AquaScooter2

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Progress Report
Document

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ABSTRACT

The Aqua Scooter currently has a two cycle gas powered engine that, as of January 2010, the EPA's regulations prevent future sales. The capstone team is tasked with designing and analyzing different alternative engine options that meet current and immediate future EPA regulations.

Emissions requirements and current technology are provided along with the constraints given by the client. A Honda GX-25, 4-Stroke engine was purchased to conduct the project's testing. The team decided to convert this engine to run on propane in order to provide the client with a long-term solution to EPA regulations. The team conducted emissions testing for the engine with both gasoline and propane fuel. To verify the power output of the engine, an experimental setup was created. This was used to determine whether the engine conversion to propane would be a viable solution. Additionally, there are experimental procedures the team can conduct to measure any potential differences in thrust created by using alternate fuels on the purchased engine.

The team also designed an updated, functional and aesthetically pleasing outer shell using Solid Works. The final design was 3-D printed for the client.

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1.0 INTRODUCTION

1.1.1 Product and Client Information

Aqua Scooter is a portable, submersible, gasoline powered water craft for individual use. Aqua Scooter is family owned and operated out of Sedona, Arizona. The client for this project, Robert Witkoff, is the owner and CEO of Aqua Scooter. The current device design is shown in Figure 1 and Figure 2. The numbered component descriptions are found in the Appendix of this report. The design incorporates a 2-stroke engine which provides approximately 2HP of power to the user. The scooter provides around 5 hours of operating time with a 2 L fuel tank capacity.

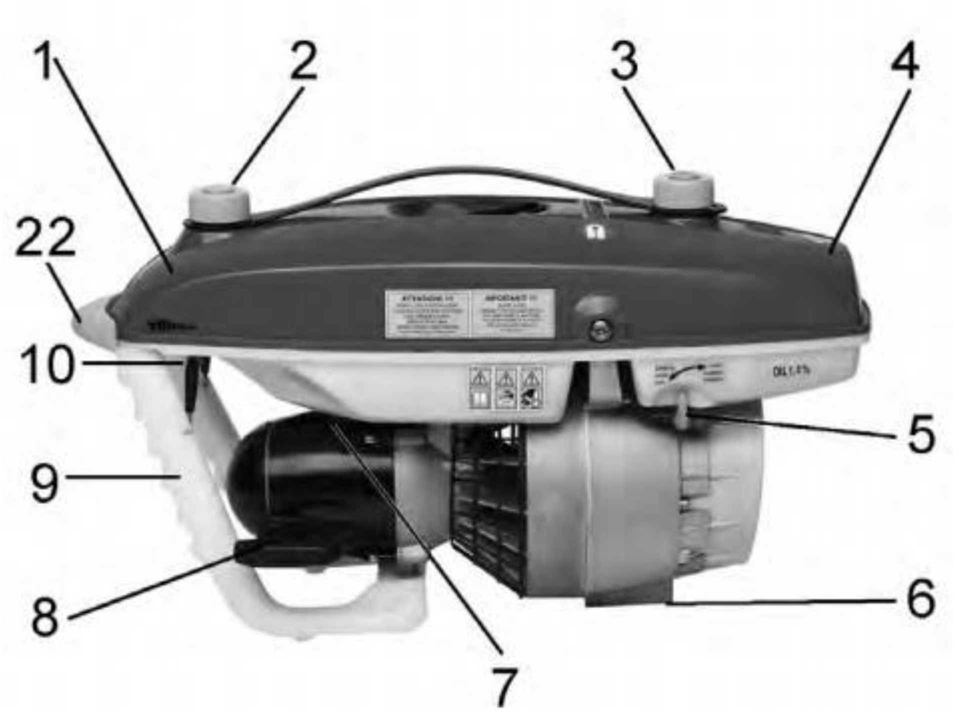


Figure 1: Aqua Scooter side view with designated components [1]

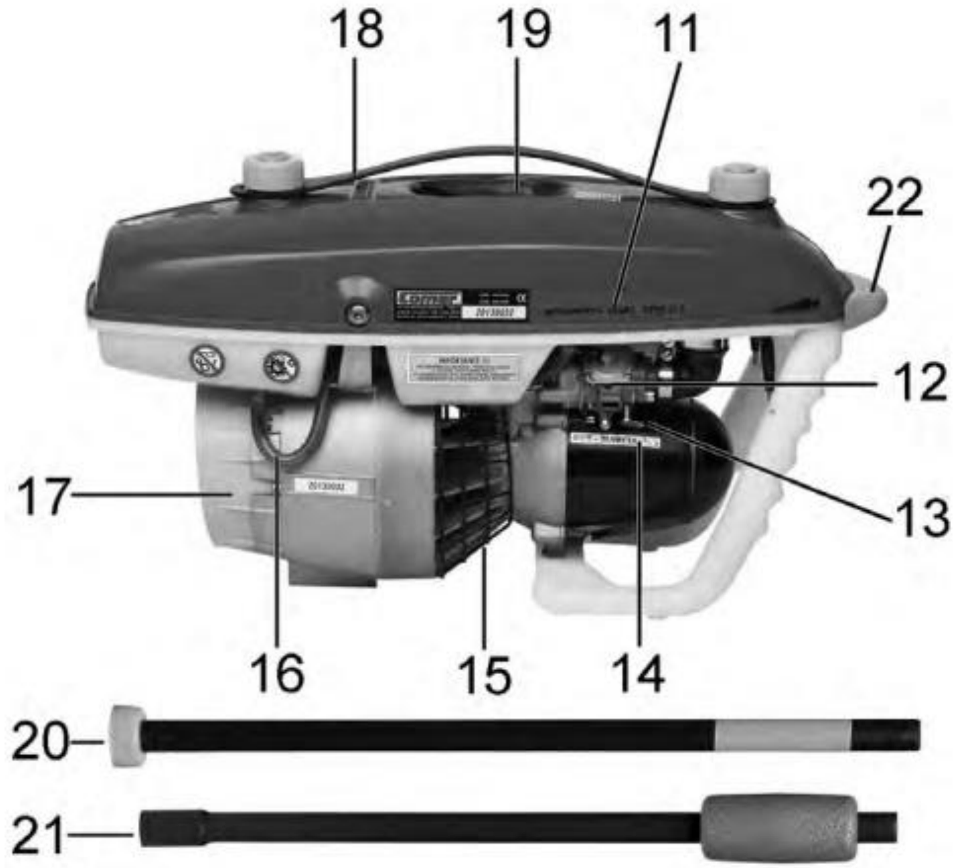


Figure 2: Aqua Scooter with designated components and snorkel extension [1]

1.1.2 Background

A chemical technician by the name of Bernd Boettgers wanted to escape from East Germany, but he knew he would need some type of machine to help pull him through the sea. His first attempt to test his “water-machine” resulted in an arrest and jail time of three months. He was convicted of an illegal attempt at border crossing. After he was released, he decided to work on a second machine, and after a year of building, he entered the sea in September of 1968 for his second attempt. He traveled by water for six hours, two of which were done fully submerged under the sea, until he was finally spotted by the Danish Lightship, named Gedser. His successful escape broke into the European Press, and by the end of January in 1978 the “Aqua Scooter” had been brought to the United States and the first commercial prototype was successfully tested.

1.1.3 Aqua Scooter Emissions

The current 2-stroke, direct drive engine does not comply with EPA regulations. As a result, the client is unable to sell the Aqua Scooter in the United States. The current emission standards that the Aqua Scooter must meet are as follows:

- It must have less than or equal to 30 g of hydrocarbons
- Less than or equal to 490 g of carbon monoxide per kilowatt hour.

Emissions testing will be done by either the Arizona Department of Transportation, or Arizona Game and Fish Department.

1.1.4 Why Test for Emissions

A good question one might find themselves asking, is why test for emissions? What benefits does it bring to the customer, if any, and why is it important to pass? It turns out that passing an emissions test and just taking the test in general, brings several advantages. Here are three reasons why emissions testing are very important:

1. It identifies necessary repairs to improve vehicle's performance and fuel economy
2. It improves air quality by reducing carbon monoxide, hydrocarbons, and nitrogen oxides
3. If emission controls are not working properly, testing ensures that owners make the appropriate repairs to aid in the reduction of ground level ozone

Although testing for emissions improves the air quality for everyone around you, it also turns out that emission testing also brings several benefits to the customers themselves.

1.2.1 Current Technology

The group researched two and four stroke engines for this project. The current technology on the market is available to implement in a possible solution for our client. Options available in the current market are conventional gas models or alternatives such as propane or compressed natural gas.

