

ASU Maroon Team

2008 – 2009 Project Year

Final Project Report

May13, 2009

Project Work By:

Andrew Davis

Tyler Dare

Anton Filatov

Matthew Magruder

Matthew Sellers

Julie Vogel

Heidi Zipperian

Table of Contents

Introduction.....	3
First Semester Recap.....	3
Final Prototype Design	3
References.....	7
Prototype Manufacturing	7
Electrical Manufacturing	7
Electrical Parts	7
Controller Programming	8
Battery Wiring	8
Motor Wiring	9
Electrical Manufacturing Complications and Considerations	10
Mechanical Manufacturing	10
Prototype to Design Comparison.....	15
Waterproofing.....	15
Shaft connection.....	15
Cooling system.....	15
Batteries	16
Recharge System.....	16
Boat arrangement	16
Testing.....	17
Table Testing	17
Wet Testing.....	19
Final Recommendations.....	21
Budget Considerations	21
Waterproofing/Professional Fabrication	22
Batteries	22
System Cooling and Thermal Modeling.....	22
Feasibility/Sustainability.....	23
Budget.....	23
Fiscal Overview for Spring 2009.....	24
Combined Battery Cost.....	25
Conclusion	25
Appendix A.....	26

Introduction

This report is documentation of all that the ASU Maroon Team has done during the second semester of our Senior Design Project. The second semester consisted of manufacturing a prototype of an electric motor conversion to an outboard motor. The prototype design is based on the ideal design we as a team created in the first semester. Also included after our final design and manufacturing documentation are difference between our prototype and ideal design, and recommendations we would make to future years who may undertake this project.

First Semester Recap

In the first semester of our design project we as a team fully defined the problem we were given by the GCROA. We then did a functional decomposition to determine what functions our design had to have and then came up with solutions to fill those functions. We then evaluated each solution to determine our top three designs. From this evaluation our top three solutions were an electric motor, an ethanol engine, and a diesel engine. We then did an in-depth study of each solution to determine that our final solution, and thus what we would build, would be an electric motor. This design process is documented fully in our first semester final report.

Final Prototype Design

The prototype design of the electric outboard alternative includes the following components:

- Perm Motor PMG-132
- Alltrax AXE 7245 Controller
- Magura Twist Grip Throttle
- White Rodgers (600 Amp Peak)
Contactor
- Bussman Fuse block and fuse
- Wire Kit
- Motor support/stand
- Modified Honda BF-30 Lower End
- Custom fabricated aluminum motor
mount and block-off plates
- Three custom fabricated motor supports
- 3.82" dia. Pulley
- 2.228" dia. Pulley
- Pulley Belt
- Manzanita Battery Charger
- Shaft Coupler
- Two LiFePO₄ (Lithium Ion Phosphate)
batteries

Each of these components serves a very simple yet specific purpose. First and most importantly, is the motor. The PMG-132 electric motor is the heart of the system. Its specifications can be found in the table, below.¹

PMG-132 Motor	
Voltage	24V-72V
Weight	24.8lb
Angular-velocity constant	50.2 rpm/V
Torque constant	27 ozf·in/A
Terminal resistance	0.025 Ohm
No-load current	6A
Rotor inertia	1370 oz·in
Inductance	19 μH
Continuous current	110A
10 minute current	200A
Terminals	8mm
48V Performance Peak efficiency	86%
Peak power	19.1hp
No-load angular velocity	2380 r/min
Stall current	960A
Stall torque	25600 ozf·in
72V Performance Peak efficiency	88.6% *
Peak power	34.3hp
No-load angular velocity	3590 r/min
Stall current	1440A
Stall torque	38500 ozf·in

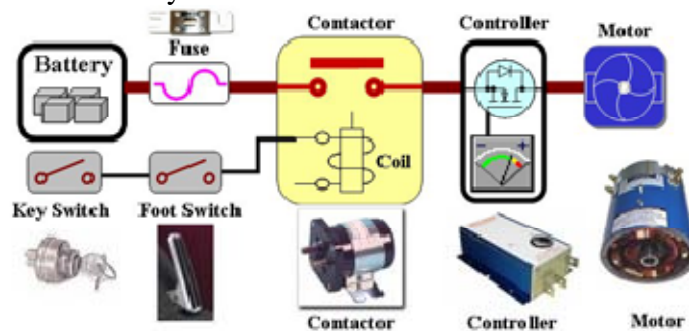
The motor is capable of performing at any voltage setting from 24 to 72 volts. It is similar in size and weight to the Lynch/LEMCO LEM-200 and the Briggs & Stratton ETEK motor. However, at the same voltage the PMG-132 has 50% higher peak output, 40% higher torque constant, and 120% more stall torque than the ETEK.¹ It is a brushed, neutrally timed, “pancake” style, permanent magnet DC electric motor. “Pancake” style refers to the way the elements within the motor are stacked, which gives it the shape of a stack of pancakes. Performance statistics for the various voltage settings at which the motor can be operated are shown below.¹

Specifications:					
Voltage	24	36	48	60	72
Current	110 A	110 A	110 A	110 A	110 A
Power	2.2KW	3.5KW	4.7KW	5.97KW	7.22KW
Speed	1080	1700	2300	2870	3480
Torque	20.5Nm	20.5Nm	20.5Nm	20.5Nm	20.5Nm

