

NORTHERN ARIZONA UNIVERSITY

Final Report

EE/ME486C – GCROA Team

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May 1, 2009

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Table of Contents	
Introduction.....	3
Problem definition	3
Requirements and Specifications.....	3
Needs and Constraints.....	5
Preliminary Solution Concepts	6
Design Decision	7
List of Deliverables.....	7
State of the Art Research	8
Modeling and Analysis	12
Calculations	12
Computer Drawings.....	13
Manufacturing.....	13
Finite Element Analysis (FEA)	14
Wiring	14
Mechanical Testing.....	15
Electric Testing: System Stability	15
Renewable Feasibility.....	16
Bill of Materials	17
Final Budget.....	17
Recommendations.....	17
Conclusion	18
Appendix A: Decision Matrix.....	19
Appendix B: Energy Calculations	20
Appendix C: CAD Drawings	22
Appendix D: FEA Models	26
Appendix E: Wiring.....	27
Appendix F: Mechanical Testing.....	28
Appendix G: Root Locus Plot.....	29
Appendix H: Solar Power Charts and Tables	31
Appendix I: Battery Charts and Drawings.....	32
Appendix J: Hydroelectric Power	33
Appendix K: Bill of Materials	Error! Bookmark not defined.
Appendix I: Final Budget.....	34
Bibliography	36

Introduction

The Grand Canyon River Outfitters Association (GCROA) is a nonprofit organization comprised of sixteen rafting companies that run rafting trips along the Colorado River. This association, in conjunction with the National Park Service (NPS), wants to replace their current four stroke outboard motor with a more environmentally friendly propulsion system that emits little to no noise and low emissions. The NAU GCROA Team is an electrical and mechanical engineering interdisciplinary team that is dedicated to the research and design of this new propulsion system for GCROA. The mechanical team is responsible for producing thermals studies and interfacing the new electrical motor solution with the boat and propeller, while the electrical team is responsible for the wiring of the motor prototype and component selection. Moreover, the electrical team is conducting research into a theoretical regenerative system that is able to replenish power while in remote locations. The goal of this project is to produce a working prototype of an electric DC motor and speed controller that has the same capabilities for speed and durability as the current motor system used by GCROA. Funding for this research and design had been provided by GCROA and the NPS.

Problem definition

The goal of this project to redesign the current four-stroke outboard motor to produce no noise and little to no emissions. This new motor propulsion system needs to be just as dependable as the old design and capable of the same amount of horsepower. The new motor solution should weigh the same if not less than the current system.

Requirements and Specifications

(note: In this document the “motor assembly” includes the motor housing, drive motor, drive shaft, etc. as a whole. When speaking of the “motor,” this refers only to the drive motor itself.)

Motor Physical Requirements and Specifications:

The motor propulsion system must conform to federal and state regulations. Noise is a key motivating factor in the design of the new motor propulsion system. Therefore, the new system must produce little or no sound. This reduced noise makes for a more pleasant drive for the passengers and will not disturb the wildlife or other boaters. Since the motor might have to be changed or repaired during the trip, it must be a size and weight that is manageable by a single person. Along the same lines, one of the goals is to reduce the size of the motor and make it easier to handle while retaining the power of the current motors in use. Due to harsh conditions the motor propulsion system must have a

driveshaft and propeller that is easy to replace. The motor must be able to mount onto the current standard outboard motor to facilitate an easy transition.

Specification:

1. Motor Assembly must weigh less than 180 lbs
*The chosen electric motor weighs 85 lbs and the adaption assembly weighs approximately 7 pounds
2. Motor's energy source must weigh less than 500 lbs
*Not applicable, as the NAU team bought batteries solely for testing purposes.
3. The motor must emit minimal amount of noise
*The motor produces a small whine upon acceleration, but ceases after approximately 300 RPM. Considerably more quite than the four stroke motor.
4. Motor must be greater than 30 HP, less than 50 HP
*Motor rated for 16 electrical (32 mechanical) horsepower.

Motor Run Time Requirements:

The motor propulsion system must be able to meet the current running requirements of GCROA as not to alter the length of their trips. In addition, the motor must be able to traverse the entire canyon without the need for additional energy as no battery recharge or refueling is available while in the canyon. The motor must be extremely durable as maintenance and rescue is very difficult during the trips.

Specification:

1. Motor must be able to run constantly for 10 hours or for 300 river miles.
*Not applicable, as the NAU team provided the energy source solely for testing purposes.

Motor Environmental Requirements:

One of the goals for this project is to design an environmentally friendly motor. The motor must run clean in order to preserve the wilderness in the Grand Canyon National Park. In addition to preserving the environment, the motor propulsion system must be resilient to the extreme conditions of the Colorado River.

Specification:

1. Motor must produce fewer emissions than the four stroke motor currently being used.
*An electric motor, which produces no onsite emissions

2. Motors must be able to survive/function in sediment filled water (algae, silt, sand, etc.)
*Mounts to same lower housing, and is therefore just as durable as before.
3. Motor and energy source need to be able to withstand temperature fluctuations of 75° F Parts must be resilient to collisions with rocks at speeds of 5-10mph
*Motor is rated to survive such temperature fluctuations. Not applicable for battery source as NAU only has enough for testing purposes.

Other Requirements:

The user interface requirements relate to how easy the motor is to operate. The motor must be designed so that it is easy to operate and learn. Operation should be similar to the current motor operation so that minimal training is needed.

* Motor still uses a mechanical reverse to switch directions and is run in roughly the same way as the four stroke motor.

Needs and Constraints

Environmental

The GCROA concessioners want to preserve the natural beauty and ambience on their rafting trips down the Colorado River. By reducing the noise emitted by the motor, the trips will be more pleasant for their customers and other rafters. This noise reduction will also help to not disturb local wildlife or guides.

The constraint is the noise level produced from any type of motor must be below the threshold of 65 dB. Because Grand Canyon is a national park nothing may be left or built in the Grand Canyon as in recharging stations or part storage containers.

Health/Safety

The changes that will be made to the motor will have to pass a level of safety to ensure that there are no health risks. With the use of an electric motor and batteries the risk of electrical shock is present. Any components that could break down need to be thought of in isolated situations, and the staff need to be aware of what to do if, for example, a battery explodes.

A main health and safety concern is that the guides do not have an engineering background, so if batteries are used the guides will have to understand what they can or cannot adjust. Since the battery power source is expected to be large, the guides will need to know how it can be disconnected and the procedure to do it in.

Preliminary Solution Concepts

For this project, we considered many different types of propulsion systems. Eventually, this number was reduced to four systems. These systems are:

- Electric motor with batteries: This concept uses either an AC induction or DC motor and is charged with a type of rechargeable battery such as lithium ion.
- Electric motor with fuel cells: This concept uses either an AC induction or DC motor and hydrogen fuel cells for power.
- Compressed air motor: Uses compressed air to run a motor.
- Biodiesel: Type of fuel that can replace diesel in a regular diesel motor.

We then put each of these four technologies into a decision matrix (Appendix a) where they were rated from one to ten based on the requirements for the project and calculations (appendix B). Then, each decision category was given a weight according to its importance to our customer. The following are a basic description of each of the criteria and how the solutions were rated:

- Safety: How safe the motor propulsion system is during installation, replacement, and storage of fuel or power source.
- Weight: Defined as the net weight of the system, includes both the weight of the motor and the weight of the fuel source.
- Power Output: How well the solution is able to reach 35 horsepower, the minimum speed for the current outboard motor.
- Compatibility: How well the motor propulsion system would fit into the current space designated for the motor and fuel.
- Ease of Replacement: How easy the motor is to swap with another motor compared to that currently being used by the customer.
- Low Sound: Amount of noise the motor propulsion system is expected to make while running.
- Low Emissions: Amount of pollution given off by the system.
- Time before Replacement: Length of time before the power source runs out based on the outboard motor currently used.
- Lifetime: Total time before failure for the given system.
- Volume: Amount of space on the raft each of the solutions is expected to take up.
- Cost: Amount to initially purchase and install the motor propulsion system.

From the decision matrix (appendix A), we came up with the following conclusions:

- Biodiesel: This is an impractical solution since we would need to replace the current configuration with a new motor propulsion system that runs on a type of diesel fuel. This solution would still emit a lot of noise.

- Compressed air: While a better solution than biodiesel, compressed air still has some drawbacks. Compared to the other possible solutions, it has a limited range of travel and takes up a large amount of volume.
- Electric motor with hydrogen fuel cell: This is more practical than either biodiesel or compressed air; however it still has some major drawbacks. For example, hydrogen fuel cells are less efficient than other power sources and have a relatively short lifespan.
- Electric motor run by batteries: This was our chosen preliminary solution concept. Electric motors produce little to no sound, which was the most important requirement by our customer. The battery system does not produce any emissions and has a longer lifespan when compared to the other possible solutions

Design Decision

Using our decision matrix and other research, we decided that an electric motor run by batteries was the best solution to this design problem. For this phase of the project, batteries will be used solely for testing purposes. However, in the future, batteries will be used to run the electric motor for the full duration of the trip, this means that batteries must be in series to achieve the motor's input voltage and in parallel to achieve the amp hours needed for the trip. The motor will need a large quantity of batteries in order to power for the entire rafting trip and this is beyond the scope of work required for this year's project.

For our electric motor we chose an Advanced DC L91, rated at 16 electrical horsepower. With the followings specifications:

- 130 amps continuous, 150 amps for one hour, 500 amps peak
- At 96 VDC, 13.6 HP continuous, 15 HP for one hour, 26.4 for 5 min., 62 HP peak
- At 120 VDC, 16 HP continuous, 17.9 HP for one hour, 31 HP for five min., 72 HP peak
- 85 lbs

A Curtis PMC 1231C was the chosen speed controller for this project. Batteries were also purchased for testing.

The team also realized the need to undo the gear ratio in the lower assembly. We purchased a 2:1 pulley system so that the new ratio was 1:1.

List of Deliverables

The following is the list of deliverables that our team has produced for the Grand Canyon River Outfitters Association:

- CAD drawings of final design
- Finite element analysis of mounting assembly
- System schematics for electric motor assembly
- Prototype of electric motor assembly
- Final Report

State of the Art Research

Here is the list of state of the art research that we have conducted in fall 2008 and spring 2009. It encompasses research into various electric motors as well as the other alternative designs that we considered.