1.2.2 Material Properties

The materials for the new design need to be lightweight so that the Aqua Scooter can float. The new scooter should also have materials strong enough to support its own weight and handle the pressure exerted when submerged to maximum operating depth. The manufacturing of the device will also need to be considered when selecting the materials so that the cost of making the new design is still feasible.

1.2.3 Possible Solutions

Current solutions to the problem are either a four stroke internal combustion engine or a fuel injected two stroke internal combustion engine. The issue with the four stroke solution is implementing an engine that is light enough to meet the weight and thrust constraints. Research to resolve this issue has been focused primarily on compressed fuels contained in cylinders. There may be an advantage in losing the weight of a gas tank to lighten the overall weight of the machine. As for the two stroke solution, current technology is available that monitors and controls fuel intake to minimize the unburned amounts of fuel that enter the atmosphere as seen with previous two stroke models. Fuel system modification, along with implementing biodegradable two stroke oils that are also recently available, can be a viable solution in designing a product that meets current EPA requirements.

1.2.4 Summary

The Aqua Scooter is a machine that has been useful for over four decades. The power system that the machine has used since its origin is obsolete based on current environmental regulations. In order for the Aqua Scooter to keep fulfilling the legacy it has created, the team has been tasked with redesigning the device. This will be accomplished through testing and implementation of state of the art technology in the field of materials, as well as internal combustion engines.

2.0 PROBLEM STATEMENT

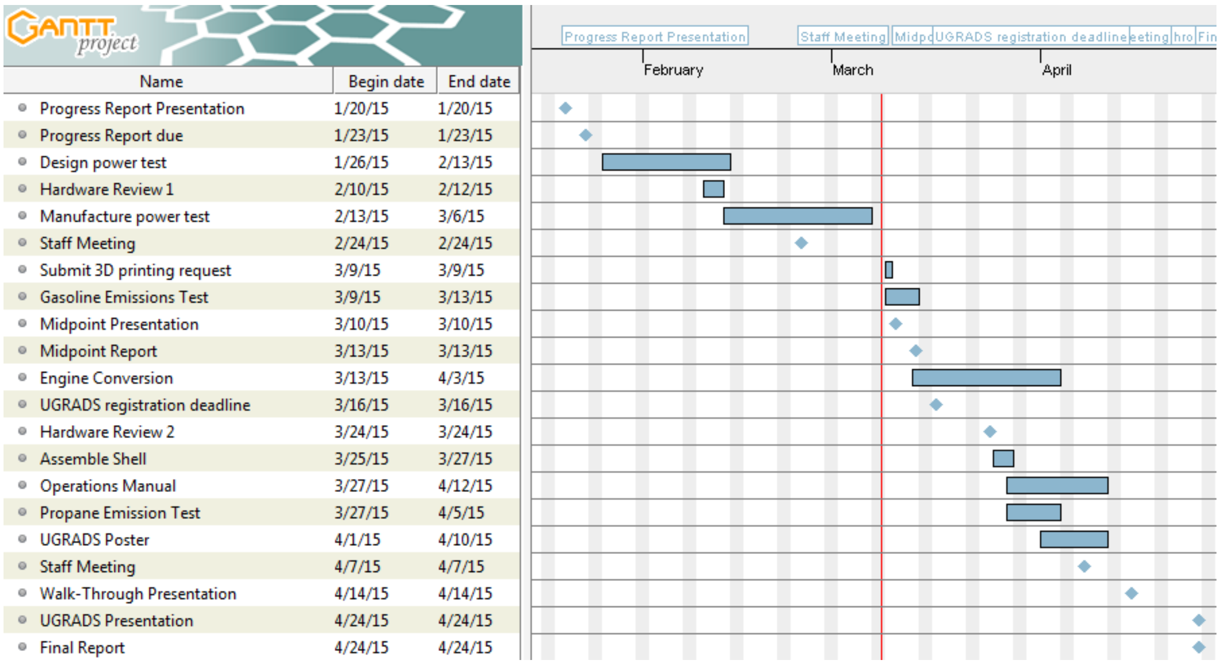
The current design for the Aqua Scooter does not comply with the most recent Environmental Protection Agency's regulations on two-stroke engines for recreational use. In order to have a marketable product, this team will design a hydrodynamic, inexpensive, aesthetically pleasing Aqua Scooter, with a marine engine that complies with EPA regulations.

2.1. Constraints

The prototype needs to meet certain constraints the team has determined based off communication with the client. The constraints are the following:

- Gasoline powered
- Engine housing must be metal
- Muffler housing must be metal
- Throttle control
- Exhaust valve
- Starter assembly made of plastic and metal
- Plastic propeller protection
- Control handle
- Must have a dry weight of 18 lbs. or less
- Must be buoyant enough to float itself
- Must provide at least 50 lbs. thrust
- Must cost no more than $450 per scooter manufactured

3.0 GANTT CHART



Name	Begin date	End date
Progress Report Presentation	1/20/15	1/20/15
Progress Report due	1/23/15	1/23/15
Design power test	1/26/15	2/13/15
Hardware Review 1	2/10/15	2/12/15
Manufacture power test	2/13/15	3/6/15
Staff Meeting	2/24/15	2/24/15
Submit 3D printing request	3/9/15	3/9/15
Gasoline Emissions Test	3/9/15	3/13/15
Midpoint Presentation	3/10/15	3/10/15
Midpoint Report	3/13/15	3/13/15
Engine Conversion	3/13/15	4/3/15
UGRADS registration deadline	3/16/15	3/16/15
Hardware Review 2	3/24/15	3/24/15
Assemble Shell	3/25/15	3/27/15
Operations Manual	3/27/15	4/12/15
Propane Emission Test	3/27/15	4/5/15
UGRADS Poster	4/1/15	4/10/15
Staff Meeting	4/7/15	4/7/15
Walk-Through Presentation	4/14/15	4/14/15
UGRADS Presentation	4/24/15	4/24/15
Final Report	4/24/15	4/24/15

Figure 3: Gantt Chart and schedule of major deliverable and tasks for project.

Figure 3 displays the Gantt chart which illustrates an estimated timeline for the first semester of the Aqua Scooter prototype design. The timeline is broken down into tasks and deliverables. Tasks are shown as blue bars and deliverables are shown as blue diamonds in Figure 3. The deliverables include presentations and reports. Based on the materials required for the presentations, the tasks are laid out in an order such that tasks relevant to specific presentations are completed before the presentation date. This layout ensures everything is completed while also ensuring there are specific timelines for certain tasks. The Gantt chart is the schedule the team will keep to, to ensure the project is completed on time.

4.0 ENGINE ANALYSIS

The main objective of this report is to analyze and compare the use of propane and butane with gasoline in a 4-stroke engine. Along with alternative fuels, the drag coefficients of the final two shell designs were calculated, as well as the drag force that each of the shells experience at the required velocity. Finally, the propeller was designed to meet the thrust requirement prescribed by the client.

4.1.1 Gasoline Analysis

The main objective for the team is to create prototype that will meet and surpass the current and known future EPA regulations for marine engines. After some initial analysis, the team decided to pursue a design which included a 4-stroke engine. The 4-stroke Honda GXH50 engine shown in Figure 4, engine currently complies with the EPA regulations. This engine will be analyzed as a foundation for all calculations in the report. This 4-stroke engine has an intake stroke, compression stroke, power stroke, and exhaust stroke. The extra 2 strokes in the 4-stroke engine result in fewer emissions and a higher percentage complete combustion of fuel. There are currently many EPA approved 4-stroke engines on the market today, so that is the direction we chose.

Dimensions	Aqua Scooter 2-Stroke Engine (AS 650)	4-Stroke Engine (Honda GXH50)
Length (mm)	530	225
Width (mm)	195	274
Height (mm)	320	353
Weight (lb)	16.53	12.1
Bore (mm)	40	41.8
Stroke (mm)	39	36
Displacement (cc)	49	49.4
Power (HP)	2	2.1 @ 7000rpm
Thrust (kg)	22	22
Fuel	Mixture	Unleaded 86 Octane or Higher
Fuel Tank Capacity (L)	2	1.89271
Price ($)	(+/-) 970	420

Figure 4: Current engine and proposed 4-stroke engine [1,19]

In the figure shown above, the existing (entire) Aqua Scooter is displayed on the left, and the Honda GXH50 4-stroke engine is shown on the right. This is a potential 4 stroke engine on which we will base our calculations. The Honda engine is both wider and taller than the entire existing Aqua Scooter, so the shell will need to be redesigned in order to accommodate the larger engine size. Also, despite the 7000 rpm capability of the Honda motor, for the desired application it will be running at less than or equal to 80% of maximum rpm. Because of this, for all future calculations we assumed a horsepower of 5600 rpm. The price of the new Aqua Scooter (with a Honda 4-stroke engine) will be considerably higher than $420 because only the engine is measured. However, since the engine is the most costly part, the total cost of manufacturing should not exceed the $970 price of the current Aqua Scooter.

