became the primary focus. Instead of throwing funding at a project that was doomed to begin with, the plan was to prove and disprove the working and non-working aspects of the project. The project in its current state has several items that need corrected but also has an abundance of great building blocks to correct those items.

The proposed ideas and design concepts offer a slew of competitive advantages that will allow for solid performance. The designs also have been tested and found to fall short in areas. With a lightweight marine analyzed hull, the project has the potential to succeed given the appropriate funding and resources that a project of this nature requires. The designs of the project clearly contain some level of weakness to be improved upon. Being a system entirely devised from thin air in a matter of months, there is certainly a considerable amount of additional troubleshooting required to have a bulletproof implementation.

The accomplishments made in the short lifespan of the project have been impressive. The improvements and advancements seen throughout the project have been inspiring even at the lowest points. The shift toward a simulated scope was far from exciting but the principles, new techniques and software used have all been enlightening. Every stage of the process has been uncomfortable and tense, but the skills and learned qualities have been invaluable. The team has learned many different engineering related skills and although no hands-on work was involved, a higher aptitude for electrical analysis, mechanical knowledge, marine principles, budgeting, projecting planning, and electrical systems design will suffice. The project has also been an eye opener to the importance of accountability and appropriate project planning. The importance of realistic but ambitious goals is apparent, especially with the circumstances that affected the project throughout. The idea of creating an entire watercraft as well as the electrical system that powers it was an ambitious endeavor, but from a realistic standpoint was never an ideal situation for a team of three.

Solar Power System

In conclusion, this system is successful in providing sufficient power output to the motor in order for the motor to operate at maximum efficiency. This power system will also provide adequate power output to motors ranging up to 1.5kW output at 36VDC operating voltage. It will power most motors of this power at full load for up to 15 minutes which would satisfy the sprint and shalom race categories. It will work for the endurance portion but will require charging during the race.

The batteries are very light weight and small in dimensional size which will meet the restrictions of under 100lbs of battery weight and still be small enough to fit inside the boat. These batteries will also be able to efficiently provide adequate power to the motor.

The solar panels are also very efficient due to their size and weight in comparison to their power output of 160W each. Giving a total of 480W, which is the maximum power output the competition will allow from the solar panels. The MPPTs are perfect for this configuration. They are waterproof, which is perfect for a boat competition. Since solar irradiance of the day is unknown, they are also a perfect fit being able to provide the specified charging voltage for the batteries.

RECOMMENDATIONS & ASSESSMENTS

Motor System

At this point it has been determined that the motor used in this simulation is not quite powerful enough to accelerate our watercraft to a competitive speed. There are a handful of other more powerful motors that would be able to fill the role:

Motor Replacement Suggestions			
Characteristic	*Caroute N300*	*Elco 9.9*	*Ray Electric 300*
Rated HP	7 HP	9.9 HP	10 HP
Voltage	36 volts	48 volts	36 volts
Motor Weight	55 pounds	65 pounds	75 pounds
Amperage	60 amps	90 amps	65 amps
Static Thrust	150 pounds	130 pounds	150 pounds
Efficiency	>65 percent	>90 percent	>85 percent
Input Power	2160 watts	4320 watts	2340 watts
MSRP	$1250.00	$2900.00	$5865.00

There are a handful of alternative motors that would be acceptable candidates for this project. The N300 is an appealing cheaper range option that produces seven times the power that the MY1020 does albeit at a lower efficiency. The motor manufacturer lists that the motor produces a peak of 150 pounds of thrust, nearly 3 ½ times the amount of thrust as the MY1020. However, the upfront cost of the motor is ten times that of the original chosen motor. The next two suggested motors are both used in boats that have been entered into the competition previously. The Elco 9.9 is a 48-volt motor with an excellent reputation for being reliable and powerful. The motor produces 130 pounds of thrust at an efficiency greater than 90 percent. It is a thirstier motor reaching a peak input power of 4320 watts. It is however a more efficient motor than most other electric outboards on the market. The manufacturer suggested MSRP is $2900, twenty-four times more expensive than a MY1020. The third suggested motor also has an appealing list of specs. It produces as much mechanical power as the Elco 9.9 in a 36-volt package. It draws less current and as a result sees a lesser input power – a great thing for a dieting watercraft. The motors peak input power is reported as 2340 watts. The biggest downfall of the product is the price tag that is nearly two times more than the Elco at $5865.00.