Deep Cycle Battery FAQ: Information on different types of batteries, battery cycles and battery life. The deeper you cycle a battery through its charge the more the overall battery life is reduced. Less batteries can be used if the batteries are cycled to 100%, however this will also greatly reduce the number of cycles the batteries can go through.¹

EIG Lithium Ion Polymer Battery: The energy density is 2-5 times higher than lead acid batteries, over 380 Wh/kg for PB4820 batteries. Can discharge is 100% at least 1000 times or 50% 5000 times. Usually 3 times lighter than lead acid and 1.5 times travel distance.²

BP Solar Panels: BP 200W panels at 24.5V and 8.16A. 50 cell in a 5x10 matrix series connection. 15.4kg with 1680mm long x 837mm wide x 50 mm deep frame.³

OutBack Charge Controller: A charge controller with maximum power point tracking which is able to take the wattage from the panel and set a output voltage and up the amps to a $P=VI$ 98.1% efficient conversion.⁴

Battery Life (and Death): Information on battery life of different types of batteries as related to temperature, pressure, amount the battery has been cycled, venting leakage and age. Higher temperatures increase the capacity of the batteries however reduces the batteries lifetime in terms of years.⁵

How Electric Motors Work: Basic explanation of an electric motor, electric motor technology has not changed in a very long time. There is still the DC motor and AC induction motor, leading to the need to look at improvements in battery technology instead of electric motor improvements.⁶

The Straight Attraction: Advantages of direct drive linear motors versus traditional rotary to linear motion motors. Direct drive motors have a greater accuracy and can attain a higher speed according to the article than belt driven motors. This article looks especially at the use of neodymium magnets in the direct drive linear motors.⁷

Nanowire Batteries: Discussion of new techniques in battery development using nanowires to produce batteries with ten times the capacity of lithium – ion batteries. The article does not go into very much detail save to say that new and improved batteries are under research at Stanford using silicon nanowires.⁸

Internal Combustion Engines: Book detailing engines, four stroke engines run under the Otto cycle, and consists of four stages the intake, compression, combustion, and exhaust. They tend to have more power and be more expensive than many two stroke engines.⁹

Low Noise Motors: Details different methods of producing low noise motors as well as equations for calculating the noise produced by the motor.¹⁰

Electric Motor Manual: Explains the difference in application between DC and AC motors as well as going into operational detail on each.¹¹

Propulsion Systems: Details propulsion systems of the rocket and jet engine type.¹²

Fuel Alternatives for heavy equipment: This source talked about both biodiesel and electric motors used to power heavy equipment. For biodiesel they use B20/B6, which refers to the percentage to biodiesel in the fuel. It is important to be consistent with the type of oil used in biodiesel to prevent corrosion. It is also important to be aware of the biodiesel blends used, if you have a warranty on your equipment (it must be certified by ASTM for warranties). Electric motors cost more than biodiesel to set-up but it's cheaper to run and has less moving parts than diesel. Electric motors won't need maintenance for up to 50,000 hours of operation and if 3-phase is already available, then running electric motor is much more efficient than biodiesel, but installing a 3-phase electrical source can be very expensive.¹³

Japanese Car manufacturers: Honda has begun the first commercial production of a zero-emissions hydrogen-fuel-cell-powered vehicle, with the first cars to be unveiled during July in southern California, one of the few places in the world where hydrogen fueling stations exist.¹⁴

Fuel Cells Portal Page: This article talks about what fuel cells are and how it is used to provide power for a propulsion system. Fuel cells are energy conversion devices set to replace combustion engines. The fuel cell converts chemical energy in fuels (hydrogen) into electrical energy. It's only by-products are heat and water and it has no combustion (it converts fuels directly into electricity via electrochemical process). The benefits are lower carbon footprint, reduces noise and air pollution, fuel bill reduces, it can produce fuel and generate heat and power onsite. It also goes into the type of hydrogen cells used.¹⁵

Electric boat Features Hydrogen fuel cell: This article talks about the Hydroxy3000, which is a catamaran that is 7m long, 2.5m wide and weighs 1.5 tons. This motor vehicle uses a 3 kW electric motor where a fuel cell is the main source of energy. It uses batteries as a backup system, can carry 7 passengers, and goes approximately 11

km/h. The motor used generates no water or air pollutions/smells and creates relatively little noise.¹⁶

Recent Challenges of Hydrogen Storage Technologies for fuel cell vehicles:

This article talks about the hydrogen supply path and hydrogen fuel storage. It addresses the problem of hydrogen being very low in density and therefore requiring much more storage space as a dense fuel. It has 1/10 energy compared to gasoline from the same volume. It talks about the hydrogen current storage methods used such as high pressurized tank and cryogenic storage and a new storage method idea of combining metal hydride and high pressure.¹⁷

Fuel-Cell Cars: This Article talks about General Motors and American Honda Motors making 300 hydrogen fuel cell cars available to American drivers: Chevy Equinox and the Honda Clarity are the two cars that will be available to consumers. After being tested by drivers, they emphasized how quiet the motor was compared to the previous made hydrogen fuel cell motors which used air compressors to push oxygen into the fuel cell. The Equinox has 120 hp, can go from 0 to 60 mph in 12 seconds, and get 39 mpg. The Chariry has 134 hp, can go from 0 to 60 mph in 9 seconds, and get s 68 mpg.¹⁸

International Overview of Hydrogen and Fuel Cell Research: This article talks about how hydrogen fuel cells can be the wave of the future if their development is launched in a well planned way and the market is prepared on how to handle it. If hydrogen is to be the future fuel of choice, there are still obstacles that need to be overcome: systems and components of hydrogen fuel in hydrogen economy need to be reduced, improvement of its performance, manufacturing technologies, infrastructure developments, international agreements, and standards and regulations.¹⁹

Motor Noise Reduction: This article discusses a new design to power boats developed by a Japanese Company. This design uses contra rotating propellers instead of a single propeller. In this design, the main propeller is attached to the rest of the engine while the other (counter rotating) propeller is powered by an electric motor in an underwater “pod”. Though powered by different sources, both propellers are aligned on the same axis. Benefits of design include lower vibration (a primary cause of noise in outboard motors), improved fuel mileage, and smaller propellers. Drawbacks are that it is a complex system, requiring complicated gearing, and mechanical systems.²⁰

Noise Reduction: Two companies who manufacture parts and materials specifically for reducing noise in the motor. There are two main type of “noises” in any type of engine: those that come directly from a component of the engine, and those that come from structural elements of it. Noises emitted directly from engine are best blocked using sound-proofing materials such as fiberglass, mineral wool, and polyimide foam. To combat structural noises in the engine, material can be used to block sound, or devices can be designed to reduce vibration or rattling of structural components.^{21 22}

Biodiesel: Biodiesel is usually made from 80-90% vegetable oil, 10-20% alcohol, and .35-.5% catalyst. Biodiesel can be stored in same environment as regular fuel. May

increase of fuel injector life, however at the same time may degrade different components in the engine.

Cloud point is the temperature in fuels where the fuel appears cloudy due to the separation of wax crystals. It occurs at colder temperatures and may lead to difficulty starting the engine. Biodiesel can become cloudy between the temperatures of 60-25F. This implies a limited temperature range compared with other fuel sources. Biodiesel can be used in lieu of petro-diesel in traditional diesel engines. However, in gas engines a mixture of both gas and biodiesel must be used since biodiesel is not combustible enough to be used alone.²³

Underwater generator: The underwater generator is an option to possibly recharge any batteries when docked for the night. It would be hung off the raft facing the river current; it only needs a foot of water depth and a charge controller. Using anything that could recharge batteries would require fewer batteries to be brought along. Though it looks like a large amount of batteries being taken.²⁴

Relevant Patents:

The following patent is a design for a compressed air engine assembly that maximizes air usage and minimizes friction between the engine components:

Patent number: 4124978
Filing date: Aug 27, 1975
Issue date: Nov 14, 1978
Inventor: William C. Wagner

The following patent is a design for a compressed air engine assembly that maintains the compression in the main supply tank for efficient and continuous operation:

Patent number: 3765180
Filing date: Aug 3, 1972
Issue date: Oct 1973
Inventor: Russell R. Brown

The following patent is a design for a compressed air engine assembly that recycles the exhaust and implements a pressure regulator to aid in recharging the system:

Inventors: Murphy, John R.
Application Number: 05/705940
Publication Date: 04/19/1977
Filing Date: 07/16/1976

The following patent is a design for a pneumatic engine implementing air as its compressed fluid fuel. The engine in question is mainly designed for use in small toys such as airplanes and wheeled vehicles:

Inventors: Kownacki, Charles D. (Erie, PA)
Rehkemper, Jeffrey G. (Chicago, IL)
Harary, Ronnen (Toronto, CA)
Application Number: 09/178595
Publication Date: 12/28/1999
Filing Date: 10/26/1998

Modeling and Analysis

There are several different subcategories we have related modeling and analysis. They encompass both the mechanical and electrical aspects of this project.

Calculations

Appendix B shows the detailed hand calculations used to determine the energy requirements for this trip. These calculations were made assuming 65% efficiency for the electric motor that was implemented and 25% efficiency for the outboard currently in use. The required information to calculate the efficiency of the outboard could not be found, and 25% is taken to be an average value for this motor. Also, being as a range of electric motors can be chosen for this system, 82.5% efficiency was used as it is a lower end of the motors researched. Furthermore, the fuel consumption on any given trip was stated to be 50 gallons, but 55 gallons was used in the calculations. All of these considerations form a large “buffer,” or factor of safety, in our design. This means that our calculated values will be higher than in actuality, but will account for unseen factors that may come in to play during the implementation of the design.

Givens:

- Lower heating value of gasoline \rightarrow 1 gallon of gasoline \approx 125,000 (BTUs) \approx **36.7184943 (kWh)**
- 55 gallons of gasoline = approximate fuel consumption on trip
- (Energy in batteries)*(efficiency of elec. motor) = (Energy in gasoline)*(efficiency of outboard)
- Using 18650 Li-ion batteries (from Tesla Roadster)
 - Energy storage per battery cell = **8.51 (Wh)**
 - Volume taken up by each battery cell = **2.106 E -5 (m³)**
 - Weight of each battery cell = **46.5 (g)**
- Volume available for fuel storage on raft = **12 (ft³)**
- Current weight for fuel on trip \approx **580 (lbs)**
- Maximum weight allowed for fuel on trip \approx **1200 (lbs)**

Calculated Values:

- Energy required for battery usage on trip implementing 25% efficiency for the outboard motor, and 82.5% efficiency for an electric motor \approx **612 (kWh)**
- Number of batteries needed to meet energy requirement \approx **71,913 batteries**
- Weight of the required batteries \approx **7,372.2 (lbs)**
- Volume of the required batteries \approx **53.484 (ft³)**

Given the values calculated, it is clear that the number of batteries required to complete the trip using only one set of batteries carried onboard is infeasible. Thus, this system will not work without some sort of regeneration system involved. However, with the quickly rising technological knowledge, this may be feasible with or without a regeneration system in the nearer future. Today, however, a regeneration system is required.

Testing is required to verify the abilities and performance of an electric driven outboard as opposed to a gas powered outboard on the river. This may warrant the use of a smaller and more efficient electric motor, yielding losses in the number of batteries required and the related categories above.

