Aqua Scooter 2.0

By
Dylan Cannon, Darin Gilliam, Eli Palomares, Elizabeth Tyler,
Jiyan Wang, Tyler Winston
Team 8

Final Report
Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design II – Spring 2015

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

ABSTRACT

The Aqua Scooter currently has a 2-stroke gas powered engine that, as of January 2010, the EPA's regulations prevent future sales. The capstone team was 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 GX25, 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 gasoline fuel. To verify the thrust 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.

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

Table of Contents

Table of Contents

List of Figures and Tables

Figures

Tables

1. 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 Appendix A 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 half-gallon fuel tank capacity.

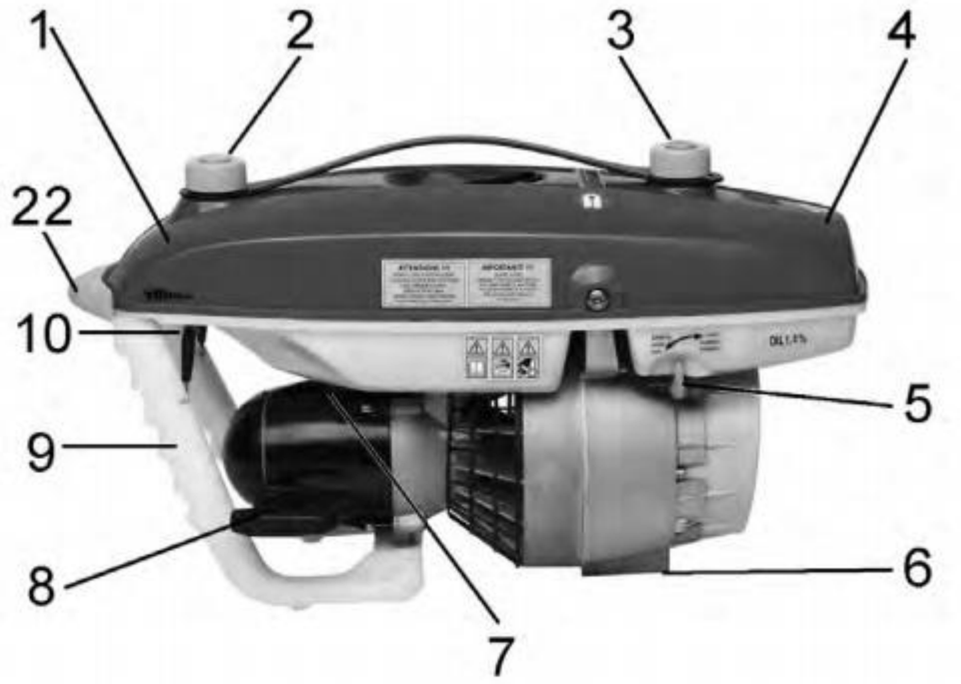


Figure 1: Aqua Scooter side view with designated components [1]

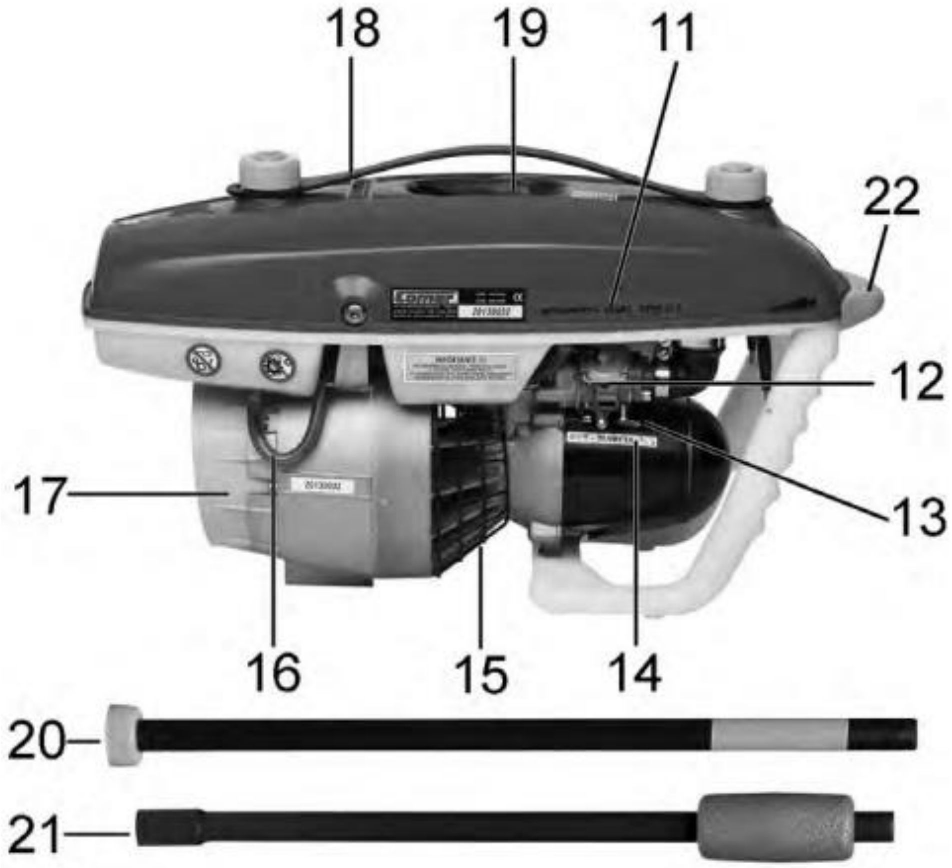


Figure 2: Aqua Scooter with designated components and snorkel extension [1]

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:

- It must produce less than or equal to 30 g of hydrocarbons
- It must produce 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

It may be unclear why a product should be tested for emissions. What benefits does it bring to the customer? Why is it important to pass? It turns out that doing emissions testing has several advantages. Here are three reasons why emissions testing are very important:

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

In addition to improving the air quality, emission testing also benefits both the company product and the end user of the product.

1.2.1 Current Technology

The group researched two and four stroke engine types for this project. The options available on the current market to implement in a possible solution for our client 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 in use 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. 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 on communication with the client. The constraints are the following:

- Internal combustion 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

2.2.1 Quality Function Deployment Summary

The quality function deployment (QFD) matrix, shown in Table 1 below, is useful for correlating the needs of the customer to the requirements that the team can quantify. The requirements that need the most attention based on the matrix are exhaust emissions, fuel capacity, weight, buoyancy, and thrust. The exhaust emissions carry a significant amount of weight because it is a primary objective for the project. The weight of the machine is important because the weight needs to be countered by the buoyancy. The heavier the device is the more effort the engine needs to exert to move through the water. Moving forward with the needs, requirements, and constraints in mind will be crucial in developing a new iteration of the Aqua Scooter.

2.2.2 Quality Function Deployment (QFD)

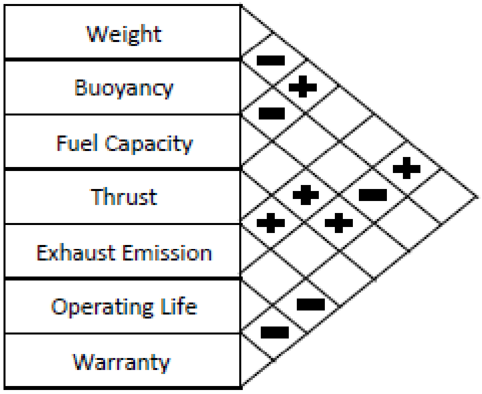
Table 1: Quality function deployment showing the engineering requirements and customer needs

Aqua Scooter QFD Matrix	Weight	Buoyancy	Fuel Capacity	Thrust	Exhaust emission	Operating Life	Warranty	Cayago Seabob	Seadoo Seascooter
Aesthetically pleasing	X		X					O	O
Child safe	X	X		X	X				O
Lightweight	X	X	X	X					
Floats	X	X	X					O	O
Propels operator through water				X	X			O	O
Runs for extended period			X						
Meets current EPA regulations					X	X	X	O	O
units	lb.	lb.	gal.	lb.	g/kW-h	Hours/Years	Hours/ Months		
	≥ 18	≥ 18	≥ 0.5	≥ 50	≤30 of Hydrocarbon, ≤490 of Carbon Monoxide	≥ 350/5	≥ 175/30		

2.4 House of Quality

The house of quality (Table 2) correlates the engineering requirements that are listed for this particular project. If the requirement is positively correlated, indicating that the increase of a particular item produces the same effect on another requirement, a (+) symbol is shown. If the requirements are negatively correlated, a (-) symbol is shown. If there is no correlation the space is left blank.

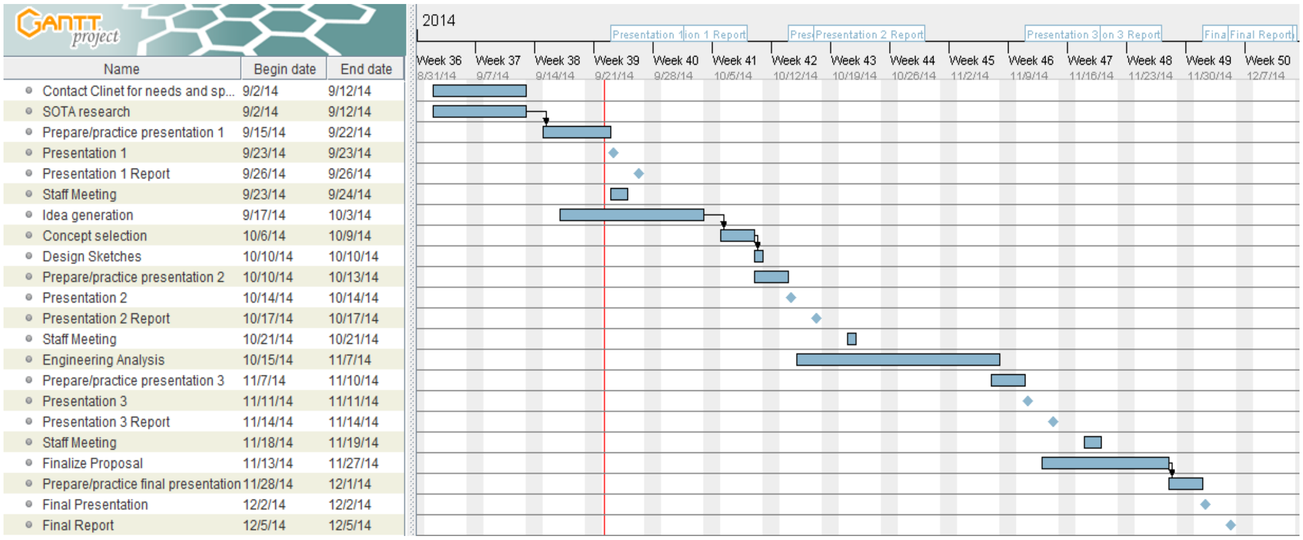
Table 2: House of quality, which correlates engineering requirements



3.0 GANTT CHART

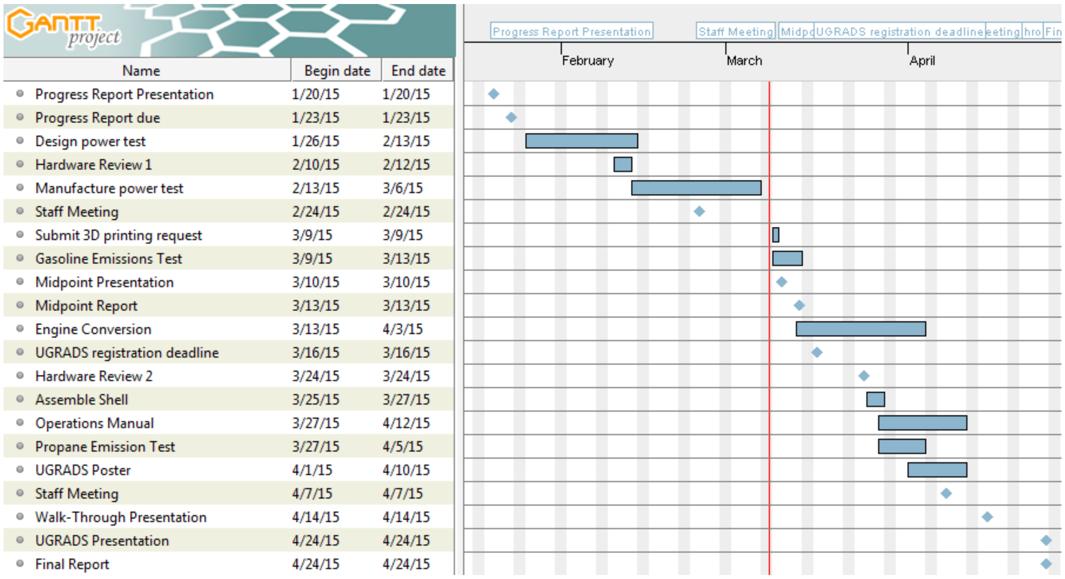
Figures 3 and 4 display the Gantt charts that illustrate an estimated timeline for the fall semester and spring semester progression of the Aqua Scooter prototype design and testing. The timeline is broken down into tasks and deliverables. Tasks are shown as blue bars and deliverables are shown as blue diamonds. 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 most important tasks and deliverables were presented on time throughout each semester. The scheduled created an environment for all team members to know the details of deliverables and intended progress.



Name	Begin date	End date
Contact Clinet for needs and sp...	9/2/14	9/12/14
SOTA research	9/2/14	9/12/14
Prepare/practice presentation 1	9/15/14	9/22/14
Presentation 1	9/23/14	9/23/14
Presentation 1 Report	9/26/14	9/26/14
Staff Meeting	9/23/14	9/24/14
Idea generation	9/17/14	10/3/14
Concept selection	10/6/14	10/9/14
Design Sketches	10/10/14	10/10/14
Prepare/practice presentation 2	10/10/14	10/13/14
Presentation 2	10/14/14	10/14/14
Presentation 2 Report	10/17/14	10/17/14
Staff Meeting	10/21/14	10/21/14
Engineering Analysis	10/15/14	11/7/14
Prepare/practice presentation 3	11/7/14	11/10/14
Presentation 3	11/11/14	11/11/14
Presentation 3 Report	11/14/14	11/14/14
Staff Meeting	11/18/14	11/19/14
Finalize Proposal	11/13/14	11/27/14
Prepare/practice final presentation	11/28/14	12/1/14
Final Presentation	12/2/14	12/2/14
Final Report	12/5/14	12/5/14

Figure 3: Gantt chart fall semester



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 4: Gantt chart spring semester

4.0 CONCEPTS

Each team member was required to develop two ideas individually. The concepts generated needed to address one of the two main client needs: EPA regulations and streamlined design.

4.1.1 Catalytic Converter with Heating Element

Using the existing Aqua Scooter design, a catalytic converter would be added to the current 2-stroke engine. Adding a catalytic converter would mean creating an exhaust system that does not currently exist on the Aqua Scooter. An exhaust system would need to be safely located so the user does not unintentionally interact with the hot exhaust system (Figure B1, Appendix B). The catalytic converter would have a heating element in order for the redox reaction to occur spontaneously while in a constantly cooled environment. The catalytic converter should effectively reduce the output of nitrous oxides and unburned carbon groups, which is the current problem with using a 2-stroke engine to power the Aqua Scooter.

