FAMU-FSU College of Engineering
Sustainable Engineered Solutions

Solar Car Design:

# Final Report

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# Executive Summary

The FAMU-FSU College of Engineering has tasked this team of engineers with the challenge of building the FAMU-FSU Solar Car. The overall goal of this year's team is to design and develop a 2 year plan to achieve a Solar Car ready for the Shell Eco-Marathon America (SEMA) in spring of 2014. The new design is a very light weight, three wheeled, one man automobile that is capable of utilizing renewable energy to produce an energy efficient vehicle. The vehicle will be designed under the guidelines of the Solar-Battery Electric Prototype division.

During this year, it is not possible to design, test and build the solar car to meet all the specifications of the Shell competition. This year's electrical engineers will focus on the simulation and design of the energy system consisting of solar panels, solar panel protection, DC-DC converter, MPPT controller, batteries, battery management system, battery protection and selection of efficient motor. This year's mechanical engineers will focus on the design, testing and building of the body/chassis, plus the necessary safety requirements, such as Exit Strategy, roll bar and bulkheads, along with the suspension and wheels.

A current and future objective of this project is to work closely with Sustainable Engineered Solutions (SES) to bring in future sponsors for the Solar Car Club. The SES website will be a cornerstone for the procurement of funds as it will act as a medium that the public can both get involved in the project and view the cars progress throughout future years. The website will also help give credit to contributors of the project by displaying their information with links to their website.

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# 1 Introduction

## 1.1 Acknowledgements

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## 1.2 Problem Statement

The FAMU-FSU Solar Car Team of 2011-2012 provided the first fully functional Solar Car. After showcasing the design and model, the car was procured by a FSU student organization called Sustainable Engineered Solutions (SES). The Solar Car Design this year relies upon three main focuses: a redesigned body and chassis, develop braking and steering systems, a solar panel-battery energy system, and a microprocessor controller. Selection of the focuses was made based on the SEMA design requirements and limitations.

The solar car this year is not be fully functional, yet a redesigned body with necessary safety requirements have be built and a newly designed energy system using solar panels and has been simulated and prototyped, along with the chassis, suspension, and wheels have been determined. Due to limited time, this year's group won't be able to complete the entire car; however the design and all the purchased parts are in line with the SEMA rules and requirements.

The following year's plan, 2013 is included in this document, located under year 2. The overall goal for these two years is to take the final designed car to competition in Houston, TX. The new design team in 2013-2014 will focus on energy system integration with motor and chassis, install brakes and regenerative braking as outlined in 2012, and finish all necessary safety requirements and communications related to the SEMA in 2014.
The proposed solution approach for all mechanical aspects includes developing models using Pro-Engineer CAD and COMSOL. A few mechanical components require the use of simulations to easily change the design parameters and determine the best design (for example, simulating air flow over the chassis the best aerodynamic design). A materials selection process has been used to properly choose the best materials possible for each component and lead to purchasing, fabricating, and installing each component. After a component is installed, testing has occur to determine if the component is working properly under regulations.
The proposed solution approach for all electrical aspects includes development of simulation models for the solar panels and DC-DC converter. The calculations determined power efficiencies and voltage/current characteristics during different driving conditions. In order to necessitate simulations, predetermined components and their real-world parameters will be used to complete each simulation scenario.
The deliverables, in March 2013, ideally replicate a working and integrated energy system along with a fabricated chassis with roll bar and the ability to conform to the predetermined exit strategy.
The final design, in March 2014, will ideally include all working components and integrations for a functioning solar vehicle ready for SEMA 2014.

## 1.3 Operating Environment

The FAMU-FSU Solar Car in 2014 shall be able to operate in standard North American climates. The car needs to be able to withstand normal wear with seasonal changes that a commercial automobile would encounter. The car will be resistant to rain, dust, debris, etc. The car's electronics will be protected electrically and physically and be able to operate in humid conditions as well as dry hot environments. The car will not be built to operate in extreme conditions such as mountainous terrain or heavy snowfall. The car will be able to handle up to a 12 percent grade which can be found on residential roads and have the ability to remain still at a 20 percent graded hill using brakes.

## 1.4 Intended Use(s) and Intended User(s)

With SES at the FAMU-FSU College of Engineering, the car will be used for future senior design projects and the Solar Car Club. The car will be taken to various events and shows such as the FSU homecoming parade in order to get publicity for current and potential sponsors. This in turn will hopefully generate donations to help the progression of SES and its related projects, and also to generate money for more research in sustainable energy solutions.
This year the intended users are solely project team members for design and testing. This will change for next year's senior design team; the solar car will be in the home stretch for competition at the SEMA. The solar car club hopes to inspire other engineering students to pursue an increased knowledge of sustainable energy and its immense applications. For either case, the 2 year goal is to design a car fitting all requirements for entering and competing in the SEMA in 2014.

## 1.5 Assumptions and Limitations

### 1.5.1 Assumptions

- Vehicle will operate safely and efficiently.
- Batteries are able to charge from solar panels.
- Mechanical energy will be recycled through regenerative breaking.
- Vehicle's completion is focused toward the SEMA.
- The vehicle will consume no more power than the batteries and solar panels can provide.
- The vehicle will be able to maintain an average speed around 15 mph.
- The motor will be able to run for extended periods of time.
- The vehicle will be able to travel greater than 6 miles.
- The vehicle must meet all specifications, rules and regulations set out by the SEMA.

### 1.5.2 Limitations

- The solar array must be fit into 0.17 square meters.
- The batteries, if Li-ion based, must utilize a Battery Management System (BMS).
- The vehicle must not exceed 3.5 x 1.3 x 1 meters in dimensions.
- The maximum vehicle weight without a driver must not exceed 140kg.

Note: More specific constraints and limitations see Need Analysis and Requirements Document

## 1.6 Expected End Product and Other Deliverables

### 1.6.1 Year 1

The end product for year 1 is a designed, tested and built chassis with roll bar, under necessary SEMA regulations. Included with the chassis has been simulated and the energy system verified . Although the energy system and chassis will not be integrated this year, necessary testing and development of prototypes has been accomplished. The overall assume energy system has been simulated and verified with MATLAB software, and each piece of the physical system will be tested using Dr. Edrington's DC load bank test set up at CAPS. The energy system including the solar panels, batteries, BMS, MPPT, converter will fully tested and properly connected.

# 2 System Design

## 2.1 Overview of the System

The goal of the project this year is to improve upon the solar car that has been built by teams over the past few years. The car has a carbon fiber body with a single-wheel powered by a motor in the rear, while the two wheels in the front allow for steering and braking. Aerodynamic testing has been done to provide the team with the chassis shape with least drag. The chassis has been built using multiple sheet of carbon fiber and balsa wood.
The energy system consists of a packaged battery system including BMS, an array of solar panels, a DC to DC boost converter, a motor controller with regenerative braking, and a 24V, 750W motor. The energy system will be equipped with an emergency shut off switch, most likely using relays or electronic breakers.

## 2.2 Major Components of the System

### 2.2.1 Chassis

The chassis is a monocoque structure meaning it will be a one piece shell capable of supporting all of the stresses that will be exerted on it. This includes the stresses from the driver, roll bar, electrical equipment, and mounts for the wheels. The chassis is rigid and does not deform to these stresses while parked or when it is in movement, see Figures 3.9,**??**. Its also a size that is able to hold the necessary components, as shown in Figure 2.1.

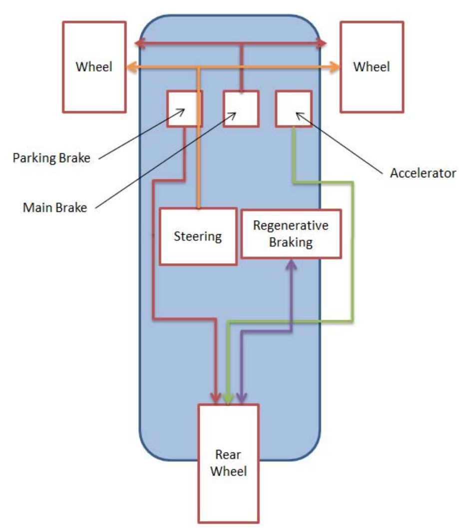



Figure 2.1: Mechanical Systems Top Level Design

### 2.2.2 Energy System

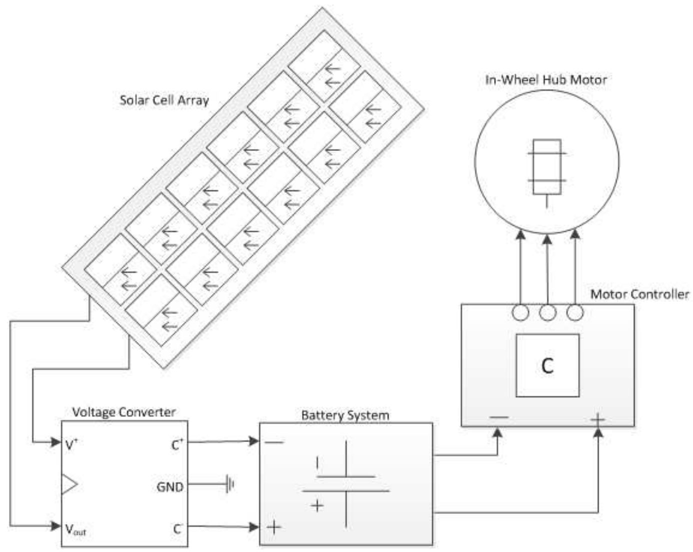



Figure 2.2: Energy System Top Level Design

**2.2.2.1 Solar Array** The Solar Array System can help run the car by charging the battery and working as a parallel power source to the motor while in motion. The Solar Array System will be mounted to the upper surface area of the solar car, above the driver. Through the carbon fiber top the solar array system will be connected to Energy Conversion System.

**2.2.2.2 Energy Conversion** The DC-DC boost converter is responsible for stepping up the energy from the solar panels to a set value of 24V or less at the batteries. Such feat is accomplished with the help of a Maximum Power Point Tracker algorithm through a microcontroller's PWM. The algorithm allows for maximum output as well as efficiency. The STEVAL-ISV005V2 is a demonstration board specially built to test the converters, in this case, the SPV1020 interleaved DC-DC boost converter.

**2.2.2.3 Battery System** To determine the battery needs of the car, the team first looked at the motor specifications and chose battery options from these specifications. The motor is rated at 24V. Mechanical calculations determined that the batteries would need a capacity of 6.71 Ah for the race. Taking into account a general rule that batteries should not be drained past 80% capacity lead the team the decision of using a 24V 20Ah battery pack.

### 2.2.3 Motor/Motor Controller

The motor selected for the Solar Car this year is not based on speed and acceleration but efficiency. Due to the limits of the voltage on the system set out by the SEMA, the normally used Nu-Gen 96V motor and controller will not be used. The nominal voltage limitation is 48V, therefore a 24V, 750W rated motor from Golden Motor was selected. Through discussion on capabilities of boosting the solar array voltage, 24V is more reasonable than 48V. To boost to 48V would require a much more elaborate converter system. This motor is a in-wheel hub motor built into a 26 inch spoked wheel. A motor controller with regenerative braking capabilities with the purchased motor kit has been order. The connections to the throttle and brakes shown in the pictures below are based on 0 - 5kΩ potentiometer, in which a simple pedal can be purchased. This motor system includes cruise control and a horn. The motor, for the future, can be integrated and programmed to work on 36V and 48V systems as well.

## 2.3 Subsystem Requirements

### 2.3.1 Chassis

The chassis will be a monocoque structure. It is made of balsa wood and Carbon Fiber. Aluminum honey comb was considered because of its very high strength to weight ratio as well with its modulus of elasticity. A decision matrix was done to weigh the benefit to cost of using this material, yet with the team's time and money contraints the use of honey comb is out of scope, and its geometry has limitations of being only in flat sheets. This causes a limitation on the structure of the chassis. Therefore the new design is made of mostly shapes cut out of sheets of carbon fiber as seen in Figures 3.2, 3.3. The use of an MDF mold, secured with Bondo and waxed with Johnson's Wax, will provide the necessary mold for laying carbon fiber and balsa wood. See Figures 3.4, 3.5, **??**

The body also has the necessary attachment points for all the components, the mechanical components can be seen in Figure 2.1. The rest of the electronic components will have bulkheads separating them from the driver. These will be made of balsa wood/carbon fiber to reduce weight. The body will also have to have a top removing hatch that has easy access to all of the electronics and for the driver's exit.

The chassis specifications were done to fit the driver and components comfortably but still be as compact as possible. Having it as small as possible will reduce drag on both rolling resistance and wind resistance to further efficiency.

COMSOL has been used to make sure the chassis is able to withstand the forces of the components, Figure 3.7. The file has been imported and the internal stresses have been minimized through the changing of geometry's to make sure the chassis does not have a catastrophic failure.

### 2.3.2 Suspension

A decision matrix was made for the suspension to decide what type of suspension the solar car should have. This decision matrix was formulated on the aspects of weight, price, size performance and complexity. The performance was actually considered low in this case because it will be driven on a smooth race track. The main consideration was the weight which was given a high weighting to its value. In the end rigid turned out winning in the decision matrix because of its light weight and low price. We will investigate if a mild small suspension can easily be implemented in case we do want to drive this car on the streets.

The rigid suspension has been found on most SEMA battery division cars. This is because it is light weight and it is a competition of efficiency. The suspension will be made as light and small as possible. It will be made of aluminum and carbon fiber to reduce weight. This will be stress tested with ComSol before manufacturing to make sure it is still strong enough to support the weight of the vehicle. An example of a rigid suspension can be seen in Figure 3.10

### 2.3.3 Steering

A decision matrix was made to decide on the steering that should be used. Three types of steering were considered including differential, front wheel steered, and rear wheel steered. The decision matrix came out with front wheeled steering being the winner because of the performance, complexity, and weight aspects. The steering will also have to meet the SEMA regulation of 6m turning radius. The Ackermann steering formula will be used to find the appropriate max steering angle needed.

The steering mechanism will be a lightweight aluminum tie rod steering. The front wheels will pivot from a connecting rod around a rigid hold point, see Figure 3.12. The connecting rod will be pulled in and out by the twisting of the steering column. The use for lightweight materials such as Carbon Fiber will be looked into more for the making of the shafts.

### 2.3.4 Braking

There will be two independently activated braking systems: one for the front wheels and one for the rear wheel. Both the front and rear braking will be done using pneumatic braking. However, the rear braking will be similar to a parking brake and will stay clamped once pressed. Only until a second press is made will it release its grip. Both of the braking systems will be pressed using foot pedals as seen in 2.1.

The brakes will be made of aluminum to reduce weight and will be disk caliper brakes. Because of the low weight of our overall system bicycle brake calipers are most cost efficient, as seen in Figure 3.11. These are low weight which is beneficial to our car.

### 2.3.5 Roll Bar

The roll bar design implemented in our design is a chromoly steel hope positioned behind the driver. The has supporting arms Figures 3.13,3.14,3.15 and be bolted to the inside bottom of the vehicle chassis. This roll bar extends in width beyond the driver's shoulders and 5 cm around the driver's helmet when he is seated in the reclined driving position with the safety belts fastened. Dimensions of the driver's shoulder width and seated height (with helmet on) where collected and implemented in the roll bar's design before construction. This roll bar has been designed to withstand a minimum static load of 700 N (approx. 70 kg) applied in any direction without deforming, see Figures 3.16,3.17,3.18. Before being constructed, the roll bar has been stress tested in Mechanica to ensure that it can at least handle 700N of stress in any direction without deformation, the requirement set forth by the Shell Eco Marathon. It will also be tested after its completion to withstand a weight of approximately 158 lbs (approx. 700N) in any direction without deformation. The material that was used is chromoly steel (steel alloyed with chromium and molybdenum), having an excellent strength-to-weight ratio, simple to machine, not overly-expensive, and being considerably stronger and harder than standard 1020 steel.