The Alltrax AXE 7245 controller functions to translate user inputs from the Magura twist-grip throttle into output voltages which are received by the motor. It is fully programmable and operates within the range of 24 to 72 volts. The programmable interface simply requires the controller be connected to a PC (windows operating system) through a standard serial cable and programmed through downloadable freeware, in a plug-n-play format. The programmable features are: throttle ramp programming, throttle response rate, plug brake on/off, plug brake current, high pedal disable on/off, battery over/under voltage cutback, and maximum output current. Added benefits to this controller are its fault tolerant control inputs, that it is epoxy potted /waterproof, and the calibration software is included at purchase.² It has a current rating of 450 amps maximum, for up to two minutes. Beyond that it can run at 350 amps for up to five minutes or 200A for up to one hour. If run below 200 amps, it has a very low voltage drop of less than 0.11 volts.² Specifications for the AXE 7245 are listed in the table below:²

Alltrax AXE 7245 Programmable Controller	
Voltage	24V-72V
Max. Current	450A
Weight	7lb
Operating Frequency	18kHz
Throttle Input	0-5K ohms, 5-0K ohms, 0-5 volts, and ITS (inductive throttle sensor)
Key Input Voltage	8 volts to 1.5 times max battery volts
Quiescent Voltage	Less than 75mA
Thermal Cutback	Begins at 75C, 95C shutdown
Programming Interface	RS232 serial to host PC running freeware Windows interface

The White Rodgers contactor (also called a solenoid) is essentially an “electromagnetically driven switch” capable of carrying large amounts of current. It is used to switch current from the batteries to the motor.³ It operates at a maximum of 600 amps and is controlled by the key switch. When the key is in “on” position, the contactor closes and supplies the controller with power from the batteries. When the key is turned “off” the contactor quickly breaks the circuit and no power is available to the motor. The diagram below illustrates a typical electric vehicle electrical system.⁴



The Bussman fuse is also represented by the above illustration. It plays a similar role to the contactor, except that it interrupts the battery power only in the event of a short circuit. Its primary purpose in the system is to protect the batteries and wiring from damage, but as a secondary measure it can prevent damage to the controller and the motor in the event of a direct short.⁴

The motor support/stand was fabricated for the purposes of mounting the prototype outboard motor and accessories. It has four 360° swiveling, locking casters attached to the base for mobility purposes. It was machined and welded out of a heavy duty steel alloy to best be able to withstand the weight of the motor assembly.

The Honda BF-30 lower end used for prototyping purposes has been modified to eliminate all unnecessary elements and refitted with custom-fabricated aluminum alloy block-off and motor mounting plates, as well as a 3-riser motor stand to enable direct insertion of the PMG-132. The lower end was necessary for the purposes of this prototype as the option of building a complete outboard was neither warranted by the task, nor allowed by the time and budget available.

The pulley assembly (2 different diameter pulleys and belt) has been keyed to fit the ends of both the motor output shaft and the driveshaft of the lower-end assembly. The pulleys are different diameters because there is a 1:2 step up between the driveshaft and the propeller, and the designed system requires a 1:1 “direct drive” gearing ratio. Therefore, the pulleys at the top of the shaft are stepped down 2:1 to compensate. It should also be noted that the original driveshaft of the existing lower end was not long enough and had the wrong splining to accommodate the attachment of the drive pulley assembly. Consequently, a new shaft was fabricated and keyed to attach to the pulley. This new shaft had to be coupled to the existing driveshaft by the assistance of a coupler.

The only remaining components of the prototype model are the batteries and the battery charger. Interestingly, the batteries purchased for prototyping are not the recommended batteries for use by the customer with the full-scale design. For testing and demonstration purposes, the batteries in use are the LiFePO₄ variety (a highly advanced technology with some prevalent limitations). The prototype requires only two batteries to achieve maximum power and the batteries are expected to last approximately 8-45 minutes before depletion depending on the power setting at which the motor is operated. This relatively low battery charge life, in addition to the instability of the core when exposed to water, is the primary reason why these batteries are not recommended for the customer’s purposes.

The Manzanita PFC-20B battery charger is one of the most versatile battery chargers available. It can charge any battery pack from 12 to 360 volts and can operate within the range of 50 to 250 volts AC. It is designed to operate at full capacity from a 30 amp circuit, so it will be usable for both the prototype batteries and the full-scale design battery bank (it will merely take more time to recharge the battery bank than the two prototype batteries).⁵ It is programmed to be a constant current source and will survive a short circuit indefinitely. Also, it is protected from reverse polarity by an internal fuse and has an efficiency of up to 96%.⁵

References

1. Electric Motorsports EV Parts. Website accessed 05/12/09. http://www.electricmotorsport.com/store/ems_ev_parts_motors_pmg132.php
2. Electric Vehicles USA. Website accessed 05/12/09. http://www.electricvehiclesusa.com/product_p/co-axe7245.htm
3. All About Circuits. "Contactors: ELECTROMECHANICAL RELAYS." Website accessed 05/12/09. http://www.allaboutcircuits.com/vol_4/chpt_5/2.html
4. Lessons Learned, Why are Fuses and Solenoid Disconnects So Important? Alltrax, Inc. Website accessed 05/12/09. http://www.alltraxinc.com/files/Doc120-046-A_TN010-Contactor-Fuse-Diode-Lessons-Learned.pdf
5. Battery Powered Systems. Website accessed 05/13/09. http://www.beepscom.com/product_p/bc-pfc20b.htm

Prototype Manufacturing

This section details how we manufactured our prototype and all the work and preparation that went into it. It also mentions some of the problems that we encountered when manufacturing.

Electrical Manufacturing

Electrical Parts

The main component of the electrical system we manufactured was our motor kit; which included the motor, battery contactor, controller, throttle, and the main system fuse. We also had a switch to act as the key switch and a variety of both 6 gauge and 16 gauge wire. The 6 gauge wire would go between the batteries, controller, and motor in order to handle the amount of power we would be drawing through our system. The 16 gauge wire was used for the throttle control and to go through the key switch. An additional diode also had to be used to go from the batteries to the key switch.