4.1.2 Enclosed Housing

The current Aqua Scooter design has the engine in direct contact with the environment. This means during operation the Aqua Scooter is submerged in water. Prolonged contact with water or saltwater would cause material damage, which would reduce the functional life of the engine. To increase the functional life of the engine it would be completely enclosed in a hard, watertight polymer. There are design concepts that would require the engine to be in contact with air; the enclosed housing could be modified for these designs if need be (Figure B2, Appendix B).

4.1.3 Fuel-Injected Two Stroke Engine

This design concept is in regards to finding a solution for a new Aqua Scooter that will meet the latest EPA regulations. It is a fuel injected 2-stroke engine. The reason the current Aqua Scooter model is not meeting EPA regulations is because the two stroke engine uses a carburetor to introduce the air and fuel into the engine, and ultimately into the combustion chamber. As a result, unburned fuel was escaping out of the exhaust port, leading to higher emissions and poor fuel economy. The direct fuel injected system directly injects the fuel into the combustion system, after the exhaust port is closed. In this way, no fuel escapes out of the exhaust, and this results in good fuel efficiency and very low emissions. The downside to implementing this design is the price and computational aspect. A fuel injector kit can start anywhere from $500, which is too expensive to consider its use considering the team's cost constraint. Unfortunately, even after purchasing the kit, the setup of the computational device is very complex. In short, the electronic fuel injection computational system assists in the timing of injecting the fuel into the chamber of the engine. For these reasons, this design concept may not be considered for final application. Refer to Figure B3 in Appendix B, for a concept design sketch.

4.1.4 Magneto Hydrodynamic Propulsion (MHP) System

The MHP system is a concept primarily for thrust and emissions rather than aesthetics. The system consists of an engine, a generator, and two metal plates. The engine would be a four stroke to ensure that the system has the capability to meet EPA regulations. The MHP system drives the Aqua Scooter with thrust created from rapid hydrolysis. This is achieved with the engine powering the generator that magnetically charges the two plates that are angled toward each other. The magnetic charge between the two plates excites the water molecules (hydrolysis) causing them to expand rapidly. The rapid change in volume forces the water between the two plates to thrust through the nozzle shape that is created by having the plates oriented at an angle. (Figure B4, Appendix B)

4.1.5 Nozzle Concept:

A conventional 4-stroke engine powers an impeller with a drive shaft. The impeller pulls water through the intake and compresses it out through a nozzle in the rear of the craft (Figure B5, Appendix B). The nozzle can be angled differently for different thrust vectors. The angle of the nozzle can be set up to be controlled one of two ways. The first is to connect the nozzle to the handles of the craft in a such a way that would allow the user to manipulate the nozzle in vertical and horizontal directions. The second would be to have the vertical movement of the nozzle controlled by a system that could be fixed in position for the duration of use and the horizontal movement be controlled by the user moving the craft. The 4-stroke engine would be within EPA regulations for emissions, while the nozzle would add functionality to the entire Aqua Scooter system. (Figure B5, Appendix B)

4.1.6 Propane Injected 4-Stroke

The propane injected 4-stroke is also aimed at achieving EPA regulations for emissions. The system consists of a conventional 4-stroke engine that is converted to run on propane. The hope when converting to a propane system is that propane is proven to burn cleaner which reduces exhaust emissions when compared with gasoline engines. Cleaner emissions would result in an engine that is more environmentally friendly and passes EPA regulations. (See Figure B6, Appendix B)

4.1.7 4-stroke Mix Engine

The 4-stroke mix engine is a hybrid of both a 4-stroke engine and a 2-stroke engine. It has the emissions similar to 4-stroke engines, while utilizing a similar fuel mixture to a 2-stroke. A 4-stroke engine uses gasoline as fuel and then has an oil tank built into the system, which provides lubrication for the engine. The 4 mix operates with oil and gasoline already mixed together which eliminates the need for oil tanks, pumps, or any other heavy components that are normally part of a 4-stroke engine. This will allow the engine to be lighter while complying with EPA regulations. (Figure B7, Appendix B)

4.1.8 Tank Housing

This concept attempts to highlight an alternative look to the Aqua Scooter that will not only reduce drag from the hydrodynamic design, but will hopefully become more appealing to the customer. The current model is simple, it is somewhat box-shaped and its configuration makes it difficult for it to navigate through the waters. The tank-housing concept is a “sporty” look that will hopefully attract more customers. (Figure B8, Appendix B)

4.1.9 Duck Scooter

The idea of this design comes from the rubber duck that has been on the toy market since the late 1800s. In hoping to attract a younger demographic the outside shell of the Aqua Scooter would be constructed with a plastic duck shape. The design includes a larger fuel tank, which would be located in the head of the duck. The engine for the scooter would be a 4-stroke engine and a single propeller much like the current Aqua Scooter design where it would be located in the body of the duck. The design will meet the EPA regulations. (Figure B9, Appendix B)

4.1.10 Two-propeller design

This design concept utilizes a similar design to the current Aqua Scooter and will potentially provide more thrust and a larger fuel tank for longer use. The design consists of two propellers that are connected by a belt and pulley system to a single 4-Stroke engine. The current Aqua Scooter design has the engine pushing the water's wake into the user's face. One advantage with the two-propeller design is that the wake will circumvent the user allowing for a more comfortable ride. (Figure B10, Appendix B)

4.1.11 Boomerang

The boomerang concept is designed to allow the user to slice through the water. Marine devices have a rounded or pointed front to help be more hydrodynamic and conserve energy and fuel. The user will have handlebars that allow for the user to adjust the throttle and the angle of the adjustable jet. The system will use one 4-stroke engine and will provide enough thrust to move the user quickly. (Figure B11, Appendix B)

4.1.12 Octopus

The octopus would have engines on each end of the tentacles. Each of the engines would be a 4-stroke engine that keeps the design complying with EPA regulations. Since the design is completely new and not seen on the market, it will be marketable to a different range of customers. The device will also rotate around the user to jet them through the water much like a bullet through the air. (Figure B12, Appendix B)

5.0 DECISION MATRIX

The decision matrix was a tool used to help the group decide on the top two ideas for potential final designs. The team created decision matrix with nine criteria. Each of the criteria was given a specific percentage weight and then all concepts were rated in each category.

Table 3: Decision matrix with group concepts and criteria

Requirement Weighting Design	Aesthetically Pleasing	Minimal Probability of Error	Ease of Manufacture	EPA Requirements	Complexity of Design	Provides Thrust	Hydrodynamically Efficient	Lightweight	Minimal Cost of Materials	Total Weighted Factor
	10%	10%	10%	20%	10%	10%	10%	10%	10%	100%
Boomerang	7 0.7	6 0.6	5 0.5	7 1.4	5 0.5	8 0.8	8 0.8	6 0.6	7.5 0.75	**6.65**
Octopus	6 0.6	3 0.3	4 0.4	7 1.4	4 0.4	8 0.8	6 0.6	6 0.6	5 0.5	**5.6**
Magnetohydrodynamic propulsion	5 0.5	3 0.3	3 0.3	7 1.4	2.5 0.25	9 0.9	6 0.6	4 0.4	3 0.3	**4.95**
Propane Injected 4 Stroke	7 0.7	7 0.7	7 0.7	8 1.6	7 0.7	5.5 0.55	7 0.7	6 0.6	5 0.5	**6.75**
Duck Scooter	8 0.8	6 0.6	6 0.6	6 1.2	6 0.6	7.5 0.75	5.5 0.55	6 0.6	5 0.5	**6.2**
2 Propeller	8 0.8	6 0.6	6 0.6	7.5 1.5	5 0.5	8.5 0.85	7 0.7	5.5 0.55	6 0.6	**6.7**
4 Mix Engine	6.5 0.65	7 0.7	8 0.8	8.5 1.7	7 0.7	9 0.9	7 0.7	6 0.6	5 0.5	**7.25**
Enclosed Housing	7.5 0.75	8 0.8	6 0.6	7 1.4	5 0.5	9 0.9	7 0.7	6 0.6	5 0.5	**6.75**
Adjustable Jet	7 0.7	6 0.6	6 0.6	8 1.6	6 0.6	8 0.8	8 0.8	6 0.6	6.5 0.65	**6.95**
Catalytic Converter and Coil	6 0.6	5.5 0.55	5 0.5	8 1.6	5 0.5	7 0.7	6.5 0.65	7 0.7	5 0.5	**6.3**
Fuel Injected 2 Stroke	7 0.7	5.5 0.55	5 0.5	8 1.6	5 0.5	9 0.9	7 0.7	7.5 0.75	4 0.4	**6.6**
Tank Housing	7.5 0.75	5.5 0.55	6 0.6	6 1.2	5.75 0.575	9 0.9	7.5 0.75	7 0.7	5.5 0.55	**6.575**

The weight values range from one to ten, with ten being the most important and one being the least important. Each weight was then multiplied by designated percentage to calculate values. Finally, all team members combined their matrices to eliminate any favoritism and the final matrix is shown in Table 3. The top concepts in either the engine category or aesthetics category were voted on by the team. These concepts were discussed and two final designs were selected.

6.0 FINAL CONCEPTS

Using the decision matrix above the final concepts for design of the new Aqua Scooter were narrowed down into two categories: engines and aesthetics. The proposed engine ideas included a fuel injected 2-stroke, a 4 Mix 4-stroke, a propane 4-stroke, and the magneto hydrodynamic propulsion system. The proposed aesthetic designs included: the boomerang, the two propellers, the duck, and the adjustable jet. Through discussion and a voting process two concepts were selected.

6.1.1 Boomerang with Propane and 4-Stroke Engine

The first concept selected utilizes the aesthetics of the boomerang design and combines the propane 4-stroke engine with an adjustable jet. The boomerang design allows for both an aesthetically pleasing design that has good opportunity to create a buoyant vessel, which has appropriate area to include necessary fuel tanks and geometry to create an effective steering system.

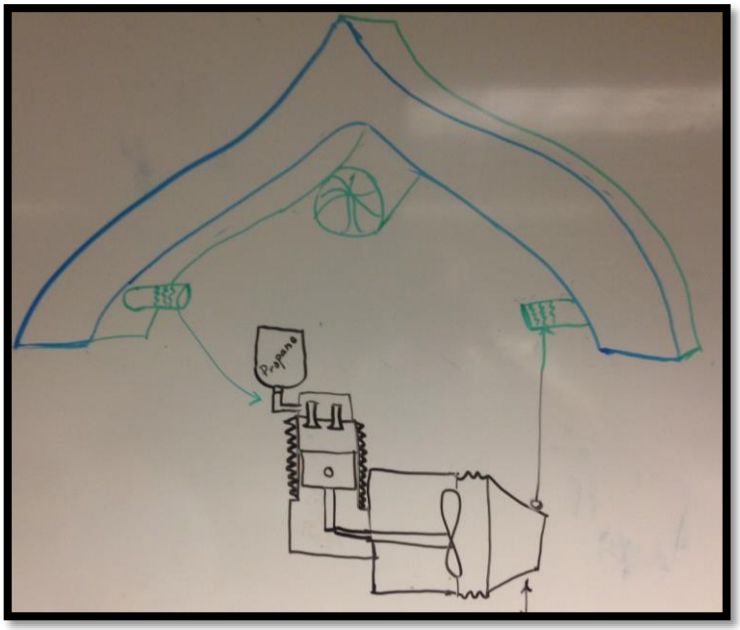


Figure 5: Boomerang with Propane Injected 4-Stroke Engine

The nozzle coupled with a propane modified 4-stroke will allow the design to have the necessary thrust required while still meeting EPA emission regulations.

6.1.2 2-Propellers with 4-Stroke 4-Mix Engine

The second concept selected utilizes the aesthetics of the two-propeller design and combines the 4 Mix 4-stroke engine and adjustable jet. The two-propeller design is an aesthetically pleasing design, which can house all necessary components for the new Aqua Scooter while being a more modern design, which should allow the design to be marketable and desired. The design of two propellers that push water with two nozzles will allow the thrust requirement to be obtained by the design. In addition to meeting the thrust requirement the dual nozzles, which are set on either side of the craft, created thrust on either side of the user rather than pushing water into the user like the current Aqua Scooter. The 4 Mix engine would be able to be housed completely in the two-propeller design and designed such that a single drive shaft from the engine will drive both propellers.

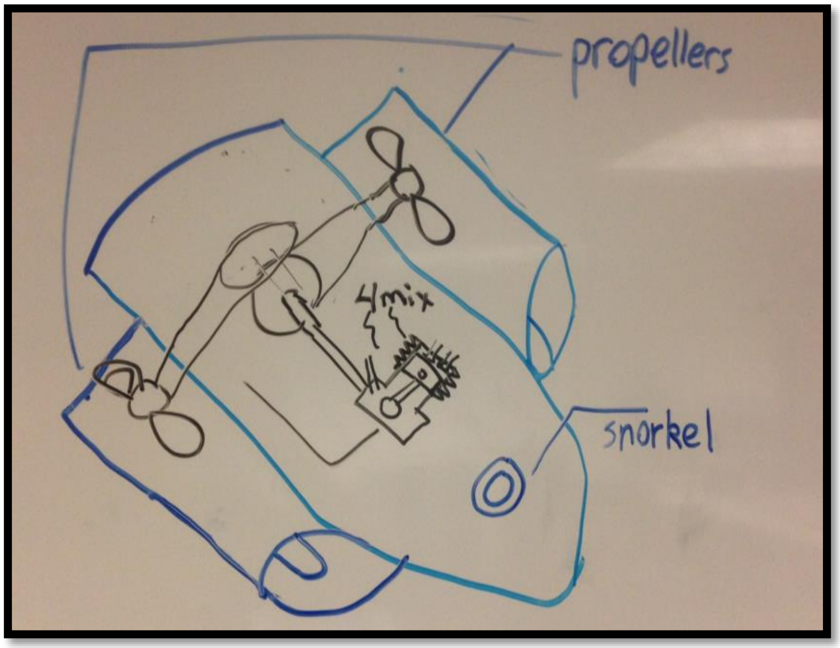


Figure 6: 2-Propeller with Belt and Pulley system including 4-Stroke 4-Mix Engine

6.2.0 Shell Analysis

Initially, the shape of the outer shell was similar to a boomerang. After estimating the drag force that the Aqua Scooter would experience with the boomerang as the shell, it was determined that a reiteration of the design was necessary to decrease the drag force. The formula for the drag force is dependent upon the drag coefficient which has been estimated for various shapes. Drag coefficients along with the formula can be seen below:

$$F = 0.5\rho V^2 \, C_d \, A \qquad (1)$$

Where:

$F = Drag\ force$ [N]

$\rho = Density$ [kg/m^3]

$V = Velocity$ [m/s]

$C_d = Drag\ Coefficient$ [unit less]