As previously stated, there are plenty of appealing alternatives to the selected motor. A higher performing motor is going to cost more than the budget friendly option simulated in this report. There are three factors when selecting a motor in a system like this: Cost, Performance and Reliability. Unfortunately, one two of these three factors can be true at any given time.

Solar Power System

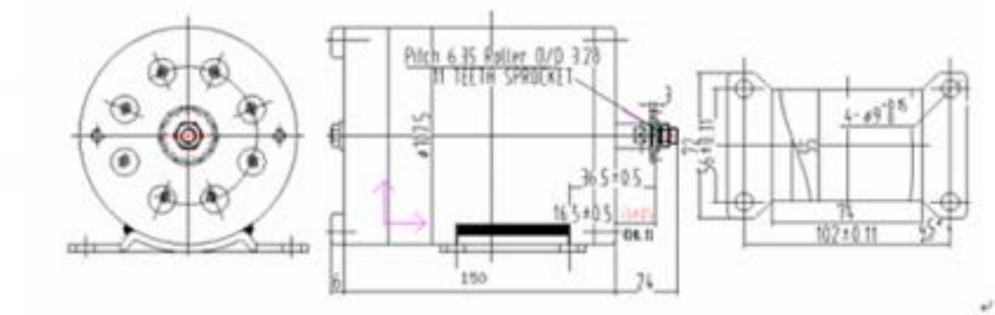
Recommendations from the power system is to try and keep this configuration. It is an expensive configuration, but it is also very versatile and efficient. This system will provide you with the power needed to compete at a very high level. If needed, the type and size of the solar panels can be changed, but please note, if you go over the 480W restriction, you will need to cover up the cells to meet their specifications. Also, higher power output panels will most likely be much heavier which will require more reinforcing on the boat during the shalom and endurance race. The panels are allowed to be taken off during the sprint race so that is insignificant.

