Team 15: SolarCycle

Final Design Report

Jack Amick, Matt De Young, Mike Houtman, Tae Lim

Engineering 340: Senior Design Project

Calvin College
Executive Summary

The United States currently faces the problem of high priced transportation fuel, as well as the destructive consequences of carbon dioxide emissions. This project proposes to resolve this problem by means of an electric powered motorcycle with solar charging opportunities. In this way the design will hold the option for both wall outlet charging in addition to solar charging. This will therefore provide the option for both low cost wall charging or charging by electricity generated from solar panels. This solar charging option frees the consumer from contributing to carbon dioxide emissions related to electricity-producing coal power plants.

The design team consists of four students pursuing a Bachelor of Science in Engineering with a concentration in Mechanical Engineering at Calvin College. The fall semester was spent on research, design, and component selection while the spring semester was put towards assembling and testing the proposed design.

For this project, the design proposed a motorcycle to travel at least 25 miles at a steady speed of 25mph, sufficient for a commuter in a city such as Grand Rapids, as well as the criteria to reach a maximum speed over 35mph, in order to be operated on most city roads. Similarly, the solar panels should provide an 80% battery charge within an 8hr time period, or a complete work day.

In order to fulfill these requirements, the motor selected was a Motenergy, 6hp continuous brushed, permanent magnet, DC motor. The batteries chosen consist of four 12V 60Ah batteries connected in series to supply a total 48V. The solar panel assembly consisted of two 30W panels mounted on each side of the bike. A production model would include two more panels onto these folding mounts in order to provide a total power of 120W. This was not included on the prototype due to time and budgetary constraints.

Final testing showed that the project met most of its initial requirements but did not manage to meet all of them. The prototype can reach a maximum speed of greater than 40mph and a range of approximately 20-30 miles while traveling at 25mph. Due to time and weather restrictions, the exact range was unable to be tested. Due to space and budget constraints, the team was unable to utilize the necessary number and power solar cells to charge the motorcycle within 8 hours. The solar charging method amounts to a 17% additional charge in an 8hr period. This yields a 3-5 mile extension of range.
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1. Introduction

   a. Problem Definition

With the price of oil steadily increasing, the global supply decreasing, and the impact of CO₂ emissions becoming more certain, consumers are seeking vehicles with a lower fuel consumption. Currently, there are few alternatives to driving fossil fuel powered vehicles and these few alternatives are very expensive.

SolarCycle's project focuses on the conversion of a gasoline motorcycle to an electric motorcycle that runs on electricity generated from solar cells. This project aimed to design an inexpensive form of transportation with zero emissions resulting from both operations and charging. The goal of the project was to design a small, 2-wheeled vehicle to be used for a short commute to and from work or school.

The major appeal of this design is the low fuel cost and carbon neutrality of the operations. The primary market for this product consists of small distance city commuters. This can be implemented for college students, high school students, businessmen, and many others for low cost, emission free transportation. The product is much more marketable in the Southern United States, providing a higher solar charging capacity as well as a longer season for comfortable motorcycle travel.

   b. Design Norms

The team primarily focused on three design norms when designing the product: stewardship, caring, and trust. Stewardship was stressed as one of the design norms because of the importance for society to ensure proper care of the environment. This was obtained in the design through a zero emission form of transportation in both charging and operation. Caring for the customer and their wellbeing is important for any design to ensure customers’ happiness through designing quality products that operate and function in the manner that was both designed and advertised. The team found it very important to design with a customer in mind for this project and aimed to make the prototype very user friendly and provide a very easy method of maintenance. Lastly, trust was a large factor in the team’s design methodology because ensuring safety of operators is the major concern when designing a vehicle fit for public roads. For this reason, the design implemented several safety precautions and additional design components that seem superfluous to the ultimate function of the design, but were implemented in order to facilitate safety at all levels of operation. This is described in more detail in section 7 of this report.
2. **Project Management**

   a. **Team Organization**

SolarCycle consists of four Calvin College Seniors: Jack Amick, Matthew De Young, Michael Houtman, and Tae-Hyung Lim. All four students anticipate graduating with a Bachelor of Science in Engineering with a Mechanical Concentration. The team members are shown in Figure 2-1, below.

![Figure 2-1. Jack Amick, Matthew De Young, Tae-Hyung Lim, Michael Houtman (L-R)](image)

i. **Jack Amick**

Jack is pursuing a Bachelor of Science in Engineering with an International Mechanical Engineering Concentration at Calvin College. He is from Lanesborough, Massachusetts. Jack is also an amateur photographer and enjoys cycling in his free time. After graduation Jack will be working in Grand Rapids. He has received some job offers and will make a decision soon.

Throughout the duration of the project Jack focused on team organization and planning. Jack also worked on assembly and design of the additional components. Jack was very instrumental in the artistic direction of the final design and testing of the prototype.

ii. **Matthew De Young**

Matthew is from Dyer, Indiana, a small suburb about 45 minutes from Chicago. In his junior year at high school he decided to pursue engineering because of his skill in math and science. Matthew is currently in his fourth year of studying German and mechanical engineering. He especially enjoys thermodynamics
and product design. After graduation, Matthew hopes to pursue a career in designing HVAC (Heating, Ventilation, and Air Conditioning) systems or designing alternative energy systems.

Matthew assisted the team by helping organize and plan the reports and presentation for the project. He also assisted with some of the main assembly of the motorcycle.

iii. Michael Houtman

Michael is a senior engineering student at Calvin College, pursuing a Bachelor of Science in Engineering with an International Mechanical Engineering Concentration. Michael is from Escondido, California in San Diego County. Michael enjoys hiking, camping, and fishing in his free time. He will be working in the Grand Rapids area after graduation and is in the process of deciding between 2 job offers.

Mike was the team’s primary shop mechanic. He spent a lot of time in the Calvin College metal shop learning to weld and fabricating the parts required to build the prototype. With additional help from Phil Jasperse, he was able to modify the frame and fabricate additional components for the final design. In addition to this, Mike performed the removal of the original combustion engine and rewiring of the lights and instrumentation.

iv. Tae-Hyung Lim

Tae-Hyung Lim is a senior student at Calvin pursuing a Bachelor of Science in Engineering with Mechanical Concentration and a minor in mathematics. He was born in South Korea and came to the U.S. to study when he was 16 years old. He enjoys music, playing soccer, and traveling. Tae hopes to pursue a career in the automotive industry or as an engineering consultant after graduation.

Tae designed and installed the electrical components for the motorcycle. He drew the electrical design and performed tests to ensure that everything was working properly before installing the components onto the prototype.

b. Project Schedule

The fall semester was spent primarily on research, component selection, and preliminary design. Lots of research was necessary to ensure the selection of correct electrical components for the project. The team also focused time contacting companies in order to obtain donations and educational discounts toward several key components. This was necessary if the team was to fulfill the project requirements within the
constraints of the allotted project budget. During this semester, the team was also able to purchase the motorcycle chassis that was to be adapted into the final prototype. Therefore time was allocated in removing all of the previous combustion engine components and designing preliminary prototype drawings.

During the spring semester the team focused on the implementation of the designs outlined in the fall. This amounted to construction and testing of the prototype. As a first step, the specified components were purchased throughout the construction process. The team began installing the initial components while simultaneously testing the components and designs before final integration. Although several setbacks and obstacles were encountered in the latter stages of the spring, the project culminated on Friday, May 9th with a working prototype that met the requirements outline previously. This prototype was displayed and presented to both the faculty of Calvin College and to the community in an open house setting followed by a technical presentation on Saturday, May 10th. Preliminary testing was performed prior to this date, however weather conditions did not allow for a full scale test of all the requirements outlined above.
3. Requirements

a. Functional

The SolarCycle prototype is powered by an electrical motor with the capability of using solar panels for battery charging. A connection for the standard 120 Voltage (V) wall outlet is also offered to provide an alternative charging method in instances of bad weather conditions or any technical failure of the solar charging system. The prototype must run on a 48V system, powered exclusively from battery power. Solar panels were installed with foldable brackets, to be conveniently positioned as needed and folded down when not in use. The SolarCycle is user friendly and easy to control, because no clutch or gear shifting is necessary. The horn, instrumentation, and lights (including brake light, head light, and turn signals) have been installed to meet legal requirements as well as to ensure passenger safety. The prototype offers enough space and power for two passengers.

b. Performance

The main goal in regards to functionality was designing a prototype able to travel up to 25 miles while going a steady 25mph on a level grade. For charging, the main goal was to charge the batteries to approximately 80% over 8 hours, or a typical work day when the solar panels were deployed. The safety and performance of the SolarCycle has been quantitatively determined with CAD, mathematical calculations, and tested experimentally. Because Michigan defines a motorcycle as a two wheeled vehicle that can attain speeds greater than 35mph, and because the prototype is designed to meet Michigan motorcycle requirements in order to operate legally on a public road, it must have the ability to reach speeds of 35mph at a minimum.
4. Research

While conducting research for the project, it was discovered that many projects have previously been done to convert personal motorcycles to run on electric motors. These projects were further researched to get context of what problems may occur in the design, what other people have done to overcome similar challenges, and how current designs could be improved. In addition, previous Calvin College senior design projects have focused on designing electric vehicles. The team utilized these reports to learn more about the motor used in the prototype design. The team discovered that many projects used chain-driven motorcycles to simplify the conversion process. However, because the team acquired a shaft driven motorcycle, a linkage and driveshaft mechanism had to be designed and tested. Brief research was done to determine availability of each component of SolarCycle, with required specifications for batteries and solar panels. The team was able to find and contact vendors for batteries, solar panels and other components, and several were generous enough to donate parts to the project.