$A = Area\ orthogonal\ to\ flow$ [m^2]

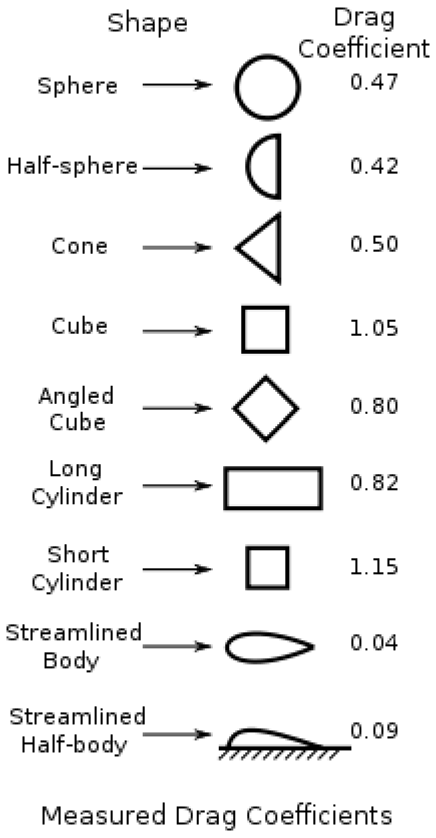


Figure 7: Example coefficients of drag and corresponding shapes [6]

6.2.1 Boomerang Shell Analysis

Coefficient of Drag Assumptions

$C_d = 0.5$

$A = 1106.3 in^2 = 0.714 m^2$

$\rho = 999 \frac{kg}{m^3}$

$V_e = 2.235 \frac{m}{s} = 5\, mph$

Coefficient of Drag Calculations

$$F = 0.5 \rho V^2 C_d A \tag{2}$$

$$F = 0.5(999)(2.235^2)(.5)(0.714) \tag{3}$$

$$F = 890.75\, N = 200.25 lbf \tag{4}$$

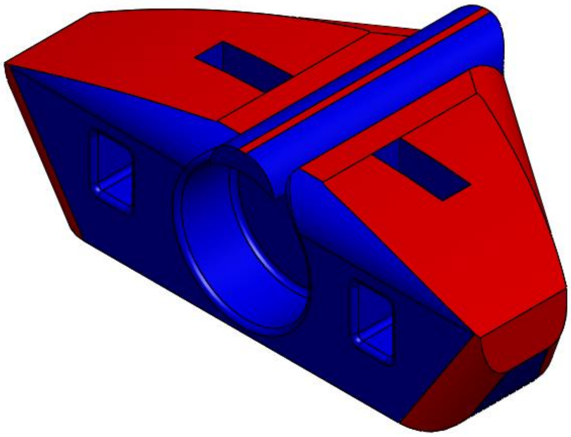


Figure 8: Final boomerang design with handlebars on the top

6.2.2 Triton Shell Analysis

Coefficient of Drag Assumptions

$C_d = 0.30$

$A = 513.20 in^2 = 0.3311 m^2$

$\rho = 999 \frac{kg}{m^3}$

$V_e = 2.235 \left[\frac{m}{s}\right] = 5\, mph$

Coefficient of Drag Calculations

$$F = 0.5 \rho V^2 C_d A \tag{5}$$

$$F = 0.5(999)(2.235^2)(.3)(0.3311) \tag{6}$$

$$F = 82.6N = 55.7lbf \tag{7}$$

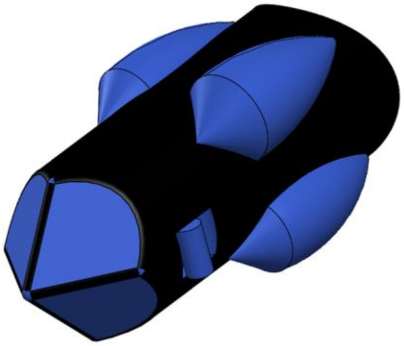


Figure 9: Final Triton design modeled after teardrop concept

6.3.1 Power Calculations for Boomerang and Triton

The power calculations performed confirmed that the boomerang design vs. the triton design would not be as hydrodynamic; therefore, making the decision process for the final design simple.

$V_e = 2.235 \left[\frac{m}{s}\right]$

$$\mathcal{P}_d = \boldsymbol{F}_d \cdot \boldsymbol{v} \tag{8}$$

$$= \frac{1}{2}\rho v^3 A C_d \tag{9}$$

$$\mathcal{P}_{d(boomerang)} = 1990.82W = 2.7\ hp \tag{10}$$

$$\mathcal{P}_{d(Triton)} = 184.611W = 0.25\ hp \tag{11}$$

6.4.1 Final Shell Status

The final iteration of the design is shown below in Figure 10. The final design facilitated the flow of water through the shell and onto the engine. It has been adjusted for ease in 3-D printing and for less time and material costs.

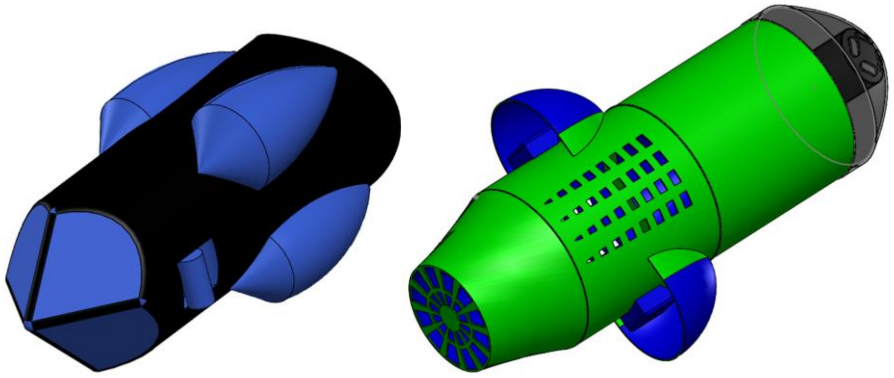


Figure 10: Initial design and final design of Triton

6.4.2 Triton Analysis

The Triton is assembled into eight distinguishable parts, each with its own function shown in Figure 11. 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.

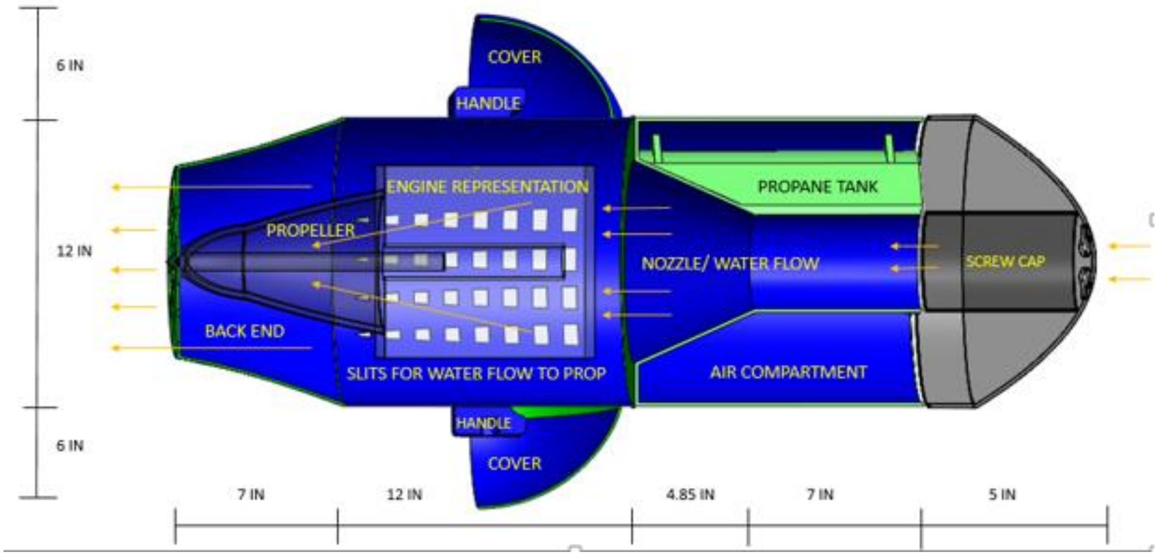


Figure 11: Internal view of the Triton

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 so that fingers and hands cannot 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.

6.4.3 Triton Prototype Printing

The Triton was successfully printed into eight individual parts at half the scale, with a thickness of 0.075in. Although lips and grooves were not printed correctly (the thickness was too thin for assembly), the team has decided to use glue and screws for assembling the parts together. All internal parts and attachments to the prototype were successfully printed, but because of the small thickness it is very important that the shell is handled with great care. The shell has been painted entirely with blue latex paint, with only the handle and cover painted green. The final price of the prototype was just under $300, not including labor costs. The support material was $95.90, while the model material was $174.60, making that a total cost of $269.65. This is further discussed in the cost analysis. An exploded view of the design is shown in Figure 12 while the descriptions of the parts are in Appendix C.

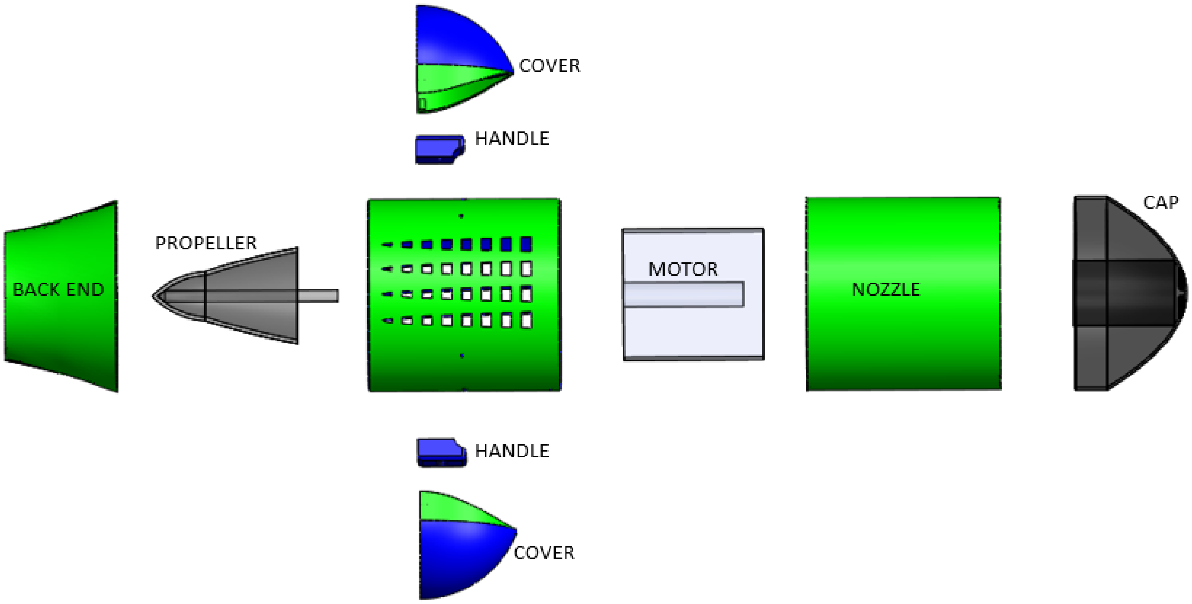


Figure 12: Exploded view of Triton design

6.4.4 Triton Manufacturing

The 3-D Printing process is not a viable option to manufacture the Triton. The current model was printed with ABS plastic material, which will absorb the water. Additionally, the printing would not be cost effective and would be time consuming to manufacture. The team suggests the client use compression molding to manufacture the Triton. Compression molding is a commonly used molding process for large intricate parts. Compression molding uses thermoset plastics, which is the ideal plastic type for the intended use of the Triton.

6.5.1 Shell Construction

The Triton shell has been constructed using a 3-D printer as mentioned in the previous section. This prototype is almost an exact replica of what the real design will be manufactured to be for production, with only a few exceptions that were unable to be added for simplicity of the printing. For example, a screw cap will be designed to manually be able to insert the propane tank directly from the front of the Triton. Unfortunately, the 3-D Printer did not allow us to add this feature due to the model having such a small thickness. Also, a throttle lever is designed into the handle in order to allow the user to adjust their speed. Finally, a snorkel will be added to the front of the shell just above the air tank.

7.0 BUOYANCY CALCULATIONS

To make the design float the team needed the weight of the design to be offset by the force of buoyancy. Buoyancy was determined by an experiment (Figure 13) where a similar sized, sealable bucket was weighed to 18 lbf and put into water. Rocks were weighed and then the amount of water displaced when they were placed in the water was recorded. The displacement amount was deducted from the total volume that a 5-gallon bucket can hold. These calculations are listed below:

$$V_{5-gallon\ bucket} = 0.67in^3$$

$$V_{18lbf\ rocks\ displaced} = 0.13in^3$$

$$V_{air} = 0.67 - 0.13 = 0.54in^3 \tag{12}$$

The experiment showed that the weighed bucket possessed enough buoyancy to float. Based on the volume of the bucket the internal air chamber of the Triton was designed to have a similar volume dedicated to air. Additionally, a MatLab program was created in order to verify calculations (Appendix D).

Figure 13: Buoyancy Experiment

Knowing the required volume of air to be dedicated in the design, the volume of the internal cylinder can be calculated by summing the following volume calculations:

Cylinder Volume Equation: $V_{1\&2} = \pi * h * (R^2 - r^2)$

Volume Around Nozzle: $V_3 = \int_a^b \pi * (R^2 - r^2)\ dx$

$$V_1 = \pi * 6.93 * (3.905^2 - 2^2) \tag{13}$$

$$V_2 = \pi * 11.85 * (5.485^2 - 3.905^2) \tag{14}$$

$$V_3 = \int_0^{4.92} \pi * (3.905^2 - (3.905 - 0.387)^2) dy \tag{15}$$

$$V_{total} = V_1 + V_2 + V_3 = 893.5\ in^3 = 0.52\ ft^3 \tag{16}$$

The calculations determined that the design may be too buoyant resulting in a design that would sit on top of the water. To fix this, counter weights should be added to the nozzle section of the design. The counter weights would keep the Triton submerged while also mediating any moment resultant from the engine being out of line with the buoyancy force.

8.0 ENGINE OPTIONS

A primary objective for next semester is to convert a 4-stroke and 2-stroke engine to run on cleaner burning propane fuel. The team decided on two options for each of the 4 and 2-stroke engine categories that the group considered. The team did not purchase and test a 2-stroke engine; however, the option for the client to convert current Aqua Scooter engines was considered.

8.1.1 2-Stroke Options

The first 2-stroke option was the powertrain of a Husqvarna 128C Line trimmer [7]. The engine has a displacement of 28 cm^3, and a cost of $169.95 for the entire unit. According to the manufacturer, the engine consumes conventional 2-stroke fuel mix at a rate of 507 g/kWh and emits 65.5 g of CO per kWh. The engine is the lightest two stroke option at a weight of 9.7 pounds.

Figure 14: Husqvarna 128C Line Trimmer [7]

The second 2-stroke model was also the powertrain of a line trimmer from Tanaka Inc [8]. The cost of the trimmer is \$200.00 and weighs in at 11 pounds. With a displacement of 32 cm^3, the engine has a power output of 1.6 horsepower. Similar to the Husqvarna line trimmer, the engine can operate at multiple angles of operation, making it a viable option for Aqua Scooter operation.

Figure 15: Tanaka Line Trimmer [8]

8.1.2 4-Stroke Options

A 40 cm^3 displacement Briggs and Stratton engine was one of the 4 cycle options for propane fuel testing [9]. For octane fuel, the engine has an output rating of 1.3 horsepower, and is the most cost effective option at \$199.00. Like the 2-stroke engines, both of the 4-stroke options can be used in line trimming operations, making them useful at varying angles which is ideal for Aqua scooter operation.

Figure 16: Briggs and Stratton 4-Stroke Engine [9]

In addition to the Briggs and Stratton, the second 4-stroke engine testing option is the Honda GX-25 multi- purpose utility engine [10]. The GX-25 has the same power rating as the Briggs and Stratton, with a displacement of 25 cm^3. At a cost of $240.00, the GX-25 is the more expensive of the two choices. However, the availability of replacement parts and conversion kit information makes the GX-25 the more desirable preference for propane fuel testing.

Figure 17: Honda GX-25 4-Stroke Engine [10]

9.0 FINAL ENGINE SELECTION

A primary objective for this semester was to convert a 4 engine to run on a cleaner burning propane fuel. The selected 4-stroke engine testing option was 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.

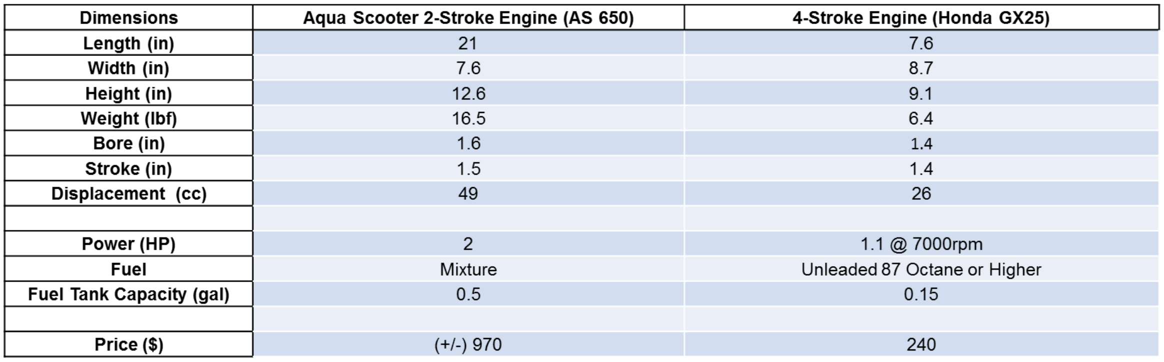
10.0 ENGINE ANALYSIS

The main objective of this section of the report is to analyze and compare the use of propane 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.

10.1.1 Gasoline Analysis

The main objective for the team is to create a 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 GX-25 engine shown in Figure 17, 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.

Table 4: Aqua Scooter and Honda GX25 Comparison [1]



Dimensions	Aqua Scooter 2-Stroke Engine (AS 650)	4-Stroke Engine (Honda GX25)
Length (in)	21	7.6
Width (in)	7.6	8.7
Height (in)	12.6	9.1
Weight (lbf)	16.5	6.4
Bore (in)	1.6	1.4
Stroke (in)	1.5	1.4
Displacement (cc)	49	26
Power (HP)	2	1.1 @ 7000rpm
Fuel	Mixture	Unleaded 87 Octane or Higher
Fuel Tank Capacity (gal)	0.5	0.15
Price ($)	(+/-) 970	240

Figure 18: Current engine and proposed 4-stroke engine [1, 10]

In Figure 18, the existing (entire) Aqua Scooter is displayed on the left, and the Honda GX-25 4-stroke engine is shown on the right. This is a potential 4-stroke engine on which we will base our calculations. We found that 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.

10.1.2 Propane and Butane 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 analyses.

10.2.1 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 (Appendix E).

- Required weight of propane is 12.52 ounces
- Required weight of butane is 12.50 ounces

10.3.1 Thrust Analysis

The thrust analysis uses the following velocity equations:

$$T = \dot{m}V_e - \dot{m}V_0 \tag{17}$$

$$\dot{m} = \rho V_i A \tag{18}$$

$$T = \rho V_i A(V_e - V_0) \tag{19}$$

$$T = A\Delta p \tag{20}$$

$$T = 2\rho A V_i^2 \tag{21}$$

Equations 17 and 18 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 18. Using equation 19 and 20 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.

$V_0 = 0$

$V_e = 2.235\,\frac{m}{s}$

$A = .0324\,m^2$

$T = 222\,N = 50\,lbg$

$$V_i = \sqrt{\frac{T}{2\rho A}} = 2.593\,\frac{m}{s} = 5.8\,mph \tag{22}$$

This value for V_i reinforces the fact that an appropriately designed engine pair with an appropriately designed propeller should adequately power the redesigned Aqua Scooter. A MatLab code for this process is found in Appendix F.

10.4.1 Dry Combustion Analysis

Dry combustion analysis is the best way to compare different fuel types against conventional octane that fuels the majority of 4-stroke engines on the market. For dry combustion analysis, stoichiometry must be computed for each theoretical dry 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:

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2 \tag{23}$$

Butane stoichiometry:

$$C_4H_{10} + 9O_2 + 33.84N_2 \rightarrow 4CO_2 + 10H_2O + 33.84N_2 \tag{24}$$

Air Fuel ratio for ideal combustion equation:

$$AF = \frac{moles\ of\ air}{moles\ of\ fuel} * \frac{M_{air}}{M_{fuel}} \tag{25}$$

AF ratio for propane

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

$$AF_{propane} = (5 + 18.8) * \frac{28.97}{44.09} = 15.66 \frac{lb\ air}{lb\ propane} \tag{26}$$

AF ratio for butane

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

$$AF_{butane} = (9 + 33.84) * \frac{28.97}{58.12} = 21.36 \frac{lb\ air}{lb\ butane} \tag{27}$$

As the above math shows the air to fuel ratios for propane and butane are not significantly different when compared to 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 G.

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 G). 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.

11.0 CONVERSION KIT

There are two companies that specialize in the manufacture of propane conversion kits that the group decided to utilize. The first of the propane kits comes from a company titled Altfuel LLC [12]. The other kit can be purchased from a company by the name of Propane Carbs Inc. [13].

The Altfuel conversion kit includes a propane regulator, fuel lines, intake adaptor, cylinder attachment line and mounting bracket. The total cost of the kit is $363, with no additional machine work to the engine necessary.

Propane Carbs Inc. manufactures 3 kit options that include interchangeable, mixed-fuel (propane and octane), and a permanent conversion kit. If the group were to pursue this conversion kit company, the permanent kit would likely be the desired choice due to the price comparison of all 3 options. Similar to the Altfuel system, the Propane Carbs Kit contains similar components and has a cost estimated at $360 prior to machining costs.

After further research, the group decided to purchase the Altfuel system. This kit is the best option because there are training instructions and example video clips that can be found online [14]. The system contains several components as seen in Figure 9, including:

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

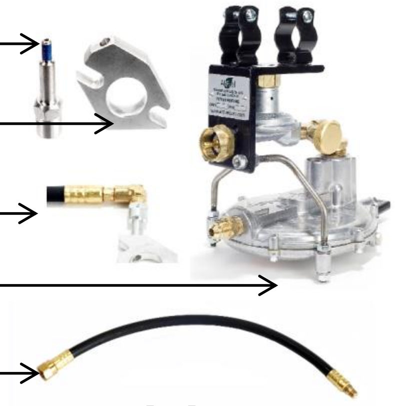


Figure 19: Propane Conversion Kit Components [15]

12.0 Testing

In order to thoroughly test the Aqua Scooter, it would need to be completely submerged in water. However, due to the complexity of the engine and what is required to waterproof the engine, all experiments were conducted out of water. All the aspects of testing (i.e. thrust, weight, functionality of all parts, fuel efficiency, and buoyancy) were conducted in the manufacturing lab on Northern Arizona University's campus. For further analysis, the team provided solutions for testing facilities including emissions.

12.1.1 Testing Apparatus

The new design for the Aqua Scooter required a specific testing apparatus allowing the team to determine thrust, buoyancy, and measure emissions. The testing apparatus needed to have strain gauges so the engine could be measured for horsepower or thrust. The two initial ideas for a testing device were a large aquarium and a trough pool. Ideally, an aquarium would have needed to be at least 150 gallons to accomplish full submersion and have adequate space to set up the gauges to measure thrust.

Figure 20: Possible Testing Aquarium [16]

The trough pool, used generally to bathe ranch animals, should be large enough to set up the thrust measurement system while also being deep enough to submerge the new design.

Figure 21: Possible Testing Trough [17]

The team used a similar apparatus for the thrust test to the trough shown in Figure 21. The tub, shown in the thrust analysis, was large enough for the testing to be conducted. If the engine was to be testing in a submerged setting, these larger options would be suggested.

12.2.1 Emissions

To gather information on emission testing the team contacted various emission-testing firms. 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. Another option is to test the design at a location in Arizona. This testing option is Deer Valley Emissions Test Facility. The third and final option for emission testing is to purchase an emission-testing device. One of the potential emission testing devices selected is the Enerac-500, which retails for $870. Of the three options it is most likely that the design will be tested at a facility like Deer Valley Emission Test Facility.

12.2.2 Emissions Testing

It was determined that a 3-gas analyzer, shown in Figure 22, 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 [18]. The amount of the gases HC, CO, and CO_2 are measured from the tailpipe of a vehicle. Although this test is not an EPA certified measurement, it provided the team with comparison data, which illustrated the viability of propane gas.

After searching for an inexpensive analyzer on the Internet, it was found that the cost of such an apparatus is prohibitive (Appendix H). 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.

Figure 22: Gas Analyzer [18]

12.2.3 First Emissions Test

For emission testing, a 3- gas analyzer from a local shop was used and measured hydrocarbon, carbon monoxide, and carbon dioxide emissions from the engine (Figure 23).

Figure 23: Emission Analyzer

The emissions tester was a large device that connected to the Honda engine exhaust (Figure 24). Originally, the exhaust port that was included with the engine was too small. A larger expansion pipe was welded and bolted to the small exhaust port in order to fix the problem (Figure 25).

Figure 24: Testing Procedure

Figure 25: 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 26, it can be seen that the hydrocarbon gas emissions never reached normal idling levels, as it would appear in Figure 27 with carbon monoxide and carbon dioxide levels. The Honda engine is already EPA certified and has a tag that proves it had been tested by Honda. The engine ran very clean during the testing process.

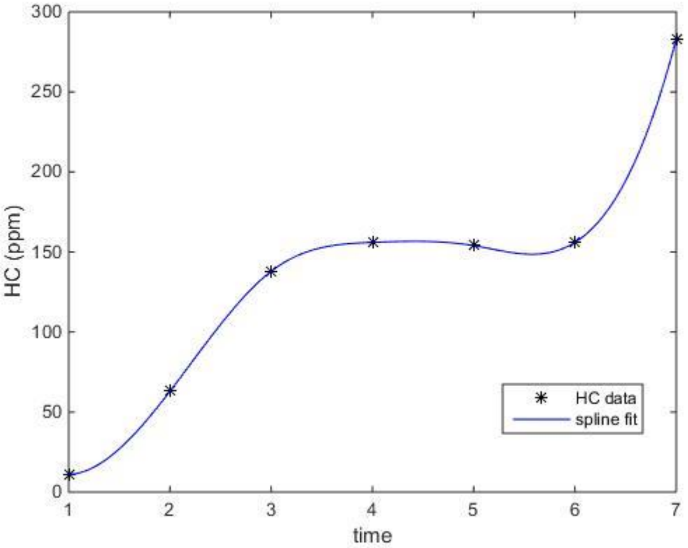


Figure 26: Hydrocarbon Emissions vs. time

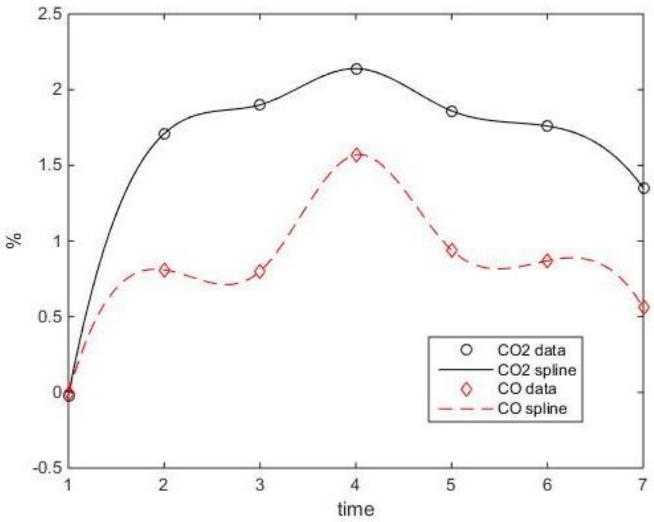


Figure 27: Carbon Monoxide and Dioxide vs. time

After the engine was converted to propane, the team contacted Flagstaff Auto Repair to conduct emission testing. This was not possible due to the gas analyzer no longer being in service. As a result, the team researched more in depth on the propane emissions difference provided by the Department of Energy [19]. In an analysis commissioned by the DOE, it stated that greenhouse gases from propane emissions are approximately 18% less than that from gasoline. Greenhouse gases included hydrocarbons and carbon monoxide. This is why the graphs differ from the data collected from the gas analyzer (Figure 28). Additionally, the analysis stated that CO_2 emissions are approximately 12% less for propane fuel (Figure 29)

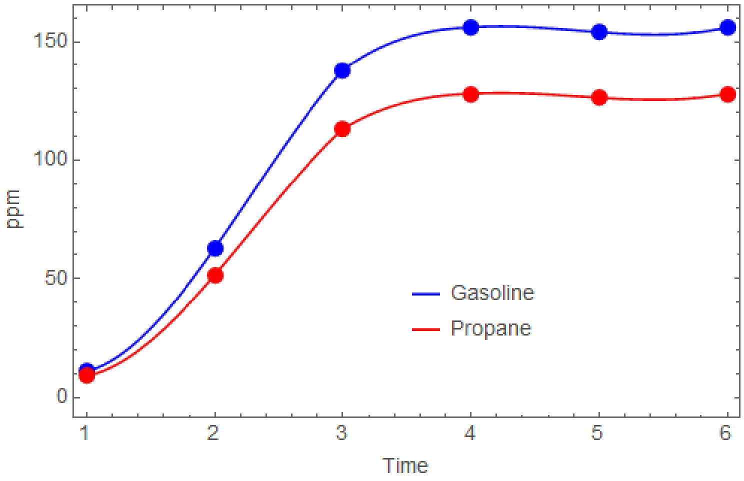


Figure 28: Propane and Gasoline Greenhouse Gas Emissions vs. time [19]

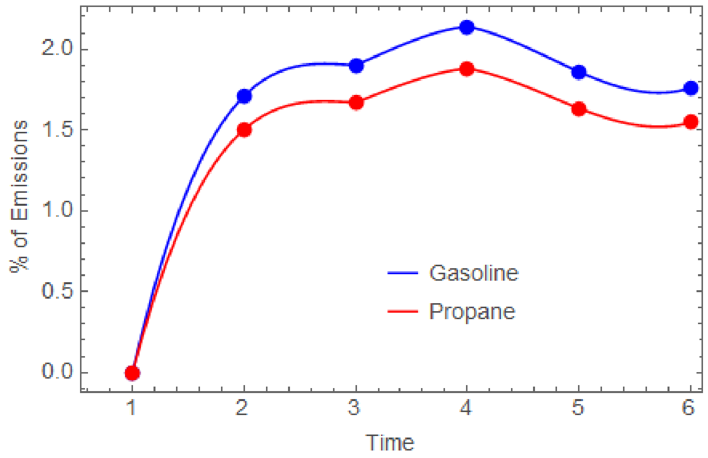


Figure 29: Carbon Monoxide Emissions for Gasoline and Propane [19]

After graphing this information against the collected data from the gas analyzer, it is easy to show the difference between the two fuel types. Finally, the research confirmed the team's recommendation of using propane for an alternative fuel source.

12.3.1 Power Output Testing

In addition to machining an exhaust pipe to accommodate an emission-testing probe, a long flange mounted shaft was needed to conduct the power testing experiment. A modified version of the Prony Brake Experiment [20] was attempted to characterize the engine's power. The Prony Brake Experiment as seen in Figure 30 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. (28) as:

$$P = (F_A - F_B) * D/t \tag{28}$$

Where:

P = Power

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

D = Distance traveled by pulley (D)

t = Time (C)

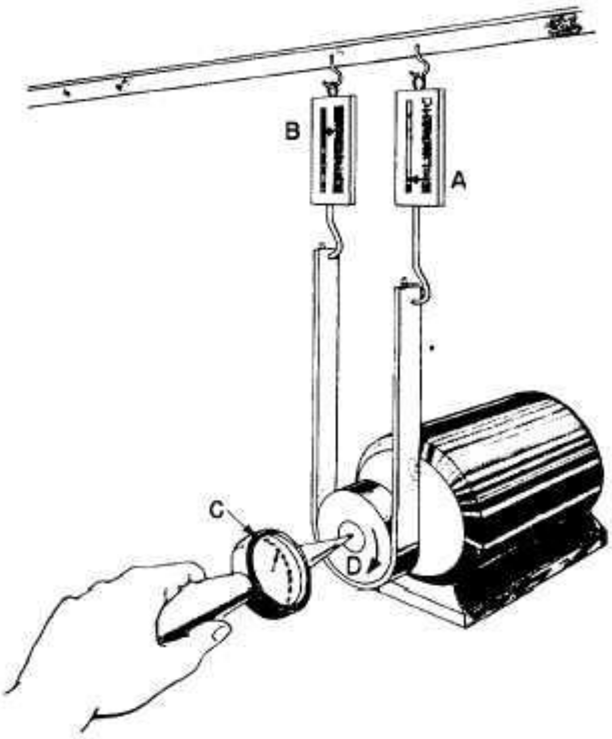


Figure 30: Prony Brake Experiment [20]

The team's version of the experiment implemented one scale and measured the rotational speed of the large shaft using a tachometer in the bottom right corner of Figure 31. The distance the pulley travels in the first experiment is replaced by a moment arm the shaft pulls down (Figure 32).

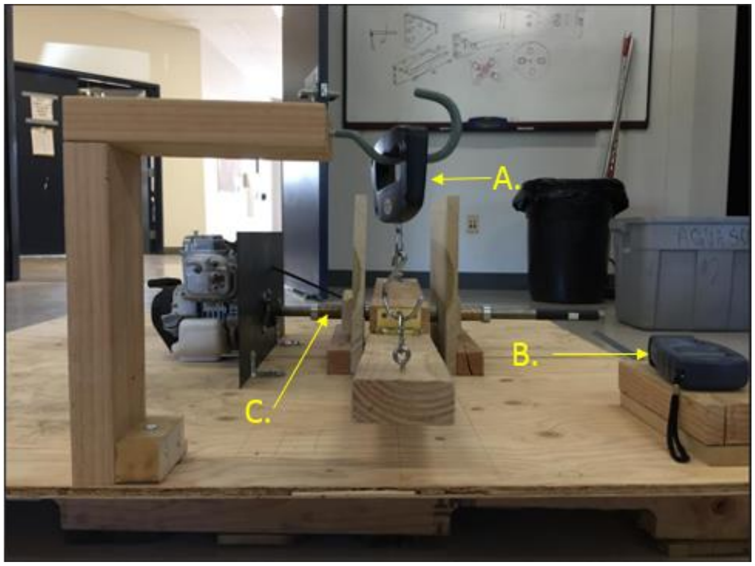


Figure 31: Side View of Experiment

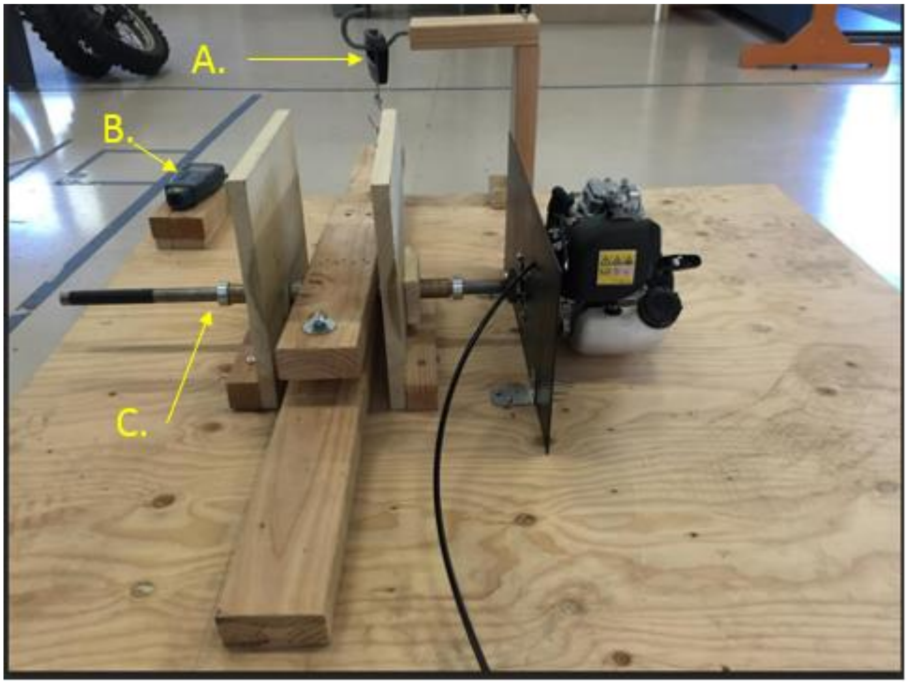


Figure 32: Isometric View of Setup

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 it was welded; therefore, several iterations were conducted to dampen out the vibrations.

The first iteration involved CNC machining a high-density polyethylene disk (Figure 33) to go between the flange and the flywheel. However, the vibrations (although somewhat dampened) were still too rough to allow the engine to run properly.

Figure 33: Polyethylene Disk

Subsequently, springs were added to the flange bolts to absorb more of the vibrations (Figure 34). The springs absorbed enough of the vibrations, but the axial movement of the shaft on the bolts loosened them from the flywheel.

Figure 34: Bolt Mounted Springs

The final iteration on the dampening system involved flange mounted Heim joints (Figure 35) that acted 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 were to theoretically absorb the eccentric axial motion of the shaft, solving both mounting issues simultaneously.

Following the attachment of the joints along with the shaft, the team attempted another test. Additionally, Lock-Tite was added to the screws to make them grip long enough to perform an adequate analysis. Even though the team attempted several times to fix the problems with the experiment, the test was deemed unsuccessful for engine verification.

Figure 35: Heim Joints

12.4.1 Thrust Output Testing

Initially the team constructed a thrust experiment that included a fulcrum and a scale set up shown in Figure 36.

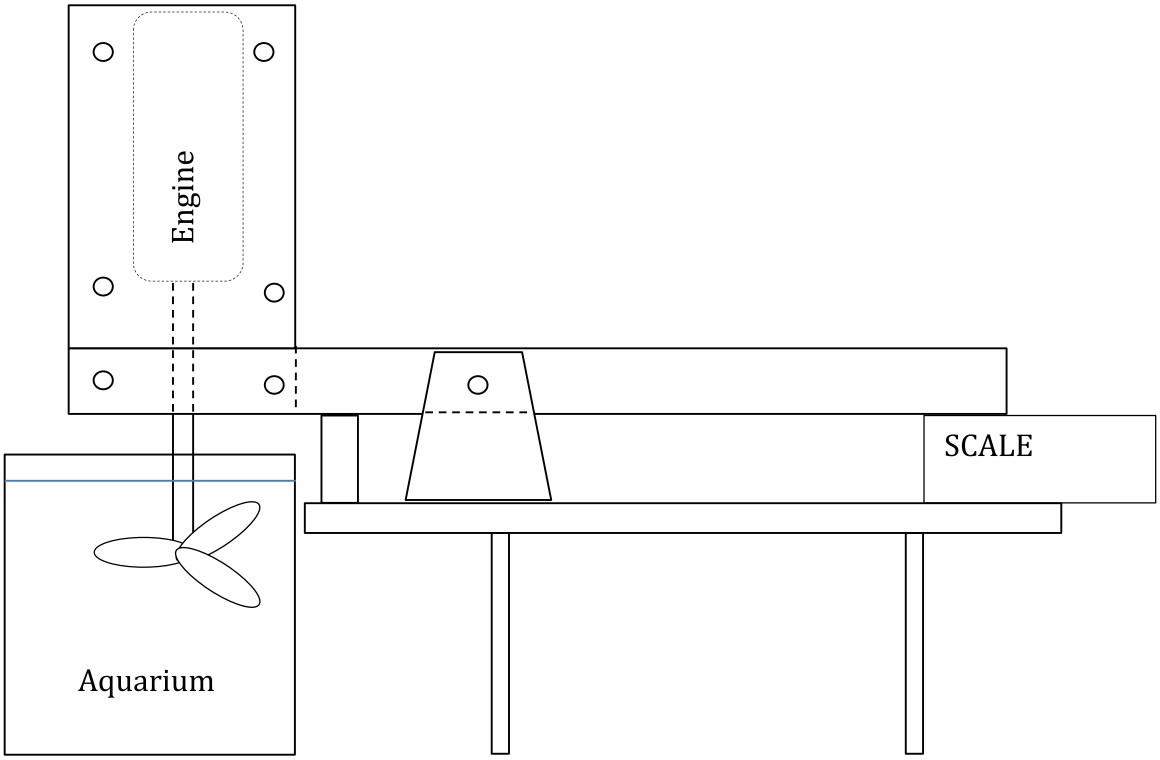


Figure 36: Teeter-totter thrust experiment schematic

The experiment mounted the engine upside-down, where the shaft and propeller were pointing to the ground. The idea was to have the thrust push the engine vertically up, and then the other side of the fulcrum would register a weight on the scale. This experiment did not provide enough support for the shaft and the same problem from the prony brake experiment occurred.

The final experiment to test engine thrust capabilities is shown in Figure 37. In the experiment the engine provided a direct drive to a propeller, which was immersed in water. The engine and propeller was on a cart that was free to be moved by force of propeller in the water. During the experiment the thrust created by the propeller caused the cart to be pulled due to an inverted propeller. This pull was recorded by taking video of a force scale during the experiment.

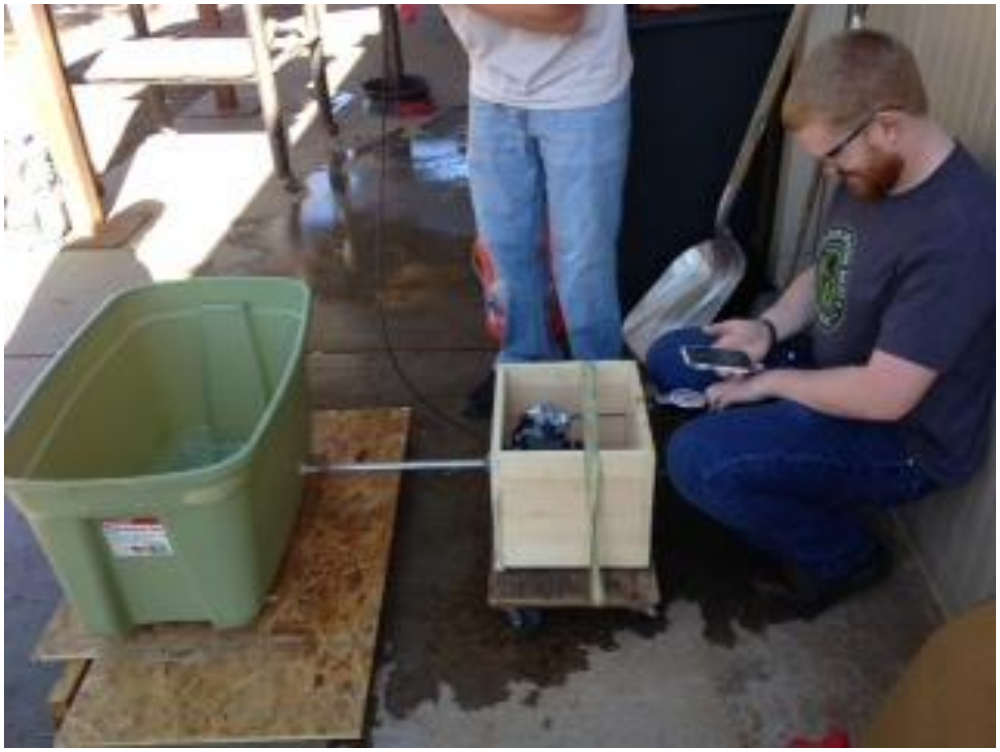


Figure 37: Thrust experiment

12.4.2 Thrust Testing Results

The thrust experiment was conducted initially with gasoline and then after the engine was converted to a propane fuel source. The parameters of the experiment were set up exactly the same for both fuel sources. The force scale was recorded and then the data points from the six trials conducted were analyzed. The highest thrust level recorded for each trial was plotted onto the graph shown in Figure 38. Then an average was taken of all the top thrust levels and this line was also plotted on the graph.

The engine was converted to propane after the six trials were conducted with gasoline. The experiment was set up again and then the results were recorded from the propane trials. Again, the top thrust recordings were plotted and an average line was created. This allowed for a comparison to be easily shown.

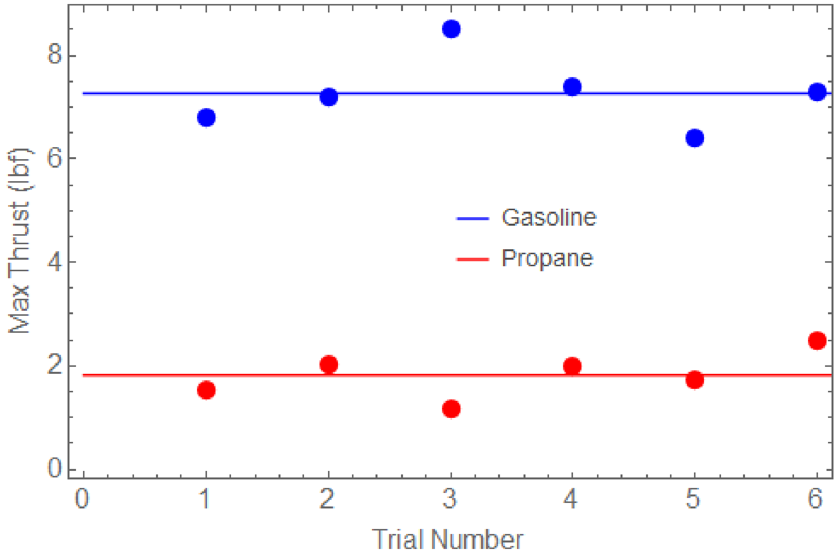


Figure 38: Thrust experiment results

There is a significant difference in the two thrust output levels. There are two major reasons why the team believed this occurred: warped flywheel and regulator weight. When the gasoline experiment was being conducted, the last trial resulted in the shaft putting additional force on the flywheel. This caused it to warp. After the experiment was finished, the top of the flywheel was removed in order to assess the damage. It was clear that some of the internal parts were rubbing; however, the test for propane needed to be conducted. The team proceeded although the flywheel was no longer at its top efficiency.

Lastly, the conversion kit for the propane fuel includes several parts as shown earlier in the report. All of these parts contribute to additional weight that the gasoline engine did not have to contest with. This additional weight almost doubles the weight of the engine on the cart. Both of these variables could have caused the low thrust output numbers for propane.

13.0 COST ANALYSIS

In order to organize the potential costs for testing the selected solutions, Table 5, was constructed. The materials are broken down into two columns, budgeted costs (Cost A) and actual costs (Cost B). 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. Due to only conducting one emission test, the cost of the experiment was negligible The client did request the potential cost of more comprehensive emissions testing which was discussed earlier in the report. The reason for this inquiry is simply that the final prototype will require more expensive and comprehensive testing facilities.

Table 5: Cost of Materials for Testing Engines

Item	Cost A	Cost B	% of Total	% of Total
Conversion Kits	$ 200.00	$ 363.00	10.31%	29.71%
Emission Testing	$ 1,000.00	$ -	51.55%	0.00%
Prony Brake Experiment	$ 175.00	$ 150.00	9.02%	12.28%
Thrust Experiment	$ 200.00	$ 100.00	10.31%	8.19%
4-Stroke Engine	$ 240.00	$ 264.00	12.37%	21.61%
Shell Prototype	$ 50.00	$ 269.65	2.58%	22.07%
Oil	$ 25.00	$ 25.00	1.29%	2.05%
Propane Gas	$ 50.00	$ 50.00	2.58%	4.09%
	$ 1,940.00	$ 1,221.65		

The pie chart shown in Figure 39 provides a visual representation of the accumulated costs of the project. The cost of the engine accounted for 22% of the project expenses, while the conversion kit accounted for approximately 30% of the total cost. The team was able to keep the cost significantly under budget.

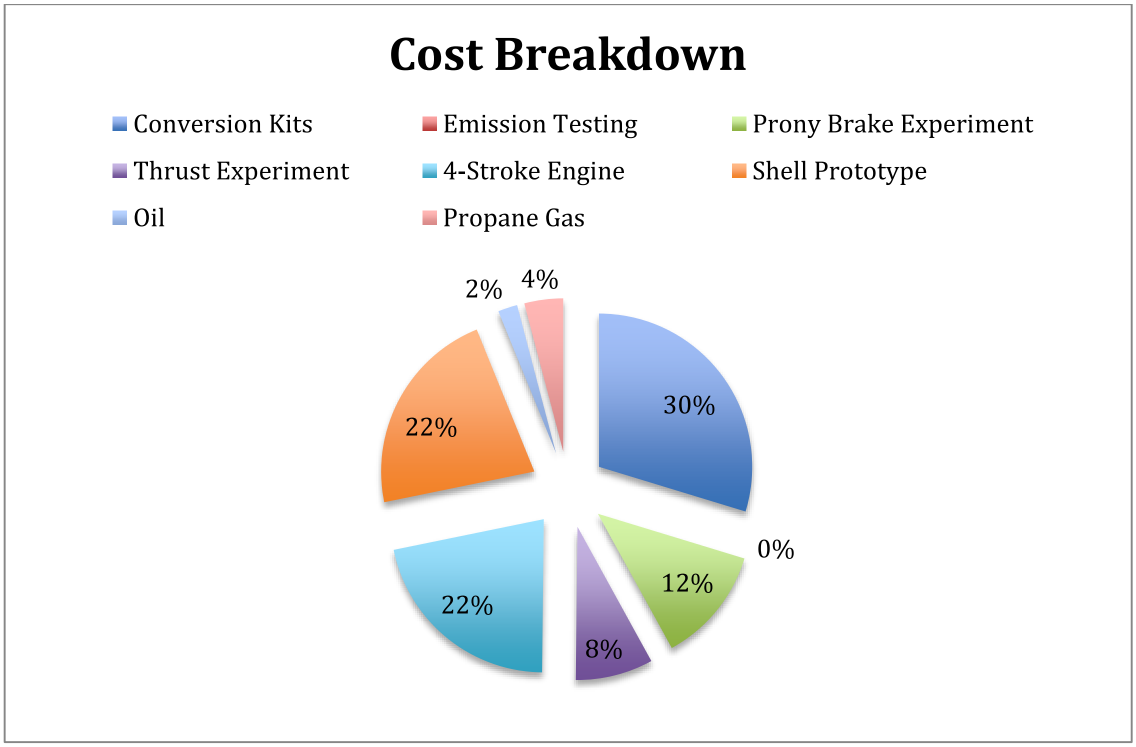


Figure 39: Pie Chart with Percentages of Total Cost

Another significant cost was the shell prototype. The cost is broken down into two separate categories: model material and support material. Table 6 shows the amount of material used and a total cost for each part. The Triton Middle-End part was the most expensive of the parts, but was designed to use the least amount of support material.

Table 6: Cost Breakdown of Prototype Parts

Shell Prototype Part	Model Material Used	Support Material Used	Cost per Part
Cap	2.01	0.83	$ 14.04
Triton End	2.72	3.68	$ 31.29
Triton Front	5.59	1.41	$ 34.73
Triton Middle	5.35	8.43	$ 67.28
Handle X 2	1.54	0.24	$ 8.85
Grip X2	2.12	2.74	$ 23.77
Triton Middle-End	15.59	2.48	$ 89.87
Total Cost			**$ 269.84**

14.0 CONCLUSION

The client, Robert Witkoff, currently markets a product that does not meet current United States' EPA regulations. The objective of this project was to design, engineer, and test an engine that will exceed the current EPA regulations. The most important points considered for the design of the prototype were to adhere to the EPA regulations, to keep the dry weight of the device under 18 lbf, and to provide a minimum of 50 lbf of thrust. Additionally, the team needed to keep the manufacturing cost per scooter under $450. The team's decision matrix assisted in providing potential solutions for the client. The top two concepts from the decision matrix were analyzed for their feasibility.

Following some preliminary calculations, one of the concepts, the two-propeller design, was ruled out and a single propeller was chosen for full analysis. The coefficient of drag and the drag force were calculated for the boomerang and Triton. The drag coefficient is highly correlated with the amount of power required to overcome drag, which for this project was limited to 2hp. As a result of these calculations the design chosen for further testing is the Triton shown in Figure 9. Next, a buoyancy experiment was conducted in order to show that the volume of air the team designed was adequate for the shell to float. Additionally, a ½ scale prototype of the outer shell was constructed for the client to present to potential manufacturers. The prototype was 3-D printed in the manufacturing lab into nine separate parts.

The engine selected for analysis was the 4-stroke Honda GX25 engine. The viability of using butane and propane gases for engine were calculated and researched. The calculations show that both of these gases are comparable to gasoline as an alternative fuel source.

The team conducted several tests on the engine including emissions testing and a thrust test. This line of analysis provided the team with a baseline for when the engine was converted. All tests were repeated after conversion utilizing the new fuel option of propane. That data was compared to gasoline results and graphed to display clear results. The emissions comparison was based on data released from the Department of Energy.

The total cost of the project was approximately $1200.00. This amount is significantly under the original budget provided at the beginning of the year. The main costs include the conversion kit, shell prototype, and the engine.

The team showed through their data and analysis that the engine model selected is an excellent option for the client and the conversion to propane will provide the client with long-term compliance with EPA marine board regulations. Lastly, the shell design is hydrodynamic and aesthetically pleasing providing a marketable product.

REFERNCES

[1] Aqua Scooter Manual. Comer SPA. Accessed 10 Oct 2014.
http://www.aquascooter.it/AQUA_GB.pdf

[2] B. Douville, P. Ouellette, A. Touchette and B. Ursu, "Performance and emissions of a twostroke engine fueled using high-pressure direct injection of natural gas," in *1998 SAEInternational Congress and Exposition, February 23, 1998 - February 26,* 1998, .

[3] P. Duret, A. Ecomard and M. Audinet, "A new two-stroke engine with compressed-air assisted fuel injection for high efficiency low emissions applications," in *International Congress and Exposition, February 29, 1988 -March 4,* 1988, .

[4] H. Huang, M. Jeng, N. Chang, Y. Peng, J. H. Wang and W. Chiang, "Improvement of exhaust emissions from a two-stroke engine by direct injection system," in *International Congress and Exposition, March 1, 1993 -March 5,* 1993,

[5] W. Mitianiec, "Direct injection of fuel mixture in a spark ignition two-stroke engine," in *SAE 2002 World Congress, March 4, 2002 - March 7,* 2002, .

[6] Drag Coefficient, wikipedia.org, 2015. [Online]
http://en.wikipedia.org/wiki/Drag_coefficient (Accessed: November 2014)

[7] Husqvarna 128C, husqvarna.com, 2015. [Online]
http://www.husqvarna.com/us/products/trimmers/128c/#specifications (Accessed: November 2014)

[8] TBC-255PF Grass Trimmer, tanakapowerequipment.com, 2012. [Online]
http://www.tanakapowerequipment.com/main-navigation/products?d=329,341&p=878 (Accessed: November 2014)

[9] Briggs Vertical Shaft Engines, brandnewengines.com, 2014. [Online]
http://www.brandnewengines.com/21132-0559.aspx?gclid=Cj0KEQiAneujBRDcvL6f5uybhdABEiQA_ojMgghvNjmKx_PmQjx (Accessed: November 2014)

[10] Meet the World’s Lightest OHC Engine, GX25, engines.honda.com, 2014. [Online] (Accessed: November 2014)

[11] 15.2 Fuel- Air Ratio, web.mit.com, online date unknown. [Online] http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node108.html (Accessed: November 2014)

[12] Altfuel Conversion Kit, 2015. [Online] http://www.pumpbiz.com/shopping_product_list.asp?pcid=5445 (Accessed: November 2014)

[13] Honda EU3000iS Tri Fuel Propane and Natural Gas Conversion Kit, 2015. [Online] https://www.propanecarbs.com/honda-eu3000-tri-fuel-conversion.html (Accessed: November 2014)

[14] AltFuel Green Conversion Kit install on Honda GX25 trimmer, October 24, 2011. [Online] https://www.youtube.com/watch?v=F5xCok8cWI0 (Accessed: November 2014)

[15] Propane Conversion Kits for Small Engines, 2015. [Online] http://propanepowerkits.com/shop/index.php?main_page=products_new (Accessed: November 2014)

[16] Aquarium, dhgate.com. 2014. [Online] http://www.dhgate.com/store/product/plants-scissors-made-of-stainless-steel-raw/152589777.html (Accessed: November 2014)

[17] Plastic Stock Tanks- Water Trough, plastic-mart.com, 2014. [Online] http://www.plastic-mart.com/category/41/plastic-stock-tanks-water-troughs (Accessed: November 2014)

[18] M500 Emissions Monitoring Equipment, megadepot.com, 2014. [Online] http://megadepot.com/product/enerac-500-1co-emissions-monitoring-equipment-m500 (Accessed: November 2014)

[19] Antes, M., Brindle, R., et. al. 2009. Propane reduces greenhouse gas emissions: a comparative analysis. http://www.propanecouncil.org/. (Accessed: April 2015)

[20] A Prony Brake, tpub.com, (online date unkown) http://enginemechanics.tpub.com/14037/css/14037_53.htm (Accessed: November 2014)

APPENDIX A: Aqua Scooter Components

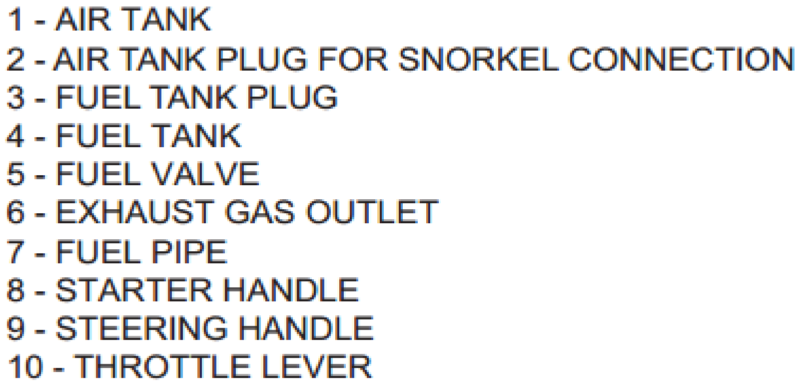

1 - AIR TANK
2 - AIR TANK PLUG FOR SNORKEL CONNECTION
3 - FUEL TANK PLUG
4 - FUEL TANK
5 - FUEL VALVE
6 - EXHAUST GAS OUTLET
7 - FUEL PIPE
8 - STARTER HANDLE
9 - STEERING HANDLE
10 - THROTTLE LEVER

Figure A1: List of components of Aqua Scooter

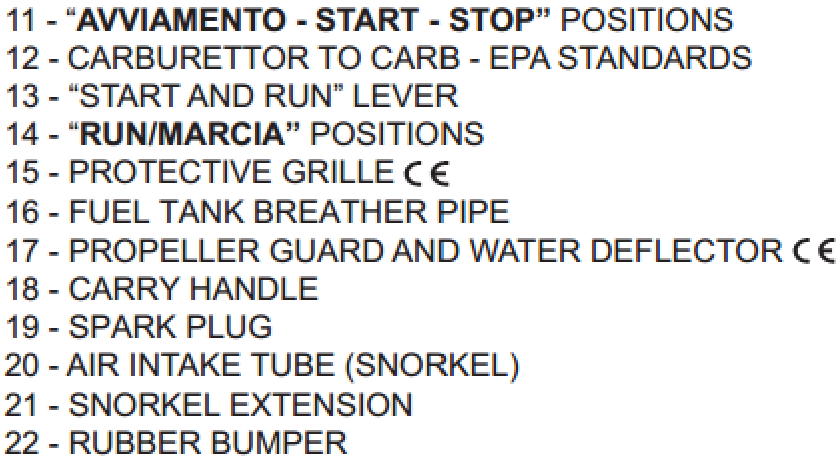

11 - “**AVVIAMENTO - START - STOP”** POSITIONS
12 - CARBURETTOR TO CARB - EPA STANDARDS
13 - “START AND RUN” LEVER
14 - “**RUN/MARCIA”** POSITIONS
15 - PROTECTIVE GRILLE CE
16 - FUEL TANK BREATHER PIPE
17 - PROPELLER GUARD AND WATER DEFLECTOR CE
18 - CARRY HANDLE
19 - SPARK PLUG
20 - AIR INTAKE TUBE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

Figure A2: Additional list of components for Aqua Scooter

APPENDIX B: Team Concepts

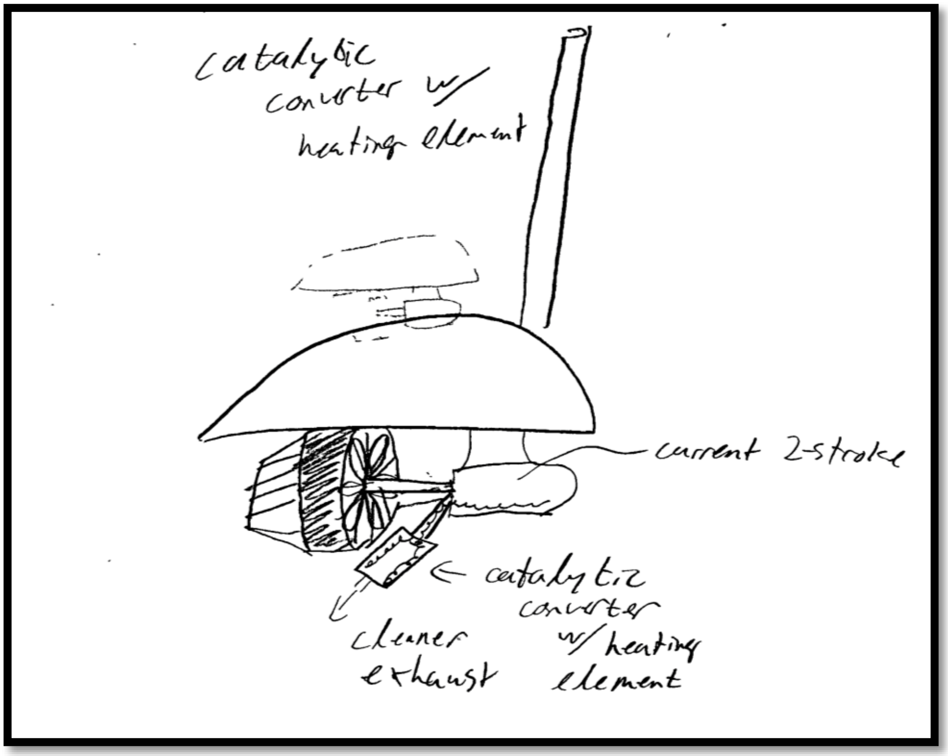


Figure B1: Catalytic Converter with Heating Element

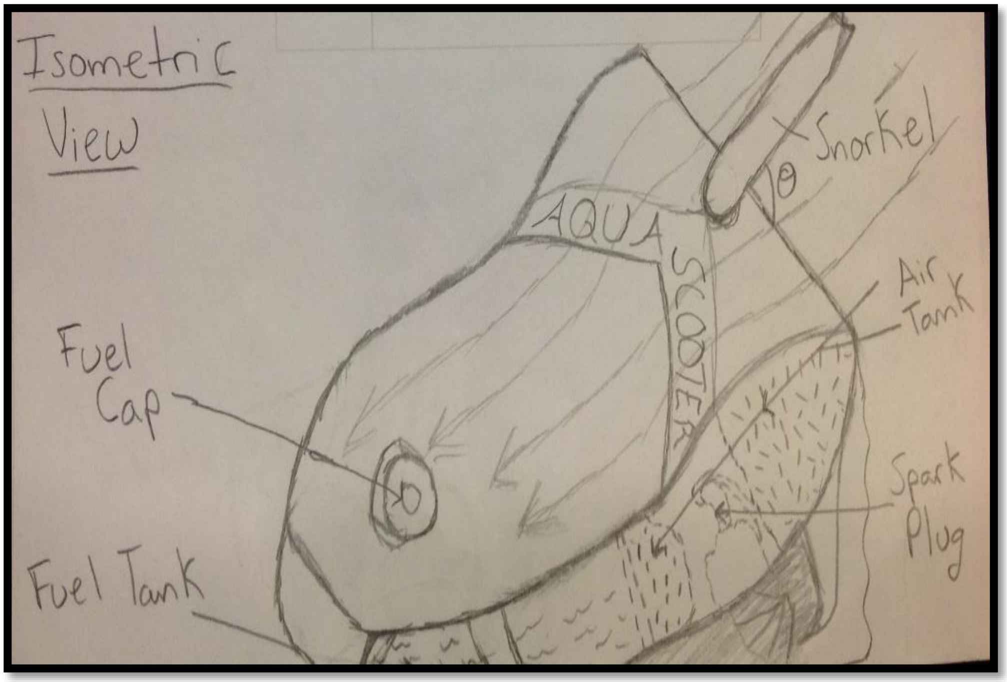


Figure B2: Enclosed Housing

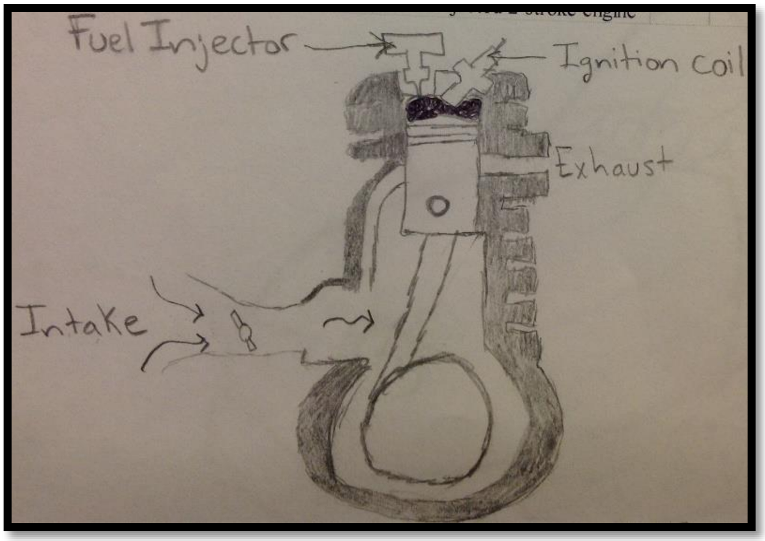


Figure B3: Fuel Injected 2-Stroke Engine

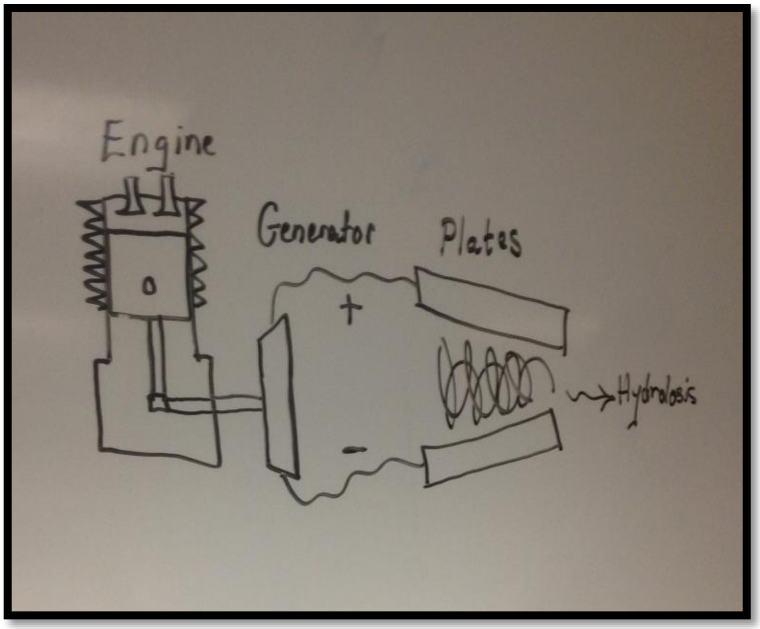


Figure B4: Magneto Hydrodynamic Propulsion System

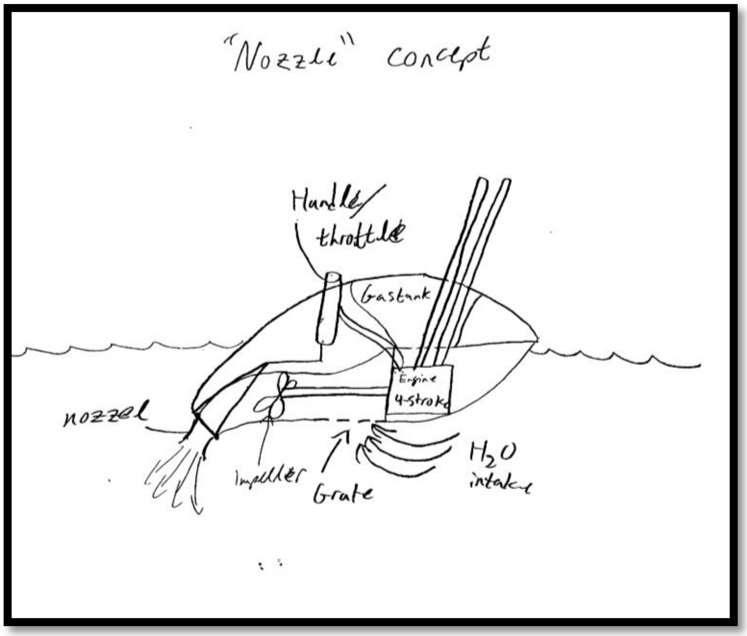


Figure B5: Adjustable Jet Nozzle Design

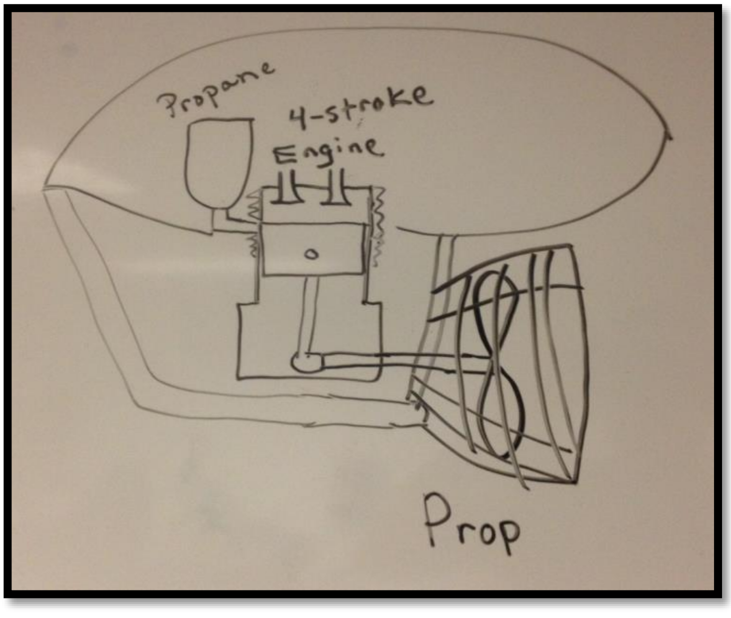


Figure B6: Propane Injected 4-Stroke Engine

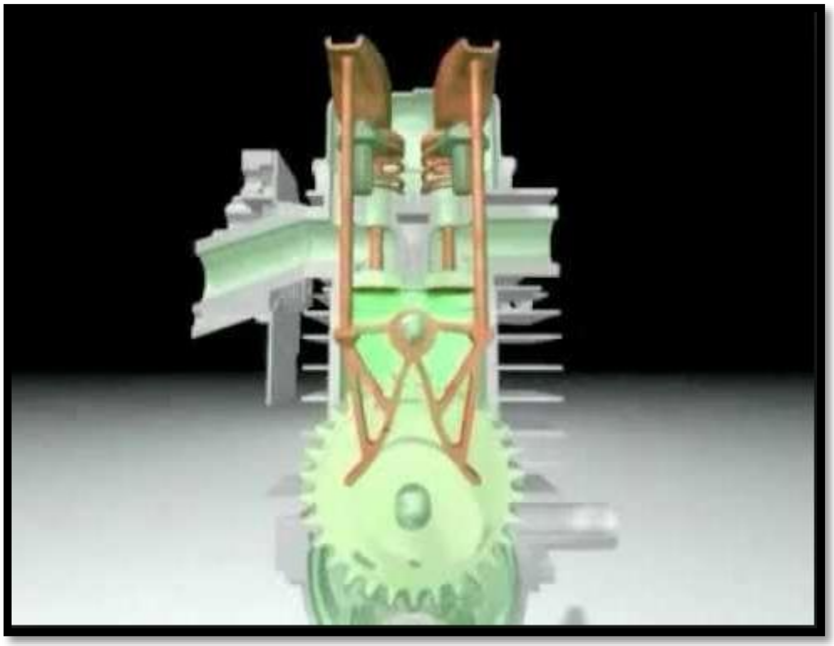


Figure B7: 4-Stroke 4-Mix Engine

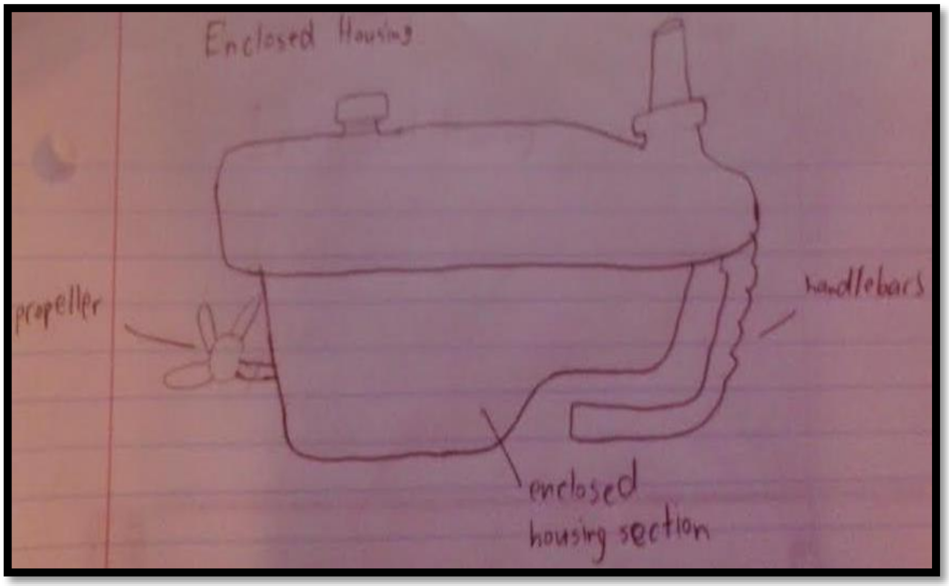


Figure B8: Tank Housing

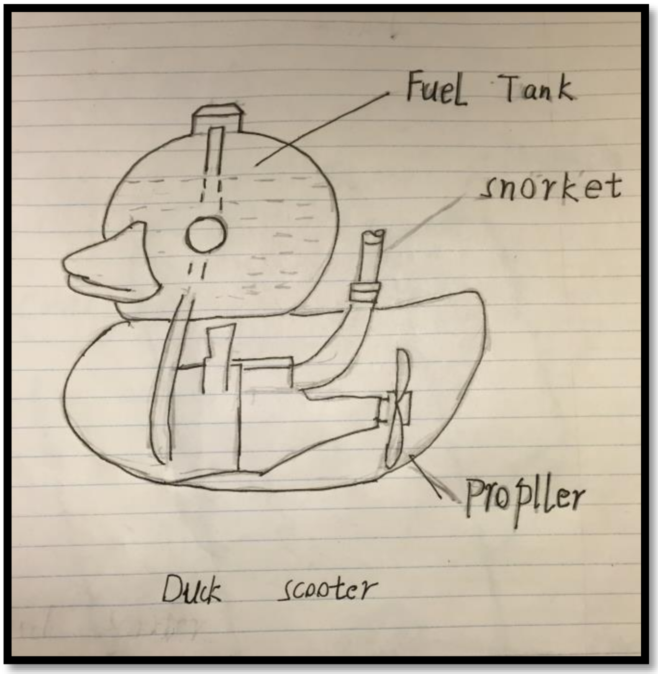


Figure B9: Duck Scooter

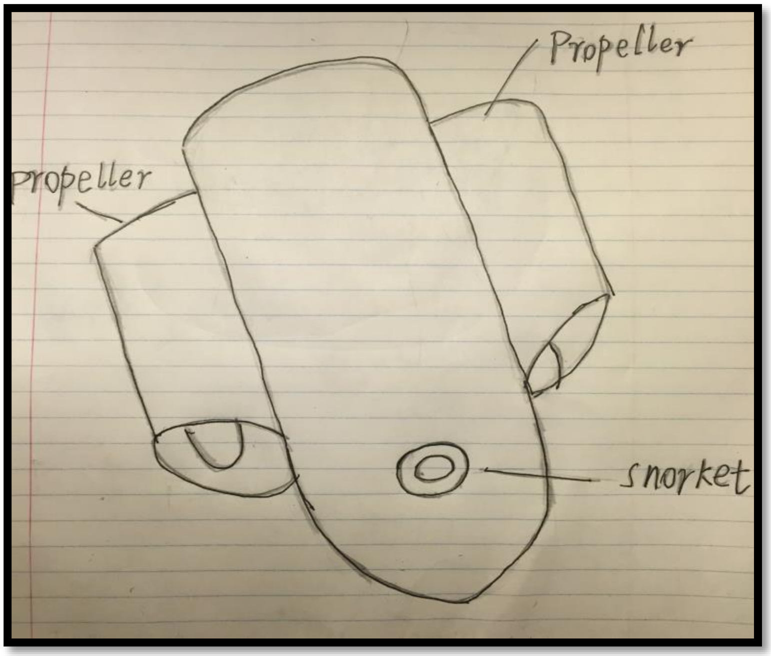


Figure B10: 2-Propeller Design with Belts and Pulleys

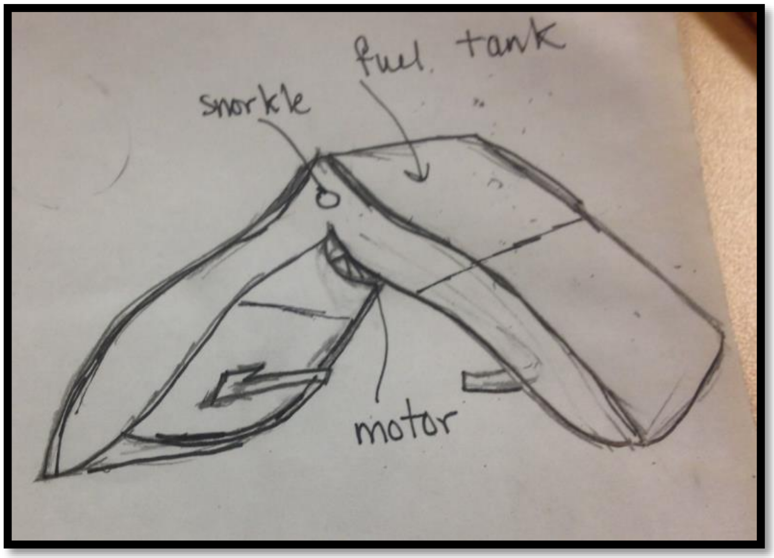


Figure B11: Boomerang with Single 4-Stroke Engine

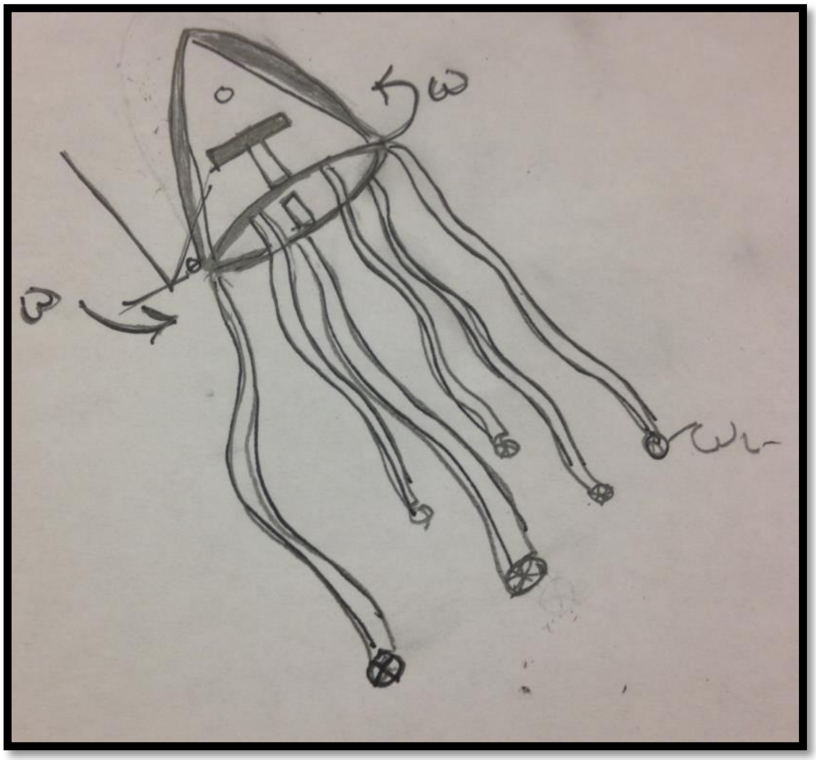


Figure B12: Octopus with Rotating Mechanism

APPENDIX C: 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 D: MatLab for Buoyancy on Shell Design

```
function V=Buoyancy(R1,R2,r,h,H)
% Calculates the Buoyancy of the aquascooter shell for values
%R1 inner radius, R2 outer radius, r radius of cone, h is height of the
%cone as measured from the back of the scooter, and H the total height of
%the cylinder. Uses Volumes of Revolution
V1=pi*(R2^2-r^2)*(H-h);
V2=pi*((R2^2-r^2)*h-(R1-r)^2/3*h-r*(R1-r)*h);
V=V1+V2;
end
```

APPENDIX E: 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);
```

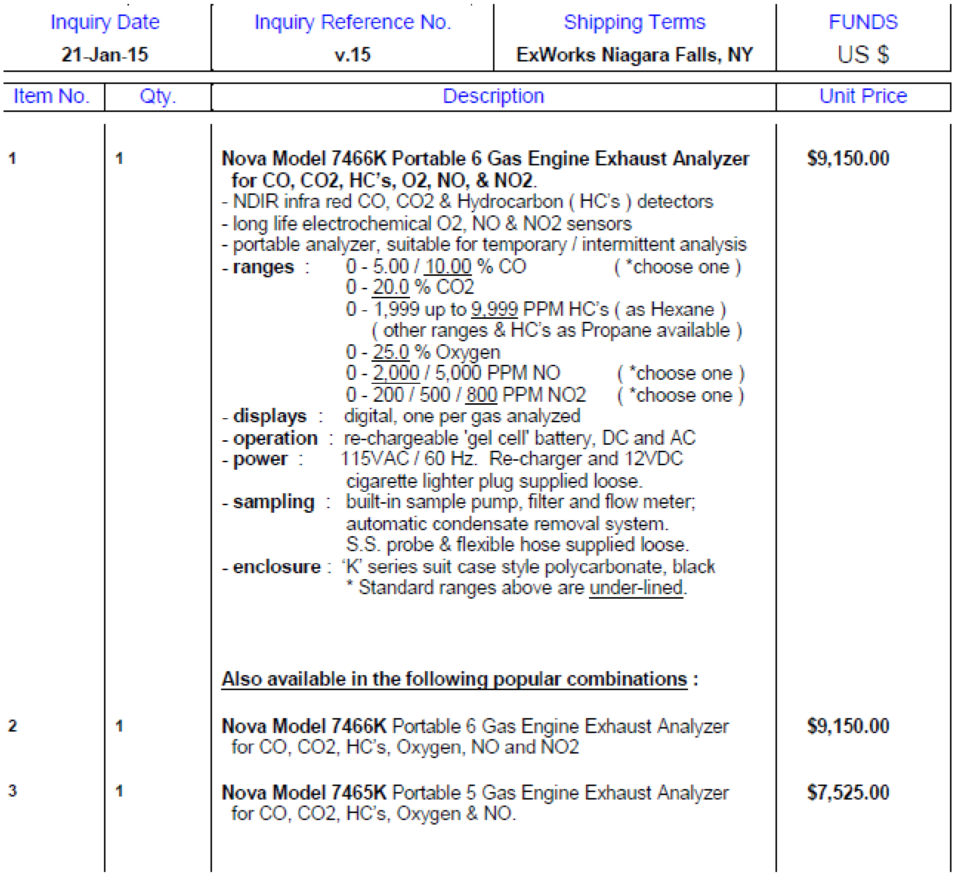
APPENDIX F: Thrust

```
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 G: 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
```

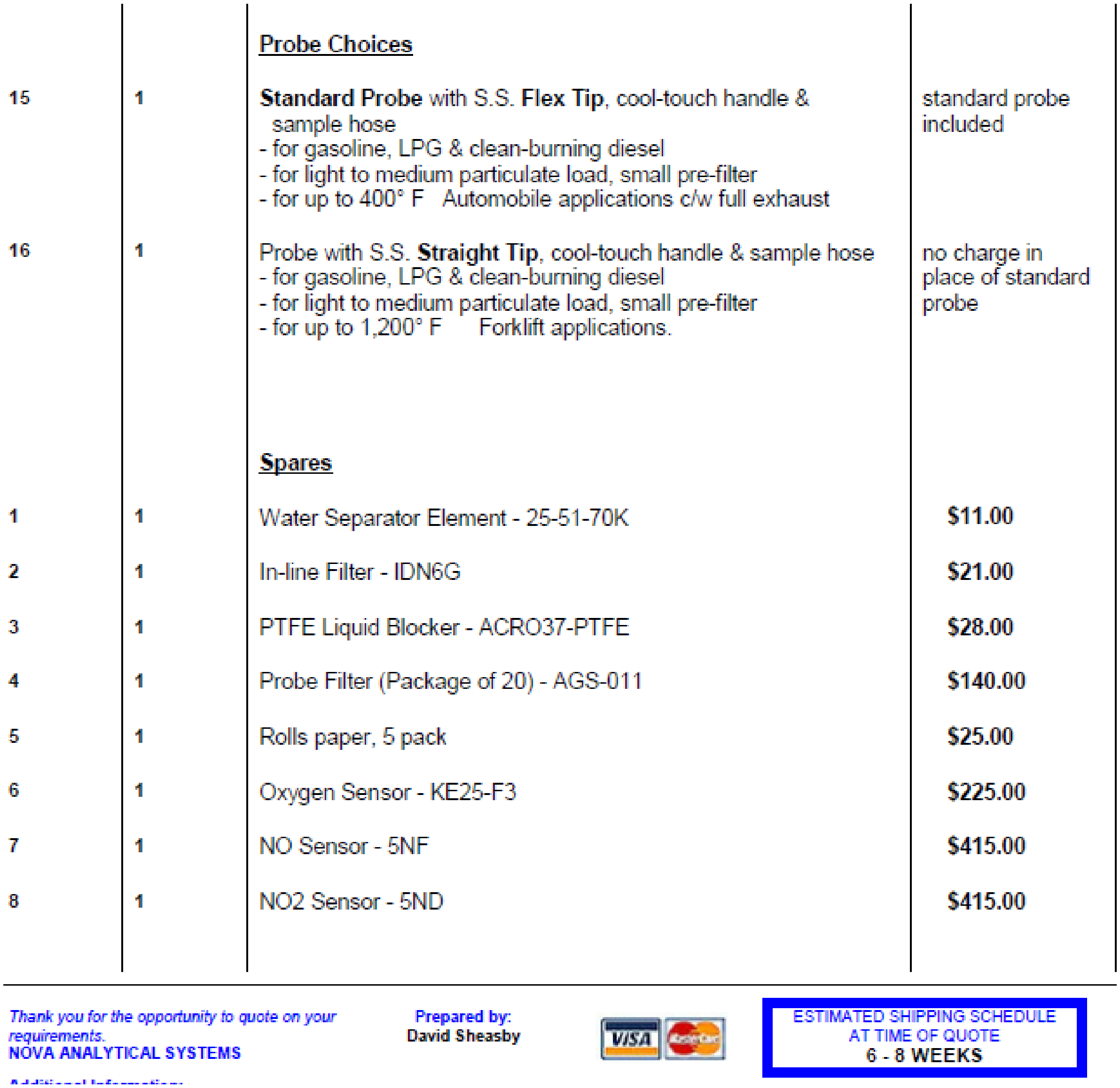
APPENDIX H: Quotes for Emissions Equipment



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.	**$9,150.00**
		Also available in the following popular combinations :	
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**
		Options	
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**



		<u>**Probe Choices**</u>	
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
		<u>**Spares**</u>	
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

Additional Information: