University of Utah

ME 4010 – Spring 2009

Grand Canyon Alternative Motor Project

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Sponsored by the Grand Canyon River Outfitters Association

1 - Front Matter

1.1 - Executive Summary

1.1.1 - Introduction

In 2008 the Grand Canyon River Outfitters Association (GCROA) initiated the Grand Canyon Alternative Motor Project (GCAMP). The goal of this project is to replace the current 30 horsepower outboard engines used in the Grand Canyon with an alternative propulsion source. Improved customer experience, environmental impact, reliability and cost are among the top concerns of the GCROA.

Most of the rafting trips through the Grand Canyon use rafts that are 37 feet long and require at least a 30 horsepower gasoline outboard motor to safely navigate the rapids and complete the 300 mile trip in less than 9 days. The noise generated by these motors is detrimental to the experience of the passengers on the raft, as well as others along the river corridor. The environmental concerns from the current outboard engines include the exhaust gases, as well as fuel and oil leaks. This type of outboard motor has been successfully used in the Grand Canyon for over 40 years.

The project requirements as specified by GCROA are to design a quieter, zero-emissions motor system with similar performance characteristics to the 30 horsepower gasoline outboard engines currently being used by the outfitters. Due to the harsh conditions encountered in this wilderness river environment, the system must be very durable, portable, protected from the elements, minimize the modifications to the raft and above all be safe to the operators and customers. Finally, the system will use natural energy sources within the canyon to supply the energy needed while maintaining the intrinsic historical appearance of the raft.

1.1.2 - Key Project Focus Areas

<u>Propulsion System:</u> The propulsion system developed at the University of Utah consists of three major components: the electric motor, the batteries and the motor controller. The motor selected must be durable and maintenance free. If problems are encountered with the motor during the trip it is intended that an on-board spare will replace the damaged

unit. This means the motor must also be compact and lightweight so it can be moved by the operator. The batteries selected must have the capacity to supply power to the motor for a full day of operation. These batteries must also be able to handle a large number of charge cycles, the extreme heat of the Grand Canyon, and be of modest weight. Finally, a controller system is needed to regulate voltage from the battery bank to the motor. Having this controller will keep the system operating efficiently, while allowing the driver a throttle control similar to the current gasoline outboard design.

Power Generation System: The power generation system developed at the University of Utah consisted of three major sub-systems: the turbine, the transmission system, and the generator. The turbine must be durable, lightweight, easily deployable, generate the required power, and fit within the given size constraints. In addition it should require as little maintenance as possible, and must be deployable by a maximum of two people (preferably one), for setup and take down. The transmission system must be simple and lightweight. Due to the high amperage and voltage involved, safety is a major concern for the transmission system. The generator must be robust, fit within size constraints, and interface properly with the battery-charging controller and batteries. The generator is to be purchased as an “off the shelf” component to the system to work in conjunction with the turbine.

1.1.3 - Conclusion

The project culminated with a working prototype system to be river tested in May 2009. All customer needs were met as specified, with the goal of designing a limited-production basis model.

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2 - Context

2.1 - Need Statement

Whitewater rafting through the Grand Canyon began in 1869 with Major John W. Powell's exploratory trip down the Colorado River. Between 1869 and 1940 less than 100 people had traveled the river corridor through Grand Canyon National Park. Throughout this period the boat of choice was a heavy wooden dory-style boat. These boats were not the ideal craft for the canyon and many of the rapids were portaged because the boats were unable to navigate the whitewater. At the end of World War II rubberized Army surplus rafts began to become available. These rafts came in all sizes from 16 feet to 37 feet in length, and greatly increased the safety with which people could navigate the Grand Canyon whitewater. With these new rafts came an explosion in canyon use up until 1973 when the National Park Service limited the number of people that would be allowed to travel the river corridor each year. Since 1973 over twenty thousand people have taken the 300 mile whitewater rafting trip through the Grand Canyon. The most commonly used raft is called the “S-rig.” The S-rig is a 33-37 foot long motorized rubber raft that is propelled with a 30 hp outboard engine, and can carry up to 17 people.

As concern for the environment and the way humans interact with the environment has changed over the years, questions have been raised about how “friendly” these outboard engines are to the environment and how they affect the visitor experience to the canyon. The major source of concern lies in the noise the motors produce and how it affects the passengers on the raft as well as the other visitors in the canyon and wildlife along the river. The trade association of the Grand Canyon River Concessionaires, the Grand Canyon River Outfitters Association (GCROA), has made a commitment to research alternatives to this motor. The project they have created to accomplish this task is the Grand Canyon Alternative Motor Project (GCAMP). Currently there are over 400 trips each summer season using the motorized S-rig, emphasizing the need for an alternative.

2.2 - Problem Statement

An alternative motor must provide the required power to safely propel the raft through the dangerous whitewater of the Grand Canyon. The top priority in this system must be overall safety to the guide driving the raft and the passengers aboard, as well as the canyon as a whole. The system must perform with reduced audible interference and should reduce or eliminate emission of greenhouse gases. Design constraints have been placed on the replacement drive system. The system must fit on an existing S-rig, and not weigh more than the raft can safely handle. The drive system must be able to be switched -out for a replacement while on the river if damaged. The rafts have an intrinsic historical value and they should not be redesigned; only the propulsion system may be modified.

2.3 - Design Team

2008 – 2009 GCAMP Design Team

Top Row (from left): Clint Holtey, Mike Coil, Dan Alexander, Sean Wilson, Tyler Jones
Bottom Row (from left): Mitch Underwood, Justin Tidwell, Kent Udell, Dan Adams, Chris Parks, Colby Radmall

2.3.1 Team Composition

Chris Parks – Team Captain / Motor Mounting
chris.parks@utah.edu

Chris brings leadership to the entire team and is part of the motor design team, with a focus on motor mounting, adapters, and machining. Chirs brings many years of valuable experience as a Grand Canyon river guide to the team.

Clint Holtey – Motor Control System
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Clint is part of the motor design team and is leading the efforts in creating a control scheme for the motor / throttle combination. Clint brings his valuable professional experience and thorough knowledge of controls to the team.

Colby Radmall – Power and Efficiency Analysis
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Colby is part of the turbine design team and is focusing on turbine efficiency and energy analysis. Colby brings valuable manufacturing abilities and programming skills gained through professional experience.

Dan Alexander – Manufacturing Specialist / Design
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Dan is part of the turbine design team and is leading the efforts in manufacturing and design of the parts. Dan brings valuable skills in various types of prototyping and rapid machining processes, as well as component design.

Mike Coil – Battery Systems
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Mike is part of the motor design team and is working on design of the battery adaption and charging system. Mike brings valuable professional experience as a project manager to the team.

Mitch Underwood – Turbine CFD and Flow Analysis
mitch.underwood@utah.edu

Mitch is part of the turbine design team and is focusing on computer simulation and flow analysis of the wing design. Mitch has experience with various CFD programs and also brings professional CAD experience to the team.

Tyler Jones – Turbine Team Leader / Design Architecture
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Tyler is the leader of the turbine design team and working on the overall design and assembly of the product. Tyler brings his leadership skills to the team as well as a strong knowledge of renewable energy technology.

Sean Wilson – Motor Team Leader / Cooling and Integration
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Sean is the leader of the motor team and is focusing on the cooling system and overall integration of the motor. Sean brings his strong leadership abilities to the motor group as well as professional design experience.

Justin Tidwell – Turbine Housing / Deployment
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Justin is part of the turbine design team and is focusing his efforts on housing and deployment of the turbine. Justin brings strong professionally developed abilities in CAD design and optimization.

Dr. Dan Adams
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Faculty Advisor

Dr. Kent Udell
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Professor and Department Chair
Faculty Advisor

2.3.2 Team Circumstances

The GCAMP Project is a complex undertaking that requires skills and knowledge in all aspects of engineering, from structural design to flow analysis, as well as leadership and project management abilities. Complete redesign of a long-established motor system requires the team to successfully mesh all of their various skills and abilities into a successfully functioning group. Each member of the University of Utah GCAMP team brings their own motivation and experience together to accomplish the task at hand.

The team is comprised of nine talented and experienced members, including a long-time Grand Canyon commercial river rafting guide. The various skills of everyone involved present the team with a strong foundation in engineering disciplines as well as the practical experience gained professionally. They all share a passion for renewable energy along with their two University advisors, who bring a vast amount of knowledge and experience to the team.

2.4 - Acknowledgments

Thanks are due to many who contributed time, effort and financial resources to the Grand Canyon Alternative Motor Project (GCAMP). First and foremost the team would like to thank the Grand Canyon River Outfitters Association (GCROA) for providing the opportunity, components, and funding for the project. As for the many others that have contributed, we would like to thank, in no particular order: David and Vicki Mackay, Brian Merrill, CCI, CGI, Lynch Motor Company, Sally Wasatch, Allright, Diamond Tools, WOI, Diamond Mold, Tom Slowik and Mike Knutson from the U of U machine shops, our adviors Dr. Kent Udell, Dr. Dan Adams, also our Professors over the course of the year Dr. William Provancher and Dr. Eberhard Bamberg and to the dedication of the team of students that participated in this project. If it was not for the efforts of these companies and people we would not have accomplished as much this year as we did, so again thanks to those who made this project a complete success.