4.2.1 Propane Analysis

Although moving forward with a design that includes a standard octane fuel for a 4-stroke engine is a viable concept, alternate fuels are being analyzed. The client stated interest in butane and propane engines when presented with the concepts; therefore, the team worked to show that these fuels were feasible. The fuels were put through volume, thrust, combustion, and adiabatic analysis.

4.3.1 Volume Analysis

Volume analysis was conducted in order to verify the fuel would be capable to provide the amount of thrust required by the client. Additionally, the amount of butane and propane required and the weight were both major concerns in the design of the Aqua Scooter. It was necessary to prove that these two gases and the sizes of the correct volume containers needed would be feasible for the client requirements.

- Required weight of propane is 12.52 ounces.

4.4.1 Thrust Analysis

The thrust analysis uses the following velocity equations:

$$T = \dot{m}V_e - \dot{m}V_0 \quad (1)$$

$$\dot{m} = \rho V_i A \quad (2)$$

$$T = \rho V_i A(V_e - V_0) \quad (3)$$

$$T = A\Delta p \quad (4)$$

$$T = 2\rho A V_i^2 \quad (5)$$

Equations 1 and 2 can be manipulated to produce thrust based on density of fluid, disk area of the propeller, and velocity of fluid immediately after the propeller (V_i), entering water velocity (V_0), and exiting water velocity (V_e) as shown in equation 3. Using equation 3 and 4 it can be shown that V_i is twice that of the V_e. This relationship allows for thrust to be determined based on area, density and V_i. The mathematical model used assumes the craft moves through relatively still water due to the nature of being a low speed recreation vehicle and therefore V_0 is assumed to be zero. Thrust and V_e are based upon client desires for the final project. The area of the propeller is an estimation for an appropriately sized propeller for a personal water craft, which will move at low speeds.

Where:

$V_0 = 0$

$V_e = 5.0mph$

$A = .349ft^2$

$T = 49\ lbs$

$$V_i = \sqrt{\frac{T}{2\rho A}} = 5.8mph \quad (6)$$

This value for V_i reinforces the fact that an appropriately designed engine paired with an appropriately designed propeller should adequately power the redesigned Aqua Scooter.

4.5.1 Dry Combustion Analysis

Dry combustion analysis is the best way to compare different fuel types against conventional octane that fuels majority of 4 stroke engines on the market. For dry combustion analysis stoichiometry must be computed for each theoretical chemical combustion to determine the air to fuel ratio (AF). For convenience the stoichiometric analysis is done to have the fuel's coefficient to be one so the AF number is easier to compare with the AF ratio for octane of 15.1 (11).

Propane stoichiometry:

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2 \quad (7)$$

Butane stoichiometry:

$$C_4H_{10} + 9O_2 + 33.84N_2 \rightarrow 4CO_2 + 10H_2O + 33.84N_2 \quad (8)$$

Air Fuel ratio for ideal combustion equation:

$$AF = \frac{moles\ of\ air}{moles\ of\ fuel} * \frac{M_{air}}{M_{fuel}} \quad (9)$$

AF ratio for propane

$$M_{air} = 28.97\ ;\ M_{propane} = 44.09$$

$$AF_{propane} = (5 + 18.8) * \frac{28.97}{44.09} = 15.66 \frac{lb\ air}{lb\ propane} \quad (10)$$

AF ratio for butane

$$M_{air} = 28.97 \; ; \; M_{propane} = 58.12$$

$$AF_{butane} = (9 + 33.84) * \frac{28.97}{58.12} = 21.36 \frac{lb\ air}{lb\ butane} \qquad (11)$$

As the above math shows the air to fuel ratios for propane and butane do no matter significantly when compared to that of octane. For this reason an adiabatic flame temperature calculation was determined to help determine which of the potential fuels would be the best alternative to octane. Adiabatic flame temperatures are determined using interactive thermodynamics equation solver software shown in Appendix D.

Examination of the adiabatic flame temperatures of products for the dry analysis of propane, butane and octane shows that the temperatures, which correlate with the fuel's ability to drive a piston in an engine, are similar given the same conditions (Appendix D). However it should be noted that dry combustion analysis and adiabatic flame temperatures are based on ideal conditions and are only used to help the design team make informed decisions without the ability to test a given fuel. With the above information it has been determined that propane would be an adequate fuel when paired with an engine designed to run on propane.

5.0 FINAL ENGINE SELECTION

A primary objective for this semester is to convert a 4 engine to run on a cleaner burning propane fuel. The selected 4 stroke engine testing option is the Honda GX-25 multi- purpose utility engine. The GX-25 has a displacement of 25 cm^3. The cost of the engine before shipping was $240.00. The only drawback to the engine is the availability of replacement parts. The purchased conversion kit is designed specifically for the purchased engine making the engine modification more efficient.

Figure 5: Honda GX-25 4-Stroke Engine [19]

6.0 CURRENT ENGINE STATUS

The testing of the engine will be conducted in several stages. The initial stage will be to test for the efficiency of the engine using gasoline. After this is analyzed, the engine will need to be tested for emissions, which is discussed in the next section. The emissions must show the viability of the engine in regards to current marine board engine regulations. Secondly, the engine will be modified and then tested with the new alternative fuel. All the aspects of testing (i.e. thrust, weight, and functionality of all parts, fuel efficiency, emissions and buoyancy) will take place during the current semester.

6.1.1 Power Output Testing

Other than an exhaust pipe that could accommodate an emission testing probe, a long flange mounted shaft was needed in order to conduct the power testing experiment. A modified version of the Prony Brake Experiment will be used to characterize the engine’s power. The Prony Brake experiment as seen in figure 4 calculates the power by measuring a force differential then multiplying that force by the distance the pulley travels and by the rotational speed. The power is defined in Eq. (1) as:

$$P = (F_A - F_B) * D/t \qquad (12)$$

Where:

P = Power

F_i = Force Measured from spring scale (A &B)

D = Distance traveled by pulley (D)

t = Time. (C)

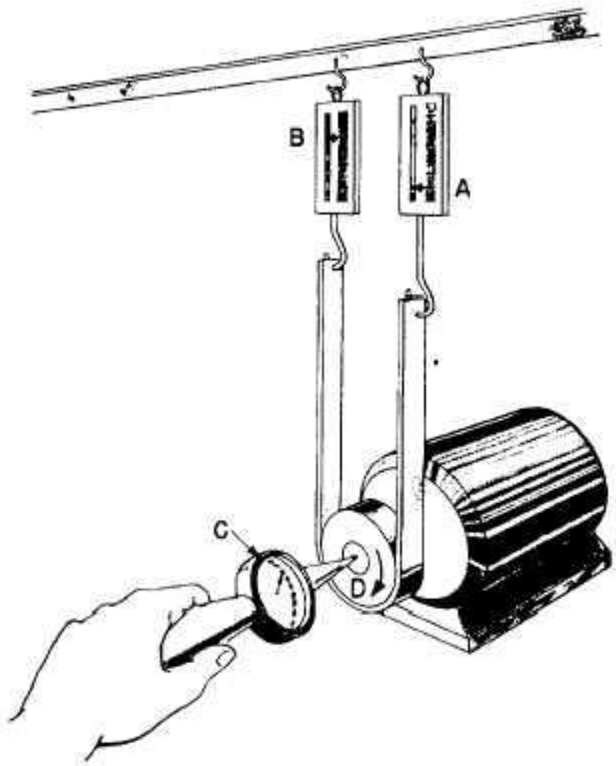


Figure 6: Prony Brake Experiment [21]

The team's version of the experiment implements one scale and measures the rotational speed of the large shaft using a tachometer in the bottom right corner of Figure 7. The distance the pulley travels in the first experiment is replaced by a moment arm the shaft pulls down (Figure 8).