NOTES

APPENDIXES

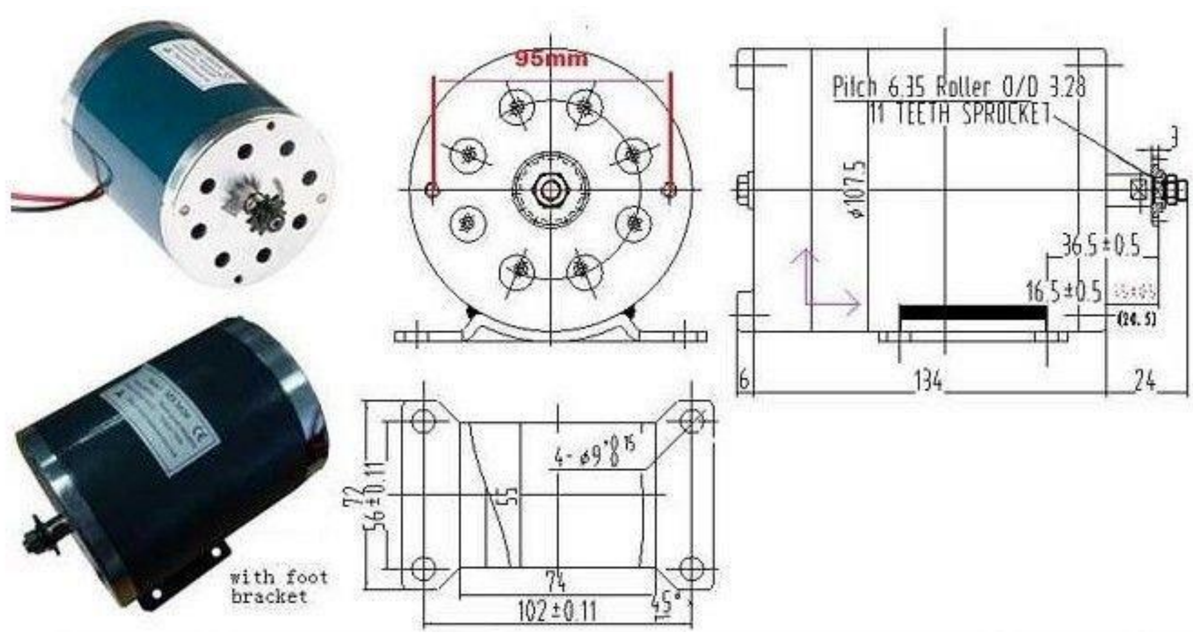
Appendix A: MY1020 Motor Datasheet

2, DIMENSIONS

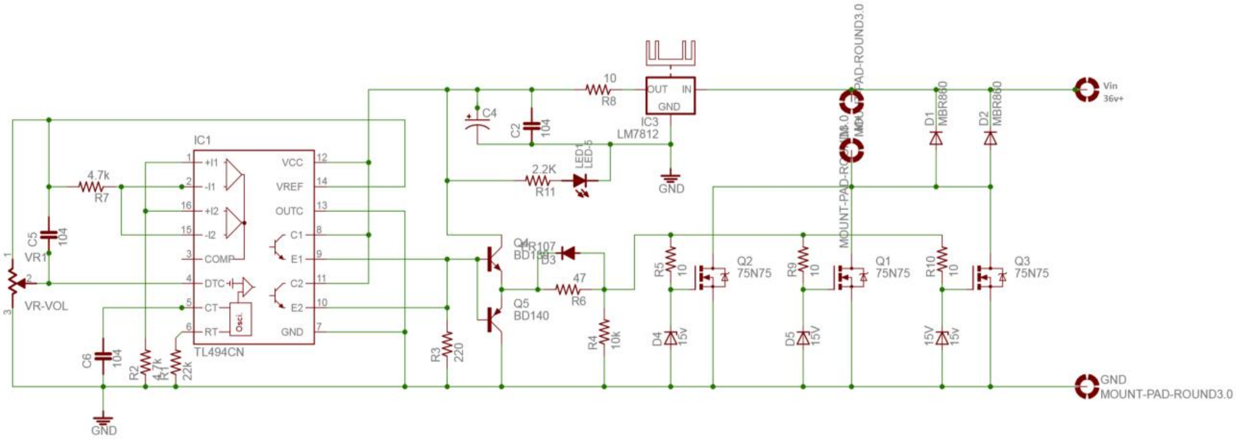


3,SPECIFICATION

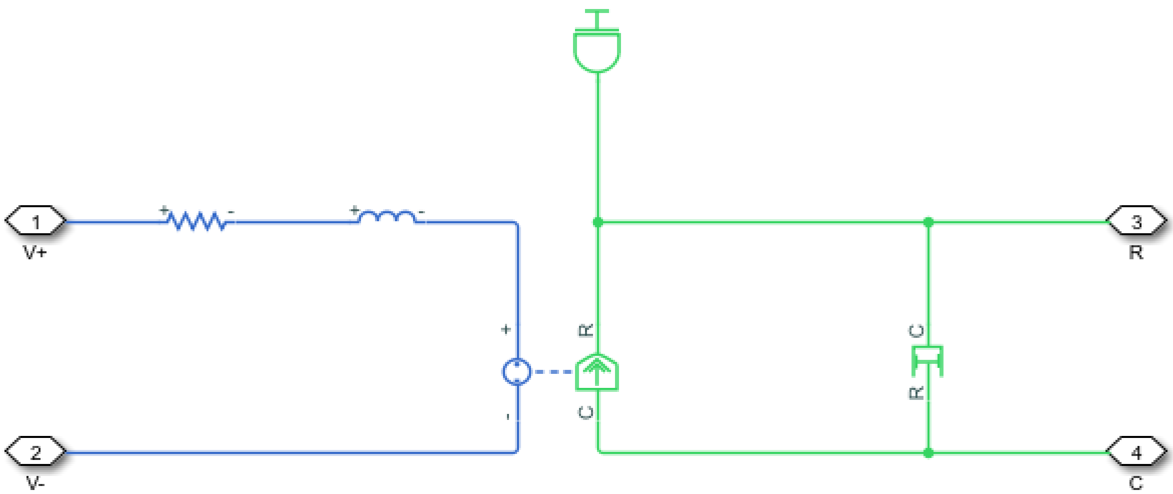
Series/Model		No load			With Load					TYPICAL APPLICATION	TRANSMISION
		Volt	Current	Rotate Speed	Torque	Speed	Out Put Power	Current	Efficiency		
		V	(A)	(rpm)	N.m	(rpm)	(W)	(A)	(%)		
1020	1000W36V	36	1.2~2.5	3700±5%	3.2	3000±5%	1000	≤35.6	η≥78	TRICYCLE	CHAIN SPROCKET
1020	1000W48V	48	1.2~2.5	3700±5%	3.2	3000±5%	1000	≤26.7	η≥78	TRICYCLE	CHAIN SPROCKET

