2024 Final Report for the Marine Energy Colligate Competition

Versatile Marine Energy Point Absorber

Duck Duck Goose

University of North Carolina at Charlotte

Lead: Jacob Silknitter

Engineering: Ada Kersh, Patrick Hultberg, Krina Patel, Anthony Grancagnolo, Kyle Overberg

Business and Community: Tejas Raj, Kashi Tumbapura, Gray Owen, Heidi Zuk

Other Contributing Members: Kevin Manoj, Fairlight Strong

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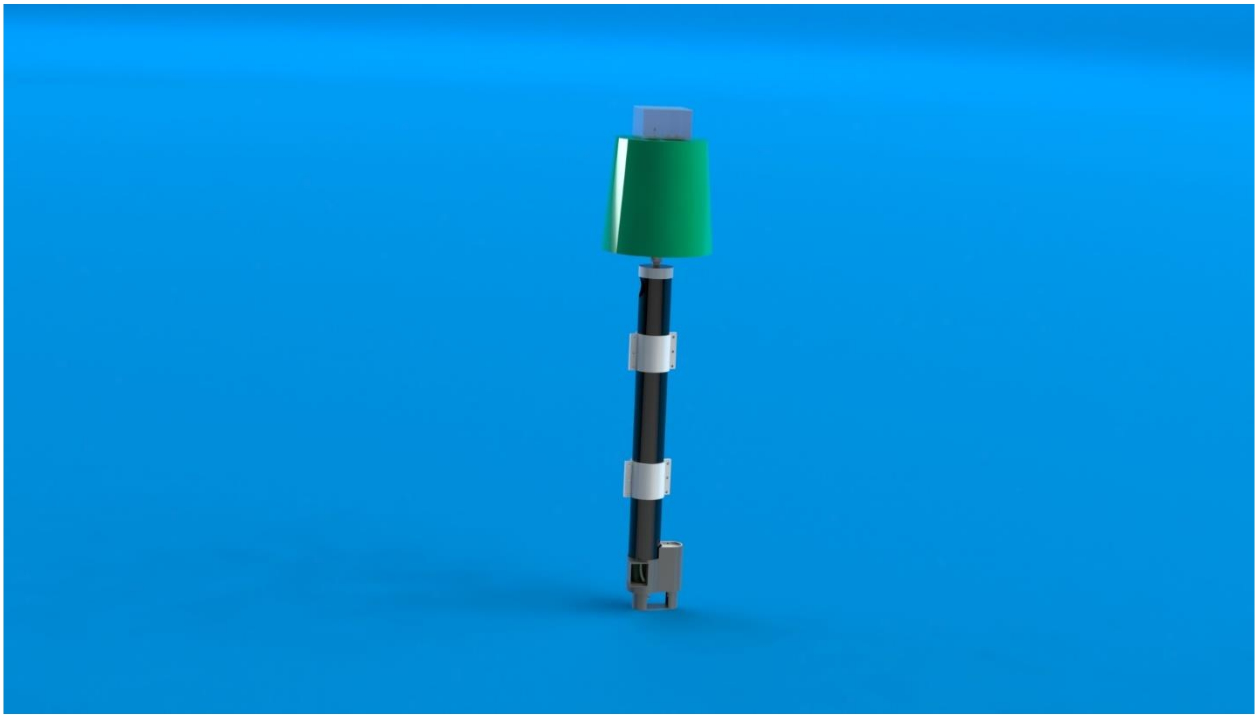
Executive Summary

Duck Duck Goose, the team from the University of North Carolina at Charlotte, has gone through the design process to develop wave energy point absorber called the Versatile Marine Energy Point Absorber or V-MEPA. The wave energy converter they developed will fulfill its purpose in remote and isolated communities. These communities have been identified as being reliant on fossil fuels and deiseal to supply their power needs. In order to aid these communities Duck Duck Goose developed their project to be able to be used with a versatile foundation that can be affixed to a variety of anchors. V-MEPA will exploit a four point of contact foundation that will be used to anchor itself to existing structures, like docks, piers, cliff edges and offshore wind devices.

V-MEPA is designed to use the flow of water to spin a turbine. It does this by creating a seal withing the anchored tube that does not allow water to flow through, and as the wave brings the floating assembly up it draws water out of the body of water and into the point absorber's system. The path of the water forces it through the turbine, which in turn produces a DC voltage on the heave, floating assembly floating up. On the ho, the floating assembly coming down on the wave, the water is forced through a similar path and through the same turbine, however due to the design of the turbine it is spun in the same direction, producing DC voltage in the same direction. The current travels to the top of the wave energy converter to where the electronics are stored. It is for the protype it is then recorded and for the design it would be rectified then used for whatever need necessary.

Using this design Duck Duck Goose hopes to power backup batteries, be implemented into the grid or charge small devices needed in an emergency situation.



Business Plan

Concept Overview

Duck Duck Goose aims to fill in the remote and isolated community market. To do so the team has developed a plan that encompasses a versatile product able to take place in multiple sectors of the market. There are two main markets the team plans to be a part of the consumer market and the industrial market.