### 2.3.6 Solar Array

The solar car uses the 125X125mm mono-crystalline solar cells with a voltage rating of 0.6V and 6A rated current the solar cells and the cell setup can be seen in Figure 3.20 and Figure 3.21. The mono-crystalline cells chosen provide IV characteristics shown in Figure 3.19. The solar panel's electrical performance is shown in Table 2.1. Since solar panels are affected by solar irradiation values in W/$m^2$, a irradiation profile is given in Table 2.2, and just for completeness a table giving temperature coefficients specific to the mono-crystalline cells is given in Table 2.3.

Table 2.1: Solar Cell Electrical Performance

| Efficiency Cell (%) | Power (W) | Max Current (A) | Min Current (A) | Short Circuit Current (A) | Max Voltage (V) | Open Circuit (V) |
|---|---|---|---|---|---|---|
| 18-18.19% | 2.67-2.7 | 5.07 | 4.19 | 5.42 | 0.53 | 0.628 |
| 17.8-17.00% | 2.64-2.67 | 5.02 | 4.87 | 5.4 | 0.528 | 0.628 |
| 17.6-17.79% | 2.61-2.63 | 5.02 | 4.86 | 5.37 | 0.524 | 0.625 |
| 17.4-17.59% | 2.59-2.61 | 4.98 | 4.83 | 5.34 | 0.522 | 0.624 |
| 17.2-17.39% | 2.56-2.59 | 4.93 | 4.79 | 5.3 | 0.522 | 0.623 |
| 17-17.19% | 2.53-3.56 | 4.91 | 4.77 | 5.29 | 0.518 | 0.621 |
| 16.8-16.99% | 2.5-2.53 | 4.88 | 4.73 | 5.26 | 0.516 | 0.620 |
| 16.6-16.79% | 2.47-2.5 | 4.85 | 4.7 | 5.23 | 0.513 | 0.619 |
| 16.4-16.59% | 2.44-2.47 | 4.82 | 4.67 | 5.21 | 0.511 | 0.618 |
| 16.2-16.39% | 2.41-2.44 | 4.79 | 4.64 | 5.18 | 0.509 | 0.616 |
| 16-16.19% | 2.38-2.41 | 4.76 | 4.61 | 5.15 | 0.506 | 0.615 |

Table 2.2: Solar Cell Irradiation Profile

| Irradiance (W/$m^2$) | $V_pm$ | $I_pm$ |
|---|---|---|
| 1000 | 1.000 | 1.000 |
| 800 | 0.992 | 0.799 |
| 600 | 0.979 | 0.598 |
| 200 | 0.922 | 0.193 |

Table 2.3: Solar Cell Temperature Coefficients

| | | |
|---|---|---|
| Current Temp Coefficients | $\alpha(I_sc)$ | 0.03%/°C |
| Voltage Temp Coefficients | $\beta(V_oc)$ | -0.32%/°C |
| Power Temp Coefficients | $\gamma(P_max)$ | -0.42%/°C |

Each one of the 125X125mm mono-crystalline solar cells has been cut into three pieces using a high beam laser. This step doubles the voltage of the solar cell by three; however this process reduces the current by factor of three; the three cell module can be seen in Figure 3.21. After this process the solar car team ends up with a voltage rating of 1.8V and 1.7A rated current. Testing of every single module took place after procuring the solar cells. The available space, a total surface area of 0.17 square meters set out by the SEMA rules, on the solar car only allows ten modules

to be mounted to the body of the car, Figure 3.22.
The modules are connected the following way: two parallel five series modules in the array string, supplying 9V rated at 3.4A rated. Circuit configuration can be seen in Figure 3.23. The solar modules deliver $\tilde{2}$5W of rated power.
Each of the solar modules will have a ”Solar Junction Box” consisting of one diode. This diode will be used to solve partial shading and loss of delivered power. At the terminating end of the solar array is another junction box with one diode to serve as a protection diode for the unwanted flow of back current into the modules. The solar junction box and the circuit with the diodes can be seen in Figure 3.23 and Figure 3.24. The specifications for the solar junction box are shown in Figure 3.25.
The team will mount the modules on the top of the car. The array mounting will be accomplished by rivet gun and punch of rivets or bolts. Four rivets will be used to mount the solar modules one at each corner of the modules, underneath each of the modules the team will drill a circular hole to allow the wires to get throw the body easily. Two color coded wires will be connected to the cells to show the positive and negative sides of each module. There will be no need for a final protective layer over the car because of the EVA encapsulation.
The diodes used are Schottky barrier rectifiers that can handle a maximum of 1000V and 7A. The diodes have a built in carrier inside the box. The box will have positive and negative side where the modules will be connected to the diode. The solar module has been connected to its own diode box.
The team is currently working on the solar array portion of simulation using Matlab, Simulink and Plecs softwares.

### 2.3.7 Energy Conversion

**2.3.7.1 Boost Converter Topology** A DC-DC boost converter is used to bring the voltage of the solar array 12V maximum to the voltage of the batteries 24V in order to act as a dual source during operation of the solar vehicle, and to charge the batteries when the vehicle is not in use. Figure 3.26 illustrates a typical boost converter circuit topology, including a DC input, an inductor, a switch, a diode, a capacitor, and a load.
The Boost converter is realized using a power MOSFET and is controlled by the PWM from the microcontroller. The duty cycle of the PWM can be changed to allow variations of the output voltage given a particular input voltage, or in this case, to maintain an output voltage given fluctuations in input voltage. This mechanism is utilized to hold the output voltage of the MPPT to as near the battery voltage as possible.

**2.3.7.2 MPPT algorithm** The Perturb and Observe method involves periodically perturbing and comparing the terminal voltage to its previous value. If the power of the previous data point is not equal to that of the current data point, the voltage is compared to its previous value and an adjustment in duty cycle is made accordingly. Figure 3.27 below illustrates the perturb and observe flow chart algorithm.

**2.3.7.3 SPV1020** The monolithic 4-phase interleaved DC-DC boost converter from ST Microelectronics is designed to maximize the power generated by photovoltaic panels independent of temperature and amount of solar radiation. Optimization of the power conversion is obtained with embedded logic which performs the MPPT (max. power point tracking) algorithm on the PV cells connected to the converter. The built-in MPPT algorithm used is Perturb and Observe.See Figure 3.28

### 2.3.8 Battery System

**2.3.8.1 Battery Pack** For determination of a 24V, 20Ah battery pack needed to power the car, the battery chemistry to use had to be decided. The determination of type of battery came down to is the size, weight, and cost. The lithium iron phosphate (LiFePO4) batteries from Electric Rider, Figure 3.30, have been chosen due to its small dimensions of 6 x 10.25 x 3.5 inches, weight of 10 lbs, and cost of under $500 including shipping. Discharge curves are shown in Figure **??**.

**2.3.8.2 Battery Management System - BMS** It is required for all lithium batteries to have proper battery management systems to protect the risk of damaging cells and potential to catch fire. Rules from the competition require the BMS to have cell over/under voltage limits, over current limit, over temperature limit. The battery pack has been purchased from Electric Rider and includes a BMS that protects and monitors the individual cells and entire pack.

**2.3.8.3 Battery Charger** The battery pack from Electric Rider also includes a lithium battery charger that supplies a 4A current to recharge the batteries, as shown in Figure 3.31.

**2.3.8.4 Battery Display/Monitor** During car operation the team would like to be able to easily monitor the battery pack. Turnigy's 130A Watt Meter and Power Analyzer has been purchased for a visual display of the batteries health and performance levels. This device is rated for 60V, 130A, 6554W and 65Ah which are well within our battery specifications. At $30 and with its small size and weight, it is the perfect option for a visual display of the battery performance levels inside the car during operation. Figure 3.32 shows the device display and Figure 3.33 shows the connection with the batteries and motor to monitor performance.

### 2.3.9 Motor/Motor Controller

**2.3.9.1 Motor** Determining the motor specifications required the use of simple physics calculations. The equation shown below (2.1) using specifications from Table 2.4. Table 2.5 shows the mechanical power needed at the wheels, the ampere-hour rating, and watt-hour need to move the car at a constant speed of 20 mph.

$$P_d = C_r mg + mg\sin(\theta) + \frac{1}{2}\rho_a C_d A_f v^2 \tag{2.1}$$

Table 2.4: Mechanical Power Specifications for Constant Speed

| Parameter | Value |
|---|---|
| Power at Wheels ($P_d$) | ? W |
| Mass (m) | 136.08 kg |
| Rolling Resistance ($C_r$) | 0.0025 |
| Gravity (g) | 9.81 m/$s^2$ |
| Road Incline ($\theta$) | 0° |
| Air Density ($\rho_a$) | 1.225 kg/$m^3$ |
| Drag Coefficient ($C_d$) | 0.15 |
| Fontal Area ($A_f$) | 1.3 $m^2$ |

| | |
|---|---|
| Velocity (v) | 67.76 m/s |

Table 2.5: Mechanical Power Calculation Table

| Parameter | Value |
|---|---|
| Weight | 300 lbs |
| Velocity | 20 mph |
| Power (mech) | 143.9702 W |
| Amperage | 5.9988 A |
| Watt-hour rating | 161.0405 Wh |
| Amp-hour rating | 6.71 Ah |

These values determined are the maximum values needed to keep the car moving at a constant speed. To determine the starting torque needed for the motor (2.1) is used adding a $m * \frac{dv}{dt}$. Determination of exact starting torque seems trivial, since its calculation would include minimal changes to the previous equation, yet usually the starting torque or stall torque is determined when the car is on a incline of say 20°. The solar car will never have to compensate power for such an angle, nor will it ever need to speed up or accelerate quickly to get up to speed. The team foresees the acceleration to be gradual and the torque/current ratio to increase by a maybe a factor of 10. Therefore the true calculation of starting torque will not be considered in this paper.

Since only a maximum of approximately 150W is needed to keep the car moving at a constant speed, and 10-15 Nm is required to move the car from a dead stop a motor from Golden Motor was selected, shown in Figures 3.34, 3.35 and 3.36. This motor is an in-wheel brushless DC motor. Figures 3.37 show the motor's voltage, current, power and torque characteristics under a nominal, max and peak efficiency 24V system.

#### 2.3.9.2 Motor Controller

The Golden motor kit comes with a motor controller, which can be programmable to from 24V to 48V. In our case, 24V will suffice. Figure 3.39 shows the controller from Golden Motor.

##### 2.3.9.2.1 Wiring

to the controller is shown in Figure 3.38.

Note: the battery voltage can be used for controller supply.

#### 2.3.9.3 Motor Accesories

Necessary accessories will need to be purchased. Since requirements from the SEMA states the throttle and brake must engage with the foot, throttle and brake pedals need to be purchased. The throttle and brakes on the Golden motor are 0-5kΩ POT. The kit includes wiring for both a horn and cruise control.

## 2.4 Performance Assessment

The current goal for the project is to have a rolling solar vehicle chassis, a fully tested and simulated energy system less a motor load test by the end of the year. Unfortunately, due to time restrictions as rolling chassis and motor integration to roll bar has not occur. HPMI helped in the building of the chassis. The chassis built is not larger in size or weight as the requirements specified in the SEMA challenge. The roll bar fits the necessary stress and weight requirements needed for the challenge. The solar array fits perfectly into the size requirements and the batteries' ratings are below requirements. A new motor has been ordered. Suspension simulation testing is currently happening.

## 2.5 Design Process

The team has chosen and used carbon fiber/balsa wood to build the chassis. Since the top half of the car will not have any stress put on it while driving or at rest, this part will be made out of only carbon fiber, 2 sheets. Cleaning and retrofitting the chassis body with the roll bar has finished, now the task of installing bulkheads and steering will occur this summer.

The boost converter and MPPT board SPV was chosen because it is an all in one circuit, with no necessary programming. The battery system has proven quite capable within calculations to provide the motor with the necessary current to spin under load. Testing of the solar panels may be difficult, since testing with a load will require the panels to be indoors and an incandescent lamp to be used. Although, PV curves can still be rendered through testing, just at much lower irradiation levels.

Issues with testing the motor have proved difficult. In order to test the motor under loaded or stall conditions, a testing rig would need to be built. This would possibly required more than a months time to build, with lots of precise measurements needed for a dyno test to be worthwhile. It can be done, with the help of Dr. Edrington's group this test may be possible over the summer on into next year.

## 2.6 Overall Risk Assesment

### 2.6.1 Technical Risks

**2.6.1.1 Solar Cell Encapsulation** DESCRIPTION The wrong way of encapsulation and mounting of the solar array could allow them to be exposed to the outside elements. This includes wind, outside atmosphere, flying objects, high speed and sun damage. PROBABILITY:Moderate

The chances of the vehicle being exposed to wind, outside atmosphere, flying objects, high speed and sun damage is moderate. This is due to the SEMA rules where the car must be able to function at any weather condition. CONSEQUENCES:Moderate

In the current stage the solar modules will be riveted to the upper body of the car which will allow the team to replace any nonfunctional solar modules easily. Replacing the modules help not lose power from the damaged modules. STRATEGY EVA protection will be used on the solar cells to increase the physical strength. Aluminum plate will be used at the bottom of the solar modules make the installation process easier.

**2.6.1.2 Solar: Diode Protection** DESCRIPTION Current flowing back into the solar module, and the partial shading of the any of the solar cells on the array. This might cause damage to the solar cells in a way where replacing them become necessary. PROBABILITY:Moderate

CONSEQUENCES:Moderate

It's possible that one of the cells or couple of them get shaded by clouds, trees or leaves. STRATEGY A protection

Diode, and bypass diodes as described previously will be used to keep the modules safe from current feedback, and stop the effect of shading.

**2.6.1.3 Energy System Electrical Wiring** DESCRIPTION The wiring of the solar array, MPPT, motor controller, and motor are all subject to the risk of failure. The improper wiring or improper choice of wiring can cause the wires to burn up. Improper use of components outside the ranges specified within the data sheet could propagate high/low voltages or high currents delivered to other components in the system. PROBABILITY:Moderate
This risk is apparent in every decision made because the replacement of a damaged component is not feasible. Since the team is well aware of the risk it is less likely to happen. CONSEQUENCES:Severe
The consequences could be severe possibly damaging all electrical components if something were to be wired incorrectly or improper gauge selected. This would also lead to budget and scheduling risks. STRATEGY

**2.6.1.4 Proper Wiring of Motor/Motor Controller Setup** DESCRIPTION Although the connections from the motor to the motor controller, motor controller to battery seems trivial. PROBABILITY:Low
Technical documents provided describe proper connections. CONSEQUENCES:Severe
Improper connection will result in damage to either the controller, motor or battery system. Budget does not allow for purchase of another motor. STRATEGY Reading instructions sent by distributor will allow for ease of connection.

**2.6.1.5 Chassis - Aluminum Honey Comb** DESCRIPTION The aluminum honey-comb might be harder to connect than previously thought. PROBABILITY:Low
We have a sample of joined aluminum honey-comb that was joined using carbon fiber. Also we will be having assistance in the manufacturing process. CONSEQUENCES:Medium
The 3D representation and simulations will be done for this material. If we would have to change to a different material it would put a strong time delay on the build. STRATEGY Making sure the process of joining the aluminum honey-comb is approved by an experienced machinist.

