ARIZONA STATE UNIVERSITY HYBRID TEAM

ALTERNATIVE MOTORBOAT HYBRID PROPULSION SYSTEM

Team 10

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1. Executive Summary

The goal of this project is to utilize hybrid technology to design a propulsion system for the Glen Canyon smooth water pontoon riverboat ride. This would reduce fuel consumption and preserve the wilderness experience for the passengers on the riverboat trip. The riverboat trip has two portions: the downstream and upstream. The downstream portion of the trip will utilize an electric motor and the upstream portion of the trip will make use of an internal combustion engine.

In order to begin brainstorming feasible systems we had to assign criteria and constraints. Using the criteria as an aid, we were able to eliminate systems by utilizing a design matrix and choose the best two options. By taking the two best options from the first design matrix we were able to create a detailed analysis of the two systems to validate the best system was chosen.

The Inline Powertrain system was the best at meeting all the criteria we define for the system. The Inline Powertrain system will utilize an inline configuration in the following order: Internal combustion engine, drive shaft, clutch/decoupler, electric motor, drive shaft, and a lower unit stern drive. Research and selection of each component had to be done to find the best devices to meet all of our system's criteria.

We have yet to validate our component selections with quantitative data because not all of them have been collected. We have a Honda AquaTrax 1296 cc turbo charged gas engine, a Mercruiser stern drive, and a small battery pack that was used by last year's capstone team. We still need an electric motor, drive shafts, a battery charging system, a steering system, fabricate the cradle system, and the decoupler.

By March 2009 we hope to have the system ready to test. Finishing early will give us plenty of time to redesign/modify our system to pass all the design specifications.

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2. Introduction

Preserving Glen Canyon and its surrounding area is important to the populace as well as the wildlife that call it home. The Colorado River Discovery tours make it possible for the general public to appreciate and see the millennia of history contained in the approximately 15 mile stretch of river. From March 1 through November 30, the Colorado River Discovery provides the general public with two tours a day, per boat. The tour starts at the base of the Glen Canyon Dam and takes approximately three hours to reach the final destination at Lee's Ferry.

Colorado River Discovery is currently using a Honda 135 horsepower outboard motor as its propulsion system for the trip up and down the river. These motors can consume anywhere from six to twelve gallons of gasoline per tour. With the increasing concern of harmful emissions, noise pollution, as well as the increasing costs of fuel, there is a need to find a more ecological and cost efficient alternative to solve these problems.

An automotive hybrid drive system adapted to a smooth water boat could be a possible solution to these problems. Our team is the first with the assignment to explore this solution, however if we used a hybrid system from an automobile, we had to consider the following:

- It would be expensive (even if we found a salvaged vehicle from a junk yard)
- An automotive hybrid drive system has many functions and components designed specifically for street driving
- We do not have the equipment or the knowledge to change parameters in the control system
    - The gas engine is designed to run only at peak efficiency
        - There are probably inputs into the vehicle control systems that must be "true" for the gas engine to turn on that the riverboat cannot satisfy
    - We would not have a way of knowing what would happen, but we know that diagnostic trouble codes are inevitable
        - Sometimes automotive system shut down if there are too many diagnostic trouble codes

After a long discussion and design process, our team decided it is best to design and fabricate our own hybrid propulsion system for the pontoon river boats.

3. Project Organization

3.1 Personnel

Our team consists of the following undergraduate seniors:

Member:	Major:
Brett Bowman	Engineering with Mechanical Focus
Christopher Clouser	Engineering with Mechanical Focus
Nicole Conner	Mechanical Engineering Technology: Aeronautical
Alejandro Frias	Manufacturing Engineering Technology
Christopher Gitter	Mechanical Engineering Technology: Automotive
Hanh Luc	Mechanical Engineering Technology: Automotive
Ryan McQueen	Mechanical Engineering Technology: Automotive
Jason Raymond	Mechanical Engineering Technology: Automotive

In addition to our team, our mentor is Jim Contes, a Senior Lecturer for the College of Technology and Innovation and for technical support, Christopher Stubbs from the General Motors Desert Proving Grounds.

In order to meet our design ambitions we divided into small teams. The smaller teams would allow us to give each subsystem of our design the extra attention and detail to produce a successful design. Each subsystem team will have its own focus and goal but will still allow us to work together and have the same design objective. The subsystems and the teams can be seen below:

<u>Internal Combustion Engine Team</u> Fuel System Mounting of the Engine	Nicole Conner Alejandro Frias
<u>Transmission and Documentation Team</u> System Control Integration Drive Shafts Systems Including Lubrication	Hanh Luc
<u>Electric Motor Team</u> Battery Storage and Safety Mounting of the Motor	Chris Clouser Jason Raymond
<u>Battery System Team</u> Switches and Circuits	Christopher Gitter Christopher Stubbs
<u>Stern Drive System Team</u> Mounting of the System Steering (hydraulic?) Required safety features pertaining to inboard engines	Brett Bowman Ryan McQueen

3.2 Planning and Scheduling

The following Gantt chart, seen in *Figure 3.1*, will be used as our timeline to stay on task and meet our design deadline. *Figure 3.2* shows our timeline on a calendar.

Task Name	Duration	Start	Finish
System Selection	16 days	Fri 9/11/09	Thu 10/1/09
River Boat Trip	1 day	Fri 9/25/09	Fri 9/25/09
Design Review with GCROA	1 day	Sat 9/26/09	Sat 9/26/09
Component Selection	6 days	Mon 10/5/09	Mon 10/12/09
Assign Groups	1 day	Mon 10/5/09	Mon 10/5/09
Analysis	13 days	Mon 10/5/09	Wed 10/21/09
Attaining Parts	21 days	Wed 10/21/09	Wed 11/18/09
ACTUAL PROGRESS CHART	0 days	Tue 11/17/09	Tue 11/17/09
System Selection	21 days	Fri 9/11/09	Wed 10/7/09
Component Selection	35 days	Mon 10/5/09	Fri 11/20/09
Assign Groups	1 day	Mon 10/5/09	Mon 10/5/09
Analysis	40 days	Mon 10/5/09	Fri 11/27/09
Attaining Parts	38 days	Thu 10/22/09	Mon 12/14/09
FALL BREAK	24 days	Fri 12/18/09	Tue 1/19/10
Design Review w/GCROA @ ASU	2 days	Fri 1/15/10	Sat 1/16/10
Design Review for Team 1st Day Back	1 day	Wed 1/20/10	Wed 1/20/10
Construction of Powertrain	28 days	Wed 1/20/10	Fri 2/26/10
Fit Powertrain to Boat Hull	7 days	Fri 2/19/10	Mon 3/1/10
Testing on Lake Near ASU	49 days	Mon 3/1/10	Thu 5/6/10
Fine Tuning to Finish of Development Process	14 days	Tue 4/20/10	Fri 5/7/10
Show Prep	5 days	Mon 5/10/10	Fri 5/14/10
Presentation of Working Prototype to GCROA	2 days	Mon 5/17/10	Tue 5/18/10
ACTUAL PROGRESS CHART	1 day?	Tue 1/19/10	Tue 1/19/10