Controller Programming

The first step in our electrical fabrication was to make sure that the controller we had worked and could be programmed to do everything that we wanted it to do. In the table below is a list of the different parameters that you can set on the controller and the values that we set them to. The controller program and instructions on what each of the parameters is was obtained from the controller manufacturer. Using this software and documentation from the controller manufacturer Alltrax Inc. gave us a great advantage when programming because we were able to follow their instructions and also had good documentation on what each parameter of the controller corresponded to.

<u>Controller Parameter</u>	<u>Setting</u>
High Pedal Disable	ON
½ Speed Reverse	OFF
Max output Current	100 %
Under Voltage	48 V
Over Voltage	80 V
Throttle Up Rate	6
Throttle Down Rate	12
Top Speed	100 %

An explanation of each of the choices in the table can be found in Appendix A. We chose to have the high pedal disable on to prevent accidents when the controller is started if the throttle is depressed. The ½ speed reverse was not engaged because we were not using the controller to put the outboard in reverse. Due to our battery selection for our prototype we chose to have the max output current at 100% because our batteries could not damage the motor with too much current. The over and under voltage were chosen as a baseline and would need further testing. The throttle rates were chosen after data was taken on each level as documented above. And finally the top speed was set at 100% in order to not limit our power output at all.

After programming the controller we connected our throttle to the controller and ran data on how fast the response time should be. We had to make sure that this time was fast enough to respond to the needs of our customer when they are steering through rapids. Located in Appendix A is the data from testing the throttle at each of the settings before deciding on the final setting.

Battery Wiring

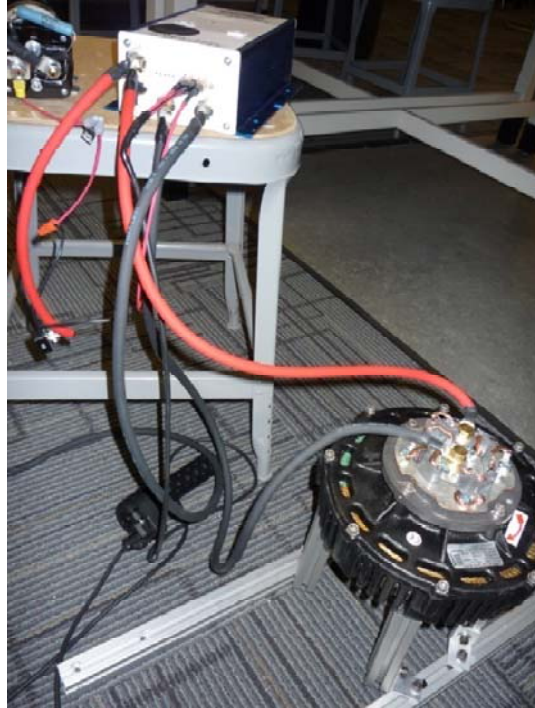
In putting together our batteries we had a total of 7 batteries for our two teams. In order to put all the batteries together in series we had to change the wiring on them. The wiring that they came with was not the correct gauge to handle the amount of current and voltage that we would be carrying through it. In order to do that we had to bypass the existing wires and connect a steel plate to the existing battery lattice. This plate allowed a more even distribution of current and also heat generated from the current. It also allowed us a better connection point for our wires. This connection may not be sufficient to dissipate the heat generated from the amount of current we are pulling so we will have to monitor this as we put more together in series.

Motor Wiring

In wiring the motor to the controller we followed the wiring diagram located in Appendix A that we obtained from the controller manufacturer as well. We followed this diagram exactly except for the 5 amp fuse on the key switch line. We obtained a fuse of this size however it had the wrong type of connections. We decided to go ahead with our wiring without this fuse as it was only one step of many having to do with safety precautions. Before putting our system in the water or through further high powered testing we would need to add this fuse.

After wiring the batteries and motor according to the wiring diagram, we connected the batteries to the controller and tested our motor to see if it would spin according to throttle control. This test was conducted as a bench test and was purely a test of the wiring, not a fully documented test. At this point in time the motor did spin according to throttle control. It was only attached to one battery with 50 volts and would not spin at full speed nor did we do any type of speed or power output testing. It was only to test that the throttle would control speed. Pictures of this setup are shown below.





Electrical Manufacturing Complications and Considerations

The first consideration that we would need to address before continuing testing, or if any other teams were to continue our work, would be the wiring. Right now the wiring is very primitive and not protected in any way from water or from stray connections that might occur from random tools being used around the motor. The second complication that occurred in our design was the fact that after we moved our controller to connect it to the bottom end it stopped working. At first we thought that it was only our throttle that had stopped working but we were able to fix that. After fixing the throttle and doing many multi-meter readings we established that something is wrong with our controller. We are not sure what is wrong with the controller and are working through some of our resources in order to figure out what the problem is and how we could possibly fix it without having to buy a whole new controller.

Mechanical Manufacturing

Overview:

The major design goal of this electric motor conversion of the Honda BF-30 outboard involved replicating the prop conditions as closely as possible using an electric motor. This involved converting the output speed of a DC electric motor to operate as closely to 6000 RPM as possible. This was achieved by attaching a pulley to the motors output shaft and transferring the power using a cogged belt to a pulley attached to the drive shaft for the propeller. The gear ratio overdrives the pulley on the drive shaft to achieve the 6000RPM condition while the electric motor is spinning at its maximum of 3500RPM.

The other goals of this system were to minimize weight while maintaining a robust system, and keeping the components simple. This was achieved by manufacturing as many of the components out of aluminum as possible because of its high strength to weight ratio as well as its corrosion resistance. The components were kept simple by not overcomplicating the system and keeping the part count to a minimum. Our system achieves the conversion using three main plates and three up rights, as well as two pulleys a belt and a minimal amount of hardware.