**2.6.1.6 Chassis - Car Strength** DESCRIPTION The predetermined strength of the car could be weaker than predicted. PROBABILITY:Low
We are assessing the strength through Pro E and ComSol to accurately depict it. CONSEQUENCES:High
If the strength of the chassis cannot support the weight the chassis will break. This will put us back many months and some money. STRATEGY A safety factor of 2.0 to 3.0 will be implemented to make sure that it will not break under the load.

**2.6.1.7 Suspension** DESCRIPTION If the ride is too harsh from the suspension being rigid vibrations could cause things to fail. PROBABILITY:Low
We will be riding at low speeds on flat ground which does not have a lot of vibrations. CONSEQUENCES:Medium
If vibrations caused a major component to fail it could set us back money and time. STRATEGY If we have a vibration sensitive object we will implement a vibration reducing agent such as rubber to preserve the object.

**2.6.1.8 Braking** DESCRIPTION If the brakes are not strong enough to hold the car in place. PROBABILITY:Low
The stopping force will be calculated before purchase. CONSEQUENCES:Low

New brake calipers will have to be ordered. STRATEGY The stopping force required will be calculated and a safety factor of 2.0 will be added to it.

#### 2.6.1.9 Steering

DESCRIPTION The steering could be under the design requirements. PROBABILITY:Low
CONSEQUENCES:Low
A longer arm would have to be fabricated. STRATEGY Calculate the required angle of turning and have it turn 10 degrees past this mark.

#### 2.6.1.10 Battery Management System

DESCRIPTION Lithium batteries require a proper battery management system to protect individual cells and the entire battery pack from over/under voltage, over current, and over temperature. Ineffective BMS may result in damaging the battery pack. PROBABILITY:Moderate
At this moment it is unknown what the protection limits are for the given BMS and how it will respond when a limit is reached. However, this company has been around for over 10 years and has sold their battery packs to other teams in the Shell Eco Marathon so the BMS should work as expected. CONSEQUENCES:Severe
How the battery pack is arranged as a pre-built system, if even one of the batteries goes bad it will be impossible to replace it. A whole new battery pack would need to be purchased. Safety is very important. We do not want someone to be driving the car and have the batteries catch fire which is a definite possibility if the BMS does not work correctly. STRATEGY Extensive testing on the BMS will need to be conducted to determine the protection limits and what will happen when each limit is reached.

#### 2.6.1.11 Roll Bar

DESCRIPTION Possibility of roll bar failure. PROBABILITY:Low
The design of the solar car chassis and tire placement is such that the likelihood of the entire vehicle overturning during operation is low. Also, the vehicle will not be traveling at high speeds, nor negotiating any extremely sharp turns. Regardless, in the unlikely event that the car somehow overturns, due to the fact that the roll bar will be designed with a good factor of safety, the light design of the car the chances of the roll bar failing are minute at best CONSEQUENCES:Catastrophic
In the unlikely scenario that the roll bar outright fails during actual operation of the vehicle, this would be considered catastrophic. Needless to say the car would suffer extensive damage due to the roll and continued momentum, and the driver could potentially incur a variety of injuries despite his protective gear. STRATEGY The team stress analysis with Creo and physical testing with weights before final roll bar installation.

### 2.6.2 Schedule Risks

#### 2.6.2.1 Chassis - Manufacturing Time

DESCRIPTION The chassis will take a longer time than this year to complete PROBABILITY:Medium
We are inexperienced in making these complicated structures out of advanced materials. CONSEQUENCES:Medium
If we do not finish the chassis structure in time we will be unable to implement any other pieces onto it. STRATEGY Help from a more experienced maker will be used to aid us in the fabrication of our car.

#### 2.6.2.2 Delivery of Parts for Solar Array

DESCRIPTION The delivery of the Solar Junction Box could be delayed due to postal reasons. As mentioned before those solar junction boxes will be used for both the protection circuit and the bypass diode. PROBABILITY:Low

The chance that the solar array delays the process of building the car is most likely impossible. The team will make sure to build the solar array as soon as possible, however sometimes some delays could happen. CONSEQUENCES:High
Even with the chances off solar array to fail is almost impossible, the consequences of the system failing is really high. If the solar array fails the car would not be able to be completed. If the solar system fails the car won't be able to charge since the solar system is the only source of charging. As result the car won't be able to make to the SEMA since it's one of the major parts of the car. STRATEGY In order to ensure that all the solar system does not fall behind in schedule the team will order the solar junction box before Christmas Break to assure that the team will have it by the New Year.

**2.6.2.3 Solar Cell Damage** DESCRIPTION Damage of existing cells and modules after the completion of the array building process. PROBABILITY:Low
After talking with Mr. Ian Winger from SunnyLand Solar, he assured the team that the solar system will be ready by the next year. CONSEQUENCES:High
Even with the chances off solar array to fail is almost impossible, the consequences of the system failing is really high. If the solar array fails the car would not be able to be completed. If the solar system fails the car won't be able to charge since the solar system is the only source of charging. As result the car won't be able to make to the SEMA since it's one of the major parts of the car. STRATEGY To make sure the solar module done as soon as possible the team will work on them during the Christmas break to assure that they ready by the new semester.

**2.6.2.4 Maximum Power Point Tracker** DESCRIPTION One of the most vital components of the project next to the motor and PV array is the maximum power point tracking system (MPPT). Without this component the vehicle would remain a divided two part system with the solar cells and the battery/motor being separate. PROBABILITY:Low
The probability of this component and its sub-parts setting the vehicle behind schedule is low. The part will be manufactured and order relatively early to avoid delay. CONSEQUENCES:Catastrophic
While the probability of the MPPT or its sub-components failing is low, the consequences of the system failing could be catastrophic to the outcome of the vehicle and delay the milestones. If the system or its components fail, the car would not be a complete system and would consist of a battery and motor with solar cells that are connected to nothing. If any subsystem of the MPPT fails it could damage other portions of that system. Without this major component the vehicle will not be able to use solar energy. STRATEGY The strategy the team has come up with to keep the probability low is to simulate, simulate, and re-simulate to ensure that the MPPT will work together and have no chance of failing and damaging other components. Other methods of preventing this would be to test each of the components to make sure the team is not putting a damaged component into the vehicle.

**2.6.2.5 Suspension** DESCRIPTION If the suspension is not finished in time the steering will also be delayed PROBABILITY:Low
It is easy to manufacture CONSEQUENCES:Low
We could focus on another aspect of the car while still working on the suspension. STRATEGY An easy , fast suspension will be made so that it does not interfere with other parts

**2.6.2.6 Roll Bar** DESCRIPTION The completion of the roll bar may be delayed due to unforeseen complications in design or carbon fiber application or necessary size and design adjustments as the car comes together. PROBABILITY:Low

The manufacturing of the roll bar should not prove challenging or time consuming for a skilled metal-worker. The design is simple and small scale. If there were to be some unforeseen problems with the fabrication of the roll bar that would cause its development to be drawn out, this would not significantly hinder or affect the development of the rest of the solar car nor would it affect its scheduled completion. CONSEQUENCES:Low
STRATEGY The team will be certain of the final design and begin manufacturing of the roll bar frame ahead of schedule so that it is definitely completed and installed properly on time, and any problems that arise will not create a time-constraint issue.

### 2.6.3 Budget Risks

**2.6.3.1 Carbon Fiber** DESCRIPTION Carbon Fiber is used extensively through our project. The price of Carbon Fiber is very high. PROBABILITY:Low
We are under budget at the moment due to the decrease of the electrical component price. CONSEQUENCES:Low
Carbon Fiber can be easily exchanged with aluminum just with an increase in weight. STRATEGY Getting a rough estimate of the budget for buying all of the carbon fiber.

**2.6.3.2 Braking** DESCRIPTION The price for the aluminum and/or carbon fiber might exceed budget PROBABILITY:Medium
A lot of aluminum and carbon fiber is needed to make these parts. CONSEQUENCES:High
We will have to settle for steel which will add a considerate amount of weight. STRATEGY Budget the price for the aluminum and carbon fiber before so that we do not run over budget.

**2.6.3.3 Carbon Fiber Roll Bar** DESCRIPTION It is uncertain approximately how many sheets of carbon fiber will have to be purchased to accomplish the desired strength requirements of the role bar if it were to be made of carbon fiber. PROBABILITY:Low
In the event that many sheets of carbon fiber need to be purchased, this should not create any substantial strain on the car's allocated funding. CONSEQUENCES:Low
The team may have to spend a bit more than previously thought for additional carbon fiber rolls. STRATEGY Always shop competitively. The team will compare price verses quantity for multiple vendors and check to see if it is possible that anyone would like sponsor the car by donating carbon fiber.

### 2.6.4 Summary of Risk Status

So far many risks described will not throw the entire project off course. Using necessary safety measures during testing will prove useful. For the mechanical engineers, this car will required proper attention to detail in strength, and time. For the electrical engineers, setting up testing using proper electrical safety and wiring prove the most important based on risk analysis.

# 3 Design of Major Components

An in depth description of all the major components and the design can be seen in Section 2 of this report.

