AquaScooter2

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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, which meet current and immediate future EPA regulations.

Information pertaining to the emissions requirements and the current technology is provided along with the constraints given by the client. The team proposes twelve solutions and provides a decision matrix to assist in the selection of two optimal solutions for further development. Finally, a schedule of deliverables for the first semester of the project is given.

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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 R.S.W. /D.I. Inc 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.

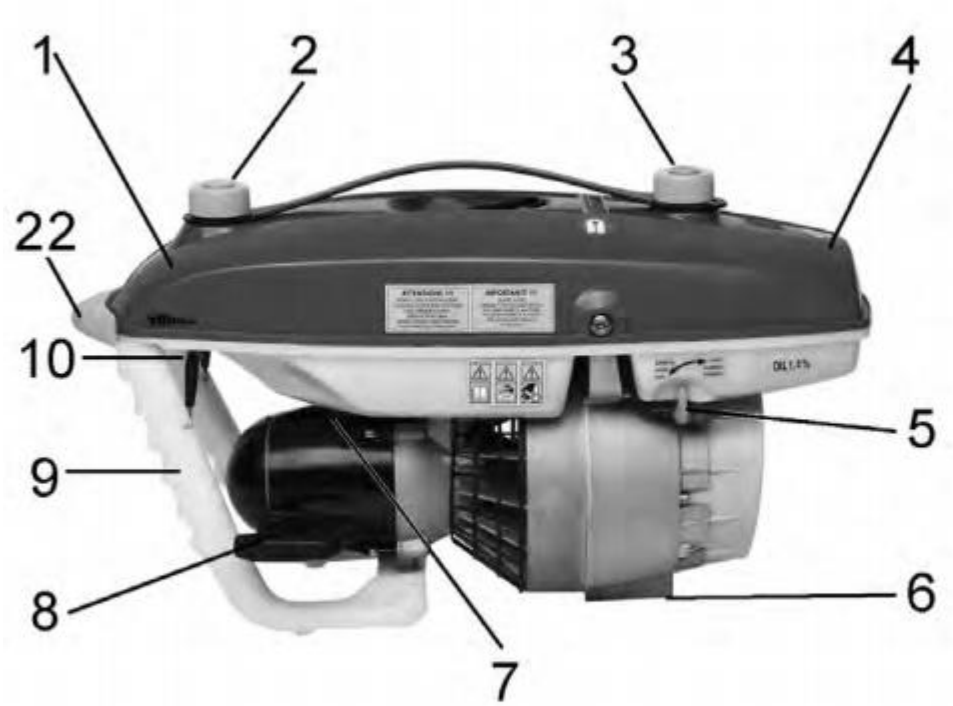


Figure 1: Aqua Scooter side view with designated components

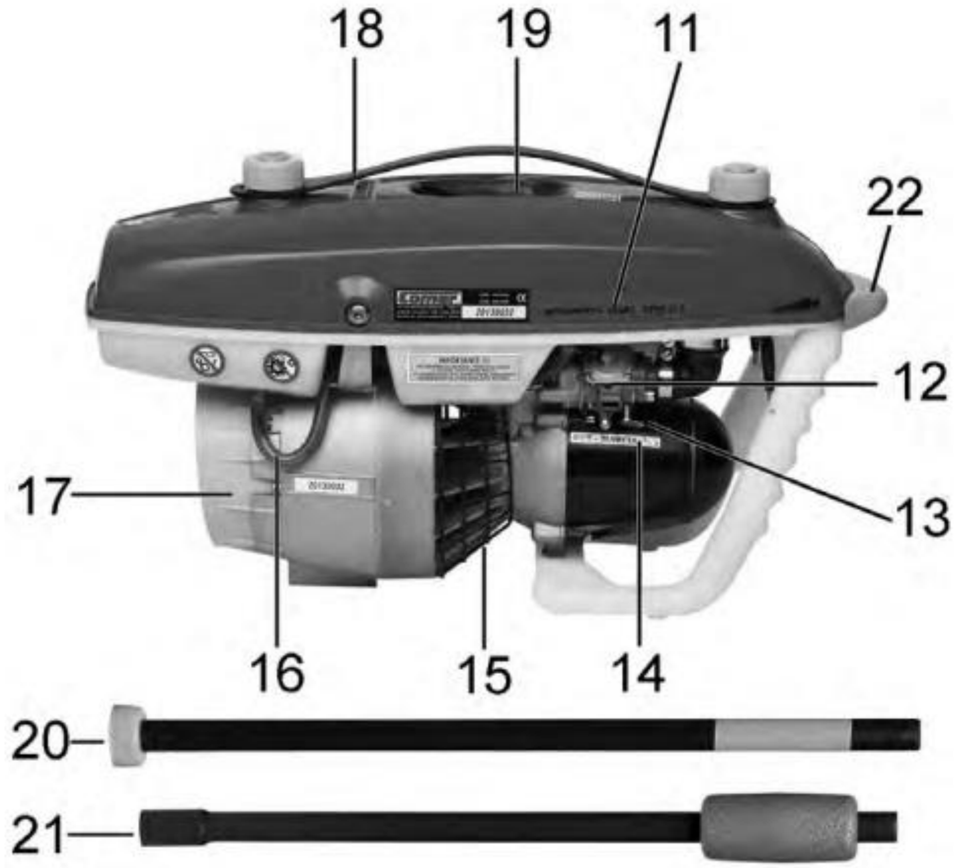


Figure 2: Aqua Scooter with designated components and snorkel extension

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 questions 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 vehicles 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 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.

1.2.1 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.

1.2.2 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.

1.2.3 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. 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
- Plastic fuel tank, with minimum volume of ½ gallon
- 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 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		

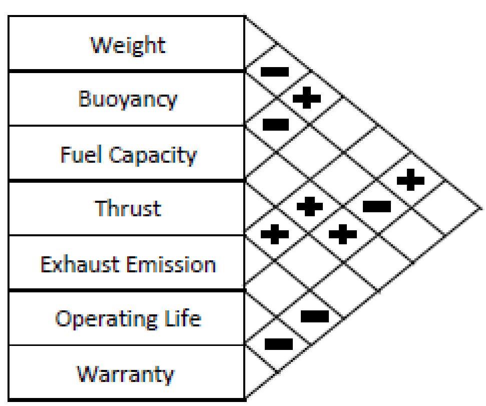
2.3 QFD Summary

The QFD matrix (Table 1) above 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 due to the fact that without falling below the constraint, the new design will not meet EPA regulations. This is not a desirable outcome because that is the main problem the current Aqua Scooter design is facing. Secondly, the weight of the machine is important because that affects the buoyancy, as well as how much exhaust gas the engine emits. For example, the heavier the device is, the harder the engine will have to work to propel the device and operator through the water. Moving forward, keeping the needs, requirements and constraints in mind will be crucial in developing an effective alternative to the current Aqua Scooter model.

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

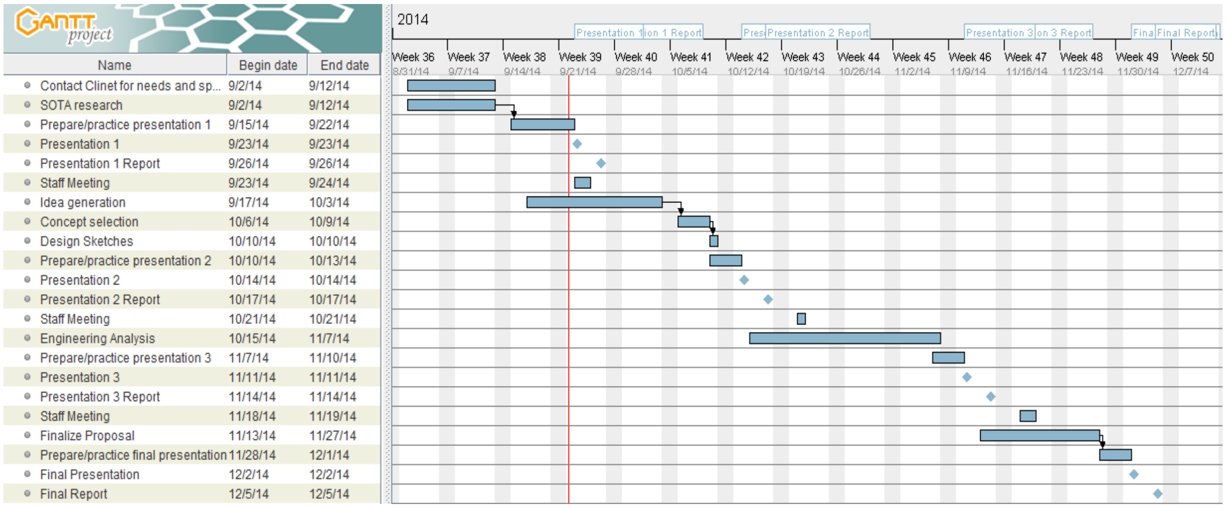


Figure 3: Gantt Chart and schedule of major deliverable and tasks for project.

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 a work in progress and may end up changing as the semester progresses to reflect changes in due dates and newly recognized tasks relevant to the prototype design and final proposal for Aqua Scooter.

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 will have a heating element in order for the redox reaction within occurs spontaneously while in an environment where convection will constantly cool the craft. 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 causes 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 to engineer 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, way too expensive to consider its use. 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 A5, Appendix A). 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 way is to connect the nozzle to the handles of the craft in a way, which would allow the user to manipulate the nozzle in vertical and horizontal directions. The second way 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 in regards to the engine. The system consists of a conventional 4-stroke engine that is altered to allow for the use of propane, rather than gasoline, to run the engine. The reason to convert to a propane system is that propane has been proven to burn cleaner which reduces exhaust emissions when compared with gasoline engines. Cleaner emissions mean 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 increase its speed 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. As a result of this design is for child use making the additional requirement for production standards. (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 is 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. The weight values range from one to ten, with ten being the most important and one being the least important. Each weight is 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.

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 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 have been 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. 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.

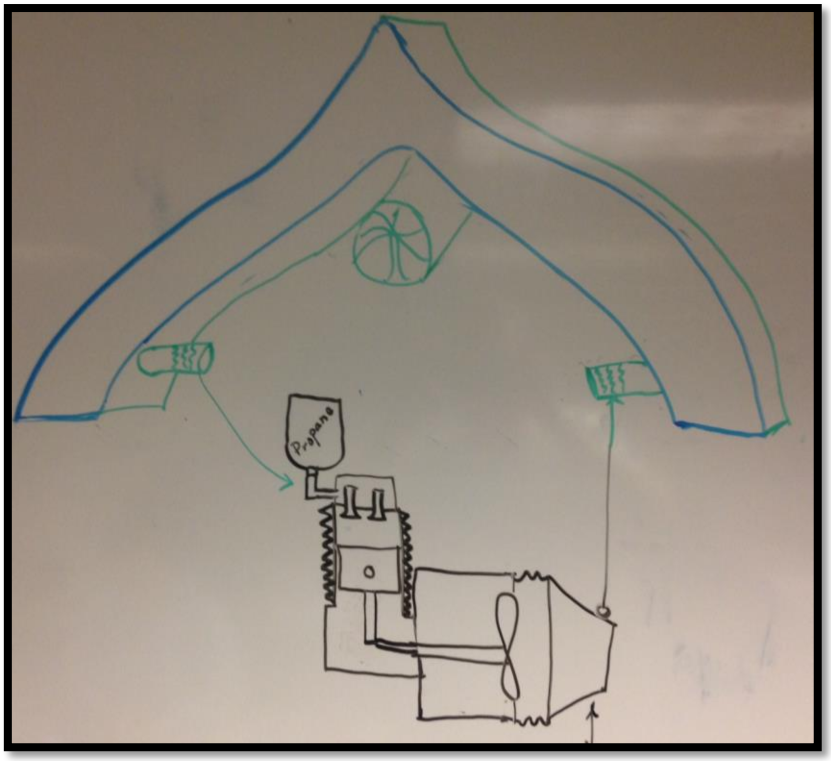


Figure 4: Boomerang with Propane Injected 4-Stroke Engine

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 use of two propellers that push water through 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, creates thrust on either side of the user rather than pushing water into the user like the current Aqua Scooter. The 4 Mix engine will 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.

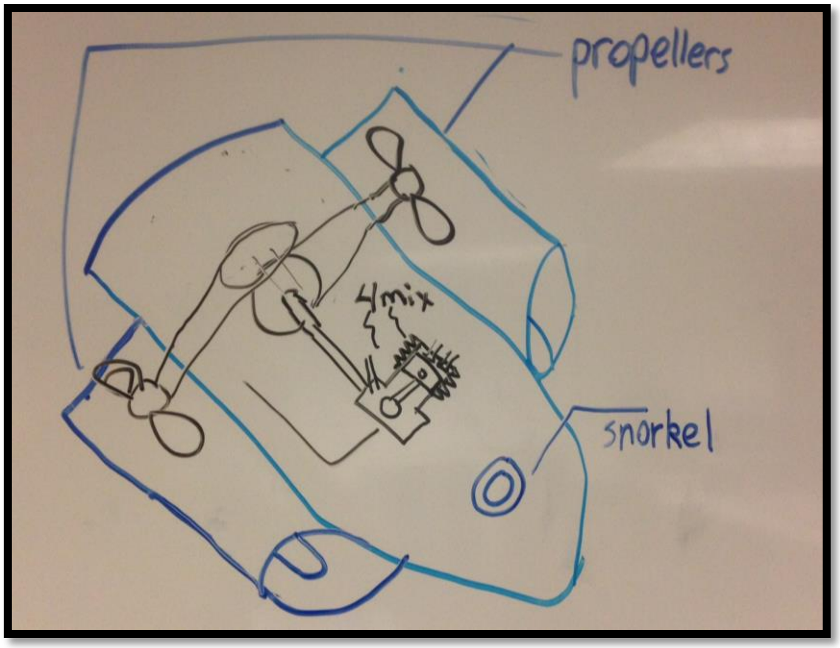


Figure 5: 2-Propeller with Belt and Pulley system Including 4-Stroke 4-Mix Engine

7.0 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.

7.1.1 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 1, 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 6: Current engine and proposed 4-stroke engine

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. 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.

7.2.1 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 analysis.

7.3.1 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.

- Calculated weight of propane is 12.52 ounces.
- Calculated weight of butane is 12.50 ounces.

7.3.2 Thrust Analysis

The thrust analysis uses the following velocity equations:

$$T = \dot{m}V_e - \dot{m}V_0 \tag{1}$$

$$\dot{m} = \rho V_i A \tag{2}$$

$$T = \rho V_i A(V_e - V_0) \tag{3}$$

$$T = A\Delta p \tag{4}$$

$$T = 2\rho A V_i^2 \tag{5}$$

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.

$V_0 = 0$

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

$A = .0324\ m^2$

$T = 222\ N$

$$V_i = \sqrt{\frac{T}{2\rho A}} = 2.593\,\frac{m}{s} \tag{6}$$

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.

7.3.3 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:

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2 \tag{7}$$

Butane stoichiometry:

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

Air Fuel ratio for ideal combustion equation:

$$AF = \frac{moles\ of\ air}{moles\ of\ fuel} * \frac{M_{air}}{M_{fuel}} \tag{9}$$

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

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

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

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.

8.0 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:

$$F=0.5\rho V^2 C_d A \tag{12}$$

Where:

$F=Drag\ force$ [N]

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

$V=Velocity$ [m/s]

$C_d=Drag\ Coefficient$ [unitless]

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

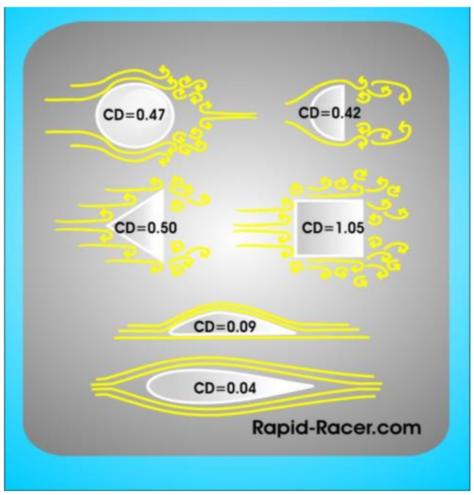


Figure 7: Example coefficients of drag and corresponding shapes

8.1.1 Boomerang

Coefficient of Drag Assumptions

$C_d = 0.5$

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

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

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

Coefficient of Drag Calculations

$$F = 0.5\rho V^2 C_d A \tag{13}$$

$$F = 0.5(999)(2.235^2)(.5)(0.714) \tag{14}$$

$$F = 890.75\ N \tag{15}$$

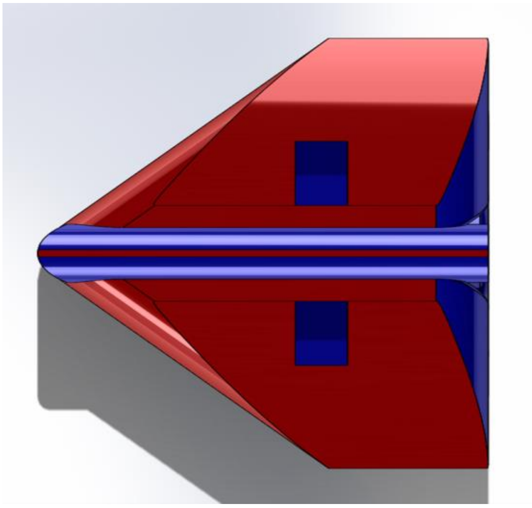


Figure 8: Final boomerang design with handlebars on the top.

8.1.2 Triton

Coefficient of Drag Assumptions

$C_d = 0.10$
$A = 513.20in^2 = 0.3311m^2$
$\rho = 999\frac{kg}{m^3}$
$V_e = 2.235\ \left[\frac{m}{s}\right]$

Coefficient of Drag Calculations

$$F = 0.5\rho V^2 C_d A \quad (16)$$

$$F = 0.5(999)(2.235^2)(.1)(0.3311) \quad (17)$$

$$F = 82.6N \quad (18)$$

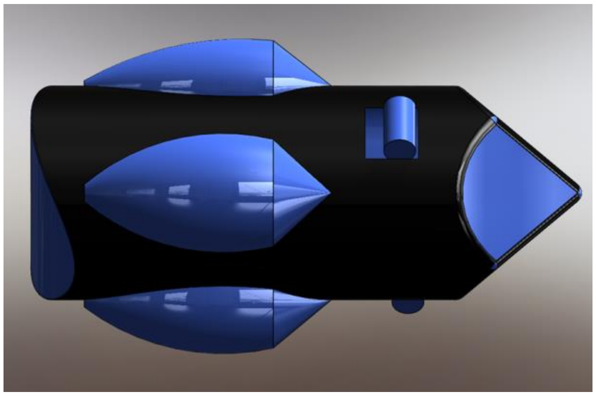


Figure 9: Final Triton design modeled after teardrop concept.

8.2.1 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.

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

$$\mathcal{P}_d = \boldsymbol{F}_d \cdot \boldsymbol{v} \quad (19)$$

$$= \frac{1}{2}\rho v^3 A C_d \quad (20)$$

$$\mathcal{P}_{d(boomerang)} = 1990.82W = 2.669hp \quad (21)$$
$$\mathcal{P}_{d(Triton)} = 184.611W = 0.2475hp \quad (22)$$

9.0 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. The other kit can be purchased from a company by the name of Propane Carbs Inc.

The Altfuel conversion kit includes a propane regulator, fuel lines, intake adaptor and restrictor (depending on engine model), cylinder attachment line and mounting bracket. The total cost of the kit is $250, not including machine work.

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 $250 prior to machining costs.

After further research, the group is currently pursuing the purchase of the Altfuel system. 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.

Figure 10: Propane Conversion Kit Components

10.0 Testing

Since the Aqua Scooter will need to be completely submerged in water, it is only fitting to test the prototype in a body of water large enough to assess the functionality. All the aspects of testing (i.e. thrust, weight, and functionality of all parts, fuel efficiency, and buoyancy) will take place during the next semester. Additionally, final testing will be conducted in a saltwater environment that is identical to the environment where our product will be marketed for use. The team will plan to test the design in the Pacific Ocean in San Diego.

10.1 Emissions

To insure that the prototype engine will meet EPA regulations, emissions testing will take place at the facilities of Arizona Department of Transportation, or Arizona Game and Fish Department. They engine will be attached to a device where the results will validate the condition of emissions and whether the engine will comply with EPA requirements.

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.

10.2 Testing Facility

The new design for the Aqua Scooter will require a specific testing apparatus which will allow the team to determine thrust, buoyancy, and measure emissions. The testing apparatus needs to have some form of strain gauges that the design can pull against and the entire system will need to be submerged under a few inches of water. Two potential options for making the apparatus include a large aquarium and a trough pool. An aquarium would need to be at least 150 gallons to accomplish full submersion and have adequate space to set up the gauges to measure thrust.

Figure 11: Fish Tank for Thrust and Power Testing

The trough pool, which is used generally to bathe ranch animals on the size of cows, should be large enough to set up the thrust measurement system while also being deep enough to submerge the new design. The team is currently inquiring within the CEFNS department of NAU to find a suitable aquarium that can be used for the testing process.

Figure 12: Water Trough for Thrust and Power Testing

11.0 ENGINE OPTIONS

A primary objective for next semester is to convert a 4 stroke and 2 stroke engine to run on a cleaner burning propane fuel. As of now, there are 2 options for each of the 4 and 2 stroke engine categories that the group is considering.

11.1.1 2-Stroke Options

The first 2 stroke option is the powertrain of a Husqvarna 128C Line trimmer. 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 13: Husqvarna 2-Stroke Engine

The second 2 stroke model is also the powertrain of a line trimmer from Tanaka Inc. 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 14: Tanaka 2-Stroke Engine

11.1.2 4-Stroke Options

A 40 cm^3 displacement Briggs and Stratton engine is one of the 4 cycle options for propane fuel testing. 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 15: Briggs and Stratton 4-Stroke Engine

In addition to the Briggs and Stratton, the second 4 stroke engine testing option is the Honda GX-25 multi- purpose utility engine. 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 16: Honda GX-25 4-Stroke Engine

12.0 COST ANALYSIS

In order to organize the potential costs for testing the selected solutions, Table 4, was constructed. The materials are broken down into two price points labeled Cost A and Cost B. The Cost A column lists the higher price point items, while Column B lists the lower price points items in each category. The category, which accounts for the highest percentage of total cost is the emissions testing. Although the client requested these costs to be included, the team's initial emissions tests will not require this expense. Upon completion of the team's testing, the final prototype may be tested using the more expensive and comprehensive testing facilities.

Table 4: Cost of Materials for Testing Engines

Item	Cost A	Cost B	% of Total	% of Total
Conversion Kits	$250.00	$250.00	11.82%	13.59%
Emission Testing	$1,000.00	$867.00	47.28%	47.15%
Testing Environment	$175.00	$104.00	8.27%	5.66%
2-Stroke Engine	$200.00	$169.00	9.46%	9.19%
4-Stroke Engine	$240.00	$199.00	11.35%	10.82%
Shipping of Engines	$75.00	$75.00	3.55%	4.08%
Shell Prototype	$50.00	$50.00	2.36%	2.72%
Oil	$25.00	$25.00	1.18%	1.36%
Butane Gas	$50.00	$50.00	2.36%	2.72%
Propane Gas	$50.00	$50.00	2.36%	2.72%
	$2,115.00	$1,839.00		

The pie chart shown in Figure 17 provides a visual representation of the potential costs associated with the testing of the two engines selected. The cost of the engines, account for 21% of the total cost for all materials. Again, it needs to be stated that the percentages are relative considering the high cost of emissions testing provided in the table.

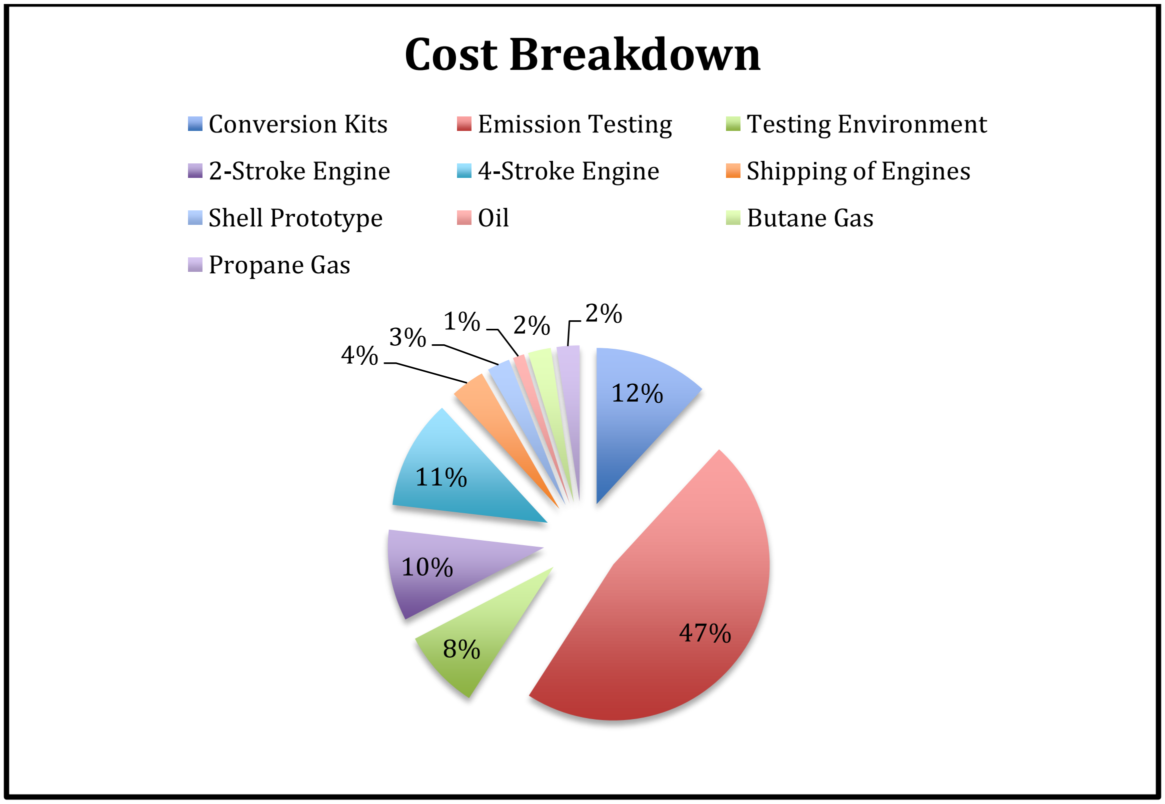


Figure 17: Pie Chart with Percentages of Total Cost

13.0 CONCLUSION

The client, R.S.W. /D.I. Inc. 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 using butane and propane gases for engine was calculated and researched. The calculations show that both of these gases are able to propel the Aqua Scooter effectively.

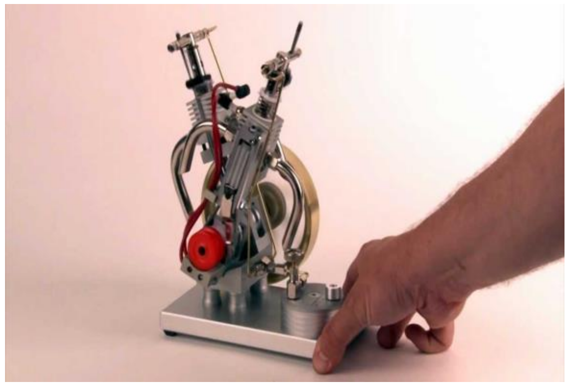


Figure 18: Possible engine design converted for gas fuel.

The boomerang outer shell design was analyzed for the coefficient of drag and the drag force needed to propel the scooter. The drag coefficient is highly correlated with the amount of power required to overcome drag, which for this project is limited to 2hp. Since the drag coefficient and drag force for the boomerang outer shell was not conducive to the team's restrictions, the design chosen for further testing is the Triton shown in Figure 19.

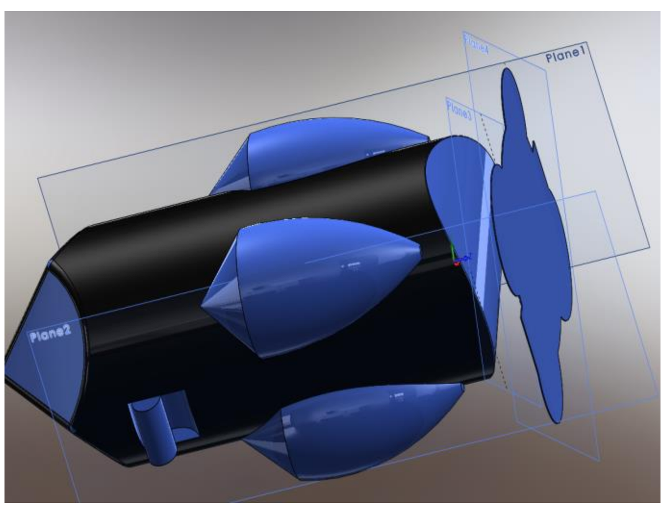


Figure 19: Final Triton design with area used for analysis

The next phase for the team is to test the recommended solutions. Two engines need to be purchased for the team to begin planning appropriate models for engine analysis and testing. The team's recommendation for the 2-Stroke engine is the Husqvarna and the recommendation for the 4-Stroke is the Honda GX-25. Both engines are able to be tested outside of water and therefore allowing the team to begin immediately after purchase. Additionally, conversion kits will need to be purchased to begin converting engines to run on butane and propane fuels.

Following the converting of the engines, the team will need to test the amount of power and thrust the engine is providing with 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. The team will drive to Phoenix to test the emissions once the converted engines successfully produce the desired thrust and power for the client.

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 conduced in ANSYS and Workbench. . .

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[15] https://www.propanecarbs.com/small_engines.html

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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: Team Concepts

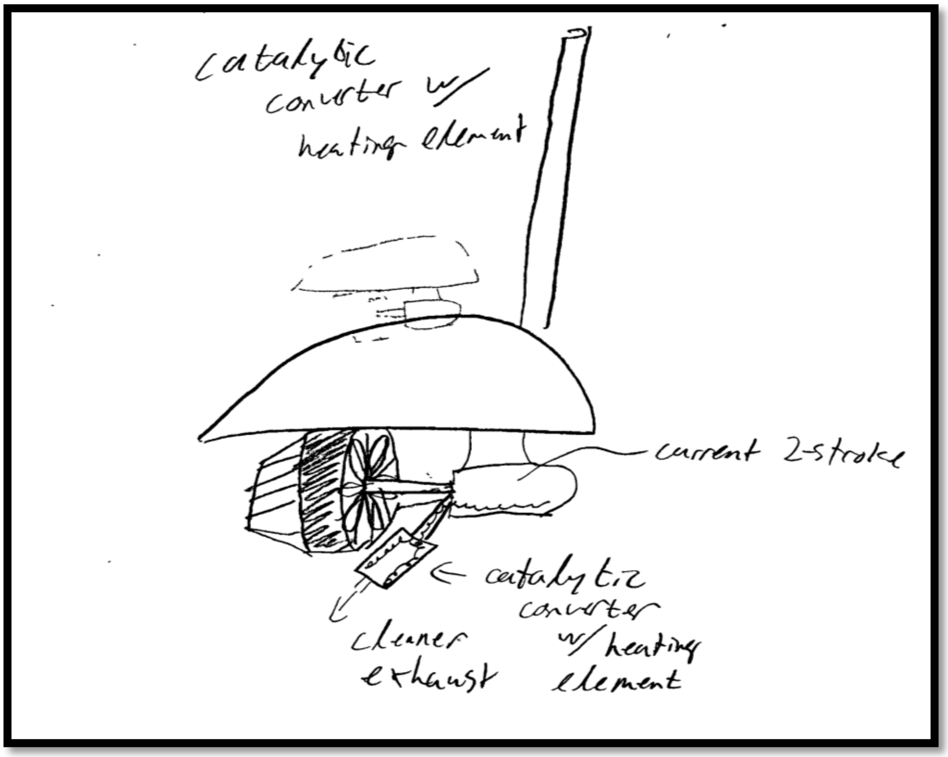

Figure B1: Catalytic Converter with Heating Element

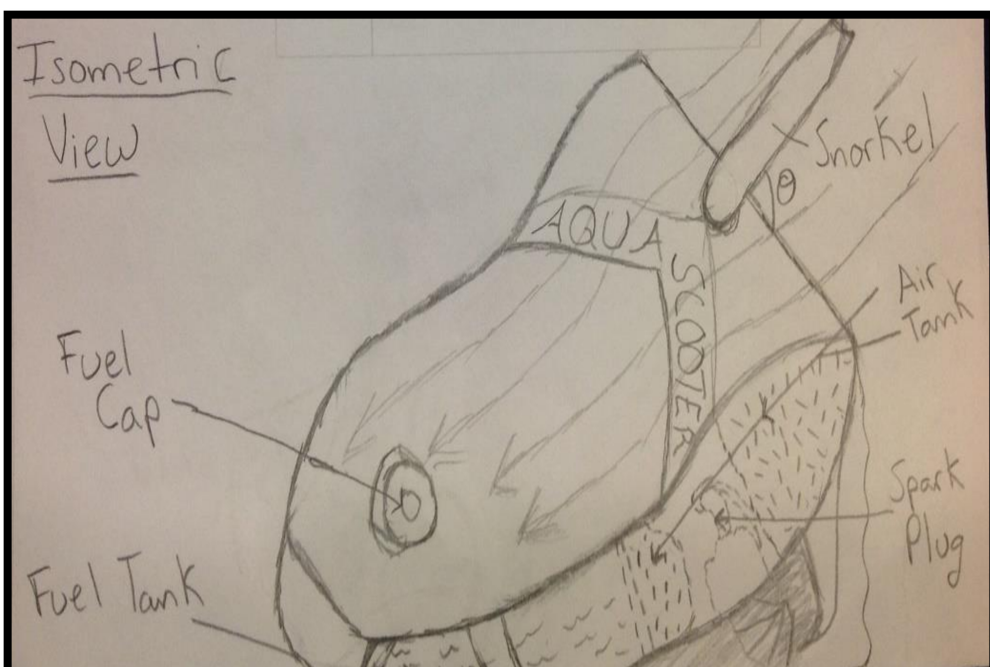

Figure B2: Enclosed Housing

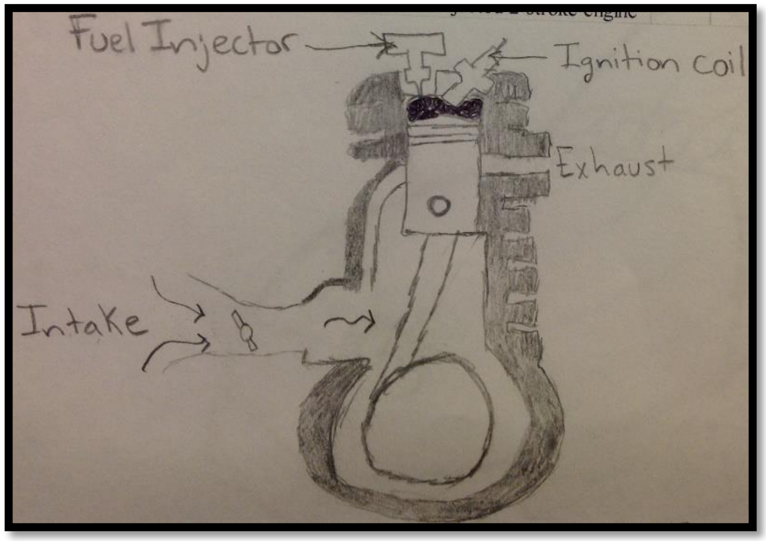

Figure B3: Fuel Injected 2-Stroke Engine

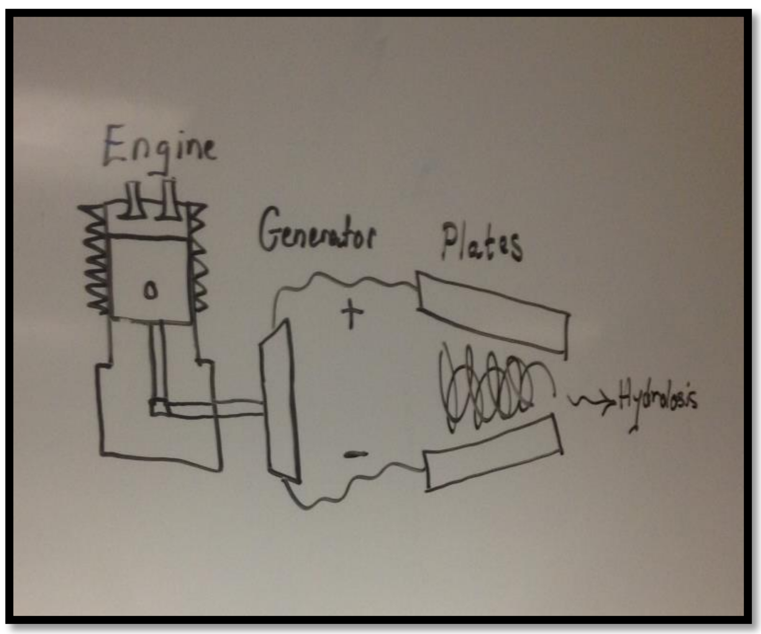

Figure B4: Magneto Hydrodynamic Propulsion System

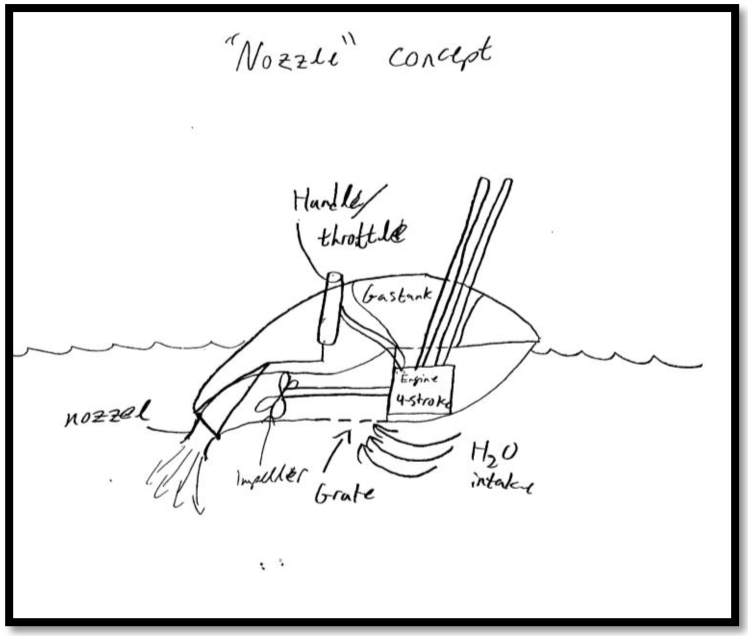

Figure B5: Adjustable Jet Nozzle Design

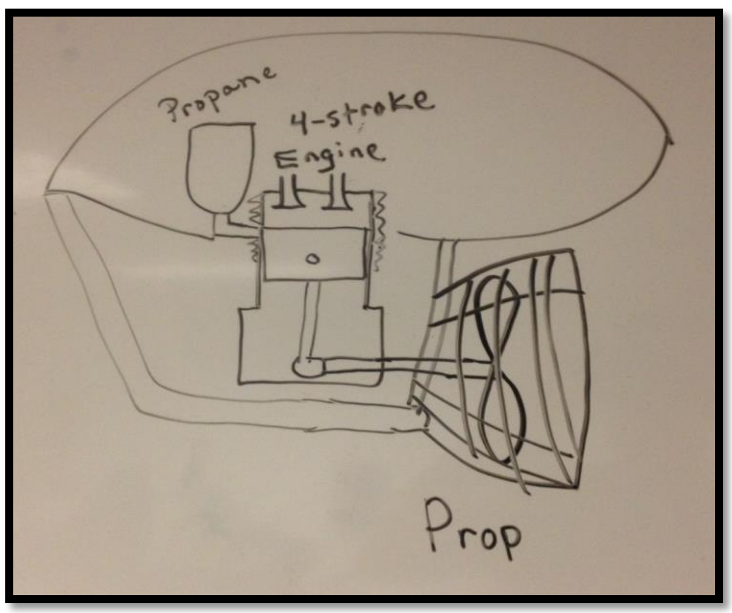

Figure B6: Propane Injected 4-Stroke Engine

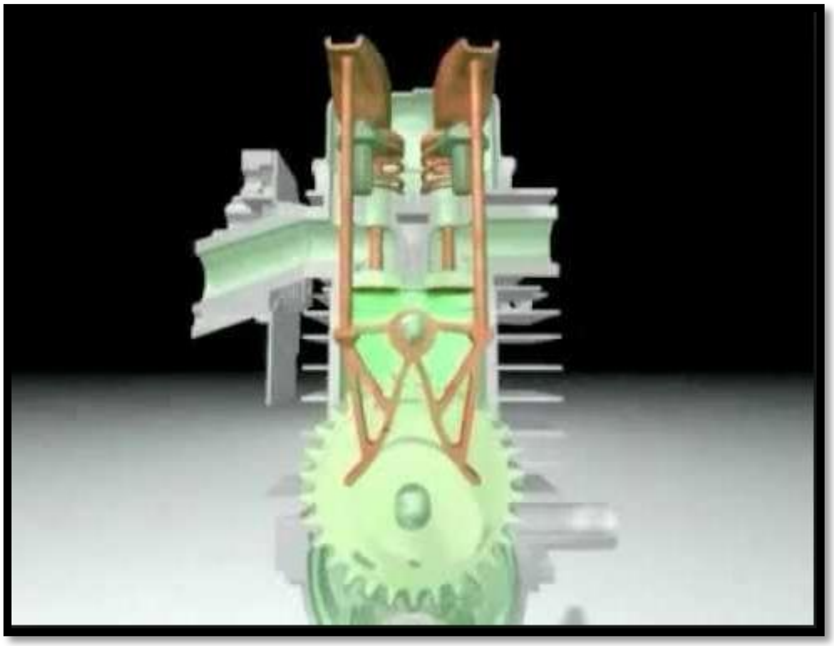

Figure B7: 4-Stroke 4-Mix Engine

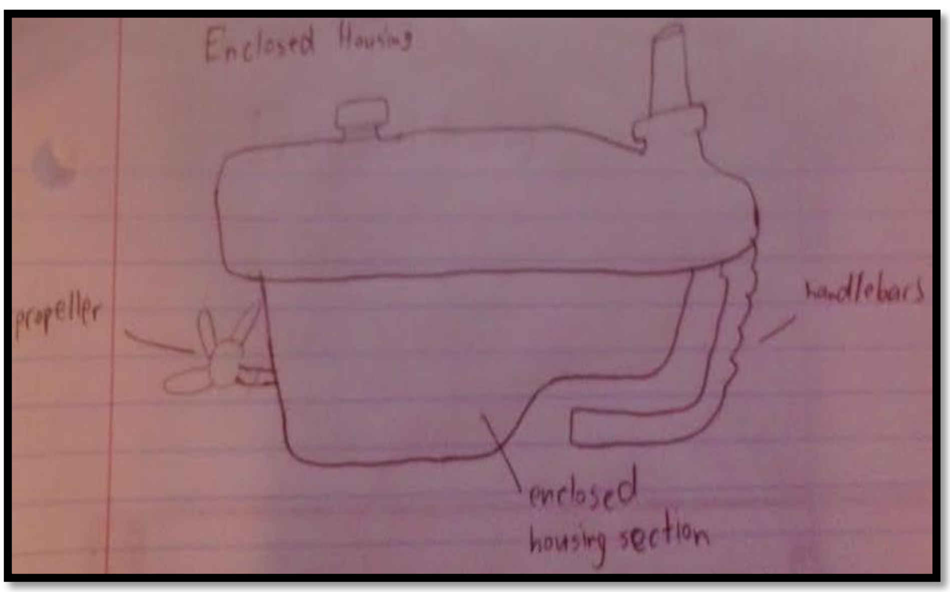

Figure B8: Tank Housing

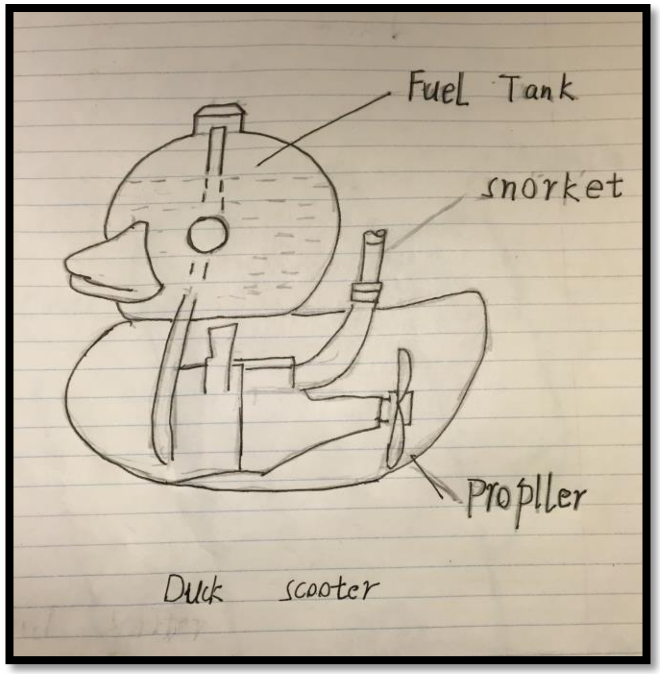

Figure B9: Duck Scooter

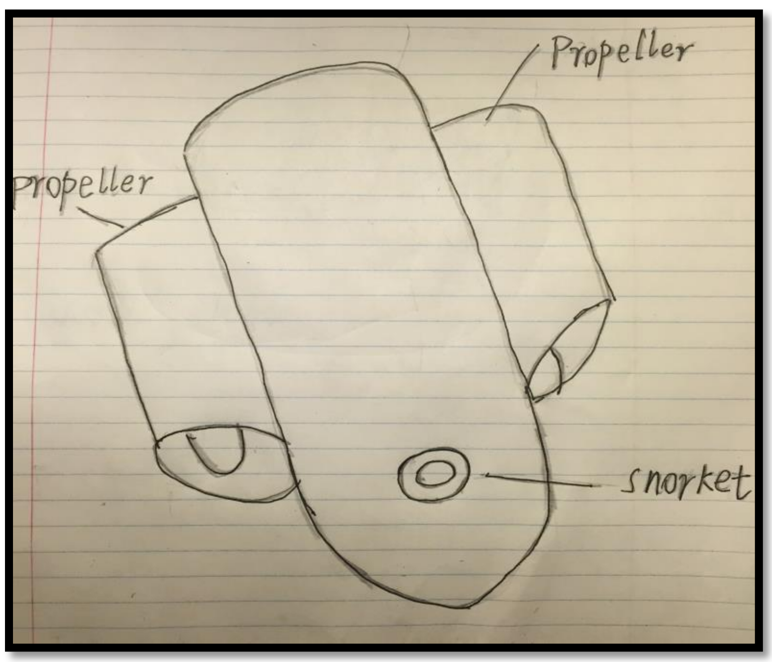

Figure B10: 2-Propeller Design with Belts and Pulleys

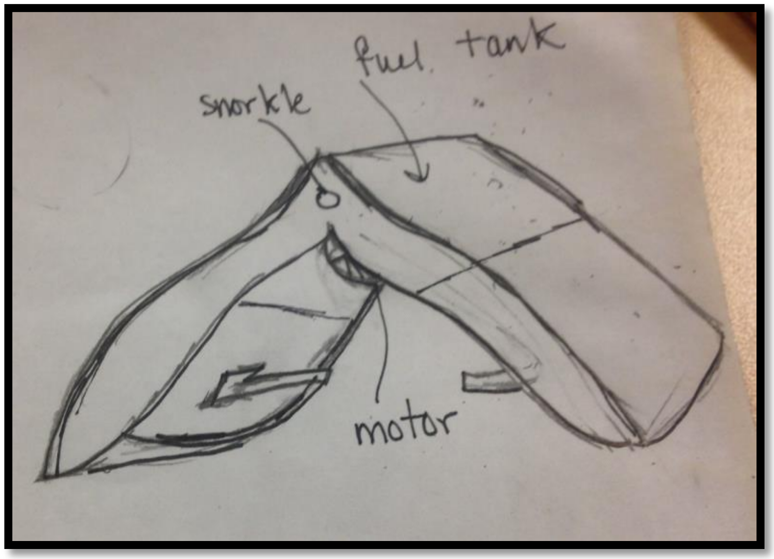

Figure B11: Boomerang with Single 4-Stroke Engine

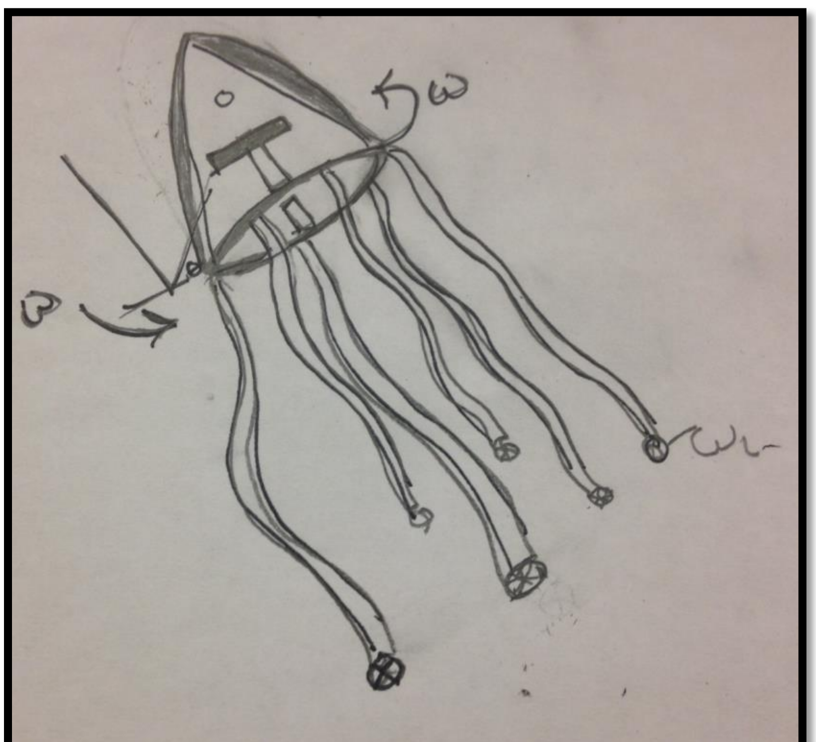

Figure B12: Octopus with Rotating Mechanism

APPENDIX C: 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 D: 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 E: 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
```