In the industrial market Duck Duck Goose will implement a large, scaled version of the product that will be able to collocate with offshore wind farms and add sufficient power to the grid. Due to the design mentioned later the V-MEPA can be easily modified to fit any reasonable wave height, and depending on the project budget can increase the yield for the wave height by increasing diameter. Implementation would happen in places that have an existing offshore wind farm or the plan to make one, like Kitty Hawk North Carolina. To continue with the Kitty Hawk example, located on the coast of North Carolina, this place does receive power from the grid, most of the time. However, when a storm comes Kitty Hawk loses that power and relies on itself to power the town. The team's product can come in as a solution to this as it could power Kitty Hawk’s own microgrid alongside the planned offshore wind farm. While it would be dangerous to operate during the storm itself, the V-MEPA would be generating power before and after the storm that can be used to help with rescue and restoration efforts. In the industry scenario we would sell the product to the offshore wind company and from there they would be the ones to introduce the power in the grid. Because of the selling of the product the team would gain profit from the materials and construction but would not see the profit from the power generation itself. Later, with more development, the team would hope to develop a rectifier and a modular way to integral into multiple grid types, but as of now, no work has been done on that end of the design.

In the consumer market an opportunity was found during the design process. The team saw an opportunity for a household version of the V-MEPA that could mount to a person dock. The goal for this version of the product would be to generate electricity to overtime to be stored in an 8-16 kilowatt battery that would be available for use at any time the owner desires. This process would be similar to how solar panels are sold to consumers to affix on the roof of personal homes. The market for this is untapped and massive. Any house, lake, ocean, bay, etc. with a dock could affix a V-MEPA and harvest energy from the waves and wakes caused by boats. For this business to be effective further work would have to be done on the power side of the design. The power generated from the generator would have to be smoothed and rectified to be able to charge a battery sufficiently. Better yet these machines would produce a high output year-round. Wave activity is often higher in the winter, depicted below.

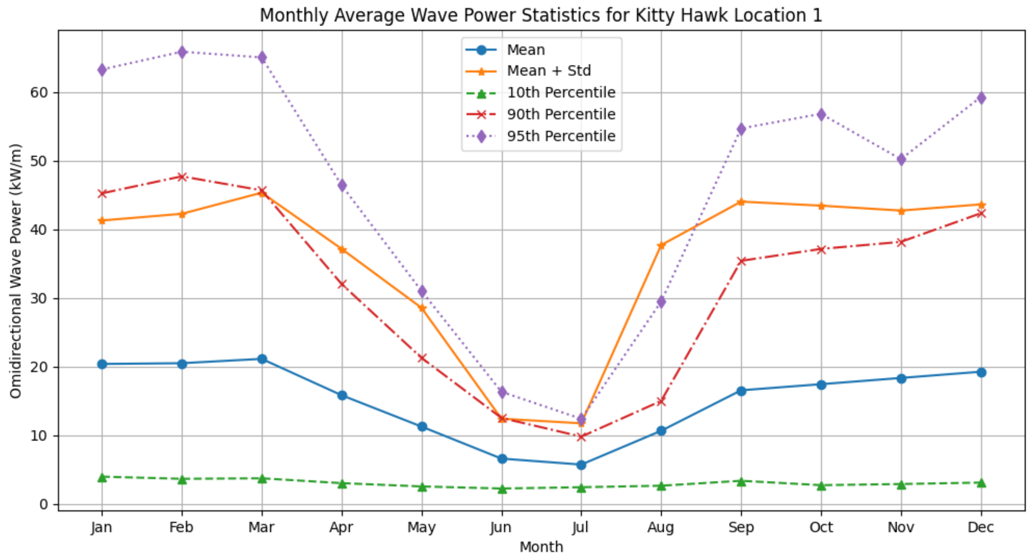


Figure 1: Plot of Monthly Variation of Omnidirectional Wave Power at a location near Kitty Hawk, NC in accordance with IEC standard 62600-101 with Data from MHK Atlas [8], [12].

From the figure through the months of April through September natural wave activity takes a dip. In an industry setting like collocation this behavior complements the trends of solar and wind, in which the activity rises during that time of year. In a consumer setting the natural wave activity is complemented by wake activity. In the summer months there is a high rise in tourism and the activities associated with it, most of which include boating. When boats travel through bays and along coastlines, they send wakes that often cause damage to docks and have to be accounted for in development. The product the team design would be able to harvest the energy from these waves while breaking the waves and protecting the infrastructure. In simple terms, Duck Duck Goose is making the most of beach season.

The purpose of V-MEPA can be fulfilled in multiple places across the country. To name a few, the team has found potential in: North Carolina, islands of Maine and the Allusion islands. There are multiple islands of Maine that are “summer only” islands. They are considered summer only due to the frosty nature of the state. In the winter months the power to these islands is shut off because the power transmission system would freeze otherwise. In this time these houses stand empty. V-MEPA would allow power generation to occur onsite, negating the need for power transmission and making the area livable for the winter, which accounts for most of the year. In the Allusion islands, many communities do not have access to the main power grid and rely on non-renewable energy sources. V-MEPA would aid these communities in not being dependent on fossil fuels and allow them to power themselves. The Allusion Islands are also an area of high potential for deep water wave energy generation, so the industrial product would work best here.

Relevant Stakeholders

Stakeholders in this market would be the offshore wind industry partners, local consumers and the community around the coast. In industry the team needs to prove that the V-MEPA is cost effective and can be profitable. The local consumer needs to see the benefit of owning a wave energy converter and that benefit must outweigh the cost of ownership.

When reaching out for interviews the team was able to interview multiple elected officials within North Carolina's commerce sector. This meeting was attended by Marqueta Welton, Emily Roach, Gena Renforw, and Jenifer Mundt from the Department of Commerce. They all discussed the changes and differences in the department that occurred under both President Trump's and President Biden's respective administrations. Another topic discussed was the collaboration between North Carolina and the surrounding states, specifically the relations between them and the familiarity with some compared to others due to past experiences. However, with Governor Cooper's term coming to an end, and a possibility of no reelection, they discussed what the next steps are currently to take for most of the current term.

During the meeting, they collectively emphasized the economic benefits that come with clean energy, as well as the increase in the potential creation of jobs as well as economic growth. She discussed the interest of companies to achieve net zero carbon emissions and how those companies must scout out a state before extending their branch there. North Carolina has done a good job of advertising itself to those companies which can lead to more jobs in the state. Another topic discussed was the importance of caution when collaborating with external countries with strained relations with the United States.

They all acknowledged the importance of public relations and how important it is to educate people about the decisions made to reduce fear. People fear the unknown, so education as to why certain decisions are made is vital to keeping the public informed on what is going on in their state. We all discussed how relationships as well as networking are key to allowing students and newcomers to grow in any field.

After which an informal interview was conducted with a fisherman local to Kitty Hawk North Carolina. He stated that he was hopeful for wave energy converters and would consider owning one. The local said that he preferred energy harvest methods that did not mess with the wildlife, which ours does not.

Market Opportunity

The market opportunity for Wave Energy Converters (WECs) has continuously grown through the past decade. Given the increasing global focus on renewable energy sources to combat climate change and reduce reliance on fossil fuels, it is natural that the focus turns to our oceans which hold untapped powers. The global wave and tidal energy market size was valued at $475.3 million in 2017 and is expected to reach $1.2361 Billion by 2025, growing at a CAGR of 11.7% from 2018 to 2025 [17]. This growth is natural as international agencies, governments, and private contractors pour millions of dollars into this USD 1.21 trillion market as of 2023 and it is expected to grow another 180 billion dollars (about $550 per person in the US) over 2024 [6].

Wave energy is a largely untapped resource with the potential to provide a significant portion of the global energy supply. According to the World Energy Council (2013), wave energy could supply more than twice the current global electricity consumption [20]. The European Marine

Energy Centre has indicated that the wave energy available along the European coasts could meet 10% of the EU's power demand by 2050, highlighting the critical role of WECs in future energy strategies [3]. The integration of WECs into the energy mix could also provide a more stable and predictable source of energy compared to other renewables, such as wind or solar power.

Technological innovation is a key driver of market opportunity for WECs. The advancement in materials, design, and deployment methods enhances the efficiency and durability of WECs, making them more competitive. A study by Cruz and Atcheson (2016) in the 'International Journal of Marine Energy' showcased that new materials like thermoplastic composites could significantly reduce maintenance costs and increase the lifespan of WEC devices [19]. Furthermore, there has been a noticeable shift towards the development of offshore and multi-use platforms, which allow for the simultaneous harnessing of wind, wave, and solar energy, thus optimizing the use of marine space and resources [14].

However, the market opportunity for WECs is not without its challenges. High capital costs, maintenance issues in the harsh marine environment, and the need for grid integration infrastructure are significant hurdles. A report by the International Renewable Energy Agency (IRENA) in 2014 suggested that government support, in the form of subsidies and incentives, is crucial in the initial stages of WEC development to make them economically viable [11]. As technology matures and scales up, costs are expected to decrease, following the trend seen with wind and solar energy developments.

The market opportunity for Wave Energy Converters is promising, supported by an increasing demand for renewable energy, technological advancements, and supportive government policies. However, realizing this potential requires continued research and development to overcome existing barriers to entry. With a concerted effort from stakeholders, WECs can play a significant role in the transition to a more sustainable and diversified energy portfolio globally.

Development and Operations

The development and operationalization of Wave Energy Converters (WECs) stand at the forefront of innovation within the renewable energy sector. The conceptualization and design phases are critical, with developers seeking to optimize the balance between energy capture efficiency and resilience to harsh ocean conditions. In the journal 'Renewable and Sustainable Energy Reviews', Falcao (2010) highlighted the diverse range of WEC technologies, including point absorbers, attenuators, and oscillating water columns, each with unique developmental challenges and operational profiles [5]. The European Union's Horizon 2020 program has been instrumental in funding research and development projects, which has led to significant advancements in WEC technology and deployment strategies [4].

Operational excellence in WECs is predicated upon the longevity and reliability of the devices in situ. A study conducted by the Scottish Government (2017) found that robust engineering and deployment strategies significantly enhance the operational life span of WECs, reducing the need for frequent maintenance and mitigating the risk of failure [19]. Additionally, real-time monitoring systems, as discussed in the 'International Journal of Marine Energy' by Nielsen et al. (2015), play a vital role in operational management, providing data to optimize performance and predict maintenance needs, thus ensuring continuous energy production and cost-efficiency [15].

The integration of WECs into the existing energy grid presents operational challenges, particularly in terms of intermittent and variability of wave energy. A study by Cornett (2008) in the 'Journal of Ocean Technology' examined various approaches to smoothing the energy supply, including hybrid systems and energy storage solutions, to ensure a consistent and reliable electricity output [2]. Further research by Babarit and Hals (2012) in the 'International Journal of Marine Energy' explored the potential of coordinated operation of WEC farms to maximize energy capture and minimize the effects of shadowing, where the presence of one device reduces the energy available to another [8].