Figure 3.1

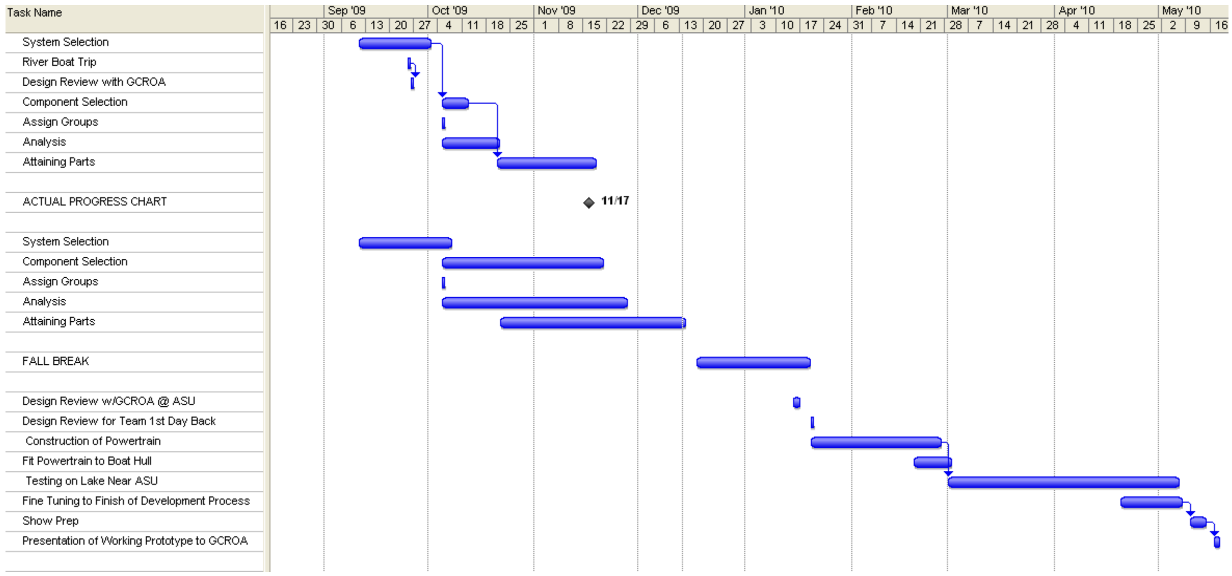

Figure 3.2

According to our Gantt chart, we are on track:

- ✓ We have selected a system
- ✓ Assigned groups
- ✓ Are in the process of component selection.

4. Methodology

4.1 Criteria

The criteria that we would like to optimize in our design are as follows:

- Low Cost
- Low Emissions
- Low Noise Level
- Ease of Maintenance
- Ease of Manufacturing
- Durability
- Ease of Operation
- Size of Module
- Low Voltage (DC)

4.2 Constraints

The following constraints have been established by our team:

- The system must use less than 3 gallons of fuel per round trip
- The time allow of the return trip must be less than one hour
- It must be modular for serviceability

- It must be safe and insurable
- It must have low liability
- The battery system must have enough energy for two trips
- The internal combustion engine must have close to 135hp
- The propeller system must have a trim capability
- The electric motor and the internal combustion engine must be coupled to have one drive shaft, but must be decoupled for electric drive only
- Must meet all EPA regulations

4.3 Design Process

The design process utilized by our team will ensure that all steps in designing the hybrid system will completely resolve the ecological and economic problems. The following steps will be accomplished by our team over the course of the year:

- Assign criteria and constraints for the system
- Brainstorm feasible systems
- Eliminate systems by utilizing a design matrix and choose the best two options
- Take the two best options from the first design matrix and create a detailed analysis of the two systems to choose the best one
- Choose components that will meet the system constraints
- Analyze choices
- Validate the choices with quantitative data
- Fabricate the system
- Test and if necessary redesign/modify to pass design specifications

4.4 Brainstorming and Design Matrices

A design matrix is used by engineers to develop the best solution for a problem given certain specifications/criteria. The matrix criterions are rated by numbers on how they meet the desired criteria. The higher number is awarded to solutions that best fit the criteria and solutions that fall below receive lower rating. We have brainstormed the following options for our hybrid system design and created a design matrix, as seen in *Figure 4.1*, to aid us in choosing the right design:

- Inline Powertrain(PT)-

  Will utilize a stern drive apparatus and have an inline configuration in the following order (as seen in *Figure 4.1*):

  Internal combustion engine (ICE), sprag clutch (SC), electric motor (M), drive shaft (DS), and lower unit stern drive (LU)
- Parallel Powertrain; Longitudinal-

  Will utilize a stern drive apparatus, have a longitudinal configuration, and consist of the following (as seen in *Figure 4.1*):

The electric motor and internal combustion engine will have separate shafts that will translate power into a transfer case that will connect to a main driveshaft. The main driveshaft will then connect to a lower unit stern drive

- Parallel Powertrain; Transverse:

  Will utilize a stern drive apparatus and have a transverse configuration to make more room for passengers. It will consist of (as seen in *Figure 4.1*):

  A transverse mounted electric motor and internal combustion engine that will be geared transversely to mesh with a gear box. The gear box will then connect it to a driveshaft and then a lower unit stern drive

- Hybrid Outboard (ICE and electric motor together as one outboard unit):

  Will utilize the 135 hp Honda Outboard Motor, an electric motor, and necessary components for smooth operation

- Locomotive Motor 3 phase ac:

  Will consist of a separate electric motor that utilizes the internal combustion engine to drive a generator to charge the batteries

PROBLEM SOLVING MATRIX

(After the River Rafting Trip)

ALTERNATIVES / SPECIFICATIONS	Low Cost	Low Emissions	Low Noise Level	Ease of Maintenance	Ease of Manufacturing	Durability	Ease of Operation	Size of Module	Low Voltage (DC)		TOTALS
Inline PT; IC-M-GB-DS-LU	11	11	11	7	11	7	11	3	16		88
Parallel PT; Longitudinal	7	7	7	3	7	3	3	7	11		55
Parallel PT; Transverse	3	3	3	1	3	1	1	1	3		19
Hybrid Out Board (IC & motor together one outboard	16	1	1	16	16	16	7	16	7		96
Locomotive Motor 3 phase ac	1	16	16	11	1	11	16	11	1		84

Rating: 16-11-7-3-1

16=good; 1=poor

Figure 4.1

We decide to explore the best two choices indicated by our design matrix to validate our final decision. The inline power train with a stern drive and the modified 135 hp Honda outboard motor were our top two choices. We created another design matrix that can be seen in *Figure 4.2*, below.

PROBLEM SOLVING MATRIX
(After the River Rafting Trip)

ALTERNATIVES / SPECIFICATIONS	Low Cost	Low Emissions	Low Noise Level	Ease of Maintenance	Ease of Fabrication	Durability	Ease of Operation	Size of Module	Ease of Reproduction	Commodity Parts	Accessibility	TOTALS
Inline PT; IC-M-GB-DS-LU	1	7	7	1	7	7	1	1	7	7	7	53
Hybrid Outboard Powertrain	7	1	1	7	1	1	7	7	1	1	1	35

Rating: Good=7 Poor=1

Figure 4.2

From the design matrix in *Figure 4.2*, we decided to design an inline stern drive hybrid system.

4.5 Component Selection

The component selection is critical to our analysis. We have been researching different engines, stern drives, and electrical motors for our inline-stern drive propulsion system. After the component selection process we will start to analyze and validate our system to meet our design constraints. As mentioned before, we've split this task between the team members into their respective teams.

4.6 Finances

All projects have a budget, and this one is the same. A grant was given to us by GCROA, for designing and construction of this project. Because of the budget, great care is taken in saving money as much as possible without compromising the integrity of the final project. Below, in *Figure 4.3*, we've outlined our budget by the items we believe will need to be purchased, and then by our estimated cost, and the actual cost as we purchase parts. At the end of the project, a complete financial analysis will be done for the project, and a review for future hybrid boats built on this design.