Calculations were also done on the last day burn (appendix B). These calculations show that the idea is feasible, but better batteries as well as room for a generation system (including its fuel) would need to be worked out. (Once again, these values are higher than what may actually be used or implemented, due to the imbedded factors of safety. This allows for design without failure, and accounts for unforeseen circumstances on the trip).

Due to this design not being feasible without a regeneration system, the new restraint on fuel storage is the last day trip across the lake. There would still need to be enough batteries stored on board to complete the 8-10 hour burn. The above energy calculations were repeated using 15 gallons of fuel as the estimated amount used on the burn, and the same efficiencies for the motors involved. The results are as follows:

Calculated Values:

- Energy required for battery usage on last day of trip, implementing 25% efficiency for the outboard motor, and 82.5% efficiency for an electric motor \approx **162 (kWh)**
- Number of batteries needed to meet energy requirement \approx **19,036 batteries**
- Weight of the required batteries \approx **1,951.5 (lbs)**
- Volume of the required batteries \approx **14.2 (ft³)**

Computer Drawings

SolidWorks CAD models were completed for the entire system. In addition, the adaption assembly the team manufactured was designed in this program. Drawings of this adaption plate and key pictures of the CAD design can be seen in appendix C.

Manufacturing

For this project, the adaption assembly needed to be designed and constructed in order to interface the electric motor onto GCROA's lower housing. The entire system was made out of T6 6061 Aluminum.

Two couplers were turned on the lathe. The first coupler (figure 7) was designed to fit on the spline shaft that connects the pulley system to the lower housing. Four set screws were used in order to secure the shaft to the coupler. The second coupler (figure 8) connects the shaft on the motor to the other pulley. In addition to being turned on the lathe, this coupler was pressed and welded to the pulley in order to ensure that it was secure during testing. (see appendix C for drawings of both pulleys).

Four plates were also manufactured in order to construct the adaption assembly. This work was done on the mill. Once they pieces were milled down to the correct dimensions holes were drilled and tapped in order to fasten the plates together. (See appendix C for drawings of the four components in the adaption assembly).

For testing purposes, another coupler was made on the lathe that attached the propeller shaft to the dynamometer.

Finite Element Analysis (FEA)

To ensure that the adaption assembly design would not fail during a trip with GCROA, finite element analysis was conducted to determine the stresses applied to the assembly in two different situations. Both FEA models can be viewed in appendix D.

The first analysis (figure 9) assessed the stresses on the assembly while the motor was sitting vertical on the top plate. This would be how the motor would be normally situated while rafting. A pressure of 2.7513 psi (weight of motor divided by surface area) was applied to the top plate where the motor will be resting and the assembly was constrained in all the places where there are bolts. From this analysis, we determined that there are no major stresses on this assembly.

Figure 10 shows the second FEA results, which was performed to determine the stresses on the motor if the raft was knocked over and the motor was turned on its side. A remote load was applied in order to obtain the proper force and moments along the top plate. While there were higher stresses on this model especially around the holes where the stress concentration is higher, we once again determined that this design will not fail.

Wiring

The test setup, as wired by our team currently only provides single directional electrical operation. Reverse is still provided in the system by the mechanical reverse integrated into the lower assembly. Our team felt this solution was preferable to an electric reverse to preserve the life of the motor. Rapidly switching the motor directions electrically can damage the motor over time and we felt the guides would switch directions without first

allowing the motor to come to a complete halt hence reducing the motor lifespan. The mechanical reverse should be familiar to the river guides as its operation is the same as the original Honda motor operation. Two features have been integrated into the circuit as safety measures, a 200A fuse and 200A circuit breaker. If the system exceeds 200 Amps the fuse will have to be replaced. The circuit breaker also acts as an emergency shutoff (appendix E, Figure 11).

The test rig uses twelve 55AH batteries wired in series for 120V. In the final implementation the circuit must use multiple 120V packs wired in parallel to provide enough energy for continuous travel. We recommend in the final implementation the fuse be increased to a 500A fuse. The motor can support up to 500A without risk and the circuit breaker will provide a more easily fixable layer of protection than the fuse.

It is possible using the schematic provided in appendix E, Figure 12 to connect the motor in a configuration that allows for bidirectional electrical operation. We have not done any testing using this layout and do not recommend it. If the figure 12 configuration is going to be used, we recommend the addition of circuitry to prevent direction change without first halting the motor.

Mechanical Testing

To verify that our system met the power requirements described by GCROA, we tested the assembly on a dynamometer (dyno). The propeller shaft was attached to the dyno, and a load was applied to it after the system reached a certain RPM level. From this testing we obtained 13 horsepower and 16.2 ft-lbs of torque at approximately 4000 RPM. From where the load was applied, the torque-horsepower-RPM (appendix F) graph was a straight line which is characteristic of an electric DC motor.

The 13hp fell short of the 16hp rated by the motor. We attribute this short coming to several different aspects. First, the batteries were running low on power and were not supplying the motor with high enough amperage. In addition, we believe by experimenting with different load conditions on the dynamometer a more accurate representation of the motor's power capabilities could have been obtained.

Electric Testing: System Stability

We originally wanted to run simulations on the motor prior to testing, however Advanced DC does not provide the necessary electrical specifications. If the electrical specifications become available we recommend simulations be run using officially provided schematics. To obtain the transfer function for the motor, the speed controller output was measured on an oscilloscope and compared to the output as measured on the dynamometer. This testing was done at a low speed with a motor output of 500 RPM and a speed controller output of 56 micro seconds high out of a 636 micro second period. From these test results we were able to derive the transfer function of:

$$\frac{E(s)}{Y(s)} = \frac{V(1 - e^{-as})}{W(1 - e^{-bs})}$$

By using the measured values and approximating the transfer function with a power series expansion to obtain a final transfer function of:

$$\frac{E(s)}{Y(s)} = 0.0211 \frac{1 - 20s - 1560s^2}{1 + 318s + 67916s^2}$$

With the transfer function we were able to plot the stability of the system using a Bode plot and Root Locus plot (see Appendix G). The bode plot and root locus plot show that the system has possibility of becoming unstable, but only at higher frequencies. At lower frequencies the system is fully stable; however at higher frequencies the system can become unstable. The speed controller alters its output at higher frequencies to shifting the stable motor frequencies to higher frequencies. The speed controller is specifically designed so that the motor will never reach its unstable frequencies under normal operating conditions.

The operating frequency of the speed controller is what causes the motor to make noise at low RPMS. The 636 μ s operating frequency of the speed controller generates a 1.57KHz sound. When operating at higher rpm the motor shifts to an operating frequency that generates a sound outside of the human hearing range.

Renewable Feasibility

Following preliminary calculations, it was understood that something would be needed to help the batteries for the 7 day trip. We researched various renewable technologies, yielding viable solutions, as well as some infeasible solutions. The ideas that we decided were infeasible included wind power (due to being at the bottom of the Grand Canyon), geothermal power (because the only temperature variation that would be significant is between the water and the deck of the boat) and tidal and wave generation (because there really aren't any tidal movements and waves). The promising generation techniques looked to be solar (appendix H) and hydro electric power. With solar power, it would be feasible to install panels in a canopy design but would be limited to daytime light and high canyon walls. Hydroelectric power would be workable however it would only be able to be functional during the down times (after boat has been anchored). The hydro electric would need a mounting system that securely holds the generator to boat (appendix J).

Renewable technology became infeasible as the motor energy consumption would be running near 120 volts dc and 130 amps continuous (appendix I). During a test we had a draw of 20 amps with no load at 70% – 80% of power. Running for 10 hours, this would consume 1300 amp hours within a day. Implementing BP-SX3200 solar panels with an Outback charge controller, the Flexmax 80 has been known to produce 21 amps in direct sunlight with 2 panels in a 12 volt system. However we are dealing with 120 volt system which would require a specialized charge controller. Currently, any charge controller models that deal with this high voltage are still in the development phase. Also to meet the requirements of an hourly usage, there would have to be 16 panels in parallel to

achieve the amp hour requirement of 130 amps, and 6 panels at max voltage in series for the 144 volts dc to charge. Looking at the power required for an hour: Take $130 \text{ A} * 120 \text{ VDC} = 15,600 \text{ Watts}$, and then divide this by the 200W maximum capability of the solar panels. This shows that it will take 78 solar panels. This is a calculation based off straight solar panel data (no factor of maximum power point tracking is taken into account).

We also researched submergible generators; the Aquair UW is a generator with the ability to generator 12 volts at 8 amps. The generator would not follow the same standard as the solar, but would look at the total 10 hour (daily) usage and try to recuperate it over the night. To find the daily wattage, take the 156,000 watts and divide by the 14 hours left in a day (overnight hours). This leaves 11,142.86 watts that will need to be generated per hour. With this requirement, it would take 117 generators to recuperate the loss; however these numbers are working at the ideal max setting (See Appendix J for more information).

Bill of Materials

The Bill of Materials of this project was relatively short due to the simplistic nature of the design; it is limited to mostly hardware fasteners and metal stock to build our system. A complete list of material and items used by our team for the construction of our Alternative Propulsion System is shown below in Appendix K.

Final Budget

The GCROA Alternative Propulsion System Project was a very well funded project. GCROA gave the Northern Arizona University Capstone class \$10,000. After administrative fees were removed our team was left with a spending budget of \$7500. Metal stock was cheaper than expected thanks to Mayorga's Welding for a discounted rate on our metal purchase. Our customer Mark Grisham bought our motor and motor controller so that GCROA retained ownership of those items. That reduced the amount of money we needed to spend from our budget by almost half. With the purchase of the motor and speed controller by Mr. Grisham we came in under budget by \$4 449.61. An itemized price of every item purchased can be viewed in Appendix I. Not every item purchased was used in the construction of our system due to a misunderstanding of the items needed in our circuitry.

Recommendations

The NAU Alternative Motor Team has several recommendations for GCROA and for future design teams working on this project.

First has to do with safety concerning electric motors on water. Before the motor is placed on the river, it should be sealed. In addition, batteries should also be sealed, cooled, and vented as well as placed inside a waterproof container. Multi-stranded weatherproof wires were implemented and should continue to be used to account for vibrations along the trip. These wires need to be environmentally sealed and waterproofed to a certain depth as specified by the IP67 specifications.

In order to aid in an accurate and complete design, it would be helpful for future teams to have a schematic of the motor as well as a user manual if possible.

Conclusion

We have provided a detailed analysis and prototype of an electric motor for rafting in the Grand Canyon. The electric motor provided gives the necessary power to propel a raft down the Colorado River. The electric solution provided by our team produces no onsite emissions at a significantly reduced sound over the currently implemented four-stroke motor. We believe this solution is viable with further study into battery technology and regeneration methods.