Environmental considerations also play a pivotal role in the development and operations of WECs. Impact assessments, as per the guidelines established by the International Maritime Organization, are fundamental to ensure that the marine ecosystem is preserved [10]. The 'Journal of Environmental Management' published a study by Henriques et al. (2019), which found that careful site selection, based on ecological sensitivity and habitat mapping, can mitigate environmental risks and enhance the sustainability of WEC projects [12].

The pathway to effective development and operations of WECs is complex and multifaceted. It requires a synergetic approach that encompasses technological innovation, environmental stewardship, and operational optimization. As the body of research grows and field data becomes more abundant, the operational frameworks for WECs continue to evolve, promising a more resilient and sustainable contribution to the global energy matrix. The ongoing collaborations between academic institutions, industry stakeholders, and governmental bodies are pivotal in addressing the challenges and harnessing the full potential of wave energy.

Financial and Benefits Analysis

In terms of financing WECs they can be broken down into four main subsections (Thomas, Stanford University 2012) connection to grid, maintenance, production, and installation. Exact expense estimates are difficult to calculate, this due to each WECs environment drastically varying in weather and physical conditions [18]. With this fact known WECs do not require frequent maintenance, though equipment quality is a factor in this. Cost repairs for WECs are known to be expensive when compared to other power sources. As time progresses WEC components, for example the triboelectric nanogenerator [1], have allowed for the decrease in price of both production and upkeep of WECs. As previously stated, the overarching cost of the four main categories is challenging. Climate differences, WEC component composition and WEC upkeep all contribute to the overall end cost. Though, the figures that have been provided include analytics on the cost of power production per unit. For example, “the United States Department of Interior [**153**], which predicted that the cost of power production from a hypothetical wave farm of 90-MW capacity will reduce from about $2600/kW in 2008–2011 to

$1325/kW in 2024–2027.” While monetary predictions are difficult to construct, the few numbers available help the business team better understand cost formalities.

When looking at WEC’s there are pros and cons in effect with the devices. WEC’s are an energy efficient device that has many benefits associated with it. On example being that the device has minimal contact with water which decreases chances of damages that come with waves [1]. This also allows the electric wiring and machinery to have as little contact with the waves themselves. WEC’s also are in need of minimal maintenance, meaning that there is no need for constant checkups, which saves time and money. One of the disadvantages to this concept is the damage that could be sustained in the event of inclement weather. However, with the use of proper equipment and cleaning, this is not something that should be a continuous problem. Finding the proper location to deploy the WEC’s is a tough task that requires a lot of planning around ocean currents and life in the surrounding area [21]. Location decisions must be strategic with the location because if the desire is to receive the most energy as efficiently as possible. Finding the locations which have the most gigawatts available is a must. This can be done by researching how the ice coverage in a particular area can affect the net gross gigawatts available [7]. The process to anchor the WEC itself can also be a costly process [21]. However, if done so properly, that process only needs to be done once, which eliminates a lot of maintenance costs if the WEC’s are long lasting.

Technical Design

Objective

The objective is to design and build a turbine-based point wave energy absorber that is efficient and versatile to meet the needs of remote and isolated communities. The V-MEPA will need to be cost effective in order to be affordable for a variety of communities that would otherwise rely on natural gas. The design should also be optimized for colocation with offshore wind sites to take advantage of existing electrical grid infrastructure. This will improve the power density of offshore sites and reduce the cost of additional energy production infrastructure. This will require synchronization of the power generated by the Wave Energy Converters, so it is compatible with the long-range transmission lines used by offshore wind farms.

Design Overview

The wave energy converter consists of a floating assembly, and an anchored assembly. The floating assembly consists of the suspension, the buoy, and the piston. The anchored assembly consists of the turbine, turbine fixture, cylinder, generator, electronics and the anchor. The buoy oscillates with the vertical motion of the waves which transfers that vertical motion to the piston via a suspension. The piston moves water up and down through the cylinder. Which forces the water through the flow diverter into the turbine which rotates and powers the generator. The anchor works to keep the anchored assembly in place as the floating assembly oscillates with the waves. The turbine fixture works to connect all parts of the anchored assembly, allow for water to flow over the turbine, and protect electronic components from seawater. After power is generated, the current is then sent to an LED diode to indicate that power is being generated and the power is sent to an Arduino uno to measure the voltage. With more development the power generated would be sent to a rectifier, which would smooth the signal and make it available for use. After which the power would be sent to the device that is desired to be charged. Duck Duck Goose main goal is to either help power a grid alongside offshore wind or charge a backup battery that could be used in emergency situations.

Floating Subsystem Assembly

The floating subsystem assembly is made up of 4 distinct parts; the floatation device, the piston, the suspension and the interface between the suspension and the bucket. The floatation device makes use of a five-gallon bucket which is filled with $2\ \frac{lb}{ft^3}$ density boat foam, calculations below. The floatation device in then screwed on to a 3D printed part that connects the bucket to the suspension. The suspension uses one bolt to connect itself to the interface, which accounts for two points of contact. The connection with the bolt is a pin connection, but the wall-to-wall interaction prevents rotation and locks it in place.