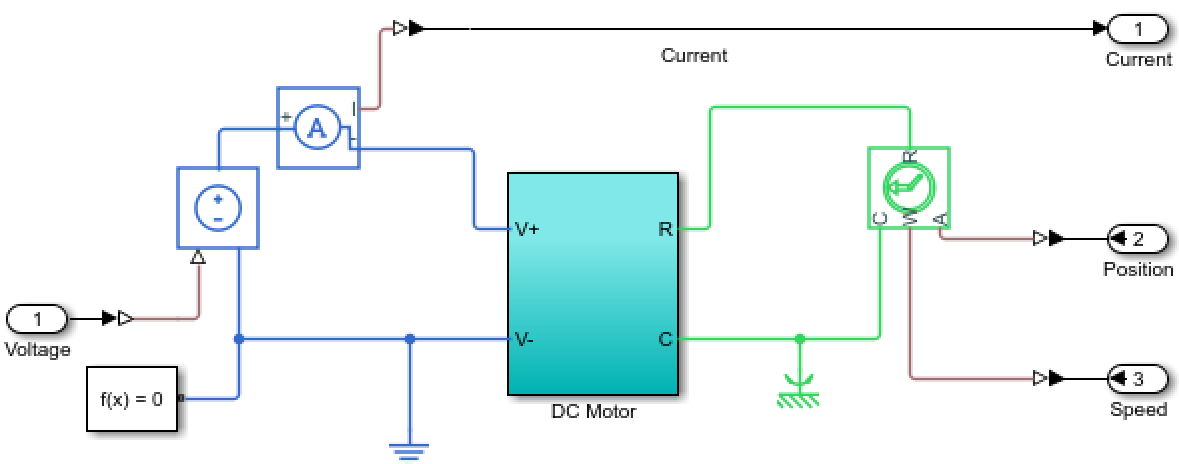


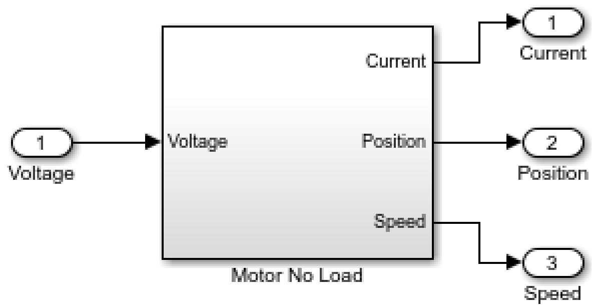
Appendix B: Motor Controller Schematic

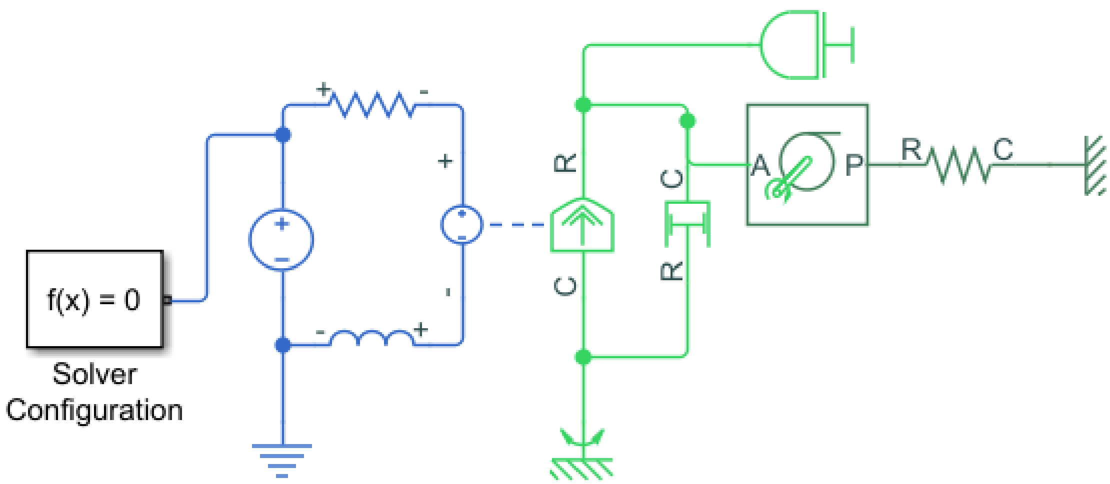


Appendix C: Motor Testing circuitry






Current
Voltage
Position
Speed
Motor No Load
1
Current
2
Position
3
Speed
1
Voltage


f(x) = 0
Solver
Configuration
R
C
A
P

Appendix D: Solar Panel Spec Sheet

RENOGY

RNG-160D-SS

160W Monocrystalline Solar Panel

Key Features

Sleek desgn and a durable frame, the Renogy 160 Watt 12 Volt Monocrystalline Panel provides you with the highest efficiency per area and is the perfect item for off-grid applications.

- High module conversion efficiency
- Top ranked PTC rating
- Quick and inexpensive mounting
- 100% EL testing on all Renogy modules
- No hot spots guaranteed

Potential Uses

The Renogy 160 Watt Monocrystalline Panel can be used in various off-grid applications that include 12 and 24 volts arrays, water pumping systems, signaling systems and other off-grid applications.

25 Years Power Output Warranty

5 Years Material and Workmanship Warranty

Renogy | www.renogy.com | customerservice@renogy.com | 909-287-7111
2775 E. Philadelphia St, Ontario, CA 91761

RNG-160D-SS