3 - Design Requirements

3.1 - Summary

The Grand Canyon River Outfitters Association (GCROA) desires to replace their 4-cylinder gasoline powered outboard boat motors with an alternative motor that will decrease the noise pollution, air pollution and environmental hazards related to the gas motors and associated oils and fuels. The Alternative Motor System (AMS) shall be limited in size to the equivalent cargo volume currently occupied by the current engines and gas tanks. It shall be reliable and safe and must provide a minimum equivalent performance of the existing gas motors currently in use. The cost of the AMS including all maintenance and operating costs shall not exceed the current purchase, maintenance and operation cost of the gas motors. These design requirements have been defined by the GCROA, design team, and team advisors. The customer needs for the motor and generation areas are listed in Tables 1 and 2 below.

Table 1 - Motor Customer Needs

Metric Number	Need Description	Importance
1	Motor is Quiet	5
2	Emissions	4
3	Motor Power	5
4	Motor Torque	5
5	Motor and Battery Safety	5
6	Change Out	5
7	Reliability	4
8	Weight	5
9	Size	5
10	Battery Weight	4
11	Steering Control	4
12	Throttle Control	3
13	Operator Fatigue	3
14	Waterproof	5

Table 2 - Generation Customer Requirements

Metric Number	Need Description	Importance
1	Generate Enough Power	5
2	Robust	4
3	Minimal Maintenance	3
4	Safe	5
5	Easy to Deploy and Store	3
6	Minimal Setup/Takedown Time	3
7	Size Constraint	3
8	Total Weight	4

3.2 - Safety

With the exception of the underwater propulsion system and the steering/ throttling actions, the alternative motor shall not have any exposed moving parts that may be harmful. The electrical system and batteries will be designed in such a fashion as to not harm the occupants in the event of a failure.

3.2.1 - Line voltage wiring and connections are shielded and/or insulated

Isolation and fusing is required for all line-voltage wiring. Except where wiring runs from one system to the next, electrical systems shall be contained in a mechanically closed weatherproof housing. Emergency cutoff switches shall be installed in all line-voltage electrical systems.

3.2.2 - All exposed sharp edges are covered or rounded

Sharp or pointed edges should be rounded off and all wiring and controls shall be isolated and weatherproofed.

3.2.3 - The AMS is mechanically fastened to the raft

The system shall be reinforced to withstand the impacts and movements associated with whitewater rafting. The seating area surrounding the guides and customers shall be maintained clear and all systems associated with the alternative motor system shall be mechanically fastened to the raft or frame in such a way that it will not shift, break free from, or release unintentionally.

3.3 - Environmental Impact

The operation of commercial rafts in a national park requires that the impact to the park environment be reduced as much as possible to preserve the natural resources of the Grand Canyon.

3.3.1 - Noise Pollution

The alternative motor is limited in decibels to 65 or less, a reasonable range that does not interfere with communications aboard the raft while running at average throttle and will not cause hearing loss or discomfort to the average person when exposed to 6 continuous hours of the same throttle operation.

3.3.2 - Air Pollution

The alternative motor shall have low to zero emissions.

3.3.3 - Environmental Hazards

It is extremely important to the GCROA and the Parks and Recreation Department that hazardous materials are not introduced into the environment throughout the Grand Canyon.

3.3.3.1 - Hazardous materials

The alternative motor design will eliminate the use of oil, fuel, lubricants and coolant wherever possible.

3.3.3.2 - Hazardous material containment

In the event that one or more of these materials must be used, the material shall be isolated within the motor system to eliminate any transfer of the material to the canyon environment.

3.3.3.3 - Hazardous material information

For each of these hazardous materials used, the volume used and product material and data sheets (MSDS) shall be supplied. Application-specific containment and cleanup instructions shall be included with the MSDS documentation.

3.4 - Performance

The nature of white water rafting requires power and maneuverability on demand over long periods of time to avoid obstacles found in the river.

3.4.1 - Hours of continuous use

The alternative motor also must be able to run uninterrupted for 8 hours at average throttle with no loss of performance.

3.4.2 - Power output

The alternative motor power output must not be less than the output of the 30 horsepower gas motors currently in use.

3.4.3 - Variable speed

The motor shall be able to run at variable speeds including 1/2 to 3/4 throttle for flat-water cruising and full throttle for evasive maneuvering during whitewater sections of the expedition.

3.4.4 - Steering

In addition to propelling the boat forward, the alternative motor design must provide a means of steering the boat.

3.5 - Cost and Life Cycle

In order for the alternative motor system to be viable the cost must not be too far above the current cost. The purchase cost of the AMS shall not exceed $25,000, and the maintenance and operation costs shall not exceed $500 per boat per year over a 10 year lifespan.

3.5.1 - Maintenance

Maintenance on the river shall be quick and easy with minimal tools required.

3.5.2 - Reliability

The alternative motor shall be able to withstand mild impacts from rocks and the riverbed with little or no damage.

3.5.3 - Longevity

The average lifespan of the alternative motor system for mechanical or design failure shall not be less than 10 years.

3.6 - Compatibility

There are several variations of rafts used commercially to float the Colorado River through the Grand and Glenn Canyons. Similar raft styles may also have different frames and equipment placement within them. The alternative motor system shall be compatible with each of these raft & frame configurations with no modifications to the rafts or frames.

3.6.1 - Size Restrictions

In order to accommodate the passengers and the supplies needed for the trip the size of the alternative motor system must be restricted.

3.6.1.1 - Spare motor

Each boat carries a minimum of two motors per trip; one primary operating motor and one spare replacement motor secured in the cargo area must fit on the raft.

3.6.1.2 - System size

The complete alternative motor system is limited to fit within the same volume as the current motors and fuel tanks.

3.6.2 - Weight restrictions

As the weight of a raft increases, its maneuverability decreases. The energy required to maneuver a raft will also increase with weight. Because maneuverability is important in whitewater rafting there is a restriction on the weight of the alternative motor system.

3.6.2.1 - Individual motor weight

The weight of each alternative motor cannot exceed 180 lbs.

3.6.2.2 - Total system weight

The total weight of the system cannot exceed 1500 lbs. The entire system must be mechanically fastened to the raft or frame and removable for storage during the off-season months.

3.7 - Aesthetic Appearance

The attraction of an expedition to rafters is directly tied to the aesthetic appeal of the Grand Canyon and the rafts used to travel through it. Outfitter advertising is centered on the appearance of the rafts and the excitement of floating the Colorado River.

3.7.1 - Visual appearance

The alternative motor system shall not detract from the visual appeal of the rafts.

3.7.2 - Surface finish

Special attention to the surface finish of all components shall ensure that the design will have a professional appearance. The design will be free from any potential hazards, making it safe for the occupants.

3.7.2.1 - Joints

Excess caulking, lubricants and sealers shall be cleaned from the exposed finish surfaces.

3.7.2.2 - Exterior

The finish surface of all mounts, covers and containers shall be clean and free from sharp edges, overspray, slag, and extraneous parts.

3.7.3 - Cables and wiring

All cables and tubes not concealed from view shall terminate with clean, isolated plug-type connections. Excess wiring or tubing shall be cut and removed or where needed for multi-frame compatibility, secured in an orderly fashion.

4 - Design Specifications

4.1 - Summary

The design specifications for the 2008-2009 Grand Canyon Alternative Motor Project are focused on the initial design for the start-up project. The design specifications are a direct result from the customer need to replace the current gas engine outboard platform of boats used to navigate down the Grand Canyon. The new outboard platform will have two sub-systems for specification: motor and generation. These sub-systems are broken down into detailed specifications to fit the customer needs. Table 3 illustrates the motor sub-system design specifications metrics, and Table 4 provides design specification metrics for the generation sub-system.