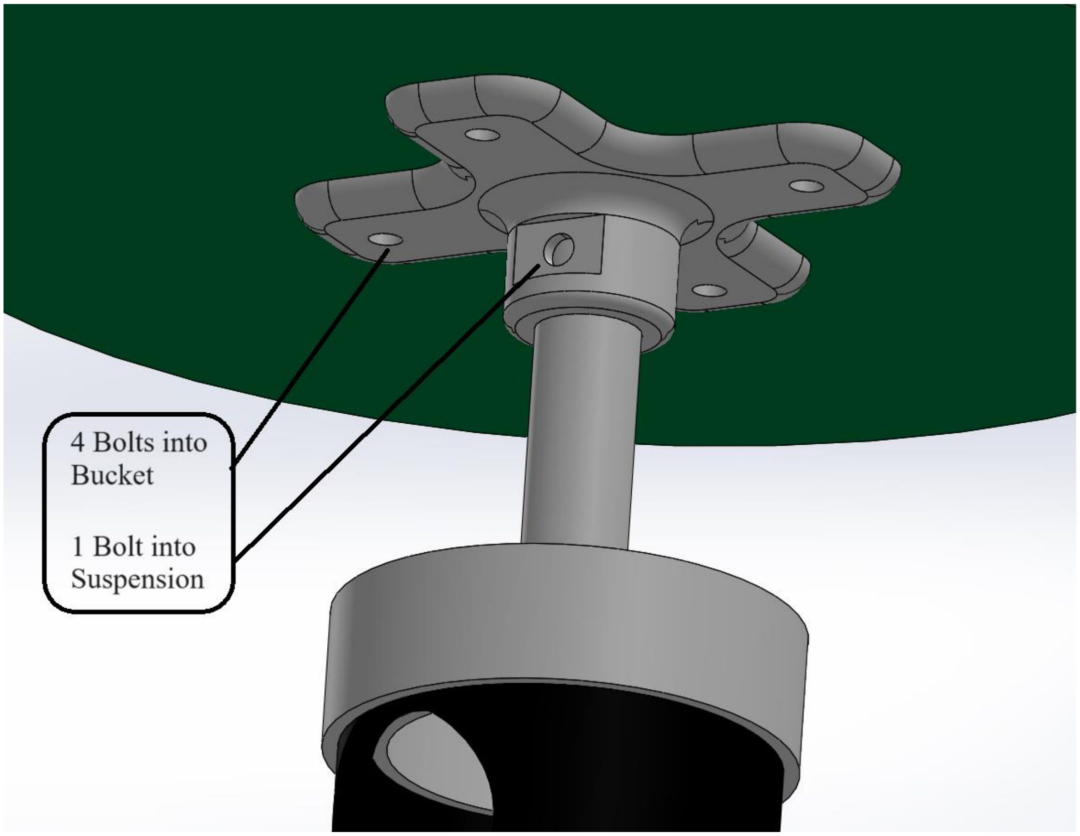


Figure 2: Bolt Locations for Floating Subsystem Assembly

The suspension itself is a ½ sch 40 PVC pipe; a readily available and useful material. The suspension then connects the piston head in a similar fashion. Inspired by a motored vehicle's piston head assembly the designed piston head has some similar features. Made in SolidWorks and 3D printed the piston head includes a cylinder like shape with two groves in the main body along the diameter and a slight shelf inside the main pushing surface to directionally guide the motion.