All components were designed using SolidEdge, and are included on the supplemental CD.

Block-off Plate:

The Block-off Plate is the foundation of our conversion system. This plate closes off all of the passages between the lower end and the engine compartment of the outboard. This plate uses the existing bolt pattern to mount to the outboard, the counter bore depth for the mounting holes was set so that the heads of the socket head cap screws did not interfere with the surface of the plate.

This plate has three threaded holes towards the back of the plate that the adjustment bolts thread into, which allows for the adjustment of the motor cage. At the front of the plate there is a through hole for the drive shaft as well as mounting holes for the drive shaft bearing support.

Motor Cage:

The motor cage is the component of the system that attaches and allows for the adjustment of the motor for belt tensioning. There are two plate components an upper and lower motor adaptor plate. The lower adaptor plate has through slots for belt tensioning adjustment. The plate also had three pockets with threaded holes in the center to capture and mount the uprights that space the upper and lower plates apart. The upper plate then mounts on top of the uprights and had pockets with through holes that attach the plate to the uprights. The upper plate has a through bore that allows the motor to drop into the plate. The motor mounts to the upper plate using existing mounting holes and corresponding holes.

Drive system:

Two standard pulleys were chosen from McMaster Carr whose diameter would produce the 1:72 drive ratio needed to replicate the RPMs of the stock BF30 motor. These two pulleys utilize an H-series timing belt that is rated in excess of the torque forces the PMG 132 motor would produce.

In order to efficiently transfer power through the system, the pulleys required to have a keyway machined into the inner diameter. It was determined that the required keyways would need to be an .125" square key for the 2.228" diameter pulley and a .250" square keyway for the 3.820" diameter pulley. A file of the modified pulleys can be found on the supplemental CD: Motor Mount System>Models>Drive Shaft.

An analysis of the torque values throughout the system was required in order to verify that the keyways would not fail under the system's load. An example of the required calculations is below:

System Torque:

Output Torque: 25 Nm = 18.4381 lbft = 221.2571 lbin

Large Pulley Keyway:

Shearing

$$F = T / (D/2) = 221.2571\text{lbin} / (.625/2) = 708.022 \text{ lb}$$

$$\text{Shear Pressure Actual} = F/A = 708.0227\text{lb} / (.250 \times 1.0) = 2832.0908 \text{ psi}$$

$$\text{Shear Pressure Designed} = .5 (\text{Shear Strength}) / N = (.5)(51000) / 3 = 8500 \text{ psi}$$

$$\text{Required Length} = 2T / ((\text{Shear Pressure Designed})DW)$$

$$= 2 (221.2571) / ((8500) (.625) (.250)) = .3332 \text{ in}$$

Compression

$$\text{Compression Pressure Designed} = \text{Shear Strength} / N = (51000) / 3 = 17000 \text{ psi}$$

$$\text{Compression Pressure Actual} = T / ((D/2)(L)(H/2)) = 5664.1817 \text{ psi}$$

$$\text{Require Length} = 4T / ((\text{Compression Pressure Actual})(D)(H)) =$$

$$= 4 (221.2571) / ((17000)(.625)(.250)) = .3332 \text{ in}$$

Transfer Torque:

$$\text{Gear Ratio} = 3.820 / 2.228 = 1.7145$$

$$\text{Drive Ratio} = 5980\text{rpm} / 3480 \text{ rpm} = .58193$$

$$\text{Torque Output through Transfer} = (221.2571)(.58479) = 129.39012 \text{ lbin}$$

Small Pulley Keyway:

Shearing

$$F = T / (D/2) = 690.0806 \text{ lb}$$

$$\text{Shear Pressure Actual} = F/A = 690.0806 \text{ lb} / (.125 \times 1.0) = 5520.645 \text{ psi}$$

$$\text{Shear Pressure Designed} = .5 (\text{Shear Strength}) / N = 8500 \text{ psi}$$

$$\begin{aligned} \text{Required Length} &= 2T / ((\text{Shear Pressure Designed})DW) \\ &= 2 (690.0806) / ((8500) (.375) (.125)) = 3.4639 \end{aligned}$$

Compression

$$\text{Compression Pressure Designed} = \text{Shear Strength} / N = (51000) / 3 = 17000 \text{ psi}$$

$$\begin{aligned} \text{Compression Pressure Actual} &= 4T / ((L)(D)(H)) = \\ &= 4 (690.0806) / ((.375)(1.0)(.125)) = 58886.877 \text{ psi} \end{aligned}$$

$$\begin{aligned} \text{Required Length} &= 4T / ((\text{Shear Pressure Designed})(L)(H)) \\ &= 4 (690.0806) / ((17000)(.125)(1.0)) = 1.2989 \end{aligned}$$

Drive shaft:

The system uses a two piece drive shaft with a coupler that connects the upper and lower shafts. The upper shaft was manufactured to accommodate the additional length needed because of the added height of the block-off plate and the bearing support. Another aspect that was better addressed through the manufacture of a custom upper shaft was the attachment of the driven pulley. The size of the shaft as well as the needed keyway was able to be made to integrate the pulley directly on to the shaft.

The lower shaft was made by cutting the factory drive shaft to a much shorter length. A coupler then attaches to both the upper and lower shafts by clamping onto them. The mating ends of the coupler pieces come together to allow the transfer of power from one shaft to the other.

Hardware:

The hardware used for this system was all either stainless or black oxide to prevent any corrosion. Cap screws were used for all applications possible and heavy duty bolts were used for all other applications.

Manufacturing:

Overview:

The manufacture and modification of all of the parts for the electric motor conversion of the Honda BF-30 was performed in house by members of the ASU MMET Maroon team. The use of Haas CNC mills and lathes as well as manual equipment allowed the manufacture of the needed components.

All manufacturing related documents such as prints and specifications, as well as CNC machining programs are included in the supplemental CD.

Block-off Plate:

The block off plate was machined from a piece of 6061 aluminum plate. The geometry of the needed mounting holes was taken from the Honda gasket that normally goes between the engine and the lower-end. This geometry allowed the same mounting locations to be utilized for this component. To keep things simple for the system a simple sliding method is being used to tension the belt drive so there are three threaded holes that were machined in the rear section of the plate. This allows the clamping bolts to go through the lower motor adaptor plate and into the block-off plate to hold the belt in tension.

There is also a through hole in the front region of the plate to allow the drive shaft to come through the plate. The drive shaft is supported by a flanged bearing, this flange mounts to the block off plate using two threaded holes, one on either side of the drive shaft hole.

Motor Cage:

The upper and lower motor adaptor plates were machined from 6061 aluminum plate. The square plate was held in the machine vise while the holes, pockets and slots were machined. Then operation two for both the upper and lower plates involved bolting the plate to a sacrifice plate and the square was machined into the round profile.

The uprights were machined from 6061 bar stock. The large diameter was machined first then the smaller diameter sections were turned on each end and both ends were threaded.

Pulley Keyways:

The required keyways were machined into the standard McMaster pulleys through the use of broaches. A set of progressive broaches and guides were used on an arbor press to manually machine the keyways.

Drive Shaft:

The drive shaft was manually machined through the use of a lathe. From 304 stainless steel, the required dimensions were machined, but with an ever-sized length to allow for test fitment. After the fitment was determined, the length of the shaft was finalized.

Prototype to Design Comparison

There are several points where the prototype the team constructed differs from our vision of the production model of our design. Those differences occurred for various reasons: time constraints, budgeting errors, or design adjustments. This section of the report will describe those differences, perhaps helping future teams concentrate their efforts.

Waterproofing

As it currently stands, the prototype is not ready for on-water testing. Many of its vital systems are not sufficiently waterproofed, including the motor housing itself. Several holes in the cover have to be plugged up. Water damage is also a concern when it comes to the battery storage and the electrical connections. Currently, no waterproof battery storage system exists, and many of the electrical connections are vulnerable. Though sufficient for initial testing, this would become a very serious danger on water. The team has considered using a truck tool box as a battery storage unit, however this has not been implemented because of time constraints.

Shaft connection

One of the early problems the team encountered during prototype construction was connecting a new motor to the existing driveshaft. The original plan was to manufacture a new connection which would connect to the existing spline of the drive shaft. However, the team lacked the proper equipment to do this, and because of the non-standard nature of the spline involved, the process would have to be carried out by an outside shop at considerable time and cost.

Progress was slow, mainly because of the unresponsiveness of the outside shop, and the team abandoned the spline connection, instead settling for cutting the shaft just above the gearbox by the propeller, and mating a new shaft onto the old using a tensioned connector. Though this connector is designed to withstand the torque loads and RPMs the system would be operating under, this solution is less elegant than the original. Also, the connector is rather bulky, and there is no room for any play in the shaft, since any lateral motion will hit the connector against the wall of the shaft housing.

Cooling system

After selecting the motor, the team realized that considering the temperatures the system had to operate in, a cooling system was necessary. Though the PMG 132 is very efficient, around 90% at max power, the temperature of the surroundings can be expected to be very close to its maximum operating temperature. Thus, any heat given off by the motor can easily drive it above safe temperature limits. The problem is compounded by the fact that the motor was designed to be air cooled, and we need it to operate in a sealed environment, in order to prevent water from reaching the electronics.

The team decided to utilize the existing water cooling system of the engine assembly, and the unlimited reservoir of very cold water to reject the heat from the motor. Estimating a figure of 1000 W of heat loss from the motor during its extended peak condition, initial designs called for the cooling system to be based on convection, with several coils of tubes positioned above the motor. Natural convection would transfer the heat from the motor into the cold water running through the tubes. However, initial modeling showed that the natural convection coefficients involved are not high enough. The air in the motor case would not be turbulent enough to transfer that much energy.

The team suggests several modifications to its initial cooling system design. First, the convection coefficients involved must be increased. This can be done by introducing a small fan into the casing in order to circulate the air, effectively adding the effects of forced convection to those of natural convection. A more elegant solution would be to use the rotational motion of the two shafts in the motor housing, by attaching fans to those shafts. The additional loads on the motor would be completely negligible. This solution would also couple the fan RPM to the motor RPM, ensuring maximum air movement during peak motor heat loss.

Another suggestion is to move the coils of water tubes as close to the motor as possible, essentially jacketing the motor in cold water, without allowing any contact with vulnerable electrical connection. This would allow the cooling system to take advantage of the higher conduction coefficients.

Batteries

The batteries used in prototype testing are not the ideal batteries for the full scale system, simply because they do not have the energy density we need. Originally, the team selected gelled lead acid batteries, at 12 V and 225 amp hours each. However, due to customer safety concerns, the batteries purchased for the prototype were lithium polymer, at 48 V and 15 amp hours each. This represents a significant drop in length of operation. In order for this system to be feasible, a new battery solution would have to be found.

Recharge System

The recharge system for the batteries did not undergo any major design change. There was simply no need to construct it, since the testing the team has preformed to date has not yet drained the batteries significantly. All of the components of the recharging system are already purchased.

Boat arrangement

Currently, the system is arranged on simple test bench. Before full scale, on water testing and operation can proceed, the components of the drive system have to be arranged on the boat. The team has suggested several such arrangements; however, because of time constraints we have not had the chance to experiment with these designs.

Testing

Before we started any testing we established some safety precautions in order to perform our tests on a high powered battery system and an electric motor.

- **Safety precautions**
 - Wear shock protection gear at all times
 - Rubber gloves
 - Rubber soled shoes
 - Eye protection
 - Make sure you and the system are properly grounded when working with the electrical components

- **Some Precautions you should be aware of before working on the electrical system**
 - Defective parts
 - Unguarded live parts
 - Bare conductors or exposed terminals
 - Metal parts of equipment may become energized when connected by cord or plug. Capacitance may cause up to 55% of line voltage to be stored on the casing of metal tools.
 - Exposed wires

- **General area (free of)**
 - Flammable vapors, liquids and gasses
 - Combustible dusts
 - Corrosive atmospheres
 - Explosive environments
 - Liquids in general
 - Lots of people traffic

Table Testing

Introduction:

Before running a test on the full assembly the group decided to run some table top tests in order to have more control. The test consisted in the collection of temperature, noise, rotational speed, and power data of our electrical system. We are running these tests in order to collect enough data to determine the optimum operating conditions for our assembly. With the collected data we will be able to set up a Designed experiment and find the desired outputs.

Problem:

There are too many variations in the assembly, which equals uncontrollability of the system. To have more control over the system we are going to run designed experiments to determine the optimum operating conditions.

Materials:

- Motor assembly
- Motor Cage (test stand)
- Batteries
- Voltmeter
- Tachometer
- Decimeter
- Thermocouple
- Timer
- Computer (with excel)

Procedure:

In order to test the motor assembly it must be properly assembled. The motor must be bolted to the cage assembly, which then should be bolted to a fixed location such as a work bench. The motor must then be wired correctly (caution when handling any of the electrical components use extreme caution there is a large shock hazard). Once the system is setup to test, the measurement devices are then needed to be turned on and checked for accuracy. The following procedure is a guide line procedure to follow when all components are initially tested, and this procedure will change after numerous tests have been completed.

1. Test batteries for charge (multimeter)
 - a. If drained of charge, use charger to charge them
2. Connect charger to power source and test its outputs (multimeter)
3. Connect the batteries to charger and charge batteries completely (multimeter, timer, thermocouple)
 - a. Record time, voltage, current, and temperature over charge period
4. Turn on gas generator and test the outputs (decimeter, multimeter, timer, thermocouple)
 - a. Record all outputs
5. Connect batteries to charger, charger to generator and charge batteries. (decimeter, multimeter, timer, thermocouple)
 - a. Record time, voltage, current, and temperature over charge period

6. Connect batteries to motor and run dry test on work bench at:
 - a. 15 second increments of throttle position
 - i. Refer to data tables for all recordable data needed
 - b. If batteries are depleted of charge, charge batteries again.
 - i. Record time, voltage, current, and temperature over charge period.
 - c. 30 seconds increments of throttle position
 - i. Refer to data tables for all recordable data needed
 - d. If batteries are depleted of charge, charge batteries again.
 - i. Record time, voltage, current, and temperature over charge period.
 - e. 1 minute increments of throttle position
 - i. Refer to data tables for all recordable data needed

Data Analysis:

After all of the table top tests have been run and all data recorded the statistics can be used to determine the optimum conditions. An example of this would be to use the temperatures, current, and voltage to determine the optimum speed for the shaft. This would be nice to know so that the system does not over heat and destroy itself. The hi and low values for each data column need to be found and a design experiment run on the values to determine the systems optimum operating conditions for temperature, voltage, current, and noise. Once these values are found they can then be used to draw conclusions on the system.

Wet Testing

Introduction:

This test procedure will also be used to accurately conclude the systems optimum operating conditions. Before this test can be run all of the following conditions must be met in order to make accurate conclusions and for the safety of the system. Firstly, all of the electrical components must be properly sealed in order to keep water out and to properly simulate working conditions on the river boats. All of the wires will also need to be properly sealed in order to keep the water out. The lower assembly and motor cage should be properly mounted so that measurements can still be taken. This set up should be very close to the same way that the actual river boat assembly will be set up in order to produce accurate results. Lastly, the system and method at which measurements are taken should be processed in a very safe manner. Remember safety is always first.

Problem:

There are too many variations in the assembly, which equals uncontrollability of the system. To have more control over the system we are going to run designed experiments to determine the optimum operating conditions.

Materials:

- Motor assembly
 - Motor Cage (test stand)
 - Boat
 - Large body of water (lake)
 - Batteries
 - Voltmeter
 - Tachometer
 - Decimeter
 - Thermocouple
 - Timer
 - Computer (with excel)
1. Make sure all initial conditions are recorded, such as battery voltage, current, and ambient temperature and initial temperature of each component. (multimeter, thermocouple)
 2. Double check all connection for proper linkage and seals for water proof.
 3. Turn system on and run the wet test at:
 - a. 15second increments of throttle position
 - i. Refer to data tables for all recordable data needed
 - b. If batteries are depleted of charge, charge batteries again.
 - i. Record time, voltage, current, and temperature over charge period.
 - c. 30 seconds increments of throttle position
 - i. Refer to data tables for all recordable data needed
 - d. If batteries are depleted of charge, charge batteries again.
 - i. Record time, voltage, current, and temperature over charge period.
 - e. 1 minute increments of throttle position
 - f. Refer to data tables for all recordable data needed
 4. Make sure to record all data in excel files.
 5. Run Design of experiment to find optimum operating conditions.

Data Analysis:

After all of the data has been collected a thorough DOE should be run on the data. The conditions that are found for this test will best fit the actual operating conditions at which the full scale assembly will see in the Grand Canyon. The data should be used to conclude to true operating conditions and these values should be reported to the GCROA during the final prototype presentation.

Final Recommendations

From the outset of this design project, all of the participating students, faculty, and representatives of GCROA and the National Park Services (NPS) have had a multi-year approach in mind. Pursuant to a voluntary agreement between the river concessionaries and the NPS, operation of fossil-fuel propulsion within the Grand Canyon will become prohibited in 2018. The objective of this year's Maroon and Gold teams representing ASU in the Alternative Motorboat Project has been to develop a solid design foundation that can serve as a launch pad for future teams. Our hope is that future participating students will be able to expand upon and refine our preliminary design and modeling to achieve a viable solution that can be implemented by the outfitters.

As mentioned earlier and throughout this report, our team has fabricated a functional, first-generation prototype and has conducted preliminary testing and data collection. However, our prototype differs from the design that was originally proposed and does not fully correspond to a solution that could be implemented on the Colorado River. In adherence with the concept that this project will transcend any single design team and will span several years, we would like to provide recommendations for the future, these include:

- Budget Considerations
- Waterproofing/Professional Fabrication
- Batteries
- System Cooling and Thermal Modeling
- Feasibility/Sustainability

Budget Considerations

One difficulty that was experienced by both ASU teams was the relatively fluid and undefined nature of our budget situation throughout this project. Better results could be expected from future teams if they are given more realistic and definite projections of what funds are available from ASU and GCROA. We recommend that representatives of GCROA, the students and faculty develop formal budgetary protocols and expectations for future years.

Our team bought many of the more expensive components necessary for the project with this year's budget. These included the PMG motor, controller, battery package (split between the two ASU teams) and the charger. All of these parts will be essential components for future teams that refine and further the development of our first generation prototype. With these large purchases taken care of, we expect there to be a lighter burden on the budgets of future teams, allowing them to focus on waterproofing, improving the professional appearance of the deliverables and eventually procuring more batteries.

Waterproofing/Professional Fabrication

In its current configuration our prototype is not suited for safe operation on the water. During assembly and fabrication the emphasis was on having a working proof of concept before the end of the year. As a result, the current wiring configuration and battery storage is not intended for exposure to water or the climate in general. A waterproof battery storage compartment will need to be designed and fabricated by a future team in accordance with industry specifications and must provide for a means to vent any and all gases generated by the batteries. All wiring of the current prototype is for dry testing only and will need to be replaced with a more robust and waterproof wiring configuration to allow for safe testing and demonstration in a wet environment. A suitable enclosure for the motor assembly will also need to be developed to prevent any exposure of the motor assembly to water and to minimize the exposure of the boat operator and passengers to moving parts. The thermal difficulties of such an enclosure are discussed below.

Batteries

Previously we discussed the fact that our team had to change our battery type to accommodate both safety and budgetary concerns. In order to continue refining our prototype to a working solution a better battery must be found. For the batteries we currently operate, to achieve the power requirements needed for one day down the Grand Canyon, we would need at least 30 batteries. This is obviously not the best solution. The idea solution would be to combine a lithium battery, which would fulfill safety requirements, and a battery with a large amp*hour capacity.

For more immediate prototype testing or refinement, simply more batteries would need to be obtained. If more batteries are obtained, then accurate testing could begin on the power needed for one day down the river and even more refinement could take place regarding calculations of battery power needed. When we as a team made our calculations on battery power required we made assumptions as to throttle level and time of usage in a day. To validate or disprove these assumptions long term battery tests would need to be performed requiring more batteries than we have at this point.

System Cooling and Thermal Modeling

As mentioned above, any version of the prototype intended for testing on the river and the final design will require an enclosure for the motor. Difficulties arise in balancing the dual goals of waterproofing the enclosure and allowing for the effective and adequate cooling of the motor assembly. Due to the scope of our work on this project, we have not been able to dedicate extensive time and design work to the cooling of the system beyond thermal modeling of the motor and initial alternative concept generation. All of our modeling and any documentation generated from testing and data acquisition will be compiled for the next team of students.

We expect that adding a cooling fan to the enclosure or making use of the integral water pump found in the lower-end of the outboard will provide adequate cooling for the motor. Both approaches, as well as others, will need to be considered in any design of the motor enclosure. With the foundations of the project in place from the work done this year, future students will be well placed to dedicate the time and funds to solve the remaining design challenges.

Feasibility/Sustainability

As detailed in our final design proposal, battery technology does not allow for pure electric solution without the ability to recharge at the end of every day of operations. We have proposed that the rafts carry ethanol and use generators configured to run on that fuel to recharge the batteries every night. Our work on the generators and recharging has been limited to selecting suitable generators available from Honda and the necessary work and components that will be required to convert the generators to operate on ethanol. For a complete proof of concept, future students will need to purchase generators, undertake the conversion and test the complete system. With further design work it is possible that another team may determine a method of recharging the batteries that better satisfies the needs of GCROA than our generator proposal.

In light of the fact that this design project is intended to extend of several more years and that ASU now possesses many of the major components and assemblies that are necessary for the project, it may be beneficial to divide the remaining design challenges and address them in succession over the coming years. For example, the next two Capstone teams working on the Alternative Motorboat project could each focus on the motor enclosure and power generation/recharging respectively. Focusing teams on specific design issues, with a year to thoroughly research and model the situation and explore multiple approaches, could be expected to deliver better results than simply having multiple teams each attempt to incrementally work on all aspects of the project.

Budget

As part of our final design selection, we provided a cost analysis that examined both our estimated expenditures for prototyping a proof of concept and our estimation of the cost of implementation of our system. As noted in that analysis, our working budget with funding from Arizona State University and GCROA was limited to \$6,405. However, our expected cost of producing a full-scale prototype would have required a budget with funding in excess \$9,027. The result of our budgetary shortfall required certain design changes. The primary differences of our delivered prototype from the original, proposed design are a direct reflection of insufficient funding. For a more thorough discussion of those differences, in a context beyond budget concerns, see the appropriate section of this report.

A breakdown of our expenditures for the spring 2009 semester can be found in the table below.

Fiscal Overview for Spring 2009

Item	Cost \$	Qty	Supplier
Generator	\$0.00	1	CSF
Motor Kit	\$1,720.00	1	Electric Motor Sport
Motor	inc	1	Electric Motor Sport
Controller	inc	1	Electric Motor Sport
Throttle	inc	1	Electric Motor Sport
Fuse Kit	inc	1	Electric Motor Sport
Guage Wire	inc	na	Electric Motor Sport
		na	
6061-T6 Al Plate 8 x 8 x 1	\$30.00		
3.82 Dia. Pulley	\$55.17	1	McMaster
2.228 Dia Pulley	\$33.52	1	McMaster
Gasket, Engine Case	\$25.95	1	N/A
Belt	\$50.00	1	McMaster
Al round stock	\$50.00	na	NA
Hardware	\$100.00	na	
Abrasives	\$50.00	na	
Hoses and fittings	\$50.00	na	
Contigency Fund	\$600.00	na	
Batteries (Maroon)	\$820.86	2	YonXing Machine Zone
Charger	\$1,860.00	1	Manzanita
Block off Plate	\$19.56	1	
Motor Mount Plate	\$15.40	1	
Standoff Feet Top	na	3	
Standoff Feet Bottom	na	3	
Standoff Body	\$10.83	3	
Coupling	\$90.00	1	
Total Spent	\$5,581.29		

As can be seen from the table above, our team was able to deliver a proof of concept while remaining under budget by \$824. There are however certain caveats. Reducing our cost to within the limits of our effective budget required compromising on our battery pack and not acquiring and converting the generators that would have been necessary for recharging. It should be remembered that such changes were acceptable to the scope of this project and consistent with a long-term, incremental approach to delivering a solution to GCROA of the next several years.

To reduce cost for both teams representing ASU, the Maroon and Gold teams selected and purchased communal batteries. For the purposes of demonstration and testing, our team was only interested in procuring two batteries and was therefore, liable for only two-sevenths the total cost of the batteries (including shipping). The details of the battery purchase can be found in the table below.

Combined Battery Cost

Vendor	Order Quantity	Item Description	Unit Price	Shipping Total	Tax	Total Price
YongXing Machine Zone (Through Ebay)	7	LifePo4 Batteries	\$249	\$1,130	\$0.00	\$2873

Conclusion

In this paper we have presented all the work that we have done to put our design into the prototype stage. We have detailed how we fabricated both the electrical and mechanical portions of our prototype and how we would go about administering test procedures. The most important part of this document however is our recommendations for changes to the prototype for future testing and teams who may undertake this project as well. These recommendations are problems that we saw with our prototype construction and how we think the prototype could be refined and made better. Our prototype budget is also detailed in this document showing where we spent our money and how we worked within our budget. This document will hopefully help teams that come after us to create an even better design and prototype than we did.

Appendix A

Battery Controller Information, Throttle Testing, Wiring Diagram

Controller Information:

High Pedal Disable – AXE and DCX Models

Checking this box enables HPD, which will prevent the controller from providing output power in the event the throttle is applied when the controller is powered on. When this box is clear, the controller will start up and provide output power, when KSI energized, if the throttle is depressed.

½ Speed Reverse – AXE and DCX Models

Checking this box enables ½ Speed reverse. When reversing this limits the vehicle speed to half of the throttle position. Top speed is reduced by half by this setting. Disabling ½ Speed Reverse does not reduce the vehicle speed when going in reverse.

Max Output Current – All models

This slider sets the maximum output current the controller can supply to the motor. Output current is adjusted as a percentage of maximum rated current of the controller. For example, an AXE4844 can supply a maximum of 400A with the slider at 100%, 300A at 75% and 200A at 50%.

Under Voltage – All models

This slider sets the under voltage shut off of the controller. It prevents battery damage by turning off the controller in case the battery voltage drops too low. Generally speaking, it is undesirable to pull the terminal voltage of a 6V lead-acid battery below 4.0V, for example 24V on a 36V system. Adjusting this slider increments the under voltage setting in 1/10ths of a volts.

Over Voltage – All models

This slider sets the over voltage shut off of the controller. It prevents damage to the controller in an over voltage situation. If the batteries get over charged or any other situation that exceeds the voltage rating of the controller, the controller will shut down. Adjusting this slider increments the over voltage setting in 1/10ths of a volts.

Throttle Up Rate – All models

This slider adjusts the rate the controller output current responds to an increase in throttle position. The rate of increase is on a scale of 1 to 15, with 1 being the slowest and 15 being the fastest. Typical settings are between 3-8.

Throttle Down Rate – All models

This slider adjusts the rate the controller output current responds to a decrease in throttle position. The rate of increase is on a scale of 1 to 15, with 1 being the slowest setting. It is recommended that this parameter typically be set to twice the value of the throttle up rate, when throttle up rate is less than 7.

Top Speed – All Models

This slider sets the top speed of the vehicle as a percentage of top speed. The controller applies this percentage to the actual throttle position. If the slider is set to 75%, whatever the actual throttle position is, the controller interprets it as 3/4ths that position.