ITEM	ANTICIPATED COST	ACTUAL COST	PURCHASE DATE
GAS ENGINE w/FUEL TANK	$2,500.00	$2,000.00	10/26/09
ELECTRIC MOTOR	$2,200.00	N/A	
MOTOR CONTROLLER	$500.00	N/A	
BATTERIES w/CABLES	N/A	N/A	
BATTERY CASE (water tight)	N/A	N/A	
STERN DRIVE	$1,500.00	N/A	
PROPELLER	N/A	N/A	
CLUTCH w/MECH. LEVER	N/A	N/A	
DRIVE SHAFTS	$300.00	N/A	
STEERING	N/A	N/A	
MOUNTING CRADLES	$150.00	$202.00	11/19/09
PRELIMINARY TOTALS	$7,150.00	$2,202.00	
GRANT	$10,000.00	$10,000.00	
GRANT OVERHEAD	$2,000.00		
WORKING CAPITAL	$8,000.00	$10,000.00	
AVAIABLE CAPITAL LEFT	**$850.00**	**$7,798.00**	

Figure 4.3

5. Internal Combustion Engine Team: Nicole Conner and Alejandro Frias

5.1 Research

To start researching what kind of engine we could use for our project, we immediately turned to the internet, which allowed us instant access to almost every detail we needed to know. We researched what different engines we could put into our boat that would work for our system, but without having to do any research, we knew we did not want to use an automobile engine, and thought the better choice would be to use a marine engine.

Next we started looking for places where we could purchase engines. Since buying a brand new engine was out of the question because of our limited budget, we started looking up places to purchase used personal watercraft.

5.2 Methodology

As mentioned previously, a marine engine is a perfect solution for this project, as it is already designed for watercraft, so we wouldn't have to worry about making any adjustments for the environment. GCROA suggested we look for an engine that has at least 90 horsepower, but we decided we should obtain an engine that had around 130 horsepower to make sure it would meet all of our requirements.

Buying a brand new engine was entirely out of the question. The budget we are on for our entire project is about the cost of the engine itself brand new, and we had to buy the rest of our system with that allotted money. We set ourselves a budget of $2500 for the engine alone, hoping to find one used. We started searching on Craig's List and eBay, and other websites like them, to hopefully find our engine. We were hoping to find the engine in Arizona, but did not rule out having to make a road trip to California or Nevada to find what we needed.

We were searching for over a month with no luck on finding an engine that fit our budget. No one was selling just the engine, so we turned to looking for personal watercraft for sale instead of just the engine alone. We were hoping to come across someone who had a wrecked personal watercraft and was looking to sell it really cheap. Unfortunately most wrecked watercraft get sent to the junkyard pretty quick and scrapped for parts. Most of the personal watercraft for sale that contained the engine we needed were in the neighborhood of $4000 to $5000. Unfortunately this was way above our budget of only $2500 for the engine. While the $4000-$5000 is a good price for what we were looking for, it simply wasn't in our budget. The reason for the price being so high is we had to look for personal watercrafts that were only about 4 to 5 years old. The reason for this was these watercrafts had four-stroke engines in them instead of two-stroke. According to state law, GCROA can only use four-stroke engines on the water, as the two-stroke variety create too much pollution compared to the four-stroke.

Thankfully not too long into our search we came across an ad on Craig's List from a man who had two wrecked personal watercraft in his possession and was looking to sell the engines in them. He had two Honda Aquatrax R12X. These jet ski's have Turbocharged 1.3 L, 165hp, 4 cylinder engines. The price was $2500 originally for one engine, but since we had the expertise to take the engine out ourselves without the sellers help, he lowered the price to $1800. After we took the parts that we needed, the seller was shocked we were able to retrieve so many parts. He then asked for extra money since we also wanted to take the fuel tank and pump to complete the fuel system. All together we spent $2000 for the engine system.

5.3 Detailed Design

Since we have the engine we are going to use, we can now begin work on the next part of the Internal Combustion Engine System, the Engine cradle. This also happens to be a very important part of the entire hybrid system, as it is the basis to the entire system mounting.

The first step in designing the engine cradle is to choose the materials. Since the boat frame is aluminum, and this cradle would be welded to that frame if in production, we also chose aluminum. 6061-T6 is our chosen grade for its strength and weldability. The engine frame was constructed from:

- 2”x4”x.25” Rectangle Tube
- 1.5”x.25” Round Tube
- 4”x.25” Strip Stock

All measurements were taken from the engine with the mounts attached. After getting the critical measurements of the mounts and width, the length was estimated to include the fuel system, internal combustion engine, electric motor, and driveline disconnect. This will make the system common to the rails but modular so that parts can be disconnected without taking apart the entire system. The cradle was drawn within SolidEdge, to stay common with all other parts being drawn in CADD. Below is a picture of the finished approved cradle.

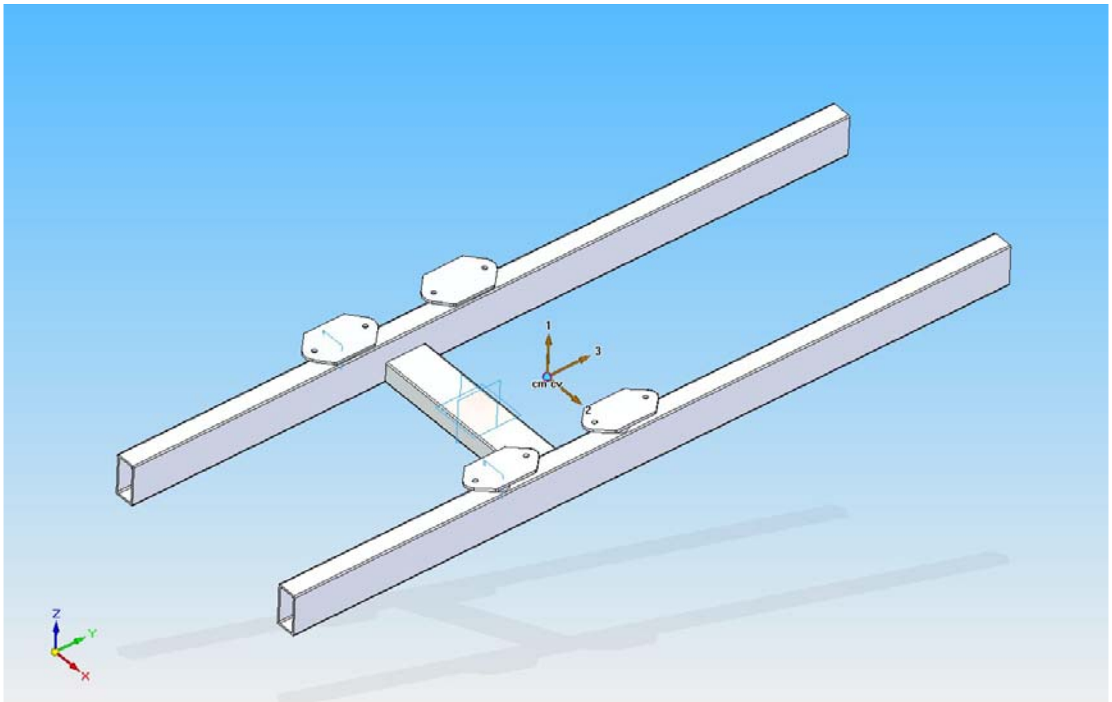

Figure 5.1

6. Clutch/ Decoupler Team: Hanh Luc

From our design selection the IC engine is going have an inline connection with the electric motor. The need for a way to disconnect these two components is a small but important piece of our design. Our system will have two operating conditions and they are:

1. The electric motor will operate and the IC engine will be off.
   The inline shaft connecting the IC engine and the electric motor will have to be disconnected or will have to freewheel so the rotation of the electric motor will not be affected by the IC engine.

2. The IC engine will operate and the electric motor will be off.
   In this mode the shaft in the electric motor will be driven by the IC engine. The output shaft of the IC engine will turn the input side of the electric motor, which would then turn the output shaft of the electric motor.

We had to find a device that will disconnect the IC engine from the electric motor's input shaft when the electric motor is running and also connect the IC engine to the electric motor's input shaft when the IC engine is operating

The criteria that we desire to optimize this device are as follows:

- Low Cost
- Ease of Maintenance
- Ease of Manufacturing/ purchasable
- Durability
- Ease of Operation
- Small and lightweight
- Mechanical operation (require no gas or electric energy)

The decoupler selected must also meet the following constraints:

- Handle the RPM and torque of the electric motor: 2500-6000 rpm, torque 10-70 ft-lbs
- Handle the RPM and torque of the IC engine 0-7000 rpm at 125 ft-lbs.

6.1 Research

6.1.1 Overrunning clutch

Our initial desire was to have an overrunning clutch, as seen in *Figure 9.1*

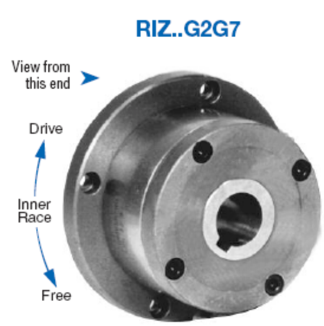

Figure 9.1

This overrunning clutch is manufactured by Formsprag. To utilize this clutch we were hoping to have the outer portion of the clutch to connect to the IC engine and the bore section receive a keyed shaft be connected to the electric motor. This would allow for the outer races of the clutch to freewheel in a counterclockwise direction and drive in the clockwise direction. When the inner shaft is turning the electric motor would be rotating in a counter-clockwise direction and the shaft that connects to the IC engine would then freewheel thus disconnecting the IC engine. Then when the electric motor is not turning the output shaft, the IC engine would then be allowed to turn in the clockwise direction. This would turn both the shaft that connects the IC engine and the shaft that turns the output shaft in the electric motor.

This seemed like a possible solution, but further research and speaking to the manufacturer it turned out to be a dead end. The unit that they recommended was approximately $3039, which we were not willing to spend. Also to use this clutch we had to manufacture a gear reduction to meet maximum RPM requirement that the clutch will operate at without failure. The clutch was also too heavy because it weighed approximately 26 lbs.

6.1.2 Transmission

The next thing we researched were transmissions that were light weight and had only forward, reverse, and neutral modes. There many transmissions available but they were not what we were looking for. Most of them were heavy, complex, had gear reductions, and more than one speed.

We found a transmission used in snow mobiles that had neutral and only one speed for the forward and reverse modes. It can be seen in *Figure 9.2*. The transmission in *Figure 9.2* is Model: 5101B and is manufactured by Snow-Nabstedt Power Transmissions. It would allow for us to connect both the IC engine output shaft and the electric motor input shaft and also allow for us to have the inline drive shaft free wheel while the electric motor is running.

Figure 9.2

Model : 5101B had a rating of a max RPM 3600, and a max torque of 200in-lbs, from the specifications found on the website. We decussed that this transmission would not work for us but we decided to test it. The clutch bands inside the unit would not hold past a torque greater than 20 ft-lb. We disassembled it thinking maybe we could modify it to meet our needs. We found that the RPM was a limiting factor because it there were no roller bearings inside that would support our high RPM constraint. If we put this in our system, it would not last. The high RPM from the IC engine would cause a failure even if we had a more robust band clutch.

Transmissions intended for marine environments would be ideal but are much too expensive. Having a marine transmision would have worked but we decided to look for another solution that was less complex and less expensive.

6.1.3 Drive shaft coupling

The drive shaft coupling by Remco was a very feasible solution to deconnect the IC engine from the eletric motor. The coupling assembly contains a shift collar and a coupling that is welded to a drive shaft. There is also a shift linkage assembly that can engage and disengage the shift collar. With this product we are able to disconnect the inline driveshaft that connects the IC engine and the electric motor by allowing the drive shaft to freewheel when the collar is disengaged. Then when we want the IC engine to drive the output shaft of the electric motor we can engage the collar.   Please see *Figures 9.3*, *9.4* and *9.5* for pictures of the shift linkage, the coupling and shift collar assembly.

Figure 9.3 Coupling and shift collar assembly welded to the drive shaft

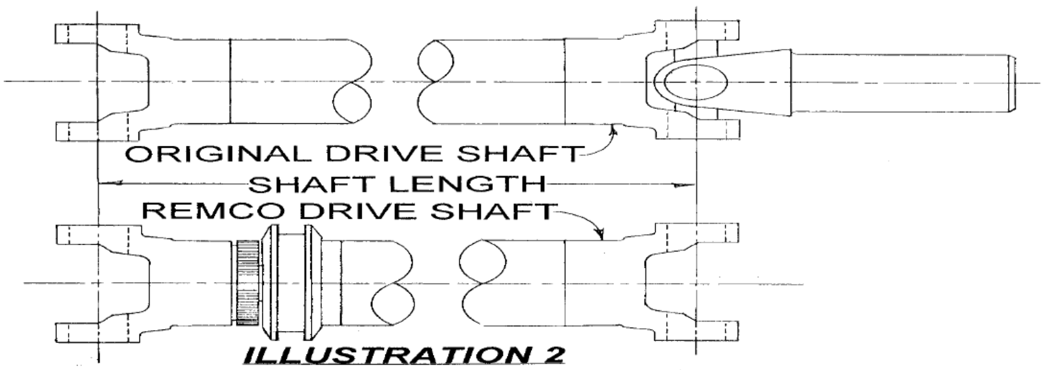

Figure 9.4 Shift collar and coupling on the drive shaft

Figure 9.5 Shift linkage, collar and coupling apparatus

This device is commonly used in cars to disconnect the rear differential from the transmission. We are confident that this device will work in our system because it will handle the max RPM and max torque of both our electric motor and or IC engine.

6.2 Methodology

To implement the Remco decoupler in our system will take the following steps:

- Obtain a shift collar and coupling
- Obtain the shift linkage assembly
- Weld the coupling and shift collar to a drive shaft
- Connect our splined shaft to a plate that can be welded to the drive shaft
- Have the drive shaft balanced
- Install it in our system
- Make a ridge housing to mount the shift linkage assembly
- Install the control knob
- Test it and make sure it functions correctly

6.3 Detailed Design

After the engine cradle is finished and we obtain the electric motor we can determine the length of the drive shaft needed and design the ridge housing to mount the shift linkage assembly. We are going to use a standard size coupling that will be donated by Cliff's Welding Shop. It requires a 2.5" X .065 drive shaft. Cliff's Welding Shop is going to help us obtain a linkage assembly as well and is waiting to hear from Remco about a donation.

We are confident that shift collar and coupling will be a feasible solution to disconnect and reconnect the inline drive shaft that connects the IC engine and the electric motor.

7. Electric Motor & Controller Team: Christopher Clouser and Jason Raymond

7.1 Motor

The motor selection is a key part in the development of this project. To begin the process, we had to first find out how the electric motor would be used on the river. Our system architecture is designed to only use the electric motor downstream so the need to have enough power to power the boat back upstream is not a requirement. This allowed us to use a motor with a lower horsepower rating. The system design that will be implemented is an inline drive system that is similar to most rear wheel drive automotive systems. Our design requires the motor be a twin shaft motor.

Currently the pontoon boats use the Honda 135 hp outboard engines. We discussed the demand of the Honda engine and its operating ranges for the downriver trip with the tour guides. With the information gathered from the tour guides we determined that the motor must make close to 30 horsepower. 30 horsepower of mechanical power will be enough energy to allow for smooth navigation of the vessel while still maintaining a decent speed.

7.1.1 Research

The options of alternating current and direct current motors were discussed, and the decision to use a direct current (DC) motor was chosen. This was decided because DC can be handled easily, it is safe, and it is cost effective. An alternating current (AC) motor has the ability to provide a much higher power output with the voltage and current supplied to the system. However, AC can be difficult to use. After speaking with a few engineers about the construction of an AC system, we found that there are too many safety factors that would need to be addressed. This would increase the cost of the system.

DC motors can be designed to have most of their safety controls built into the controller so that if something catastrophic were to happen in the motor drive section, the controller would take all of the damage. This seemed to be a better option when it comes to the safety of the passengers. DC motors also proved to be less expensive in this situation due to the fact that the system will only need to provide 30hp of mechanical work. Also, after searching for motors, we found motors that operate in the 72 volt range, makes battery and controller selection easy and cost effective. The low voltage DC system proves to be easy to wire and control with minimal parts. Essentially, a DC system is fairly simple.

Other issues we wanted to address were system construction, part accessibility, and the ability to build a modular design. It became apparent during our visit with GCROA that one of the major factors that needed to be addressed was if this system could be built with minimal custom parts and be extremely easy to work on. The system also needed to be as modular as possible. Both of these issues are also amplified by the fact that none of the boats used are identical. With this in mind, the motor needed to be easily removable from the drive system, and easy to work with in the event that something was to break. Commodity parts became the key phrase while addressing these issues.

7.1.2 Methodology

With the criteria set, we began searching for a motor. As we began the process of making a motor selection we found the market for DC motors in the operating range that held to our criteria, turned out to be rather slim. Two motor companies showed to be the prime leaders in low voltage, user friendly, DC motors. The two companies are D&D Motors and NetGain Motors. The D&D Motors units were extremely cost effective units with simple designs. However, they seemed to be a bit, "cheap." Also, the D&D motors had a shaft design that was not user friendly, to say, it was very generic. Because of these two factors, we decided to go with a NetGain Motors unit, more specifically a NetGain TransWarp 9 motor. The NetGain units have shown to be much sturdier and reliable than the D&D units. Another advantage to the NetGain motor we chose was the excellent design implementation of commodity parts used in shaft design, wiring and mounting. Although the NetGain motor is about $800 more in initial cost, its design makes up for it in the savings that will be acquired by not having to have custom parts made and in the motors reliability and life span.

7.1.3 Detailed Design

The NetGain TransWarp 9 motor was chosen for our system. This motor has an excellent torque curve and power curve that meets the requirements for our power output. The NetGain TransWarp 9 motor has many great features:

-9.25" diameter, series wound DC motor
-Weight, approx. 160 pounds
-32.3 HP (72 Volts, 335 Amps)*
-70 Ft. pounds torque*
-Advanced timing – factory set for CCWDE (CWDE available)
-1.125" keyed CE shaft (matches 00-08219 DE)
-Commutators key locked onto the shaft
-High quality, large style brushes, factory pre-seated over 90%
-Exceeds Class "H" insulation – temperature snap switch + brush   wear indicator
-Turbo 400, 32 spline shaft
-Slip yoke assembly and tail shaft housing also available as options

As mentioned earlier, the NetGain TransWarp 9 motor is a bit more expensive; however it is an extremely durable unit. Most importantly is the fact that the TransWarp 9 motor uses common parts for its power transmission and mounting. This is accomplished by utilizing an output shaft from a General Motors TH400 transmission as the motors primary shaft. The back of the motor is designed to have a General Motors TH400 tailshaft housing bolted directly to it. These two features allow for multiple great abilities. First, the output shaft accepts a standard General Motors TH400 slip yoke. This slip yoke is an industry standard in many applications. The yoke uses a 1350 style u-joint, the same as the stern drive unit we are using, along with most other stern drive systems. Second, the tailshaft housing already has a mounting point integrated into it, due to General Motors utilizing it as the transmission mounting position. The mount used is a very simple yet sturdy design which translates to easy and solid mounting. These two parts, the slip yoke and tailshaft housing, can be obtained from many different places; from junkyards for pennies on the dollar, or at local auto parts stores for under $50, or in a performance-minded version for extreme life expectancies. On the front side of the motor, the same configuration can be utilized or a common sized General Motors TH400 input shaft configuration could accept torque limiting or overrunning clutches. In our case, the later of the two will be utilized with a simple plate to accept a driveshaft coupler.

The electric motor will use the Remco driveshaft decoupler as the connection to the engine. The motor's keyed shaft will be fitted directly into the driveshaft decouplers housing. The Remco driveshaft decoupler will be mounted to the cradle and thus support the motor on the input side. The General Motors TH400 tailshaft housing has a mount already incorporated into it and will thus provides the output side mounting for the motor. This mount will go directly to the cradle. The output yoke will use a 1350 u-joint which will be the same as the stern drive and thus a driveshaft will be easy to fit. With this motor choice no custom pieces will need to be made. The only modified part needed to utilize this system will be the Remco decouplers rear housing have a keyway cut into it to connect to the motor.

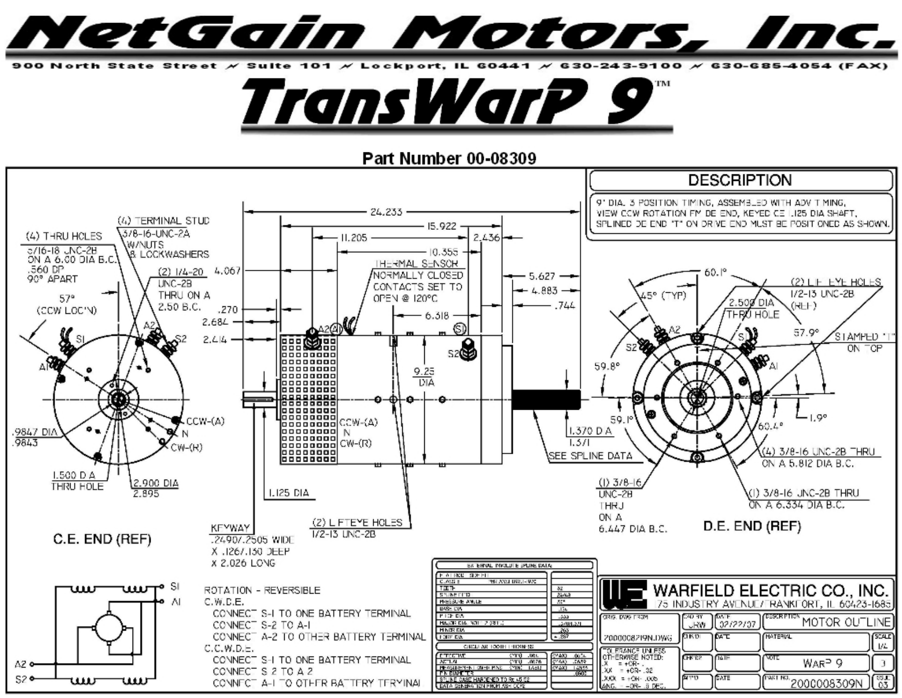

Figure 7.1

NetGain Motors, Inc.

900 North State Street ⁄ Suite 101 ⁄ Lockport, IL 60441 ⁄ 630-243-9100 ⁄ 630-685-4054 (FAX)

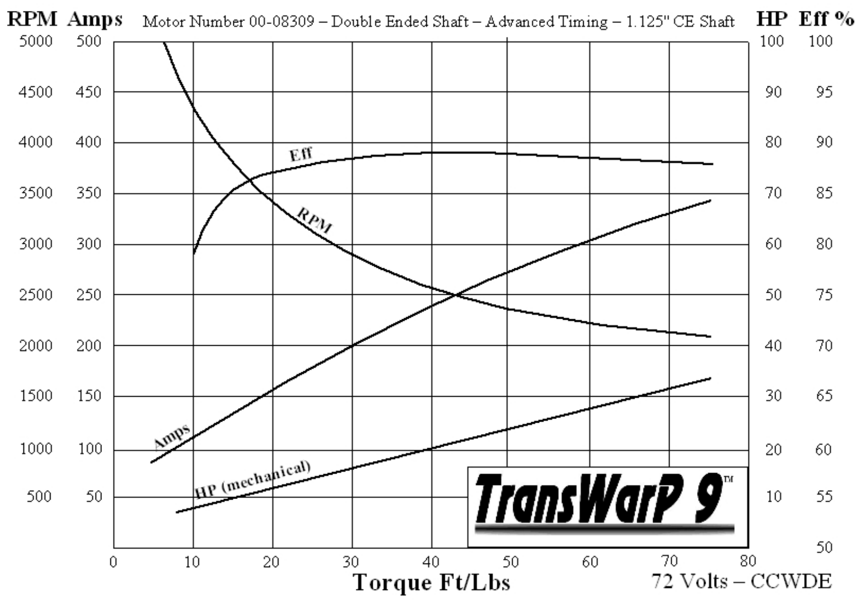

Figure 7.2

NetGain Motors, Inc.

900 North State Street ⁄ Suite 101 ⁄ Lockport, IL 60441 ⁄ 630-243-9100 ⁄ 630-685-4054 (FAX)

Motor Number 00-08309 – Double Ended Shaft – Advanced Timing – 1.125" CE Shaft

Counter Clockwise Rotation			Plot Results	Advanced timing		Droop Data	Volts 72	Ri 0	
			P/N	00-08309					
Test voltage	72		Advanced timing CCWDE						
lbs.-ft.	amps	rpm	volts	lbs.-ft.	amps	rpm	H.P.e	H.P.m	eff. %
5	81.8	5582	72.0	5.0	81.8	5582	7.9	5.3	67.3
7	93.8	5033	72.0	7.0	93.8	5033	9.1	6.7	74.1
10	108.5	4429	72.0	10.0	108.5	4429	10.5	8.4	80.5
12	120.5	4128	72.0	12.0	120.5	4128	11.6	9.4	81.1
15	136.3	3769	72.0	15.0	136.3	3769	13.2	10.8	81.8
20	154.8	3425	72.0	20.0	154.8	3425	14.9	13.0	87.3
25	173.8	3147	72.0	25.0	173.8	3147	16.8	15.0	89.3
30	196.3	2908	72.0	30.0	196.3	2908	18.9	16.6	87.7
40	241.8	2601	72.0	40.0	241.8	2601	23.3	19.8	84.9
50	264.8	2387	72.0	50.0	264.8	2387	25.6	22.7	88.9
60	307	2233	72.0	60.0	307.0	2233	29.6	25.5	86.1
70	334.5	2158	72.0	70.0	334.5	2158	32.3	28.8	89.1

Figure 7.3

TransWarP 9™

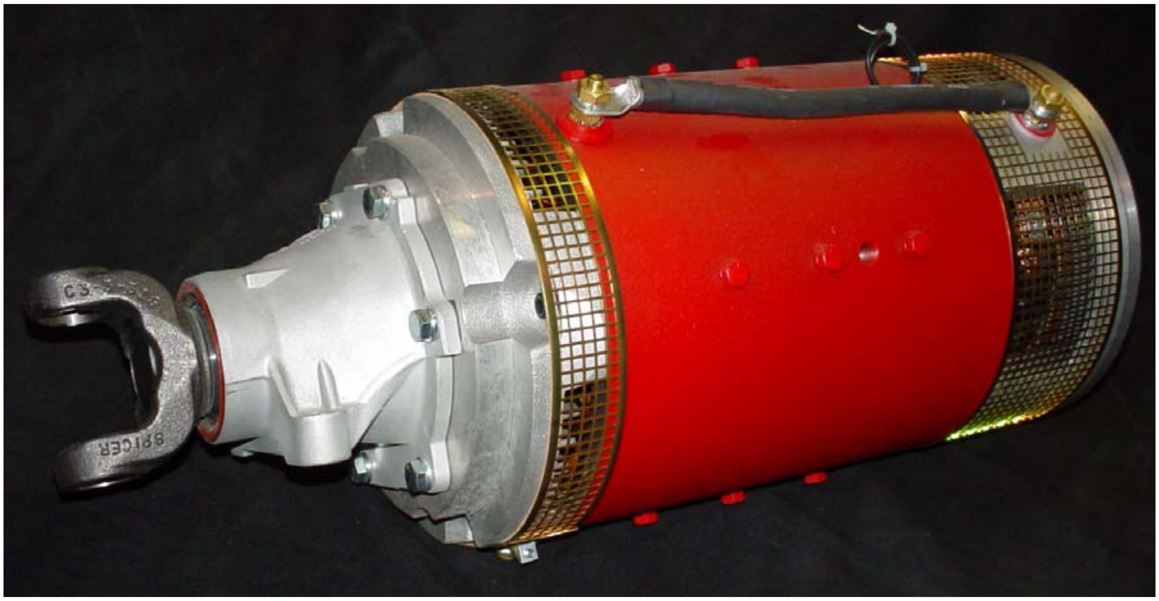

Figure 7.4

7.2 Controller
7.2.1 Research

Research for the controller started before the type of electric motor was decided. So AC and DC systems were being looked into. For AC systems, taking an already existing system and tailoring it to fit our application was introduced. The Prius Hybrid was an option to using that already existing platform. We then decided on using a DC system because it would be safer, so the Prius system was no longer a viable option. Now that we knew that the electric motor was going to be DC, we looked to see what other people were using in their home made electric car conversions. This gave us a couple of options for controllers. During our research, we noticed a trend that any system requiring over 72 volts, the price raises dramatically. So we wanted a controller that will meet the 72 volt requirement to help keep cost down.

7.2.2 Methodology

Once the type of electric motor was chosen, in this case a DC electric motor, we were able to start looking at different types of controllers. The Prius Hybrid option that we were initially researching was not going to work since the electrical system is AC. From there I started to look at what other people were using on their electric car conversions. One electric car conversion that we found was using a Curtis 1231C controller; this controller will handle voltages from 72-120 volts. This one will work with our application, but at a price of $1397.00 it is more than we can afford. We then looked at the one that was recommended by the electric motor manufacturer, NetGain, which is the Alltrax AXE series. It will handle up to 72 volts and costs around $650.00; a more realistic price for our budget. We also found that Alltrax controllers are a popular brand and are readily available.

7.2.3 Detailed Design

Figure 7.5

The controller that is recommended for the NetGain electric motor is the Alltrax AXE series. These controllers will handle the 72 Volts required by the electric motor. The controller needs to be programmed with some basic settings, so that it’s customized for each application.

Electrical components that are required for the Alltrax controller are as follows: resistors, 2 diodes, fuses, potentiometer, solenoids, and a key switch. One of the fuses, the main fuse, is included with the controller. Another 100 volt 5 amp fuse is needed to protect the potentiometer. A 1000 ohm 10 watt resistor is needed for the main battery solenoid and this is also where one of the diodes is used. The other diode is used as reverse protection for the key switch and the potentiometer. Two solenoids are needed, the first is the main battery solenoid this disconnects the battery pack from the controller and motor. The second solenoid is specific to our application. It is mounted on the positive side of the electric motor. This needs to be disconnected when the internal combustion engine is running and the electric motor is freewheeling because the electric motor cannot be used as a generator. The potentiometer is the throttle for the electric motor; this part is offered from Alltrax suppliers and cost around $80.00. Last is the key switch which activates the throttle. The Bill of Materials is listed below.

Bill of Materials		
Component	**Cost**	**Quantity**
Controller	$650.00	1
Solenoid	$120.00	2
Potentiometer	$80.00	1
Resistor	$10.00	1
Diode	$10.00	2
Fuse	$5.00	1
Total		**$1,005.00**

Figure 7.6: Controller Bill of Materials

Software is needed for the controller. The software is fairly user friendly and straight forward. There are 3 tabs on the window that opens, control panel, throttle response, and monitor. Under the first tab Control Panel, sets basic parameters for output voltages that the controller can send to the motor under certain conditions. For example maximum output current can be limited, or top speed can be limited. This is to help with power management and to limit what the driver can do with the vehicle. The second tab is Throttle Response. This section is used to calibrate the potentiometer to the controller. Finally, the Monitor Tab will help with the testing of the Hybrid boat. It will display real-time data of the system. This function will help during testing and trouble shooting of the system.

8. Battery System Team: Christopher Gitter and Christopher Stubb

8.1 Research

8.1.1 Battery Requirements for Electric Operation on Downstream Trip The power needed for the downstream trip was estimated by converting fuel used during this portion of the trip into energy (kilowatts/hour). Then this conversion was extended through the Lithium Iron Phosphate batteries recommended by last year's teams.

$$Energy\ Density\ Equation\ \ (Gasoline -> Batteries\ )$$

$$*(2.5gal)(3.7833\tfrac{L}{gal}) = 9.46L$$

$$*Energy\ Density\ of\ Gasoline\ = 32\tfrac{MJ}{L}$$

$$*Engine\ Fuel\ to\ Power\ Percentage\ Assumption: 33\%$$

$$*Energy\ From\ Gasoline: (32\tfrac{MJ}{L})(9.46L)(.33) = 99.90MJ$$

$$*1MJ = .278KWh$$

$$*(99.9MJ)(.278\tfrac{KWh}{MJ}) = 27.772KWh$$

$$*1Battery = 48Volts, 50Amp - hrs = 2.4KWh$$

$$*\frac{27.772KWh}{2.4KWh} = 11.57\ Batteries\ needed$$

LiFePo4	
Manufacturer	China Hipower Energy Group
Battery Type	Li-ion Phosphate
Volts	48 V
Amp-hrs	50 Ah
Length	13.5 in
Width	12 in
Height	7.7in
Weight	63 lbs
Life Cycle	2000 cycles
Cost	$1,200.00
2008-9 Gold Team's Recommendation	

Figure 8.1

Assumptions made:

- 2.5 gallons of gasoline are used during the downriver half of the Smooth Water trip.
- 33 percent of the energy in gasoline is converted into usable power to drive the boat.
- There is a small amount of energy wasted idling.

Lithium ion batteries can only be discharged to 80% of their capacity; the requirements were revised to 15 batteries.
[11.57 / (.8) = 14.46 Batteries (34.715kW)]

8.1.3 Battery Alternatives:

Since there are only six lithium-ion battery packs available, alternative batteries were researched. Included are the recommended Lithium-Ion batteries, Optima's 31M deep cycle marine batteries, Trojan's J185H and L16HC deep cycle batteries, and US p cycle battery were compared.

The following chart displays the price difference of each battery:

		72V	360 amps	Batteries	Cost per battery	TOTAL
Battery	**Specifications**					
Li-ion	48V50A	2	7	14	$1,200.00	$16,800.00
Optima31M	12V75A	6	5	30	$230.00	$6,900.00
US AGM 185	8V234A	9	1*	9	$448.95	$4,040.55
Trojan J185H	12V180A	6	2	12	$293.95	$3,527.40
Trojan L16HC	6V395A	12	1	12	$384.95	$4,619.40

Figure 8.2

Due to budget constraints, the six battery packs from last year will be used. Although there are cheaper batteries in this chart, many factors need to be analyzed when choosing batteries. Size, weight, discharge/recharge rates and capacities, must all be taken into account. Each of these alternatives would add over 200 extra pounds of batteries compared to the Lithium-ion type batteries being used.

8.1.4 Lithium Ion Technology:

Lithium-ion batteries are a good choice for a river application. They are more environmentally safe than lead-acid batteries, and the lithium iron phosphate batteries chosen are also the most environmentally friendly type of lithium-ion batteries available. These batteries can be constantly discharged down to 80% of their capacity without affecting their cycle life, compared to lead acid batteries, which are affected if they are constantly discharged below 45% of their capacity.

8.1.5 Battery Maintenance:

Voltage and temperature will be the main two things monitored on these packs during use. We currently plan to use voltmeters and thermocouples to monitor these variables. As the discharge rate increases under heavy load, the batteries will heat up and the risk of fire and cell explosions becomes greater. Every effort will be made to minimize chances of this occurring.

8.1.6 Battery Charging:

Currently the batteries will have to be charged overnight, or swapped at Lee's Ferry. Charging batteries on the trip upstream is not possible with our DC series electric motor, or with the gas engine as it does not have an alternator large enough for the task. Future groups may want to consider swapping in a regeneration DC motor, or even an AC motor to recharge batteries on the upstream trip.

8.1.7 Recommended Batteries:

One of the main limiting factors of this project is the amount of energy available to run the electric motor. Currently running the motor at its specified 72 volts, would equate to an available 60 amp-hrs to use. To run this trip at the motor's full capacity, 35 kilowatts of batteries are recommended. Currently Lithium-ion batteries are sold for about 55cents a watt. An investment of $13,200 – $16,800 on a new battery pack will meet these needs.

8.2 Methodology:

The current battery setup is in the lab for inspection. Evaluation of cell and battery connections will be made and will determine if the batteries need to be reexamined. The 7th battery pack that caught fire last year will be evaluated for cell integrity and possible reusability. Battery charge will be analysis as well as charge/discharge times. Quick connect cables will be used to make the battery pack modular, so our team can run in parallel and the other team can run the packs in series.

All battery decisions and information will be coordinated through both Glen Canyon River teams.

8.3 Detailed Design:

Due to cost constraints we decided to continue using the prototype batteries from last year's capstone team.

8.3.1 Battery Specifications:

- **Manufacturer:** ATL (Amperex Technology Limited)
- **Type:** Lithium Iron Phosphate (LiFePo4)++
- **Serial:** IFR86500
- **Origin:** China
- **Voltage:** 3.2Volts per cell
- **Capacity:** 1.1 - 1.4Ah per cell

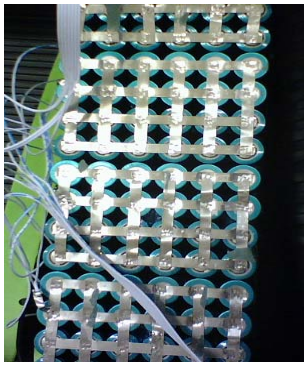

Figure 8.3

The cells are formed into Battery Pack Modules, there are 192 cells; 16 series each with 12 cells in parallel. Each module is rated for 48 volts at 15Amp-hrs. There are six packs that will be used in parallel with each other for a total of 48 volts at 90 Amp-hrs. Three batteries will be incorporated on each side of the electric motor, connected to the controller.

8.3.2 Available Horsepower Calculations:

Once the TransWarp9 electric motor was chosen for our project, energy requirements were recalculated using its amperage needs. These calculations are for continuous use based on the TransWarp9's 72Volt hp-amp data. The bench test data will be offset slightly by our use of a 48-volt system. The voltage is directly proportional to the RPMs of the motor. Due to our 48 volt system all the RPM values of the TransWarp9 bench test are 2/3rds the value of the test data. The battery requirements on the right side of the following chart include both the 80% battery discharge capabilities, and the 90% controller efficiency estimate.

Calculations based on TransWarp 9 Motor												
Battery	**Bat AMPS**	**AMPS/HP**	**HP**	**2hr A**	**3hr A**	**4hr A**	**5hr A**	**1hr bat.**	**2hr bat.**	**3hr bat.**	**4hr bat.**	**5hr bat.**
LiFePo4	15	334.5	**28.8**	669.00	1003.50	1338.00	1672.50	31	62	93	124	155
	15	307	**25.5**	614.00	921.00	1228.00	1535.00	28	57	85	114	142
	15	264.8	**22.7**	529.60	794.40	1059.20	1324.00	25	49	74	98	123
	15	241.8	**19.8**	483.60	725.40	967.20	1209.00	22	45	67	90	112
	15	196.3	**16.6**	392.60	588.90	785.20	981.50	18	36	55	73	91
	15	173.8	**15**	347.60	521.40	695.20	869.00	16	32	48	64	80
	15	154.8	**13**	309.60	464.40	619.20	774.00	14	29	43	57	72
	15	136.3	**10.8**	272.60	408.90	545.20	681.50	13	25	38	50	63
	15	120.5	**9.4**	241.00	361.50	482.00	602.50	11	22	33	45	56
	15	108.5	**8.4**	217.00	325.50	434.00	542.50	10	20	30	40	50
	15	93.8	**6.7**	187.60	281.40	375.20	469.00	9	17	26	35	43
	15	81.8	**5.3**	163.60	245.40	327.20	409.00	8	15	23	30	38

Figure 8.4

9. Stern Drive System Team: Brett Bowman and Ryan McQueen

9.1 Research:

In looking at propulsion systems for our hybrid motor system, it was vital that we only look at systems that already exist. This is due to one of our constraints that states that all components must be off the shelf components. After researching various marine drive systems, there are only three systems that are applicable to our problem. The first is a jet drive system that utilizes a jet pump, with inset impellers that pressurize the water before it is excreted out the back at a very high velocity. This system is commonly used in shallow water application but require certain amounts of horsepower, generally about 120 or more. These systems are especially adapted to shallow water applications, but a main disadvantage is that they have a very high decibel rating when running, commonly 80-90 Db, depending on the application.

Figure 9.1

The next drive system that was examined is the v-drive propulsion system. This system is commonly used by drag racing boats because of the lack of space in the boats. The system consists of the v-drive, similar to a transfer case in a car, which takes rotational energy in one end of the system and sends it out in the same direction. The two driveline or shaft connection points are each angled at whatever specification you set. This system utilizes a straight propeller shaft through the bottom of the hull of a boat, with a rudder for steering the boat. This means that there is no trim/tilt for the drive system, mostly because it is commonly used in deep, open water applications. One main disadvantage of this system is

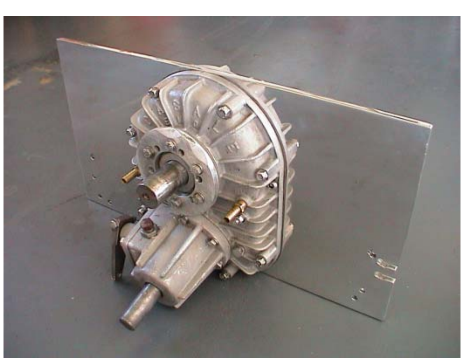

Figure 9.2

the noted mechanical loss of the system. Industries have noted that this system does have a certain amount of mechanical loss, which is another reason it is used in high horsepower applications. The common boat of the international hot boat association uses this system, but has horsepower ratings of about 7000+ horsepower so the mechanical loss is not really a factor.

The final drive system is the stern drive, which is basically the same as the lower unit of a typical outboard motor. It consists of all the gearing that is found in an outboard, but comes in a much more compact system. The stern drive system has the advantage over the other two systems in that it has a trim/tilt system, which is needed for the shallow waters of the Glen Canyon. Another main advantage of the stern drive is that there are many different gear ratios for it, making it applicable for many different motor systems. All that is needed after selecting a stern drive with the correct gear ratio is to calculate the correct propeller pitch and diameter that will work for the engine that is being used in the application.

Figure 9.3

9.2 Methodology:

In looking for a propulsion system for our hybrid drive system, we first set about to find out what types of propulsion systems are on the market and readily available. We knew that the propulsion system had to be an off the shelf component of the system. Therefore, after researching, we found the three main types of drive systems as described above. They are the jet drive, v-drive, and stern drive systems; each of which has its own purpose in the marine industry. While going through the design process, we found that the only propulsion system that would work under our given constraints is the stern drive system. This is because it can be geared to fit the engine and motor system that we have, but also because of all the added and needed bonuses it gives. Stern drives have trim/tilt which is needed for the shallow water of the Glen Canyon portion of the river. Another key factor is that is has through propeller exhaust which will allow us to direct the exhaust through the hub of the propeller, reducing noise levels tremendously. The stern drive was the only, on-the-market propulsion system that would meet our constraints and that is why it was chosen to be our propulsion system. The reason the jet drive system wasn't chosen is that it makes too much noise for our application, and the amount of debris in the water may cause the impellers and pump system to seize. The v-drive system was immediately discarded because of the fact that it has no trim/tilt, making it far more susceptible to rocks and any other impediments that the river may have. Also, because of the rudder system that is needed, we would have to fabricate many more control components than that of the stern drive, or even the jet drive. Therefore, the stern drive was an easy and well judged decision, as it will contain all that we need in a very compact and versatile package.

9.3 Detailed Design:

After concluding that the stern drive system would be best for our application, we set out to understand which of the many types of stern drives would work for our specific system. In talking with stern drive engineering, a company out of Florida, we found that a 1.84:1 gear ratio would be best for the amount of rpm's that the jet ski engine will produce. This is because if you spin a propeller too fast you will get cavitation, which is where you increase the pressure of the water so much that you actually start to boil water and seriously affect the performance of not only your propeller but the entire drive system. In knowing what gear ratio we needed, we set out to find a stern drive that contains the same gear ratio, but includes all of the necessary components. These components include: the transom plate, the gimbal housing, and the power trim pump and hoses. We found one using craig'slist.org, which is a Mercruiser Alpha 1, Generation1 165 hp with a 1.84:1 gear ratio. It came with everything that is needed for mounting, but needs new hydraulic hoses and a few cables. This stern drive is perfectly adapted to the needs of our system, and all that is needed now is to calculate the pitch and diameter of the propeller that will work for the 7000 rpm that the jet ski engine can produce. This is a very complex task and we will be working with the engineers at stern drive engineering to help us select the correct propeller for our application. Once we have the correct propeller for our application, the next step will be the fabrication and implementation of the stern drive to the boat hull that will be delivered during the GCROA presentation in early January.

10. Summary

Our design is an ecological and cost efficient alternative to resolve the increasing concern of harmful emissions, noise pollution, as well as the increasing costs of fuel problems. Currently we are in the process of acquiring parts, to begin mock up of the system. We have purchased the Aquatrax engine, the Mercruiser stern drive, and some material for the construction of the cradle system. The battery pack is being used in conjunction with the electric smooth water river boat team. All other components are being negotiated to achieve the best price.

After receiving parts, fabrication will begin to mount all the components to the cradle system. The cradle system will then be adapted to the river boat hull, along with modifications to the hull to adapt the stern drive. After all the hard mounting is done, the small portions of the system that will eventually make the entire hybrid system become functional. Shortly after, testing will then proceed to verify the boat will actually work.