DR. Michael Walker.

PROJECT REPORT

TUBERCLE EFFECT IN HYDRODYNAMIC SYSTEMS

TEAM 2

BIOMIMICRY

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I.Abstract

Our main goal was to conclusively prove that ongoing research in using tubercle propellers in aerodynamic systems could successfully be adapted to hydrodynamic systems in the form of boat propellers. We were attempting to raise awareness of this impressive possibility by comparing a traditional propeller with one created with tubercles, to prove that the tubercle propeller was capable of increasing the efficiency of the fuel consumed by causing a boat to go faster with the same motor speed. To do this, we have created two boats that were as close to identical as possible, as well as a two trough system in order to race them.

Our project depended on two different propellers, in order to compare the speed of the boat and therefore the efficiency of the propellers. Our research into the wind turbines created with tubercles showed that they increased the power generated by up to 35%, so we initially thought we would see similar results in our comparison. However, when we actually ran the tests, we found that the tubercles increased speed by 44% while using the same boat and switching out the propellers. Although there are many factors that could have affected the speeds in our trials, we endeavored to remove as many as possible by testing the propellers with the same boat, on the same day. Our tests consistently showed that the tubercle propellor went significantly faster, and when we raced them for several hours, the tubercle boat outperformed the boat with a traditional propeller in every successful test.

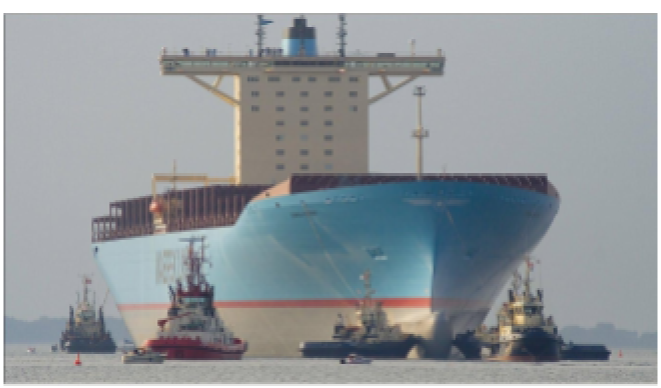

Figure 1.1 The Emma Maersk is the largest cargo ship in the world. It burns 14 tons of fuel each hour. (Culp, 4)

These results have massive implications for sustainability and the reduction of fossil fuel consumption and greenhouse gas emissions. Cargo ships are the largest source of pollution in the world. All the ships in the world produce 260 times the sulfur oxide as all the world's cars, and boats use 370 million tons of fuel per year (Evans, 5). If we could increase the efficiency of the propellers used by these massive cargo

ships and reduce fuel consumption by only 1%, we would not only greatly reduce the greenhouse gas production of these ships, but also save 15 billion dollars in fuel costs.

Therefore, our project has massive implications for both the environment and economic prosperity of the planet, which shows the benefits of drawing from the millions of years of iterative design already present in nature.

II. Introduction

i. Concept

Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies.

Species on the earth have evolved over billions of years with the goal of survival and propagation by adapting themselves to their surroundings. Seeking mechanical solutions by drawing inspiration from the masters of survival is the core idea of biomimicry.

Over the years, thousands of ideas have been inspired by nature in the disciplines of engineering, architecture and design. These include engineering feats such as the Japanese bullet trains inspired by kingfisher beaks, velcro inspired by burdock seeds, hypodermic needles by mosquitos, and sustainable architecture by drawing from termite nests. In the words of Leonardo da Vinci:

"Those who are inspired by a model other than nature, a mistress above all masters, are laboring in vain."

ii. Purpose

The purpose of our project was to mimic the fins of humpback whales to create propellers that are more efficient than the more conventional propellers currently in use.

"Megapetra novangilae," or Humpback Whales, are creatures of surprising maneuverability, considering they weigh 40 tons on average. The reason for their ease of motion, as discovered by Frank. E. Fish of West Chester University, is the presence of irregular bumps called 'tubercles', which increase the lift and reduce the drag of the system leading to a remarkable improvement in the amount of power generated by wind turbines with these irregularities. When compared to a traditional wind turbine, the tubercle blades had up to a 35% increase in the amount of power generated with the same amount of mechanical work done (Hamilton, 6).

The purpose of our project was to find experimentally if the tubercle effect was also applicable to hydrodynamic systems, and to discover the extent of the improvement. The design goal was to have comparative prototypes that minimized the steric factor. 3D printed prototypes of propellers (Fig. 2.1) were used with a primary objective of minimizing the dissimilarity hindrances. Our goal was to cause an impact on three pillars of sustainability.

Figure 2.1.The contrast between a conventional and a tubercle propeller.