A large amount of time was devoted to the research and contact of battery suppliers. It was decided that the pursuit of lithium ion batteries should no longer be considered due to both price and safety concerns brought up by Professor VanderLeest. Instead, deep cycle marine batteries were selected as the prime candidate to fulfill the design specifications. In addition to battery specifications, the solar assembly was researched and a solar map was found for the month of June to be representative of the motorcycle riding season, this can be seen in Appendix C. After further research, it was determined that the power rating given to solar panels corresponds to the DC output under standard test conditions. Therefore, this design will require more efficient solar cells, in order to achieve high power rating in a smaller area. It is essential to get this power rating in a PTC rating form, or under real world conditions.

In order to aid in the disassembly of the Honda 1984 Nighthawk, the service manual for the bike was found available online. This document was invaluable in the removal of the motorcycle gas tank, carburetors, exhaust, and engine. In addition to the chassis documentation, the motor and controller documentation have been found available in Appendix D. The motor specifications have been found from the Etek database and the controller diagram was found from the Alltrax website.
5. Main Component Selection

a. Motorcycle Chassis

The motorcycle acquired was a 1984 Honda CB700S. This is a shaft driven motorcycle which added some complexity to the project, but the team was able to design an efficient drivetrain to connect the motor to the shaft. The motorcycle was in good condition, and the frame easily supported the additional electrical components. This was purchased from a local Craig’s List dealer and was modified to fit the project.

b. Electric Motor and Controller

The motor was acquired from the Calvin College Engineering department. This was used on a previous electric car project in 2001, The Knight Riders. The motor is a 48V 6-horsepower (hp) continuous Briggs and Stratton Etek electrical motor with a 15hp maximum output. Calculations confirmed that this motor was sufficient to power the design and these may be found in section 8. Initially it was planned that the team would use the same motor controller that was previously used with this motor, but that controller had many damaged components and would not work. As an alternative, the team contacted Alltrax Inc who generously donated a programmable motor controller. The controller is an Alltrax SPM-48400. It can control a maximum of 400 amps, which is more than enough for the motor that is being used. It is also able to be programmed and settings, such as the maximum and minimum throttle position and power curves, can be adjusted for performance optimization. The controller required a contactor to act as a relay between the batteries and the motor. The team used a 48V, 200 amp contactor from EV Drives. The controller was connected to a Curtis PB-6, 0-5K Ohm potentiometer to convert the mechanical throttle to an electrical signal for the motor controller. After a short period of testing, the Etek motor unfortunately was damaged. After repairs were attempted and the entire motor was reassembled, it was determined that a new motor was necessary. After brief research, a Motenergy ME0708 was selected to replace the ETEK motor. This was selected because it maintains the same bolting pattern as the ETEK and the same torque constant as the ETEK. After an overnight delivery, the motor was delivered and installed just prior to May 10th, the Calvin College engineering senior design open house.

c. Battery Pack and Power Supply

Because the motor is restricted to a voltage range of 36V-48V, the battery pack must supply this to the motor. Therefore a steady supply of 48V must be used in this design. To keep the project simple, four 12V
batteries were selected and connected in series to increase the overall voltage to 48V. To achieve the requirement that the vehicle will run at 25\textit{mph} for 25 miles, the batteries were selected to supply a minimum of 35 amp-hours \textit{(Ah)}. This is further discussed in section 8 where the calculations may be found to confirm this result. VMAX USA generously donated four batteries that exceeded these specifications. The SLR60 VMAX batteries donated are 12V deep cycle AGM batteries with an amp-hour rating of 60. These batteries fulfilled all the necessary requirements and are designed for use in a residential solar system, experiencing frequent large discharge rates, making them ideal for this design.

The final obstacle addressed was in the power supply to the instruments and lights of the vehicle. These run on a 12V system and cannot be connected directly to the 48V battery system. The team remedied this through the use of a DC/DC converter. The team purchased a DC/DC converter to lower the voltage level for the lights and instrumentation. This solution was selected because it did not require the use of a separate 12V battery to power these systems.

d. Solar Panels and Charge Controller

As estimated in section 8, when charging four 12V batteries rated at 60\textit{Ah} within an 8 hour period, the solar panels must supply a minimum of 346 watts \textit{(W)}. This is assuming that the batteries are completely empty, and that the sun is shining directly on the solar panels throughout the entirety of the 8 hours. Therefore the calculations may be lowered to account for the unrealistic scenario, discussed further in section 8. Solar panels that will provide this much power while still being small enough to fit on the sides of the motorcycle could not be found. As an alternative, the team purchased two 30\textit{W} panels which will both be mounted in a folding bracket on each side. This was designed for the prototype that met the team’s budget. A production model would include a total of four 30\textit{W} panels in a folding array shown in Figure 5-1, with an approximate charging time of 16 hours.
Charging is accomplished through a Genasun 48V 105-350W solar charge controller. This charge controller has maximum power point tracking (MPPT) to adapt to the changing light conditions and allows for an increase in voltage from a nominal 12V panel to 48V in order to charge the 48V battery pack. Although this decreases the current output of the charging system, and therefore increases the total charging time, this is necessary for charging a 48V system with only 2 panels.
6. Design

a. Criteria

A list of criteria relating to the prototype was compiled in order to fulfill the design objectives and norms. The first outlined that the motorcycle must travel a minimum of 25 miles at 25 mph on a single charge. The motorcycle must also support two methods of charging, through solar panels mounted on the sides of the motorcycle and through a standard 120V wall outlet. The motorcycle must be street legal to fulfill the design norm of caring and designing a prototype inherent to the needs of the customer. The solar panels must not impede or restrict the safety of the driver or passenger in order to fulfill the safety of the design. The solar panels must adequately charge the batteries within an 8 hour time frame in order to extend the range of the vehicle. The prototype must reach speeds in excess of 35 mph in order to be considered a road worthy vehicle. In order to achieve the necessary hill climbing ability and power for two passengers, the design must supply a minimum torque of 9.8 foot-pounds (ft-lb) to the driving wheel. Lastly, the prototype must allow for simple maintenance and passenger safety for an average residential user. All these criteria were factored into the selection of the components.

b. Alternatives

The team considered a number of alternative designs to meet the criteria. One of the first design alternatives considered was whether the power from the motor will be delivered through a shaft or chain. The team also had to consider the option to use a brushless or brushed motor when selecting the motor. In addition to regular charging, the team also considered designing a system so that batteries could be easily swapped for charged ones. A hybrid system was also considered in place of a pure electric drive system. In addition to these larger decisions, the team also had many other decisions to make while they were designing the prototype. In order to run the lights and instrumentation, the team had to choose between using a DC/DC convertor, a fifth 12V battery, or wiring the instrumentation to run off of one of the four VMAX batteries. The team also had to choose between many different designs and locations for mounting the solar panels and installing some other components. While choosing a gear ratio between the motor and the rear wheel, the team had to make a decision between maximum speed and safety. In addition to this, the throttle had the option of an electronic or mechanical throttle system. An electronic system involved the purchase of a new rheostat controlled throttle and a mechanical system involved the modification of the current mechanical wire-fed throttle in collaboration with a potentiometer. The latter
system was chosen in order to utilize the existing components of the chassis and to reduce the additional cost burden of an electronic system. Finally, the team chose to use the original speedometer instead of installing a digital one.

c. Decisions

After discussing the alternatives, the team made informed decisions for each of them. The team chose the brushed motor for budgetary and availability constraints. A permanent magnet brushed electric motor was found available within the Calvin College Engineering Building. A shaft-driven power system was chosen because the motorcycle that was purchased for a frame is shaft-driven, and the conversion to a chain-driven system would require additional time for very little payout. The team decided against the easy swap battery system because it was determined the limited space within the frame would not support such a modification. This idea could be used for a final production model, but is outside the scope of this project. The team also decided to discard the hybrid concept because a hybrid vehicle would not fulfill the requirement of 100% emission free drive. In addition, the motorcycle frame does not allow for both a functioning gasoline motor and a functioning electric motor with required battery bank, given the space provided. A confirmation of the space available for both the batteries and motor can be seen in Figure 6-1, below.

![Figure 6-2: A SolidWorks model showing possible component locations](image)

A DC/DC convertor was selected to power the 12V instrumentation panel. This was chosen because it could be connected directly to the 48V battery pack and would evenly drain power from all four batteries
without requiring an additional battery. This component was selected through tests determining the maximum current required from all the necessary lights and instrumentation. The motorcycle was geared to achieve a top speed of 40 mph because, while the motor provided enough power for the motorcycle to go even faster, safety was a major concern for the team and it was decided that 40 mph was a safe top speed, while maintaining the required torque. In order to fulfill this speed requirement, a chain was selected to drive the two gears from the motor to the driveshaft. A chain was selected, as opposed to a belt, because a chain would allow for flexibility with the suspension system and the flexing of the frame over bumps. A belt was discounted due to slipping. In order to tension this chain, slotted holes were chosen to be fabricated into the motor mount, rather than a chain tensioner. A chain tensioner was discounted for time and budgetary reasons.

The batteries selected were donated from VMAX USA and chosen according to the specifications previously outlined. These batteries were selected with safety in mind, and the Absorbed Glass Mat (AGM) characteristic provides a safeguard in the event that a battery becomes punctured or ruptures. This type of battery will prevent acid from draining out and will also allow flexibility in the mounting design. This allowed for the batteries to be mounted sideways, if need be. Similarly, the batteries were mounted in order to be removable and allow for customization and battery replacement. To further protect the batteries from any debris kicked up from the front tire, a guard was designed to cover the main chassis. Additionally, to protect the wiring of the components the decision was made to design and fabricate a chain guard to protect both wires and the driver’s clothing from interacting with the path of the chain.