160W Monocrystalline Solar Panel

Electrical Data

Maximum Power at STC*	160 W
Optimum Operating Voltage (V_{mp})	20.2 V
Optimum Operating Current (I_{mp})	7.92 A
Open Circuit Voltage (V_{oc})	22.9 V
Short Circuit Current (I_{sc})	8.37 A
Cell Efficiency	21.0%
Maximum System Voltage	600 VDC UL
Maximum Series Fuse Rating	15 A

Mechanical Data

Solar Cell Type	Monocrystalline (6.10 x 6.10in)
Number of Cells	32 (4 x 8)
Dimensions	51.3 x 25.9 x 1.38 in (1304 x 657 x 35 mm)
Weight	22.1 lbs (10 kg)
Front Glass	Tempered Glass 0.13 in (3.2 mm)
Frame	Anodized Aluminium Alloy
Connectors	MC4 Connectors
Fire Rating	Class C

Thermal Characteristics

Operating Module Temperature	-40ºC to +80ºC
Nominal Operating Cell Temerature (NOCT)	47±2ºC
Temperature Coefficient of Pmax	-0.42%/ºC
Temperature Coefficient of Voc	-0.31%/ºC
Temperature Coefficient of Isc	0.05%/ºC

MC4 Connectors

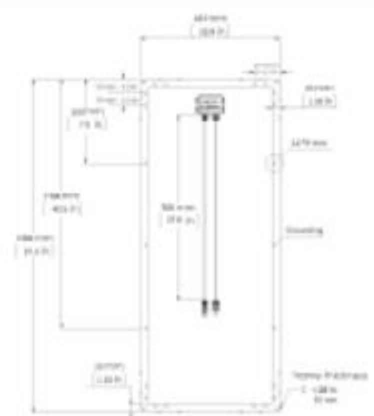
Rated Current	30A
Maximum Voltage	1000VDC
Maximum AWG Size Range	10 AWG
Temperature Range	-40ºF to 194ºF
IP Rating	IP 67

Junction Box

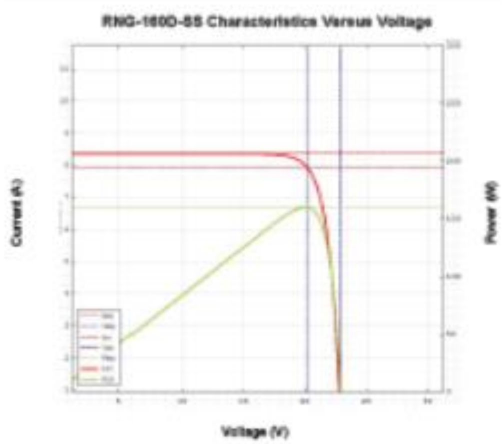
IP Rating	IP 65
Diode Type	HY 10SQ050
Number of Diodes	2 Diode(s)
Output Cables	12 AWG (2.30 ft long)

Certifications

Module Diagram



IV-Curve



*All specifications and data described in this data sheet are tested under Standard Test Conditions (STC - Irradiance: 1000W/m², Temperature: 25°C, Air Mass: 1.5) and may deviate marginally from actual values. Renogy and any of its affiliates has reserved the right to make any modifications to the information on this data sheet without notice. It is our goal to supply our customers with the most recent information regarding our products. These data sheets can be found in the downloads section of our website, www.renogy.com

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Appendix E: Battery Spec Sheet

genesis™ EP

PURELEAD

RANGE SUMMARY

The Genesis EP thin plate pure lead battery excels in demanding environmental and cycling applications such as:

- Electronics
- Medical Equipment
- Telecommunications
- Lawn & Garden Equipment
- Computer Backup
- UPS

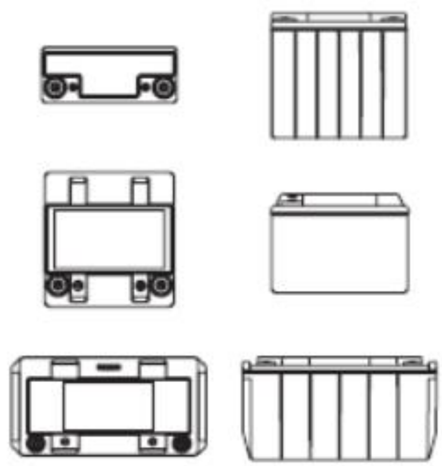
Specifications

Battery Design

- 12V pure lead-tin VRLA AGM battery
- UL 94V0 flame retardant case and cover optional
- M6 female no-maintenance terminals
- Can be installed in any orientation except inverted
- Rugged construction (optional metal jacket)
- Approved for shipping as non-hazardous, nonspillable

Performance Features

- -40°C to 80°C (-40°F to 176°F) with metal jacket
- 300+ full depth of discharge cycles
- High rate charge and discharge
- 2 year shelf life at 25°C (77°F)
- Superior deep discharge recovery
- UL listing - file No. MH12544



EnerSys™

Power/Full Solutions

Publication No: US-EP-RS-001 April 2006

General Specifications

Type	Nominal Voltage (V)	Nominal Capacity (Ah) 10hr rate to 1.67Vpc @ 25°C/77°F	Nominal Dimensions Length mm	Length in	Width mm	Width in	Height mm	Height in	Overall Weight kg	Overall Weight lbs	Torque in-lbs	Torque Nm	Internal Resistance (mΩ)	Typical Short Circuit Current (A)
G13EP	12	13	175.5	6.91	83.3	3.28	129.8	5.11	4.9	10.8	50	5.6	8.5	1400
G16EP	12	16	181.6	7.15	76.2	3.00	167.9	6.61	6.1	13.5	50	5.6	7.5	1600
G26EP	12	26	166.9	6.57	175.8	6.92	126.0	4.96	10.1	22.3	60	6.8	5.0	2400
G42EP	12	42	197.4	7.77	165.9	6.53	170.7	6.72	14.9	32.9	60	6.8	4.5	2600
G70EP	12	71	330.7	13.02	168.1	6.62	176.0	6.93	24.3	53.5	60	6.8	3.5	3500

Constant Current Discharge Performance

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

Battery	Minutes 5	Minutes 10	Minutes 15	Minutes 30	Hours 1	Hours 5	Hours 8	Hours 10	Hours 20
G13EP	70.8	43.6	32.2	18.6	10.4	2.5	1.6	1.3	0.7
G16EP	90.0	54.8	40.1	23.0	12.7	3.0	2.0	1.6	0.8
G26EP	143.4	90.7	67.4	39.0	21.7	5.0	3.2	2.6	1.4
G42EP	212.0	138.4	104.1	60.8	33.8	7.9	5.1	4.2	2.3
G70EP	342.4	228.5	173.4	102.5	57.4	13.4	8.7	7.1	3.9