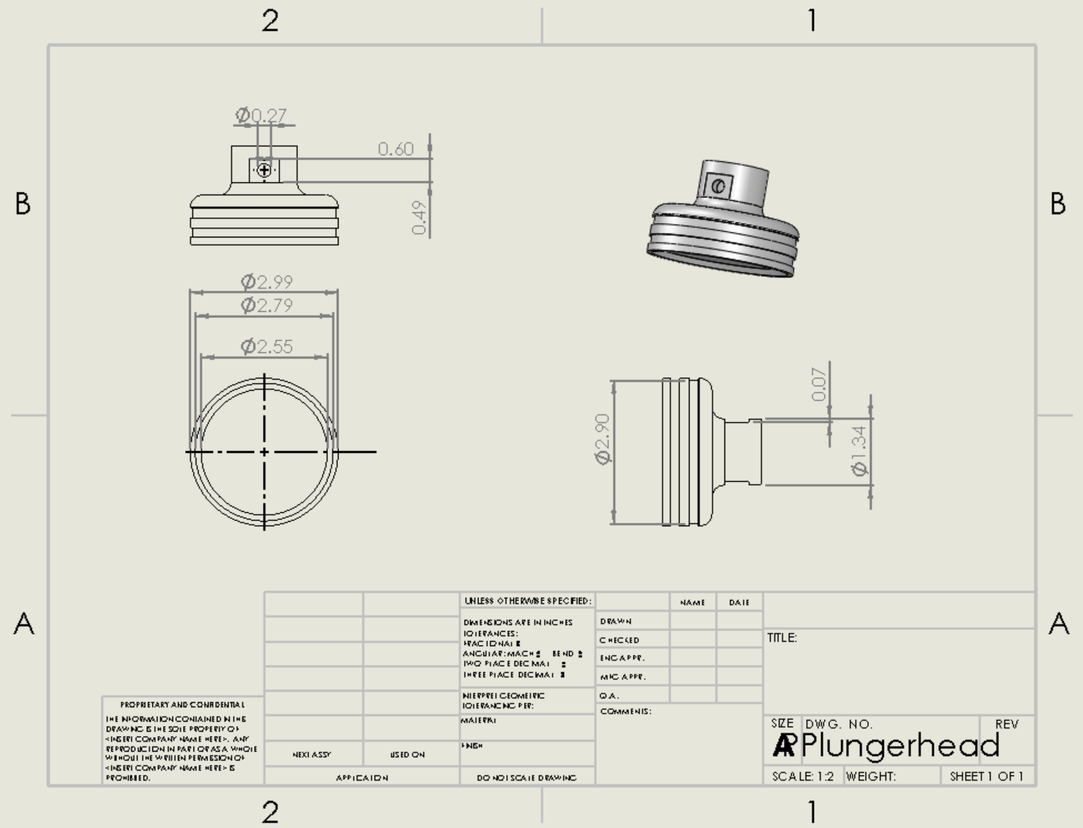


Figure 3: Piston Head Drawing

The clearance on the max diameter leaves one hundredth of an inch. This clearance allows for less friction while sliding but still creates a seal with water. To better the seal the piston cylinder assembly polytetrafluoroethylene or PTFE tape is used in the grooves of the piston head. The length of the structure prevents any rolling inside of the anchored tube, as if it starts to roll the wall pushes back onto it keeping it in a linear direction.

The connection between the floating assembly and the anchored assembly is the lid. It is a 3D printed part that fits over and seals the top of the main cylinder, except for a hole just big enough to allow the suspension to slide back and forth.

<u>Anchored Subsystem Assembly</u>

The anchored subsystem assembly comprises the main cylinder, foundation, and motor mount assembly. Made with a 3-inch ABS tube, the main cylinder's dimensions are what determines most of the other parts. The diameter dictates how much water is allowed to flow at a time and the length of the tube determines the max wave height the V-MEPA can harvest energy from. Knowing this, the team ensured the design could change the diameter and length of the main cylinder, and the V-MEPA would still work as designed. This goal was accomplished by keeping most parts circular, only needing to change with the diameter. In the main cylinder there are two holes made to be an inlet and an outlet on the top and bottom of the cylinder. These holes would be covered by a filter to prevent organisms and debris from getting inside. The main cylinder is held in place by the foundation, which is a 3D printed part that works similarly to a clamp. The clamp is a friction hold which has two halves of a diameter slightly smaller than the outer diameter of the main tube, so when they are bolted together, they squeeze onto the main tube.