If correct cooling is used the electric motor solution will be more durable than the four-stroke motor. Electric Motors have less moving parts to break than the combustion engines giving fewer parts that can fail. The lower assembly is already used by GCROA, providing the same durability for the lower assembly as the previous motor. In addition to durability using the same lower assembly means that GCROA should have all the tools already accessible to repair broken lower assemblies.

The NAU design team has implemented several electrical safety features in addition to safety studies and simulations. The circuit provided by the NAU design team implements both a 200 Amp circuit breaker and a 200 Amp fuse. The breaker and fuse prevent any possible electrical runaway in addition to providing a way to cut all power to the motor for transport. The simulations run by the NAU design team show that while it is possible the motor to go into an unstable, runaway condition it is extremely unlikely. Any input provided to the motor by the speed controller will be a stable input. The worst stability effects that can happen while the speed controller is connected is a small amount of vibration in the motor.

The mounting bracket designed to by the NAU design team should be more than durable enough to withstand the rigors of travel down the Grand Canyon. The mounting bracket was designed with 6061 aluminum, a high quality aircraft grade metal. The Finite Element Analysis (FEA) stress testing simulations done show that there is an extremely large factor of safety on the housing. Even under the most extreme conditions on the Grand Canyon, the motor bracket should not fail.

We believe our design has satisfied the requirements specified by GCROA. While our design is not currently attached to a boat we believe it provides a good platform for future teams to build upon. In the future when battery technology improves, we look forward to

seeing new alternative solutions being implemented by GCROA, preserving the environment and improving the ambiance of the Grand Canyon.

Appendix A: Decision Matrix

	Electric Motors Batteries		Electric Motors Fuel Cell		Compressed Air Motor		Biodiesel	
Safety (x2)	6	12	7.5	15	8	16	10	20
Low Weight (x1.5)	5	7.5	5	7.5	6	9	6.5	9.75
Power Output (x1.5)	10	15	10	15	8	12	10	15
Compatibility (x1)	10	10	8	8	8	8	10	10
Ease of Replacement (x1)	9	9	7	7	10	10	10	10
Low Sound (x3)	10	30	10	30	7.5	22.5	0	0
Low Emissions (x2.5)	10	25	10	25	10	25	7	17.5
Time Before Replacement (x2)	9	18	9	18	9	18	10	20
Lifetime (x1.5)	10	15	10	15	10	15	10	15
Volume (x1.5)	2	3	1	1.5	2	3	10	15
Initial Cost (x1)	5	5	2	2	8	8	9	9
Total		149.5		144		146.5		141.25

Table 1: Decision Matrix

Appendix B: Energy Calculations

* CALCULATIONS FOR LAST DAY BURN *

Assumptions: 15 (gal) used on last day burn
 (This is 0.275 \Rightarrow 27.5% of fuel used on entire river trip).

$$\text{Using 15 (gal) gives } \Rightarrow (0.825)x = (36.7185 \text{ (kWh/gal)} \cdot 15 \text{ (gal)} \cdot 0.25)$$

$$x = \frac{36.7185 (15) (0.25) \text{ (kWh)}}{0.825}$$

$$x = 166.9 \text{ (kWh)}$$

$$\frac{166.9 \text{ (kWh)}}{8.51 \times 10^{-3} \text{ (kWh/battery)}} = 19,612.5 \approx 19,613 \text{ batteries needed}$$

$$[19,613 \text{ (batteries)}] 46.5 \text{ (lb/batt)} \left(\frac{0.00225462262 \text{ (lbs)}}{\cancel{\text{lb}}} \right) = \rightarrow$$

$$\rightarrow = 2,056.23 \text{ (lbs)}$$

$$[19,613 \text{ (batteries)}] (2.106 \times 10^{-5} \text{ (m}^3 \text{/batt)}) \left(\frac{35.3146667 \text{ ft}^3}{\cancel{\text{m}^3}} \right) = \rightarrow$$

$$\rightarrow = 14.59 \text{ (ft}^3 \text{)}$$

With these values, it is seen that it could be possible to use batteries to power the boat for the trip, using regeneration at night (ethanol generator?)

Figure 1: Calculations for the last day burn

MORE CALCULATIONS:

- GIVEN: · L91 DC motor (82.5% ave. efficiency)
 · Assumption of 25% for gas motor
 · 55 gal. ^{gas} consumed on trip
 · lower heating value of gas ≈ 36.7185 (kWh/gal)

CALCS: (eff. elec. motor) $\left(\frac{\text{total energy}}{\text{energy}}\right) = (\text{eff. gas motor}) \left(\frac{\text{total energy}}{\text{energy}}\right)$

* total electrical req'd = $\frac{(0.25)(55 \text{ gal}) \cdot 36.7185 \text{ (kWh/gal)}}{(0.825)}$
 $= 611.98 \approx 612 \text{ (kWh)}$

* $\frac{612 \text{ (kWh)}}{8.51 \times 10^{-3} \text{ (kWh/batt)}} = 71,913 \text{ (batt's)}$

* $71,913 \text{ (batt's)} \cdot 46.5 \text{ (lb/batt)} = \frac{(0.0027 \times 462262 \text{ (lbs)})}{2}$
 $= 7372.1577 \text{ (lbs)}$

* $71,913 \text{ (batt's)} \cdot 2.1065 \times 10^{-5} \text{ (ft}^3\text{/batt)} \cdot \left(\frac{35.3146667 \text{ ft}^3}{\text{m}^3}\right) = 53.484 \text{ (ft}^3\text{)}$

<u>TOTALS:</u>	→ 612 (kWh)
	→ 71,913 (batteries)
	→ 7372.1577 (lbs)

Figure 2: Calculations continued

Appendix C: CAD Drawings

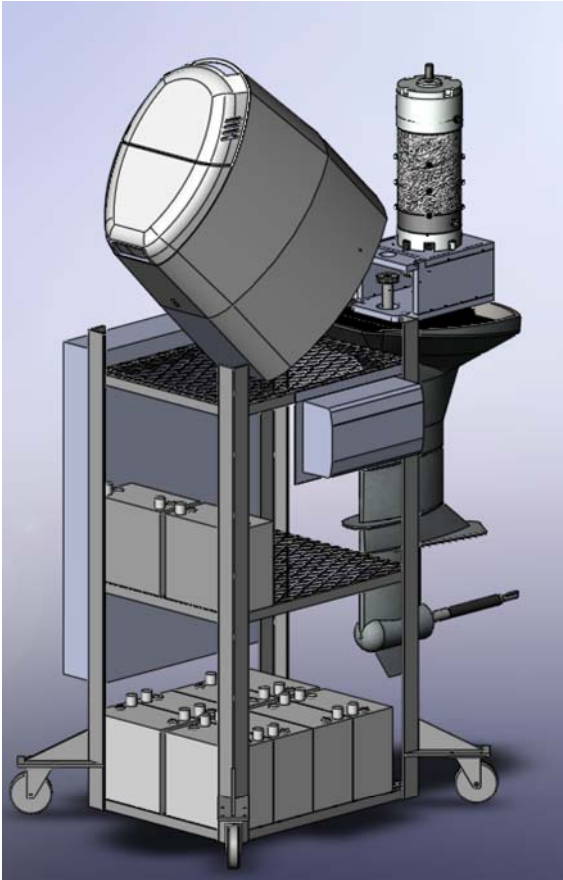


Figure 3: CAD model of entire system including testing cart

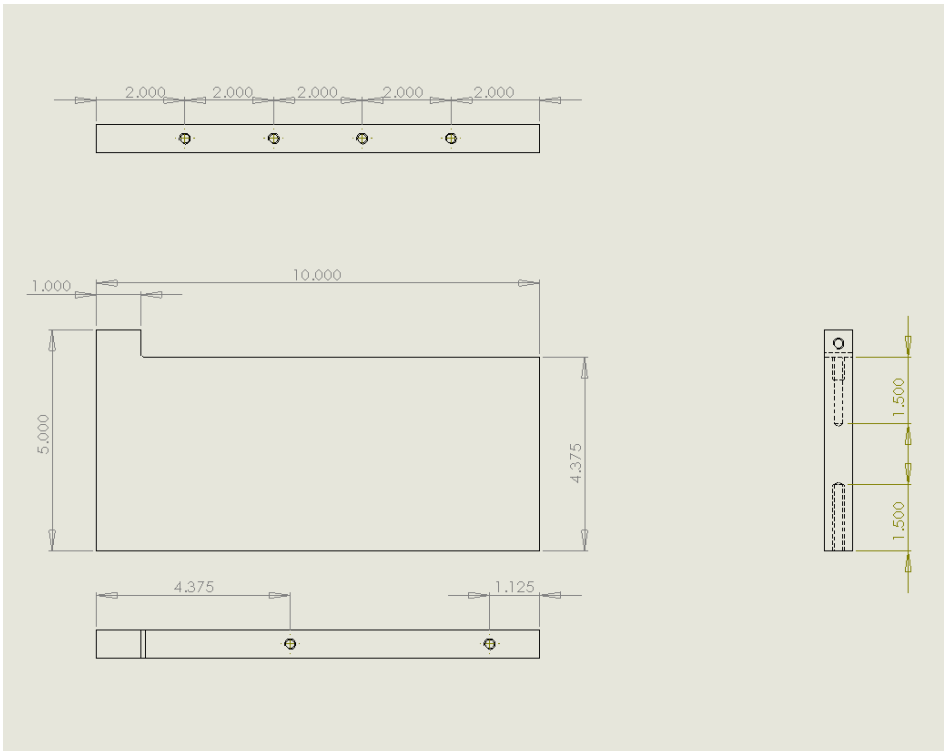


Figure 4: Drawing of vertical components of mounting assembly

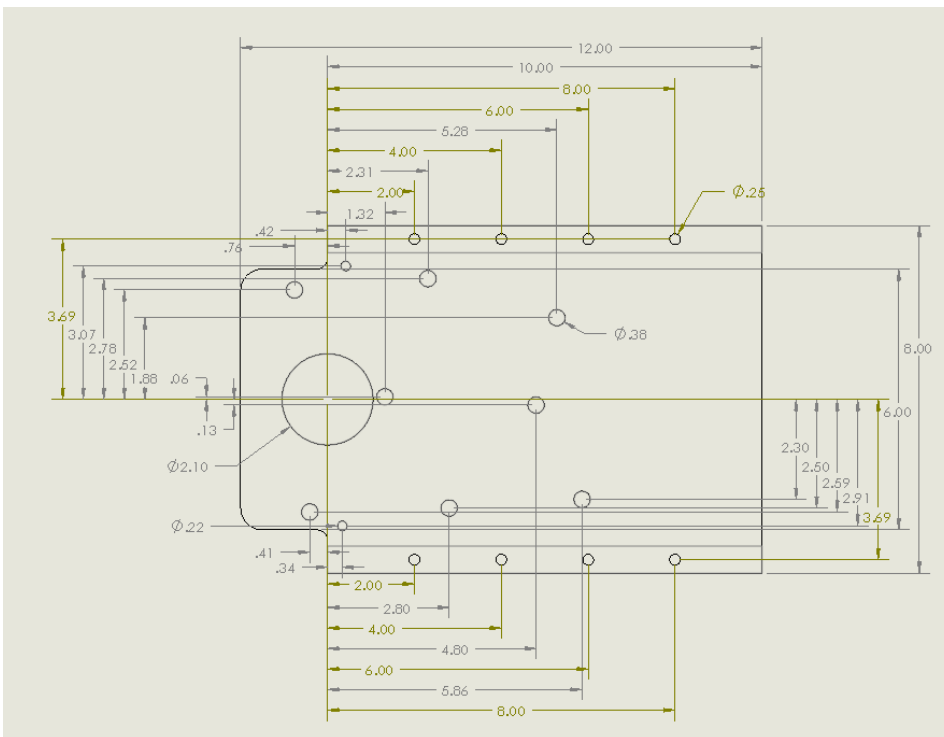


Figure 5: Drawing of lower plate of mounting assembly

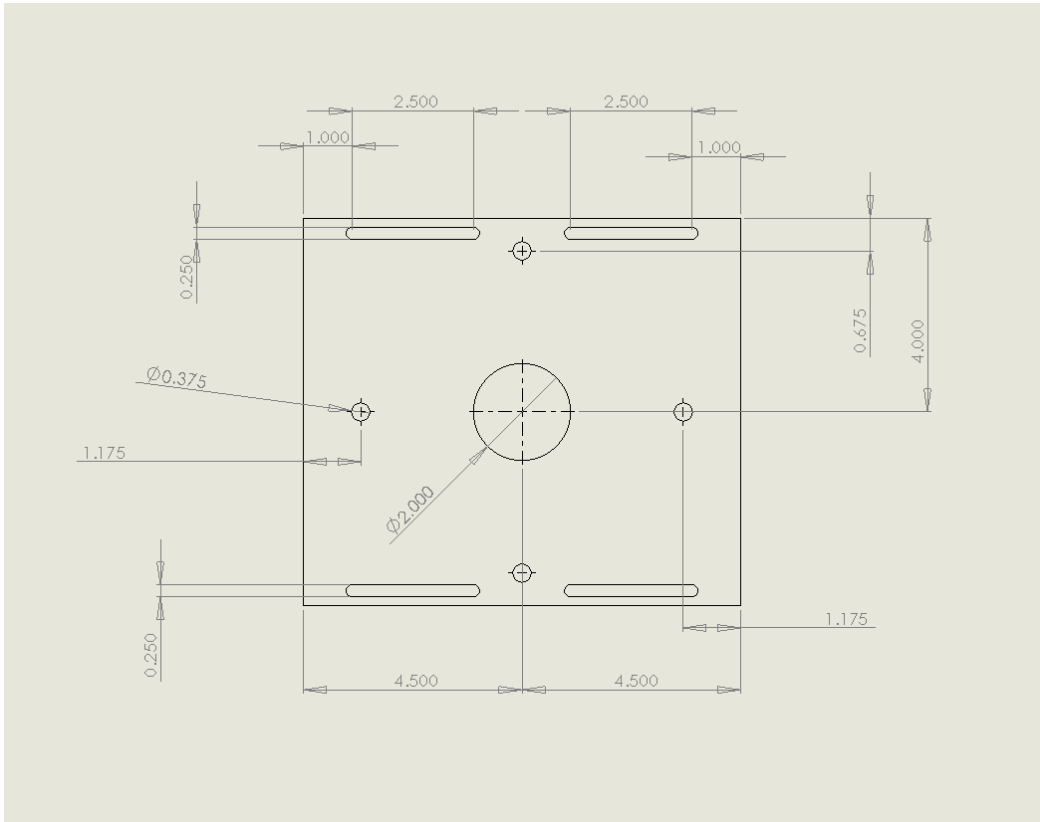


Figure 6: Drawing of top plate of adaption assembly

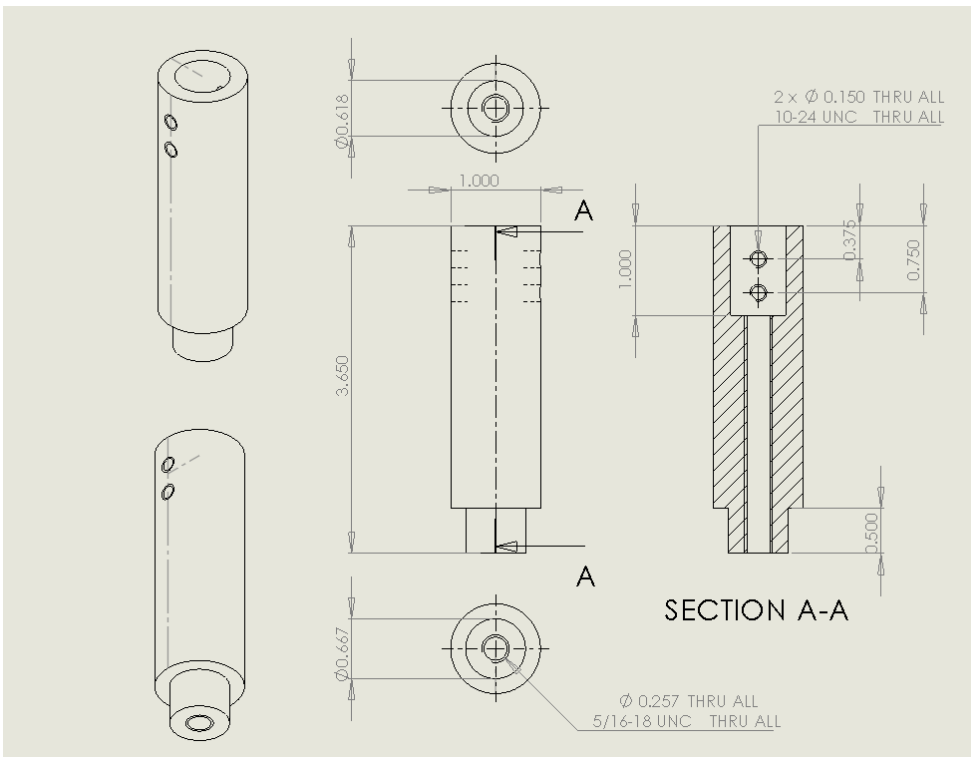


Figure 7: Drawing of coupler that attaches lower housing to adaption assembly

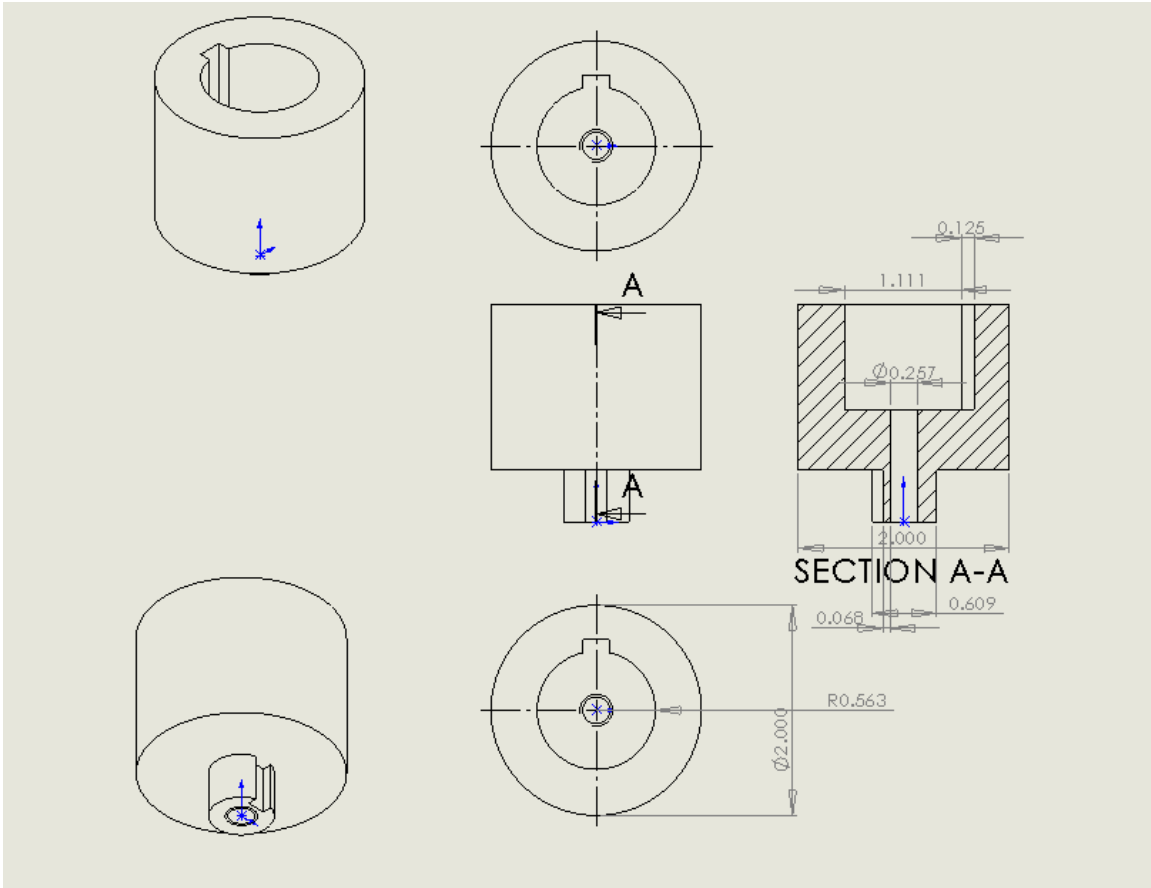


Figure 8: Drawing of coupler that attaches electric motor to pulley

Appendix D: FEA Models

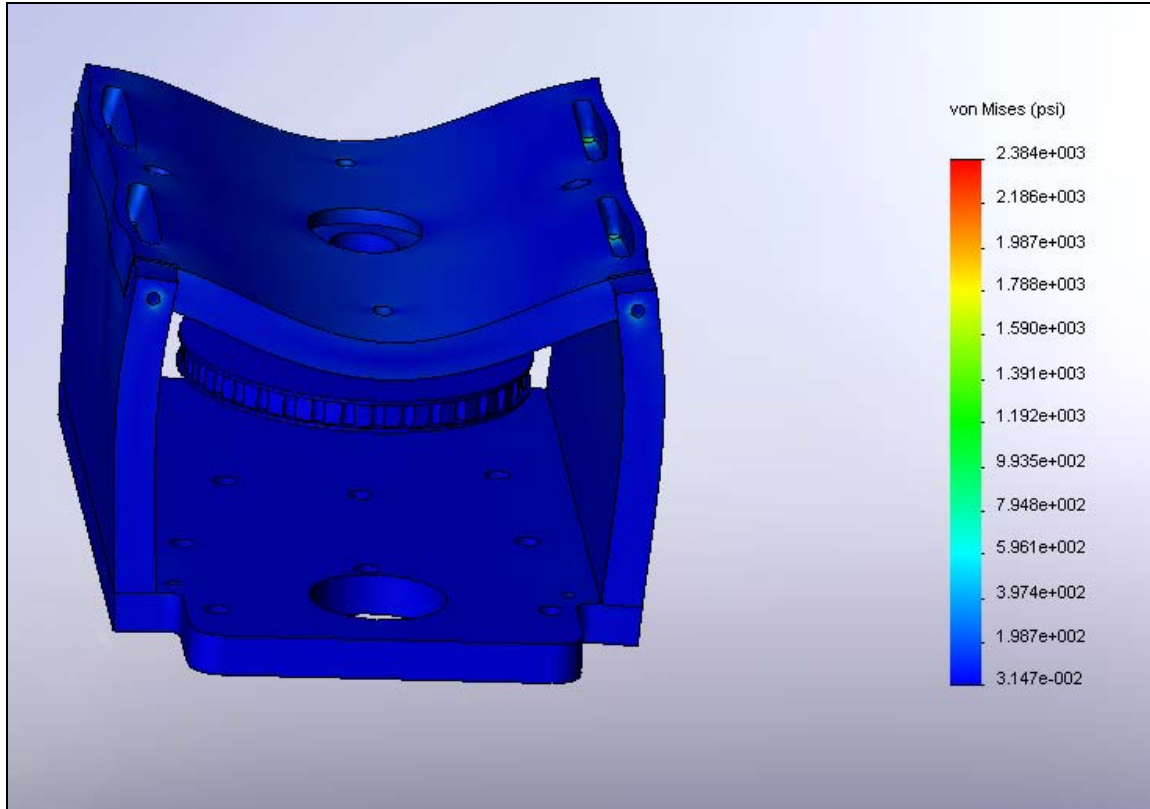


Figure 9: Drawing of plate under normal operating conditions

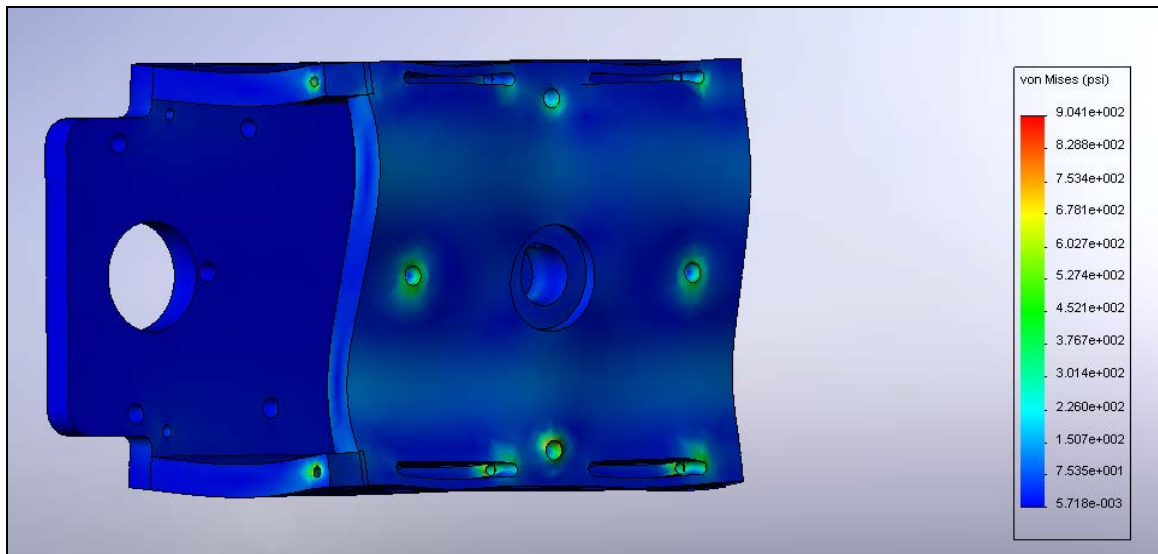


Figure 10: Drawing of plate if the raft tipped over and assembly was on its side.

Appendix E: Wiring

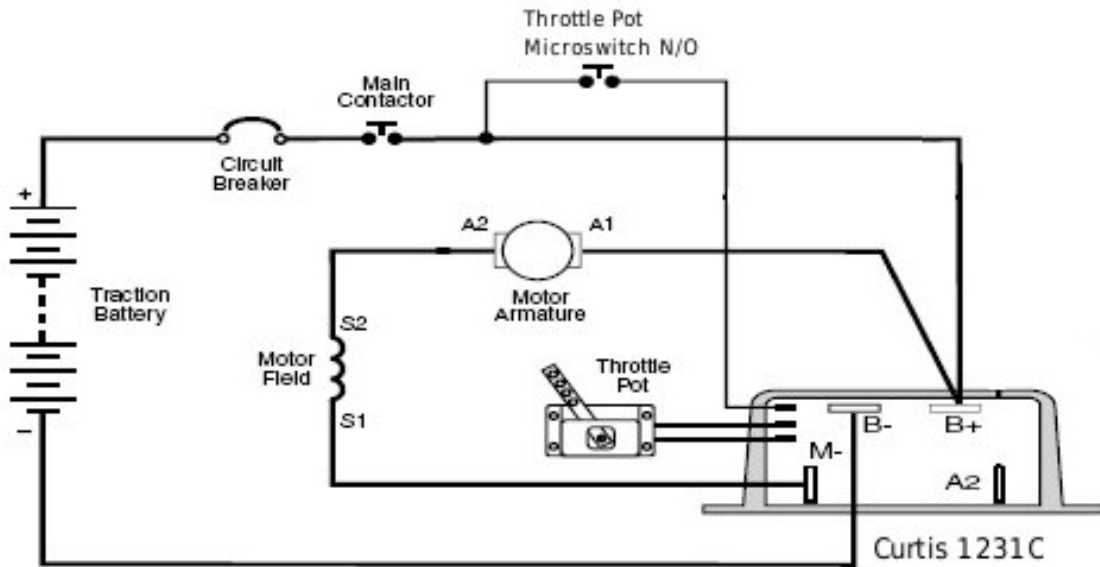


Figure 11: Recommended Wiring for Advanced DC L91

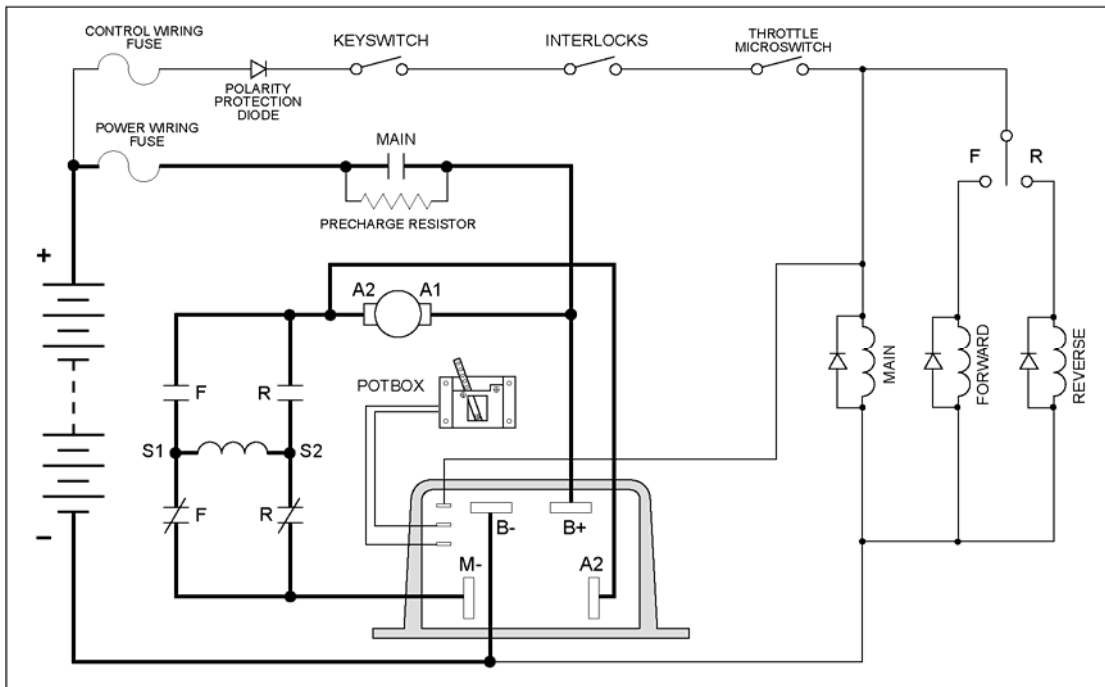
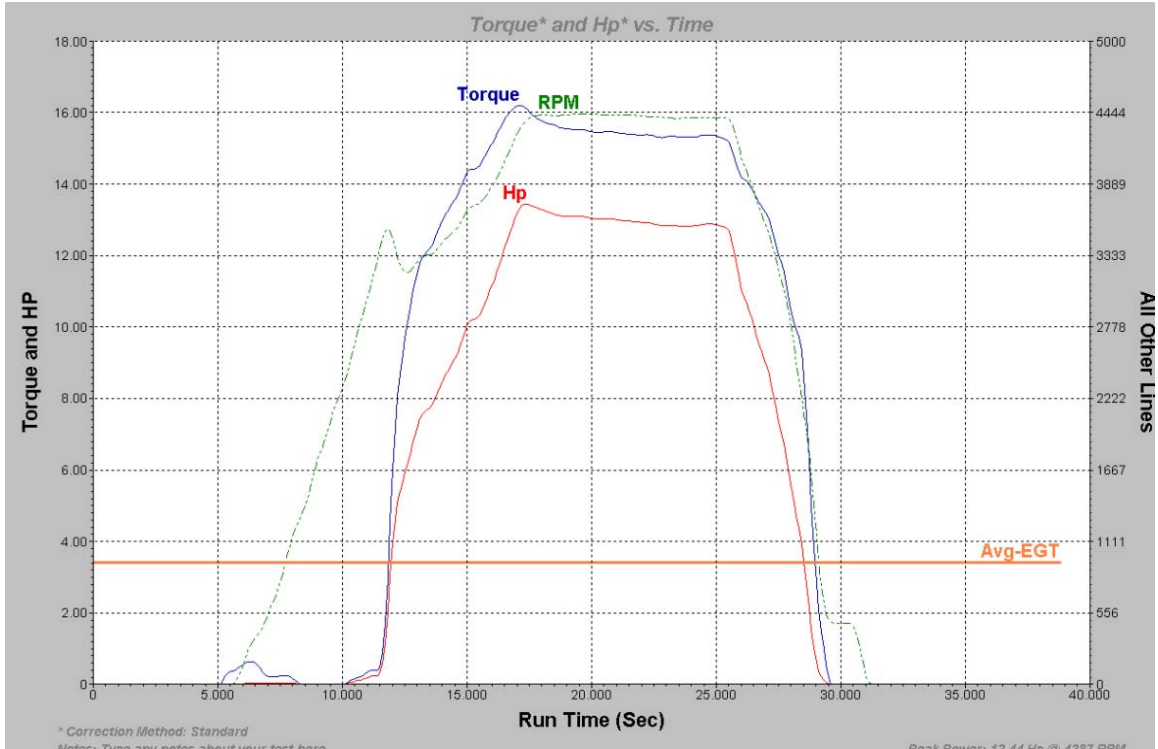


Figure 12: Bidirectional motor wiring

Appendix F: Mechanical Testing



Appendix G: Control Theory Plots

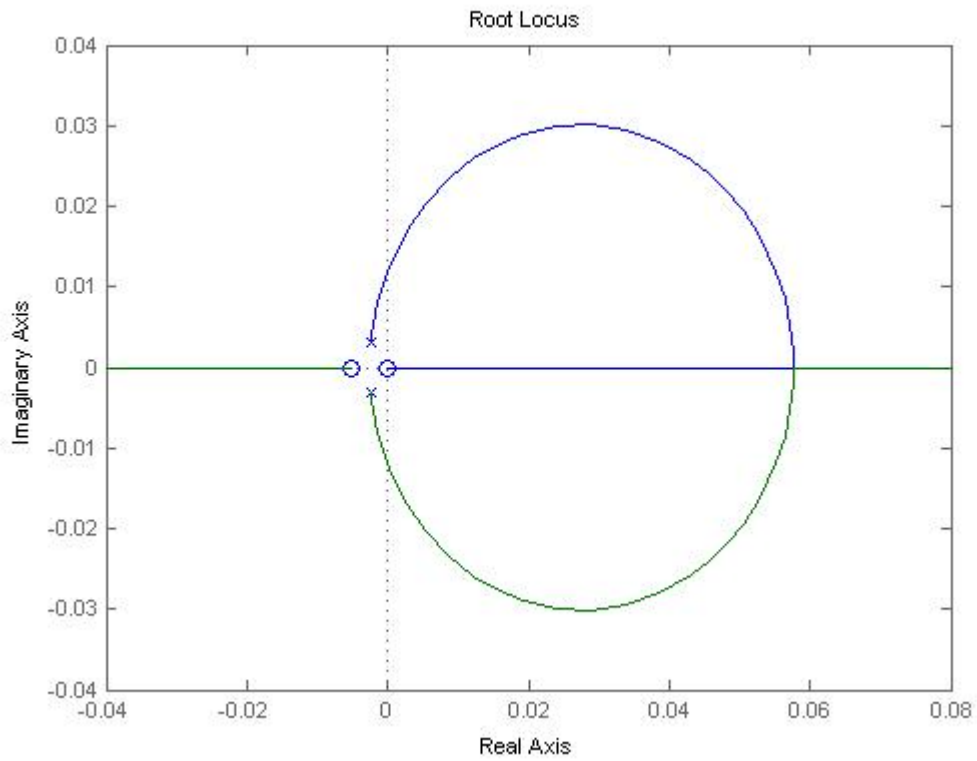


Figure 14: Root Locus Plot

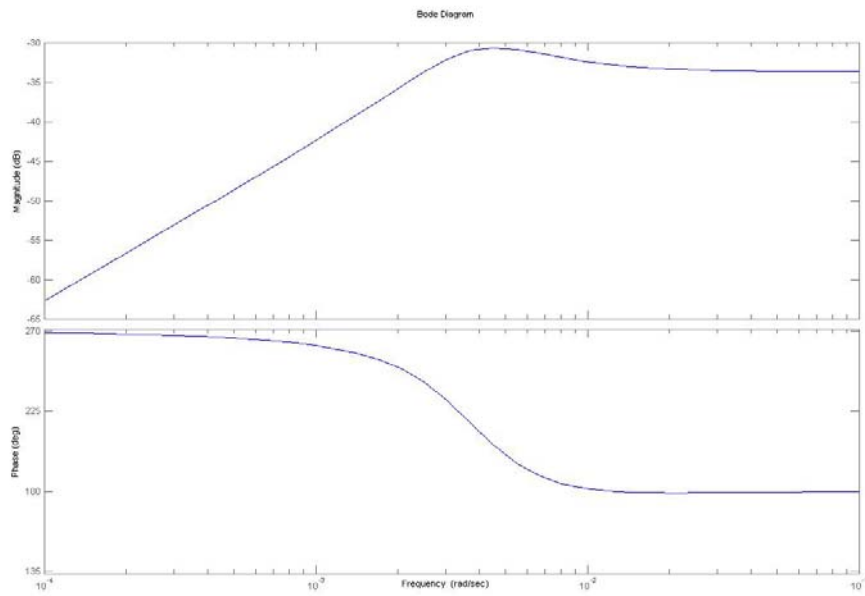


Figure 15: Bode Plot

Appendix H: Solar Power Charts and Tables

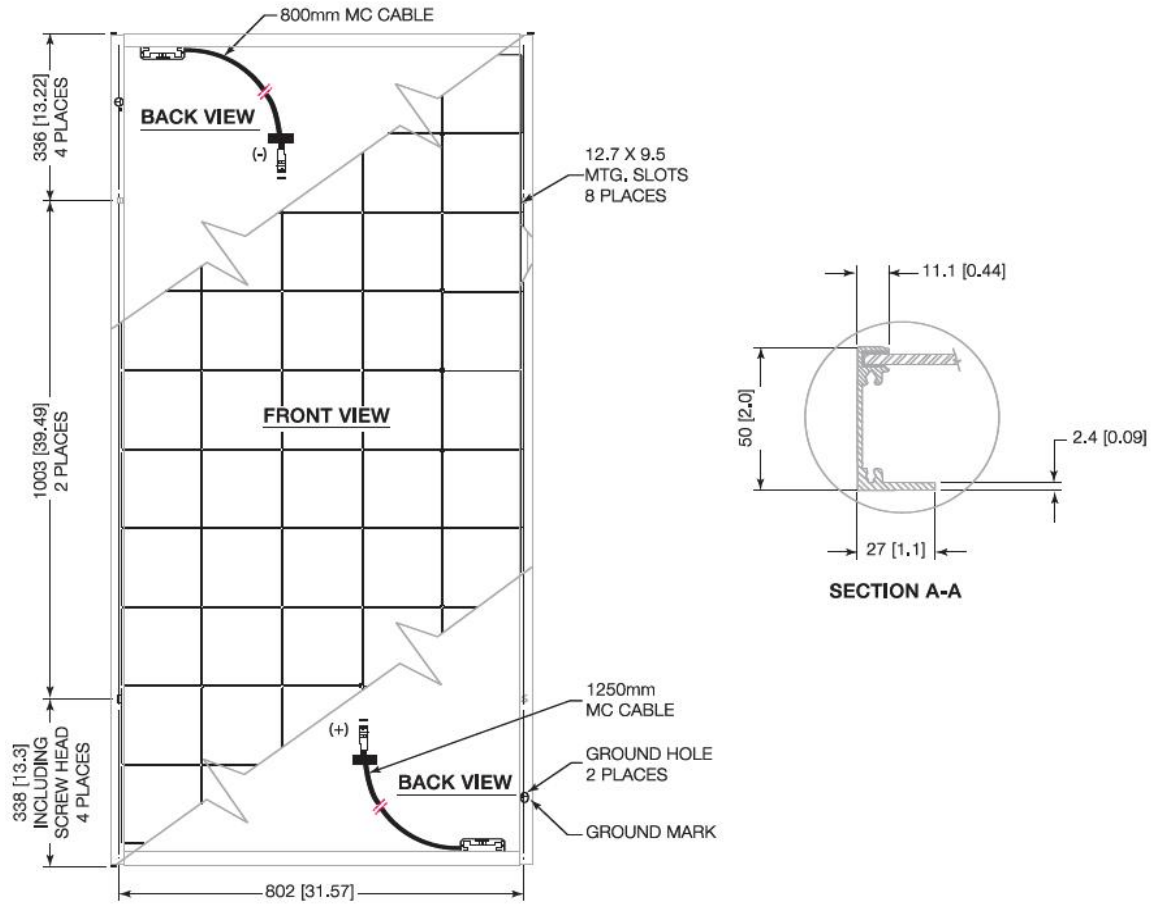


Figure 16: Solar Panel Schematic

SX 3200	
Maximum Power	200W
Voltage	24.5V
Current	8.16A
Length	1680mm (66.14")
Width	837mm (32.95")
Depth	50mm (1.97")
Weight	15.4 kg (33.95 lbs)
Maximum System Voltage	600V

Table 2: Solar Panel Specifications

Appendix I: Battery Charts and Drawings

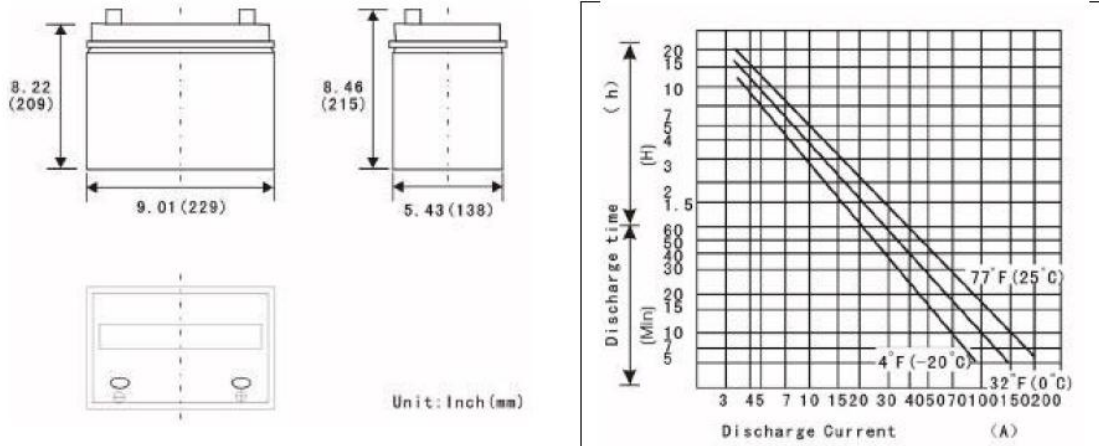


Figure 17: Battery Charts and Drawings

PUBP 55-12	
Nominal Voltage	12V
Rated Capacity (20 hour rate)	55Ah
Height (With terminals)	209mm (8.22") (215mm (8.46"))
Length	229mm (9.01")
Width	138mm (5.43")
Weight	34.77 lbs

Table 3: Battery Specifications

Appendix K: Bill of Materials

Part #	Purpose	Description	Vendor	Qty:	Unit
	Electrical Circuitry	40ft. Double Aught Wire	Buddy's Welding and RV	40	Ft.
TGHGCR0005FE	Electrical Circuitry	Current sensing resistor	www.Digikey.com	1	Each
Pb	Electrical Circuitry	Throttle Pot	www.tecknowledgey.com	1	Each
98065501	Electrical Circuitry	Heat Shrink 1"	www.delcity.net	1	Each
901575	Electrical Circuitry	marine insulator	www.delcity.net	40	Each
8G22NF	Electrical Circuitry	12v 55AH battery	nationalsolarsupply.com	10	Each
Truecharger 10	Electrical Circuitry	TrueCharge 10 Amp Portable Charger	nationalsolarsupply.com	1	Each
N/A	Safety	Heat Sink, Compound, Fan, Plate	http://www.ev-america.com/	1	Each
	Safety	Breaker Box 200 Amp	Home Depot	1	Each
#150-SK-00	Safety	ELECTRICAL SAFETY GLOVE KIT	http://industrial.gloves-online.com	3	Each
N/A	Propulsion	L-91 DC Motor	http://www.ev-america.com/	1	Each
N/A	Propulsion	1231C-8601 Curtis Controller	http://www.ev-america.com/	1	Each
	Adaptor Plates	18"x24"x5/8" T6 6061 Al	Mayorga's Welding	1	Each
	Adaptor Plates	5/16"-20 x 3" bolt	Ace Hardware	4	Each
	Adaptor Plates	5/16"-20 x 3.5" bolt	Ace Hardware	9	Each
	Adaptor Plates	5/16"-20 nut	Ace Hardware	25	Each
	Adaptor Plates	1/4"-28 x 2" bolt	Ace Hardware	14	Each
	Adaptor Plates	1/4" ID Washer	Ace Hardware	14	Each
	Testing Cart	1"x3/16" Angle Iron	Mayorga's Welding	22'	Ft.
	Testing Cart	2"x.25"x4' Angle Iron	Mayorga's Welding	4	Each
	Testing Cart	Expanded Metal 4'x4' sheet	Mayorga's Welding	1	Each
9279	Testing Cart	Caster Wheel, swivel 200lbs	Ace Hardware	2	Each
9630	Testing Cart	Caster Wheel, swivel, locking 200lbs	Ace Hardware	2	Each
	Testing Cart	5/16"-20 x 1" bolt	Ace Hardware	16	Each
	Coupler	#8-32 Set Screw	Ace Hardware	8	Each
	Coupler	#10-32 Set Screw	Ace Hardware	4	Each

Table 5: Bill of Materials

Appendix I: Final Budget

Part #	Purpose	Description	Vendor	Qty:	Unit	Cost/Unit	Cost
TK20P750RJE	Electrical Circuitry	20watt 750ohm resistor	www.mouser.com	1	Each	3.42	3.42
TAH20P33R0JE	Electrical Circuitry	20watt 33ohm resistor	www.mouser.com	1	Each	5.33	5.33
TP158HC	Electrical Circuitry	250Amp Circuit Breaker	www.mouser.com	1	Each	143.72	143.72
BK/AGC-V-5-R	Electrical Circuitry	200A fuses	www.mouser.com	10	Each	1.84	18.4
	Electrical Circuitry	40ft. Double Aught Wire	Buddy's Welding and RV	40	Ft.	5.5	220
TGHGCR0005FE	Electrical Circuitry	Current sensing resistor	www.Digikey.com	1	Each	27.46	27.46
Pb	Electrical Circuitry	Thottle Pot	www.tecknowledgey.com	1	Each	86	86
98065501	Electrical Circuitry	Heat Shrink 1"	www.delcity.net	1	Each	7.66	7.66
901575	Electrical Circuitry	marine insulator	www.delcity.net	40	Each	0.91	36.4
8G22NF	Electrical Circuitry	12v 55AH battery	nationalsolarsupply.com	10	Each	\$154.36	1543.6
Truecharger 10	Electrical Circuitry	TrueCharge 10A Charger	nationalsolarsupply.com	1	Each	\$200.20	200.2
N/A	Safety	Heat Sink, Compound, Fan, Plate	http://www.ev-america.com/	1	Each	50	50
	Safety	Breaker Box 200 Amp	Home Depot	1	Each	134	134
#150-SK-00	Safety	ELECTRICAL SAFETY GLOVE KIT	http://industrial.gloves-online.com	3	Each	\$79.95	239.85
AML24EBA2AA06	Safety	Forward/Reverse Switch	www.mouser.com	1	Each	14.29	14.29
GW22LHH-RO	Safety	Rocker/Paddle Switch	www.mouser.com	1	Each	3.73	3.73
CKL12BFW01	Safety	Key Switch	www.mouser.com	1	Each	12.67	12.67
N/A	Propusion	L-91 DC Motor	http://www.ev-america.com/	1	Each	880	880
N/A	Propusion	1231C-8601 Curtis Controllor	http://www.ev-america.com/	1	Each	1495	1495
	Adaptor Plates	18"x24"x5/8" T6 6061 Al	Mayorga's Welding	1	Each	80	80
	Adaptor Plates	5/16"-20 x 3" bolt	Ace Hardware	4	Each	0.75	3
	Adaptor Plates	5/16"-20 x 3.5" bolt	Ace Hardware	9	Each	1	9
	Adaptor Plates	5/16"-20 nut	Ace Hardware	25	Each	0.1	2.5
	Adaptor Plates	1/4"-28 x 2" bolt	Ace Hardware	14	Each	0.6	8.4
	Adaptor Plates	1/4" ID Washer	Ace Hardware	14	Each	0.1	1.4
	Testing Cart	1"x3/16" Angle Iron	Mayorga's Welding	22	Ft.	N/A	N/A
	Testing Cart	2"x.25"x4' Angle Iron	Mayorga's Welding	4	Each	N/A	N/A
	Testing Cart	Expanded Metal 4'x4' sheet	Mayorga's Welding	1	Each	N/A	N/A
9279	Testing Cart	Caster Wheel, swivel 200lbs	Ace Hardware	2	Each	17.49	34.98
9630	Testing Cart	Caster Wheel, swivel, locking 200lbs	Ace Hardware	2	Each	17.99	35.98
	Testing Cart	5/16"-20 x 1" bolt	Ace Hardware	16	Each	0.5	8
	Coupler	#8-32 Set Screw	Ace Hardware	8	Each	0.2	1.6
	Coupler	#10-32 Set Screw	Ace Hardware	4	Each	0.3	1.2
		Poster Printing	Kinkos	1	Each	117.6	117.6
						Total	5425.39

Table 6: Final Budget

Bibliography

- ¹ (1998-2007). Deep Cycle Battery FAQ. Retrieved October 17, 2008. From Northern Arizona Wind & Sun.
http://www.windsun.com/Batteries/Battery_FAQ.htm
- ² (2008) About EPIb Retrieved November 24 , 2008 From Energy Information Group
<http://www.eigbattery.com/>
- ³ (2008) BP Solar Panels Retrieved November 24, 2008 From Northern Arizona Wind and Sun <http://store.solar-electric.com/bpsol195wasop.html>
- ⁴ (2008) Outback Charge Controllers Retrieved November 24, 2008 From Outback Power Systems http://www.outbackpower.com/products/charge_controllers/flexmax/
- ⁵ (2005). Battery Life (and Death). Retrieved October 14, 2008. From MPower Solutions Ltd. Web site: <http://www.mpoweruk.com/life.htm>.
- ⁶ Brain, Marshall. (2000). How Electric Motors Work. Retrieved on October 15, 2008. From HowStuffWorks, Inc. Web site: <http://electronics.howstuffworks.com/motor.htm>
- ⁷ Morcos, Tony. (2000). The Straight Attraction. Retrieved on October 18, 2008. From the Magnequench.
- ⁸ Dan Stober (2008). Stanford News Service, Nanowire Battery . Retrieved October 15, 2008. From Stanford news service.
<http://news-service.stanford.edu/news/2008/january9/nanowire-010908.html>.
- ⁹ Rowland S. Benson and N.D. Whitehouse. (1979) Internal Combustion Engines. Oxford. New York, New York
- ¹⁰ S.J. Lang (1981) Low Noise Electrical Motors. Oxford : Clarendon Press
- ¹¹ Lawrie, Robert J. (1987) Electric Motor Manual. McGraw-Hill Book Co.
- ¹² A.N. Hosny. (1974) Propulsion Systems. Columbia, University of South Carolina Press
- ¹³ (2008, August). Biocycle Energy, Aug 2008, Vol. 49, Issue 8, p.50-52.
- ¹⁴ (August 2008). (Honda motor company LTD) geographical 80.8: 11 (1). Academic One file. Gale. Northern Arizona University—AULC. Retrieved 14 October 2008. <http://libproxy.nau.edu:2124/itx/start.do?prodId=AONE>.
- ¹⁵ Fuel Cells Portal page. Retrieved on 15 October 2008 from http://www.fuelcellmarkets.com/fuelcell_markets.com/fuel_cell_markets/fuel_cells/4,1,1,2114.html.

-
- ¹⁶ FH Yuerdon, Institute Energie et Systemes Electriques. *Retrieved on 16 October 2008 From.* www.evid.ch
- ¹⁷ Hirose, Mori D. (2008). International Journal of Hydrogen Energy. Doi:10.1016/j.ijhydene.2008.07.115
- ¹⁸ Healy, J (November 2007) Scientific American, 18(4), 80-81. *Retrieved October 27, 2008*, from Academic Search Premier.
- ¹⁹ Neef H.-j. Energy (2008).. Doi: 10.1016/j-energy.2008.08.014.
- ²⁰ Excell, Jon. (July 2003). Reinventing the Propeller. The Engineer, vol. 292, p.43-44.
- ²¹ (2004,). The Worldwide Leader in Noise Control Engineering. Retrieved October 23, 2008, from Soundown: For Peace and Quiet Web site:
http://www.soundown.com/index_Marine.htm
- ²² OEM Noise Control Solutions. Retrieved October 23, 2008, from SoundCoat Web site:
<http://www.soundcoat.com/about.htm>
- ²³ Tickell, Joshua. (2000 December). From the Fryer to the Fuel Tank: The Complete Guide to Using Vegetable Oil as an Alternative Fuel. Tickell Energy Consulting. p. 30-31
- ²⁴ (2007). Aquair UW Submersible Generator. *Retrieved November 23, 2008*, from NoOutage.com LLC: Aquair-UW Web site:
<http://www.nooutage.com/aquair-uw.htm>