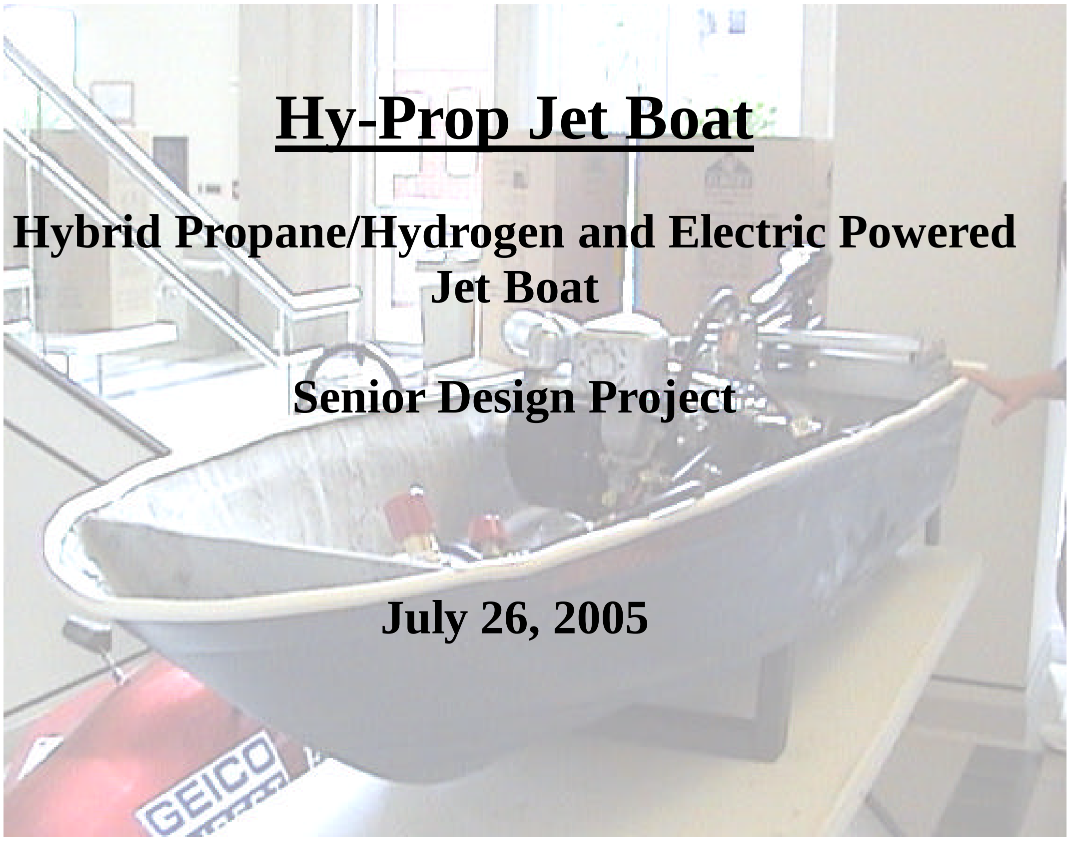

Hy-Prop Jet Boat

Hybrid Propane/Hydrogen and Electric Powered Jet Boat

Senior Design Project

July 26, 2005

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Executive Summary

The Hy-Prop boat is a dual fuel source, hybrid electric, water jet propelled watercraft. It is designed to investigate the future feasibility of alternate fuel integration and hybrid technology on a water based platform. The team, using an existing 1/8th scale hull, designed and outfitted it with all the necessary components to create a self-contained watercraft. Through testing and observation the craft exceeded previously set expectations and proved its commercial viability as a hybrid vehicle if scaled to a full-size application. Currently, the boat is calibrated to run on propane and will accept hydrogen as a fuel source.

The Hy-Prop Jet Boat team would also like to thank those individuals whose help was invaluable to the success of this project:

Advance Auto Parts of Palm Bay

Bateau Corporation

Bob Wells

Central Hydraulics and Equipment Inc.

David Whitehead

The Florida Tech Hydrogen Research Center

F.I.T. Machine Shop

Jose Agala

Mark Cencer and Mikhail Dembicki

Mike O'Kelly

Rich Escagne from Import Generators

Tractor Supply Company

US Carburetion

Dr. Zborowski and Dr. Thosteson

And most importantly, our friends and family that endured our long hours and surly dispositions while working on this project.

The information provided herein will serve to explain the various aspects of the project itself and the work that was done. Procedures used to complete the project, results of applicable design, construction, testing, discussion of said results, concluding remarks and future recommendations are explained in greater detail in the subsequent sections.

The history of true hybrid/alternative fuel vehicles can be traced back to Francois Isaac de Rivaz in 1807. He was the inventor of the first internal combustion engine which, curiously enough, was powered by mixture of hydrogen and oxygen. In 19th century manufactures and inventors alike first mated gasoline and electric power sources on one platform. It wasn't until the late 1980's, however, that the full potential and basic necessity of these vehicles was realized. As gas prices continue to rise and environmental concerns about emissions standards mount, the technology and popularity of these systems continues to grow exponentially. Manufacturers and worldwide governments are starting to realize the benefits for both the environment and themselves and are currently pumping billions of dollars every year into the research and development of these vehicles. The current source of power for hybrid automobiles is based on gas/diesel-electric platforms; however, there is a strong push for further development on hydrogen-electric platforms. Scientists and engineers are predicting that rapid advances in fuel cell technology will eventually find themselves in almost all automobiles, however the technology is currently not perfected and more advances will have to be made in order for general production. The next logical step is to utilize what is currently available, namely the standard internal combustion engine, and convert it to run on hydrogen fuel. Ford has done exactly this and created one of its newest concept cars, the Hydrogen Hybrid Research Vehicle (H2RV), which is based on their current gas-electric platforms, with the only difference being gasoline replaced with hydrogen. The result has been astounding; as compared with regular gas engines, the H2RV can easily achieve comparable performance with "more than 99 percent reduced CO^2 vehicle emissions" (Jan. 2005, focaljet.com) and a 25 to 50 percent increase in fuel economy. While most of the focus has been on the automotive industry, it will be necessary that this new hybrid technology will slowly adapt to other areas such as the watercraft industry.

One of the problems plaguing the advancement of hydrogen as a vehicle power source stems from the difficulty in storing it effectively. Classically, hydrogen is stored as a liquid at -320 F°. This poses two distinct problems. First of all, keeping the hydrogen at this temperature requires that the pressure be maintained in the vessel. This means that in the (relatively) highly likely event of a vehicle collision, the vehicle could puncture the hydrogen container, causing it to leak out. This would create a very dangerous explosion/fire hazard that would be unacceptable in mainstream vehicles. Secondly, this method of storage is not very space efficient. Overall, storing hydrogen in liquid form is not very effective. A new method of hydrogen storage must be perfected before mass production of commercial vehicles could realistically be made to run safely off of it.

For the boat to be considered a hybrid vehicle there needs to be two different drive trains that work independently or in combination to propel the craft. The primary drive train used in this project, the one to be used at speed, was a jet drive, which will have an engine driven water pump at its heart. The engine will be converted to run off hydrogen so it can be used in conjunction with the hydrogen storage units, and utilize propane as a back up energy source. This drive train will be connected through an alternator to the second drive train, the electric trolling motor. The trolling motor is considered a secondary drive train because it is used mainly at slow speeds and possibly in conjunction with the jet drive at higher speeds.

In order to maintain longevity out of the secondary source of propulsion, the trolling motor, the onboard battery must be at a maximum level of charge at all times. In order to accomplish this task an alternator was added to the engine assembly and connected to the battery to maintain its full operating potential. The alternator may also be reconfigured to act as a starter motor.

To create a vessel that is both efficient and effective in its desired purpose, its hull must possess two main characteristics. In order to minimize the amount of boat in the water and, therefore, the amount of drag it produces, weight must be one of the prime considerations. Therefore, there must not be any material present that may add unneeded weight. The second of these two characteristics, dealing with the effectiveness of the vessel to perform its desires tasks over a long period of time, requires that the hull must be structurally sound. If structural soundness is not achieved, various elements may break down over time, causing catastrophic failure of the hull.

The rudders for the boat will be a dual rudder setup, this will allow sufficient surface area to maneuver the craft as well as leave room for the trolling motor and the jet drive to be centered on the stern of the boat. This will also increase the maneuverability of the craft.

The other valuable sources of information available to the team were David Whitehead (fiberglass and PVC expert,) Bob Wells (small jet-drive expert,) and Rich Escagne (alternator expert).

Procedures

In order to complete this project, a working hull needed to be acquired. The hull provided by the Department of Marine and Environmental Systems (DMES) was a scale model used for another design project in 2001. The goal of that project was to compare a v-hull design that contained a step in the hull with a standard one. This allowed for two groups to use essentially the same hull in two different hybrid boat projects. Our group received the stepped hull.

Figure 1: Initial hull

Initially, the hull was in very bad shape. The fiberglass was severely delaminated, reducing the structural stability of the entire craft. After initial testing, it was discovered that the sides and back of the hull were far too short (see Figure 1.) This would cause the boat to fill with water in any kind of wave action or tight maneuvering. The solution to this problem was twofold:

The first problem that needed to be addressed was the issue of available freeboard with the hull. During the original Eureka testing, no people or components were placed in the hull; therefore, freeboard could be kept at a minimum. In order to outfit the hull to the present projects specifications which included the addition of a driver, power train, and other various components, freeboard had to be increased in order to ensure that the fully loaded hull would remain afloat. To fix this problem, a material was needed that had to

Figure 2: Freeboard build

be structurally sound and able to continue the smooth curves of the hull while keeping weight addition to a minimum. Several different materials were considered but, in the end, Nida-Core was used.

Nida-Core, which is made of recycled plastic containers and molded into a honeycomb pattern, utilizes a thin sheet of fiberglass mat on each side, allowing it to remain pliable and light. Thickness of Nida-Core material varies according to its specified application; however, when wetted with resin and fiber glassed into place, Nida-Core is stronger than traditional materials, yet adds only a fraction of the weight compared to conventional materials.

In order to add additional freeboard to the stern of the hull, panels were cut from a 1/4” Nida-Core sheet. These panels were fit so that the entire hull had a constant height throughout its length. A combination of Bateau Inc, resin and hardener was used in conjunction with West System brand 404 high-density adhesive filler to create a “putty” that would hold each panel in place. In order to maintain traditional boat transom appearance, the port and starboard corners of the transom section were cut, and wedge-shaped pieces of Nida-Core were inserted and held in place with more of our “putty” (see Figure 2.) This gave the transom more of a pronounced corner, rather than a curved edge. Once the panels were set, 8oz fiberglass cloth was used to ensure a secure and watertight fit. As soon as the resin had a chance to harden, 80-grit sandpaper was used to rough up the area so that the next step of the hull restoration process could take place.

With the Nida-Core freeboard build-up now in place, transitions between the original hull and the Nida-Core panels, both inside and out, had to be filled with a similar type of “putty”. To create this new fairing compound, Bateau resin and hardener were again used. West System brand 410 microlight fairing filler was used along material transitions as well as any areas that needed to be filled for aesthetic purposes. As with the panels previously discussed, once the faired regions had a chance to harden, 80-grit sandpaper was used to fashion the desired shape.

The next major issue to be resolved came in the form of its structural members, more specifically its floorboard and associated bulkheads. During the Eureka project, the hull had to be structurally able to withstand the forces present during high-speed tow testing. The floorboard consisted of 3/4” marine-grade plywood. In addition, there was approximately 1/2" resin and fiberglass mat combination on either side. The bulkheads were 1/2” marine-grade plywood, which were also fiber glassed on each side. These structures proved to be impractical for our desired use and a solution had to be formulated to maximize the full potential of the hull.

In order to accommodate this requirement, the entire floorboard needed to be removed and the entire floor layout had to be redesigned. Because this material was not being recycled, disassembly was done through the use of saws, grinders, crowbars, and any other means that would allow for easy removal. Once the bulk of the scrap material was removed, a grinder was used to remove any delaminated fiberglass and smooth out any rough spots to ensure a clean bare hull with which to work.

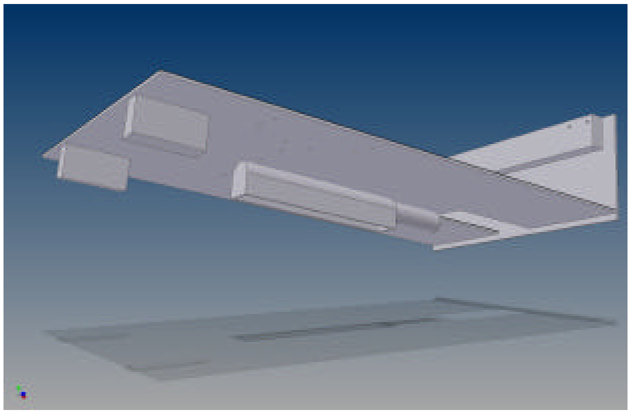


Figure 3: Floorboard design

Once all unnecessary material was removed from the hull, a 1/2-floor design was constructed from much lighter-duty material (see Figure 3.) The new 1/2 floor, exactly 4 feet long, was made of 1/4” marine-grade plywood with 8oz fiberglass mat attached to each side. This new floor design proved to be structurally sufficient in withstanding any forces that may have acted upon it.

The final problem to be addressed was the inherent instability of the hull. Because the hull was originally built as a scale model, the addition of a driver and components that did not fit to scale led to the fact that the hull contained a notable degree of instability in the rolling direction. As such, the dimensions of the hull limited the amount of rolling stability that could be achieved. While a minimum of additions were added to the hull, the boat was still unstable.

In order to minimize the problem of axial instability in the rolling direction, placement of the new 1/2 floor, based on stability calculations, was found to be as far back and as low as possible, so that the metacentric height, was no larger than necessary. To ensure no flexing of the floor would occur, two wooden supports were added toward the front of the floor. The rear portion of the floor rested on the intake scoop, and the whole floor was supported along the entire outside edge. This made for a solid, stable platform with which to add components and a driver. As mentioned before, the dimensions of the hull proved to be a limiting factor with respect to overall stability.

Although the finished product was not incredibly stable, instability of the hull was kept to a minimum.

In theory, converting an engine to run on propane (or hydrogen) should be a relatively simple affair. After all, internal combustion just requires a flammable substance mixed with air to encounter a spark in an enclosed area. The ensuing explosion is used to move a piston that drives an engine. The only differences between gasoline and other fuel sources are in the delivery and application of this combustible material and the fuel efficiency.

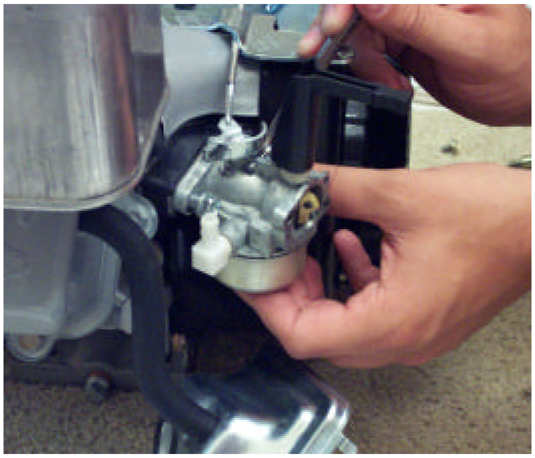


Figure 4: Carburetor refit

In order to provide the engine with gaseous fuel, a new jet had to be installed. After purchasing a 5.5 hp Briggs and Stratton engine (with water pump) and breaking it in with regular gasoline, it was ready to be converted. The old carburetor was relieved of its float and bowl. The old jet was removed by drilling out the entire intake area (see Figure 4) and a new jet was installed. This longer jet allows for the gaseous fuel to get into the engine. Normal gasoline comes into the carburetor and is sucked into the engine, but as a gas, the fuel would dissipate before it had a chance to be sucked into the firing chamber. The longer extension of the jet applies the gas much closer to the intake, making sure it gets into the engine.

After jet installation, the propane regulator was installed as per the manufacturer’s instructions. It was bolted onto the engine in the area where the (now removed) gas tank was. It was attached to the secondary regulator that fit into the propane cylinder. One of the advantages of this setup was that it used all standard fittings already present on the market. Any propane container commercially available could be added to the boat with no alterations needed to either the container or the engine.

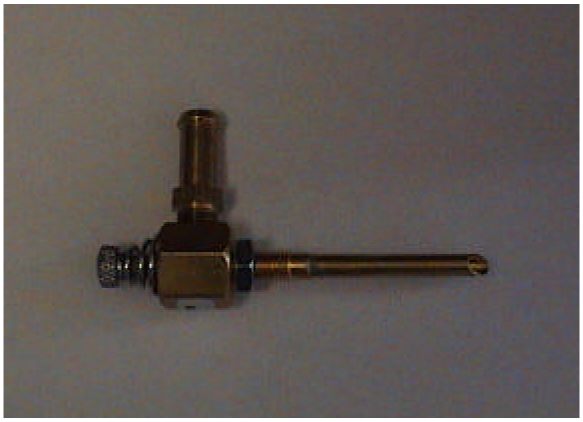


Figure 5: Jet with setscrew is on left

To actually control the amount of fuel-air mixture, a setscrew on the propane jet was adjusted to physically limit the amount of fuel that got into the engine (see Figure 5.) The choke was put to its minimal setting and the throttle to its maximum. The setscrew was adjusted to its lowest setting and the engine was started. After 3 tries, the setscrew was adjusted to allow more fuel into the engine and it was started again. This process continued until the engine started and continued running on its own. After that, the choke was readjusted and the setscrew restricted until the engine's output and tonal quality was maximized.

Further converting the engine to hydrogen was accomplished by adjusting the fittings. For safety, the connectors for different gasses cannot be interchanged, so a conversion had to be made. The connector for the propane bottle was removed from the regulator and a new regulator was added. This 2-valve system (see Figure 6) serves two purposes. First, it has a gauge that displays the pressure in the hydrogen tank. This ensures that the tank was not depleted

Figure 6: Hydrogen regulator

too far. The second function is to regulate the pressure of gas that is delivered to the propane regulator. Without this, the pressure in the tank would blow out all the seals in the second propane regulator. Further adjustments to the setscrew were needed to compensate for the new fuel.

In order to steer the boat, a rudder system needed to be developed. A single rudder (placed in the middle of the stern) would interfere with the jet output and the trolling motor, so a dual rudder setup was used. At first small kayak rudders were considered, but were thought to be too small and too expensive. It would have cost hundreds of dollars to have two of these mounted to the back of the boat. Also mounting such short rudders would have created a problem on the relatively large stern. The next idea was to completely design and build them from scratch.

The rudders were designed using a formula found in naval architecture. It is as follows:

Area of Rudder(s) = 0.05 * Beam * Length

where all measurements are at the waterline. For our craft, this calculation yielded an area of 114”, which was divided between the two rudders. The entire rudder design was drawn in Pro-Surf and checked for accuracy (see Figure 7.) High-density foam rudders were acquired from DMES and hand carved to the exact area needed. These were connected to poplar wood boards with oak dowels and the entirety was fiber glassed and finished for strength.

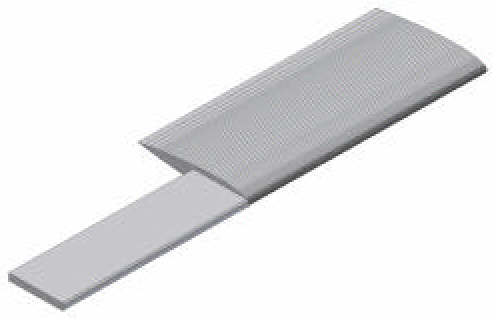


Figure 7: Rudder design

To interface the rudders with the boat, the team contacted the FIT sailing club and borrowed two mounting brackets from one of their smaller sailboats. These were easily mountable to the new transom added to the boat. In order to make our rudders fit; a new layer of fiber glass was added and ground down to properly seat in the bracket assembly. The entirety was modeled in Inventor to ensure fit with itself and the other parts.

The rudder steering system consisted of four store bought mounts attaching the rudder plates to the stern of the boat, which will allow them to pivot. These were attached to the stern with stainless steel nuts and bolts. The rudder assembly fitted to these mounts using clevis pins and washers for spacing. The top end of the rudders extended up through the rudder plates and above the stern of the boat. Each rudder was attached to a section of 1” square aluminum stock and connected using another piece of stock aluminum. The connected structure would be able to turn both of the rudders at the same time and allowed for the driver to control the steering of the boat (see Figure 8.)

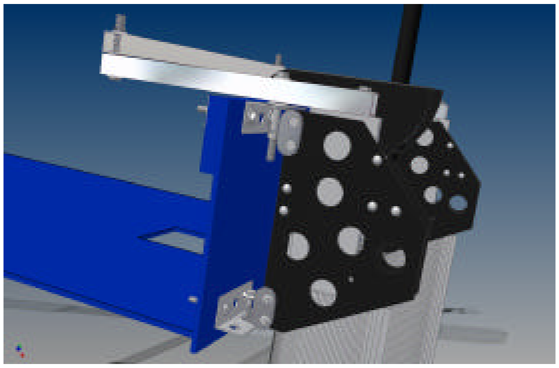


Figure 8: Rudder controls

The jet-drive system was main drive train of the boat. Once running, the pump will pull water from one location, accelerate it, and expel it out that back of the boat. This is the same concept used in jet skis, jet boats, or wave runners; the difference is in the pump design. The type of pump found in these types of watercraft is designed for optimal performance for their intended use. For cost purposes, the team used a pump intended for utility work and designed a new intake and output for optimal performance as a jet-drive system.

In order to supply the pump with water, a proper intake had to be designed. For this, we turned to Bob Wells, an expert in jet drive applications in small craft. Through talks with him, a list of intake requirements were established, such as shape and size of the intake to allow for sufficient water flow into the pump, placement of the intake to ensure maximum inflow of water, and hull characteristics needed to ensure a steady, unhindered flow.

The first step in properly retrofit our hull with a water intake system was to decide exactly where on the hull the intake should be. Proper placement and design would ensure ample water flow to allow the boat to run through the full throttle range. Based on discussions with Bob Wells, it was recommended that the intake be on the rear half of the hull, along the centerline, with enough smooth surfaces around the intake to limit air from entering the system.

Figure 9: Intake grate

The shape and size of the intake were fairly straight forward. The volume of water entering the intake had to be large enough so that the water pump would not be starved. Through a calculation performed by Bob Wells, it was decided that a standard stainless steel rectangular marine air intake grate approximately 16” long by 2” wide would allow for ample flow (see Figure 9.)

Now that placement, shape, and size of the intake were established, the final aspect of the intake implementation process dealt with the amount of smooth surface around the intake grate. As it turns out, the stepped hull we used for this project added another unforeseen difficulty. By design, hull steps are meant to introduce a layer of air along the bottom of the hull, which is precisely what the team needed to avoid.

To create enough smooth surface around the intake grate and, at the same time, eliminate the effects of the hull step it was decided that the area around the grate must be built up. To do this, poplar planks, approximately 20” long by 8” wide were custom fit around the grate in order to build up a smooth transition with the hull step (see figure 10.)

Figure 10: Intake preparation

The area was roughed up, and once again, “putty” made of Bateau epoxy and West System brand 404 high-density adhesive filler was used to secure each plank piece into place. Once the pieces were solidly in place, 8oz fiberglass mat was glassed into place over the entire area, creating a watertight, smooth form. As soon as the resin had hardened, the surface was sanded with 80-grit sandpaper and the similar “putty” made of Bateau epoxy and West System brand 410 microlight fairing filler was spread over the entire area. Again, upon hardening, this area was sanded with 80-grit sandpaper to remove any imperfections, and then sanded again with 150-grit sandpaper to prepare for painting.

To properly channel the water from the intake grate to the piping system that would feed the pump, a type of collection box/scoop had to be incorporated. Many commercially-available designs were considered, yet each had a specific drawback that would not allow for simplicity or ease of installation. In the end, it was decided that in order to maximize the efficiency and performance of water flow into the pump, a custom-built intake scoop made from Nida-Core and PVC pipe had to be assembled.

In order to precisely build a correctly dimensioned intake scoop, the size of pipe leading to the pump was first considered. Because the inlets and outlets of the water pump are each 2” diameter, the pipe leading to the pump was also selected to be 2”. For the connection from the intake scoop to the inflow pipe, 2 ½” diameter thick-walled PVC was selected. This larger diameter allowed that sufficient water would enter the pipe system at all times.

Once the diameter had been established, 180 degrees of the pipe diameter needed to be removed. A short section of pipe remained intact, as to allow for solid connections to be made see Figure 11.) This now-open section of pipe would face down, and once the Nida-Core form was created around it, would allow for direct water flow up and through the intact portion, directly into the 2” diameter inflow pipes.

Figure 11: Intake scoop build

In order to properly attach the Nida-Core housing around the PVC, “putty” made from epoxy and filler was used in steps to wrap the Nida-Core around the PVC shape. The ends of the “U-shaped” design were closed using custom-fit Nida-Core pieces. All voids were filled using filler to ensure a watertight seal. Once this “trough” or “U-shaped” form was set, the open end was faced down over the intake grate. A heavier material called woven roving was employed to secure the intake scoop. Using such heavy material ensured that under any conceivable amount of pressure, the intake scoop would not fail. Attachment of the woven roving material follows the same steps as working with fiberglass cloth.

When deciding on where the jet output should be with respect to the waterline, several conflicting reports were encountered. Some sources claimed below the waterline was best for optimizing power, while some claimed at, or even above the waterline were best. Due to the uncertainty, it was decided that outlet location with respect to the waterline would be incorporated into the testing phase of this project. This adjustable system of outlets allowed for it to be proven which placement was indeed the best.

The first step in placing the output through the transom of the boat was to cut the proper size hole. Because the outflow pipes leading from the water pump were 3.25” in diameter, a 3.25” hole was used. Once the hole was cut, the fitting was fiber glassed in the precise location in which it would sit when the boat was fully assembled. This area was allowed to harden, and sanding and fairing procedures described previously were performed to ultimately prepare this portion of the boat for paint (see Figure 12.)

Figure 12: Fitting installed

Next, in order to maintain ease of testing, a 2” threaded coupling was inserted into the 3” fitting in the transom. This threaded coupling allowed for different sized fittings to be screwed on or off to test the effectiveness of different nozzle sizes. The adjustable outlet height fitting was constructed of two 45-degree PVC elbows attached together in an “S-shape”. This arrangement allowed for the outlet to be at the waterline, as well as a few inches above and below the waterline if so desired. The team decided to apply this procedure in the testing in order to determine the most effective placement.

The most frequent engineering hurdle involved with making a hydrogen-powered craft revolves around the storage of the hydrogen itself. The problem of hydrogen storage could be solved in two ways. One was to use a metal hydride storage unit, such as the PAssively-Cooled Electrically heated (PACE) unit. This uses lithium hydride powder and heat to store the hydrogen gas at up to 200 times volume. This hydrogen could be extracted by careful heating of the unit, allowing for variable production at low pressures. Two of these units were designed and built by us using the Department of Chemical Engineering materials. All parts for the PACE units were constructed from Stainless Steel. The individual pieces were brazed together using a silver solder compound. This provided structurally stable joining for the parts and insured that the hydrogen did not leak out of the welds and that the individual components would not melt.

The end plates and spacer units needed to be lathed from stock material, as this made them measurably stronger and will allow for the very fine machining of the necessary components. This also ensured that the pieces would custom-fit the rolled tube material used in the case construction. The welded “bead” running along the inside of the tube was not uniform, requiring a custom fit each time. The actual working process of the PACE unit can be found in detail in the Appendix A.4.

The second alternative was to use a pressurized tank. This method provided for a less efficient storage method, but was less costly and more reliable. A Q-sized tank purchased commercially holds 80 cubic feet of hydrogen gas and would fit in the bow of the boat in the same area as the propane tank. This insured that if the PACE units could not be used; there was a back-up system in place.

The second source of power for the hybrid system was generated from an alternator. It needed to be compact, light, relatively inexpensive, internally regulated and easy to wire. The alternator needed to keep a 12-volt battery charged while the trolling motor was running. Knowing that the trolling motor needed 30 amps to run at peak efficiency, and that only a few more amps were required for the battery to remain charged, a 40-45 amp rating on the alternator would be required.

The model chosen was a Nippon-Denso 12 volt, 45 amp, two wire, internally regulated alternator. It is one of the smallest alternators used in automobiles and is reasonably priced when refurbished models can be found (see Figure 13.)

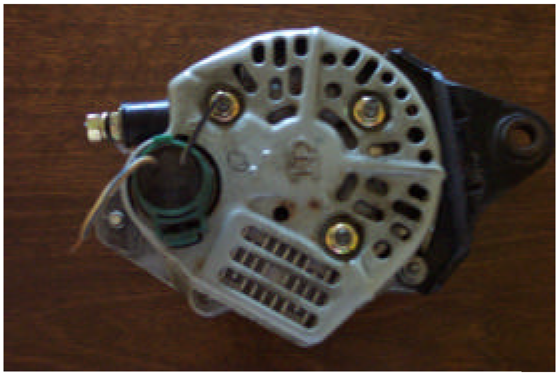


Figure 13: Alternator

Once a suitable alternator was acquired, integration system was designed using Inventor. A bracket was designed that would use the existing mounting points on the engine's pull start assembly to mount the alternator to. As this was the point at which all the remaining alternator parts were to be mounted to, it was made extra strong through the use of 1/8th in. steel plate. This design also required that the pull start itself would need to be distanced from the assembly. A drive shaft extension was designed to shift the entire assembly and spacers were designed to displace the pull start; completing the design.

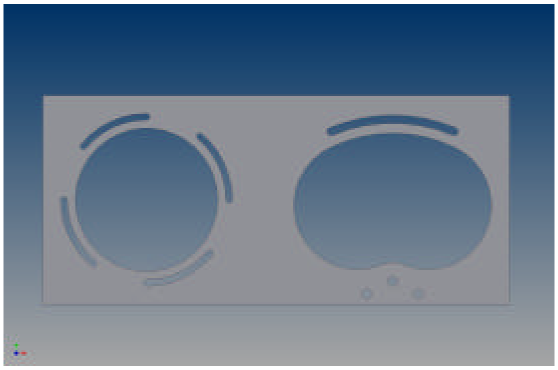


Figure 14: Alternator bracket

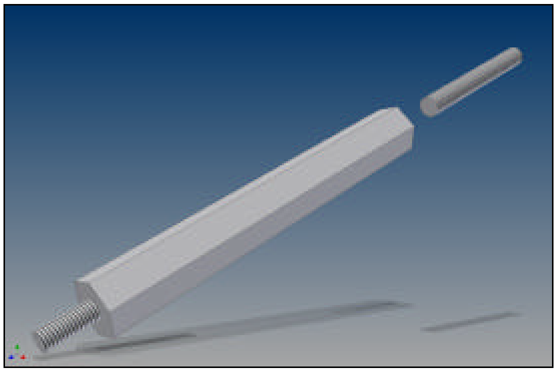


Figure 15: Original standoff design

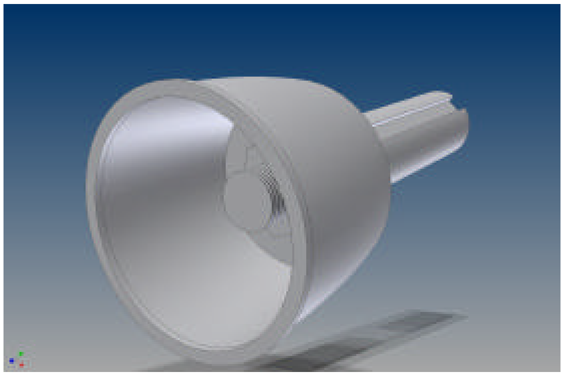


Figure 16: Drive shaft extension

After numerous revisions, most of the necessary parts were ordered from McMaster-Carr. The Inventor file was transferred to blueprints and was taken to the Florida Tech Machine Shop. The parts were then assembled and wired and testing was done in accordance with the procedures in the testing section to follow.

Tests

The completed boat underwent a series of tests to determine the best configuration and to show the resulting effectiveness of the design. The tests were conducted in the Indian River Lagoon, as it is sparsely populated and has a minimal current to affect our testing. The tests included:

- Output Diameter

- Waterline Position
- Speed
- Thrust
- Fuel Usage
- Electrical system
- Maneuverability
- Compete with other hybrid boat team

<u>Output Diameter Test:</u>

(This procedure was applied to the speed and thrust tests to determine the most efficient size nozzle for the jet output.)

Figure 17: Nozzle fittings

1. Gather different screw-in nozzles to fit the base installed in the boat. Each succeeding nozzle will be ¼" smaller in diameter than the last one.
2. Apply Teflon Tape to the threads of the adapter to ensure a waterproof connection.
3. Install the fitting into the base of the nozzle.
4. Perform the required testing.
5. Repeat the test using a new nozzle size until all are used.

<u>Waterline Position:</u>

1. Load the boat with all components.

2. Mark the high water line in still water.
3. Take notice of the water line throughout all other tests to ensure that it does not come within 1” of the top of the freeboard of the boat.

Speed Test:

1. Using only the trolling motor and the GPS, measure the speed attained both with and against the current for three separate trials.
2. Record the average of the three trials.
3. Run the boat using the jet drive measure the speed again using the procedure in steps 1 and 2.
4. Run the boat again using both the jet drive and trolling motor and collect more speed data.

Static Thrust Test:

Figure 18: Static thrust test

1. Attach a spring scale to the stern of the boat with a section of low-stretch rope.
2. Secure the rope to a dock to secure it.
3. Run the boat at full throttle until it scale reads a consistent value. Record this measurement.
4. Pull the boat towards the dock and release it. Wait until the scale reads a consistent value again and record this value.
5. Repeat step 4 two more times. Calculate and record the average value of these results.

Fuel Usage Test:

1. Carefully weigh the propane tank and place it into the boat.
2. Run the boat at full speed for 10 minutes and quickly stop the engine.
3. Take the propane tank out of the boat and weigh it again.
4. Record the difference in the weight and calculate the amount of propane that was used.
5. Repeat the test again to ensure the accuracy of the results.
6. Install the hydrogen tank and adjust the engine to run properly.
7. Repeat steps 2-5 using the hydrogen tank. Instead of weighing the tank, record the PSI in the tank using the regulator gauge both before and after the test.

Electrical System:

1. Secure the boat to the dock. Run it up to full throttle
2. Using a multimeter, measure and record the voltage being produced by the alternator.
3. Using a current clamp, measure and record the current that the battery is drawing from the alternator.
4. Start the trolling motor and bring it up to full speed. Repeat steps 2 and 3.

Maneuverability Test:

1. Start with the boat at one area, mark this location
2. Mark second location down shore giving the boat enough distance to get up to speed.
3. Run the boat up to full speed using the jet drive and trolling motor.

4. As the center of the boat reaches this second marked area, turn the boat as fast as is safely possible.
5. Have someone mark the peak of the semi-circle path of the boat from shore. Measure and record this distance. The distance between the marked location and the person at the peak is the radius of the boat's turn.
6. Repeat steps 1-4 three times and record the average of the three values.

<u>Compete with other hybrid boat team:</u>

For Speed Race:

1. Begin with both boats secured to the dock.
2. Start both boats and release them at the same time.
3. Run the boats out to a specified location about 100 yards away and return to the starting location.
4. The boat the returns first is the fastest.

Figure 19: Speed race

Results

Table 1: Static thrust test results

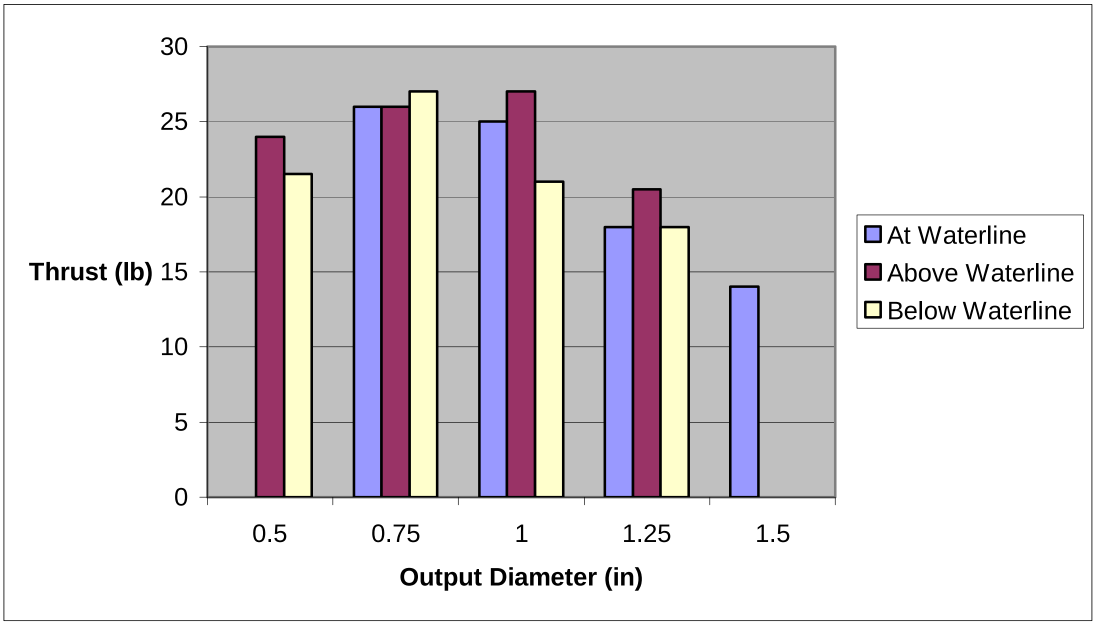
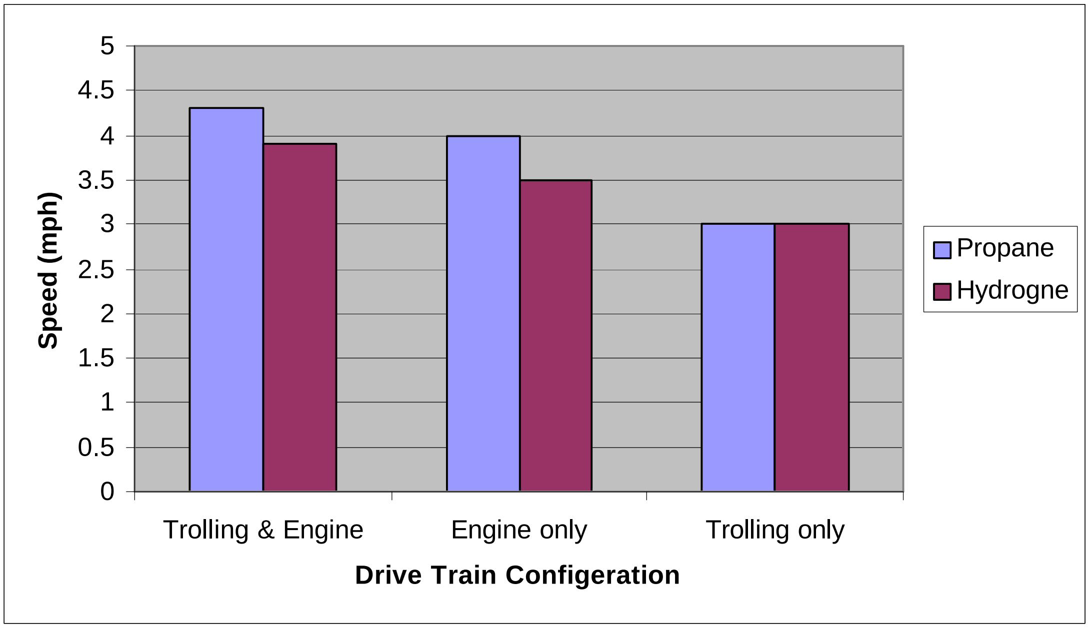


Table 2: Speed test results



Fuel type	Amount of fuel at beginning of test	Amount of fuel at end of test	Fuel consumed per minute	Time on given tank of fuel
Propane	14.25	12.25	0.08 lbs	4.17 hours
Propane	Test was inconclusive			
Hydrogen	1750	1200	55.0 psi	45 minutes
Hydrogen	1200	720	48.0 psi	42 minutes

Table 3: Fuel consumption test

Original voltage on battery	Voltage drop after applying trolling motor	Voltage after alternator applied
12.9 volts	-0.01 volts/second	12.6 volts, steady

Table 4: Electrical system test

Turning radius of completed craft:	3.5 feet

Cost Analysis:

This is the initial cost estimate for the project:

Pacer Water Pump from Tractor Supply	$200.00
Boat material:	$282.92
Propane Convert. Kit	$130.00
Pipe fittings, glue, and associated materials	$67.00
Rudder System	$30.00
Alternator	$50.00
Odds and ends	$120.00
TOTAL	**$879.92**

This was the actual cost of the project:

Engine and Pacer Water Pump	$200.00

Boat material:	$315.50
Propane Convert. Kit	$116.45
Pipe fittings, glue, and associated materials	$92.00
Rudder System	$30.00
Fittings and Hardware	$419.54
TOTAL	**$1173.49**

Engineering Standards Addressed

All engineering projects are expected to address the main engineering standards set by the industry to insure that all projects are in done in the best interest of all who might work on or with them. In order to accentuate this requirement, three of these standards which are particularly applicable to this project are:

Environmental- In order to combat the world-wide problems associated with the use of fossil fuels as a primary energy source, many governments are turning to alternative methods of energy production. As the chief producer of emissions, vehicles are among the first to be considered for new fuel technologies. Converting even a small fraction of these vehicles to run off of hydrogen, which produces no output other than water, would serve to reduce the harmful emissions by 100%. Over time, a full conversion to hydrogen powered cars could actually improve the environment.

Safety- The use of hydrogen gas as a fuel raised concerns about researcher safety. No project, no matter how significant, is worth crippling or killing a person over. In order to use the pressurized container of hydrogen in our experiments, Greg Peebles of the FIT Hydrogen Center was invited to oversee the testing of the hydrogen setup. He transported the container strapped down on a dolly and insured that it was not harmed during the installation process. All fittings were carefully wrapped in Teflon tape and tested for leaks prior the starting of the engine. Finally, the hydrogen level was monitored to ensure that an unsafe level of gas was not escaping. This allowed for us to concentrate on the task at hand and not be worried that the boat or the team were in undue danger.

Economic- With the rising costs of fossil fuels at all-time highs, a new source of power for commercial craft would save billions every year in gas prices alone. This process could easily be applied to any commercial craft, with a water-based application only needing to be scaled to fit the size of the boat. This could allow for any company willing to accept a slight initial investment the opportunity to significantly lower their supply costs while not sacrificing performance.

Discussion

During the floor removal, it was discovered that nearly all of the fiberglass work used to hold the deck and associated bulkheads in place had, at some point, begun to delaminate. This threatened the structural integrity of anything placed over top of the old fiberglass work; therefore, all of it was removed. What was left was a basic bare hull, allowing for clean and structurally sound additions to be made later.

Initially it was thought that pontoons, similar to those found on outrigger canoes would be the ideal solution to the instability issue. However, after lengthy discussions to the effect, it became evident that a professional needed to be considered. This help was found via Doug Wright, President of CNC Design Automation, which specializes in making molds for high-speed offshore powerboat-racing catamaran hulls. His advice was to abandon the pontoon concept, as although stability would be gained, increased drag would ultimately hinder performance. He concluded that, if loaded properly, there was no real need to increase the stability of the boat.

The propane conversion kit encountered some problems revolving around the acquisition of the correct kit for our carburetor, as it was a brand new design. After consulting with the customer service people at US Carburetion, the issue was resolved and the insulation was a success. The propane kit was perfectly tuned for our application and it was obvious through observation that the loss in efficiency between gasoline powered and propane powered engine performance was minimal.

Testing of the propane consumption was difficult. The propane drew so little fuel that the test had to be altered. The first test, lasting 10 minutes, did not use enough fuel to measure so a second test, lasting 25 minutes, was used. This produced workable data that showed that the propane could run an exceptionally long time, reinforcing the idea that a gas stored in liquid had a more viable commercial application.

The hydrogen conversion itself was minimal in scope. One problem encountered with the hydrogen setup was apparent when the motor was being tuned after the conversion. While turning the setscrew to allow more hydrogen gas into the carburetor, the engine produced a very loud knocking sound. This caused the engine to shutter to a stop and the researchers to run away at top speed. After some research, it was found that the propane conversion kit did not provide the extra oxygen needed to burn the hydrogen effectively. This meant that the hydrogen fuel-air mixture could not be corrected short of forcing more oxygen into the carburetor through the use of a super-charger. More adjustments to limit the flow of hydrogen gas ensured that the motor ran effectively.

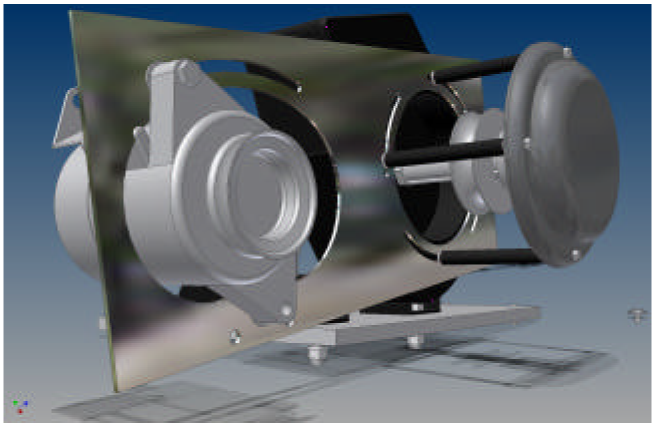


Figure 20: Final alternator assembly

The alternator design, while not completely perfect, was a success. Testing was accomplished using a multi-meter and measuring the output voltage while the alternator was running. The battery voltage was first measured using the multi-meter and recorded as 12.86 volts. The trolling motor was then run at full capacity until the battery voltage dropped to 12.62 volts. The engine was then started, the alternator was turned on, and the trolling motor was once again measured. The battery voltage remained constant at 12.62 volts proving that at the alternator was able to provide enough charge to keep the electrical system running at full potential. While the load on the alternator was not significant due to an almost fully charged battery, there could be little question that the system would fail.

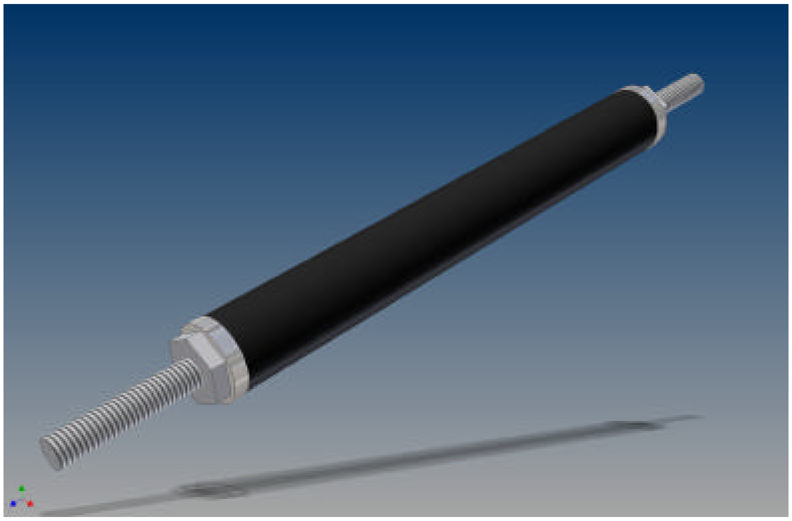


Figure 21: New standoff design

One alteration that had to be made was to the standoffs. The original design called for solid aluminum bar stock to be tapped and for threaded rod to be installed to attach the rudder plate to the pull start. Construction based on this design was attempted twice with poor results. The aluminum was not strong enough to hold the tapped threads, and so a new system had to be designed. The solution was to take threaded rod and pass it though steel tubing and cap it with steel bushings (see Figure 21.)

Maneuverability of the craft, thanks to the carefully calculated rudder area, was at a maximum. Testing confirmed the boat’s turning radius was 3.5 feet. This is less than half the length of the boat, more than sufficient for most commercial boat designs. This low turning radius also was a safety issue, as the boat could not be reversed while the jet drive was active. A tight turning radius was necessary to ensure that the boat did not run into any obstacles.

The original idea for the intake was to run two pipes, one over each side of the boat, in hopes of avoiding air getting into the pump and avoiding problems with cuts being made through the hull. The two pipes would ensure that one was always in the water even during hard banked turns. The issue of drag from these pipes would be substantial. Also, the team could not insure that both pipes would stay in the water the entire time.

The intake grate system was far more effective. Only two problems were observed in testing. One was that the water present in the intake after the boat ran could not be purged from the system. This became an issue after the boat was set out of the water for some time, as bacteria and other undesirables grew in the stagnant water and caused an unpleasant aroma. There were no cavitations in the water pump observed, leading to the conclusion that it was sufficient.

The PACE unit that was built to store the hydrogen was not successful. The designs for the unit were completed correctly, and there was sufficient time to complete their construction. Two “working” units were constructed (see Figure 22) and submitted to Dr. Brenner. The problem with putting them into service was that the stainless steel tubes used were not of the correct wall thickness.

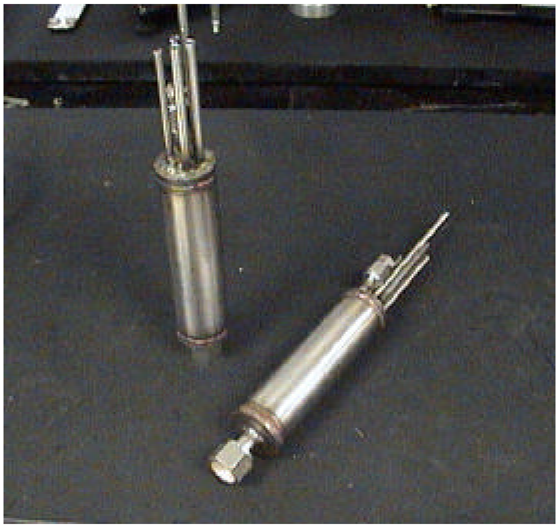


Figure 22: PACE units constructed

As such, they could not accommodate the heaters needed to control the hydrogen storage/release process and they were discarded. Luckily, the hydrogen tank backup idea was a complete success. The only problem with this design was the relatively low storage capacity. With only 45 minutes of run time, the pressurized tank design would not be commercially viable. A liquid storage tank would work, but the metal hydride system would be preferred.

The winner of the race between our team and Team PHISH, the other hybrid boat team, was Team PHISH, by half a boat length. It is interesting to note that immediately after the race, the Hy-Prop boat had to be sent out to rescue the other boat because it was dead in the water.

Conclusions

The current state of the hull is a vast improvement from what it used to be. Old rotten wood, delaminated fiberglass and other unnecessary materials weighing roughly 75 pounds were removed. All repairs were made with technologically advanced materials that were thinner and lighter than the old materials, and in most cases were equally as strong, if not stronger.

For the most part, Bateau Inc two part epoxy and 8oz fiberglass mat was used to make hull modifications and add structural stability to the hull. A common theme during the fiber glassing portion of this project seemed to be the inconsistency found when using the Bateau Inc two part epoxy. Slight variation in resin/hardener ratios tended to have dramatic effects on material performance. In some cases, the epoxy acted as it should, hardening in a matter of hours; in other instances, the epoxy required days to harden. In one of the extreme cases, chemical hardening reactions took place in a matter of minutes; at the other extreme, sometimes hardening never occurred and the area had to be redone.

Because of inconsistencies found when using Bateau Inc two part epoxy, vital fiberglass work such as attachment of the intake scoop and placement of the through-hull outflow fitting dictated that we use a much more trustworthy, however substantially more expensive epoxy called West System. Much more care and precision is used in manufacturing West System epoxy, and the results directly illustrate this. Hardening times are consistent and work in conjunction with West System® fillers and fairing compounds is easy and worry-free.

Using the fiberglass mat and assorted epoxies previously stated, freeboard was added to the rear of the hull and a custom-made intake scoop, half-floor, and through-hull components were added. The structural integrity of the hull far exceeds the physical requirements placed on the hull; therefore, hull stability is not an issue.

The propane conversion met with little difficulty. Some of these parts, as it turned out, were incredibly light-duty and needed to be treated with a certain amount of delicacy. During the conversion process, several of the plastic and thinner metal pieces were broken and replacement parts had to be purchased. Once all parts of the conversion kit were assembled properly, the motor was now ready to be run on propane gas and propane-fueled performance could be optimized using a setscrew that controlled the fuel/air mixture entering the carburetor.

Once propane-fueled performance had been maximized, all propane-based testing was performed, with little or no difference in power noted with respect to a gasoline fuel source.

The conversion of the engine to run off hydrogen gas came after all running and testing using propane gas was complete. In order to outfit the engine to run off hydrogen gas, only fittings used to connect the hydrogen fuel storage tank had to be swapped out. Once this change had been made, the engine was ready to be run, with only slight changes to the setscrew controlling fuel/air mixture to be made.

With respect to the propane fuel/air mixture, the hydrogen fuel/air mixture required a greater amount of air. Because hydrogen molecules are smaller than propane molecules, there are in turn, more of them per unit area. In order to maintain the maximum performance of the engine, the ratio of hydrogen gas to air had to be less. The reason for this difference is the efficiency of the fuel itself. Propane burns according to the equation:

$$C_3H_2 + 5O_2 = 3CO_2 + 4H_2O$$

This is compared to hydrogen’s formula:

$$2H_2 + O_2 = 2H_2O$$

Because more 19 times more hydrogen can fit into an area than propane, almost 4 times the oxygen is needed to properly combust hydrogen. As the second propane regulator is designed to mix fuel-air for propane, the engine was not going to run properly on hydrogen. As a result, in order to gain more horsepower from the engine, air would need to be force-fed to the carburetor through the use of a turbo or supercharging device.

During the preliminary stages of the conversion process, it was thought that using hydrogen as a fuel source would yield a greater power output than propane gas. Through testing it was found that indeed the opposite was true; hydrogen gas-powered engines see a drop in horsepower when compared to propane gas-powered engines. As stated before, this outcome is most likely the result of the lack of air in the carburetor, leading to a deficit in maximum performance.

As previously stated, the size and shape of the dual rudder setup used on this project were the result of a relationship between rudder surface area and 5% of the product of the wetted beam and length of the boat. These dimensions resulted in ample maneuverability while maintaining a minimum amount of drag.

Placement of the intake portion of the jet drive was found to be immediately behind the hull step, with the transition from hull to intake grate being smoothed out by a custom hull modification. The actual grate itself measured roughly 16” long by 2” wide. These dimensions and placement allowed for an unhindered, sufficient flow to be achieved.

Originally it had been planned that piping to and from the intake grate, water pump, and outflow were to be kept to a minimum. This concept would minimize friction within pipes, resulting in less thrust loss through the drive train. In order to properly place a driver in a comfortable and functional position in the boat, rerouting of the pipes was necessary in which the pipes now traveled along the side of the boat, around the driver, to the outflow location. Subsequent layout modifications caused by this change tended to aid the simplicity of the entire layout as a whole.

Through the intense testing process, the optimum location of the jet drive outflow was found. Placement of the jet drive outflow was just above the water surface. At this location, thrust through the entire throttle range was maximized, while at the same time, friction and drag due to outlet pipes was virtually eliminated.

Recommendations

There are several conclusions the team came to in the project. Firstly, it might be useful to use a hydrogen storage unit that is already developed. Over 50 man-hours of work were dedicated to the design and manufacture of the PACE units and they could not be used in the final design. This was a great deal of time to devote on such a lofty goal.

The main concern is to stick to one project instead of trying to do several things at a time. The jet intake and output design alone could be a whole project in and of itself. Later design projects would do well to learn from our mistake and narrow their scope to only one design project and not one project consisting of many such efforts.

If this project is going to be incorporated into future research and the alternator assembly will be included, there are some small changes that could be made to increase its performance. The first would be to add some bearings at the base of the driveshaft extension to overcome any lateral forces applied when the belt is tightened. The second would be to increase the length of the standoffs by about ¼ in. to give the starter cup more room to operate.

If one wanted to continue the work done in this project, it would be advisable to keep to the basic design and try to see how different engines would perform. A larger engine would be ideal for a jet boat design. Or perhaps dropping the jet boat idea all together and working with a regular propeller unit would have removed that complication from the design, allowing for the hydrogen conversion itself to be studied and independently analyzed.

It was also found that companies are more willing to sell an item at cost then to donate one. This should be taken into consideration for the cost estimations in a proposal. We relied on Mary Dyer to acquiring funds and equipment but we found her to be inadequate for our needs. Future groups might want to keep this in mind, while still giving Ms. Dyer an opportunity to excel.

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Appendix

A.1. As they were not used, the following stability calculations are included for reference purposes only

Radius of Gyration

Rolling

Radius of Gyration:

axis	* 1" off side	
axis	13.78	from CG

trial	time (sec)	avg t (sec)
1	9.27	1.545
2	9.4	1.566667
3	9.79	1.631667
4	9.34	1.556667
5	9.31	1.551667
6	9.28	1.546667
7	9.33	1.555
8	9.21	1.535
9	9.4	1.566667
10	9.23	1.538333
		1.559333

time per 6 rolls

k^2	137.8037	in^2
k	11.73898	in

Pitching

Radius of Gyration:

axis	* 1" in front of step, 3.5" above deck (gunnel)	
axis	19.08	from CG

trial	time (sec)	avg t (sec)
1	17.98	2.996667
2	17.68	2.946667
3	17.78	2.963333
4	17.77	2.961667
5	17.87	2.978333
6	17.53	2.921667
7	18.09	3.015
8	17.83	2.971667
9	17.52	2.92
10	17.78	2.963333
		2.963833

time per 6 rolls

k^2	1275.127	in^2
k	35.70891	in

Roll Frequency

? (lb)	64	
GM (in)	13.18	
Beam:	27	in

Time (s)	Cycles	Avg (s)
7.31	6	1.218333
7.65	6	1.275
7.33	6	1.221667
7.29	6	1.215
7.55	6	1.258333
7.21	6	1.201667
7.16	6	1.193333
6.92	6	1.153333

6.91	6	1.151667
7.05	6	1.175
		1.206333

k	37.68764

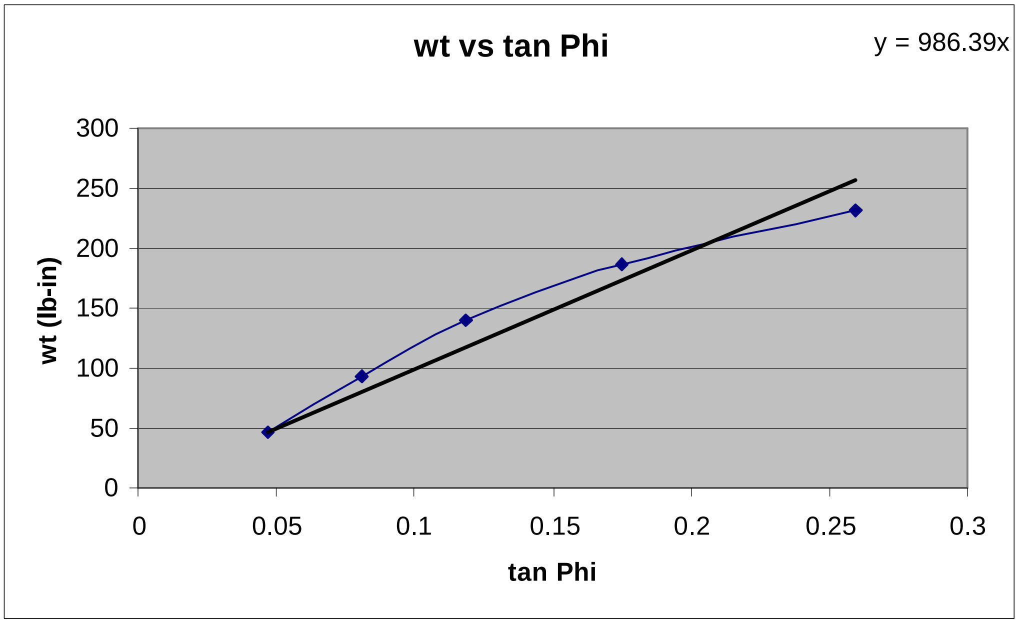
Inclining Experiment

Determine vertical center of gravity

L (in)	40	
t (in)	15.5	
? (lbs)	110	
Deck	16.5	in
KMT (in)	19.6	

w (lb)	a(in)	w*t (lb-in)	Tan F
3	1.875	46.5	0.046875
6	3.25	93	0.08125
9	4.75	139.5	0.11875
12	7	186	0.175
15	10.375	232.5	0.259375
18	xxxx	xxxx	xxxx

Slope	986.39
GM1 (in)	8.967182
KG1 (in)	10.63282
GM (in)	13.18422
KG (in)	6.415781



Balance Experiment

Determine Longitudinal Center of Gravity

Fish scale not available

Hull balanced at: 35 in from aft

*Transverse center of gravity assumed along centerline

HydroStatics

Displacement	64	lbs	Bare Hull
Draft	3.42	in	
LCB	50	in from aft	
VCB	1.71	in from keel	
Immersion	28	lb/in	
WPA	5.922	ft^2	
LCF	50	in from aft	
M/trim	11.88	lb/in	
KML	2.67	ft	
KMT	32	in	

A.2. This is the timeline for the boat build