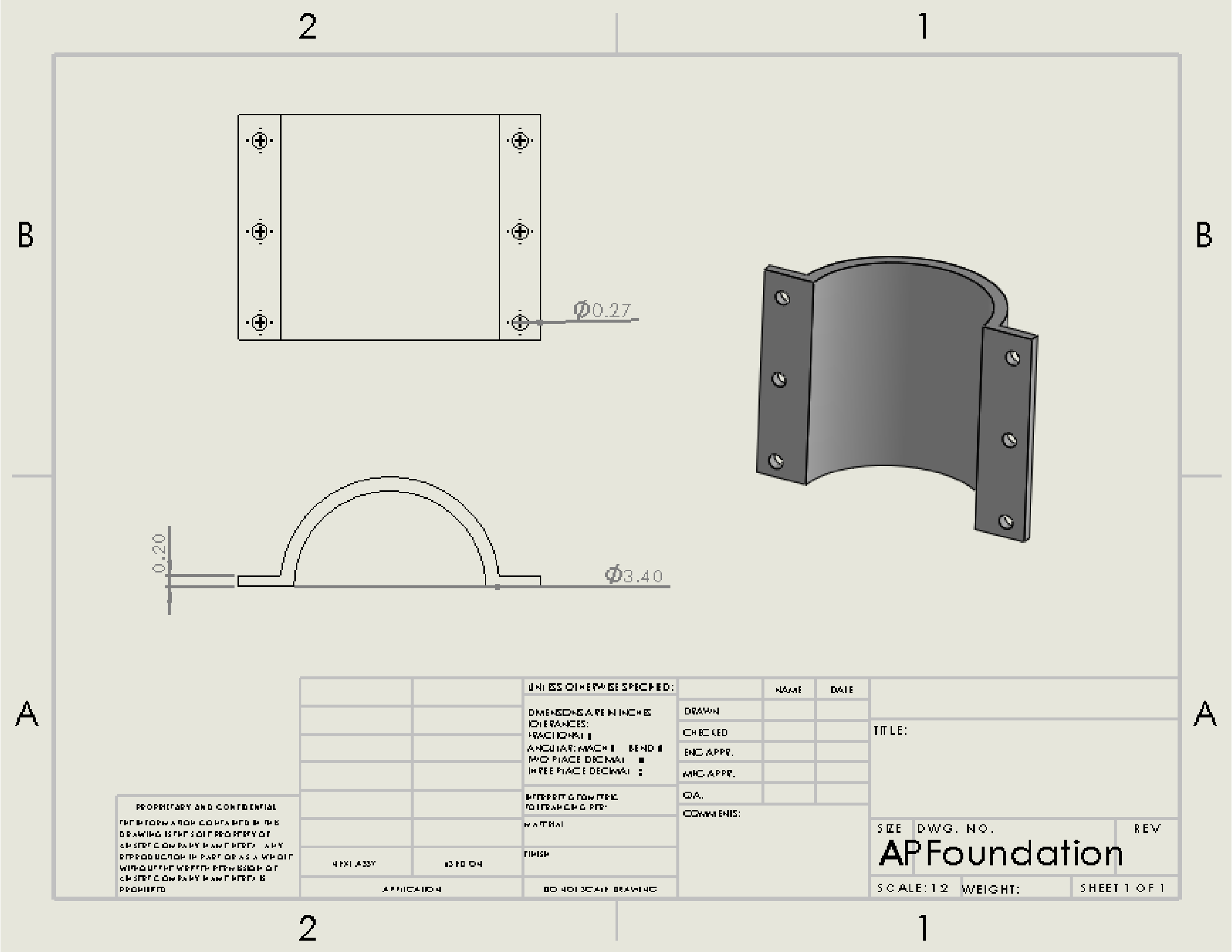


Figure 4: Foundation Drawing

This design allows for the foundation to be placed anywhere along the length of the main cylinder, as many times as necessary. Duck Duck Goose says to use a minimum of two pairs of foundations, 4 individual parts in total, but the more foundation pairs used the more stable the whole system will become. Mounting bars would be affixed in between the two foundation pieces those would then be connected to the existing anchor, whether it is a dock, pier or a heavy plate.

On the bottom of the main cylinder the motor mount assembly contains most of what is needed to generate power.

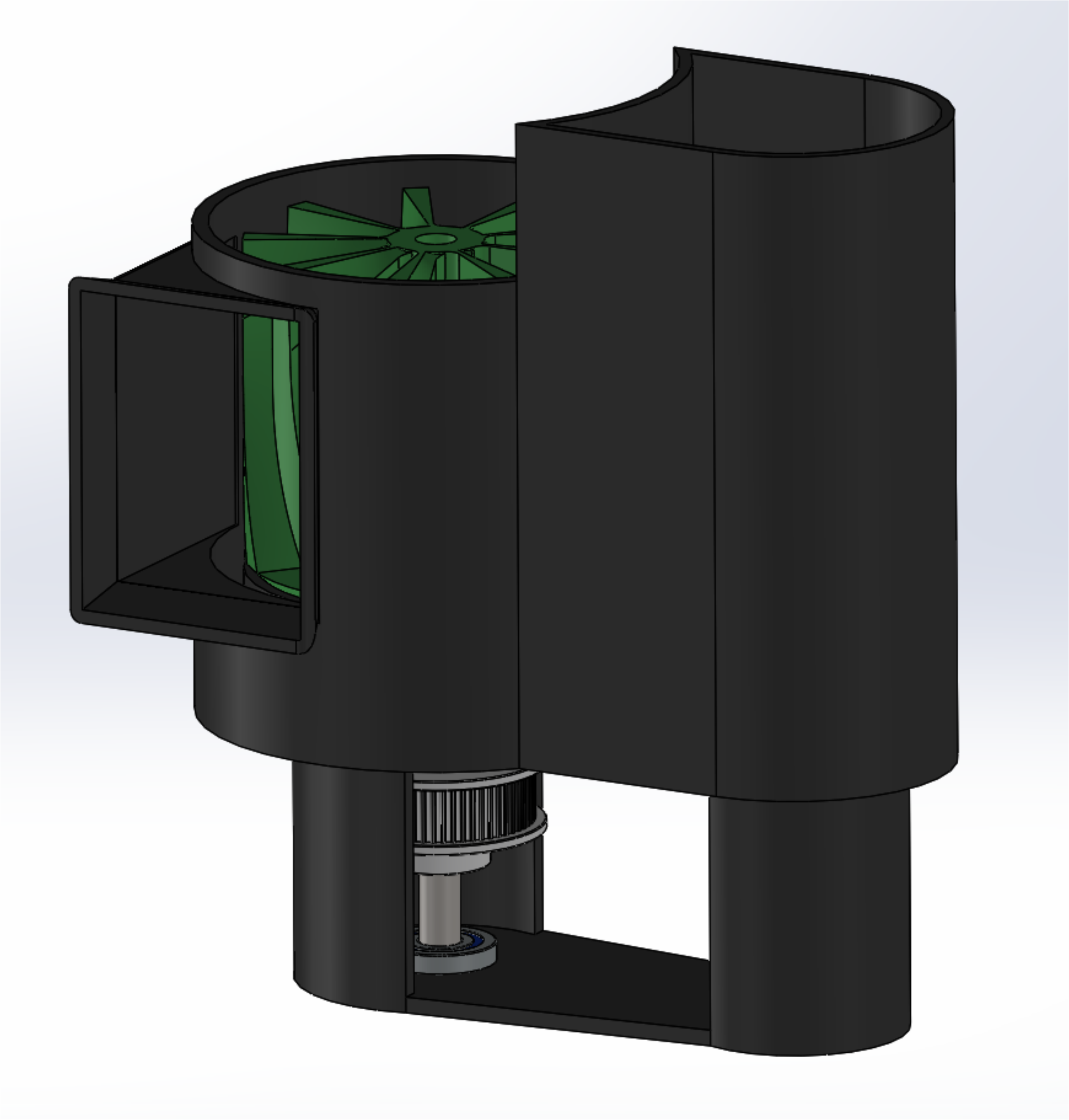


Figure 5: Motor Mount Assembly

Within the assembly there is the motor mount, the turbine, the motor, the sealant, the pully belt system (belt not depicted) and the flow controller (not depicted). The mount itself is a 3D printed part which mounts onto the tube, encapsules the motor, and gives two points of contact for each axil. This design keeps both the motor and the turbine straight to prevent any rubbing on the walls, preventing friction. The inlet of the mount also guides the direction of the water, so the velocity goes in the correct direction. After the water goes through the inlet it then is forced through the turbine laterally spinning it.