Table 3 - Design Specifications for the Motor Sub-System

Metric Number	Customer Need	Need Description	Importance	Marginal Requirement	Ideal Requirement	Engineering Units
1	3	Motor is quiet	5	>70	70	dB
2	15,16	Emissions	4	0	0	ppm
3	4,5	Motor Power	5	18	22	kW
4	4,5	Motor Torque	5	20	TBD	N-m
5	1,2,12,17	Motor & Battery Safety	5	Safe	Safe	Binary
6	10	Change Out	5	120-180	30	s
7	13,19,20	Reliability	4	40	>40	trips
8	7,9,11	Weight	5	~175	100	lbs
9	7,18	Size	5	5	5	ft
10	11	Battery weight	4	1500	n/a	lbs
11	6,23	Steering Control	4	-	-	-
12	22	Throttle Control	3	-	-	-
13	22,23	Operator Fatigue	3	-	-	-
14	8	Waterproof	5	Waterproof	Waterproof	Binary

Table 4 - Design Specification for the Generation Sub-System

Metric Number	Customer Need	Need Description	Importance	Marginal Requirement	Ideal Requirement	Engineerin Units
1	4	Generate enough power	5	>5.0	9.9	kW
2	13,19	Robust	4	-	n/a	-
3	20	Minimal maintenance	3	>.5	1	years
4	1,2,12	Safe	5	safe	Safer	binary
5	21,24	Easy to deploy & Store	3	180	120	lbs
6	14,24	Minimal setup & storage time	3	40	20	min
7	18	Size restraint	3	30	20	Ft^2
8	11	Generation weight	4	>100	100	lbs

4.2 - Motor Specifications

4.2.1 - Motor is quiet

The electric motor decibel level must be lower than the current 30 HP four-stroke engine decibel level. The current decibel (dB) level of the gasoline engine is 97 dB and the target level is 60-70 dB. This is needed because the biggest complaint by customers is the engine noise caused by the 30 HP four-stroke internal combustion engine. Minimizing this noise will allow the customers to better enjoy the pristine setting of the Grand Canyon.

4.2.2 - Emissions

The replacement of the gasoline engine with an electric motor will eliminate the emissions. Charging the batteries with an inflow river based charging system will eliminate any fossil fuel emissions and noise from a conventional gas-powered generator.

4.2.3 - Motor Power

The gasoline powered engine has been proven to operate well in the Grand Canyon environment. For this reason, it is important to match the electric motor to the performance of the gasoline engine. The only way to compare a gas engine to an electric motor is by a common unit of power in kilowatts (kW). The 30 hp gas engine is approximately 22 kW, and the electric motor is rated at nominal 12.5 kW with a maximum of 25.4 kW. This range effectively covers the operating characteristic of the current internal combustion engines.

4.2.4 - Motor Torque

An electric motor provides more torque per RPM than a gasoline engine. This is a crucial detail in matching the electric motor to the performance of the gasoline engine. Torque will play a big role in matching the outboard platform as it is now to the new electric motor platform.

4.2.5 - Change Out

The extreme environment in which this system will be applied can inflict damage to the lower end of the outboard platform. The current outboard platform can be changed out in approximately 180 seconds. Minimizing the weight of the platform will provide an opportunity to change out the platform in roughly the same amount of time.

4.2.6 - Reliability

Each motor will be run on approximately 40 trips down the canyon each year and the target is to exceed this current demand. The reduction of complex mechanical systems from the gas engine to the simple electric motor will greatly increase the reliability of the entire platform.

4.2.7 - Weight

Currently the weight of the gasoline powered outboard platform is close to 180 lbs. and the target weight for the new platform will be approximately 100 lbs. The reduction in weight will allow the motor to be easily moved by a single person. This will reduce injuries to river guides from improper lifting of the heavier gasoline powered outboard platform.

4.2.8 - Size

The size of the platform should not exceed the size that has been set aside for the current platform. By constraining the design to the 5 ft^3 already allotted to the platform no modification will be needed to incorporate the new platform. The complete system has gone through a long history of trial and error which has led to the current design that is used in the canyon today and as such the new motor should not occupy more than the current system space.

4.2.9 - Battery weight

Interchanging the gasoline platform with the electric platform will utilize the designated space for the fuel tank to be replaced with batteries. This will be a significant issue considering the energy density of the batteries is less than the energy density of the gasoline. The estimate for the weight of the batteries is 1500 lbs., and they will be replacing approximately 500 lbs. of fuel which decreases as the boat progresses down the canyon. The weight of the batteries will remain constant for the trip.

4.2.10 - Steering Control

The electric motor will be adapted to the existing lower half of the outboard platform to use the current steering control system. The steering will not be changed at all, which will provide a smooth transition for the operator from the gasoline powered motor to the electric motor.

4.2.11 - Throttle Control

The throttle control will be modeled from the current control. However, the cable that attaches to the gas engine throttle will be attached to an electric potentiometer that will control the voltage to the motor to control the speed. This allows the usage of the existing throttle control mechanism on the gasoline powered outboard platform.

4.2.12 - Operator Fatigue

By using the existing steering and throttle controls the possibility of introducing new sources of operator fatigue will be removed. The reduction in noise will also reduce the possibility of damaging the river guides’ hearing.

4.2.13 Waterproof

Since the new system is electric, a waterproof system is even more essential than with the gas motor. High voltage and water are a major safety issue that has to be addressed. A watertight design will also lead to a minimization to the interfaces with the battery pack and other power transmission lines that go to the motor and from the generation system.

4.3 - Generator Specifications

4.3.1 - Generate Needed Power

The generator must supply enough power to operate the electric motor at its required specifications throughout the entire trip. The ideal requirement would be 9.9 kW for 10 hours of use, or 99 kWh of energy per day. The marginal value would be approximately half this energy, 49.5 kWh.

4.3.2 - Be Robust

Due to debris within the river flow, the river turbine must be robust enough to withstand such collisions. The blade material must be strong enough to resist impacts from small rocks and flotsam. The turbine structure must also be reliable within a large fatigue life to resist fatigue failure.

4.3.3 - Minimal Maintenance

Considering that a motorized river trip lasts up to 10 days, it is necessary that any emergency maintenance that must be performed on the river be accomplished using the given tools on-board the boat. This means that any fasteners must be in common SAE and metric units. It is ideal that required maintenance be performed only once a year and marginally every 6 months.

4.3.4 - Safe

Safety is always a concern; therefore, the generator must be safe for passengers and river guides. To ensure safety, line-voltage wiring and connections will be shielded and/or insulated. All exposed sharp edges will be covered or rounded off to prevent injury to any person and to the boat.

4.3.5 - Easy to Deploy & Store

The turbine weight, due to deployment and storage considerations, shall not exceed 180 lbs, with an ideal requirement of 120 lbs. Currently, river guides are required to be able to lift a maximum of 180 lbs. Limiting the deployment and storage weight will help ensure that a river guide will avoid injuries.

4.3.6 - Minimal Setup Time

Due to time restraints that river guides have to properly manage the river trip for the customers, the set-up or storage time must be kept to a minimum. The maximum allowable set-up or storage time is 40 minutes and ideally would be 20 minutes.

4.3.7 - Fits within Size Constraint

The space that the generator occupies should be kept to a minimum. The customer allows for up to 30 ft^2 of deck space on the boat for the generator. This value comes from the space presently occupied by the gasoline tank. It would be advantageous to limit the residing space to 20 ft^2 or less. The height of the generator is currently not restricted as long as it is deemed reasonable by the GCROA.

4.3.8 - Total Weight

Along with a size constraint, there is also a weight constraint. The turbine needs to be light enough to maneuver, deploy, and store safely. Ideally, a weight of 100 lbs or less would allow for a river guide to easily maneuver, deploy, and store the turbine. However, a maximum value of 180 lbs would be acceptable.

5 - Design Development

5.1 - Summary

The customer needs as defined by the GCROA were general in nature, consisting of noise reduction, moderate cost, low to zero emissions and minimal deviation from the current control system. Noise reduction was the primary customer need of the alternative motor system. In a team brainstorm session early in the design process, many options were proposed on how to power the boat down the canyon. At each milestone in the design process, further brainstorming sessions and selection matrices were used in the decision process. Some of the discussed options for the alternative motor system were: to use different fuels; adapt the outboard to an electric motor; a complete redesign of the propulsion using a paddle wheel; and the use of various hybrid systems.

With the application of this alternate motor system, it was also desirable to examine the natural energy sources that could be harnessed to provide energy to recharge this motor system. The unique environment of the Colorado River in the Grand Canyon offers many possibilities for energy generation. A number of energy sources were evaluated during brainstorming, including: extracting kinetic energy from the flow of the river, using solar power arrays, using thermopiles and the large temperature difference between the river water and ambient air, and using hydrogen fuel cells.

5.2 - Motor and Battery System Selection

5.2.1 - Motor Selection

The team met together and decided an electric motor system would best meet the customers' needs. To choose the right electrical motor, the team had to benchmark the current technology and adapt it to the project requirements. Various motor characteristics were determined and used in a decision matrix to assist in selecting a motor (see Figure 2, Section 7.2). Some of the primary characteristics taken into consideration were: the motor peak and continuous power output, the cost of the motor, the availability, the geometric size of the motor, and whether the motor runs on AC or DC power. The team determined the LEM 200 series, brushed, DC permanent magnet motor was the optimum motor.