## 3.1 Diagrams of Components and Subsystems

### 3.1.1 Chassis

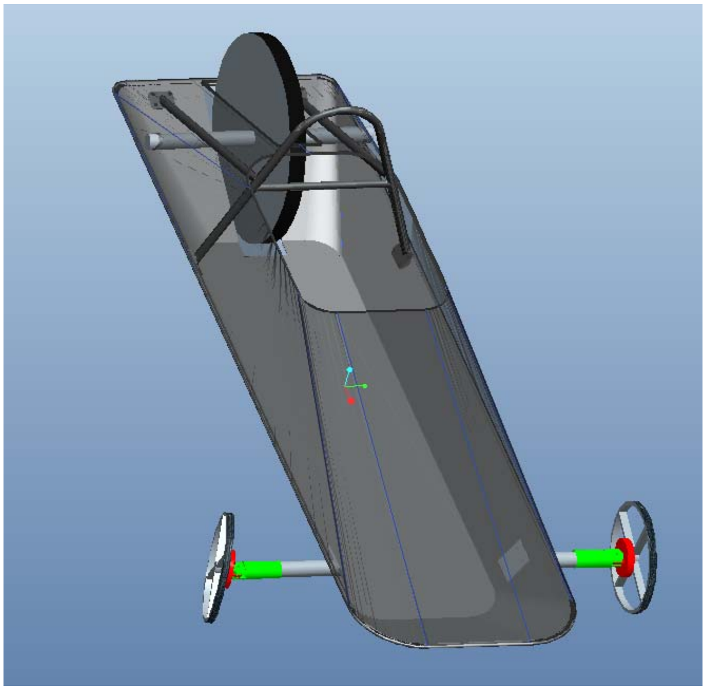


Figure 3.1: ProE Chassis Assembly Concept

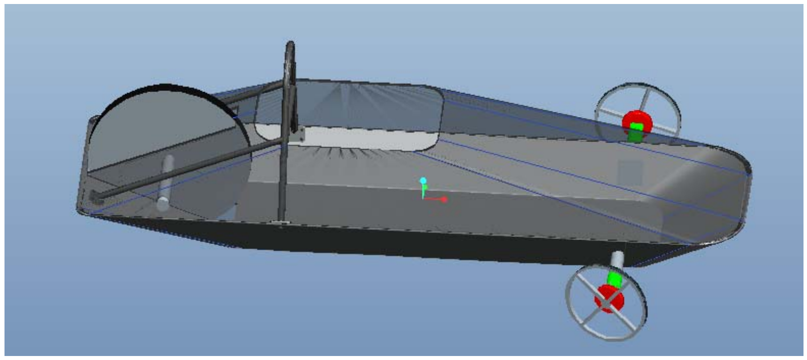


Figure 3.2: ProE Chassis Assembly Concept Side

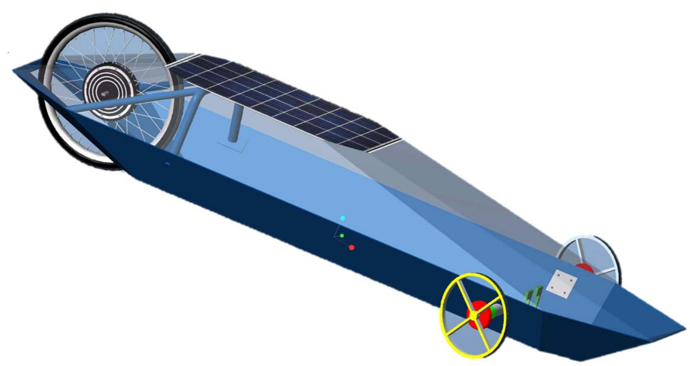


Figure 3.3: ProE Final Chassis Concept

Figure 3.4: Completed MDF Top Chassis Mold

Figure 3.5: Completed MDF Bottom Chassis Mold

Figure 3.6: Completed Molds

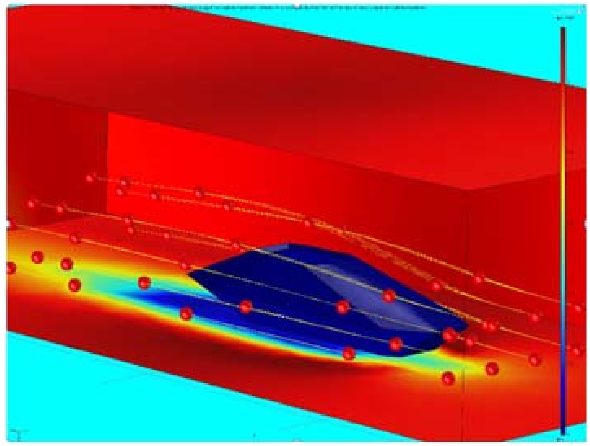


Figure 3.7: COMSOL Aerodynamic Testing

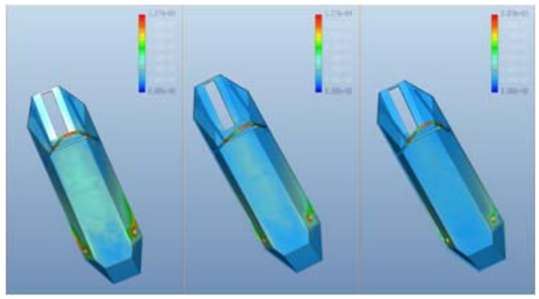


Figure 3.8: ProE Stress Concentration

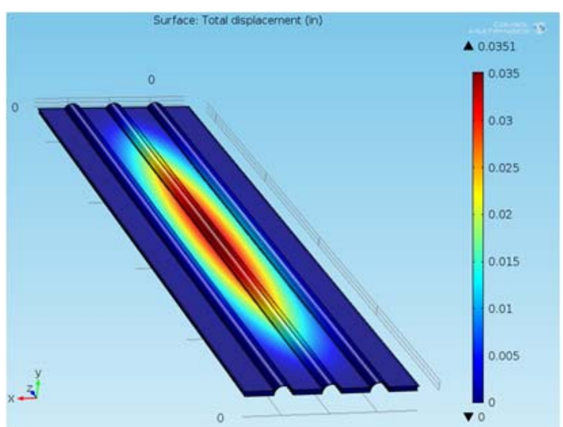



Figure 3.9: ProE Bottom Plate Stress Concentration

### 3.1.2 Suspension

Figure 3.10: Rigid Suspension Example

### 3.1.3 Braking


Figure 3.11: Brake Calipers

### 3.1.4 Steering

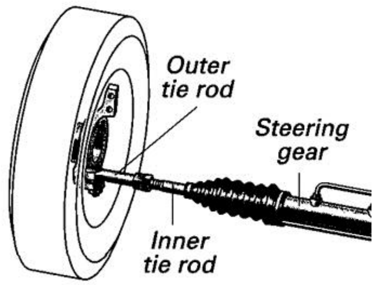



Figure 3.12: Steering at the Wheel

### 3.1.5 Roll Bar

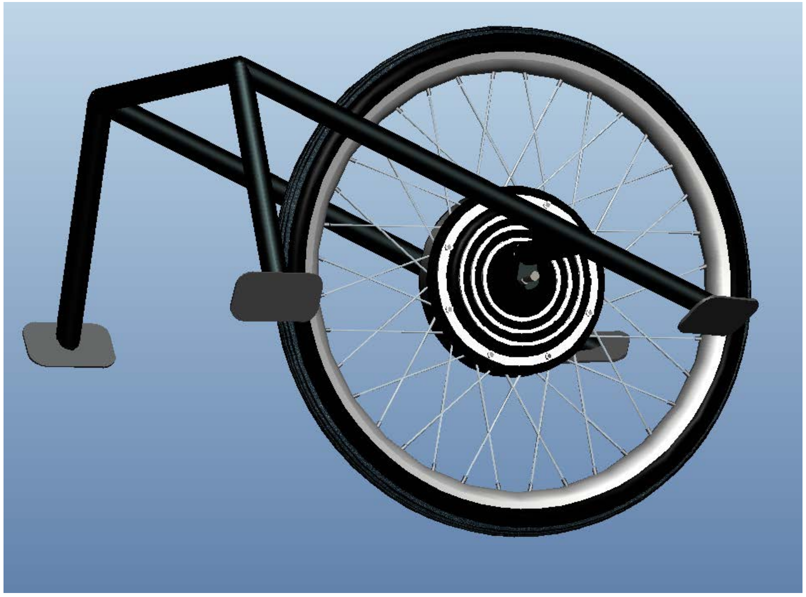


Figure 3.13: Roll Bar Wheel Assembly 1

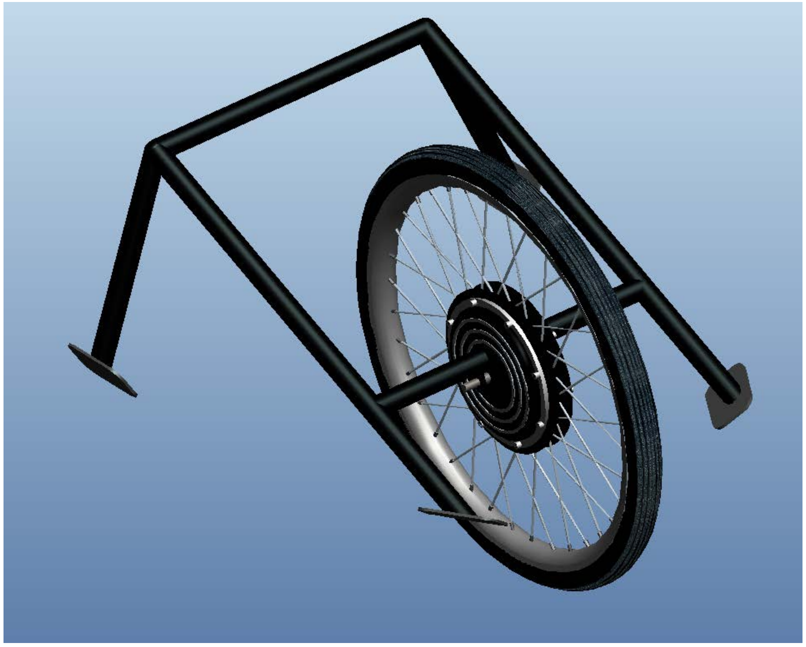


Figure 3.14: Roll Bar Wheel Assembly 2

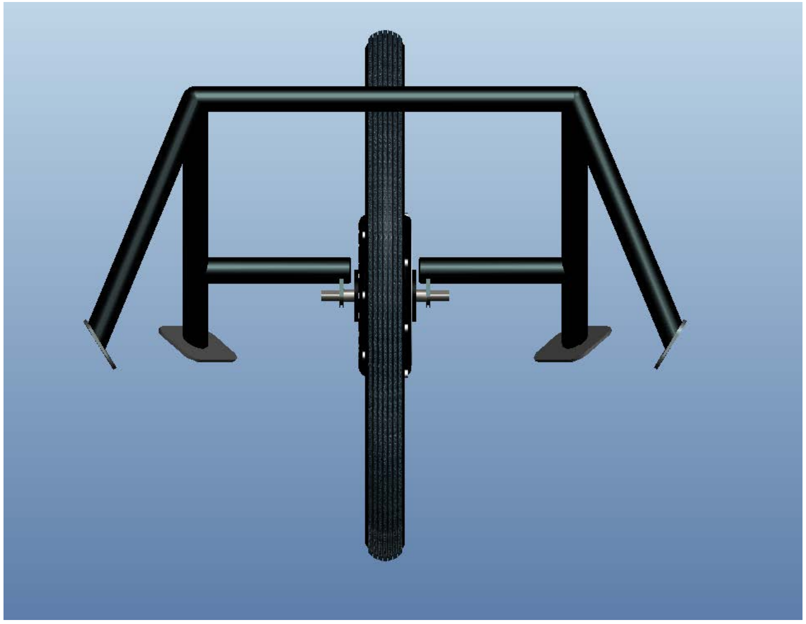


Figure 3.15: Roll Bar Wheel Assembly Back

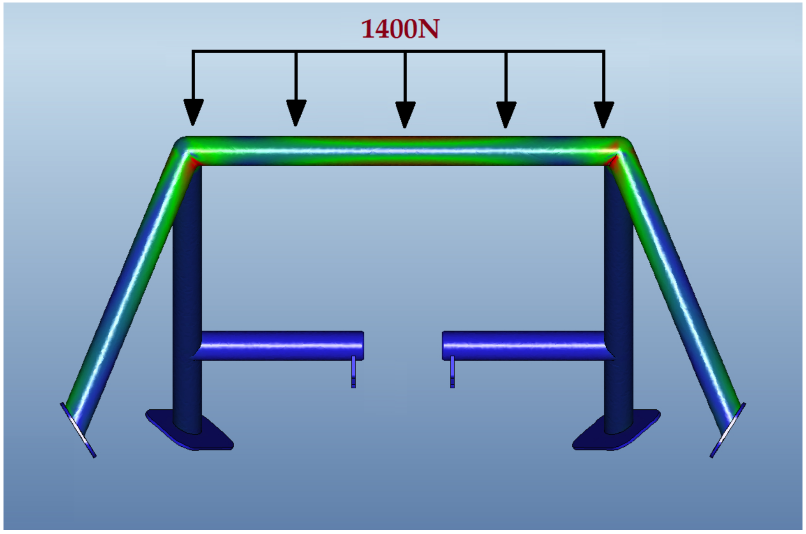



Figure 3.16: Roll Bar-Top Down Stress

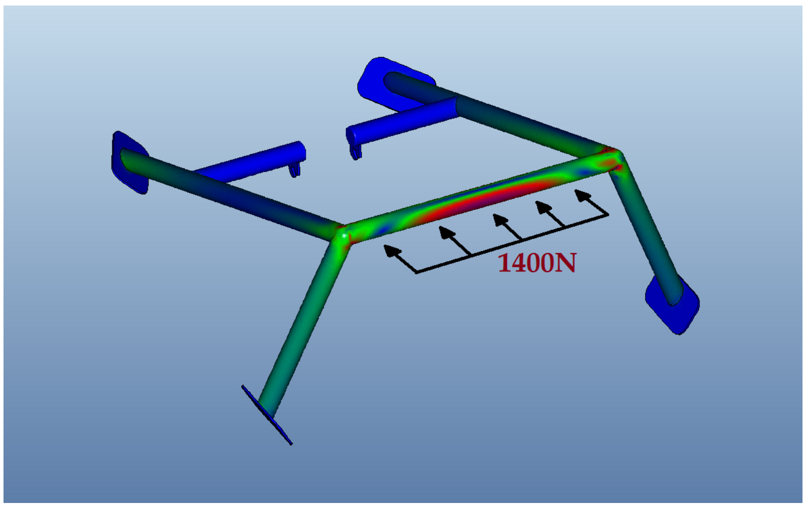



Figure 3.17: Roll Bar-Front to Back Stress

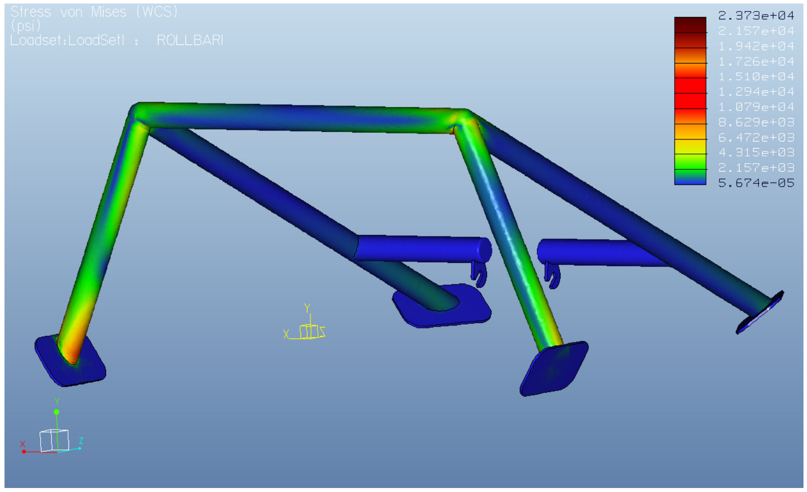



Figure 3.18: Roll Bar-Side Stress

### 3.1.6 Solar Array System

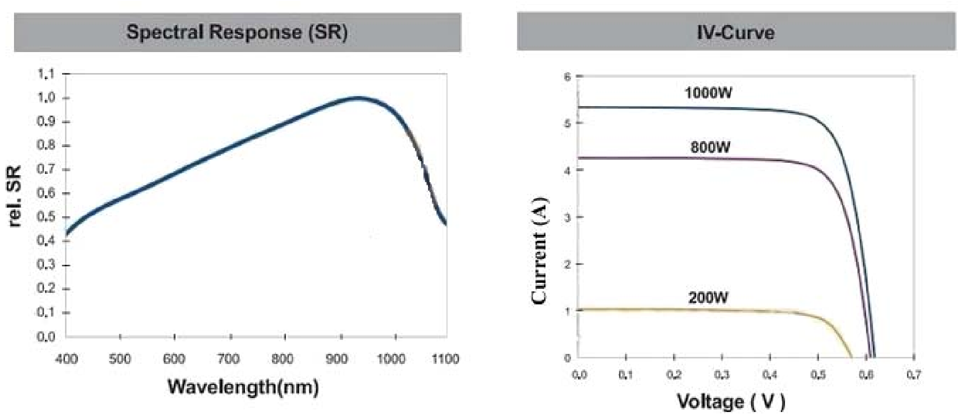



Figure 3.19: 125x125mm Mono-Crystalline IV Profile

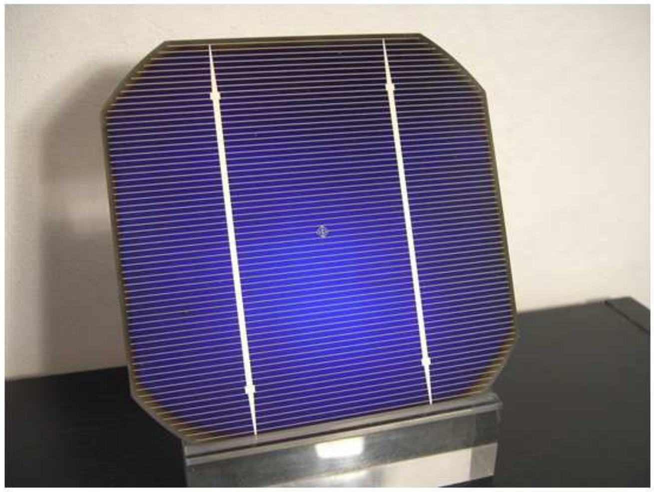


Figure 3.20: 125x125mm Mono-Crystalline Solar Cell

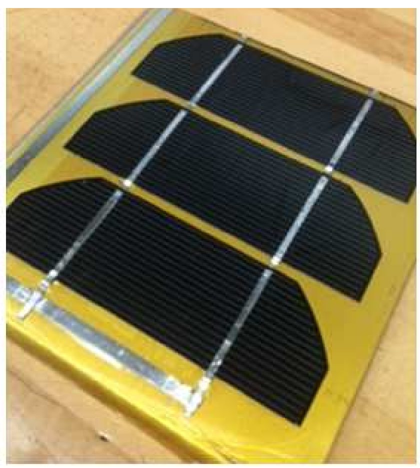
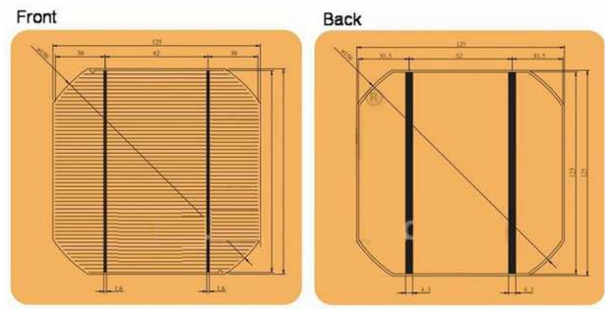


Figure 3.21: Three Mono-Crystalline Solar Module provided by SunnyLand Solar




| | |
|---|---|
| Format | 125x125mm ±0.5mm |
| Diameter | 150±1.0mm (round chamfers) |
| Thickness | 240um±40um, 200±40um,180um±30um |
| Weight | 6.7±0.5g |

Figure 3.22: Mono-Cystalline Dimensions

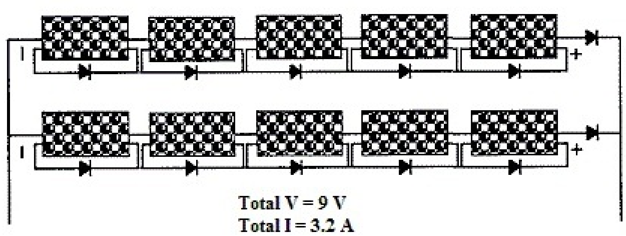



Figure 3.23: Solar Array Configuration Options

Figure 3.24: Solar Junction Box

# Solar Junction Box Specifications

### Electrical Features

Current for PV Module: 7A
Rated Voltage: DC 1000V
Power Capacity: 40-50W Solar panel
Touch Protection Class: Ⅱ

### Mechanical Features

Temperature Range: -40°C ~ 85°C
Diodes Details: 1pcs
Number of terminals: 3 rails
Wire Size: 1.5mm2__ 4mm2 or2.5mm2__ 4mm2
Contact Resistance: <5 Ohm
Protection Degree: IP65
Flame Class: UL94-V0