III. Design Requirements

I. Overview

Due to the intricacy of our project there were several requirements that needed to be met to ensure the success of our design. The first aspect that needed to be accomplished to ensure the success of our design was the 3D printed boats. The boats needed to be simple enough to construct; however, they also needed to demonstrate stability and large amounts of buoyancy while accelerating through the water. The boats needed to be identical in every way and thus the construction and printing needed to be simple in order to ensure identical copies. These identical copies were placed in identical troughs designed out of air ducting. Any discrepancies between the boats or the troughs would compromise the legitimacy of the experiment and thus symmetry was crucial.

Fig 3.1 3D printed parts after glueing

Another crucial design requirement was the motors that powered the boats. The motors had to spin at exactly the same RPM for exactly the same amount of time, to ensure that any difference in speed was due to the propellers. Through the use of Arduino, we were able to exactly set the RPMs of the motors and ensure that each boat was being driven by the same amount of energy. The motors were being powered and controlled by lipo batteries and electronic speed controllers, so the layout of the electronics in the boat themselves was also a central requirement to our design process.

Ensuring that the boats had the same center of gravity was a necessity. If the center of gravity of the boats was different, there would have been serious problems regarding the legitimacy of the race itself, as any shift in weight would cause the boats to veer into the sides of the trough and slow down. In addition to their center of gravity, the boats' components needed to be waterproof. During the EXPO we anticipated running the boats ten to fifteen times and if the electronics were not water-proofed at all, any splash water may have destroyed them.

Fig. 3.2 The final format of the boats.

The element of our project that was central to testing our theory was the propellers. The propellers were the only piece of equipment in our system that was not supposed to be exactly the same in regards to the other boat. The discrepancy in propellers was crucial in proving the effect of tubercles in a hydrodynamic system.

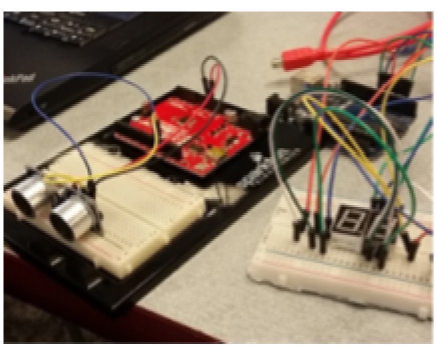

Fig 3.3 Testing the speedometer

In order to determine the actual success of our design, we relied on an Arduino powered speedometer that uses sound waves and refraction. This speedometer allowed us to actually compare the differences in both acceleration and velocity between the two boats. One boat was racing with the tubercle propellor and the other was racing with an unmodified propellor. Therefore, we needed a device to give us numerical data that could be used to support our theory that the tubercle effect could be applied to hydrodynamic propellers. By using the speedometer, we could easily compare the differences in velocity and therefore the change in efficiency between the two propellers.

ii. Boats

The first design aspect we tackled was the boats. We brainstormed a few ideas, such as buying remote control boats and modifying the existing propellers, constructing them from wood or acrylic, or 3D printing. We agreed 3D printing was the best option because of the flexibility of the design, the precision, and the fact it implemented an element of construction that might have otherwise been missing.

Figure 3.2. Durability issue perpendicular to layers

Our original boat design was 3D printed and 10 inches long. We found a 3D model of a boat on Thingiverse that had already been tested and could be turned into a fully functioning remote control boat. Once these models were printed, we realized there were stability and waterproofing issues with 3D printing boats. These issues arose from how the 3D printer stacks small layers of plastic atop one another. The strength is very high in the direction running along each layer, but very weak perpendicular to the layers. Basically, the layers do not stick together. Also, when we went to place the drive shaft, the designated hole in the model was much too small and the boats broke under the force.

The final boats used the same model, but scaled up to 11 inches long, and were still 3D printed, but had plastidip on the outside for waterproofing and stability. They held all of the electronic components and everything necessary to power the final product. We printed the final boats 8% larger, with 0% infill, layer height of 3.0mm, layer width of 0.6mm, on spiral vase method, and with no support structure. Spiral vase method slowly decreases each layer width as it builds up so the structure does not collapse. The boats were printed in two pieces because of both stability and size issues.

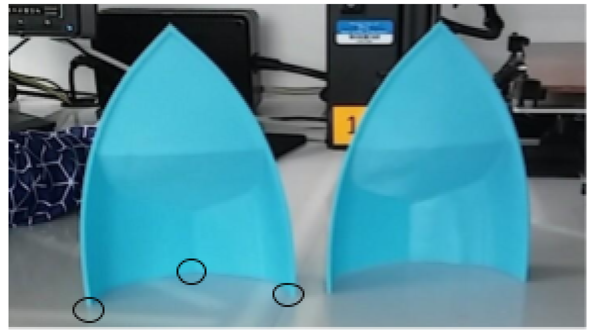

Figure 3.2.1 The top half of the boats

Once the four pieces were printed, we had to glue the halves together. We did this using hot glue and Loctite super glue. We put small dabs of hot glue at each corner in the design (the two highest points and the lowest point on the models circled in Figure 4). We quickly stuck them together and adjusted the temporary hot glue so everything was aligned perfectly. Once the hot glue dried, we used the caulk gun and the super glue to thoroughly attach the pieces of the boats. We pushed glue into the crack and on both the inside and outside of the boats to ensure the boats remained waterproof and together.

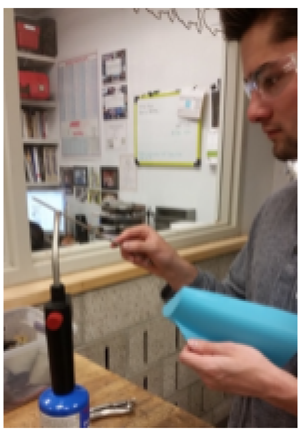

Figure 3.2.2 Heating drive shaft

In the model, there is a pre-designated hole for the drive shaft. However, the hole diameter was slightly smaller than the drive shaft diameter. To solve this problem, we heated bolts with slightly increasing diameters and pushed them through the hole. The hole widened until the shaft was a snug fit. The last step of boat construction was to plastidip the outside of the boats to increase the waterproofing and strength of the print. We applied three very thin layers of plasti dip then increased the next 5 layers of paint until there was a thick layer of rubber on the outside of the boats. The plastidip proved to be waterproof and kept the second round of boats from cracking as easily.

We tested the print before adding plastidip by filling the boat with 800g of weights to make sure there was enough buoyancy to hold all of our electronic components. The boat floated well, but water began leaking between the outside and inside layer of the boats. Once we plastidipped the outside and installed all of the electronics, we did more testing in the sink. The boat was more buoyant, and no water leaked through the plastidip. Our final testing was performed during our practice races.

<u>iii. Propellers</u>

Propeller design was one of the most important aspects of our project. The tubercles had to be precisely shaped in order for the effect to improve efficiency. Originally, we were going to print the propellers based off of a Solidworks model. We designed the stock propeller on Solidworks and did a few test prints. However, we noticed the printer did not have enough accuracy to make the curved shape of the propeller blades. The layers looked like steps instead of a smooth surface.

Once realizing the propellers could not be printed, we settled on buying small quadcopter propellers and figuring out how to form tubercles on the blades. The major requirements for the tubercle effect are: the bumps along the edge of the blade, and a bevel in the z direction going from the trough of the bumps towards the middle of the propellers. To form the tubercles, we used a thin dremel cutting tool. We cut against the blade at approximately a 45-degree angle so the blade cut the bumps while beveling the surface. The testing on the propellers occurred in the final stages of testing because everything else had to be constructed before testing could occur. In initial testing, we used the same boat and simply changed propellers to keep all variables constant. The modified propellers proved to be more efficient.

Figure 3.3 Modified propellor

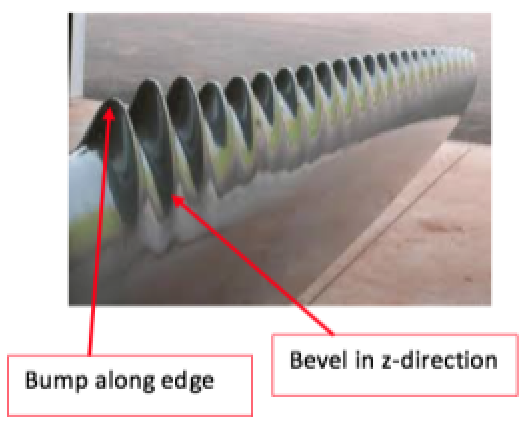

Figure 3.3.1

iv. DC Motor

To control the propeller, our initial plan was to use an arduino and brushless motor. However, we quickly ran into the problem of how exactly we were going to connect the motor and propellor to the boat. We found a 3D printed motor mount that would do nicely for running the motor underwater. However, a bit of research showed that while it was possible to run a brushless dc motor underwater, it wasn't recommended, due to problems with dirt getting into the motor and causing friction. We briefly thought about solving this problem by using an air propellor to drive our boat, but ultimately we were worried about how much more difficult the balancing would be, as it would be easier to tip the boat over, especially because it would be causing a force and therefore torquing the rest of the boat downwards. Finally, we weren't certain if we would be able to get the speed we needed to properly test our hypothesis. In addition, we weren't sure if we could find a propellor that we could modify that would work for an air propellor. Therefore, we scrapped our air propellor idea and proceeded by finding a drive shaft, which is the most common way of propelling rc boats.

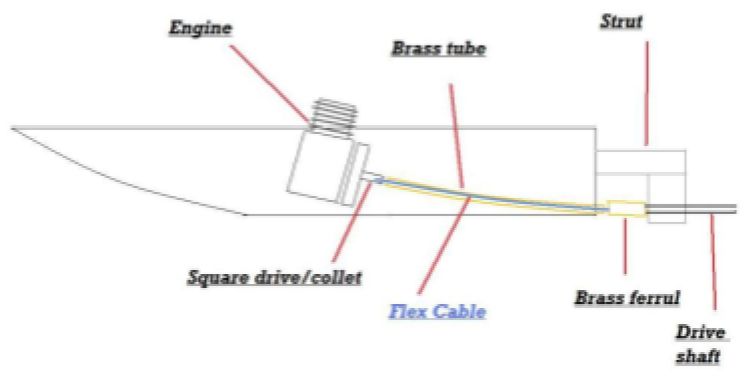

Figure 3.4 The Flex Shaft System

There are many different RC boat motor drive systems available. One of the more popular is known as a flex shaft drive.

This mainly consists of a brass tube, known as a "prop shaft," and a flexible metal cable called the "flex cable." The brass tube is usually bent and passed through the bottom or the back of the boat. This protects the cable and allows it to spin freely when it is passed through the tube outside of the boat. One end of this cable is connected to the motor through a collet, and the other end is down in the water and is attached to the propellor. Although this can work quite well for RC boats, we determined that it would be difficult to find and adapt all the parts for our purposes, as many of them are sold completely separately and chances were slim of all of them working together perfectly. Therefore, we decided to go for a "straight shaft" system. This is very similar, but rather than a flexible tube being bent through an angled metal tube, the flex cable is replaced with a straight metal shaft, requiring the motor to be put in at an angle. However, this would work quite well for our purposes, as the motor we chose was a small, brushless motor that would be fairly easy to mount.

The next step was learning how to control the motor using an esc, electronic speed controller. This device would allow us to send signals from the arduino using analogWrite(), based off of signals from the wireless communication system we were developing.

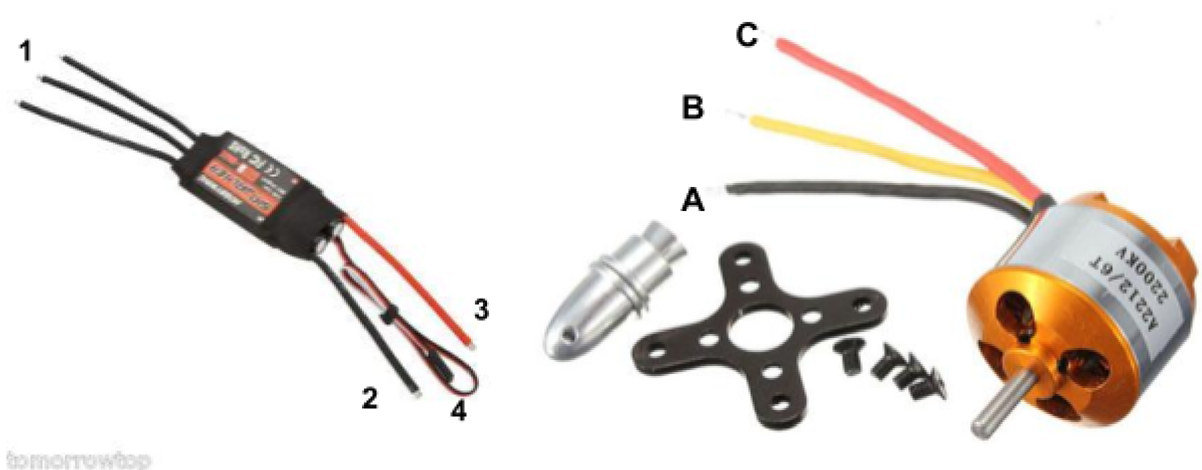

Figure 3.4.1 The esc we decided on was a 60A skywalker. The three black leads (1) lead to the three leads on the motor (A, B and C), while leads 2 and 3 go to the battery and 4 goes to the arduino.

The most important discovery we made was that we had to initialize the esc before we could use it by sending it the lowest signal of 1000 and waiting for two seconds. That's why we eventually made a circuit with three buttons- one green, to start turning the motor, one red, to stop it turning, and one yellow, to run the start up. In order to calibrate the motor, you had to turn the arduino on, then plug in the battery, and then push the yellow button and wait for the calibration program to run. This discovery was key to making the motor and esc work consistently.

v. Wireless Control

As we were working in our project, we ran into the problem of how we would be able to start the two brushless motors at the exact same time, with the purpose of comparing the different velocities with accuracy. We decided that it would be best if we could somehow control the motors with some type of wireless connection.

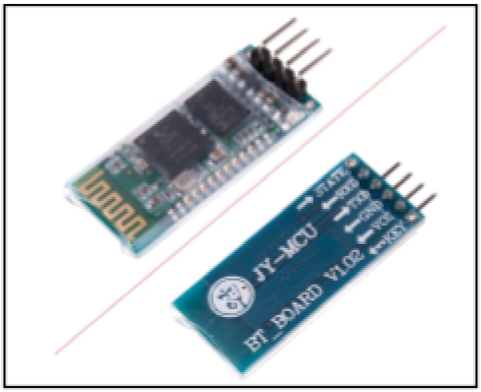

Figure 3.10 The HC-06 Bluetooth modules

Our first approach was to try this with HC-06 Bluetooth modules (Fig 3.10), we started by doing research and making sure that these would serve our purpose, however, after we configured the modules and got them to communicate with an Android phone, we quickly realized that the HC-06 modules would only act as slave modules. Meaning that they would be capable of receiving signals directly from a phone, but would never be able to transmit signals between each other. We tried to change their configuration to make them act like master-slave connection, but after doing more research about the specific modules we had bought, we discovered that this was not possible.This was a huge setback, as we needed to control two slave modules with a single master module.

Our next step was to try to find a different way of setting up our wireless connections. We looked at different HC modules, XBees, and NRF modules. After a lot of research and thought, we settled for NRF24 transmitters. These modules seemed to have all the features we were looking for as they communicated parallelly(One to many channels). We coded the NRF 24's and got them to communicate in multiple channels. However, the real problem was when the RadioHead library we used for communication was incompatible with the servo library used for the DC motors. Our debugging didn't work, so our next option was to get rid of the servo library. We switched to analog instead of servo but the Electronic Speed Controller required the servo library preventing us from doing so. Keeping the library intact, we were persistent and two days prior to the EXPO borrowed some Xbee modules from Dan Godrick to make a final attempt at the wireless communication. After a lot of convincing we got to work with the Xbees only to realize they were bricked, meaning they had a serious misconfiguration, corrupted firmware or a hardware problem. Still refusing to give up we unbricked and configured one of them while the other two modules failed to communicate with the AT command software (unrecognized by XCTU). Unfortunately, we did not have enough time to work on these issues, we ended up deciding to take out all wireless connection and control the boats manually.

vi. Radar Gun

We needed a way to compare the performance of the boats at all times while they were racing. To do this, we built a radar gun to compare the individual velocities of each boat. The most important aspect of this system was an ultrasonic sensor, which is able to detect the distance of objects in a similar way to a bat or a dolphin, using sound waves. It is made up of two different parts, a speaker that sends out waves, and a microphone that receives the waves after they hit an object and bounce back. (Fig 3.11) There were a few things we had to make sure to do right if we wanted the sensor to work properly. Since there is no way of programming the sensor to detect a specific object, it simply measures the distance of the closest object it can find.

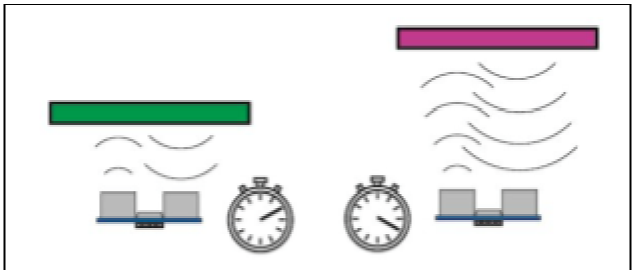

Figure 3.11 Ultrasonic Sensor

It sends out waves in a cone-like shape, so in order for it to detect only the boat moving, it would have to be placed in the right place. Once we were reading values from the sensor, we had to come up with a way to convert the distance measured from the sensor to the object to velocity. The distance was established by the distance traveled by the sound waves, and time was

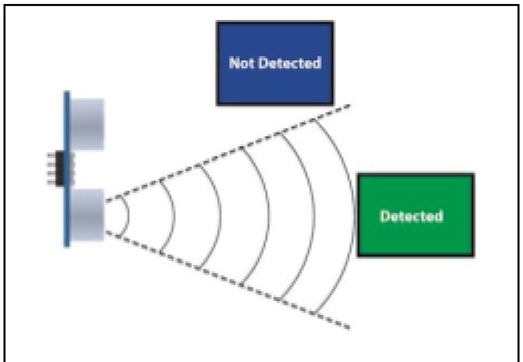

Figure 3.12 How the ultrasonic sensor uses sound waves to detect an object.

how long it took the waves to hit the object and then bounce back. This information allowed us to use the equation:

Rate = Time/Distance

With rate being the speed of the sound waves. Since the ping travels in microseconds, and the distance in our target was measured in inches, we also had to use dimensional analysis in order to convert these variables to miles per hour:

(Rate in Inches/Microsecond)*(1000000 Microsecond/Second)*

(3600 Seconds/Hour)*(1 Mile/63360 Inches)

Once we had the ultrasonic sensor and the calculations figured out, the next step was to think of a way to show these values to the public. The velocities were being outputted to the Arduino serial monitor, but we wanted to display them in a better way. Our first approach was to use 7 Segment LED Displays. It only took a couple of days to figure out how they worked, but we soon ran into the problem that each of them required too many wires, since each LED segment has to be controlled individually, and that there was a certain delay in displaying the values after they were received from the ultrasonic sensor. This wasn't accurate enough to display the velocities, so it would not serve our purposes.

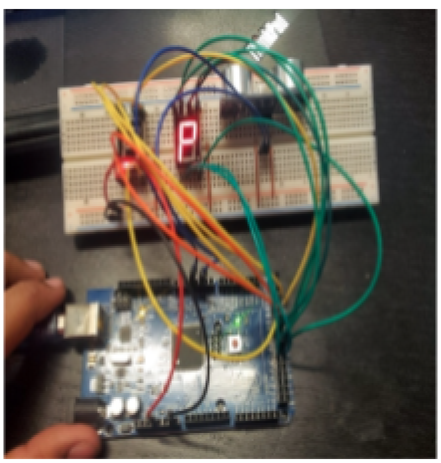

Figure 3.13 The flickering seven segment displays

We decided to try LCD Screens, which could be easily programmed and were able to display as many characters as we wanted. We connected the screens to the ultrasonic sensors and they worked out perfectly. We programmed them to display the distance of the target in

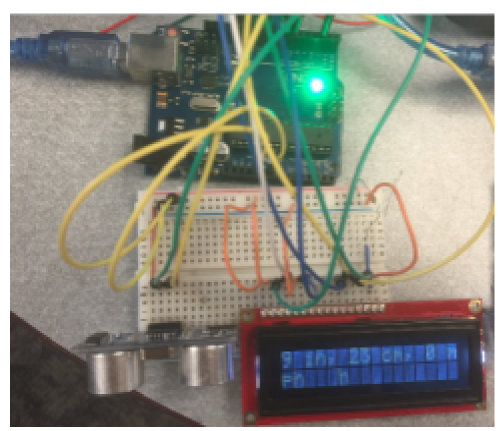

Figure 3.14 LCD screen showing the readings of the ultrasonic sensor

inches and centimeters, as well as showing the speed of the boats in miles per hour.

3.7 Racing Troughs

In order to conduct a boat race, we knew that the boats were going to need track in which they could race side by side in. With this in mind we had several ideas including building an acrylic box, buying a fish tank, cutting PVC in half, buying rain gutters, or using air ducting pipes. Through extensive brainstorming and financial limitations we were able to settle on just one of these ideas.

While considering building an acrylic box, there were several factors that contributed to the overall disadvantages of the idea that made us chose an alternative design. The first disadvantage to building an acrylic box was the overall cost of the box itself. Because we needed a track at least five feet in length, the amount of acrylic needed to create a box would have been absurd. Another trouble with the acrylic box was the fact that we couldn't find a binding agent that would be strong enough to keep water from leaking out of the joints. The box would have had to hold over fifteen gallons of water which would have excerpted a considerable force on the joints, one that we weren't sure we could build around. Similar to an acrylic box, the fish tank idea was also not a financially viable option. A majority of fish tanks are extremely deep relative to their length. In order to get a fish tank that was five feet long, we were looking at a price tag of over $200 used. Even if we were able to find a cheaper fish tank, we did not want to have to use that much water in order to race our boats. With sustainability at the forefront of our minds, we concluded that the cost and amount of water required to build and fill an acrylic box or fish tank was not a feasible option.

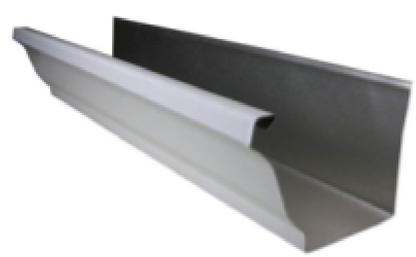

Figure 3.15 Rain Gutter Consideration

Our other two ideas for boats tracks were either to cut an eight inch diameter PVC pipe in half or purchase rain gutters. While both of these ideas would require less water, we encountered other problems. With the PVC, we came to find out that the largest diameter PVC we could find in the local area was six inches in diameter which wouldn't give our boats enough depth to operate. To get larger PVC pipes shipped to us would have cost around $150 which was not going to work with our project budget. Our alternative idea of raingutters was well within our budget; however, we were unable to find wide enough pieces of gutter that would fit our 3D printed boats. The rain gutter designs we found were either too narrow or asymmetrical which would have caused water flow issues.

After thoroughly analyzing the weaknesses of our design ideas, we realized that none of them would work due to finances or their lack of sustainability. Upon realizing this, we became even more creative with our ideas and began thinking about air systems in houses and realized that air ducting would work for our racing troughs. Not only was air ducting pipe the perfect length, it was very cheap in comparison to all of our other ideas. We decided that seven inch diameter ducting would be the best option because it was deep enough and wide enough for our boats to race down. We purchased eight inch diameter caps to place on each end of the ducting pieces that we would fasten and seal with caulk and Loctite. The air ducting not only offered us a cheap and easy construction, it was lightweight and easy to transport and handle. (Fig 3.16)

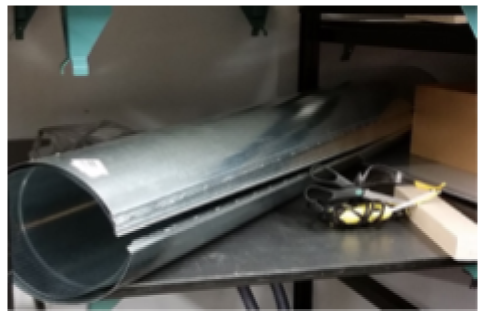

Figure 3.16. Five foot seven inch diameter ducting

After purchasing the ducting, we glued the end caps onto the ends of the ducting and let the Loctite cure for 24 hours. We placed pressure on the ducting and the cap to ensure a tight seal between the two. Once the Loctite was finished curing, we placed copious amounts of caulk on the outside and inside of the ducting to ensure it would hold the water we were going to fill it with. We gave the caulk 24 hours to cure as well and then we cut the ducting, which allowed us to fold it into a parabolic shape. We did

Figure 3.17 Our primary adhesive

so through the use of metal shears, with which we cut two inches into the ducting parallel to the caps on each end. We then applied force to each side of the ducting in order to bend it open to allow the boats to fit within the troughs. Because the ducting was made out of thin aluminum, it was easy to bend and held its shape while we were working on the frame work that would be used to secure the troughs.

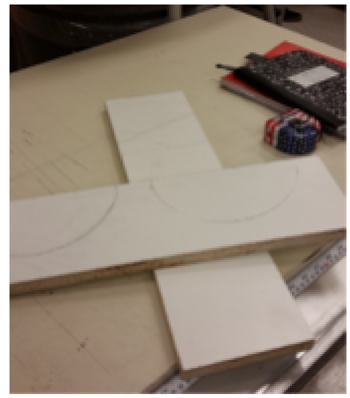

Figure 3.18 Tracing on the particle board for curvature of end pieces

The design for the framework was relatively simple. We decided to run five pieces of five foot long two by fours the length of the troughs. These two by fours would be fastened into two end pieces of particle board which would be cut to match the curvature of the ducting itself. We began first by using a hacksaw to cut the two by fours into five foot long segments. Once we achieved this, we traced half the end cap onto the particle board so that we knew were to cut. Initially we tried to cut this half circle with a circular drill, but soon realized our most feasible option was to use a bandsaw. Though a band saw is hand guided, we were able to achieve a relatively high degree of precision. In the areas where the cut wasn't perfectly round, we used a sander to achieve a smoother curvature.

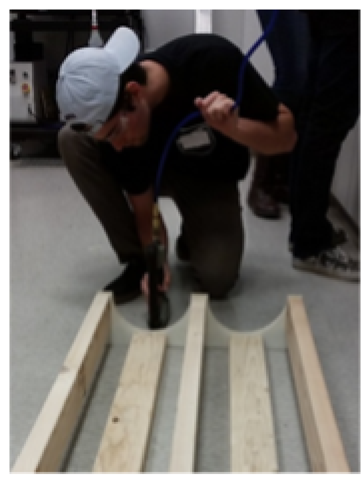

Figure 3.19 Brad nailing the framework for the troughs

The finals element of this procedure was to put all of the pieces together. We did so through the use of brad nails and a nail gun in order to ensure proper placement before we screwed in the two inch long screws. (Fig 3.19) After the pieces were all held in place with brad nails, we predrilled for all of the screws and then inserted them into their respective spots with an electric drill. The final product was exactly what we expected; however, in our design we forgot to account for the thickness of the particle board and as a result the framework was five foot two inches in length. Though aesthetically this was not ideal, the functionality of the framework itself was not compromised in the slightest.

There were no small scale tests that could be done in order to test our design, and as a result, we were forced to conduct the test without any preliminary trials. In order to test both the troughs and their framework, we simply filled them up very slowly with a hose. By filling them up slowly we were able to more thoroughly observe how the air ducting behaved under pressure and how the framework supported the center of the trough. Our first test went extremely well and we only observed a single, small leak coming from the cap of the ducting. The framework functioned exactly as we planned and supported the ducting along its full length.

Figure 3.20 Slowly filling troughs

Figure 3.21 Small leak while testing

While we did observe a leak, the EXPO was too close for us to entirely redesign the end caps so we were constricted to simple and fast fixes. While we did have hydrophobic spray, none of us were that knowledgeable on using it or how to apply it so we chose to simply use more caulk which was more difficult than expected. The Loctite and the caulk did not bind to each other due to their chemical composure. In an attempt to bypass this, we simply applied caulk wider and further up the cap in order to give the caulk a chance to bind to the medal instead of the glue. While this solution looked haphazard, the abundant caulk served to seal the ends of the troughs and allow us to put as much water in them as we felt necessary.

IV. Testing and Analysis:

One of the most challenging aspects of this project was bringing together many different parts to all work together in one system. In order for this project to succeed, we needed to not only develop a system that would clearly and easily show the difference in propellor speeds, but also one that was fairly reliable, so we could run multiple tests and get good data.

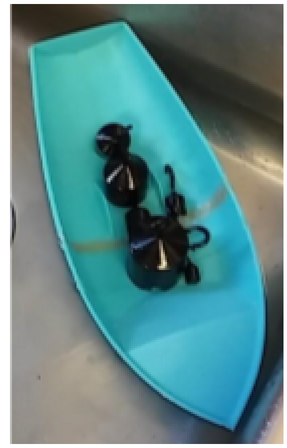

Figure 4.1 Weight testing the buoyancy of the boat.

The first tests performed were buoyancy tests on the boats. We needed the boats to hold the weight of the electronics while maintaining stability. Our initial tests showed the boats were able to hold up to 800 g, with the prediction that if we were able to spread the weight more evenly than the weights we were using allowed, we could get it up to 1 kg. As our initial estimates for the weight of the electrical components and the motor drive system were indicating that the boat only needed to hold 300 g, we decided that with plasti-dip on the outside, the 3D printed boat would work well for our purposes.

Once we had determined that our plans for the boat would work, we completed the motor drive system, and integrated it into the boat. In order to check that the motor was spinning the right direction, we turned it on in the sink to see if the motor would propel the boat forward. This was done very carefully, as we hadn't completed any waterproofing yet, but it was a very necessary step, as we discovered that the motor was spinning the wrong direction. This was a very easy fix, we just had to swap two wires, but it was an important part of early testing as we found that the propellers and motors we were using would work.

To test the efficiency of the propellers, we took one boat to our track and did multiple runs switching the types of propellers. The supersonic sensors recorded the boat speed, and we averaged the speeds to determine the increase in velocity. The velocities in some of the speed trials are in the table below.

The final results for the propellor tests

	Boat #1 (Regular propeller)	Boat #2 (Modified propeller)
Trial #1	8 mph	12 mph
Trial #2	10 mph	16 mph
Trial #3	12 mph	14 mph

V. Conclusion

During our final tests, we measured the velocities and accelerations of our boats inside the troughs using the two different propellers. This was the ultimate test of both our propellor efficiency and the efficiency of our radar gun system. During this test, we were able to prove our hypothesis with a remarkable 44% increase in velocity between the traditional propeller and the tubercle propeller. Measuring both velocity and acceleration(velocity at each point) was essential as we had to make sure that , on a larger scale the boats don't hit a threshold where the values go spiralling down. The velocities were pretty consistent (constant acceleration) proving that the threshold doesn't exist at a farther distance. As we previously mentioned, this has huge implications for reducing the fuel usage of large cargo ships.

VI. Budget

Date	Merchant	Item	Amount	Purchaser
2/26/2016	Electrical engineering shop	Bluetooth modules HC-06(3)	$23	Sophia
2/29/2016	home depot	2 2x4s	5.18	Wyatt
2/26/2016	Online	Motors (3)	$26.34	Maxine
2/29/2016	ITLL	PLA	$25	Sindhu
2/29/2016	Off Shore Electrics	Shafts	$43.66	Sindhu
3/1/2016	SDSHobby	Collets (3)	$18.64	Maxine
3/4/2016	Amazon	ESC for Motor	$13.47	Maxine
3/4/2016	Lowes	Ducting, Ducting Caps, Caulk, Cau	$60.43	Wyatt
3/16/2016	Amazon	propellors	$10	Wyatt
3/29/2016	Home Depot	Plasti dip, glue	$21.30	Jeremy
4/6/2016	Amazon	NRF24 Wireless Transmitors	$11	Sophia
4/15/2016	Amazon	Arduino stuff (shields, wires, solde	$54	Sindhu
4/22/2016	FedEx	Poster	$78.00	Sindhu
4/15/2016	Amazon	Battery and banana plugs (becaus	$23.00	Sophia
4/15/2016	Amazon	Batteries	$34.00	Maxine
4/12/0206	Amazon	solder materials and wires	$25.00	Sindhu
4/27/2016	ITLL	Toolbox	$13	Sindhu
4/27/2016	DAN GODRICK	Arduino replacement stuff	$15	Sindhu

Individual spending	Total Budget
Sophia	$410.02
$34.00	
Wyatt	
$75.61	
Maxine	
$92.45	
Sindhu	
$186.66	
Jeremy	
$21.30	

7. Timeline

Tasks	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Brainstorm, overall design							
Boat construction							
Trough construction							
Propellor construction							
Motor arduino element							
Speedometer arduino element							
Poster and expo presentation							

8. References and Citations:

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