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SeaVolt: The Hydro-Powered Underwater Turbine

Prof. Bala Maheswaran, Northeastern University

Bala Maheswaran, PhD Northeastern University 367 Snell Engineering Center Boston, MA 02115

Dylan Brady Wolter, Northeastern University

Undergraduate student at Northeastern University College of Engineering studying Mechanical Engineering. Interested in Robotics and ROVs. Specifically passionate about underwater robotics.

Julia Ariano
Gabriella Marie Green

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Julia Ariano, Noah Babcock, Gabriella Green, Dylan Wolter, and Bala Maheswaran
College of Engineering
Northeastern University

Abstract

While the generation of energy via water has been around since the ancient Romans, hydropower turbines have become more prevalent in our increasingly renewable energy-focused society. However, most turbines are stationary and the full potential of portable turbines has not yet been reached. Thus, we came to the idea of creating a turbine that attaches to boats and generates energy using the flow of water resulting from the movement of boats. The energy created by the turbine would charge a battery and could be used to power mobile devices or fixtures on the boat.

Preliminary testing was conducted using the Subnado underwater sea scooter by Waydoo. This was placed in a tank of water with the turbine. The scooter was then set to low power (the thrust was not listed) which provided a flow to turn the turbine. Given the testing conditions, the turbine was found to generate a maximum of about 0.85 volts. However, because the generator used was an AC motor and the Arduino was reading DC voltage, the rapid oscillation of voltage did not give a definite result. After the installation of a bridge rectifier, a more stable voltage was recorded at approximately 0.5 volts, but the bridge rectifier provided a 1.2 voltage drop. Using an actual generator, instead of a brushless AC motor inverted to a generator, more voltage could be produced. Coupled with a boat, or other aquatic vehicles, that can travel faster than the flow provided by the scooter, even more energy could be created by this turbine. For now, however, the turbine we created has successfully conveyed our idea and could be used and modified in the future to fully realize our idea for this device.

The SeaVolt turbine was created as a final project for a project-based learning first-year engineering course that followed a model of experiential learning. Experiential learning stresses the importance of student-led experience rather than textbook memorization. Throughout the creation of the turbine, we conducted our own research and tests, seeking guidance from the Professor or our peers as needed. While aiding in the enrichment of our academic abilities (such as important physics principles), this final project was effective in strengthening key engineering skills such as following the engineering design process to create a product, working with a team of other engineers, and presenting technical, quantitative, and qualitative data professionally.

Introduction and Background

Water wheels and hydropower date back to the ancient Greeks and Romans, but the first water *turbine* was created in the 19th century.[1] Water turbines are mainly used in hydroelectric power plants, with famous examples being the Three Gorges Dam in China and the Itaipu Dam on the border of Brazil and Paraguay.[2] [3] [4] However, the growing push for renewable energy sources has popularized hydropower past hydroelectric dams and water wheels.[5] [6] Our idea was to create a turbine that could be used in applications other than a hydroelectric dam to make hydropower more accessible to the general public.[7]

The SeaVolt turbine is portable and meant to be attached to the back of a boat so the movement of the vessel generates electricity. Ideally, the SeaVolt turbine would be attached to a non-motor boat, such as a sailboat, to truly generate clean energy. The turbine charges a battery that would be placed on the boat which could then be used to power other components. Since we were changing the hydrodynamics of a boat, we took drag into great consideration and tried to design a turbine that would minimize the effect of drag. Our design utilizes a Kaplan turbine (a type of propeller turbine) which generates electricity as water flows over the blades. The SeaVolt turbine is currently a prototype but is designed to act as a proof of concept.

The SeaVolt project showcases the effects of experiential learning: a type of teaching that encourages student learning and builds skills through hands-on experience rather than lectures and tests. Throughout the process of creating the turbine, short lessons on CAD software, engineering ethics, and coding were given in class. These lessons were then applied to small group projects such as creating a small wind turbine or coding an Arduino-based car to follow a specific path. Once these smaller projects were completed and we were given feedback, the same ideas would then be applied to our final project. For example, the code used to project the voltage readings onto the Arduino screen was a modified version of a code we analyzed in class. Real-life application of the lessons taught in class allowed for a richer understanding of the engineering concepts needed for a successful future. The SeaVolt turbine is a direct application of the lessons we learned in class and encouraged us to engage with a real-world engineering issue. Furthermore, the progression and creation of the turbine is an example of how experiential learning can often be more effective than other pedagogical methodologies.[8]

Methods and Approach

For the final project in our Intro to Engineering class, the class was tasked with designing a product that would be a source of renewable or reusable energy. Using the knowledge we already had on fluid mechanics and our new information about engineering ethics, we decided as a group to pursue a form of hydropower.

The project was completed throughout the latter half of the course which allowed us to draw from the experiences we had in class. Homework and classwork were continually assigned to help improve our knowledge of certain aspects of the engineering design process. Every one and a half weeks, the groups were required to complete a milestone–an evaluation of the final project's progress–and a checklist of requirements. This provided students with the opportunity to properly manage their time while also simultaneously learning skills that would be beneficial in designing and completing the final project.

When creating the initial design for the turbine, our main focus was designing it in such a way as to minimize the drag that would be created by the turbine. Several readings we were assigned described the balance most engineers had to maintain between real-life functionality and efficiency. We understood that we were adding an extra part to the boat and drag would be inevitable, but we strived to minimize this hindrance as much as possible.[9]

A large amount of research was done to create the most efficient model possible. Peer papers regarding energy generation through rain gutters or sinks served as talking points throughout our research.[10][11] Since the course stressed the importance of "good" research, databases such as Gale were used to find credible academic sources. The freedom to choose was daunting, but it made the project more enjoyable and realistic. We were allowed to pursue one of our interests and, in turn, increase our engagement with the project. However, in an earlier project for the course, the class had created small wind turbines that generated electricity. Drawing off the previous experience, we decided that a turbine would be the most efficient product compared to the other ideas we had created such as energy generation via tidal change.

We started with researching the type of turbine that would be most effective and decided upon a Kaplan turbine as the most efficient for our purposes. Kaplan turbines are a type of reaction turbine (a turbine that has blades attached to the runner as opposed to buckets attached to the runner) that generate electricity when water flows over the blades.[12] They are efficient with high flow conditions; the conditions under which our product was intended to be used.[13]

We also wanted the turbine to be environmentally friendly as turbines can have adverse effects on marine environments. For example, fish can often get sucked into turbines or the turbine can rip up plant life.[14] We wanted to avoid these effects by making our turbine on the smaller side (less room for fish to swim in) and the shaft adjustable with the use of a hose clamp (so the turbine can be moved upwards or downwards if there are clumps of plants at deeper or shallower depths).[15] This adjustable shaft also allows the turbine to be effective for many different types of boats since they sit at differing heights above the water. Furthermore, the turbine is designed to be quiet to prevent audio disturbances, a problem prevalent in many turbine designs, especially those that make use of gasoline. All of these ideas were reinforced by the structure of the class, as it stressed ideals and ethics. The effects of products on human populations, the environment, and the cost-efficiency are all extremely important for any engineer and we wanted to make sure we upheld those standards. Knowing the implications that the turbine might pose to the environment and taking into consideration user variability, we strove to meet both of these concerns.

Design Details

Our design can be broken into four main parts: the blades, the motor, the shaft, and the electrical housing.[9] The electrical housing holds the electrical components such as a Redboard, a breadboard with circuitry, a battery pack, and a rechargeable battery.

Blades

The blades of the turbine were 3D-printed with PLA. A large problem at the beginning of the design process was determining the most effective pitch for the blades. We had to be precise with the angle of the blades since we had limited 3D-printing resources due to the many other experiential engineering projects going on simultaneously. After thorough research, we found that 25° would be the most efficient angle for our purpose, as it had the best pressure distribution compared to other angles that had been tested for turbines around the same size as ours.[16] Our turbine blades are of a smaller diameter which results in a larger angular velocity meaning that the blades turn a greater amount of times per unit time for optimal energy generation. In addition to researching the most appropriate pitch for our blades, we also spent time researching the twist of propeller blades. The twist present in propeller blades counteracts the loss of efficiency in the pitch angle of the blades as the radius changes along the length of the blades. Ultimately, we decided to base the twist of our new blades on the original twist of the store-bought propeller, as determining a unique design would require math or testing beyond what we would be able to do.[17] [18] [19] [20] [21]

The initial print of the blades functioned well enough for several prototype tests, however, we noticed the blades slipping off their axis and had to make adjustments to the print. The reprint of the blades allowed us to gain more experience in 3D printing, CAD, and the Engineering Design process. To improve the blades, multiple iterations had to be completed to find the fitting solution. This reiterative process is one of many examples of why experiential learning is effective because no textbook would have given us the exact answer to improve the blades and we would not have understood *why* the blades were slipping. Instead, we had to find a solution ourselves and develop the skills to effectively reiterate our design. The solution to our problem was the addition of a lip on the front of the propeller component that could fit into a gap in the hubcap which kept the propellers from being pushed off of the axis.

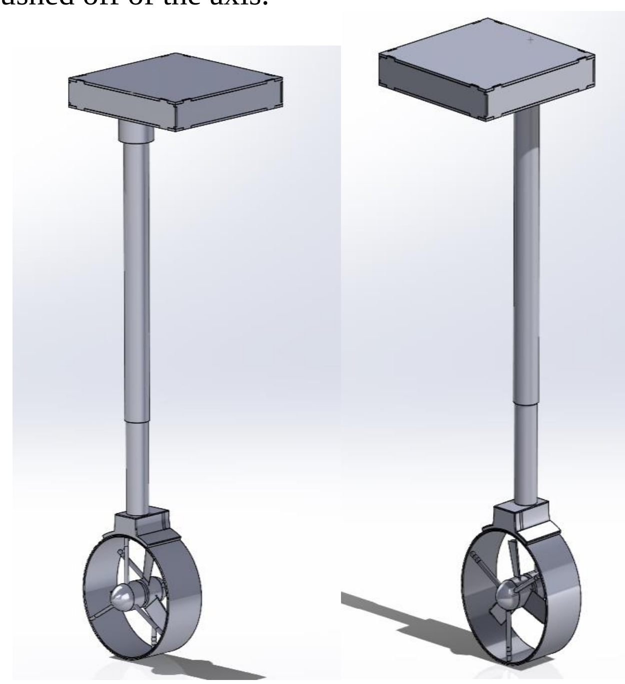

Figure 1: The Solidworks assembly of our design.

Motor

The motor of our prototype is the "Underwater Thruster 16V 300W Brushless Motor with CW 3-Blade Nylon Propeller for RC Bait Tug Boat Nest Ship Submarine," which we bought from Amazon. [22] Another concern to us was waterproofing the electrical parts, so we opted to buy a motor that was already waterproofed. However, after significant testing, we realized that the motor, when used as a generator, did not create as much electricity as we had originally planned.[23] Furthermore, the data from our initial testing had alternating sections where no voltage was read, prompting us to suspect that the motor was not emitting direct current (DC), but rather alternating current (AC) which cannot be read by an Arduino (more about this in Results). However, this was remedied by the addition of a bridge rectifier in our circuit. This roadblock was one of our first major issues with our project and allowed us to discover engineering challenges firsthand and would prepare us for other issues that arose in the future.[24] [20] [25]

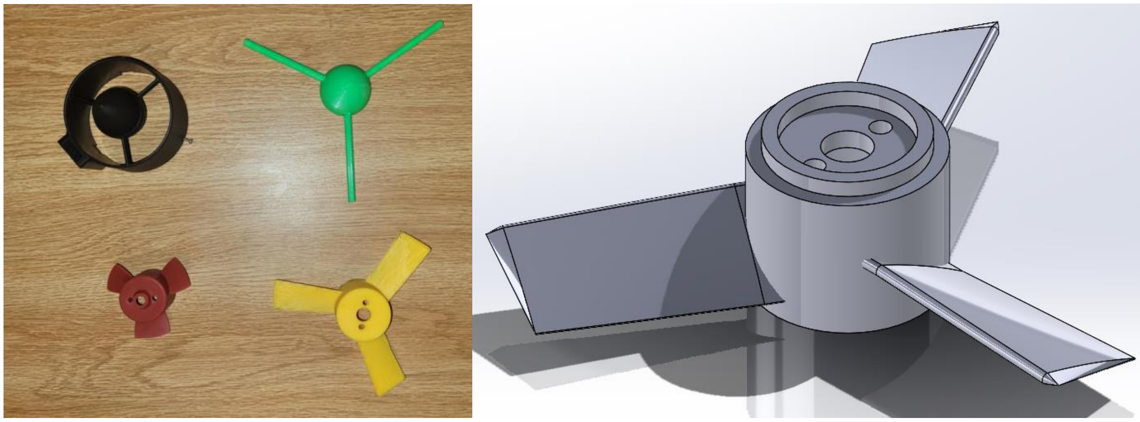

Figure 2: An image of the progression of the blades (left) and the Solidworks sketch of the blades (right).

Shaft

The shaft was created out of PVC pipe and a garden hose clamp. We wanted the shaft to be adjustable so the SeaVolt turbine could be attached to numerous types of boats. The garden clamp secures the two pipes into each other and can be loosened and tightened at will. The shaft serves as a way for the wires from the motor to be connected to the Arduino safely underwater. While this is still a prototype, none of our electrical components were damaged after several days of testing in water which shows the effectiveness of our design.

Figure 3: The shaft. The two pictures on the left show the shaft in person. The right two pictures show the Solidworks sketch. The shaft is shown in various stages of length.

Electrical Housing
The housing is made of laser-cut acrylic. It is held together and sealed with silicone to be waterproof since it would be near the surface of the water. The housing is meant to sit outside of the water to further protect the electrical components and has a lid that can be opened from the top.

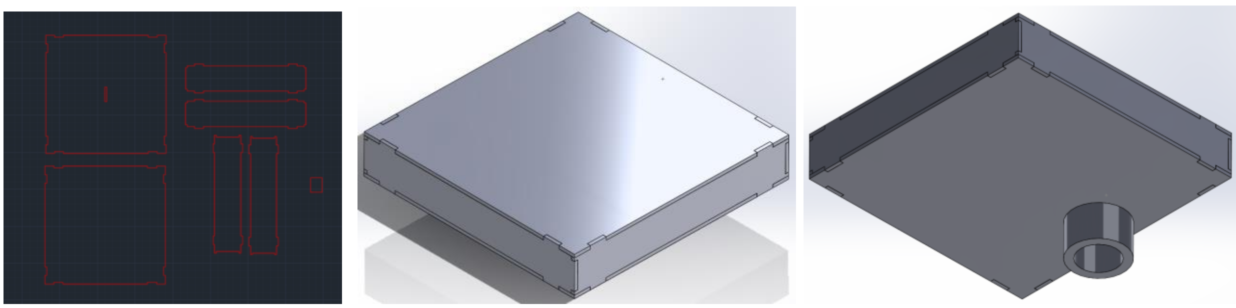

Figure 4: The AutoCAD drawing and Solidworks assembly of the electrical housing.

Circuitry
A main part of the circuit is the powering of the LCD (liquid crystal display) screen that displays the time and voltage reading. The circuit we used is from the SparkFun Inventor's Kit Guide and is called "Circuit 4A: LCD 'Hello, World!'" [26] This circuit was completed earlier in the course and provided us with ample opportunity to explore the needed circuitry and electronic skills to complete this project. However, we also modified it slightly: the turbine is soldered to a bridge rectifier to convert the AC voltage produced by the motor to DC voltage. This was then plugged into the analog pin so the voltage generated from the turbine–not the battery pack–was read on the screen. Furthermore, we took the charging cable for the rechargeable battery and altered it to be compatible with the Arduino.

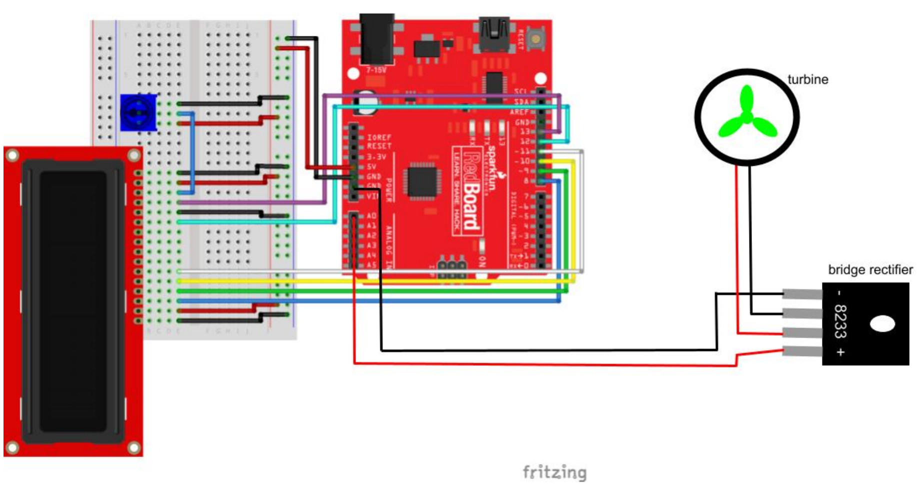

Figure 5: The wiring diagram for our turbine. It is derived from the SparkFun Inventor's Kit's "SIK_Circuit_4A_LCDHelloWorld" schematic.

The Arduino code we used is a modified version of the SparkFun Inventor's Kit's "SIK_Circuit_4A_LCDHelloWorld" code and a previous code we created as part of another turbine project in our Cornerstone class. Parts of the code were adapted from "Device Plus: The

Basics of Arduino: Reading Voltage" [27] which was a code we had used for the original wind turbine project. The altercation of the wiring shows the effectiveness of experiential learning: the various SparkFun assignments allowed us to have a deeper understanding of how a red board works and allowed us to modify a circuit that would have been incredibly difficult if we had only read about the functions of a red board. These circuit skills will also come in handy in the future.

Results and Analysis

Early proof of concept tests were done within the First Year Engineering Learning and Innovation Center with an air compressor and a hose. While the turbine was still in the stages of being constructed, we did not want to put it into the water and damage it. Using the air compressor simulated fluid against the propellor. Although not water, it would allow the blades to move, test whether voltage was created, and ensure that the circuit was working correctly.

All tests and group meetings were done independently of class time as our professor wanted us to create schedules that worked for us individually. While data collection was required for the final presentation of our product, the specifics were not listed and we were forced to approach this on our own. Using our knowledge built from hands-on activities, we applied a similar testing strategy from the previous Arduino car project by collecting multiple tests and trials to limit statistical error. Knowing the importance of limiting variables, consistent test strategy, and simulating real-life conditions, we devised a simple procedure to collect adequate data that could represent the success of our turbine and data that we could analyze to diagnose issues.

Preliminary aquatic testing was conducted using the Subnado underwater sea scooter by Waydoo. This was placed in a tank (approximately 35" by 19" by 13") of water with the turbine. The scooter was then set to low power–the thrust was not listed–which provided a flow to turn the turbine, simulating the conditions as if the prototype was attached to a boat. These steps were repeated five times for approximately ten-second intervals with the Subnado at low power. The voltage was then recorded using the serial monitor in Arduino. Only the scooter's lowest power was used, so various flow rates were not tested.

After the implementation of the bridge rectifier, the same method of testing was repeated. The initial round of testing supported our conclusion that the motor being used produced alternating current rather than direct current: a problem since the Arduino only could read DC voltage. This is apparent through the data points at zero, as the Arduino is only capable of reading positive voltage and would read zero if a negative value was produced. The plot for our initial five trials exhibited sinusoidal behavior which is characteristic of an AC voltage current graph.

After adding a bridge rectifier to the circuit, we tested our turbine again and found that it produced an average of about 0.5 volts. However, the bridge rectifier produced about a 1.2-volt drop (a four-diode rectifier wired in parallel with each diode providing about a ~.3-volt drop) (we learned this information from an older student who is studying electrical engineering) in the results. The data (as seen above and in appendices 1 & 2) is more consistent; there is less of a jump from wildly different voltages.

Most of the fluctuation can be attributed to cavitation. As the testing was completed in a small bucket, air bubbles were created as the scooter produced flow and formed waves. The bubbles were then churned up within the scooter intake as well as the propeller, making it less efficient; a constant flow of water was not completely achieved. This also explains the drop-off over time. As more air was introduced into the system, there was less water flowing over the blades, decreasing efficiency and the voltage produced.

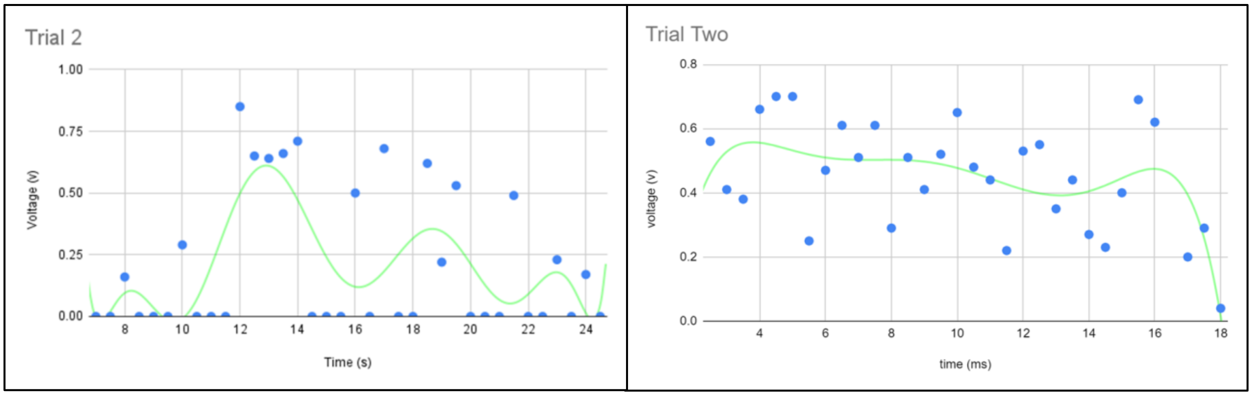

Figure 6: An initial trial graph exhibiting sinusoidal behavior (left) vs. a later trial graph when a bridge rectifier was added to the circuit (right). The trend line is shown in green.

Discussion

Overall, the SeaVolt turbine performed sufficiently. While it did generate electricity, it did not generate as much as we had hoped. However, many factors could have contributed to this result with a large issue being that the motor is not a generator. Further imperfections include monetary and time constraints (this was a final project due at the end of the semester). While the intention of producing enough voltage to charge a battery was not reached, the SeaVolt turbine serves as a proof of concept to show that if the aforementioned issues were corrected, the turbine would create enough electricity.

However, the more valuable part of the project was the experience we had creating a senior-design-like product. The time and effort put into the class and this learning experience were beneficial in the long run as we came out of the class with tangible skills and projects that aided in our learning. Rather than just being able to recreate a 3D Model, we were able to produce the model and make further edits to our designs s we noticed real-life flaws that we could not have expected with just a 3D figure. The course was also much more enjoyable as we were tasked with creating solutions rather than answering test questions.

Furthermore, the experience of our peers also reflected that the experiential learning model taught them more than just simple lectures would have. Our university has students rate courses using the TRACE (Teacher Rating and Course Evaluation) survey required at the end of each semester. Students can rate the course on a 5-point scale based on learning objectives and course-related questions. After our Cornerstone class ended, we were able to see the anonymous results of the TRACE survey for our specific section.

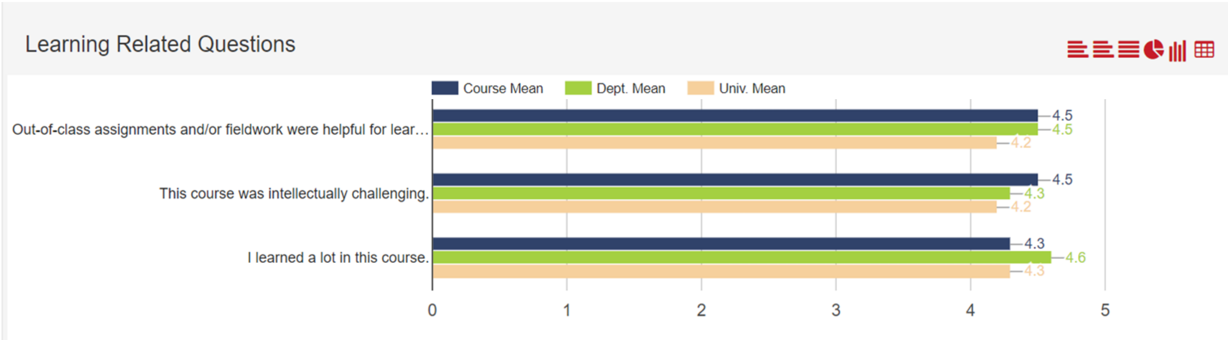

Figure 7. TRACE Evaluation (Learning Related Questions)

As the data suggests, our peers agree that the out-of-class assignments, such as the final project, were vital to our learning as engineering students. Specifically, the way our professor taught the course was rated either on par or higher than the department and university mean in the effectiveness of instruction. Along with the 5-point scale, students were also able to leave anonymous feedback about their opinions of the course. A response from one of our peers sums up our views on the course by saying, "If you devote the time and energy to [our professor's] class[,] it is extremely rewarding as you will come out with coding experience, 3D modeling, as well as tangible products and technical writing."

The course also helped us with our time management skills. One of our peers said, "He [our professor] has a strong focus on hands-on group projects outside of class. A large number of assignments can be a strain at times, but it allows the student to learn time management and also learn a wide variety of skills." It is extremely possible that many of us will enter careers where we will be juggling multiple projects or tasks at one time and building these time management skills in college with be extremely beneficial. Experiential learning and the hands-off nature of the professor with our schedules helped stress the importance of prioritizing certain assignments when needed and creating a week-long or even month-long calendar to keep on track. The creation of milestone assignments helped keep the projects at a doable pace and allowed us to decide what we needed to work on week by week. (Two parts of the milestone rubrics are included in Appendix 4 with sections of our submitted work along with the outline of the rubric for the final project).

Furthermore, the course was also thought-provoking and taught students a multitude of topics within a single semester which helped undecided students declare a major. The course also had a focus on group work which is a main component of engineering experience. Another one of our peers commented on the TRACE survey that "The course was very effective in its ability to foster an inclusive learning environment and community, as us students were provided many opportunities to work with each other on a myriad of different topics and had us all engage with each others' final projects through things like presentations and demos." The experiential learning not only fostered an engineering mindset but also fostered a community within our class that is comparable to real-life engineers.

Finally, revisions and improvements were talked about at length throughout the course. We were allowed to recreate projects if they did not meet our standards and re-do certain assignments if we wanted another shot at what was being taught. This also applies to our final project. To further improve the SeaVolt turbine, we would first replace the motor with an actual generator.

Waterproofing the generator would be necessary, but the voltage output would be much greater than an inverted AC motor. The removal of the bridge rectifier would be another improvement. Given that the rectifier dropped the output voltage, it would be beneficial to avoid the conversion. As a result, a solution other than the Arduino analog pin would be needed to record the voltage. This would eliminate the drop caused by the rectifier and a higher voltage could be produced.

One other improvement would be a more consistent testing strategy, for example, testing in a larger bucket or actual running water with a boat. As noted in the analysis section, the bucket used for testing caused cavitation and air bubbles to enter the system. By using testing methods that produced a more consistent flow of water, without fear of cavitation decreasing efficiency, the voltage output would be more consistent and higher which could allow for the charging of a battery.

Conclusion

Our data and tests prove that the SeaVolt turbine can produce energy. However, to charge the battery as intended, the prototype would need to be scaled up, the proper testing environment would need to be used, and improvements would need to be implemented. Despite this, with the implementations described in the discussion, SeaVolt could become a functional and marketable product. This could lead the way for green renewable energy for aquatic vehicles.

Throughout this project, and our Cornerstone class, we have gained invaluable experience and knowledge as a result of this project which allowed us to get a deeper understanding of the engineering design process and the importance of collaboration. SeaVolt allowed us to learn new skills in design, research, planning, and technical writing. Most importantly, we learned how to communicate and work together effectively under various constraints to achieve our goals.

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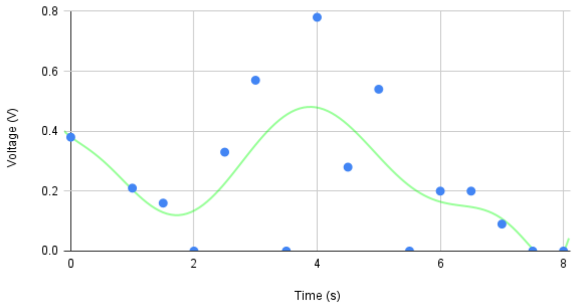
Appendix 1: Arduino Code for LCD Screen to Read Voltage

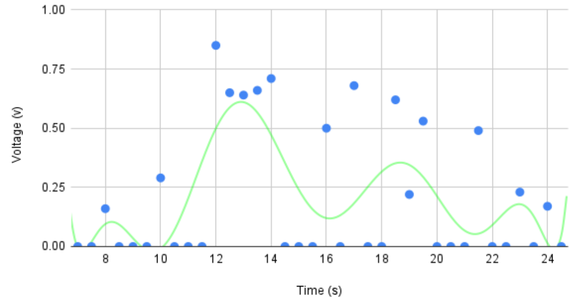
```
  SparkFun Inventor's Kit
  Circuit 4A-HelloWorld

  The LCD will display the words "Hello World" and show how many seconds have passed since
  the RedBoard was last reset.

  This sketch was written by SparkFun Electronics, with lots of help from the Arduino community.
  This code is completely free for any use.

  View circuit diagram and instructions at: https://learn.sparkfun.com/tutorials/sparkfun-inventors-kit-experiment-guide---v41
  Download drawings and code at: https://github.com/sparkfun/SIK-Guide-Code
*/

#include <LiquidCrystal.h>          //the liquid crystal library contains commands for printing to the display

LiquidCrystal lcd(13, 12, 11, 10, 9, 8);   // tell the RedBoard what pins are connected to the display

const int VOL_PIN = A0;
void setup() {

  lcd.begin(16, 2);                 //tell the lcd library that we are using a display that is 16 characters wide and 2 characters high
  lcd.clear();                      //clear the display
  Serial.begin( 9600 );
}



void loop() {
 int value;
    float volt;
    value = analogRead( A0 );
    volt = value * 5.0 / 1023.0;
    delay(500);
    Serial.print (volt);
    Serial.print ( " ");
    Serial.println( millis()/1000);

  lcd.setCursor(0, 0);              //set the cursor to the 0,0 position (top left corner)
  lcd.print("voltage: ");       //print hello, world! starting at that position
  lcd.print( volt );

  lcd.setCursor(0, 1);              //move the cursor to the first space of the bottom row
  lcd.print( millis() / 1000);       //print the number of seconds that have passed since the last reset
}
```

Appendix 2: Initial Tests without the Bridge Rectifier

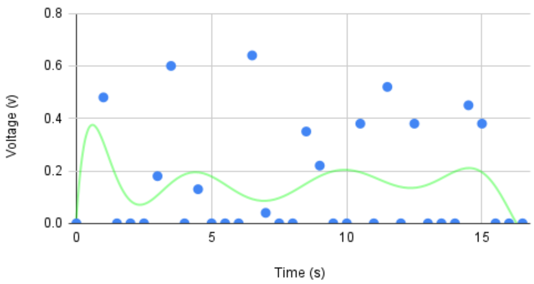
Trial 1



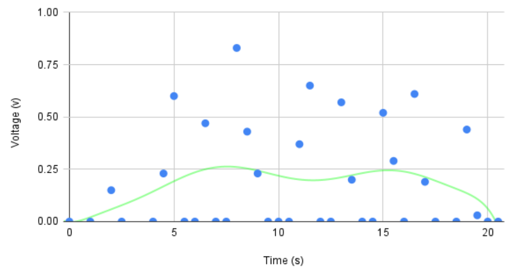
Trial 2



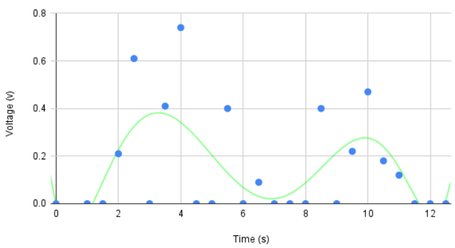
Trial 3



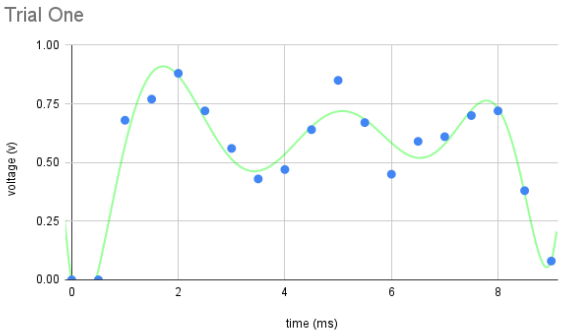
Trial 4

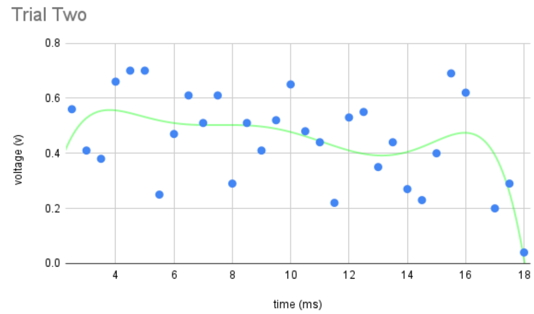


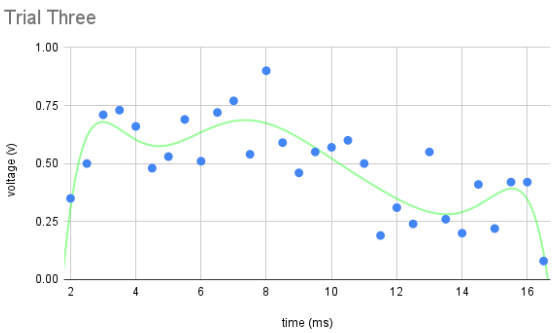
Trial 5

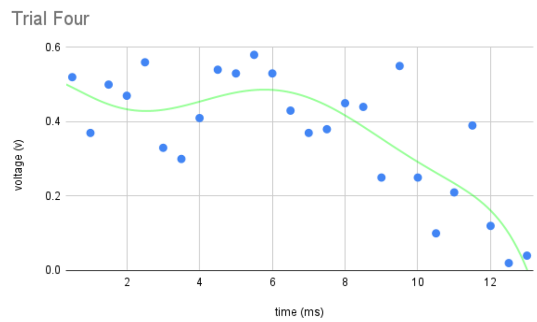


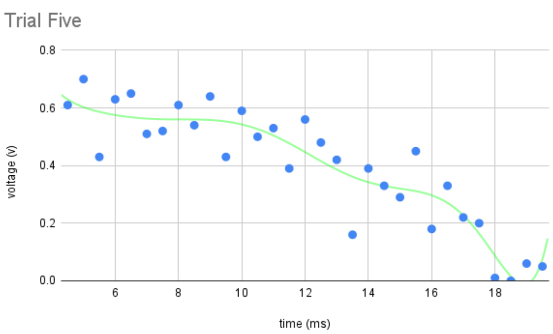
Appendix 3: Testing with the Bridge Rectifier











Appendix 4: Rubric

Milestone 1

Concerns	**Comments**	**pts**
Problem Statement	Many sailboats operate by diesel-powered motors which are noisy, impractical, and a waste of fuel. This source of power conserves minimal energy and puts an unneeded burden on the user who is required to run the motor to produce energy even when the boat is stationary.	
Identify the following: The Engineer, the Client, and the User.	The four of us are the engineers on this project. In the scope of this project, the client is our Professor. However, outside of the educational setting, the clients are boat companies and mechanics, and the users are also people who own boats.	
Design Goals	One of our major design goals is to minimize drag. We want our design to be efficient, and minimizing drag is a major part of that. We also want our turbine to optimize the amount of clean energy produced. The energy would power a battery for use by the passengers on board. We also want to minimize our environmental impact; fish and other aquatic greenery could be at risk of getting caught in the blades. Finally, we want to minimize auditory disturbances–many turbines can be noisy. We want ours to be the least annoying.	
Design Constraints	One of our biggest constraints is funding: when outsourcing components for our design, our project team must pay for them ourselves. Furthermore, there is an experience constraint. As first-year engineering students, we are learning as we progress through the design process and our prior experience and knowledge on hydropower turbines is limited. We have done a lot of research, but research cannot replace hands-on experience. Finally, another constraint is our resources- our prototype is designed for sailboats, which are difficult to obtain. Our most accessible boat is approximately 20 minutes away.	
Literature / References / Similar work	A company called Watt&Sea has a water turbine similar in design and function to ours.	
Diagrams / Drawings	*File upload*	
Team plan	In order to meet all of the design needs, time requirements, milestone presentations, prototypes, and more our group plans to meet at least once a week. As of right now, we have decided to meet every Thursday for at least an hour so that constant progress will be made. If need be we have also backed up a second time during the week so that more weeks need to be accomplished. ● Milestone 3: Nov 8 ● Milestone 4: Nov 22 Plus, we will need to meet to test our turbine. Ideally, we'd like to have most of the project done a little bit before the November 22 deadline for milestone 4.	
Project-related concerns / Issues	One of our biggest concerns is the time constraints for this project. In addition to our other schoolwork, we have about a month and a half to build, test, and present our turbine which means we will have to manage our time well. Another concern is the environmental cost of our turbine as stated earlier Another concern is the monetary cost since we are buying most of the products.	
Total		

Milestone 2

<table>
<tr><th>Concerns</th><th>Comments</th><th>pts</th></tr>
<tr><td>Generating Solution - Methods</td><td>We primarily talked and threw ideas out at each other. During DE 6, we talked about a lot of our ideas such as the blade type/shape, the motor, and how we were going to attach the turbine to the motor.</td><td></td></tr>
<tr><td>Alternative Designs</td><td>Different Blade Types:
- To produce the most amount of energy, we need to maximize the efficiency of the propeller we use to produce energy. Therefore, we need to maximize blade and propeller efficiency.
- different model blades for faster/more efficient results? Speed boat models?
- Change propeller diameter to maximize RPM and produce the most energy.
- We also need to design the propeller to reduce drag by minimizing surface area and maximizing hydrodynamics.
Mounting Location and Variability:
- On the hull itself (Suction cups to the bottom)
    - Subject to falling off but can move location (harder to remove when underway)
- On the motor/Rudders
    - May be difficult to the various types of motors
    - Would have it all centrally in one location
- Similar to a separate motor
    - Almost like a small motor that goes over the back but would just generate electricity instead
- Clip on
    - Especially for motorboats with a swim platform (close to the water and easy to mount and remove)
Waterproofing:
- We are going to try to locate most of the electronic components above water level; while this will not guarantee waterproofing, it will lessen the impacts of constant water damage
    - maybe a casing for the electronic parts?
- for the parts of the turbine that will be underwater, we will waterproof them (polyurethane? not terribly environmentally bad.)
    - Candle wax? easier to obtain, perhaps cheaper than other resins
    - Flex Seal or other water-proof coatings
    - Epoxy (also not too environmentally impactful; no styrene)
Energy Storage:
- The energy generated by the hydro-powered turbine will be connected to a battery on the boat that could be used to power all or any electrical needs.
    - Power the boat’s battery and help with the sustainability/usage of its functions
    - (Most likely) House a separate battery for the user to use later
        - Charge their phone or electronics</td><td></td></tr>
<tr><td>Decision making Approach</td><td>In order to prioritize each of the design decisions, we had a preliminary design discussion. In this discussion, we rated the different designs against each other and how they compared. In addition, we rated them to our design goals and saw how they met and fit in with our design constraints. Seeing how feasibility and</td><td></td></tr>
</table>

	time are crucial aspects of this project, most of the decision-making regarding the alternative designs was clear and easy to make. However, we also thought about using a rank order chart but due to the ease of decision-making, we didn't have to use it.	
Final Designs	Our final design is not completely finalized, but our prototype is about what we are looking to create. It is not the exact same as the turbine project, but it's similar. We will adjust our design based on testing results. Design choices: - Mounting: Motor mount - Electronics: Housed above water as much as possible - Energy Storage: Battery	
Drawing 2D/3D	(See Solidworks design)	
Science/concepts/theories	The main scientific theories and concepts of our project revolve heavily around the field of fluid dynamics but more specifically hydrodynamics. In essence, our design is mimicking a wind turbine but the medium is different. As water is denser, our design has to be resilient and the fluid dynamics are different as a result. However, the overall objective is very similar to the fan project and was very beneficial. - Drag/Hydrodynamics - Lift - Blade pitch - faraday's law of induction (emf) - Moment of inertia - Rotational motion/angular motion - Torque - Newton's laws - Dynamics - Thrust	
Paper prototype		
Team-related concerns / Issues	Largest team-related concerns: - Time concerns–Given the other graphics and programming labs along with the other design activities, we do not have as much time as we would like. With the demo being due November 22, 2022, we must budget our time appropriately to meet this deadline	
Total		

Milestone 3

Concerns	Comments	pts
Final Design Solidworks	Our Solidworks design reflects our final design (excluding the clamps and internal electrical components, as well as smaller mechanical aspects.)	
Final Drawing Solidworks drawing	*File upload*	
Drawing 3D – Graphic test2	- Noah: blades + assembly - Julia: shaft - Dylan: housing - Gabriella: box	
Needed elements list	- Acrylic - PVC/Scooter handle - Clamp (screw clamp?) - 3D printed Blade - Marine Grade epoxy	
Elements collected	- Motor - Portable phone battery - Arduino - Kayak (testing purposes)	
Any design/elements related issues	At the moment there are no real design/element related issues, however, a major concern was the pitch and angle of the blades. A good deal of research was done to determine the best angle. Nonetheless, we are in the final stages of design so we haven't had much time with the physical elements. However, based on the similarity to the fan project, we are hopeful and we don't expect too many problems.	
Member contribution (by each member)	We each have our individual Solidworks assignments and have worked collaboratively to solve the problem together. Most of our testing has been done together and the only real individual aspects were the Solidworks assignments, although we did work on this together.	
Ethics-related concerns / Issues	We are still quite concerned with the timing of this project. We are on track to be done with the physical project and testing before Thanksgiving, but timing is still our primary concern. We plan to create the presentation and report after the break. We are also concerned with waterproofing. Although the generator purchased is waterproof and we plan to use acrylic, waterproofing is always a concern in terms of a leak, especially since an expensive SparkFun kit is being used near water. We are also concerned about the fish and other marine wildlife when we go to test our model, as we plan to test on the Charles. This is our primary ethics issue.	
Total		

Milestone 4

Concerns	Comments	pts
Elements Display	*In class display*	
Initial Assembly	*In class display*	
Incomplete or complete demo	*In class demo*	
Data Collection Method	We gathered initial data using a large tub of water and an underwater scooter. (see videos on presentation).	
Initial Data	Our data was collected through five tests that we put into graphs. The data appeared to be sinusoidal with many intervals with 0 which initially confused us.	
Theories and data analysis info	We were initially troubled by the voltage readings fluctuating between 0.7 and 0; there was no in-between. We thought there were issues with the circuit or the motor but after further analysis of the results indicated that the motor was producing AC. This explained the fluctuations as the Arduino can't read a negative value. This is reflected in the graphs as the values fluctuate in a sinusoidal fashion.	
Final Report writing plan	We plan to meet and work on our final presentation and final report together over the next week. We will have our presentation hopefully done before the expo and we will work to improve our testing strategy.	
Member contribution (by each member)	We all met and worked on this project together several times throughout the week. We all contributed to the product, the final report, any modeling such as Solidworks, and all presentations. We chose not to divide most of the work so we could all be on the same page.	
Abstract (Turned in ASAP)	*File upload*	
Total		