Figure 3.25: Solar Junction Box Specifications

### 3.1.7 Energy Conversion System

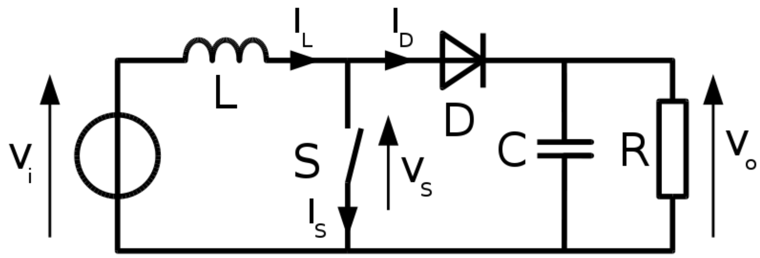



Figure 3.26: Boost Converter Topology

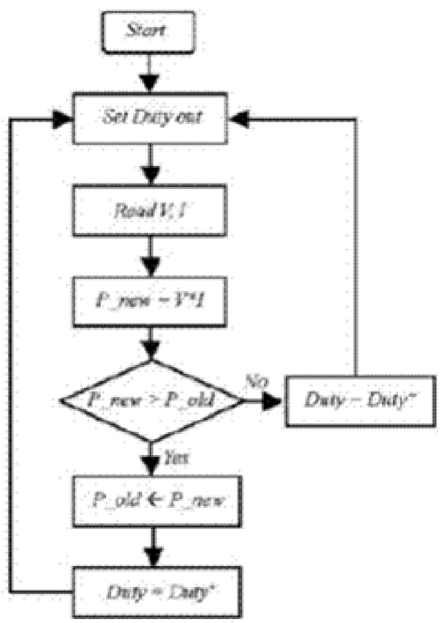



Figure 3.27: Perturb and Observe Algorithm Flowchart

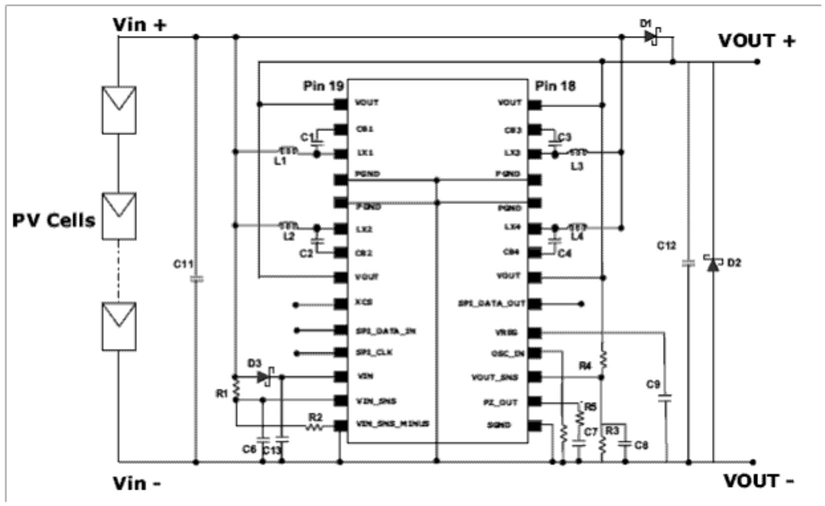



Figure 3.28: Application Circuit of SPV1020

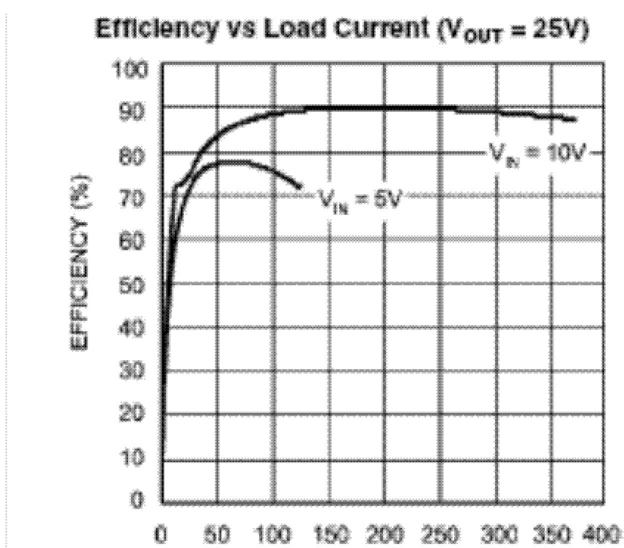



Figure 3.29: SPV1020 - Efficiency Curve

### 3.1.8 Battery System

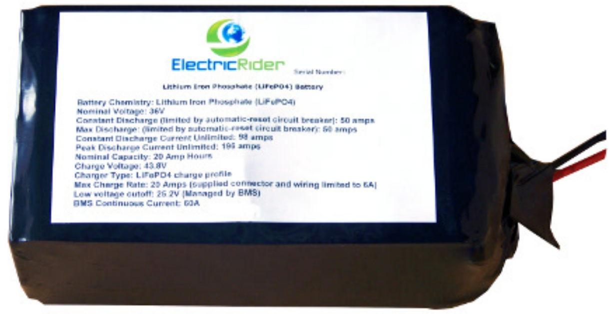
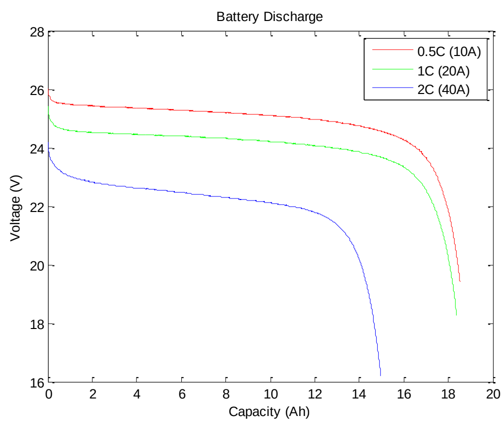



Figure 3.30: Electric Rider LiFePO4 Battery Pack

Figure 3.31: Lithium Battery Charger


Figure 3.32: Turnigy Watt Meter and Power Analyzer




| | 0.5C (10A) | 1C (20A) | 2C (40A) |
|---|---|---|---|
| **Start Voltage** | 26.03 V | 26.88 V | 24.19 V |
| **End Voltage** | 19.43 V | 18.28 V | 16.18 V |
| **Capacity** | 18.5297 Ah | 18.3863 Ah | 14.9716 Ah |
| **Time** | 1:51:29 | 54:32 | 22:31 |

Figure 3.33: Battery Discharge Graphs

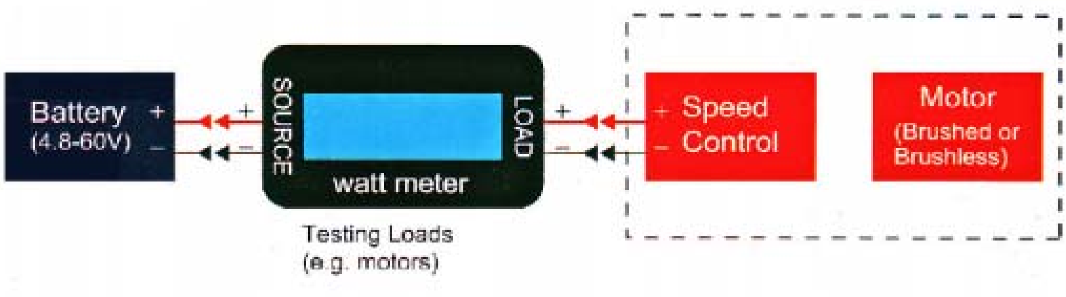



Figure 3.34: Turnigy Monitor Connections

### 3.1.9 Motor


Figure 3.35: Magic Pie 2 Conversion Kit

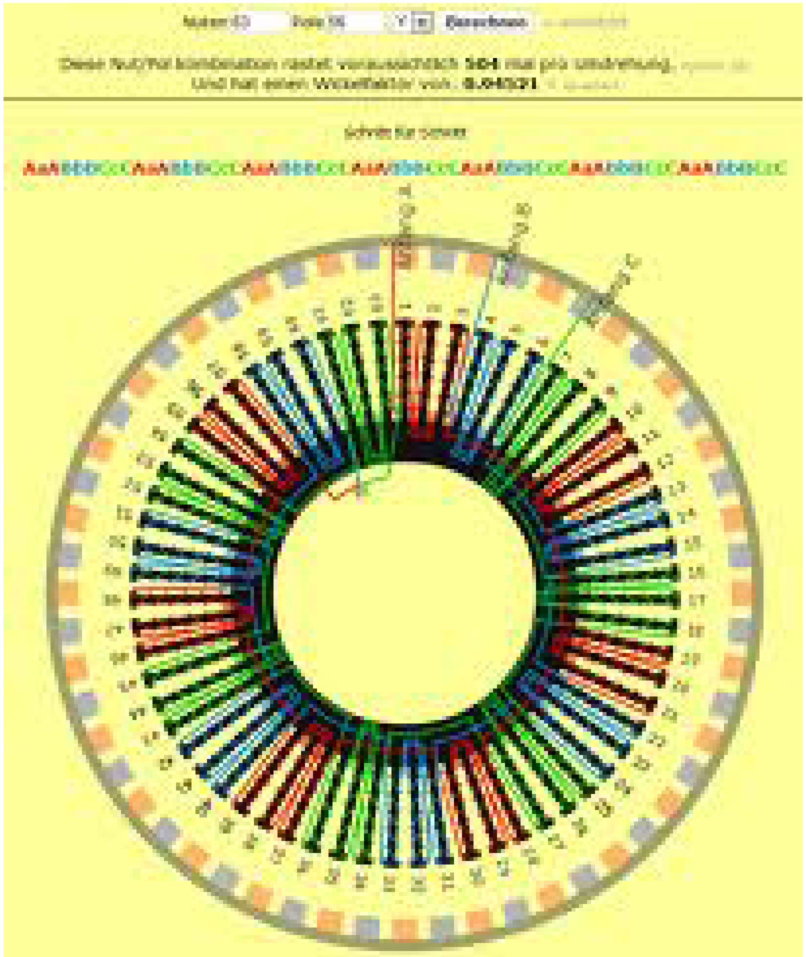


Figure 3.36: Magic Pie 2 - BLDC Motor Design

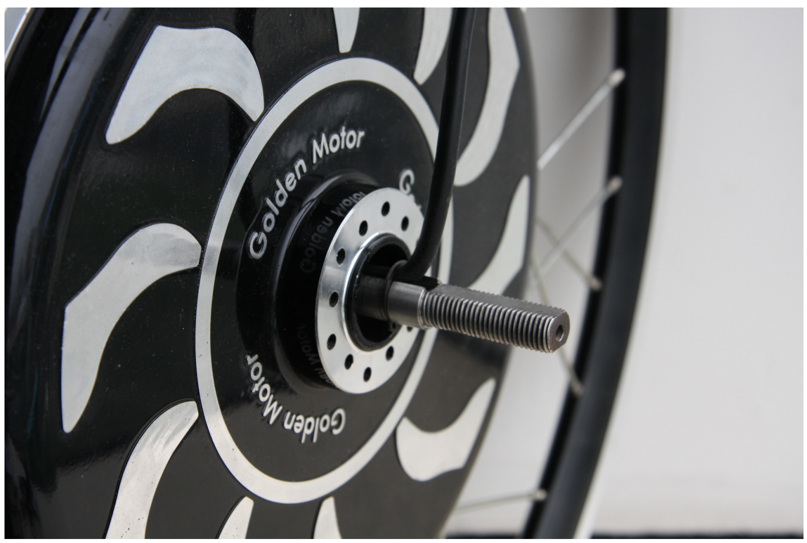



Figure 3.37: Motor with 26inch wheel and tire

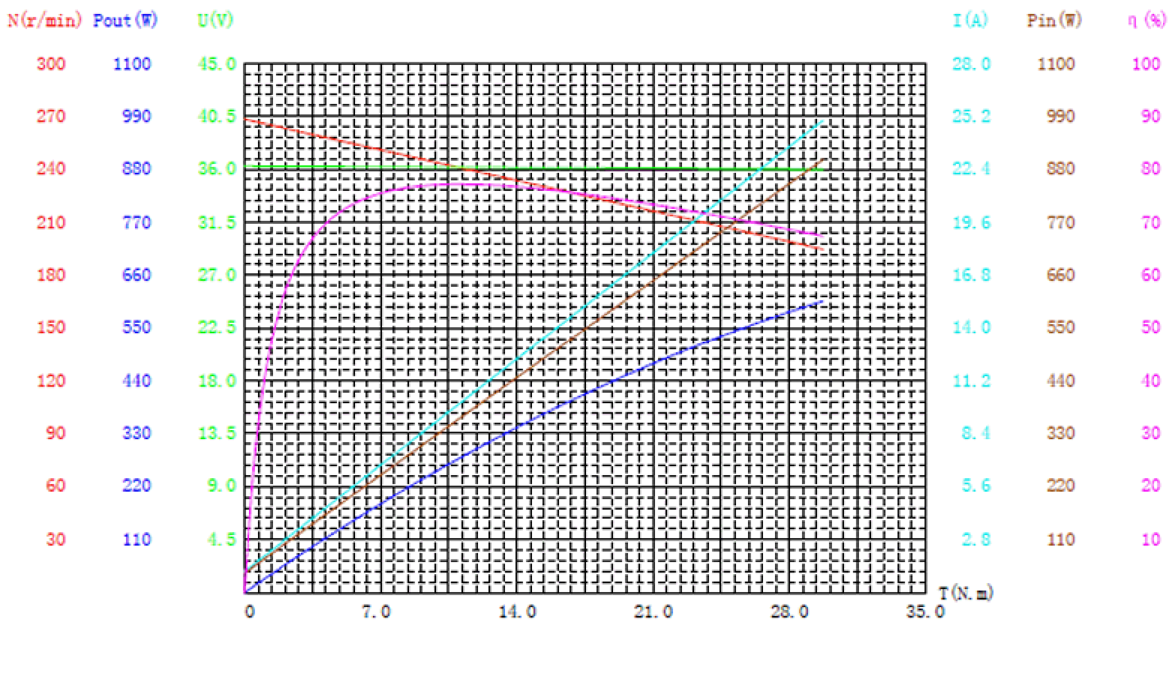


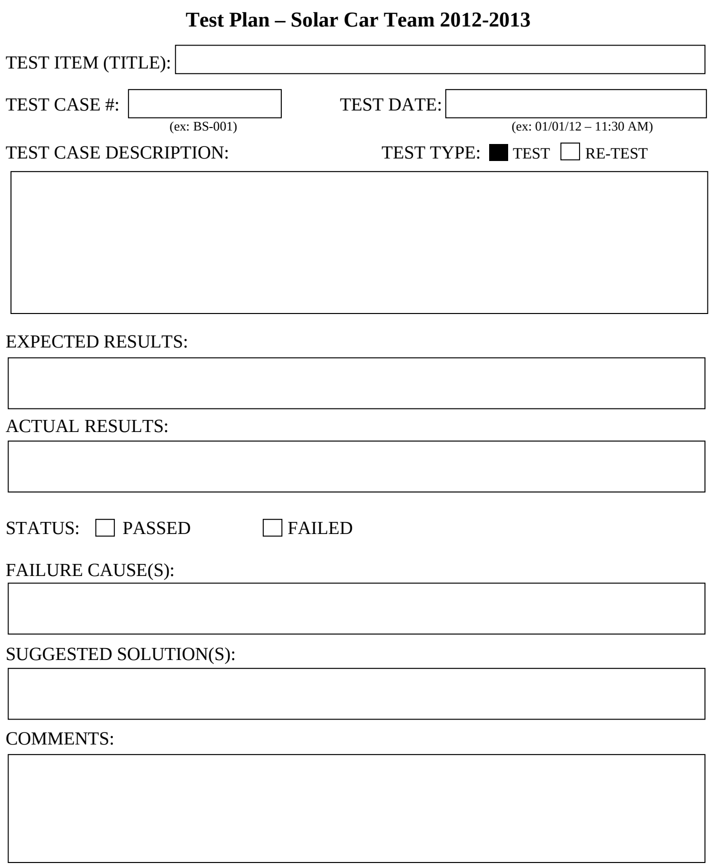

Figure 3.38: Ratings and Curves for Motor


Figure 3.39: Motor Kit Wiring Diagram


Figure 3.40: Motor Control Box

# 4 Test Plan

A test plan document was created by the members of the previous phase as seen in Figure 4.1. In order to keep consistency this phase of the project will also implement the same test plan document. This template displays all the pertinent information about each test, including what is being tested, the goals of the tests, and final results.



**Test Plan – Solar Car Team 2012-2013**

TEST ITEM (TITLE):

TEST CASE #: (ex: BS-001) TEST DATE: (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION: TEST TYPE: ■ TEST ☐ RE-TEST

EXPECTED RESULTS:

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Figure 4.1: Test Plan Template

## 4.1 Summary of Test Plan Status

Table 4.1: Test Plan Summary

| Test Number | (Pass/Fail) or N/A | Completed |
|---|---|---|
| SA-01 | Passed | 02/13/13 |
| SA-02 | Passed | 02/18/13 |
| SA-03 | Passed | NA |
| SA-04 | Passed | 04/01/13 |
| SA-05 | Passed | 02/11/13 |
| SA-06 | Failed | 04/01/13 |
| SA-07 | NA | During Summer |
| SA-08 | NA | Next Year |
| BC-01 | NA | 02/06/13 |
| BC-02 | NA | TBD |
| BS-01 | Passed | 01/31/13 |
| BS-02 | Passed | 01/31/13 |
| BS-03 | Passed | 01/16/13 |
| BS-04 | Passed | 02/08/13 |
| BS-05 | Failed | 04/09/13 |
| MC-01 | Failed | NA |
| MC-02 | Failed | NA |
| MC-03 | Failed | NA |
| SI-01 | Passed | March 2013 |
| SI-02 | Failed | March 2013 |
| SI-03 | Failed | March 2013 |
| SI-04 | Failed | March 2013 |
| CH-01 | Passed | 01/20-02/5 |
| CH-02 | Passed | 01/20-02/5 |
| CH-03 | NA | 01/20-02/5 |
| CH-04 | NA | 01/20-02/5 |
| CH-05 | Failed | 01/20-02/5 |
| CH-06 | Passed | 01/20-02/5 |
| CH-07 | Passed | 01/20-02/5 |
| RB-01 | NA | Next Year |
| RB-02 | NA | TBD |
| RB-03 | Passed | 03/30/13 |
| RB-04 | Passed | 02/04/13 |
| RB-05 | Passed | 02/04/13 |

# 5 Schedule

| | | | | |
|---|---|---|---|---|
| **Chassis** | **138 days** | **Mon 10/1/12** | **Wed 4/10/13** | |
| Development/Modeling Pro-Engineer | 21.8 wks | Mon 10/1/12 | Thu 2/28/13 | |
| Chassis Material Decision | 10 days | Thu 2/7/13 | Wed 2/20/13 | |
| Stress and aerodynamics testing | 3 wks | Thu 2/7/13 | Wed 2/27/13 | |
| Start of Chassis | 29 days | Fri 3/1/13 | Wed 4/10/13 | |
| **Steering Simulation** | 2 wks | Thu 2/7/13 | Wed 2/20/13 | |
| **Steering Wheel Selection** | **0 days** | **Mon 3/4/13** | **Mon 3/4/13** | |
| ~~**Steering Ordering and Manufactoring**~~ | ~~**21 days**~~ | ~~**Fri 3/1/13**~~ | ~~**Fri 3/29/13**~~ | |
| **Research on Brakes** | **16 days** | **Sat 3/2/13** | **Fri 3/22/13** | |
| ~~Suspension Research/Design~~ | ~~11 wks~~ | ~~Tue 10/2/12~~ | ~~Mon 12/17/12~~ | |
| **Final Prototype Design Chosen** | 0 days | Thu 2/28/13 | Thu 2/28/13 | 14,27 |
| **HPMI Design Development** | 6 wks | Fri 3/8/13 | Thu 4/18/13 | 23 |
| **Roll Bar Design and Development** | 1.2 wks | Thu 4/11/13 | Thu 4/18/13 | |
| ~~Research on Sheild/Cockpit~~ | ~~3 wks~~ | ~~Mon 10/1/12~~ | ~~Fri 10/19/12~~ | |
| ~~Hatch Design~~ | ~~7 wks~~ | ~~Tue 9/11/12~~ | ~~Mon 10/29/12~~ | |
| ~~Cockpit Design~~ | ~~2 wks~~ | ~~Fri 3/1/13~~ | ~~Thu 3/14/13~~ | ~~23~~ |
| **Roll Bar Design** | 1 day? | Tue 9/11/12 | Tue 9/11/12 | 27 |
| Roll Bar Simulation in PROe **PROe** | 35 days | Mon 1/7/13 | Fri 2/22/13 | 29 |
| **Integration of Roll Bar** | **0 days** | **Thu 4/18/13** | **Thu 4/18/13** | |
| **Car Chassis Open/Close/Locking** | 12 wks | Tue 9/11/12 | Mon 12/3/12 | 28 |
| **PRO-Engineer w/ Fully Articulated Model** | 23.6 wks | Mon 11/19/12 | Wed 5/1/13 | 23 |

Figure 5.1: Mechanical Schedule

| | | | | |
|---|---|---|---|---|
| **Solar Panels** | **120 days** | **Mon 10/1/12** | **Fri 3/15/13** | |
| Research into Manufactoring at COE | 6 wks | Mon 10/15/12 | Fri 11/23/12 | |
| Manufactoring or Purchasing? | 1 day | Mon 11/26/12 | Mon 11/26/12 | 38 |
| Time needed to purchase or manufacture | 6 wks | Tue 11/27/12 | Mon 1/7/13 | 39 |
| Protection Design/Purchasing | 4 wks | Tue 11/27/12 | Mon 12/24/12 | 39 |
| Verification of Design | 2 wks | Tue 1/8/13 | Mon 1/21/13 | 40,41 |
| Build Array w/ Protection | 4 wks | Tue 1/22/13 | Mon 2/18/13 | 42 |
| ~~Energy System Integration~~ | ~~2 wks~~ | ~~Tue 2/19/13~~ | ~~Mon 3/4/13~~ | ~~43~~ |
| Solar Panel Testing | 2 wks | Thu 2/7/13 | Wed 2/20/13 | |
| ~~HF Transformer~~ | ~~115 days~~ | ~~Mon 10/8/12~~ | ~~Fri 3/15/13~~ | |
| **Converter Selection** | **0 days** | **Tue 1/8/13** | **Tue 1/8/13** | |
| **Converter Testing** | **2 wks** | **Thu 2/7/13** | **Wed 2/20/13** | |
| **Battery System** | **120 days** | **Mon 10/1/12** | **Fri 3/15/13** | |
| Company interactions | 4 wks | Mon 10/8/12 | Fri 11/2/12 | |
| Model Development | 2 wks | Mon 11/5/12 | Fri 11/16/12 | 56 |
| Ordering and Shipping | 4 wks | Mon 11/5/12 | Fri 11/30/12 | 56 |
| BMS Testing with DC load bank | 6 wks | Mon 12/3/12 | Fri 1/11/13 | 58 |
| Battery Testing with DC load bank | 6 wks | Mon 12/3/12 | Fri 1/11/13 | 58 |
| Verification of Devices | 2 wks | Mon 1/14/13 | Fri 1/25/13 | 59,60 |
| ~~Integration~~ | ~~26 days~~ | ~~Mon 1/28/13~~ | ~~Mon 3/4/13~~ | ~~61~~ |
| Battery Testing | 30 days | Mon 1/14/13 | Fri 2/22/13 | |
| **Motor** | **120 days** | **Mon 10/1/12** | **Fri 3/15/13** | |
| Discussion with Different Companies | 3 wks | Mon 10/1/12 | Fri 10/19/12 | |
| Motor Determination | 0 days | Mon 10/22/12 | Mon 10/22/12 | 65 |
| Purchasing and Shipping | 4.2 wks | Thu 1/31/13 | Thu 2/28/13 | 66 |
| ~~Simulation Model of Motor~~ | ~~3 wks~~ | ~~Fri 2/8/13~~ | ~~Thu 2/28/13~~ | ~~65~~ |

Figure 5.2: Electrical Schedule

# 6 Final Budget

Table 6.1: Budget as of April 17th

| Part | Cost |
|---|---|
| Chassis Materials and Manufacturing | $1000.00 |
| Steering Materials | $0.00 |
| Roll Bar Materials and Manufacturing | $500.00 |
| Latching/Locking Mechanism | $0.00 |
| Solar Cells* | $0.00 |
| Solar Array Manufacturing* | $0.00 |
| Solar Junction Box (x2) | $65.00 |
| Boost Converter* | $0.00 |
| MPPT Controller* | $0.00 |
| Battery System including BMS | $480.00 |
| Old Hub Motor plus shipping | $265.00 |
| KBS24101,40A,12-24V, Mini Brushless DC Controller | $119.00 |
| Motor Control Box(KBS) | $39.00 |
| Throttle/Brake Pedal (x2) | $138.00 |
| Meter LED 24Volt State of Charge | $19.00 |
| Amperemeter with a free diode | $29.00 |
| Main Contactor CZ 24VDC Coils 100Amps | $29.00 |
| New Hub Motor Kit plus shipping | $495.00 |
| Miscellaneous Production Materials | $400.00 |
| TOTAL | $3578.00 |

*-Items donated or received for educational purposes. Note: Includes purchases made under ME and EE department

# 7 Conclusion

All goals for the solar car team have been accomplished as forseen. Several pertinent tasks were not fully completed, such as the steering, braking or motor setup, yet these will be finalized this summer.

# References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# A Test Plan Reports

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): 2D Aerodynamics of Chassis Design

TEST CASE #: CH-01
(ex: BS-001)

TEST DATE: 01/30/13 TILL 02/04/13
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Modeling aerodynamics in 2D will help get an estimation of the actual flow over the car. The advantage of 2D is that the time for each iteration is decreased significantly. The disadvantage is the flow could behave very differently in 3D. 2D flow analysis can be mainly used as a tool as a first start to minimizing aerodynamic drag. It also will be able to answer the question on how the flow will react with the open top of the car.

EXPECTED RESULTS:

Aerodynamic profile of Velocity and Pressure. Along with this the Coefficient of Drag and Lift.

ACTUAL RESULTS:

Aerodynamic profile of the Velocity and Pressure, and the Coefficient of Drag and Lift.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): 3D Aerodynamics of Chassis Design

TEST CASE #: CH-02
(ex: BS-001)

TEST DATE: 01/16/13 TILL PRESENT
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Modeling Aerodynamics in 3D will help greatly with finding a highly accurate Coefficient of Drag and Coefficient of Lift for the chassis design. With these Coefficients we can then change the geometry of the car to lower these values as much as possible without hurting the structural integrity. COMSOL 3D is used for the Aerodynamic tests and require a transfer of geometry from Pro Engineering to carry out the procedure. Then air at 15mph will be simulated going over the chassis

EXPECTED RESULTS:

The expected result is an aerodynamic profile for the geometry of the chassis that shows a close estimate to the actual flow. Along with this would be a Coefficient of Drag and Lift for the chassis.

ACTUAL RESULTS:

Failed to mesh the imported Geometry.

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

The geometry is imported as an STL file which might be hard for COMSOL to remesh

SUGGESTED SOLUTION(S):

Remake the geometry in COMSOL. Or try remaking the geometry in Pro Engineering that would transfer more easily.

COMMENTS:

This test is undergoing right now. The task now is to try remaking the geometry in Pro Engineering. This was selected as the first solution because of its much shorter time to making the geometry in COMSOL; however, it is not guaranteed to work. If it does not work the geometry will have to be made in COMSOL.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): After Fabrication Testing of Strength

TEST CASE #: CH-03 (ex: BS-001)

TEST DATE: 04/05/13 (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

After making the car we will want to that it will be able to handle the full stress of all the components. Therefore we will apply weight appropriately placed to mimic all of the forces that will be exerted on the body. With this applied we will measure the displacement if there is any and deem the chassis fit for competition or not.

EXPECTED RESULTS:

The chassis will have minimal to no deflection with the full force applied to it

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Full Stress Simulation and Analysis of Chassis

TEST CASE #: CH-04
(ex: BS-001)

TEST DATE: 02/13/13
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Accurate Simulation must be done on the solar car to determine the thickness and cell size of the material needed for the lower half of the car. To do this material properties of Aluminum Honeycomb Carbon Fiber will have to be found out. With these iterations will be made to determine the optimum parameters. These tests will be done with Pro Engineering or COMSOL depending on availability. They will include a safety factor of 2 on the forces to make sure a failure does not happen.

EXPECTED RESULTS:

A stress profile for a variety of thickness's and cell sizes. Along with this a deflection profile to make sure it is acceptable.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Integrated Roll bar in Chassis Stress Test

TEST CASE #: CH-05
(ex: BS-001)

TEST DATE: 01/09/13 – 3:30PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The Shell Eco-Marathon requires that the car must be stable even when an extra 700N load is applied to the top of the roll bar. A stress simulation will be used to make sure the chassis and roll bar will be able to support this added load along with the load of the driver. This simulation was done with Pro Engineering Mechanica and was used on a combined roll bar and chassis. The simulation had a 700N load applied to the roll bar and a 200lbf load applied to the driver's position.

EXPECTED RESULTS:

A stress profile that shows points of high and low stress. Along with a deflection profile that shows an accurate representation of what the deflection will be.

ACTUAL RESULTS:

Failure of simulation

STATUS: ☐ PASSED ■ FAILED

FAILURE CAUSE(S):

Simulation failed one hour into test. Reason: "Attempted to request 1.04 Gb more of memory. Request denied."

SUGGESTED SOLUTION(S):

Separate the chassis and roll bar to lower the computations necessary for stress analysis. Or find a computer with Pro Engineering that has more RAM. And/or transfer model into COMSOL which has a better physics simulator.

COMMENTS:

Multiple attempts were made to resolve issue with the help of Dr. Hollis. All were met with a request for more memory.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Preliminary Stress Analysis on Chassis

TEST CASE #: CH-06 (ex: BS-001)

TEST DATE: 12/16/12 – 2:30PM (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

With the chassis design finalized. Stress analysis must be done to determine thickness of Aluminum Honeycomb Carbon fiber. Pro Engineering Mechanica was used to determine an approximate value of the stress throughout the chassis when a fake load of a person is applied. This will also help with determining the weak points of the material and the deflection of the material.

EXPECTED RESULTS:

A profile that has points of high stress concentration that needs to be accounted for in designing the car.

ACTUAL RESULTS:

A high stress profile was found in the bottom panel (where the person will be sitting). Therefore the panel was doubled in thickness which made all stresses acceptable.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

There were three iterations in conducting the simulation. The first failed due to improper constraints which is a user error. The second failed because of the thickness of the material. And the third passed with having adequate stress distribution.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): FULL SIZE WOODEN DEMO CHASSIS

TEST CASE #: CH-07
(ex: BS-001)

TEST DATE: 1/20, 1/27: 2 Hours each day
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Is this case, a wooden full size chassis will be built from plywood. The chassis is made up of multiple polygons joined a many angles. After measuring and cutting all polygons for both the top and bottom half of the chassis, each piece will be simply joined with bendable brackets and wood screws. The angles for each polygon will not be needed, since the lengths and locations of all polygons per half will join and create the proper angles.

EXPECTED RESULTS:

To have a full size wooden demo chassis built.

ACTUAL RESULTS:

In progress

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Physical Roll Bar Stress Testing

TEST CASE #: RB-01
(ex: BS-001)

TEST DATE: TBD
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Upon completion of the fabrication of the chromolly steel roll bar and its subsequent instillation in the chassis, it will be stress tested by applying a load of 700N (~158lbs) in various directions on the bar. As per Shell regulation, the roll bar must be able to handle this load from the top, front, back, and sides without deformation. Our roll bar will be load tested in accordance with these standards. This can be done simply by having a 160lb weight applied to the roll bar different orientations with chassis movement restricted.

EXPECTED RESULTS:

Considering the safety factor of 2 implemented in the roll bar design, the expectation is that the roll bar should have no issues or experience any deformation with these loads separately applied.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Roll Bar Stress & Deformation Simulation

TEST CASE #: RB-01A
(ex: BS-001)

TEST DATE: 02/07/13 – 4pm
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Per the Solar Eco Marathon standards, the roll bar must be capable of accepting a 700N load (~72kg or 158 lbs) from the top, sides, front, and rear (separately) without deformation. This will be negotiated within the Pro Engineering mechanica program where a factor of safety of 2 will be added and deflection and stress distribution profiles will be compiled. The material used in mechanica will be that of regular steel which, although weaker than chromoly steel, is the closest approximation that can be applied at this time. Should the testing show the roll bar to perform far beyond expectations (with the factor of safety implemented), the roll bar will be tested again employing tubing with less thickness to see how it performs under the same conditions. Presently, the roll cage is designed with a standard 1.25" x 0.065" tube throughout, but it is feasible that a 1.25" x 0.049" could accomplish the same ends, decreasing both tube weight and cost.

EXPECTED RESULTS:

Several stress and deflection profiles will provide sufficient results to ensure that the roll bar material, structure, and tube size is acceptable to withstand 1,400N from multiple directions without deformation.

ACTUAL RESULTS:

The stress and deflection profiles show clear evidence that our roll bar size can be decreased without sacrificing performance. Its current simulated construction exceeds the safety requirements by a large margin. Simulation will be conducted again using the 1.25" x 0.049" tube size, a wall thickness decrease of 0.016".

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

In the Pro Engineering simulations of the roll bar to follow, the actual material properties on 4130 normalized chromoly steel will be utilized for more exact results.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Roll Bar Stress & Deformation Simulation II

TEST CASE #: RB-01B
(ex: BS-001)

TEST DATE: 02/09/13 – 4pm
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test is a follow up to the results of test RB-01A. To recap, per the Solar Eco Marathon standards, the roll bar must be capable of accepting a 700N load (~72kg or 158 lbs) from the top, sides, front, and rear (separately) without deformation. This will be negotiated within the Pro Engineering mechanica program where a factor of safety of 2 will be added and deflection and stress distribution profiles will be compiled. The material used in mechanica this time will be that of normalized 4130 chromoly steel. For this test, the roll cage is designed with a standard 1.25" x 0.049" tube throughout.

EXPECTED RESULTS:

Several stress and deflection profiles will provide sufficient results to ensure that the roll bar material, structure, and tube size is acceptable to withstand 1,400N from multiple directions without deformation.

ACTUAL RESULTS:

The stress and deflection profiles showed that the roll bar is capable of withstanding the various load directions with a safety factor of two implemented. The bar undergoes the most stress concentration in particular areas when a force is applied to the front of the roll bar.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

The decision has been made to reduce the roll bar size no further. The vehicle's roll bar will be constructed of type 4130 chromoly steel, size 1.25" x 0.049" tube. This steel tubing will provide excellent driver protection and will without doubt satisfy Shell's standards. Reducing the tube size further has no real gain for the solar car project, as depending on the smaller tube size selected it will either: a) Drive up the tube cost while reducing the roll bar weight by (at best) a single pound and making it weaker overall, or b) Drop the cost of the tubing by $0.48 per foot and bar weight by roughly 2 lbs but suffer a substantial loss of strength in the bar, so much so that a safety factor of just 2 causes close encroachment on tensile yield values for the steel. Seeing as this is just a simulation, and the actual purchased steel may not be as strong as the steel simulated, it is best to err on the side of caution and reduce the tube size no more.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Roll Bar Stress & Deformation Simulation IV

TEST CASE #: RB-01D (ex: BS-001)

TEST DATE: 04/13/13 – 8am (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test is necessary as the roll bar's structure has been changed to fit inside the new chassis profile. The driver will now be sitting lower in the car and there will be opening in the top of the car body to sit up through. The only change this makes to the roll bar is the housing bar now does not extend past the cross-member bar. This design simplifies the roll bar, upgrades its effectiveness at protecting the driver from harm, and will reduce its overall weight by roughly 1.5 lbs. To recap, per the Solar Eco Marathon standards, the roll bar must be capable of accepting a 700N load (~72kg or 158 lbs) from the top, sides, front, and rear (separately) without deformation. This will once again be negotiated within the Pro Engineering mechanica program where a factor of safety of 2 will be added and deflection and stress distribution profiles will be compiled. The tubing used in mechanica remains unchanged: 1.25" x 0.065" 4130N chromoly steel.

EXPECTED RESULTS:

Several stress and deflection profiles will provide sufficient results to ensure that the roll bar material, structure, and tube size is acceptable to withstand 1,400N from multiple directions without deformation.

ACTUAL RESULTS:

The stress and deflection profiles showed that the roll bar is more than capable of withstanding the various load directions with a safety factor of two implemented.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Rear Wheel Fork Stress Simulation

TEST CASE #: (ex: BS-001)

TEST DATE: 03/30/13 – 5pm (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Once the rear driving wheel position has been decided within the Pro Engineering model, a stress and deflection test will be conducted through mechanica to examine the impact of the vehicle's rear weight (when driver occupied) on the roll bar. The axel fork extends outward from the rear supports of the roll bar to hold the axel for the rear wheel, much like a fork for the front wheel of a bicycle. The resulting stress profile will reveal any structural issues with the fork and/or roll bar design in regards to supporting the vehicle's rear weight. A factor of safety of 2 will be implemented for this test to ensure stability and structural integrity in our final design.

EXPECTED RESULTS:

The rear wheel fork design will prove sufficient for negotiating the rear load of the vehicle when occupied, showing either minimum or no deflection.

ACTUAL RESULTS:

The rear of the roll bar was capable of withstanding a 400lb distributed load on the axel fork. Minimum stress and deflection was seen and the values exceeded expectation. The design has proven to be sufficient in handling a very heavy load on the rear of the car, reaching stresses far below the yield stress of 4130N chromoly.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Roll Bar Size Simulation

TEST CASE #: RB-04
(ex: BS-001)

TEST DATE: 02/04/13 – 7pm
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

The size testing of the chromoly steel roll bar design involves the construction of a virtual three dimensional model within the Pro Engineering program. The virtual roll bar will be formed so that it's four mounting plates rest evenly and securely within the bottom half vehicle chassis, ensuring that the roll cage weight will be evenly distributed on both its left and right side and that the mounting plates are flush with the lower chassis interior for secure bolting. This 3D model will also serve as a check that the roll cage top successfully passes through the top of the vehicle chassis (the cockpit) without complication and that the driver will be adequately protected by the roll bar should the vehicle overturn. Per the Shell Eco Marathon competition standards, the roll cage top housing bar must pass at least 5 cm above the top of the driver's helmet and securely encompass the driver's shoulders. This sizing simulation will provide adequate feedback regarding whether the roll bar satisfies these protection parameters or not.

EXPECTED RESULTS:

The roll bar will fit into the simulated vehicle chassis with mounting plates flush to the bottom interior with no overlapping of the two parts and provide the at least the minimum desired protection of the driver.

ACTUAL RESULTS:

The roll bar fit within the simulated chassis with no issue as per expectations and does provide the minimum required protection of the driver (this utilizing an average male body type and height for the driver).

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Roll Bar Size Simulation

TEST CASE #: RB-04
(ex: BS-001)

TEST DATE: 02/04/13 – 7pm
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST □ RE-TEST

The size testing of the chromoly steel roll bar design involves the construction of a virtual three dimensional model within the Pro Engineering program. The virtual roll bar will be formed so that it's four mounting plates rest evenly and securely within the bottom half vehicle chassis, ensuring that the roll cage weight will be evenly distributed on both its left and right side and that the mounting plates are flush with the lower chassis interior for secure bolting. This 3D model will also serve as a check that the roll cage top successfully passes through the top of the vehicle chassis (the cockpit) without complication and that the driver will be adequately protected by the roll bar should the vehicle overturn. Per the Shell Eco Marathon competition standards, the roll cage top housing bar must pass at least 5 cm above the top of the driver's helmet and securely encompass the driver's shoulders. This sizing simulation will provide adequate feedback regarding whether the roll bar satisfies these protection parameters or not.

EXPECTED RESULTS:

The roll bar will fit into the simulated vehicle chassis with mounting plates flush to the bottom interior with no overlapping of the two parts and provide the at least the minimum desired protection of the driver.

ACTUAL RESULTS:

The roll bar fit within the simulated chassis with no issue as per expectations and does provide the minimum required protection of the driver (this utilizing an average male body type and height for the driver).

STATUS: ■ PASSED □ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Steering – Determining Turning Radius

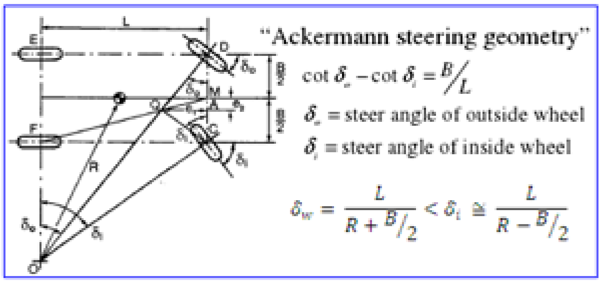
TEST CASE #: ST-002
(ex: BS-001)

TEST DATE: 2/21/13 – 5:30PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

We will be testing a steering design that incorporates Ackermann, which causes the inside (closest to the radius of the turn) wheel to turn a greater amount than the outside wheel. We need this difference in steering angle because the inside wheel runs on a smaller circle or arc than the outside wheel. To test, we will model our system in Pro/E and simulate using Simulink, a MATLAB based software. In conjunction with computer based simulations, we will employ the Ackermann equation to determine comparison solutions.




EXPECTED RESULTS:

The proper turning radius will be determined and implemented into design specifications.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Steering – Determining Turning Radius (After Manufacturing)

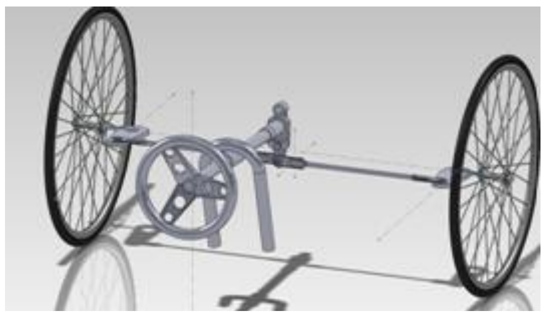
TEST CASE #: ST-003
(ex: BS-001)

TEST DATE: 3/21/13 – 5:30PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☐ TEST ■ RE-TEST

We will be testing a steering design that incorporates Ackermann. We will be testing the results of our modeled system in Pro/E and simulated using Simulink, a MATLAB based software. We have already created a full scale demonstration model of the solar car, so we would simply mount the steering components to the body. The linkages should fit together as specified from the Pro/E model, so all is needed is implementation. The turning radius must be a minimum of 6 meters.



EXPECTED RESULTS:

The true turning radius will be known and corrections will be made to ensure the required specification of 6 meters have been met.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

The turning radius must be sufficient to enable safe overtaking as well as negotiating the turns of the track. The slalom course in Asia and the Americas will require a turning radius of 6 m,

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Preliminary Stress Analysis on Steering

TEST CASE #: ST-001
(ex: BS-001)

TEST DATE: 2/21/13 – 5:30PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

After the steering system modeled, stress analysis must be done to determine what the allowable forces are before failure occurs. Pro Engineer/Mechanica software was used to determine an approximate value of the stress throughout the steering system, from the steering mount to the wheel connection. Once the testing is complete, fabricated can be completed.

EXPECTED RESULTS:

A profile that has points of high stress concentration that needs to be accounted for in designing the car.

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

This stress testing would be front mounted steering *only*. This included and is limited to the components of the front mount. The rear wheel is not used in steering thus testing for that mounting would be separate.

# Test Plan – Solar Car Team 2012-2013

**TEST ITEM (TITLE):** **Solar Module Test**

TEST CASE #: SA-01
(ex: BS-001)

TEST DATE: 02/14/13 – 2:00 PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test is to check all 17 solar modules for Voc and Isc to land within 1.6 -1.8 V and 18-22 A respectively.
This will ensure that all modules being used are working properly before installation on the car. The test will be conducted in clear weather mid-day.

EXPECTED RESULTS:

All modules will output as specified on the data sheet.

ACTUAL RESULTS:

All Solar Modules have been tested, 15 of them matched the expected results
2 of the modules failed and had lower Voltage and Current than expected

STATUS: [X] PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

The team will have extra modules for replacing purposes

# Test Plan – Solar Car Team 2012-2013

**TEST ITEM (TITLE):** Protection Circuit Continuity Test

TEST CASE #: SA-02 (ex: BS-001)

TEST DATE: 02/18/13 – 9:30 AM (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

There are two parts to this test to be repeated for all 35 circuits:
Part 1 is to make sure that there are connections between the different nodes.
Part 2 is to make sure there is no connection if there is any reverse current.

EXPECTED RESULTS:

Part 1: There is a connection between the nodes in forward bias
Part 2: There is not a connection between the nodes in reverse bias

ACTUAL RESULTS:

The solar array that have been built worked perfectly, all the connections worked as wanted and there where no problems with array.

STATUS: [X] PASSED [ ] FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

**TEST ITEM (TITLE):** Protection Circuit Test on Single Solar Panel Set

TEST CASE #: SA-03
(ex: BS-001)

TEST DATE:
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test checks that the designed protection circuit and the solar junction boxes are functional and outputs desired voltage and current.
Part 1: Test Panel Voltage and Current with no shading.
Part 2: Test Current and Voltage with shading one of the solar modules each time

EXPECTED RESULTS:

The design is functional and allows for partial shading of panels without total loss of power output. Voltage will be affected by shading but current will stay the same.

ACTUAL RESULTS:

The protections circuit worked as expected. After the solar junctions boxes the array tested in different weathers. Every single cell got shaded and the solar junction boxes did what they where suppose to do.

STATUS: ☒ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

**TEST ITEM (TITLE):** **Solar Array Test**

TEST CASE #: SA-04
(ex: BS-001)

TEST DATE: 04/01/13 – 11:30 AM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

There are three parts to this test to be done to the whole Array after the final connection:
Part 1 includes testing each array for voltage in direct sunlight.
Part 2 includes testing each arrays current output in direct sunlight.
Part 3 includes partial shading current output.

EXPECTED RESULTS:

Part 1: Voltage off the array should be between 8V and 9V.
Part 2: Current output for each array should be between 3A and 3.5A.
Part 3: When a single module in the array is shaded the current output should not change.

ACTUAL RESULTS:

Part 1: Voltage off the array between 8V and 9V.
Part 2: Current output for the array between 3A and 3.5A.
Part 3: When a single module in the array is shaded the current output changeged a little.

STATUS: [X] PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

**TEST ITEM (TITLE):** Solar Modules Physical Strength

TEST CASE #: SA-05
(ex: BS-001)

TEST DATE: 02/11/13 – 10:30 AM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

There are three parts to this test to assure the solar modules strength:
Part 1 Dropping the module from 5 feet high.
Part 2 Driving over the module with a car.
Part 3 Use a rubber hammer on the top of the solar module.

EXPECTED RESULTS:

The solar module should be fine to use and no voltage or current lost should occur.

ACTUAL RESULTS:

The solar Cells after protection completed became really strong and passed all the tests without any voltage and current drops

STATUS: ☒ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

**TEST ITEM (TITLE):** Installation Methods Testing

TEST CASE #: SA-06
(ex: BS-001)

TEST DATE: 04/01/13 – 11:30 AM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test will allow the team to decide between screws or other implementation

EXPECTED RESULTS:

Team should find the right and most convenient way to install cells into the car

ACTUAL RESULTS:

Since that car is not completed and the solar cells never installed to the car it's still not clear what the best way would be

STATUS: ☐ PASSED X FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Solar Array - DC Electronic Load Simulation

TEST CASE #: SA-07
(ex: BS-001)

TEST DATE:
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connect an individual solar cell to the BK Precision 2400W Programmable DC Electronic Load. Use a bright light bulb shined onto the solar cell to simulate the voltage and current characteristics of the solar cell.

EXPECTED RESULTS:

Obtain the I-V and P-V curves for the solar cell

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Installation Methods Testing

TEST CASE #: SA-08 (ex: BS-001)

TEST DATE: 04/01/13 – 11:30 AM (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test will allow the team to decide between screws or other implementation

EXPECTED RESULTS:

Team should find the right and most convenient way to install cells into the car

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

## Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Boost Converter Test

TEST CASE #: BC-01 (ex: BS-001)

TEST DATE: 02/08/13 – 11:00 AM (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connecting the boost converter to a shift voltage and a DC load bank and observing the output.

EXPECTED RESULTS:

Output is regulated as expected

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Boost Converter Test

TEST CASE #: BC-02 (ex: BS-001)

TEST DATE: 02/06/13 – 9:00 AM (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This test will be done into multiples stages to simulate different weather conditions: Early in the morning at 9AM, midday at 12 PM, afternoon at 4PM and evening at 6PM. This test is to check that the voltage output of converter does not exceed 24V and the current is high enough to ensure that the battery is charged.

EXPECTED RESULTS:

Output is as expected at all times

ACTUAL RESULTS:

STATUS: ☐ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

BK Precision - 85522 Programmable DC Electronic Load

The BK Precision 8522 Programmable DC Electronic Load was made available to the solar car team for testing purposes at CAPS by Dr. Edrington under the guidance of Jesse Leonard. The DC Electronic Load will be primarily used to simulate the discharge curves of the battery and test the limits of the battery management system. The load will also be used to observe the characteristics of the solar cells using an artificial light in the lab. Further testing possibilities using the electronic load have yet to be finalized but could include DC-DC converter testing as well as full system integration of the batteries, solar cells, and converter with the load representing the motor.

- Operates between 0-500 VDC, 1 mA-120 A, 2400 W max
- Constant current (CC), resistance (CR), voltage (CV) and power (CP) operation
- Built-in high resolution (1 mA/1 mV) voltage and current measurement (range dependant)
- Programmable via RS232 or USB interface. RS232 to TTL serial converter cable, USB to TTL serial converter cable, and application software included
- Battery testing mode to provide Ah rating of battery
- Low minimum operating voltage of <0.1 V and minimum input resistance of $5m/omega$ allowing the load sink high current at low voltages, required for fuel and solar cell applications
- Over-Current/Over-Voltage/Over-Power/Over-Temperature Protection

Figure A.1: Battery Testing with Dr. Edrington’s DC Load Bank

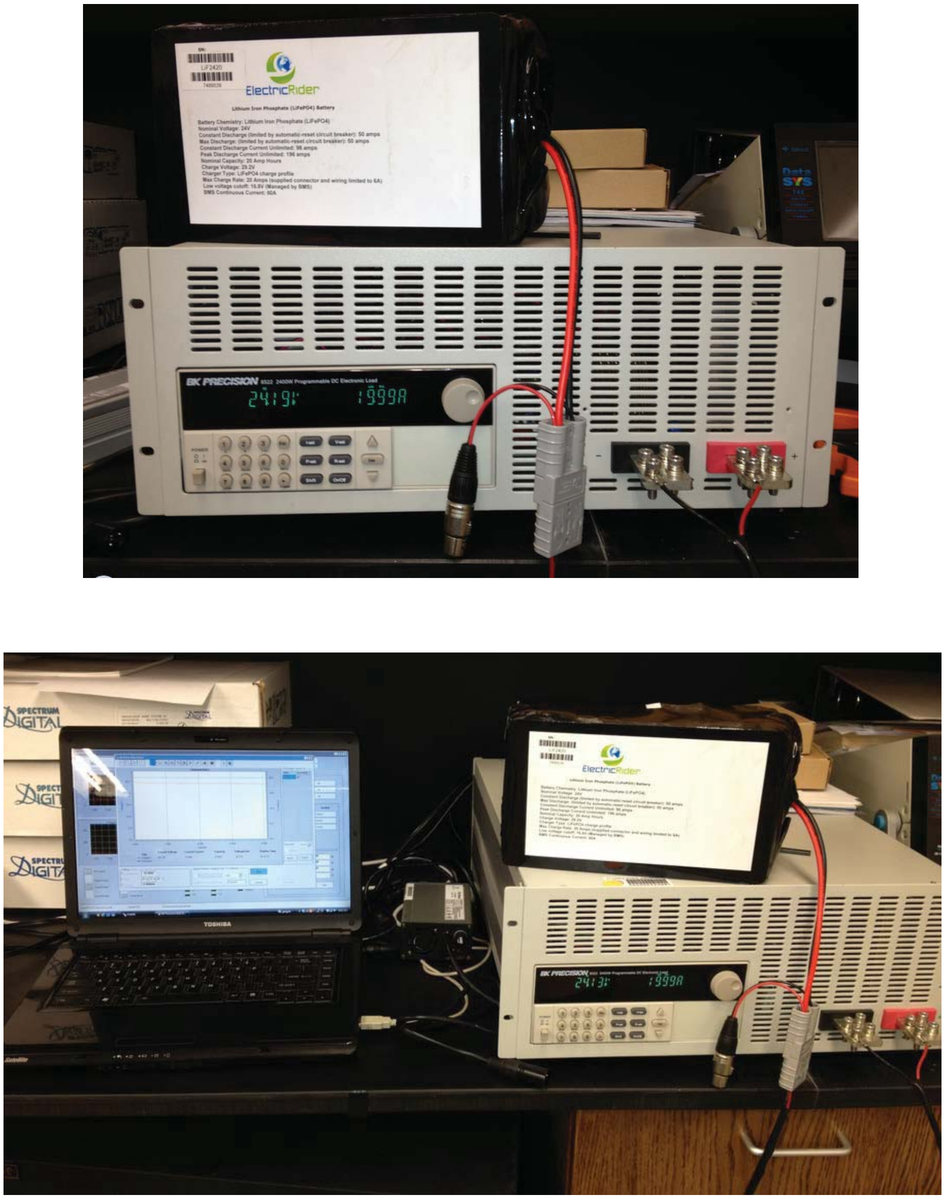



Figure A.2: Battery Testing with Dr. Edrington's DC Load Bank

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Battery Discharge - 1C

TEST CASE #: BS-01
(ex: BS-001)

TEST DATE: 1/31/13 – 9:00 AM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connect the battery to the BK Precision 2400W Programmable DC Electronic Load and observe the battery discharge for the 1C battery rating.

EXPECTED RESULTS:

When the battery is supplied 20A with a nominal voltage of 24V, the battery should be able to supply power for 1 hour before it is fully discharged.

ACTUAL RESULTS:

The elapsed test time was 51:20. The simulation was set up to end when the battery reached 20V. Data results plotted in MATLAB.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

Battery may not have been fully charged, will retest when batteries are confirmed to be fully charged to check validity.
Once the initial test was over the testing was quickly continued until the battery management system cutoff at 17.8V.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Battery Discharge - 2C

TEST CASE #: BS-02
(ex: BS-001)

TEST DATE: 1/31/13 – 2:30 PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connect the battery to the BK Precision 2400W Programmable DC Electronic Load and observe the battery discharge for the 2C battery rating.

EXPECTED RESULTS:

When the battery is supplied 40A with a nominal voltage of 24V, the battery should be able to supply power for 30 minutes before it is fully discharged.

ACTUAL RESULTS:

The elapsed test time was 22:31. The simulation ended when the battery management system cutoff the voltage at 16.18 V. Data results plotted in MATLAB.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

During testing the wires being used to connect the thick gauge main battery wires to the electronic load became very hot at this high current. To continue testing at a higher current the supplemental wires will need to be replaced with a higher gauge wire. Should probably even consider using a higher gauge wire when connecting the battery in the final design of the car.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Battery Discharge – 0.5C

TEST CASE #: BS-03
(ex: BS-001)

TEST DATE:
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connect the battery to the BK Precision 2400W Programmable DC Electronic Load and observe the battery discharge for the 1C battery rating. Record the elapsed time, capacity, and the voltage cutoff.

EXPECTED RESULTS:

When the battery is supplied 10A with a nominal voltage of 24V, the battery should be able to supply power for 2 hours before it is fully discharged. Voltage cutoff should be at the BMS rating of 16.8V

ACTUAL RESULTS:

Elapsed time = 1:51:29. Voltage cutoff = 19.43 V. Capacity = 18.5297 Ah
Data results plotted in MATLAB.

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Battery Charging Capabilities

TEST CASE #: BS-04 (ex: BS-001)

TEST DATE: 2/08/13 – 5:00 PM (ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connect the charger to the battery and time how long it takes until the charger LED turns green and the charging stops indicating that the battery is fully charged.
Battery Charger – 29.2V, 4A

EXPECTED RESULTS:

Elapsed time should be 5 hours.

ACTUAL RESULTS:

Elapsed time = 5 hours 29 minutes

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Solar Array/Converter Integration

TEST CASE #: BS-05
(ex: BS-001)

TEST DATE: 04/09/13 – 2:00 PM
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

Connect the solar array to the converter and the converter to the battery to test the charging capabilities from the solar array. In order to measure the voltage and current entering the battery, a Turnigy watt meter was placed in series between the converter and battery.

EXPECTED RESULTS:

The solar array and converter will provide enough voltage and current to charge the battery.

ACTUAL RESULTS:

The output of the converter was providing 20V. The battery needs over 26V to properly charge.

STATUS: ☐ PASSED ■ FAILED

FAILURE CAUSE(S):

1. The converter was programmed for 28.8V and without the consideration of a load. Once the load was applied, the previously measured voltage was significantly different.
2. Connecting the Turnigy watt meter in series absorbs 5V in order to turn on the LCD display screen.

SUGGESTED SOLUTION(S):

1. Adjust the converters output to 35V by changing the output resistors.
2. Remove the Turnigy watt meter in series and test to see the new output voltage from the converter into the battery.

COMMENTS:

After failing to charge the battery with the solar array integration, the battery was connected to a power supply that was set to 29V. At 29V, the power supply switched into constant current mode allowing for the current to be adjusted, showing that the battery was now properly being charged.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Simulation of BLDC Motor in MatLab

TEST CASE #: MC-001
(ex: BS-001)

TEST DATE: TBD
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

A trapezoidal back emf, star wound stator type brushless dc motor MatLab/Simulink model will be used. This model's parameters will be changed for known specifications of the Conhis Motor being used with the car.
During this test the simulated motor will be put under min to max torque values, min to max speed predetermined to determine current drawn on the battery.

To do this test many characteristics of the motor need to be acquired from the vendor.

EXPECTED RESULTS:

Measurements expected are current and torque characteristics similar to manufacturers specifications.

ACTUAL RESULTS:

STATUS: ☐ PASSED ■ FAILED

FAILURE CAUSE(S):

No way to measure or find out proper parameters needed to simulate motor.

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Controller Wiring and Safety Design/Build

TEST CASE #: MC-002
(ex: BS-001)

TEST DATE: 3/02/13
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

All parts and pieces needed to connect to battery and motor will be mounted to aluminum. The wiring will be soldered and heat wrapped for safety, and proper wires will be selected to keep heat low.
Measurements will be taken to show proper conductance from one end of a wire to another, plus short circuits will be tested for to examine for wire fray.

EXPECTED RESULTS:

This mounted board will be ready to connect to the motor and battery with two easy Anderson connectors. No conductance or short circuits.

ACTUAL RESULTS:

Wiring is proper, no shorts and conductance is proper

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Connecting Battery and Motor to Controller Board

TEST CASE #: MC-003
(ex: BS-001)

TEST DATE: 3/02/13
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ■ RE-TEST

Three phase and three hall wires need to be connected in proper combo, to power the motor. Connect battery through controller board, connect phase and hall wires from motor to controller board then power on controller.

EXPECTED RESULTS:

Wheel will spin, based on POT throttle position

ACTUAL RESULTS:

Motor did not spin.

STATUS: ☐ PASSED ■ FAILED

FAILURE CAUSE(S):

Error Code 4-2
Loose wiring, incorrect wiring or bad hall sensor

SUGGESTED SOLUTION(S):

Solutions: all connections tested and checked. All wiring checked for frays. Motor will still not spin, same error code. All 36 combinations of hall phase wires tried, still same error code. Opened up motor to test hall sensors, still same code.

COMMENTS:

Not motor purchased.

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Solar Array connected to Converter

TEST CASE #: SI-01
(ex: BS-001)

TEST DATE: March 2013
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This case tests the connection and action when the solar array is connected to the converter. The converter's output will be measured.

EXPECTED RESULTS:

The converter is properly boosting the voltage

ACTUAL RESULTS:

The voltage is steady around 24 V. The converter properly boosts voltage

STATUS: ■ PASSED ☐ FAILED

FAILURE CAUSE(S):

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Converter connected to Battery

TEST CASE #: SI-02
(ex: BS-001)

TEST DATE: March 2013
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This case tests the connection and action when the converter is connected to the battery. The converter's output will be measured, with a stiff source at its input

EXPECTED RESULTS:

The converter is properly boosting the voltage and charging battery

ACTUAL RESULTS:

In order to charge the battery, a voltage of 26V or higher is needed at the battery. Once the converter is connected to the battery the voltage drops, and the battery will not charge.

STATUS: ☐ PASSED ■ FAILED

FAILURE CAUSE(S):

In order to charge the battery, a voltage of 26V or higher is needed at the battery. Once the converter is connected to the battery the voltage drops.

SUGGESTED SOLUTION(S):

Reorder the resistors on the converter to provide necessary voltage to charge the battery.

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Battery connected to Motor Controller connecter to DC Load Bank

TEST CASE #: SI-03
(ex: BS-001)

TEST DATE: March 2013
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ☒ TEST ☐ RE-TEST

This case tests the connection and action when the battery is connected to the motor controller while the DC Load bank simulates the motor load. The output current and voltage of the motor controller, and the battery will be monitored. The DC load will simulate an acceleration, constant speed, and deceleration of the motor.

EXPECTED RESULTS:

The motor controller is properly sending the proper current for the conditions the motor is under. The battery can handle the current draw.

ACTUAL RESULTS:

Motor controller has been changed, thus this test will not happen currently until a new motor controller is received

STATUS: ☐ PASSED ☒ FAILED

FAILURE CAUSE(S):

Motor controller is the wrong controller

SUGGESTED SOLUTION(S):

COMMENTS:

# Test Plan – Solar Car Team 2012-2013

TEST ITEM (TITLE): Solar Array connected to Converter connected to the Battery

TEST CASE #: SI-04
(ex: BS-001)

TEST DATE: March 2013
(ex: 01/01/12 – 11:30 AM)

TEST CASE DESCRIPTION:

TEST TYPE: ■ TEST ☐ RE-TEST

This case tests the connection and action when the solar array is connected to the converter which is connected to the battery. The output current and voltage at the battery will be monitored.

EXPECTED RESULTS:

The battery is being charged by the converter/solar array combo.

ACTUAL RESULTS:

Converter voltage is to low to charge the battery

STATUS: ☐ PASSED ■ FAILED

FAILURE CAUSE(S):

The voltage of the converter must be 26 V or higher to charge the battery.

SUGGESTED SOLUTION(S):

COMMENTS: