Alternative Motor Boat Project for Smooth Water Operation in the Glen Canyon
Presented by Arizona State University College of Technology and Innovation

INTRODUCTION

The Alternative Motor Boat project consists of the design and implementation of an environmentally sound alternative motorboat propulsion system to be used in the Glen Canyon National Recreation Area. The alternative system must utilize a non-fossil fuel energy source and must possess the appropriate power and endurance to navigate efficiently from the Glen Canyon Dam to Lees Ferry. This represents a distance of approximately 15 miles with two roundtrips per day representing a total distance of approximately 60 miles.

The alternative propulsion system proposes to replace a conventional 135 horsepower Honda outboard motor and its traditional fossil fuel system with self-sufficiency necessary to navigate without resupply. The project focuses specifically on the propulsion system only and not on the watercraft.

The alternative system must be:

- Durable and achieve a life cycle similar to the existing power system
- Safe for paying customers
- Safe for crewmembers operating the vessel
- Reliable and require equal or less maintaining than existing system
- Operate silent or nearly silent on the downstream cruise

Ideal design would operate silent or nearly silent on both the downstream and the upstream cruise and thus minimize the impact to the Glen Canyon National Recreation Area, the passengers riding on the boat, and other canyon visitors not participating in the motorboat tour.

Design Constraints

- Noise output < 65 dB
- Emissions < Honda 135 hp exhaust output
- Maintains dependability level –
  (breakdowns/season = or < Current)
- Final project cost < $7,000
- Meets 6 year life cycle
- Maintains existing ergonomics –
  (steering wheel, throttle, etc.)
- Energy/fuel volume < or = to 15-30 gallons

- Operation time hours/day
- Capable of traveling up river (15 miles) in –
  1-1.25 hours
- Lower outboard unit operates in 47-49° F
- Engine operates in ambient up to 120° F
- Able to be adjusted for shallow (18 in.) water
- Capable of 60 river miles/day travel (2 trips)
- Propels 2-3 tons at required speed
- Requires little to no changes to boat

From top left: Embarking on a pontoon tour with the CRD fleet in the background; Pontoon rafts in the shadows & the Glen Canyon Dam; Captain Andrew at the wheel; Water flows from the stone; Towering walls of the Glen Canyon; Enjoying the sights and sun in the canyon.

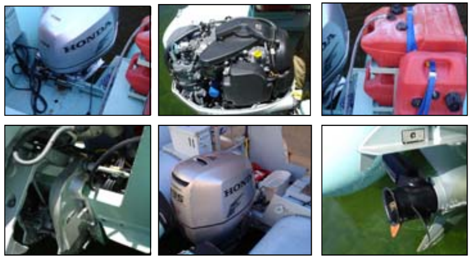
CONCEPT

Concept development began with an initial review of all criteria and constraints. This included the identification and evaluation of all crucial components. The evaluation incorporated a complex and in-depth process involving function decomposition, evaluative matrix, and nonbiased solution generating formulas. The development process also included an in-depth assessment of the mechanical function and energy requirements necessary for an alternative motorboat system.

Mechanical Function

Mechanical function was evaluated for thrust requirements, ergonomics and durability. Ergonomics of the system were focused towards keeping many of the same components in the identical location in order to minimize negative effects on the operator. Durability of the system was analyzed to reduce risks to the vessel and maintain the same or greater level of dependability. Thrust requirement were broken down into two separate categories, downstream and upstream. Some of the current mechanical configurations can be seen in (Figure 1) below.

Figure 1. Hydraulic Steering, Current Engine Configuration, Fuel Storage, Lower Unit Mount, Engine Compartment Configuration, Composite Propeller



Energy Requirements

Energy requirements were derived from outfitter input on throttle settings used during boat tours. The average throttle setting, duration of each throttle setting, and power requirement for achieving on-plane status were used. From the throttle setting, the corresponding motor output in horsepower was determined. Once the required horsepower was calculated, a power conversion was utilized to establish the energy rate for both the downstream tour and the upstream return trip. Sample energy requirement calculations can be found in (Figure 2) below.

Figure 2. Energy Requirements

Assumptions:
1.5hr 40-70% throttle (average 55%)
55% throttle ≈ 30hp (electric) 22.37kW
1.5 hr 10% throttle (assuming negligible)
1hr to travel upstream
Achieve on plane for entire upstream leg
45hp (electric) 33.56kW required for plane

Motor/Battery Specs:
125V System (Motor)
134Amp Draw (Motor)
48V Unit (Battery)
50Amp-hr (Battery)

Downstream Power Needs:
(22.37kW)*(1.5 hrs) = 33.56 kW-hrs

Upstream Power Needs:
(33.56kW)*(1 hrs) = 33.56 kW-hrs

Total Power Needs:
67.12kW-hrs

Battery Requirements:
(134Amp)*(2.5hrs)=335Amp-hrs
125V

Batteries Needed:
P=IV Batteries needed=P/(IV)

28 Battery Units Needed

One of two viable alternative power systems was chosen for prototyping. The first alternative was a hybrid system. This system integrated an electric motor for the down-river tour and utilized the existing Honda 135 hp outboard motor with a fuel system modification to burn ethanol for the return up river trip. The second option was an electric power system that utilized an industrial strength electric motor for the down river tour as well as the rapid return up river.

ELECTRIC SOLUTION

The most viable solution was determined to be the electric power system. The system would include an electric motor for a near silent down river tour as well as a near silent up river return. The electric power system would include a water cooled electric motor manufactured by Siemens (Figure 3). This motor powered the Ford Ranger EV, demonstrating that it will withstand harsh operating environments and provide adequate power. Along with a simple motor gearbox, a composite propeller system would be incorporated to reduce weight, and more importantly, cost. The system would also encompass several lithium-ion phosphate batteries (Figure 5). This system would provide a reduction in motor maintenance costs by reducing the number of system parts. Combining proven motor technology with a composite propeller and lithium batteries, the pure electric power system would provide near silent river tours.

Figure 3. Water Cooled Electric Motor

Figure 4. DC-AC Inverter & Speed Control

Figure 5. Lithium Ion Phosphate Batteries

Water Cooled AC Motor

Manufacturer - Siemens
Supplier - Electro maven

Voltage - 250V
Peak Power - 67 KW
Current Draw - 268 Amp

Length - 14 in
Width - 12 in
Height - 13.375 in
Weight - 140 lbs

Life Cycle – 10 years min
Cost - $2,000.00

System Benefits

Zero emissions in Glen Canyon
Customer preference
Lower long-term cost
Much higher efficiency
Eliminates fuel transfer to dock
EV technology transferability
Imminent technology breakthroughs
Prevalence reduced cost

System Disadvantages

Personnel training
Possible electrical shock
High startup cost

Lifepo4	
Manufacturer	YongXingMachineZone
Battery Type	Lithium-Ion Phosphate
Voltage	48V
Amp-Hrs	15
Length	13.5 in
Width	12 in
Height	7.7 in
Weight	9 lbs
Required	7 units
Cost	$1,743.00

Figure 6. Electric Power System Prototype Cost

Component	Quantity	Shipping	Cost:	Sub Total
Shaft Coupling	1	$12.03	$268.00	$280.03
Water Pump Hardware	1	$0.00	$139.33	$139.33
Mounting Plate	1	$0.00	$179.98	$179.98
Controller/Inverter	1	$115.27	$2,283.29	$2398.56
Motor	1	$126.00	$1,874.00	$2000.00
Batteries	7	$130.00	$1,743.00	$1873.00
Accelerator Sensor	1	$7.55	$299.99	$307.54
Wire & Battery Box	1	$0.00	$70.00	$70.00
Prototype Cost Total:				**$7248.44**

Figure 7. Annual Fuel Expense Saving Electric System

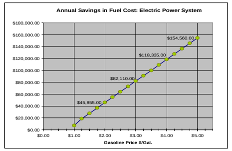


Figure 8. Fuel Cost & Savings Model

Honda 4-stroke Gasoline Cost Report	
Average Cost Per Gallon Gasoline	$3.00
Average Fuel Consumption Down River (gals gasoline)	4
Average Fuel Consumption Up River (gals gasoline)	6.5
Cost per trip down river	$12.00
Cost per trip up river	$19.50
Cost per trip	$31.50
Trips Per Season	3,450.00
Annual Fuel Consumption (gals gasoline)	36225
Total Seasonal Cost	**$108,675.00**

All-Electric Trip Cost Report	
Average Cost Per kWh	$0.11
Average Electric Consumption Per Trip (kWh)	70
Cost per trip	$7.70
Trips Per Season	3,450.00
Annual Electric Consumption (kWh)	26565.00
Total Seasonal Cost	**$26,565.00**
Savings Per Trip (Pure Electric vs. Gasoline)	**$23.80**
Savings Per Season	**$82,110.00**

The Future is Electric

As the cost of batteries decrease and battery energy density increases, the feasibility of a completely electric motorboat tours in the Glen Canyon draws nearer. Batteries are becoming lighter while performance continues to improve. Recent developments have progressed battery technologies to a competitive level in recent years. Today, we are on the verge of a new frontier in battery technology that will transform the transportation and recreation industries. The implementation of a full scale pure electric motorboat propulsion system is not far off.

IMPLEMENTATION

Implementation: The Siemens water cooled 90 hp electric motor was fitted with a high torque backlash free elastomer coupling (Figure 11 & 12). The coupling transfers the applied torque from the electric motor to the drive shaft of the lower-end while allowing for drive shaft variability and connection flexibility. The RW America coupling is rated at 325 Nm or proximity 250 lbs/ft of torque while the Siemens motor produces only 149 lbs/ft or 202 Nm of torque. This allows for a greater margin of safety and a better overall design. Other coupling specification and images can be found below (See Figure 10 to 12).

Figure 9. Coupling

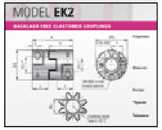


Figure 10. Coupling Specifications

Model EK 2 Series 300

- Rated torque: 325 Nm
- Max. torque TK: 350 Nm
- Overall length A: 114 mm
- Outer diameter B: 82 mm
- Outer diameter with screwhead BS: 85 mm
- Mounting length C: 45 mm
- Inner diameter range H7 D: 20-45 mm
- Inner diameter max. elastomer DE: 36.2 mm
- Mounting screw: ISO 4762/12.9
- Tightening torque; mounting screw: 70 Nm
- Distance between centers F: 29 mm
- Distance G: 15 mm
- Hub length H : 66 mm
- Moment of inertia per Hub: 0.4 (10-3 kgm2)
- Approx. weight: 1.1 kg
- Speed: 9500 rpm

Figure 11. Coupling Attached to Motor Shaft

Figure 12. Coupling on Motor Shaft

Mating the Siemens electric motor to the outboard lower-end required the design and manufacture of a transitioning face plate. The aluminum transition plate provides motor stability, proper driveshaft alignment, and ample force distribution. A Coordinate Measuring Machine or CMM was utilized for mapping the attachment face of the electric motor and the mating face of the lower-end. Once a complete set of measurements had been obtained the two faces were mated with the assistance of solid modeling software. The transition plate can be seen before motor and lower-end installation (Figure 13 through 15).

Figure 13. Transition Plate Computer Model

Figure 14. Plate Machining Tool Path

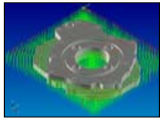


Figure 15. Motor to Lower-end Transition Plate

The electrically generated thermal energy is dissipated through the convection heat transfer process utilizing the cool Colorado River water and the existing water pump system. Water pump modifications consisted of the reconfiguration of the water supply tube and the addition of a flow throttle for optimal fluid flow. The water tube modifications can be seen below (Figure 17) as well as a custom manufactured bracket that supports proper water tube orientation within the water pump. Figure 18 shows the temporary shift linkage lock block that prevents the output driveshaft from inadvertently slipping out of gear.

Figure 16. Water Tube Reconfiguration

Figure 17. Shift Linkage Lock Block

Figure 18. Water Pump & Shift Linkage Location