To match the prop speed at full throttle with the most efficient speed of the electric motor, it was necessary to design and construct a transmission pulley system. The driveshaft from the lower unit was extended to a pulley system with a ratio of 1.61:1. A high-speed bearing assembly and adaptor plate provides a motor mount and reinforces the extended drive shaft.

5.2.2 - Power Storage

The decision to use an adapted electric outboard motor governed the need for an electric power source. The team calculated the amount of energy needed to run the motor for 8-hours to be approximately 46 kW-hrs. Hydrogen fuel cells, batteries and super-capacitors were researched. After evaluating the cost, weight, availability, and energy storage capacity of these systems, batteries were selected as the energy storage medium. A decision matrix was formulated for optimal battery selection and the lithium polymer battery was found to meet the project needs (see Figure 3, Section 7.2).

5.2.3 - Speed Control

The GCROA required similar performance between the alternative motor system and the current 4-stroke motors. Using the lower unit of the existing motor minimizes adaptation costs, maintains compatibility and familiarity between the motor and the user, and is consistent with existing steering control. However, speed control for the electric motor system required a motor controller and battery management system. The ALL-TRAX 7245 is a pulse-width modulating electric motor controller that receives user input from a potentiometer to vary the motor speed. A 0-5k ohm potentiometer was retrofitted to the existing lower unit throttle mechanism.

5.3 - Generation System Selection

5.3.1 - Energy Extraction Method

Using the kinetic energy from the river proved to be the most compact and practical solution. This method does not interfere with normal operations of the boats during the day and does not contain many of the technically complex shortcomings of other options.

Options for river flow generation include: axial turbines, vertical axis turbines, paddlewheels, and Archimedean screws.

5.3.2 - Benchmarking of Current Technology

Through a benchmarking analysis, the options of using existing technologies for extracting the kinetic energy from the river were evaluated. There are a significant amount of low-head and marine hydro systems currently in production. However, many of these systems were designed for larger power generation systems than needed typically over 15kW and were physically too large to fit on the boat. During the benchmarking process it was found that a vertical axis turbine offered significant efficiency advantages that would be needed to minimize the physical size of the turbine. The currently developed vertical axis design has been deployed in testing situations, but not in a commercial power generation scheme, which did not allow a benchmark for this type of turbine.

5.3.3 - Turbine Type Selection

The selection of a vertical axis turbine over other designs was based on many of the positive qualities of this turbine. Due to the turbulent nature of the river, flow in only one direction cannot be guaranteed. A vertical axis turbine is unaffected by changes in planar flow direction, whereas a typical horizontal axis turbine may lose all generating capacity in this situation. The vertical axis turbine has a lower blade speed and higher efficiency than horizontally-oriented turbines. The advantage of the lower blade speed is that it is more environmentally friendly to the local aquatic life within the river. The orientation of the vertical axis of rotation also allows for generators and other related equipment to be easily placed above water, reducing the complexity of waterproofing needed in other designs.

5.3.4 - Design Refinement

As the power requirements are determined from battery charging loads, the generator sizing as well as its torque and speed inputs will be drivers for the sizing of the turbine. Current spar and rib construction of steel and aluminum will be replaced by a lighter construction method employing a carbon fiber reinforced polymer skin on a foam mold. This will reduce the weight of the turbine blades while maintaining their rigidity, strength and impact resistance.

5.4 - Review Final Design

There were many vital decisions early in the design process that affected the overall system. These early decisions generated secondary and tertiary design requirements. Brainstorming sessions and specific selection matrices addressed the design requirements as they arose. The final alternative motor system consists of an electric motor adapted to the existing outboard chassis and lower unit. Lithium-Polymer batteries with a modulating controller and throttle successfully power and control the system. Field test validation of the completed electric outboard motor will be complete by mid-April 2009. Using similar methodologies, the generation sub-team was able to examine current technology and explore new alternatives to generating power in the Grand Canyon. The final design that was chosen will be a Gorlov helical vertical axis type turbine. The helical sweep of the blades has advantages over the vertical blades of the Darius design. The helical nature of the Gorlov turbine allows for a portion of the blades to always be at an optimal angle of attack, which eliminates the torque pulses that are found in the Darius style turbine designs. The Gorlov turbine design needs no external torque to start the rotation, unlike a Darius, and it is approximately 15% more efficient than a Darius design.

6 - Final Design

6.1 - Bill of Materials

6.1.1 - Motor System Bill of Materials

Table 5 - Motor System Materials

Item	Material	Quantity
Parts		
Electric Motor	LEM-200	1
Spline Adapter	Hardened Steel	2
Battery Cables	4/0 cable	25'
Cable Connectors	Brass	2
Strain Reliefs (IP68)	Plastic	3
Bolts	M8X1.25	18
Bolts	M6X1.00	5
Timing Pulleys	Steel	2
Belt	Rubber/Kevlar	1
Shaft Clamps	Steel	2
Hole Sealant	Carbon Fiber	3'
Metals		
Aluminum		
Adapter Plate	.875 Plate	12” x 12”
Risers and Bearing carriers	1.0 Plate	14” x 12”
Seal Plate	.125 Plate	12” x 14”
Spacer	.020 Sheet	6” x 6”
Motor Mount	1.5” Plate	14” x 12”
Steel		
Spacer	.25” Plate	6” x 6”
Drive Shaft	.75” bar	12”

6.1.2 - Battery System Bill of Materials

Table 6 - Battery System Materials

Item	Quantity
High current water proof plugs (black)	2
High current water proof plugs (red)	2
water proof plug receptacles (red)	2
water proof plug receptacles (black)	2
Motor Controller	1
Battery Management System	1
Lithium Polymer Batteries	24
2/0 350 Amp welding cable	2
2 conductor signal cable	25
2/0 cable termination lugs	4
sundry wiring supplies	1
single pole; single throw; normally open 400 amp contactor	1
0-50 Kohm potentiometer for throttle	1
Sundry Aluminum and Steel	1
Battery Charger	1
high speed bearings	2
Timing belt	1
Timing Pulley (large)	1
Timing Pulley (small)	1

6.1.3 - Generation System Bill of Materials

Table 7 - Generation System Materials

Item	Material	Quantity
Fasteners	Various	66
Blades	12K Uni-directional Carbon Fiber/Epoxy	6
Hub Arms	6061-T6 Aluminum	9
Shaft Collar	6061-T6 Aluminum	3
Hub Plate	6061-T6 Aluminum	6
Shaft	1018 Mild Steel	1
Sliding Contact Bearing	Various	2
Thrust Bearing	Various	1
Generator	Wind Blue Alternator	1

6.2 - Solid Models

6.2.1 - Motor System Solid Model

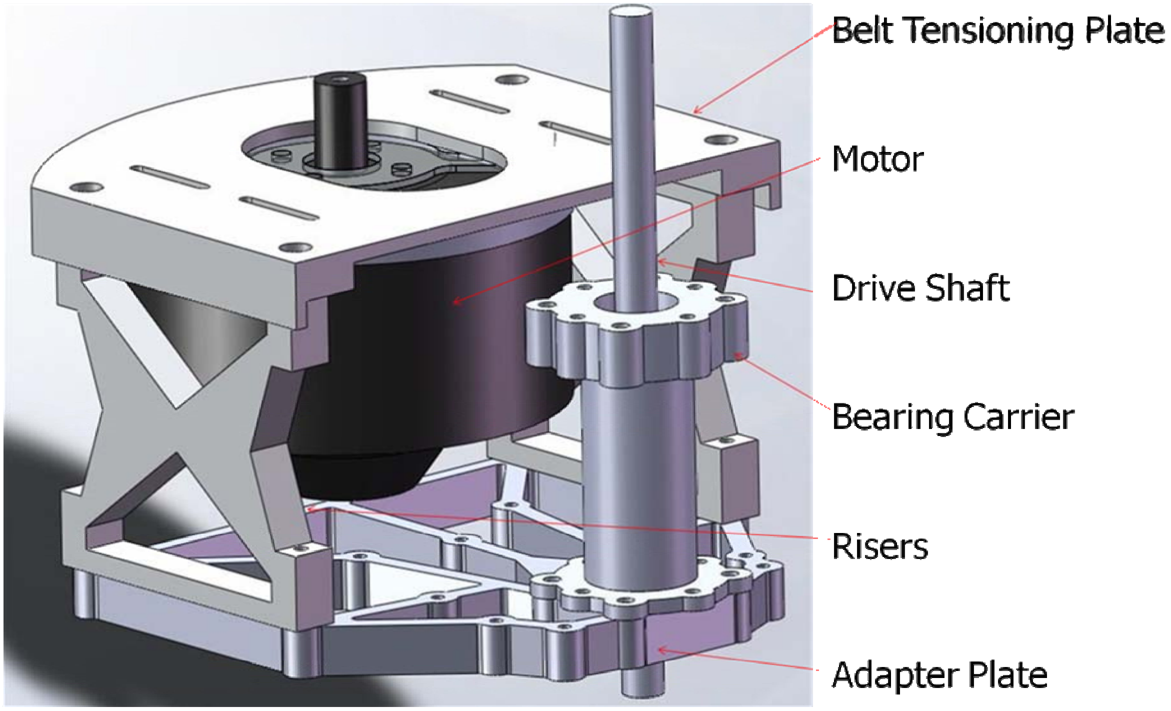


Figure 1 - Motor System Assembly

6.2.2. - Generation System Solid Models

Figure 2 - Turbine System Assembly

6.3 - Detail Pictures

6.3.1 - Motor System Detail Pictures

Figure 3 - Motor System Enclosed in Cowling

Figure 4 - Motor with Bearing Carrier and Adapter Plates

Figure 5 - Throttle Linkage to Actuate Motor Controller Potentiometer

6.3.2 - Generation System Detail Pictures

Figure 6 - Gorlov Turbine Assembly with Generator

Figure 7 - Helical Blade Section Coupling

Figure 8 - Blade Hubs and Support Arms

6.3.3 - Battery System Detail Pictures

Figure 9 - Battery Box

Figure 10 - Batteries and Controller Wired Inside Box

Figure 11 - Battery Management System LED Touch Screen

7 - Testing Data

7.1 - Motor Team Testing Methods/Data

The dynamometer was determined to be a non-useful test since the horsepower of both motors could not be accurately determined. The dynamometer for boat motors is based on creating a pressure being built up by the propeller which will act as the load to determine the horsepower. According to specifications of the dynamometer it needs 100 hp or more to build the right pressure to get an accurate value for power.

Another testing method considered was to use strain gages mounted to an aluminum block on the lower half of the outboard to determine the force from the propeller due to the strain on the lower half of the engine. This testing option seemed viable, but the method itself was untested and a study would be needed to validate the test. Since the dynamometer was not a valid solution there was no way to validate the data from the strain gages, and because of this complication the strain gage testing method was abandoned due to deadlines. This test method could be confirmed as project for teams after this year.

The final method for testing the motor is to implement the motor in the actual environment it will be used in and this is the test that was completed because of the above mentioned tests being inadequate. The validation of this test is by the expert judgment of a river guide that has being running the river for over fifteen years. The quantification of the test was to load a boat similar to a day trip on the Colorado River and then with that boat go down a river with the system in place.

The test proved to be very successful in the results obtained for motor draw from the batteries. The quantification from the test was the voltage drop during the four hour run of the motor over a twelve mile stretch of the Green River in Southern Utah. The voltage drop over the four hour trip was 5 Volts with an estimated maximum usage of 26 Volts. This usage was approximately 20% of what was calculated from the gasoline used in the current system. The variation of the actual usage compared to the calculated values is most likely due to how each motor operates. Accessing the power of the gasoline motor means the motor has to be running the entire time, in comparison to the electric motor in which to access the power all that needs to be done is turn on the motor. Since the calculations of total power needed to traverse the canyon based on the power density of gasoline and then converted to kilowatt-hr would be high since a large amount of the energy was employed to provide availability to the power. Using less of the batteries than anticipated will loosen the requirements for generation and possibly reduce the size of the turbine and the size of the battery pack. Further testing will be needed to optimize the system and determine the proper size of the system.

7.2 - Generation Team Testing Methods/Data

Tests on the Darius prototype were performed by attaching the turbine to a small cataraft shown in Figure 1 below. Two steel rectangular tubing pieces were attached to the uprights of the turbine housing with four u-bolts. The assembly was then lowered into the water in the middle of the cataraft between the two pontoons. A 5 hp motor then propelled the turbine assembly through the water at varying motor speed. To measure the flow velocity for different river speeds, a flow probe was placed in the water as the cataraft moved at different velocities. A laser tachometer, shown in Figure 2 below, was used along with the flow probe to measure the different turbine RPM at varying flow speed. A 2.2 kW DC permanent magnet motor was fixed to the shaft and electrical power was produced through a power resistor with the intention to measure torque. Figure 3 shows the motor used as a generator, the 3.1 ohm power resistor as a load, and the digital multi-meter to measure voltage at different turbine RPM. The recorded voltage values were not very useful in determining potential energy but the turbine RPM data was taken and shown in Figure 4. Turbine RPM increased with flow speed and maxed out at 90 RPM. This data can be used to compare with other turbine designs like the final Gorlov design. Testing will be done on the Gorlov turbine during the team's Grand Canyon trip in mid-May.

Figure 12 - Small boat test platform at Utah Lake

Figure 13 - Tachometer measurement

Figure 14 - 3.1 ohm Power resistor circuit

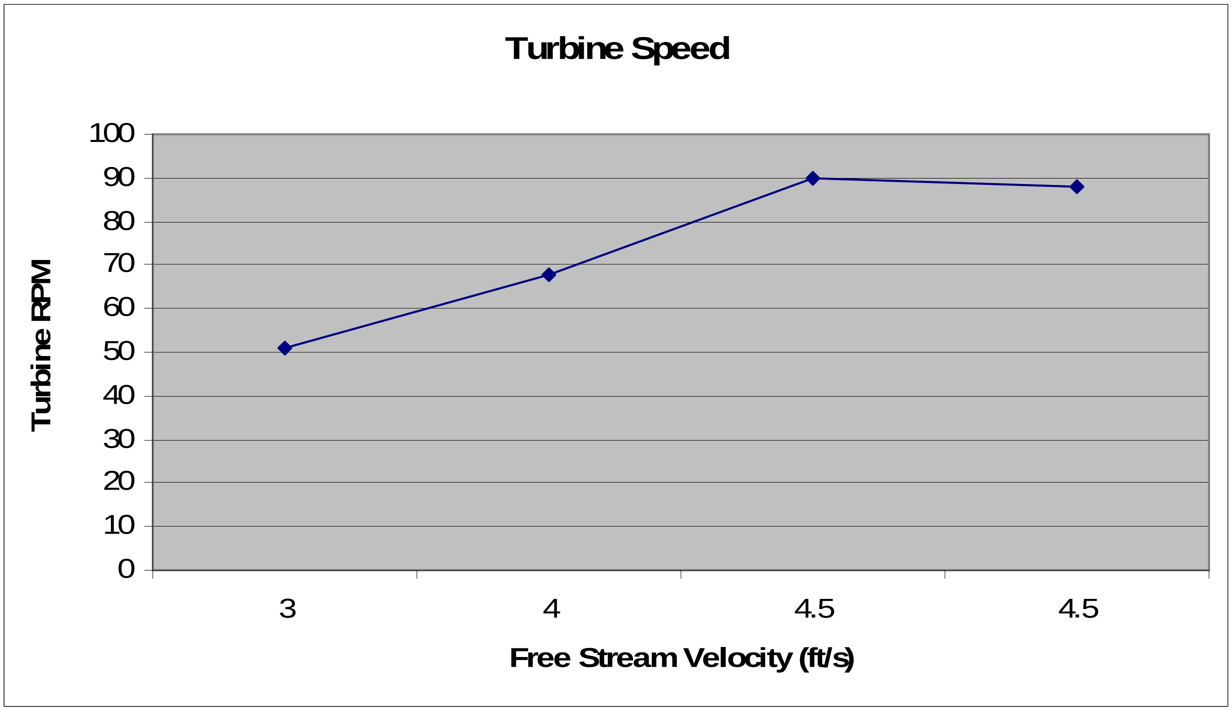
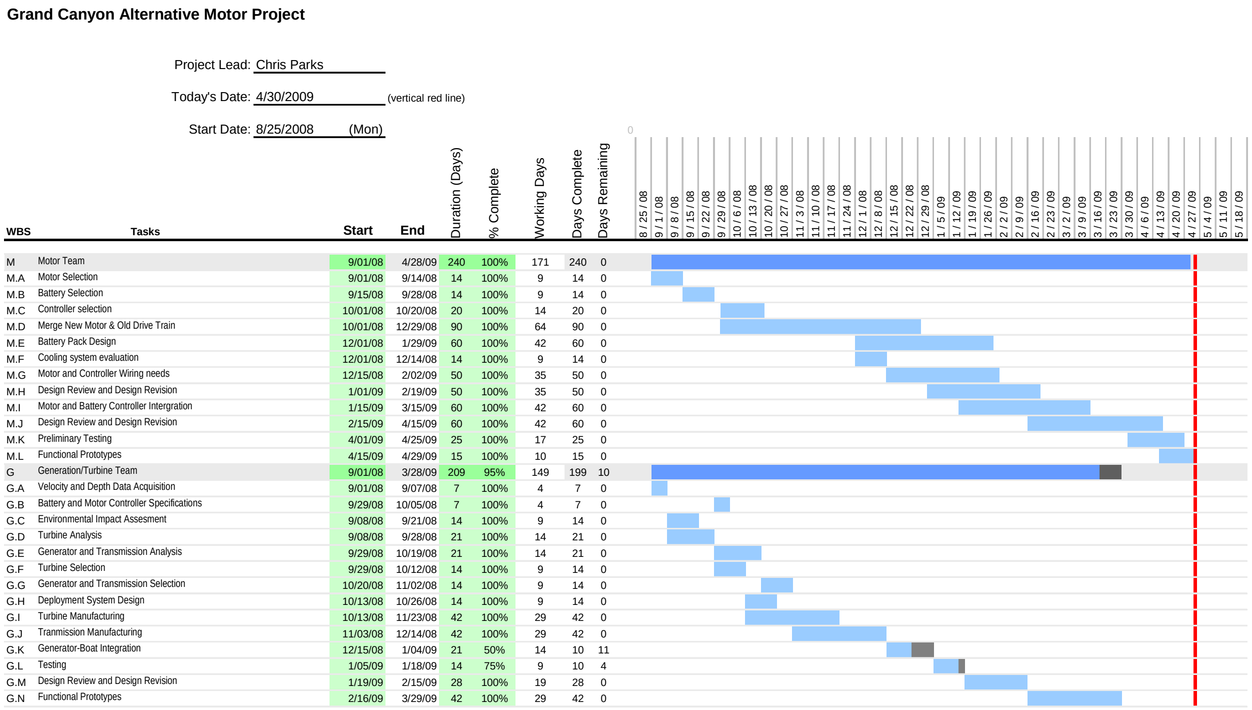


Figure 15 - Turbine RPM vs. Flow Speed

8 - Project Planning

8.1 - Project Timeline

A Gantt chart was used throughout the project development to ensure proper and timely completion of all the required tasks. As with the team, it was separated into two sections, for more for the motor and power storage sub-team, and one for the generation sub-team. The chart is shown below in Figure 1:



Grand Canyon Alternative Motor Project

Project Lead: Chris Parks
Today's Date: 4/30/2009 (vertical red line)
Start Date: 8/25/2008 (Mon)

WBS	Tasks	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
M	Motor Team	9/01/08	4/28/09	240	100%	171	240	0
M.A	Motor Selection	9/01/08	9/14/08	14	100%	9	14	0
M.B	Battery Selection	9/15/08	9/28/08	14	100%	9	14	0
M.C	Controller selection	10/01/08	10/20/08	20	100%	14	20	0
M.D	Merge New Motor & Old Drive Train	10/01/08	12/29/08	90	100%	64	90	0
M.E	Battery Pack Design	12/01/08	1/29/09	60	100%	42	60	0
M.F	Cooling system evaluation	12/01/08	12/14/08	14	100%	9	14	0
M.G	Motor and Controller Wiring needs	12/15/08	2/02/09	50	100%	35	50	0
M.H	Design Review and Design Revision	1/01/09	2/19/09	50	100%	35	50	0
M.I	Motor and Battery Controller Intergration	1/15/09	3/15/09	60	100%	42	60	0
M.J	Design Review and Design Revision	2/15/09	4/15/09	60	100%	42	60	0
M.K	Preliminary Testing	4/01/09	4/25/09	25	100%	17	25	0
M.L	Functional Prototypes	4/15/09	4/29/09	15	100%	10	15	0
G	Generation/Turbine Team	9/01/08	3/28/09	209	95%	149	199	10
G.A	Velocity and Depth Data Acquisition	9/01/08	9/07/08	7	100%	4	7	0
G.B	Battery and Motor Controller Specifications	9/29/08	10/05/08	7	100%	4	7	0
G.C	Environmental Impact Assesment	9/08/08	9/21/08	14	100%	9	14	0
G.D	Turbine Analysis	9/08/08	9/28/08	21	100%	14	21	0
G.E	Generator and Transmission Analysis	9/29/08	10/19/08	21	100%	14	21	0
G.F	Turbine Selection	9/29/08	10/12/08	14	100%	9	14	0
G.G	Generator and Transmission Selection	10/20/08	11/02/08	14	100%	9	14	0
G.H	Deployment System Design	10/13/08	10/26/08	14	100%	9	14	0
G.I	Turbine Manufacturing	10/13/08	11/23/08	42	100%	29	42	0
G.J	Tranmission Manufacturing	11/03/08	12/14/08	42	100%	29	42	0
G.K	Generator-Boat Integration	12/15/08	1/04/09	21	50%	14	10	11
G.L	Testing	1/05/09	1/18/09	14	75%	9	10	4
G.M	Design Review and Design Revision	1/19/09	2/15/09	28	100%	19	28	0
G.N	Functional Prototypes	2/16/09	3/29/09	42	100%	29	42	0

Figure 16 - GCAMP Gantt Chart

8.2 - Design Selection Matrices

As discussed in Section 5.2.1, selection matrices were used by the motor and power storage sub-team to determine the best motor and battery choice for the project application. These are presented in Figures 2 and 3, below.

DC Motors

							Power rating - kW					
Vender Contact	Manufacturer	Part Number	Nominal Voltage	nominal amp draw	torque ft-lb	Nominal Speed RPM	Continuous	peak	efficiency	Weight - lb	availability	Cost
------------	Current Gas Motor	-----------	------	---------		6000	~1/3 peak	22.4	~30%	184	------------	--------
	Danaher Motion	B-806-B	230			3000	16.2			n/a		call
	Electricvehiclesusa.com	ADC #FB1-4001 9.1"	72-144			n/a	14.5			n/a		$1,773.36
	D&D motor sys	ES-31B	72-144			n/a	13.4	36.5		83		$1,154.00
510-839-9376	PMG	PMG132	72			10800	7.22	34.3		25	in stock (CA)	$985.00
	LEMCO	LEM-200	96		24		16.8	33.6	91%	24		
	Baldor Motor	D5020P	150			1750	14.9			286		$6,410.00

*2.08:1 gear ratio in lower unit

Figure 17 - Motor System Design Selection Matrix

Batteries

Vender Contact	Manufacturer	Part Number	Nominal Voltage	Amp Hours	Weight - lb	Cost	availability	estimated # of batteries needed
	Full River AGM	FRL16	6	400/501	56	$355.00		60
	KoKam	200K02-0101A	9	200	2.3	call		84
	EnerSys	6-E155-9	12	620	528	call		20
	EnerSys	36-E155-9 or 36-E155-17	72	620 or 1240	3168 or 5616	call		4 or 2

Figure 18 - Power Storage Design Selection Matrix

9 - Project Budget and Expenditures

The primary source of funding for the GCAMP project is the GCROA, which has appropriated $20,000 to the team. The expenditures for the motor and generation sub-systems are summarized in the following tables. The total cost of the alternative motor and charging system is approximately $15250.

9.1 - Motor System and Power System Expenditures

Table 8 - Motor System Costs

Item	Material	Quantity	Cost
Parts			
Electric Motor	LEM-200	1	$ 1576
Spline Adapter	Hardened Steel	2	$ 100
Strain Reliefs (IP68)	Plastic	3	$ 23.52
Fasteners	Misc		$ 113.67
Timing Pulleys	Steel	2	$ 189.31
Belt	Rubber/Kevlar	1	$ 31.78
Shaft Clamps	Steel	2	$ 27.75
Hole Sealant	Carbon Fiber	3'	donated
Bearings	Steel/Taper	4	$ 79.72
Metals			
Aluminum			
Adapter Plate	.875 Plate	12” x 12”	donated
Risers and Bearing carriers	1.0 Plate	14” x 12”	donated
Seal Plate	.125 Plate	12” x 14”	$ 12
Spacer	.020 Sheet	6” x 6”	$ 5
Motor Mount	1.5” Plate	14” x 12”	$ 96
Steel			
Spacer	.25” Plate	6” x 6”	Donated
Drive Shaft	.75” bar	12”	$ 5
Total Cost			**$2259.75**

Table 9 - Battery System Costs

Item	Quantity	Cost
High current water proof plugs (black)	2	$ 50.52
High current water proof plugs (red)	2	$ 50.52
water proof plug receptacles (red)	2	$ 62.20
water proof plug receptacles (black)	2	$ 62.20
Motor Controller	1	$ 450.00
Battery Management System	1	$ 2,000.00
Lithium Polymer Batteries	24	$ 7,200.00
2/0 350 Amp welding cable	2	$ 244.00
2 conductor signal cable	25	$ 25.00
2/0 cable termination lugs	4	$ 52.60
sundry wiring supplies	1	$ 200.00
single pole; single throw; normally open 400 amp contactor	1	$ 150.00
0-50 Kohm potentiometer for throttle	1	$ 8.00
Sundry Aluminum and Steel	1	$ 200.00
Battery Charger	1	$ 200.00
high speed bearings	2	$ 40.00
Timing belt	1	$ 15.00
Timing Pulley (large)	1	$ 80.00
Timing Pulley (small)	1	$ 60.00
Battery Box	1	$ 655.00
Total Cost		**$ 11805.04**

9.2 - Generation System Expenditures

Table 10 - Turbine/Generation Costs

Item	Quantity	Cost
Fasteners	66	$ 121 total
Blades	6	$ 72
Hub Arms	9	$ 20
Shaft Collar	3	$ 18
Hub Plate	6	$ 15
Shaft	1	$ 70
Sliding Contact Bearing	2	$ 80
Thrust Bearing	1	$ 56
Generator	1	$ 150
Total Cost		**$ 1184**

10 - Conclusions and Future Work

10.1 - Project Achievements

10.1.1 - Generation Team Accomplishments

The 2008-2009 GCAMP turbine/generation team has identified these accomplishments that were completed for the 2008-2009 school year:

- Created a design basis for the future turbine teams
- Identified the river flow as an alternative energy generation source
- Designed, manufactured and field tested a Darius type turbine design
- Designed, manufactured and will soon field test a Gorlov turbine design
- Designed, manufactured and implemented a manufacturing process to develop helical turbine blades that can be used for Gorlov turbine systems
- Identified that the Gorlov turbine is the most suitable design out of the two turbine types

10.1.2 - Motor Team Conclusions

The alternative motor was successfully adapted to fit the chassis of the Honda BF30A. The motor was adapted to fit the current drive shaft configuration of the existing four-stroke internal combustion engine and utilize the same lower unit out-drive. The adaptation allows for the removal and service replacement of the lower unit.

All functionality of the four-stroke outboard was maintained in the new alternative motor system including: throttle handle, tilt-lock mechanism, cowling seal, lower unit, and steering arm. This will allow for an easy switchover of the current fleet of internal combustion motors.

The motor was tested in a river environment including flat water and rapid situations by two commercial river guides. In all cases the motor performed equally well or better that the four-stroke internal combustion motor.

10.1.3 - Battery System Conclusions

The battery system is properly controlled and operational. Further testing is needed to determine the hours of operation from one charge. The battery box is sealed and houses the batteries, controller, contactor, BMS, and the LCD touch screen is mounted to the box lid.

Existing twist-grip throttle from the gas motor was successfully adapted to control the batteries using a 50k ohm potentiometer. The controller input is for 0-5k ohms resistance

(5k ohms or greater = 0% throttle; 0 ohms = 100% throttle). By rotating the potentiometer through 30 degrees, the twist-grip throttle moves through the 0-5k ohm position. This system properly controls the motor speed. Because the controller registers any resistance above 5k ohms as 0% throttle, this allows for the safety benefit that if the throttle control wires were to be disconnected or severed in anyway, the controller would register infinite resistance and shut down the motor.

10.2 - Future Work Recommendations

10.2.1 - Generation Team Future Work

In retrospect, the GCAMP turbine/generation team has identified these aspects for future GCAMP teams to possibly address:

- Gather velocity and depth measurements of actual camping sites along the Grand Canyon
- Use the gathered data to refine the Gorlov design such as size, power generation and airfoil profile
- Refine the generator such as electrical output, size, gearing system, and compatibility with the boat electrical system
- Develop, manufacture, and implement a deployment system for the turbine
- Develop, manufacture, and implement an electrical transmission system that interacts with the boat electrical system
- Develop and implement a design to make stowage of the turbine more practical
- Identify and resolve possible corrosion issues with the turbine mounting frame

10.2.2 - Motor Team Future Work

Future work for the motor system should focus on improving the efficiency of the motor system to maximize battery life. Possible solutions could include the use of a CVT transmission, or cooling of the motor. Other considerations could include improving the “water-proofness” of the cowling, redesigning a new cowling so that the battery cables can be run through the lower portion of the cowling, installing a thermocouple to measure the motor temperature during operation, and modifying the existing system to reduce weight.

10.2.3 - Battery System Future Work

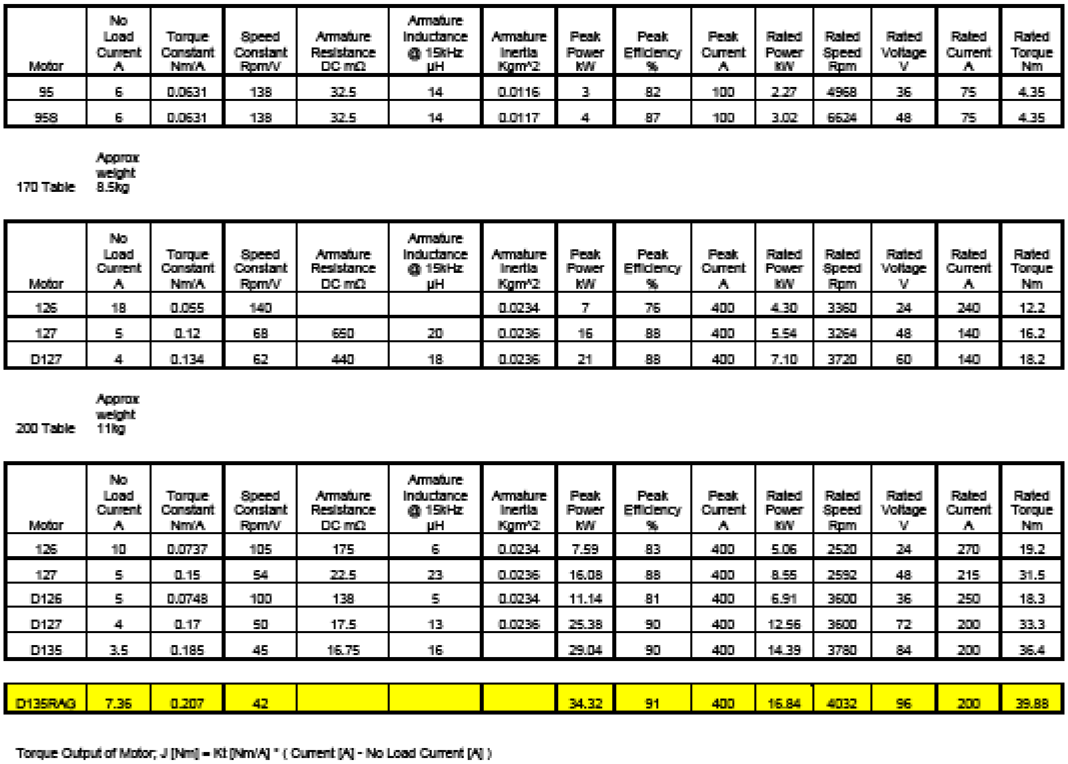
Future needs for the battery system would include re-building the twist grip throttle for smoother, more accurate throttle response and should include a spring which would return the throttle to the slow and stop position when not engaged by the user. It is critical that this spring return does not hinge on the potentiometer shaft as this will present high stresses on the potentiometer shaft which could dramatically enhance wear on the potentiometer and lead to failure.

A communicating battery charger from Thunder Sky whom sold the team the batteries and battery management system, was beyond this year's budget. The BMS wiring includes connections to a communicating battery charger which would allow the BMS to keep track of the amount of charge being extracted and recharged during the life of the batteries. This charger would give warning for various battery problems that may occur during charging. The lithium-polymer batteries also rely on two-stage charging that cannot be safely accomplished by any other charging system.

Installation of the thermocouple inside the motor housing would help identify if a cooling system is needed. Over heating in the sealed motor housing as well as the sealed battery box poses a hazard to the sophisticated electronic systems.

11 - Supplemental Information

11.1 - Motor Selection Sheet



Motor	No Load Current A	Torque Constant Nm/A	Speed Constant Rpm/V	Armature Resistance DC mΩ	Armature Inductance @ 15kHz µH	Armature Inertia Kgm^2	Peak Power kW	Peak Efficiency %	Peak Current A	Rated Power kW	Rated Speed Rpm	Rated Voltage V	Rated Current A	Rated Torque Nm
95	6	0.0631	138	32.5	14	0.0116	3	82	100	2.27	4968	36	75	4.35
95S	6	0.0631	138	32.5	14	0.0117	4	87	100	3.02	6624	48	75	4.35

	Approx weight
170 Table	8.5kg

Motor	No Load Current A	Torque Constant Nm/A	Speed Constant Rpm/V	Armature Resistance DC mΩ	Armature Inductance @ 15kHz µH	Armature Inertia Kgm^2	Peak Power kW	Peak Efficiency %	Peak Current A	Rated Power kW	Rated Speed Rpm	Rated Voltage V	Rated Current A	Rated Torque Nm
126	18	0.055	140			0.0234	7	76	400	4.30	3360	24	240	12.2
127	5	0.12	68	650	20	0.0236	16	88	400	5.54	3264	48	140	16.2
D127	4	0.134	62	440	18	0.0236	21	88	400	7.10	3720	60	140	18.2

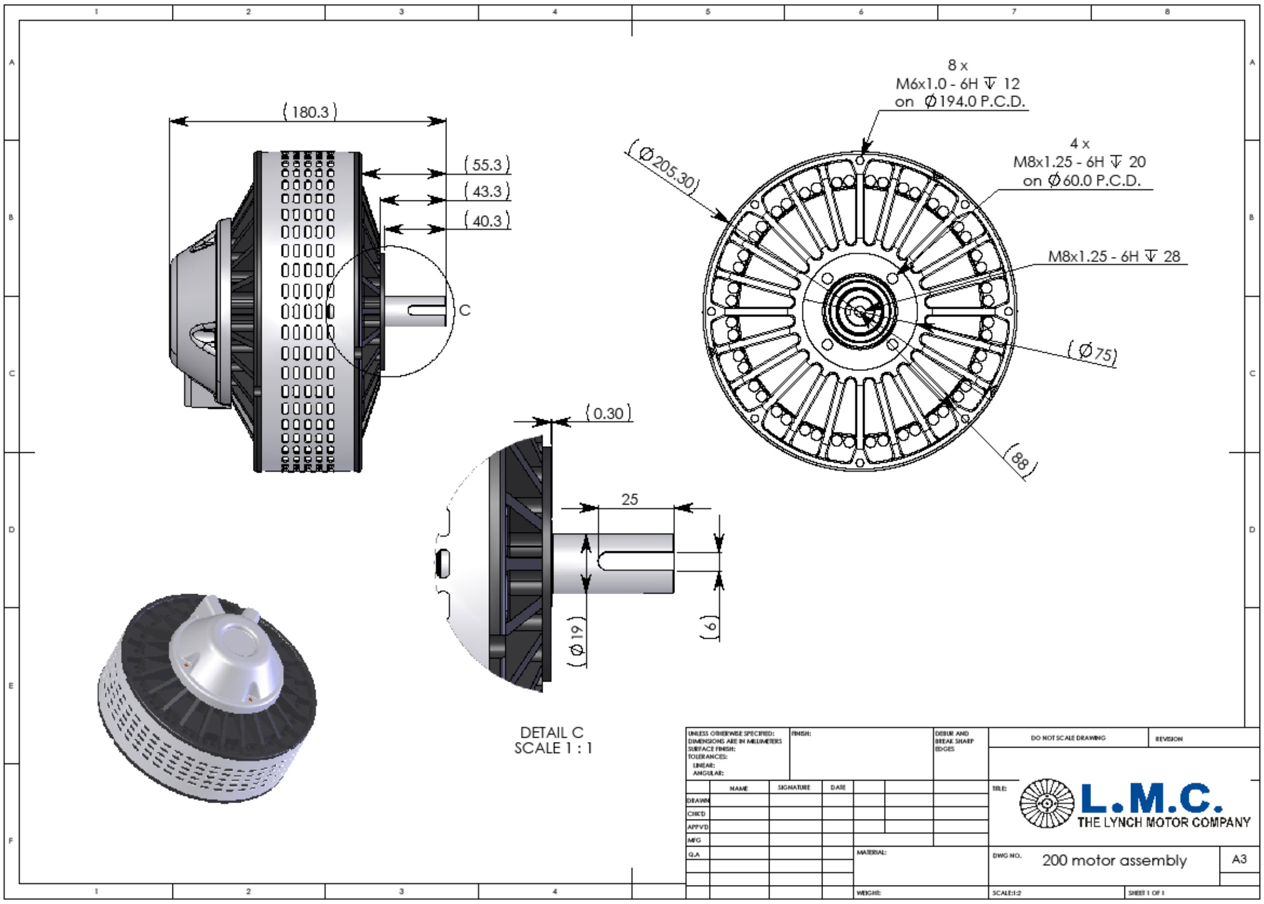
	Approx weight
200 Table	11kg

Motor	No Load Current A	Torque Constant Nm/A	Speed Constant Rpm/V	Armature Resistance DC mΩ	Armature Inductance @ 15kHz µH	Armature Inertia Kgm^2	Peak Power kW	Peak Efficiency %	Peak Current A	Rated Power kW	Rated Speed Rpm	Rated Voltage V	Rated Current A	Rated Torque Nm
126	10	0.0737	105	175	6	0.0234	7.59	83	400	5.06	2520	24	270	19.2
127	5	0.15	54	22.5	23	0.0236	16.08	88	400	8.55	2592	48	215	31.5
D126	5	0.0748	100	138	5	0.0234	11.14	81	400	6.91	3600	36	250	18.3
D127	4	0.17	50	17.5	13	0.0236	25.38	90	400	12.56	3600	72	200	33.3
D135	3.5	0.185	45	16.75	16		29.04	90	400	14.39	3780	84	200	36.4

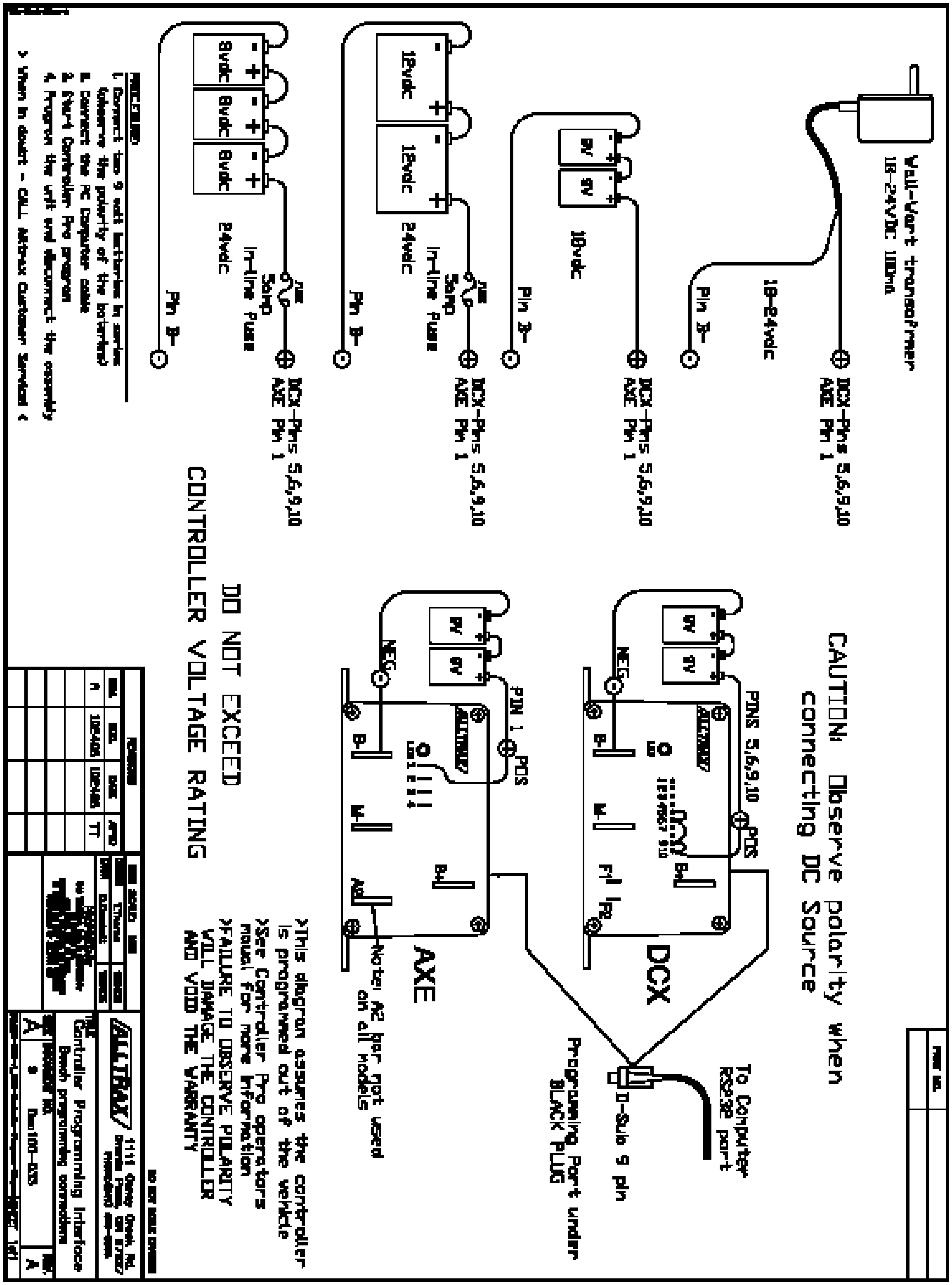
D135RAG	7.36	0.207	42				34.32	91	400	16.84	4032	96	200	39.88

Torque Output of Motor; J [Nm] = Kt [Nm/A] * (Current [A] - No Load Current [A])

11.2 - LMC Motor Specifications



11.3 - Motor Controller Wiring Schematic



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