Constant Power Discharge Performance

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

Battery	Minutes 5	Minutes 10	Minutes 15	Minutes 30	Hours 1	Hours 5	Hours 8	Hours 10	Hours 20
G13EP	758.4	481.8	361.2	231.6	121.2	28.4	19.2	15.6	8.4
G16EP	975.6	609.6	453.6	264.6	190.2	36.0	23.4	19.2	10.2
G26EP	1532.0	995.0	751.0	444.0	251.0	59.0	38.0	31.0	16.0
G42EP	2291.0	1540.0	1173.0	698.0	394.0	94.0	62.0	51.0	28.0
G70EP	3680.0	2519.0	1940.0	1173.0	678.0	161.0	105.0	86.0	47.0

Charge Voltage

Cyclic use: 14.7V to 15.0V at 25°C (77°F) No current limit

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

ISO 9000

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Appendix F: MPPT Spec Sheet

Specifications:

	GVB-8-WP, All Models
Rated Panel (Input) Current:	8A*
Minimum Panel Voltage for Charging:	5V
Minimum Battery Voltage for Operation:	9.5V
Maximum Input Panel:	60V
Recommended Max Panel Voc at STC:	50V
Input Voltage Range:	0-60V
Maximum Input Short Circuit Current**:	8A*
Maximum Input Current***:	15A
Tracking Efficiency:	99+% typical
MPPT Tracking Speed:	15Hz
Operating Temperature:	-40°C – 85°C
Maximum Full Power Ambient:	70°C
Enviromental Protection:	IP68, Waterproof
Connection:	Flying Leads, 16 AWG tinned wire, pre-stripped
Weight:	10.3oz (290g)
Dimensions:	5.5x3.2x2.2", (14x8.1x5.5cm)
Warranty:	5 years

	GVB-8-Pb-12V-WP	GVB-8-Pb-24V-WP	GVB-8-Pb-36V-WP	GVB-8-Pb-48V-WP
Charge Profile:	Multi-Stage with Temperature Compensation			
Nominal Battery Voltage:	12V	24V	36V	48V
Maximum Recommended Panel Vmp:	13V	26V	41V	43V
Maximum Recommended Panel Power (8A Panel w/-156mm cells):	105W	210W	325W	350W
Bulk Voltage:	14.4V	28.8V	43.2V	57.6V
Absorption Voltage:	14.2V	28.4V	42.6V	56.8V
Absorption Time:	2 Hours			
Float Voltage (Pb models) or CV Voltage (Li models):	13.8V	27.6V	41.4V	55.2V
Battery Temperature Compensation:	-28mV/°C	-56mV/°C	-84mV/°C	-112mV/°C
Electrical Efficiency:	95% - 97% typical	96% - 98% typical	96% - 98% typical	96% - 99% typical
Night Consumption:	7mA	6mA	6mA	5mA

	GVB-8-Li-14.2V-WP	GVB-8-Li-28.4V-WP	GVB-8-Li-41.7V-WP	GVB-8-Li-54.2V-WP	GVB-8-Li-56.8V-WP
Battery type:	4S LiFePO4	8S LiFePO4	10S Li-ion	13S Li-ion	16S LiFePO4
Charge Profile:	CC/CV				
CV Voltage:	14.2V	28.4V	41.7V	54.2V	56.8V
Battery Temperature Compensation:	Disabled				
Maximum Recommended Panel Vmp:	13V	26V	39V	43V	43V
Maximum Recommended Panel Power:	105W	210W	325W	350W	350W
Electrical Efficiency:	95% - 97% typical	96% - 98% typical	96% - 98% typical	96% - 99% typical	96% - 99% typical
Night Consumption:	7mA	6mA	6mA	5mA	5mA

*Panel ratings have increased since we designed the GVB. Although we don't believe in changing specifications without a corresponding engineering change, based on both our customers' experiences over the years as well as the headroom we designed into the GVB, we feel comfortable recommending the GVB for panels with Imp up to 9A.
**Panel Isc. Maximum input power and maximum input voltage requirements must also be respected.
***Maximum current that the controller could draw from an unlimited source. This specification is not intended for determining PV input.

Certifications:

REFERENCES

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