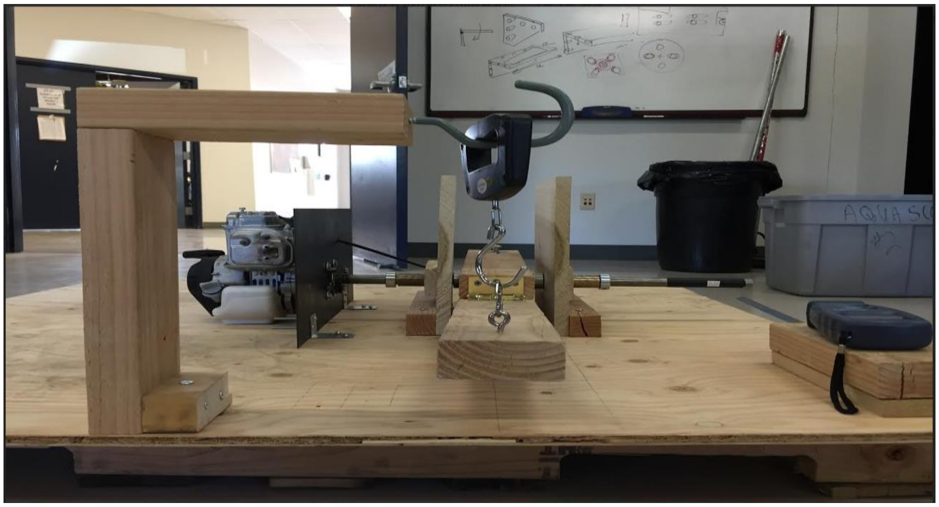


Figure 7: Side View of Experiment

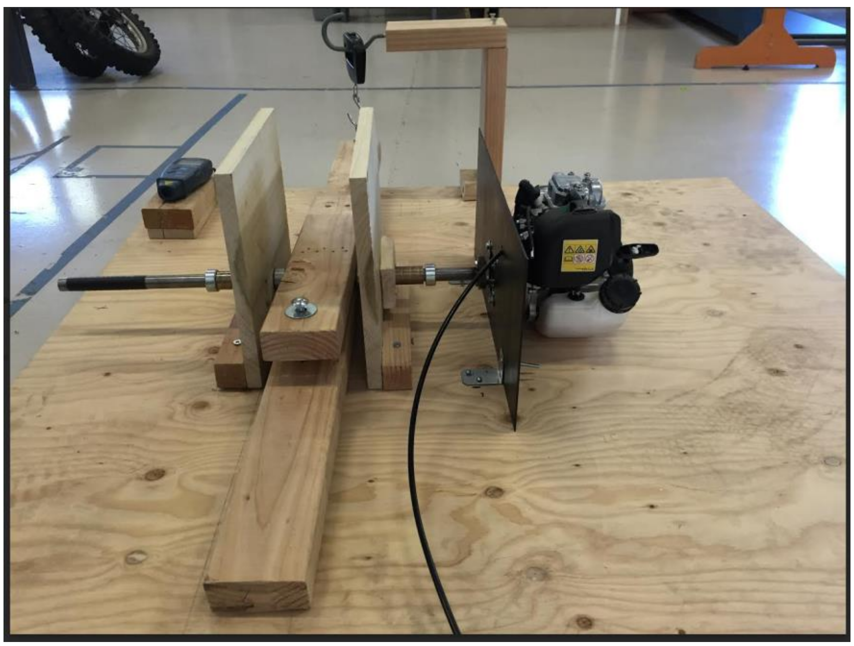


Figure 8: Isometric View of Setup

The construction of the shaft for the power analysis caused major eccentricities in the rotation as the engine spun the shaft. The flange became warped when welded thus, several iterations were conducted to dampen out the vibrations. The first iteration involved CNC machining a high density polyethylene disk to go between the flange and the flywheel. However, the eccentricities (although somewhat dampened) were still too rough to allow the engine to run properly. Subsequently, springs were added to the flange bolts to absorb more of the vibration. The springs absorbed enough of the vibrations, but the axial movement of the shaft on the bolts loosened them from the flywheel. The final iteration on the dampening system involves flange mounted Heim joints that will act as a makeshift universal joint. The bolts can be tightened with more force to the flywheel and the ball bearing motion of the Heim joints will theoretically absorb the eccentric axial motion of the shaft, solving both mounting issues simultaneously. The disk, spring dampening system, and Heim mounts are in Figure 9,10,and 11.

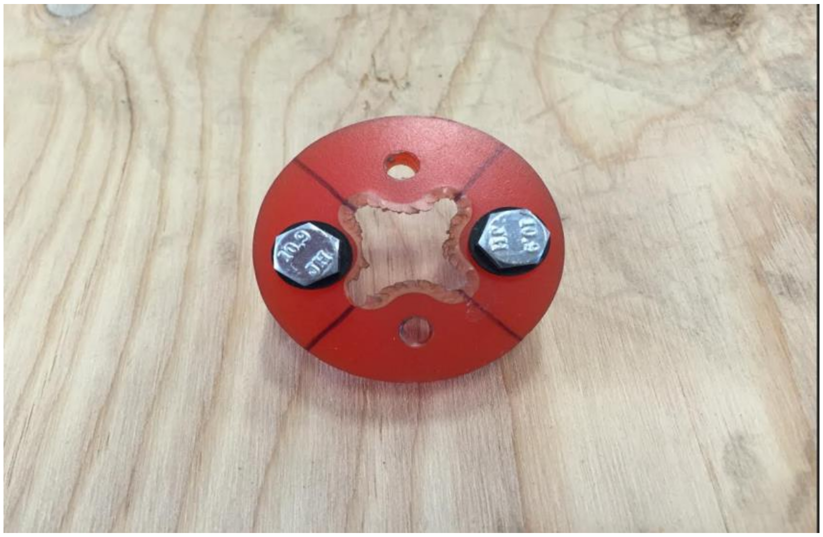


Figure 9: Polyethylene Disk

Figure 10: Bolt Mounted Springs

Figure 11: Heim Joints

Following the attachment of the joints along with the shaft, the team will complete another attempt at the test. Additionally, Lock Tight will be used to provide a better grip between the screws and the flywheel.

6.2.1 Emissions Testing

Multiple options of emissions testing locations and devices were researched. The first company contacted was Carnot Emission Testing Services (210-928-1724). This company quoted a price of $5000 to do the emission testing and help get the product through the EPA regulations process. Olson-Ecologic Engine Testing Laboratories (714-774-3385) was also contacted with similar results.

It was determined that a 3-gas analyzer, shown in Figure 13, is needed to perform the proper emissions tests on the motor. A 3-gas analyzer is an apparatus that determines the composition of gasses in an exhaust system [22]. The amount of the gases HC, CO, CO_2, and O_2 are measured from the tailpipe of a vehicle. Although this test is not an EPA certified measurement, it will provide the team with comparison data, which will illustrate the vitality of propane gas.

Figure 12: Gas Analyzer [22]

After searching for an inexpensive analyzer on the internet, it was found that the cost of such an apparatus is prohibitive (Appendix E). As an alternative, multiple auto shops and mechanics were contacted in the Flagstaff and Sedona area. Due to the lack of emissions testing in Coconino County only one facility, Flagstaff Auto Repair had the required gas analyzer. The analyzer is usually used on a car by connecting the reader to the muffler to measure the exhaust as it exits the tail pipe.

6.2.2 First Emissions Test

For emission testing, a gas analyzer from a local shop was used and measured hydrocarbon, carbon monoxide, and carbon dioxide (Figure 13). The emissions tester is a large device that connects to the Honda engine exhaust just like a vehicle (Figure 14). Originally, the exhaust port that was included with the engine was too small. Welding a larger expansion pipe and bolting it to the small exhaust port fixed the problem (Figure 15). Multiple iterations were attempted for each modification to allow for better test results.

Figure 13: Emission Analyzer

Figure 14: Testing Procedure

Figure 15: Modified Exhaust

During emission analysis, data points were collected as the engine was idling, revved to roughly 6,000 rpm and back to idling. From Figure 16, it can be seen that the hydrocarbon gas emission never reached normal idling levels as it would appear in figure 3b with carbon monoxide and carbon dioxide levels. The cause of the hydrocarbon increase is believed to have been from burning adhesive that came with the gasket material used to seal the exhaust port.

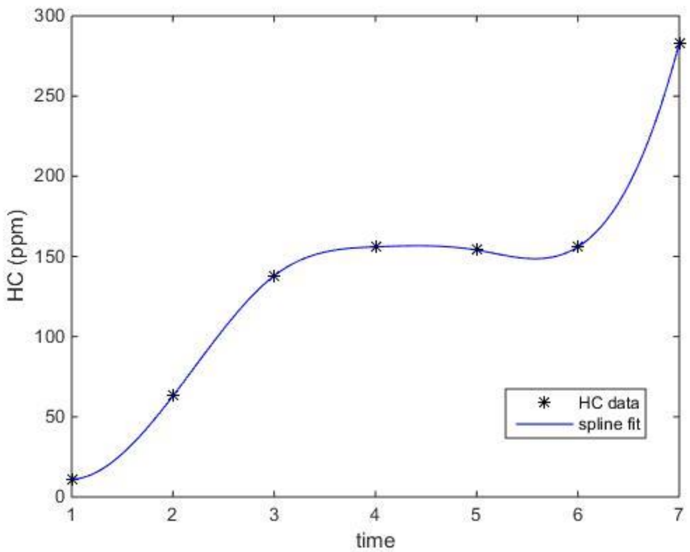


Figure 16: Hydrocarbon Emissions vs. time

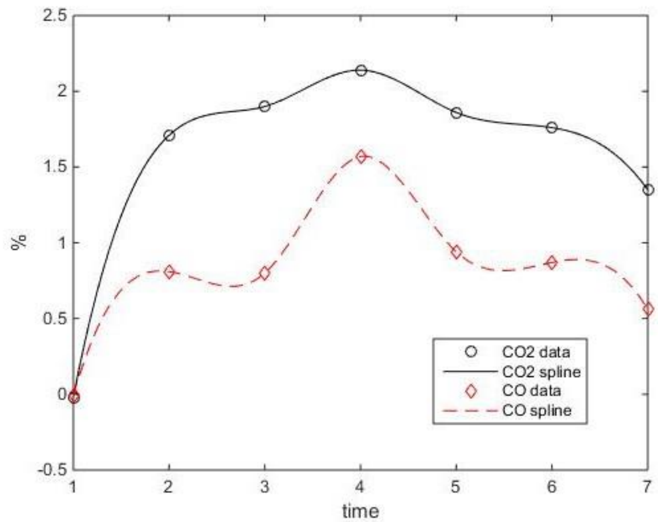


Figure 17: Carbon Monoxide and Dioxide vs. time

6.3.1 Thrust Output Testing

The design to test engine thrust capabilities is shown in Figure 18. In the experiment the engine will provide direct drive to a propeller, which will be immersed in water. The engine and propeller will be on one side of a lever arm supported by a simple support. The simple support ensures the engine and propeller will not rotate into the aquarium. The other end of the lever arm will rest on a scale. During the experiment the thrust created by the propeller will cause the lever to rotate about the fulcrum creating an equal and opposite force into the scale. The force value from the scale will output thrust forces for the system.

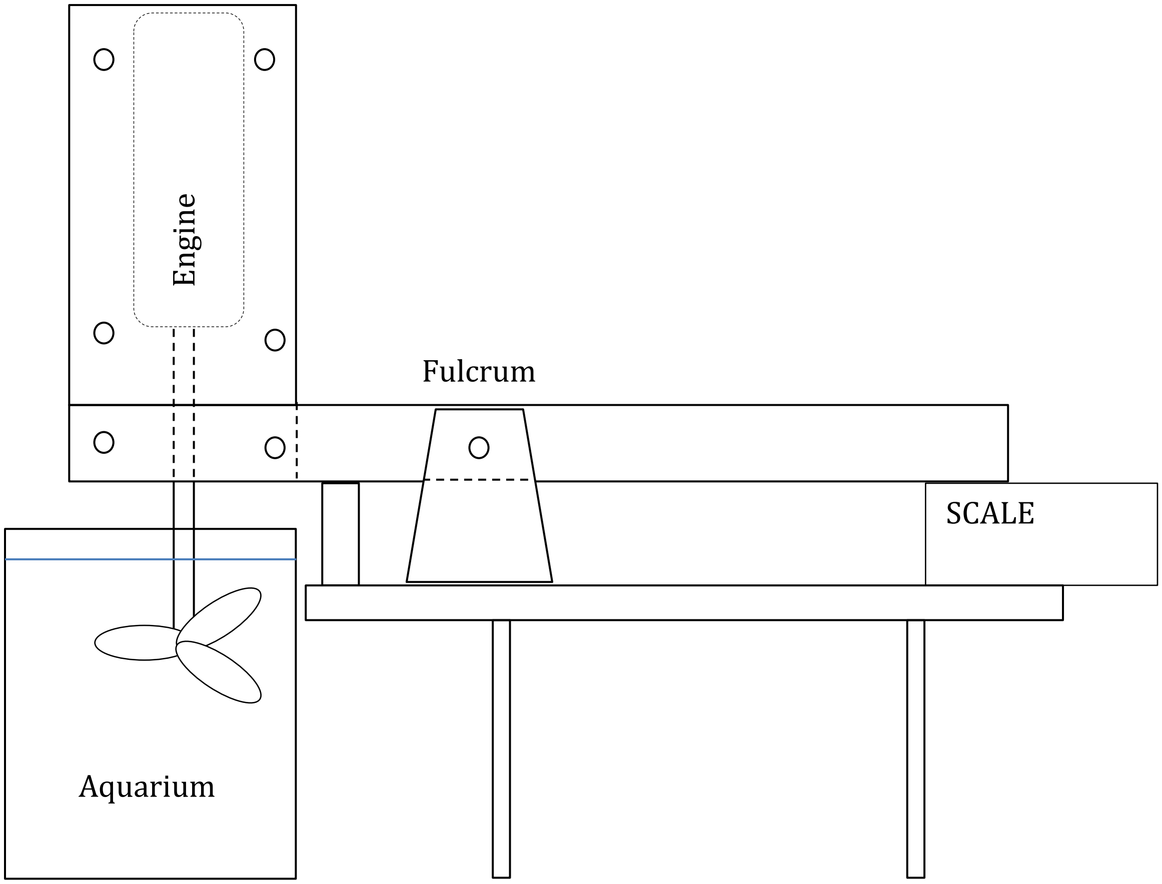


Figure 18: Thrust experiment schematic

7.0 CURRENT SHELL STATUS

The most recent design has been improved to facilitate the flow of water through the shell and onto the engine. It has also been adjusted for ease in 3-D printing and for less time and material costs.

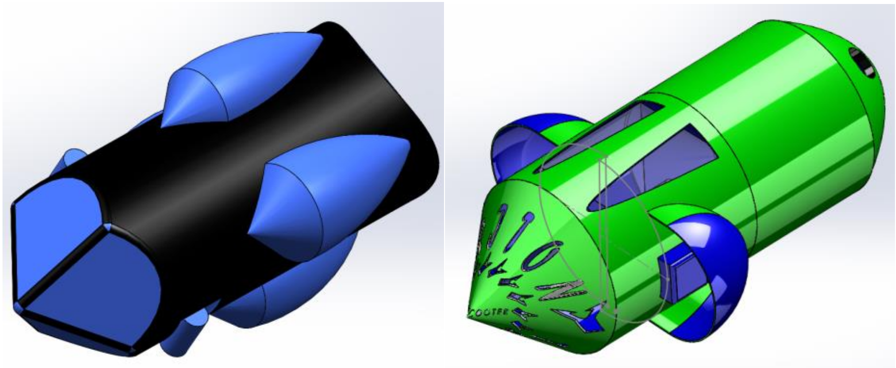


Figure 19: Initial design and final design of Triton

7.1.1 Triton Analysis

The Triton is assembled into 8 distinguishable parts, each with its own function shown in Figure 7. At the front end in the shape of a bowl is the screw cap. The cap has been cut with four equally spaced holes to allow water to pass internally through the shell and cool the engine. Attached to the cap is a nozzle that guides the flow of the water directly into the face of the engine. Around the nozzle are compartments specifically designed to hold air and for placement of the propane tank.

Buoyancy calculations have been done for dimensioning purposes of the air tank, in which there is more than enough air to allow for the floatation of the Triton shell. Moving along, the next section of the shell holds the engine as well as part of the propeller. The shell is slotted with holes along this portion of the shell to allow for water flow from the outside to come in and hit the propeller for better thrust results. It is also at this section that handles have been placed proportionally on each side of the Triton to allow for the user to hold and steer the device. Covers have been placed over the handles to withstand the flow of the current from hitting the user's hands.
Finally, a cone shaped lid has been attached to the very end of the Triton to fully cover the propeller blades in order for fingers and hands to be in any way inserted into the assembly. The full-scale dimensions of the Triton are approximately 34in. in length, and about 24in. in height, with a circular shell diameter of 12 in.

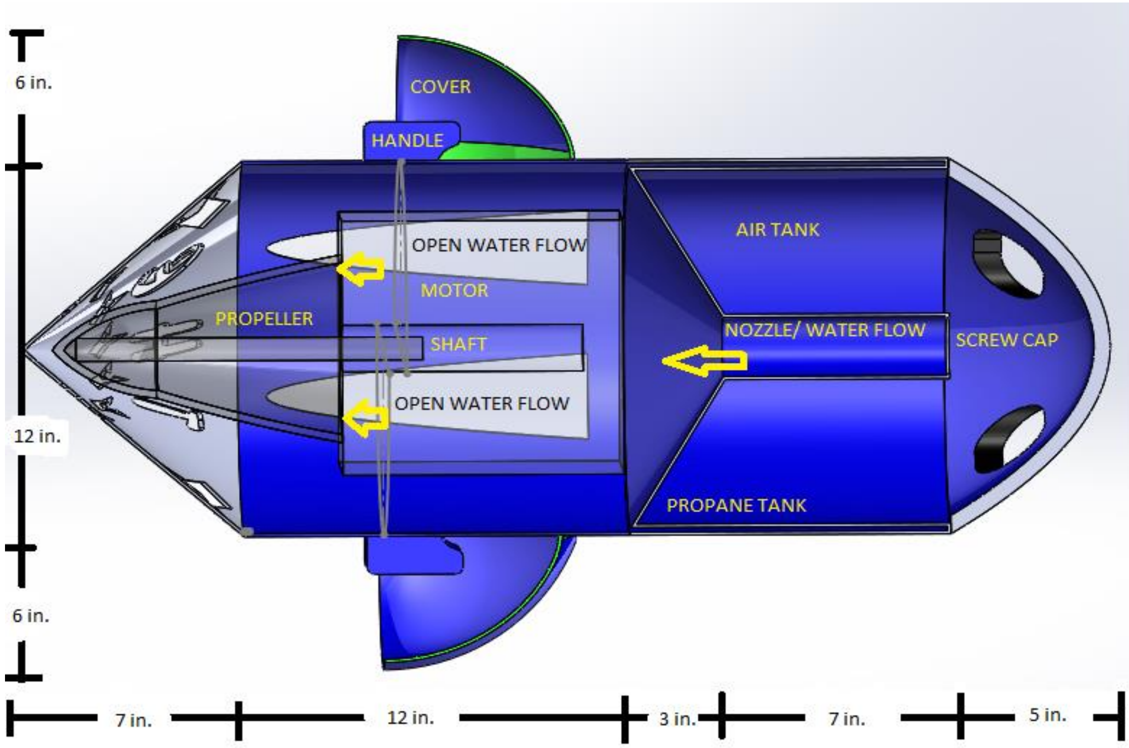


Figure 20: Internal view of the Triton

7.1.2 Triton Prototype Printing

As mentioned previously, the Triton is broken up into 8 parts. Each part will be individually printed and designed especially for the ease of printing. In order for the Triton to be assembled properly, fasteners, holes, and lips will be added in designated areas to allow for strong, rigid attachments between all parts. An exploded view of the design is shown in Figure 8 while the descriptions of the parts are in Appendix E.

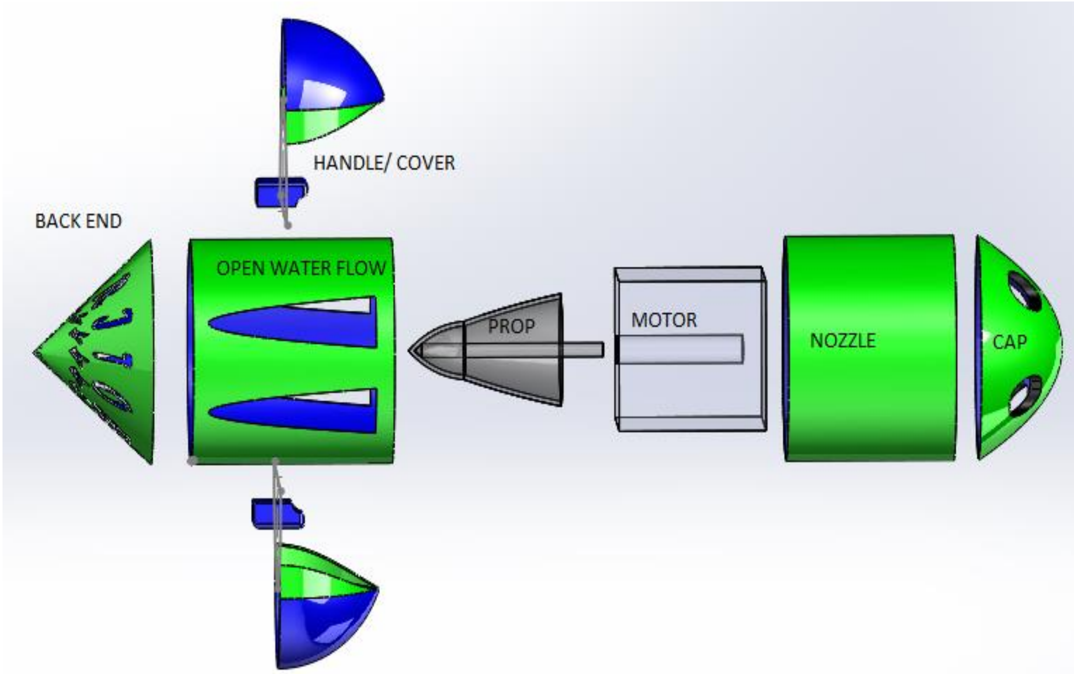


Figure 21: Exploded view of Triton design

The prototype will be scaled down to about half the size with a thickness of 0.075in. In regards to timing, another team is currently having their prototype 3-D printed which will not be completed until after spring break. The estimated time for our prototype to be completely printed is approximately three to four days, which means it should be in the printing phase within two weeks. The cost can potentially be anywhere between 300 and 600 dollars; however, based on our conversation with Dr. Tester, the cost should be closer to $450.

7.1.3 Necessary Future Adjustments

After speaking with Dr. Raju preceding our presentation, there are several adjustments that need to be made to the design. First, the lettering design on the cone end of the Triton needs to be simplified to slits cut out all across the surface. Also, the spacing for the engine and the propeller needs to be improved by designing the shell around the engine and propeller, rather than the opposite, as it was done before. This will provide accurate dimensions to accommodate the engine and allow for adequate water flow.

Lastly, the assembling fasteners, threads for the cap, and lips still need to be added to the design in time for the 3-D printing as well as slight changes to the current designs in order for printing to be more feasible.

7.2.1 Shell Construction

The team will go ahead and proceed with a shell prototype. The team spoke with Dr. Tester and he provided points to consider. First, the team needs to find out where and how the engine will be mounted onto the shell. Also, the 3-D printer that will be used is not big enough to produce a full-scaled prototype of actual size; therefore, the shell will need to be cut into halves, possibly quarters, and shell out the inside. Each individual half, or quarter, will be printed out individually and a lip will be added to all the edges. With the edges added, the parts will be able to be assembled together, rather than having just one part printed out. Again, the prototype will be scaled down from its actual size by about 1/5 of its total ratio.

8.0 BUOYANCY CALCULATIONS

To make the design float the team requires the weight of the design to be offset by a force of buoyancy. Buoyancy is found by determining the volume of water that is displaced. By assuming a maximum weight for the design, the volume of water that needs to be displaced can be calculated. The volume that needs to be displaced is then factored into the internal design of the Triton as a sealed compartment filled with air.

Assumed maximum weight: 18 lb

Specific weight of seawater: 64 lb/ft^3

Volume necessary to offset maximum weight: V

$$F_{buoyancy} = W_{aquascooter}$$

$$64\frac{lb}{ft^3} * V\ ft^3 = 18\ lb$$

$$V = 0.281\ ft^3$$

Knowing the required volume of water that needs to be displaced, the volume of the internal cylinder can be calculated using the following integral:

Length of the tapered portion of the air tank: h_0

Distance from centerline of water nozzle to the beginning of the tapered portion: r

Distance from centerline of water nozzle to the end of the tapered portion: R

$$V_1 = \pi * 6^2 * (10 - h_0) - \pi * r^2 * (10 - h_0) \tag{13}$$

$$V_2 = \int_0^{h_0} \pi * 6^2 - \pi \left(\frac{r - R}{h_0} * y + R \right)^2 dy \tag{14}$$

$$V_2 = \pi * h_0 \left(-\frac{(r-R)^2}{3} - (r - R) + 36 - R^2 \right) \tag{15}$$

$$V_{total} = V_1 + V_2 \tag{16}$$

9.0 CONVERSION KIT

There are machining operations that need to be made to the engine in order for the kit to work properly, that group members will undertake in the NAU machine shop. The Altfuel kit is the best option because there are training instructions and example video clips that can be found online. The machining operations conducted in the machine shop will reduce the overall cost of designing the engine to run on propane.

After researching several conversion kits, the group purchased the Altfuel system shown in Figure 9. The system contains several components including:

- Intake Adaptor
- Bracket for Tank
- Regulator
- Attachment Line
- Fuel Line

Figure 22: Propane Conversion Kit Components [15]

10.0 COST ANALYSIS

In order to organize the potential costs for testing the selected solutions, Table 1, was constructed. The materials are broken down into two columns, budget costs and actual costs. As the project culminates the cost of items purchased and anticipated are adjusted. The category, which accounts for the highest percentage of total cost, is the purchase cost of the conversion kit. The budgeted amount was considerably less than the actual cost. This is balanced out by the emissions budgeted cost and the quoted cost provided by the local provider. The client did request costs of more comprehensive emissions testing which was discussed earlier. The reason for this inquiry is, the final prototype may be tested using the more expensive and comprehensive testing facilities.

Table 1: Cost of Materials for Testing Engines

Item	Budget Costs	Actual Costs	% of Total	% of Total
Conversion Kits	$200.00	$363.00	11.49%	25.55%
Emission Testing	$1,000.00	$100.00	57.47%	7.04%
Prony Brake Experiment	$175.00	$170.00	10.06%	11.96%
4-Stroke Engine	$240.00	$263.00	13.79%	18.51%
Shell Prototype	$50.00	$450.00	2.87%	31.67%
Oil	$25.00	$25.00	1.44%	1.76%
Propane Gas	$50.00	$50.00	2.87%	3.52%
	$1,740.00	$1,421.00		

The pie chart shown in Figure 14 provides a visual representation of the accumulated costs of the project up to date. The cost of the engine, accounts for 18% of the total cost for all materials, while the prototype cost will be 32% of the total cost. Another significant percentage is the cost of the prony brake experiment, which is 12% of the total cost.

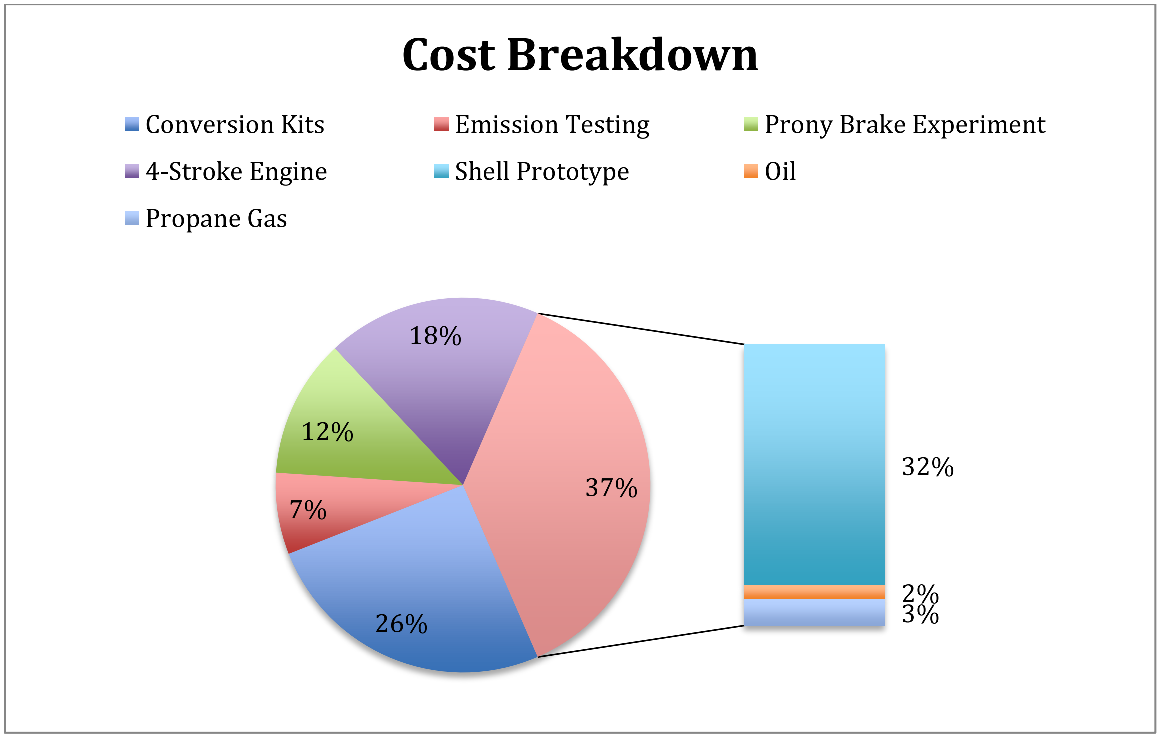


Figure 23: Pie Chart with Percentages of Total Cost

11.0 CONCLUSION

The client, Robert Witkoff, currently manufactures a product that does not meet current United States' EPA regulations. The objective of this project is to design, engineer, and test an engine that will exceed the current EPA regulations. The most important points to consider for the design of a prototype are to adhere to the EPA regulations, keep dry weight of device under 18 lbs. and provide a capacity of a minimum of 50 lbs. of thrust. Additionally, the team must keep the manufacturing cost per scooter under $450. The team's decision matrix assisted in providing potential solutions for the client. Two concepts were selected and were analyzed to assess feasibility.

After some primary calculations, the two-propeller design was ruled out and a single propeller was chosen for full analysis. The engine chosen for analysis was the 4-stroke Honda GXH50 engine. The feasibility of propane gas for engine was calculated and researched. The calculations show that this gas will be able to propel the Aqua Scooter effectively.

The team has conducted several tests on the engine including emissions testing and a power test. This line of analysis will provide the team with a baseline for when the engine is converted. The engine will also need to have a second emissions testing done prior to the conversion.

All tests will need to be repeated after conversion utilizing the new fuel option. This is where the team will need to construct accurate and viable models for testing. The emissions testing will be conducted following several iterations of engine modeling.

A prototype of the outer shell will be constructed for the client to present to potential manufacturers. The prototype will be 3-D printed in the manufacturing lab. Although there will be a prototype the shell analysis will be conducted in ANSYS and Workbench to verify the drag forces.

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APPENDIX A: Aqua Scooter Components

1 - AIR TANK
2 - AIR TANK PLUG FOR SNORKEL CONNECTION
3 - FUEL TANK PLUG
4 - FUEL TANK
5 - FUEL VALVE
6 - EXHAUST GAS OUTLET
7 - FUEL PIPE
8 - STARTER HANDLE
9 - STEERING HANDLE
10 - THROTTLE LEVER

Figure A1: List of components of Aqua Scooter

11 - "**AVVIAMENTO - START - STOP"** POSITIONS
12 - CARBURETTOR TO CARB - EPA STANDARDS
13 - "START AND RUN" LEVER
14 - "**RUN/MARCIA"** POSITIONS
15 - PROTECTIVE GRILLE CE
16 - FUEL TANK BREATHER PIPE
17 - PROPELLER GUARD AND WATER DEFLECTOR CE
18 - CARRY HANDLE
19 - SPARK PLUG
20 - AIR INTAKE TUBE (SNORKEL)
21 - SNORKEL EXTENSION
22 - RUBBER BUMPER

Figure A2: Additional list of components for Aqua Scooter

APPENDIX B: Volume Calculations for Butane and Propane

Propane

```
%Propane volume calculator

Hp = input('Enter horsepower here\n'); %User input for engine horsepower

Bhr = Hp*2544.43358; %[Btu/hr] Converts input horsepower to Btu/hr

t = 3; %[hr] Time that aquascooter needs to run from full to empty fuel tank

B = Bhr*t; %[Btu] Energy needed from propane for aquascooter to run for time
t

IE = 84250; %[Btu/gal] Internal energy of propane

V = B/IE; %[Gal] Volume of propane needed to provide the energy for the
aquascooter

rho = 65.8285503; %[oz/gal] Density of propane

W = rho*V; %Weight of propane needed to run for time t

fprintf('The weight of propane needed is %4.2f oz.\n',W);
```

Butane

```
%Butane volume calculator

Hp = input('Enter horsepower here\n'); %User input for engine horsepower

Bhr = Hp*2544.43358; %[Btu/hr] Converts input horsepower to Btu/hr

t = 3; %[hr] Time that aquascooter needs to run from full to empty fuel tank

B = Bhr*t; %[Btu] Energy needed from propane for aquascooter to run for time
t

IE = 102600; %[Btu/gal] Internal energy of butane

V = B/IE; %[Gal] Volume of propane needed to provide the energy for the
aquascooter

rho = 79.9823563; %[oz/gal] Density of butane

W = rho*V; %Weight of propane needed to run for time t
 fprintf('The weight of butane needed is %4.2f oz.\n',W);
```

APPENDIX C: Thrust

```
function thrust
RPM=input('What is the required RPM?\n');
Vo=input('What is the required speed (in miles/hour)[Vo]?\n');
Vo=Vo*(0.44704);    % mi/hr  ---->0.44704 m/s
P=input('What is the required Pitch [P]?\n');
F=input('What is the required minimum thrust (in lbs) [F]?\n');
F=F*(4.448);     % Lbs ----->4.448 N
syms d

d1=solve(F==1.225*(pi*(0.0254*d)^2)/4*((RPM*0.0254*P*(1/60))^2-
(RPM*0.0254*P*(1/60))*Vo)*(d/3.29546*P)^1.5,d,'Real',true);
d2=solve(F==4.392399e-8*RPM*(d^(3.5)/sqrt(P))*(4.23333e-4*RPM*P-
Vo),d,'Real',true);
fprintf('The full equation gives the diameter needed as %g \n',double(d1));
fprintf('The short equation gives the diameter needed as %g \n',double(d2));
```

APPENDIX D: Adiabatic Flame Temperatures using interactive thermodynamics

```
TR = 50 // sea water temp in F

//Propane anaysis for adiabatc flame temp
//evaluate reactant and product enthalpies hR and Hp
hR = hC3H8 + 5*hO2_R + 18.8*hN2_R
hP = 3*hCO2_P + 4*hH2O_P + 18.8*hN2_P

hC3H8= -44680
hO2_R = h_T("O2",TR)
hN2_R =  h_T("N2",TR)
hCO2_P = h_T("CO2",TP)
hH2O_P = h_T("H2O",TP)
hN2_P = h_T("N2",TP)

hP=hR
TP = 3833 // adiabatic flame temp in F
////////////////////////////////////////////////////////////////
TR = 50 // sea water temp in F

//Butane anaysis for adiabatc flame temp
//evaluate reactant and product enthalpies hR and Hp
hR = hC3H8 + 9*hO2_R + 33.84*hN2_R
hP = 4*hCO2_P + 10*hH2O_P + 33.84*hN2_P

hC3H8= -44680
hO2_R = h_T("O2",TR)
hN2_R =  h_T("N2",TR)
hCO2_P = h_T("CO2",TP)
hH2O_P = h_T("H2O",TP)
hN2_P = h_T("N2",TP)

hP=hR

TP = 3931 // adiabatic flame temp in F
///////////////////////////////////////////////////////////////////
TR = 50 // sea water temp in F

//Propane anaysis for adiabatc flame temp
//evaluate reactant and product enthalpies hR and Hp
hR = hC8H18 + 12.5*hO2_R + 47*hN2_R
hP = 8*hCO2_P + 9*hH2O_P + 47*hN2_P

hC8H18= -107530
hO2_R = h_T("O2",TR)
hN2_R =  h_T("N2",TR)
hCO2_P = h_T("CO2",TP)
hH2O_P = h_T("H2O",TP)
hN2_P = h_T("N2",TP)

hP=hR
TP = 3833 // adiabatic flame temp in F
```

APPENDIX E: Parts of Final Design

- Screw Cap: Open holes allow for water flow through nozzle
- Nozzle: Directs water into motor for cooling
- Open Water Flow: Directs water into propeller for thrust
- Handle/ Cover: Cover protects users hand from direct current
- Back End: Slits used to release water and avoid fingers into propeller
- Air Tank: Allows enough air to keep shell afloat/ buoyant
- Propane Tank: Placement of propane tank

APPENDIX E: Quotes for Emissions Equipment

Inquiry Date	Inquiry Reference No.	Shipping Terms	FUNDS
21-Jan-15	v.15	ExWorks Niagara Falls, NY	US $

Item No.	Qty.	Description	Unit Price
1	1	**Nova Model 7466K Portable 6 Gas Engine Exhaust Analyzer for CO, CO2, HC's, O2, NO, & NO2.** - NDIR infra red CO, CO2 & Hydrocarbon (HC's) detectors - long life electrochemical O2, NO & NO2 sensors - portable analyzer, suitable for temporary / intermittent analysis - **ranges** : 0 - 5.00 / 10.00 % CO (*choose one) 0 - 20.0 % CO2 0 - 1,999 up to 9,999 PPM HC's (as Hexane) (other ranges & HC's as Propane available) 0 - 25.0 % Oxygen 0 - 2,000 / 5,000 PPM NO (*choose one) 0 - 200 / 500 / 800 PPM NO2 (*choose one) - **displays** : digital, one per gas analyzed - **operation** : re-chargeable 'gel cell' battery, DC and AC - **power** : 115VAC / 60 Hz. Re-charger and 12VDC cigarette lighter plug supplied loose. - **sampling** : built-in sample pump, filter and flow meter; automatic condensate removal system. S.S. probe & flexible hose supplied loose. - **enclosure** : 'K' series suit case style polycarbonate, black * Standard ranges above are under-lined. **Also available in the following popular combinations** :	$9,150.00
2	1	**Nova Model 7466K** Portable 6 Gas Engine Exhaust Analyzer for CO, CO2, HC's, Oxygen, NO and NO2	$9,150.00
3	1	**Nova Model 7465K** Portable 5 Gas Engine Exhaust Analyzer for CO, CO2, HC's, Oxygen & NO.	$7,525.00

4	1	**Nova Model 7464K** Portable 4 Gas Engine Exhaust Analyzer for CO, CO2, HC's & Oxygen.	**$6,300.00**
5	1	**Nova Model 7463K** Portable 3 Gas Engine Exhaust Analyzer for CO, CO2 & HC's.	**$5,450.00**
6	1	**Nova Model 7462K** Portable 2 Gas Engine Exhaust Analyzer for CO & HC's.	**$4,950.00**
7	1	**Nova Model 7461AK** Portable 1 Gas Engine Exhaust Analyzer for CO.	**$4,550.00**
8	1	**Nova Model 7461CK** Portable 1 Gas Engine Exhaust Analyzer for HC's.	**$4,550.00**
		<u>Options</u>	
9	1	**Built-in Printer**. - add a " P " suffix to Model #…ie Model 7466K becomes Model 7466PK - printout header contains 24 characters, spaces included. Specify header text on PO.	**$550.00**
10	1	**Low Range PPM CO** Channel by Electrochemical CO sensor in place of NDIR % CO detector. - **range** : 0 - 2,000 / 5,000 / 10,000 PPM CO* (10 PPM Res.) * choose one range & specify on PO - add an "L" suffix to Model #. ie. Model 7466LK	**$25.00**
11	1	**Add Nitrogen Oxide** Channel to any 7460 series analyzer - **range** : 0 - 2,000 / 5,000 PPM NO (* choose one) - add an "N" suffix to Model #. ie Model 7461NK	**$1,360.00**
12	1	**Add Nitrogen Dioxide** Channel to any 7460 series analyzer - **range** : 0 - 200 / 500 / 800 PPM NO2 (* choose one) - add an "X" suffix to Model #. ie Model 7461XK	**$2,090.00**
13	1	**Serial Output & Data Logging** PC Software Package - real-time data logging of analyzer results - communication format un-polled (half duplex) RS-485 - RS-485 to USB Adapter Plug / Cable Assembly included.	**$495.00**
14	as req'd	**4 - 20mA recorder output**, max. one per gas analyzed	each **$95.00**

		Probe Choices	
15	1	**Standard Probe** with S.S. **Flex Tip**, cool-touch handle & sample hose - for gasoline, LPG & clean-burning diesel - for light to medium particulate load, small pre-filter - for up to 400° F Automobile applications c/w full exhaust	standard probe included
16	1	Probe with S.S. **Straight Tip**, cool-touch handle & sample hose - for gasoline, LPG & clean-burning diesel - for light to medium particulate load, small pre-filter - for up to 1,200° F Forklift applications.	no charge in place of standard probe
		Spares	
1	1	Water Separator Element - 25-51-70K	**$11.00**
2	1	In-line Filter - IDN6G	**$21.00**
3	1	PTFE Liquid Blocker - ACRO37-PTFE	**$28.00**
4	1	Probe Filter (Package of 20) - AGS-011	**$140.00**
5	1	Rolls paper, 5 pack	**$25.00**
6	1	Oxygen Sensor - KE25-F3	**$225.00**
7	1	NO Sensor - 5NF	**$415.00**
8	1	NO2 Sensor - 5ND	**$415.00**

Thank you for the opportunity to quote on your requirements.
NOVA ANALYTICAL SYSTEMS

Prepared by:
David Sheasby

ESTIMATED SHIPPING SCHEDULE
AT TIME OF QUOTE
6 - 8 WEEKS