When considering the solar charging system, a number of decisions became necessary for the final solar design. The first decision involved the use of tracking or stationary panels. A tracking system would allow for the solar panels to track the sun as it moves across the sky and would therefore provide additional energy harvesting. However, both the space and time constraints of the project did not allow for the design and fabrication of an additional motor and driving assembly. Additionally, the energy required for a tracking system does not justify the additional energy obtained from this system. This is primarily due to the low power panels chosen for the prototype. Therefore a stationary solar system was chosen. In order to faithfully fulfill the budgetary and space constraints, two 30W panels were chosen as the solar charging power for the prototype. After the panel size and power rating were determined, the issue of
vibrations and damage from road debris was brought up. In order to remedy this, semi-flexible panels were chosen, containing no heavy sheet of glass on the surface of the part. This allows for the panel to bend and vibrate without damage to the photovoltaic (PV) cells. Additionally, two fiberglass panels were designed to be molded to cover the panels and to fold down after parking. Although this will both reduce drag and protect the panels, this needed to be sacrificed after the setback mentioned in section 10 of this report. In line with this protection of the panels, the current design integrated aluminum plates to protect the underside of the panels and the proposed folding design, would protect the faces of the panels by folding the panel cells to face one another.
7. Safety Concerns

In order to fulfill the norm of trust, a large emphasis was placed on safety of the operator. This included the fabrication of additional designs, the purchase of additional components, and the integration of additional checks on behalf of the user. More specifically, the team implemented many devices and components into the design including fuses, battery covers, key switch, emergency stop, PV panel angle, front cover, street legalization, helmet, and AGM batteries.

Two fuses were installed in the motorcycle to ensure safety and protection from any parts overdrawing current. A 5A fuse was used for instrumentation and solar charging circuit, along with a 300A fuse for main power line to protect motor controller and the motor. These fuses were in addition to the fuse box prewired from the original Honda lights and instrumentation circuit.

A key switch, charge switch, and the emergency stop button were installed to improve the user friendliness and safety. The original Honda key switch was utilized so that the motorcycle would be safe from thefts, and the charge switch and the emergency stop were to ensure user safety by not allowing charging and discharging of batteries simultaneously to avoid any possible electrical failure as well as the emergency stop for any possible dangerous situations.

The chain guard, battery covers, and the front cover were included on the motorcycle to protect from any injuries that might occur from mechanical parts. The covers and guards were carefully designed to protect both the operator from moving parts and the motorcycle from any external obstacles such as small debris on the road.

The battery brackets were analyzed to withstand the heavy weight of the batteries and they were firmly installed to remain at position without moving during operation. The batteries selected were AGM types to avoid any battery failures relating to spills or explosions, and to allow mounting options since they can be places sideways unlike other typical car batteries.

The team also applied all of the requirements for the motorcycle to be street legal and wore a helmet during testing. One concern that was raised during testing was that the prototype was too quiet during operation, which could be dangerous for pedestrians at certain circumstances. In order to solve this problem, the team ensured that the motorcycle had an operating horn.
The last issue the team faced was the weather. The designed prototype consists of many electrical components which can be critically damaged due to rain and snow. The prototype does not have sufficient protection to ensure all weather proof availability due to limitations of time and tight budget. However, since motorcycles are mostly used only under good weather conditions, the team evaluated this as a non-major issue. Yet motorcycle side panels to cover the entire sides of the vehicle are necessary and are included in the improvements outlined in section 10 of this report.
8. Calculations

The primary calculations for this design focused on the motor, battery, and gear selection process. The motor was selected based upon preliminary research of the Coefficient of Drag ($C_D$) for a motorcycle and the Rolling Friction Coefficient ($r$) of the tires on pavement. Research yielded a $C_D$ ranging from 0.6 - 1.2 depending on the riding position. Similarly $r$ was found to range from 0.005 - 0.025 for motorcycle tires on paved asphalt. In addition to these coefficients, the total weight of the vehicle ($W$), maximum velocity ($v_{max}$), average velocity ($v_{avg}$), incline climbing velocity ($v_{climb}$), and frontal area ($A_x$) were used for calculating the forces applied to the motorcycle, in equations 8-1 and 8-2, resulting from air drag ($F_{air}$) and road-tire friction ($F_{rolling}$).

\[ F_{rolling} = Wr \quad \text{[Eq. 8 - 1]} \]

\[ F_{air} = \frac{1}{2}[C_D \rho_{air} A_x (v_{max})^2] \quad \text{[Eq. 8 - 2]} \]

Using these forces, the power required may then be calculated. This was achieved using equations 8-3, 8-4, 8-5, and 8-6. These calculate the power required for a steady speed under maximum velocity ($P_{steady}$), power required to overcome hills and inclines given a maximum road grade ($\beta$) of 5% ($P_{climb}$), power required to accelerate to maximum velocity ($P_{accel}$), and a steady power of the motor under average velocity ($P_{avg}$).

\[ P_{steady} = (F_{rolling} + F_{air})v_{max} \quad \text{[Eq. 8 - 3]} \]

\[ P_{climb} = W v_{climb} \beta + (F_{rolling} + F_{air})v_{climb} \quad \text{[Eq. 8 - 4]} \]

\[ P_{accel} = \frac{\frac{1}{2} W}{t_{accel}} (v_{max}^2) \quad \text{[Eq. 8 - 5]} \]

\[ P_{avg} = (F_{rolling} + F_{air})v_{avg} \quad \text{[Eq. 8 - 6]} \]

Using the inputs in the Table 8-1, the calculations confirm the choice of a Briggs and Stratton ETEK 6hp continuous, 15hp maximum electric motor.
### Table 8-1: Power Equation Variable Inputs and Justification

<table>
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<tr>
<th>Input Variable</th>
<th>Assigned Value</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_D$</td>
<td>0.80</td>
<td>A conservative estimate to the range found in research</td>
</tr>
<tr>
<td>$r$</td>
<td>0.02</td>
<td>A conservative estimate to the range found in research</td>
</tr>
<tr>
<td>$\beta$</td>
<td>5%</td>
<td>Maximum grade allowable for a city road or highway</td>
</tr>
<tr>
<td>$A_x$</td>
<td>10.8 $ft^2$</td>
<td>Preliminary measurement of frontal area for both rider and bike</td>
</tr>
<tr>
<td>$t_{accel}$</td>
<td>10 sec</td>
<td>Iterated in order to achieve a realistic motor size</td>
</tr>
<tr>
<td>$W$</td>
<td>630 lb$_f$</td>
<td>Calculated combined weight of frame (230 lb$_f$), motor (30 lb$_f$), batteries (170 lb$_f$), and passenger (200 lb$_f$).</td>
</tr>
<tr>
<td>$\rho_{air}$</td>
<td>1.187 kg/m$^3$</td>
<td>Density of air at standard environmental conditions (25°C, 1 atm)</td>
</tr>
<tr>
<td>$V_{max}$</td>
<td>55 mph</td>
<td>Minimum speed required for highway use</td>
</tr>
<tr>
<td>$V_{climb}$</td>
<td>35 mph</td>
<td>Minimum speed required for licensing of a street motorcycle</td>
</tr>
<tr>
<td>$V_{avg}$</td>
<td>25 mph</td>
<td>Minimum speed required for road use</td>
</tr>
</tbody>
</table>

The frontal area was calculated through a rectangular estimation of the cross section containing both the rider and motorcycle. Similarly, the weight of the motorcycle frame was measured after the removal of the engine and internal combustion components. This is seen in Figure 8-1, shown below. This rectangular estimation resulted in a frontal area of $10.8 ft^2$ and the frame is measured at 228 lb$_f$. 
In order to achieve our selected speeds, the team had to choose a proper gear ratio from the motor to the wheel. The final drive gear ratio of the motorcycle’s shaft was found to be 3.54. This would allow the motorcycle to travel at 69mph. To ensure that our motor could deliver enough torque to overcome friction, an additional gear ratio of 1.2 was added. An 18 tooth gear was added to the shaft and a 15 tooth gear was added to the motor. These were connected by a chain. This brought the motorcycle’s theoretical top speed down to 57mph but would also improve acceleration. These calculations can be found in Appendix B.
In addition to the calculations for the motor selection, calculations were also performed in regards to battery selection. The battery selection calculations are dependent on the voltage and amp hour rating of the battery (Ah). Because the Motenergy motor and Alltrax controller is a 48V system, the battery layout must provide a 48 input voltage. This will be achieved through four 12V batteries connected in series for a combined voltage of 48V. In order to obtain specifications for the desired battery Ah to be purchased (B_{bah}), equation 8-7 was employed. This uses the inputs of system voltage (B_v), minimum required Power (P_{avg}), and the range of the motorcycle of 25 miles (d). The total calculations and iterated solutions to the battery sizing may be found in the MathCAD document, Appendix B.

\[ P_{avg} = \frac{B_{ah}B_v v_{avg}}{d} \]  

[Eq. 8 − 7]

When solving for the battery amp hours needed (B_{ah}), equation 8-7 will provide the total necessary Ah needed for the 48V system. Because the 12V batteries must be connected in series to provide the necessary 48V input, B_{bah} represents the minimum Ah needed for each battery to be purchased. This is primarily due to the condition of circuit current remaining constant when connected in series. Therefore if it were to become necessary to integrate batteries of a lower Ah than B_{bah}, it would require connecting of both 12V in series and parallel wirings to achieve a higher current rating. This is not only a more complex wiring addition, but also it is not feasible to add more batteries due to space constraints on the frame.

Calculations for the solar panels required to fully charge the battery system implement equation 8-8, in which the power required from the panels (P_{solar}) is found from the power of the batteries and the objective charging time of 8 hours (t_{charging}).

\[ P_{solar} = \frac{B_{ah}B_v}{t_{charging}} \]  

[Eq. 8 − 8]

Equation 8-8 represents the necessary power rating of the solar panels in order to fully charge the system from emptied cells. This, however, is very unrealistic and it must be remembered that the system will almost never be expected to charge from completely emptied battery cells. Therefore a correction factor (C_{battery}) may be added to account for this. This correction factor, C_{battery}, may be assigned a value of 0.80 or 80% battery level. In addition to this over calculation, this preliminary calculation also neglects the sun coverage and view factors associated with solar charging. This represents a severe under calculation and the equation may be modified to account for the view factor relating to solar movement and availability.
within Michigan ($F_{solar}$). For this factor, a solar map was implemented and can be found in Appendix C. This modification results in corrections that may be found in equation 8-9.

\[ P_{real,solar} = C_{battery} F_{solar} P_{solar} \]  

[Eq. 8 – 9]

After batteries were selected and ready to be installed onto the motorcycle, a brief calculation was conducted to ensure the safety of the battery mounting brackets. The team decided to use steel brackets to hold the batteries in place since total of four batteries would result in an additional 200 lbf weight. Using the values found in textbook for Young’s modulus, $E$, and tensile strength, $TS$, the necessary moment of inertia for brackets was found to be $0.023 in^4$ with the safety factor of 3. Selected steel angle was well above the calculated value, which ensures safety under dynamic conditions. This calculation process can be seen in more depth in Appendix B and Figure 8-2 shown below.
In addition to battery mounting calculations, calculations were also performed to analyze the stress on the shaft due to both bending and fatigue at the applied torque. These may be found in Appendix B and amount to a safety factor of greater than 3, fulfilling the design’s qualifications.

When all of the necessary parts were ordered, another set of calculations was made to find theoretical and realistic run times, and solar charging time based on the parts the team was able to acquire. Two separate calculations were conducted to find the run time to compare the theoretical value, based on rated specifications, to the realistic value, based on real data. However, in order to estimate the realistic value, an average driving scenario was needed to be found to account for different driving conditions since driving downhill would require much less power than rapid acceleration on uphill. This average driving scenario was found by fractioning each condition and combining into one as shown in Table 8-2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady</td>
<td>0.70</td>
</tr>
<tr>
<td>Top Speed</td>
<td>0.10</td>
</tr>
<tr>
<td>Accelerate</td>
<td>0.15</td>
</tr>
<tr>
<td>Uphill</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The calculated theoretical run time was found to be 125 minutes and this was found using the provided numbers from each of the component specifications. The realistic run time was calculated assuming the average scenario shown above and also assuming only 50% of the battery capacity to be used. This yielded 26 minutes.

The solar charging time was found by using the Sunny Design software to estimate the daily power yield. The software takes geological location and type of panels as inputs and outputs yearly power yield estimation. Hence, the solar charging time was estimated by taking the power capacity of the batteries and dividing it by the estimated yield, and it was found that batteries would need 16.1 hours to be fully charged on solar panels amounting to 120W total. The details of this calculation can be found in the Appendix B.
9. Cost Analysis

a. Operational Budget

Team 15 requested and was granted $850 as its total operational budget for the academic year. This allocation corresponds to the purchase of a motorcycle chassis, batteries, battery charger, solar panels, and additional assorted electrical and mechanical components. A breakdown of the budget can be seen in Table 9-1 below. The final costs associated with completing the project can be seen in Table 9-2. The team exceeded the budget because of last minute problems with the motor, outlined in Section 10.

Table 9-1. Projected Operational Budget

<table>
<thead>
<tr>
<th>Description</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycle</td>
<td>$100.00</td>
</tr>
<tr>
<td>Motor</td>
<td>$0.00</td>
</tr>
<tr>
<td>Controller</td>
<td>$0.00</td>
</tr>
<tr>
<td>Batteries</td>
<td>$350.00</td>
</tr>
<tr>
<td>Solar Panels</td>
<td>$250.00</td>
</tr>
<tr>
<td>Other Electronics</td>
<td>$75.00</td>
</tr>
<tr>
<td>Other Parts</td>
<td>$75.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$850.00</strong></td>
</tr>
</tbody>
</table>

Table 9-2. Actual Project Budget

<table>
<thead>
<tr>
<th>Purchased Parts</th>
<th>Vender</th>
<th>Brand</th>
<th>Part Number</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td></td>
<td></td>
<td></td>
<td>$850.00</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>Craigslist</td>
<td>Honda</td>
<td>CB700S</td>
<td>$(100.00)</td>
</tr>
<tr>
<td>Electrical Components</td>
<td>EV Drives</td>
<td>SEE PO#1</td>
<td>SEE PO#1</td>
<td>$(67.45)</td>
</tr>
<tr>
<td>Solar Panels</td>
<td>DiscountPV</td>
<td>SEE PO#2</td>
<td>N/A</td>
<td>$(176.00)</td>
</tr>
<tr>
<td>Charge Controller</td>
<td>Genasun</td>
<td>Genasun</td>
<td>N/A</td>
<td>$(255.00)</td>
</tr>
<tr>
<td>Battery Gauge</td>
<td>Amazon</td>
<td>N/A</td>
<td>N/A</td>
<td>$(36.95)</td>
</tr>
<tr>
<td>DC/DC Converter</td>
<td>Amazon</td>
<td>N/A</td>
<td>N/A</td>
<td>$(96.87)</td>
</tr>
<tr>
<td>Tail Lights</td>
<td>Ebay</td>
<td>Honda</td>
<td>N/A</td>
<td>$(22.85)</td>
</tr>
<tr>
<td>Ammeter</td>
<td>Amazon</td>
<td>RioRand</td>
<td>N/A</td>
<td>$(19.69)</td>
</tr>
<tr>
<td>Motor</td>
<td>Motenergy</td>
<td>Motenergy</td>
<td>ME-0708</td>
<td>$(200.00)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>-$124.81</strong></td>
</tr>
</tbody>
</table>
A large part of the budget was allocated towards the purchase of deep cycle marine batteries. However, the team was able to acquire these batteries through a donation. The solar panels were the other main cost associated with this budget and the team was not able to find these at any discounted prices.

b. Production Cost Estimate

If the product were to be put into large scale production and assembly, additional costs are necessary. Table 9-3, below, outlines the cost estimation for product design, components, materials, and production. Additionally, Table 9-4 includes the annual production cost, assuming 5000 bikes are made per year, and the total yearly profit assuming all bikes are sold. This includes the estimated marketing and shipping costs of the product. A break-even analysis was performed and it was found that approximately 300 bikes need to be sold to break-even, with a retail price of $6500.

This is a ground-breaking selling price because it is similar to the price of other motorcycles, but includes the additional benefit of free solar charging. The team hopes that we can keep this price-point low, but understand that it may change as the future design also changes. The government also sponsors a federal tax credit 10% of the purchase cost, up to $2,500, for an electric motorcycle. This may be very appealing to any potential customers who are concerned with an expensive selling price.
Table 9-3. Production Cost Estimation

<table>
<thead>
<tr>
<th>Design</th>
<th>Task</th>
<th>Hours</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>500</td>
<td>$50,000</td>
<td></td>
</tr>
<tr>
<td>Drivetrain</td>
<td>500</td>
<td>$50,000</td>
<td></td>
</tr>
<tr>
<td>Battery Mount</td>
<td>250</td>
<td>$25,000</td>
<td></td>
</tr>
<tr>
<td>Solar Mount</td>
<td>250</td>
<td>$25,000</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$150,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components</th>
<th>Component</th>
<th>Price/Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td></td>
<td>$500</td>
</tr>
<tr>
<td>Solar Panels</td>
<td></td>
<td>$350</td>
</tr>
<tr>
<td>Batteries</td>
<td></td>
<td>$800</td>
</tr>
<tr>
<td>Wheels and Steering</td>
<td></td>
<td>$400</td>
</tr>
<tr>
<td>Lights &amp; Electrics</td>
<td></td>
<td>$300</td>
</tr>
<tr>
<td>Controller</td>
<td></td>
<td>$600</td>
</tr>
<tr>
<td>Suspension</td>
<td></td>
<td>$250</td>
</tr>
<tr>
<td>Brakes</td>
<td></td>
<td>$150</td>
</tr>
<tr>
<td>Total/Bike</td>
<td></td>
<td>$3,350</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials</th>
<th>Material</th>
<th>Amount/Bike</th>
<th>Cost/Bike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (lbs)</td>
<td>200</td>
<td>$160</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production</th>
<th>Task</th>
<th>Hours</th>
<th>Price/Bike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame (Form/Weld)</td>
<td>3</td>
<td>$300</td>
<td></td>
</tr>
<tr>
<td>Solar Mount Assembly</td>
<td>2</td>
<td>$200</td>
<td></td>
</tr>
<tr>
<td>Battery Mount Assembly</td>
<td>2</td>
<td>$200</td>
<td></td>
</tr>
<tr>
<td>Drivetrain Assembly</td>
<td>3</td>
<td>$300</td>
<td></td>
</tr>
<tr>
<td>Electrical Wiring</td>
<td>2</td>
<td>$200</td>
<td></td>
</tr>
<tr>
<td>Final Bike Assembly</td>
<td>2</td>
<td>$200</td>
<td></td>
</tr>
<tr>
<td>Paint/Detail</td>
<td>2</td>
<td>$200</td>
<td></td>
</tr>
<tr>
<td>Total/Bike</td>
<td></td>
<td>$1,600.00</td>
<td></td>
</tr>
</tbody>
</table>

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Table 9-4. Annual Production Cost and Profit

<table>
<thead>
<tr>
<th>Annual Production Cost (Assuming 5000 bikes/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
</tr>
<tr>
<td>Components</td>
</tr>
<tr>
<td>Materials</td>
</tr>
<tr>
<td>Production</td>
</tr>
<tr>
<td>Shipping</td>
</tr>
<tr>
<td>Marketing</td>
</tr>
<tr>
<td>Total Cost</td>
</tr>
<tr>
<td>Cost/Bike</td>
</tr>
<tr>
<td>Selling Price</td>
</tr>
<tr>
<td>Profit per year</td>
</tr>
</tbody>
</table>

c. Cost Drivers and Tradeoffs

The project operated on a budget of $850. This was a primary driving constraint for many of the designs that were implemented. The most apparent of this budgetary dilemma was through the battery selection. Ideally and if put to market, the design would be best suited with a lithium-ion battery system in order to reduce weight and space required and subsequently obtain a further range with the bike. However, due to the large costs associated with lithium ion batteries the decision has been made to implement deep cycle marine batteries for the power system. This achieved the desired energy levels for the design for a significantly lower cost of a similar lithium ion system. The tradeoff comes in the form of larger mass and more space taken up by this design.

In addition to the battery tradeoff, there also exists a tradeoff in motor and controller selection. Obviously more money amounts to a larger motor and more speed, which means an alternative cooling method, as air-cooling would not be sufficient. For this tradeoff, the design salvaged a 6hp continuous motor and 48V controller was donated from Alltrax Inc. This allowed for more money to be spent on other components of the bike and helped meet the budgetary goals.

The final budgetary tradeoff was mentioned previously in section 5 regarding solar panel selection. The design calls for an estimated total solar power of 350W, however this conflicted with the low budgetary and space constraints also placed on the design. Therefore, in order to more accurately fulfill this
monetary issue, the panel size may be reduced to keep costs low, at the expense of charging time and capacity. This did not pose a significant alteration to the design and did not affect the feasibility of the project.

d. Payback Time

The payback time was estimated to show how long it would take to start profiting from converting a motorcycle to run on electricity and using it for a daily commute. It was found that the money spent converting the motorcycle would be regained about 6.5 years after purchase. This was calculated assuming following conditions shown in Table 9-5.

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Additional Parts Cost</td>
<td>757</td>
<td>$</td>
</tr>
<tr>
<td>Yearly Mileage</td>
<td>1500</td>
<td>Miles</td>
</tr>
<tr>
<td>MPG</td>
<td>45</td>
<td>MPG</td>
</tr>
<tr>
<td>Gas Cost</td>
<td>3.5</td>
<td>$/Gallon</td>
</tr>
<tr>
<td>Panel Capacity</td>
<td>120</td>
<td>W</td>
</tr>
<tr>
<td>Electricity Cost</td>
<td>0.13</td>
<td>$/KWh</td>
</tr>
<tr>
<td>Solar Power Yield</td>
<td>1567</td>
<td>KWh/Year</td>
</tr>
<tr>
<td>Sun Hour</td>
<td>9</td>
<td>hr/day</td>
</tr>
<tr>
<td>Yearly Usage</td>
<td>25</td>
<td>%/Year</td>
</tr>
</tbody>
</table>

This suggests that after 6.5 years, the operator would be saving money on gas when the motorcycle is used 1500 miles a year by 100% solar charging. The estimation was found assuming a lot of different values, but also includes safety factors for each of approximation. So the team believes the estimation seems reasonable.
Figure 9-1. Payback Time
10. Design Integration and Testing

a. Integration

In order to begin installation of the electrical components, the original internal combustion engine was removed from the motorcycle. Afterwards the motorcycle was cleaned up and the paint was ground off of the frame. This allowed for new parts to be welded in place.

Once the motorcycle was prepared, a new coupling was created to attach a universal joint to the shaft of the motorcycle. This universal joint allowed for a gear to be attached to the end of the shaft. This is shown in Figure 10-1.

![Figure 10-1. Universal Joint and Bearing Spacer Installed](image)

Next, a motor mounting plate was created and clamped in place to ensure that it was parallel with the face of the gear and both of these parts were welded onto the frame. A gear was installed on the shaft of the motor and this was connected by a chain to the motorcycle’s shaft, as shown in Figure 10-2.
With the motor connected to the rear wheel, the batteries were the next components to be installed. Two boxes were created using steel angle brackets. Two batteries were installed in each box and these were mounted on top of each other in the place of the old internal combustion engine. The battery boxes were designed to be easily disassembled for when the batteries might need to be removed and replaced. They also have a slight offset to allow for additional electrical components to be mounted above the lower box. These are shown in Figure 10-3.
Some additional components were installed in the empty spaces left on the motorcycle. The motor controller was mounted on its side next to the batteries, the throttle was attached to the original mechanical throttle cable and mounted next to the motor, a 400 Amp fuse was mounted directly under the seat, and the DC/DC converter was mounted behind the motor and in front of the rear wheel. The grid charger was installed inside the gas tank. With these smaller components installed the final components included the solar panels and charge controller. The charge controller was installed in a small empty space in front of the batteries. The solar panels were installed onto aluminum sheets to add rigidity to the panels. These sheets had hinges installed and the hinges were mounted to the sides of the gas tank. A metal flap was added to the bottom of the panels which could swing out to hold the panels up when they are in use. When the panels are in use this flap rests in a slot cut into the side of the gas tank. When the panels are not in use this support is held in place by a rare earth magnet on the bottom of the panel. This can be seen in Figure 10-4. A picture of the motorcycle with all of the components installed is shown in Figure 10-5.

Figure 10-4. Solar Panel Support
b. Electrical Integration

The electrical circuitry for the motorcycle was optimized to allow for the team to keep as much of the original wiring as possible. This includes many of the wires for the key switch, horn, and lights. A Curtis PB-6 potentiometer was used to convert the mechanical throttle to an electrical signal. The horn and lights were connected to the 48V battery pack through a 25 Amp DC/DC converter and the key switch was integrated directly into the motor controller. A detailed model of the electrical design can be seen in Appendix E.

The instrumentation panel of the motorcycle was altered to include new gauges and features. This included a state of charge meter, a voltmeter, an ammeter, a toggle switch to select the desired charging method, and a USB port to charge a GPS or cell phone. These were designed to blend in with the original instrumentation panel and can be seen in Figure 10-6.
c. Setbacks

Throughout the duration of the project the team came across a few major setbacks. The first problem that the team ran into was a lack of electrical knowledge. Being four students studying mechanical engineering electrical knowledge was mostly limited to what was previously learned in an introductory electrical engineering class. However, the team was able to use this knowledge, along with help from some professors, to learn more about the components required for the motorcycle and to construct a working prototype. The team also had many issues with broken components. First it was discovered that some parts inside of their motor controller were dysfunctional and would be very complicated to repair. A picture of this can be seen in Figure 10-7.
Figure 10-7. Broken Motor Controller

The team was quickly able to find a different controller that could be used and were generously donated one from Alltrax Inc. It was also discovered that the 48V battery charger was not working properly. This controller was sent to the company, Battery Tender, for repairs and the team used a 24V charger in the meantime. The 24V charger only allowed two batteries to be charged at a time. The final component that failed was the team’s original motor. The motor starting grinding after a few miles of testing and eventually became far too hard to turn. This was most likely due to all of the metal shavings around the engineering building and while the team tried cleaning out the motor, it was not successful. A new motor was ordered and this motor was covered with paper while it was not being used in order to avoid the same problem reoccurring. After installing this new motor, a few new problems were discovered. First of all, the bearing lock-ring had become loose and the bearing was starting to slip off. This required the drivetrain to be disassembled and the lock-ring to be punched into place. Afterwards, the collar on the motor shaft was starting to slip off and a hole was drilled to insert a pin to keep this from slipping.

d. Testing

Various tests were performed on the final motorcycle design. These tests include tests on the maximum speed, distance, solar panels, and grid charging.
The maximum speed was determined by accelerating the bike at full throttle on a fresh battery charge. This ensured that the motor was able to provide its maximum output. The speed was recorded using a Garmin GPS unit and averaged over multiple tests. The average maximum speed was found to be 38 mph, however these tests were performed before the new motor was acquired. The new motor has a theoretical maximum speed of 57 mph, but the team did not have enough time or a safe location to test this.

In order to compare the motorcycle’s actual mileage to the team’s requirement of 25 miles at 25 mph the team set up a test course in a parking lot at Calvin College. The course was setup to ensure that the driver would be able to maintain a constant speed of 25 mph throughout the test and the bike was driven until the batteries could no longer provide enough power to run the motor. Due to the issues encountered with the first motor and inclement weather the week before senior design night, the full range has not yet been tested. However, the team’s calculations indicate that approximately 35 Ah would be needed to achieve the range goal, so the 60 Ah supplied by the current system should be more than sufficient. The team was also able to estimate their full range by riding 5 miles and comparing the state of the battery before and after the charge.

The solar panels were tested by measuring the current being produced and multiplying that times the voltage to give the power delivered to the batteries. This allowed the team to calculate that over 8 hours of sunlight in Michigan assuming ideal conditions, the battery bank will recover about 17% of a full charge. This amounts to a mileage range extension of 3-5 miles.

Finally, the team measured the time that it took to fully charge the motorcycle from a standard 110 V grid outlet. The team used a 48 V 10 Amp Battery Tender charge controller and found that it took roughly 6 hrs to reach an 80% charge level, and a total time of 8 hrs to reach 100% battery level after the charger has gone into a “float” charging rate of 2.0 amps.

e. Proposed Improvements

Various improvements were considered for this design to improve the functions of SolarCycle. The most pronounced of these improvements would be using lithium-ion batteries in place of the AGM batteries used in the original design. While lithium-ion batteries would require more safety precautions, these batteries would cut down on the overall weight of the bike and are capable of carrying more power than
lead-acid batteries. Both of these advantages would lead to a drastic increase in the range of the bike. In addition the team would want to add an easier way to change the batteries, this would allow for one battery pack to charge while the bike is being used.

Currently, the slotted holes in the motor mount make it hard to acquire the correct tension on the chain. In the future a chain tensioner should be added to avoid having to tension the chain by moving the entire motor.

Another improvement that was considered was the design and construction of a solar charging station for home use. Instead of relying on the small solar panels on the bike to charge the battery, a much larger panel would be used to charge a larger bank of batteries. This system would allow the user to collect additional power during the day and use it to charge their bike at night. In order to improve the solar panels that are installed on the bike, the team suggests adding a method to allow the panels to be moved to more positions, or possible track the sun to harvest the most power possible. The team also wants to add covers to protect the solar panels while the bike is in use.

Aesthetics are also an important aspect for any road vehicle, since many people choose their next car based on how it looks. Besides improving the wiring, it was hoped that fiberglass covers could be fabricated to hide and also protect some of the internal components of the bike such as the motor, controller, and battery bank.
11. Business Plan

The complete marketing and business plan for the SolarCycle may be found on SolarCycle’s website:

http://www.calvin.edu/academic/engineering/2013-14-team15/links.html
12. Conclusion

When the project began, the team hoped to create a motorcycle that uses stored electric energy instead of gasoline to run. The end result had to be affordable, reliable, and in compliance with Michigan motorcycle laws. The team also decided that in order to fit most commuters’ needs, the motorcycle would need to travel approximately 25 miles at a steady 25 mph on a full charge. In order to increase the range of the bike, it was fitted with solar panels that are mounted on brackets and can be deployed when the vehicle is parked to replenish some of the energy lost during the commute. The original intention was to select solar panels capable of bringing the battery to 80% charge from a nearly depleted state over the course of a standard work day. Calculations showed that this would not be feasible, as the cost and size of panels capable of providing that amount of power would be too large and expensive. The team had to settle for smaller solar panels which would not be able to provide as much power but were within the size and budget constraints. These smaller solar panels would be able to add approximately 17%, or 5 miles, during a standard 8 hour workday. The team was, however, able to meet the other project requirements. The motorcycle is able to reach speeds greater than 35 mph, allowing it to be used around a city such as Grand Rapids. It also has the ability to travel approximately 20-30 miles. All of the original lights on the motorcycle are functional, making it a legal form of transportation.

While the team was not able to meet their requirements regarding solar charging rates, the team was able to create a reliable alternative form of transportation that runs exclusively on electrical power and can be charged through sustainable solar energy. All of the members of the team were able to learn so much throughout the entire process of the project. One of the first lessons that the team learned was to be flexible with their schedules. The team was most efficient when they were flexible with when they worked and what they worked on. They also learned to be flexible with designs and how to make changes in order to produce parts that worked the best but might have not always be the most aesthetically pleasing options. Related to this, the team also had to learn how to work well together in order to complete such a large project in the given amount of time. Since the team was also using old equipment to build their prototype, they learned to test all of their equipment. Many of the parts that were found in the engineering building were not actually functional and the team did not realize this until later during the course of the project. Because the team was made up of students studying mechanical engineering, they learned to practice humility. They often had to ask professors for help, especially regarding the
electrical components of the project. Finally, the team learned to never assume that a project is finished. On multiple occasions the team claimed that their motorcycle was complete without completing all of their tests. However, they often found new things that had to be optimized and fixed in order to finish the project and were required to disassemble the prototype many times. All of the lessons that were learned throughout the course of the project will be very useful for the members of the team as they graduate from college and start a career in engineering.
13. Acknowledgements

The team would like to thank the following for their support and encouragement throughout the project:

- Calvin College Engineering Department
- The team’s advisor, Professor Ned Nielsen
- The team’s industrial consultant, Ren Tubergen
- Calvin College electrical engineering professor, Professor Yoon Kim
- The Calvin College mechanics shop manager, Mr. Phil Jasperse
- The Calvin College electronics shop manager, Mr. Chuck Holwerda
- The Calvin College engineering lab manager, Mr. Robert DeKraker
- Alltrax Inc, VMAX USA, and Motenergy for supplying key components
- The team members’ friends and family
14. Appendix

a. Bibliography


<http://www.therenewableyou.com/BattCycle_adam@try.com_08_10_04.pdf>.


<https://www.4shared.com/download/3CfX4-82/Honda_CB750_CB_750_F2_Workshop.pdf>.

b. Calculations

**Inputs**

Coefficient of Drag

\[ C_{\text{drag}} = 0.80 \]

Rolling Resistance

\[ r = 0.02 \]

Max Incline Grade

\[ \beta = 5\% \]

Frontal Area

\[ A_x = 10.8 \text{ft}^2 \]

Max Acceleration Time

\[ t_{\text{accel}} = 10\text{s} \]

Total Weight

- Weight of Frame: 226 lbf
- Weight of passenger: 200 lbf
- Weight of motor + batteries: 300 lbf

\[ W = (226 + 200 + 300)\text{ lbf} = 726\text{ lbf} \]

Environment Conditions

\[ \rho_{\text{air}} = 1.187 \frac{\text{kg}}{\text{m}^3} \]

Velocity

\[ v_{\text{max}} = 55\text{mph} = 80.667 \frac{\text{ft}}{\text{sec}} \]

\[ v_{\text{climb}} = 35\text{mph} = 51.333 \frac{\text{ft}}{\text{sec}} \]

\[ v_{\text{avg}} = 25\text{mph} \]

Travel Distance

\[ d = 25\text{mi} = 1.32 \times 10^5 \text{ft} \]
Travel Time
\[ t_{\text{run}} = \frac{d}{v_{\text{avg}}} = 3.6 \times 10^3 \text{ s} \]

Efficiency and Correction Factors
\[ \eta_{\text{motor}} = 0.9 \quad F_{\text{solar}} = 1.2 \quad C_{\text{battery}} = 0.8 \]

**Force Calculations**
\[ F_{\text{rolling}} = W \cdot r = 14.52 \text{ lbf} \]
\[ F_{\text{air.max}} = \frac{1}{2} \cdot C_{\text{drag}} \cdot \rho_{\text{air}} \cdot A_x \cdot v_{\text{max}}^2 = 64.743 \text{ lbf} \]
\[ F_{\text{air.climb}} = \frac{1}{2} \cdot C_{\text{drag}} \cdot \rho_{\text{air}} \cdot A_x \cdot v_{\text{climb}}^2 = 26.213 \text{ lbf} \]
\[ F_{\text{air.avg}} = \frac{1}{2} \cdot C_{\text{drag}} \cdot \rho_{\text{air}} \cdot A_x \cdot v_{\text{avg}}^2 = 13.377 \text{ lbf} \]

**Power Calculations**
\[ P_{\text{steady.max}} = (F_{\text{rolling}} + F_{\text{air.max}}) \cdot v_{\text{max}} = 11.625 \text{ hp} \]
\[ P_{\text{hills}} = W \cdot v_{\text{climb}} \cdot \theta + (F_{\text{rolling}} + F_{\text{air.climb}}) \cdot v_{\text{climb}} = 7.19 \text{ hp} \]
\[ P_{\text{steady.avg}} = (F_{\text{rolling}} + F_{\text{air.avg}}) \cdot v_{\text{avg}} = 1.86 \text{ hp} \]
\[ P_{\text{accel}} = \frac{\left( \frac{1}{2} \cdot \frac{W}{g} \cdot v_{\text{max}}^2 \right)}{t_{\text{accel}}} = 13.348 \text{ hp} \]

**Energy Calculations**
\[ E_{\text{avg}} = \frac{P_{\text{steady.avg}} \cdot d}{v_{\text{max}}} = 2.269 \times 10^6 \text{ J} \]
\[ E_{\text{elec}} = 80 \cdot \frac{J}{s} \cdot t_{\text{run}} = 2.88 \times 10^5 \text{ J} \]
\[ E_{\text{motor avg}} = \frac{P_{\text{steady.avg}} \cdot t_{\text{run}} + E_{\text{elec}}}{\eta_{\text{motor}}} = 5.867 \times 10^6 \text{ J} \]
Battery Calculations

Battery Specifications

\[ B_{Ah} = 60 \text{Ah} \]  
\[ B_c = B_{Ah} \cdot 3600 \cdot \frac{s}{\text{hr}} \]  
\[ B_V = 48 \text{ V} \]

Battery Calculations

\[ B_J = B_c \cdot B_V \]  
\[ N = \frac{E_{motor avg}}{B_J} = 0.566 \]  
Number of Battery Packs Required (Must Be <1)

Solar Calculations

Solar Panel Specifications

\[ t_{charge} = 8 \text{ hr} \]  
\[ P_{solar} = \frac{B_J}{t_{charge}} = 360 \text{ W} \]  
\[ P_{solar,real} = C_{battery} \cdot F_{solar} \cdot P_{solar} = 345.6 \text{ W} \]
Battery Mounting Calculations

\[ F_{\text{battery}} := 50 \text{ lbf} \]

\[ L_{\text{beam}} := 11 \text{ in} \]

\[ w_{\text{beam}} := \frac{F_{\text{battery}}}{L_{\text{beam}}} = 4.545 \, \text{ lb} / \text{in} \]

\[ V_{\text{max}} := -w_{\text{beam}}x_{\text{force}} + \frac{F_{\text{battery}}}{2} = 25 \text{ lb} \]

\[ M_{\text{max}} := \frac{-w_{\text{beam}}x_{\text{moment}}}{2} + V_{\text{max}}x_{\text{moment}} = 68.75 \text{ lb} \cdot \text{in} \]

\[ S_{\text{stress}} := N_{\text{safety}} \frac{M_{\text{max}}}{E_{\text{steel}}} = 5.688 \times 10^{-3} \text{ in}^3 \]

\[ I_{\text{deflection}} := -5N_{\text{safety}}w_{\text{beam}}L_{\text{beam}}^4 + \frac{4}{384E_{\text{steel}}}x_{\text{deflection}}^4 = 0.023 \text{ in}^4 \]

see tables in 305 p. 694
Shaft Bearing and Keyway Calculations

\[ T_{\text{max}} := 200\text{ lbf\cdot in} \]
\[ d_{\text{shaft}} = 0.75\text{ in} \]
\[ r_{\text{shaft}} := \frac{d_{\text{shaft}}}{2} = 0.375\text{ in} \]
\[ T_a = \frac{T_{\text{max}}}{2} \]
\[ T_m = \frac{T_{\text{max}}}{2} \]
\[ F_a := \frac{T_a}{r_{\text{shaft}}} = 266.667\text{ lbf} \]
\[ F_m := \frac{T_m}{r_{\text{shaft}}} = 266.667\text{ lbf} \]
\[ \tau_a := \frac{F_a}{A_{\text{shear}}} = 2.844 \times 10^3\text{ psi} \]
\[ \tau_m := \frac{F_m}{A_{\text{shear}}} = 2.844 \times 10^3\text{ psi} \]
\[ \sigma_{\text{prime.a}} := \left(3 - \tau_a^2\right)^{\frac{1}{2}} = 4.927 \times 10^3\text{ psi} \]
\[ \sigma_{\text{prime.m}} := \left(3 - \tau_m^2\right)^{\frac{1}{2}} = 4.927 \times 10^3\text{ psi} \]
\[ \sigma_{\text{max}} := \frac{F_m + F_a}{A_{\text{bearing}}} = 1.138 \times 10^4\text{ psi} \]
\[ N_{\text{fatigue}} := \frac{1}{\frac{\sigma_{\text{prime.a}}}{S_{\text{endurance}}} + \frac{\sigma_{\text{prime.m}}}{S_{\text{ultimate}}}} = 3.255 \]
\[ N_{\text{bearing}} := \frac{S_{\text{yield}}}{\sigma_{\text{max}}} = 3.867 \]

all is ok in the world
Operation Time Calc. - 03/05/14 T.Lim

Inputs

\[ P_{\text{max}, \text{avg}} = 1.86 \, \text{hp} \cdot \left( \frac{745.7}{\text{hp}} \right) \]

\[ P_{\text{max}, \text{max}} = 7.19 \, \text{hp} \cdot \left( \frac{745.7}{\text{hp}} \right) \]

\[ P_{\text{acc}} = 13.35 \, \text{hp} \cdot \left( \frac{745.7}{\text{hp}} \right) \]

\[ P_{\text{hill}} = 7.19 \, \text{hp} \cdot \left( \frac{745.7}{\text{hp}} \right) \]

Fractions of Each Scenario

\[ x_{\text{sa}} = 0.7 \quad \text{Steady Avg.} \]

\[ x_{\text{sm}} = 0.1 \quad \text{Steady Max.} \]

\[ x_{\text{a}} = 0.15 \quad \text{Accel.} \]

\[ x_{\text{h}} = 0.05 \quad \text{Hills} \]

\[ x_{\text{tot}} = x_{\text{sa}} + x_{\text{sm}} + x_{\text{a}} + x_{\text{h}} \quad \text{To check final fraction} \]

Battery Spec. (EA)

\[ V_{\text{B, rated}} = 12 \, \text{[V]} \]

\[ A \cdot h_{\text{B, rated}} = 60 \, \text{[A\text{"h}]} \]

\[ DF_B = 0.5 \quad \text{Factor to assume maximum energy draw is 50% of rated capacity of the battery} \]

Solar Panel Spec.

\[ Y = 3918.3 \, \text{[kW\text{-}hr]} \cdot \left( \frac{120}{300} \right) \quad \text{Estimated Annual Yield - SunnyDesign} \]

\[ Y_a = \frac{Y}{365 \, \text{[day]} \cdot 24 \, \text{[hr/Day]}} \cdot \left( \frac{1000}{\text{kW}} \right) \quad \text{Estimated Daily Power Yield} \]

\[ SH = 9 \, \text{[hr/Day]} \quad \text{Estimated Sun Hours} \]

Calculations

1. Theoretical - Based on Rated Specifications

\[ P_{\text{in, rated}} = \frac{4 \cdot V_{\text{B, rated}} \cdot A \cdot h_{\text{B, rated}}}{H_{\text{th}}} \]

\[ H_{\text{th}} = \frac{P_{\text{in, rated}}}{P_{\text{avg, avg}}} \]
2. Realistic - Based on Realistic Numbers

\[
P_{t,real} = P_{t,real} \cdot DF \]

\[
P_{real} = x_{sil} \cdot P_{static,avg} + x_{sm} \cdot P_{static, max} + x_{ac} \cdot P_{acout} + x_{th} \cdot P_{th}
\]

\[
H_{real} = \frac{P_{t,real}}{P_{real}}
\]

\[
Min_{real} = H_{real} \cdot \frac{60}{hr}
\]

3. Charging Time Using Solar Panels

\[
T_{chg} = \frac{P_{t,real}}{Y_d}
\]

\[
D_{chg} = \frac{T_{chg}}{SH}
\]

Payback Calc.

\[
Cost_{Panel} = 88 \ [\$]
\]

\[
Cost_{Controller} = 255 \ [\$]
\]

\[
Cost_{Misc} = 150 \ [\$]\ MISC\ Parts\ and\ Labor
\]

\[
N_{Panel} = 4
\]

\[
Cost_{Gas} = 3.5 \ [\$/Gallon]\ Gas\ Cost
\]

\[
MPY = 1500 \ [\text{miles}]\ Annual\ Mileage
\]

\[
MPG = 45 \ [\text{Miles/Gallon}]\ MPG\ of\ motorcycle
\]

\[
Cost_{Gas} = \frac{Cost_{Gas}}{MPG}
\]

\[
Cost_{total} = Cost_{Panel} \cdot N_{Panel} + Cost_{Controller} + Cost_{Misc} - Cost_{Gas} \cdot T_{PB}
\]

\[
Cost_{electricity} = 0.13 \ [\text{[$kW-hr]}]\ \text{http://www.npr.org/blogs/money/2011/10/2/141785341/the-price-of-electricity-in-your-state}
\]

\[
Cost_{Esac} = Cost_{electricity} \cdot Y
\]

\[
U = 0.25\ \%\ Usage
\]

\[
T_{PB2} = \frac{Cost_{Panel}}{Cost_{Esac} \cdot U} \cdot 1 \ [\text{year}]
\]

\[
T_{PB2} = 0
\]

\[
Cost_{TS} = -\ Cost_{total}
\]
SOLUTION

Unit Settings: SI c kPa kJ mass deg

\[\begin{align*}
\text{Ah} &= 60 \text{ [A.hr]} \\
\text{Cost1w} &= 203.8 \text{ [\$]} \\
\text{Cost1s} &= 3.5 \text{ [\$/Gallon]} \\
\text{Cost1s} &= 150 \text{ [\$]} \\
\text{Cost1s} &= 1.505\times10^{-3} \text{ [\$]} \\
\text{F1s} &= 0.5 \\
\text{H1s} &= 0.4406 \text{ [ft]} \\
\text{M1s} &= 25.43 \text{ [mph]} \\
\text{MPG} &= 42 \text{ [Miles/Gallon]} \\
\text{N1s} &= 4 \\
\text{P1s} &= 5362 \text{ [W]} \\
\text{Pr1} &= 1440 \text{ [W-hr]} \\
\text{Pr1} &= 1397 \text{ [W]} \\
\text{SH} &= 9 \text{ [hr/day]} \\
\text{Tr1} &= 6.489 \\
\text{U} &= 0.25 \\
\text{x1} &= 0.15 \\
\text{x2} &= 0.7 \\
\text{x3} &= 1 \\
\text{Ys} &= 179.2 \text{ [W]} \\
\text{Y} &= 1567 \text{ [kW-hr]} \\
\end{align*}\]

1 potential unit problem was detected.

KEY VARIABLES

\[\begin{align*}
\text{Min} &= 124.6 \text{ [min]} \\
\text{Min} &= 25.43 \text{ [mph]} \\
\text{H} &= 2.076 \text{ [hr]} \\
\text{H} &= 0.4406 \text{ [ft]} \\
\text{T} &= 16.1 \text{ [hr]} \\
\text{DCE} &= 1.789 \text{ [day]} \\
\text{T} &= 6.489 \\
\end{align*}\]

Parametric Table - Table 1

<table>
<thead>
<tr>
<th>(T_{PB})</th>
<th>(\text{Cost}_{15})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>-640.3</td>
</tr>
<tr>
<td>Run 2</td>
<td>-523.7</td>
</tr>
<tr>
<td>Run 3</td>
<td>-407</td>
</tr>
<tr>
<td>Run 4</td>
<td>-290.3</td>
</tr>
<tr>
<td>Run 5</td>
<td>-173.7</td>
</tr>
<tr>
<td>Run 6</td>
<td>-87</td>
</tr>
<tr>
<td>Run 7</td>
<td>59.87</td>
</tr>
<tr>
<td>Run 8</td>
<td>178.3</td>
</tr>
<tr>
<td>Run 9</td>
<td>293</td>
</tr>
<tr>
<td>Run 10</td>
<td>409.7</td>
</tr>
<tr>
<td>Run 11</td>
<td>526.3</td>
</tr>
<tr>
<td>Run 12</td>
<td>683</td>
</tr>
<tr>
<td>Run 13</td>
<td>759.7</td>
</tr>
<tr>
<td>Run 14</td>
<td>872.3</td>
</tr>
</tbody>
</table>

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c. Solar Resources

Average Daily Solar Radiation Per Month

JUNE

Flat Plate Tilted South at Latitude + 15 Degrees

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 203 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

National Renewable Energy Laboratory
Resource Assessment Program

Figure 14-1. Solar Radiation
d. Parts Documentation

Figure 14-2. Motor Documentation
Briggs & Stratton is renowned worldwide for leadership in power technology.

You can count on our gas engines for performance, power, reliability, and profitability. Now, you can get these same benefits from our Elek™ Electric Motor System. An innovative product in battery powered equipment.

Do not let the small size fool you. The uniquely integrated Elek™ system provides an highly efficient combination of hardworking power and torque. Compared to other DC motor systems, the Elek™ system reduces maintenance costs, uses less energy and offers a longer operating life. All in a smaller, lighter weight design.

The compact size, 50% smaller and 20 lbs. lighter than other motors, results in a high power-to-weight ratio. You get high torque at low speeds and longer run life between charges.

SAFETY

The safety alert symbol is used to identify safety information about hazards which can result in death, serious injury, and/or property damage.

WARNING indicates a hazard which, if not avoided could result in death or serious injury.

CAUTION indicates a hazard which, if not avoided might result in death or serious injury.

CAUTION when used without the alert symbol, indicates a situation that could result in damage to the motor.

HAZARD SYMBOLS AND MEANINGS

Moving Parts ⚠️ Shock ⚠️ Fire ⚠️

WARNING

Electrocution or serious injury can occur if proper precautions are not followed.

• DO NOT pour or spray water on the motor while running or cleaning.
• DO NOT attempt to repair or make adjustments to the motor while in operation.
• Keep the motor clean of grass, Scale, and dirt. An accumulation of combustible material around on the motor will prevent cooling and may result in a fire, and personal injury.

WARNING

Rotating parts can contact or entangle hands, feet, hair, clothing, or accessories. Traumatic amputation or severe laceration can result.

Operate unit with guards in place.
Keep hands and feet away from rotating parts.
Tie up long hair and remove jewelry.
Do not wear loose-fitting clothing, dangling drawstrings, or items that could become caught.

FEATURES

Motor provides 32 ft-lbs of torque independent of vehicle voltage. Maximum speed is self-regulating and is set by the manufacturer to meet specific application requirements. Improved regenerative braking can be set to meet terrain requirements and individual needs for “feel.” Reduces brake wear and enhances battery life.

• Axial air gap DC disc armature motor means a lot of power in a small package.
• Permanent magnet field provides high efficiency and minimal loss of speed as motor increases.
• Reliability and rugged construction, with no commutator connections, reduces maintenance costs and extend motor life.
• High power-to-weight ratio due to compact disc construction and integral commutator.
• Lightweight aluminum frame.

GENERAL INFORMATION

Voltage Constant: 72 RPM per Volt
Torque Constant: 1:14 in lb/amp (0.13 Nm/Amp)
Maximum Motor Current: 330 amps for 1 minute
Motor Weight: 21 lbs.
Motor Output: Maximum 15 Hp, 8 Hp continuous
Maximum Motor Voltage: 48 V.D.C.
Maximum No Load Current: 6 Amp

OPERATION

In tests, the Briggs & Stratton Elek™ motor outperformed the competition by maintaining consistent speed and optimal efficiency across a wide range of loads.

Briggs & Stratton Motor
Competitive Motor
**APPLICATION**

**WARNING**
Briggs & Stratton does not approve or authorize the use of this motor on 3-wheel All Terrain Vehicles (ATVs), motor bikes, aircraft products or vehicles intended for use in competitive events. Use of this motor in such applications could result in property damage, serious injury (including paralysis), or even death.

**WARNING**
Battery gas can explode.
- Keep sparks and flames away from batteries.
- Never place a metal object across battery posts to check for charge - use a voltmeter or hydrometer.
- Keep battery post and electrical connection covers in place.

**MAINTENANCE**

**WARNING**
Batteries can develop extremely high currents. Motor removal, or brush housing replacement should be done by a qualified technician.

**DEBRIS CLEANING**
Periodically remove grass, chaff or dirt around the air cooling vents of the frame to prevent overheating of the motor.

**BRUSH INSPECTION**
Yearly or every 100 hours have brushes inspected for wear. Replacement of brush housing is recommended when brush length is at 1/8” above brass holder. Torque brush cover bolts to 9.8 in. lbs.

**SERVICE**

The Briggs & Stratton Etek™ motor is so durable and efficient, we are only offering the brush pack as a service item.

**Brush Housing** To order use:
P/N 6969822, includes complete brush set along with cover/p/n 5669803, bolts and washers.

**WARNING**
DO NOT disassemble the motor. Voltage and output have been pre-set by the factory. Any tampering with the magnet settings may cause serious damage to the motor.

To obtain replacement parts, you may locate your nearest Authorized Briggs & Stratton Service Dealer in our dealer locator map on our web site www.briggsandstratton.com or in the "Yellow Pages" directory under "Engines, Gasoline" or similar category.

**Briggs & Stratton**
ABOUT YOUR ENGINE WARRANTY

Briggs & Stratton warrants engine material and workmanship only for the engine to be mounted. Nor does the warranty extend to repairs required because of:

1. Problems caused by parts that are not original Briggs & Stratton parts.
2. Gaskets, washers, or other parts that prevent water or other foreign material from entering the engine.
3. Leaking carburetor, clogged fuel lines, stem valves, or other damage caused by using contaminated fuel.
4. Worn spark plugs or engine damage caused by lack of oil.
5. Parts which are scored or broken because an engine was operated with insufficient or contaminated oil or otherwise operated at less than normal speed for long periods of time.
6. Damage or wear to parts caused by dirt, which entered the engine because of improper maintenance as well as the engine being operated in a dusty environment.

This warranty covers engine-related defects in material and workmanship only, and not replacement or repair of the equipment to which the engine may be mounted. Nor does the warranty extend to repairs required because of:

1. Problems caused by parts that are not original Briggs & Stratton parts.
2. Gaskets, washers, or other parts that prevent water or other foreign material from entering the engine.
3. Leaking carburetor, clogged fuel lines, stem valves, or other damage caused by using contaminated fuel.
4. Worn spark plugs or engine damage caused by lack of oil.
5. Parts which are scored or broken because an engine was operated with insufficient or contaminated oil or otherwise operated at less than normal speed for long periods of time.
6. Damage or wear to parts caused by dirt, which entered the engine because of improper maintenance as well as the engine being operated in a dusty environment.

BRIGGS & STRATTON OWNER WARRANTY POLICY

LIMITED WARRANTY

Briggs & Stratton Corporation warrants engine material and workmanship only for the engine to be mounted. Nor does the warranty extend to repairs required because of:

1. Problems caused by parts that are not original Briggs & Stratton parts.
2. Gaskets, washers, or other parts that prevent water or other foreign material from entering the engine.
3. Leaking carburetor, clogged fuel lines, stem valves, or other damage caused by using contaminated fuel.
4. Worn spark plugs or engine damage caused by lack of oil.
5. Parts which are scored or broken because an engine was operated with insufficient or contaminated oil or otherwise operated at less than normal speed for long periods of time.
6. Damage or wear to parts caused by dirt, which entered the engine because of improper maintenance as well as the engine being operated in a dusty environment.

There is no other express warranty. IMPLIED WARRANTIES, INCLUDING THOSE OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, ARE LIMITED TO ONE YEAR FROM PURCHASE, OR TO THE EXTENT PERMITTED BY LAW ANY AND ALL IMPLIED WARRANTIES ARE EXCLUDED. LIABILITY FOR CONSEQUENTIAL DAMAGES UNDER ANY AND ALL WARRANTIES IS EXCLUDED. EXCEPT FOR THE EXCLUSION OF INCIDENTAL DAMAGES PERMITTED BY LAW, SOME COUNTRIES OR STATES DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LASTS, AND SOME COUNTRIES OR STATES DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE LIMITATION AND EXCLUSION MAY NOT APPLY TO YOU. THIS WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS AND YOU MAY ALSO HAVE OTHER RIGHTS WHICH VARY FROM COUNTRY TO COUNTRY AND STATE TO STATE.
Figure 14-3. Controller Specifications

<table>
<thead>
<tr>
<th>SPM AVAILABLE NOW</th>
<th>24-48V</th>
<th>Cabinet</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXE-493P</td>
<td>50A</td>
<td>10.0 inch</td>
</tr>
<tr>
<td>AXE-493P</td>
<td>400A</td>
<td>10.0 inch</td>
</tr>
<tr>
<td>AXE-493P</td>
<td>600amp</td>
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<table>
<thead>
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<tr>
<td>AXE-493P</td>
<td>400A</td>
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<td>AXE-493P</td>
<td>600amp</td>
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</tbody>
</table>

For more product information: www.alltraxinc.com

Made in USA
Figure 14-4. Throttle Documentation
Figure 14-5. DC/DC Converter Documentation

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Figure 14-6. Battery Indicator Documentation
e. Electrical Model

Figure 14-7. Electrical Diagram