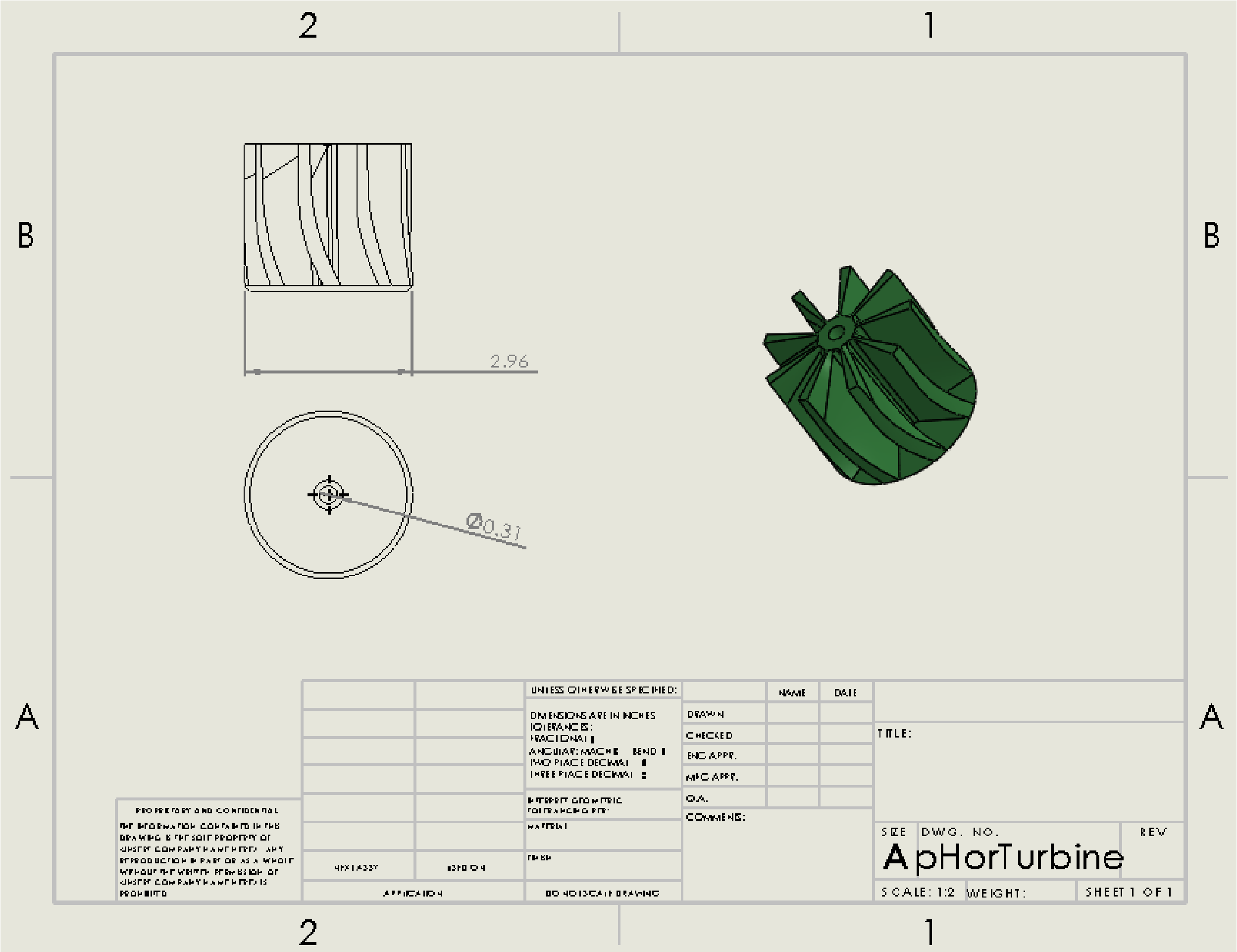
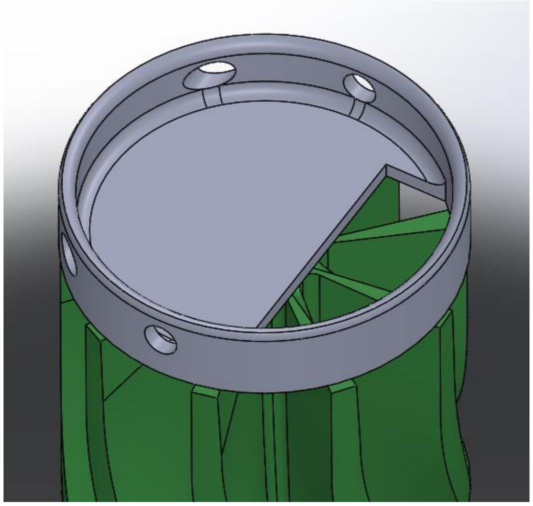


Figure 6: Turbine Drawing

Due to the design of the fins, no matter if the water comes in from the inlet or down from the main cylinder it will spin in the same direction. Just above the turbine is a small piece that only allows the water to flow up in a designated location, after spinning the turbine some distance.



Caption

The flow controller ensures that the water does not enter the turbine area then immediately flow upwards, not spinning the turbine.

As the turbine is spun it spins an 8mm axil that spins a 3to1 gear ratio from the turbine to the motor. This relationship allows for the high torque nature of the water to produce higher RPMs on the motor.

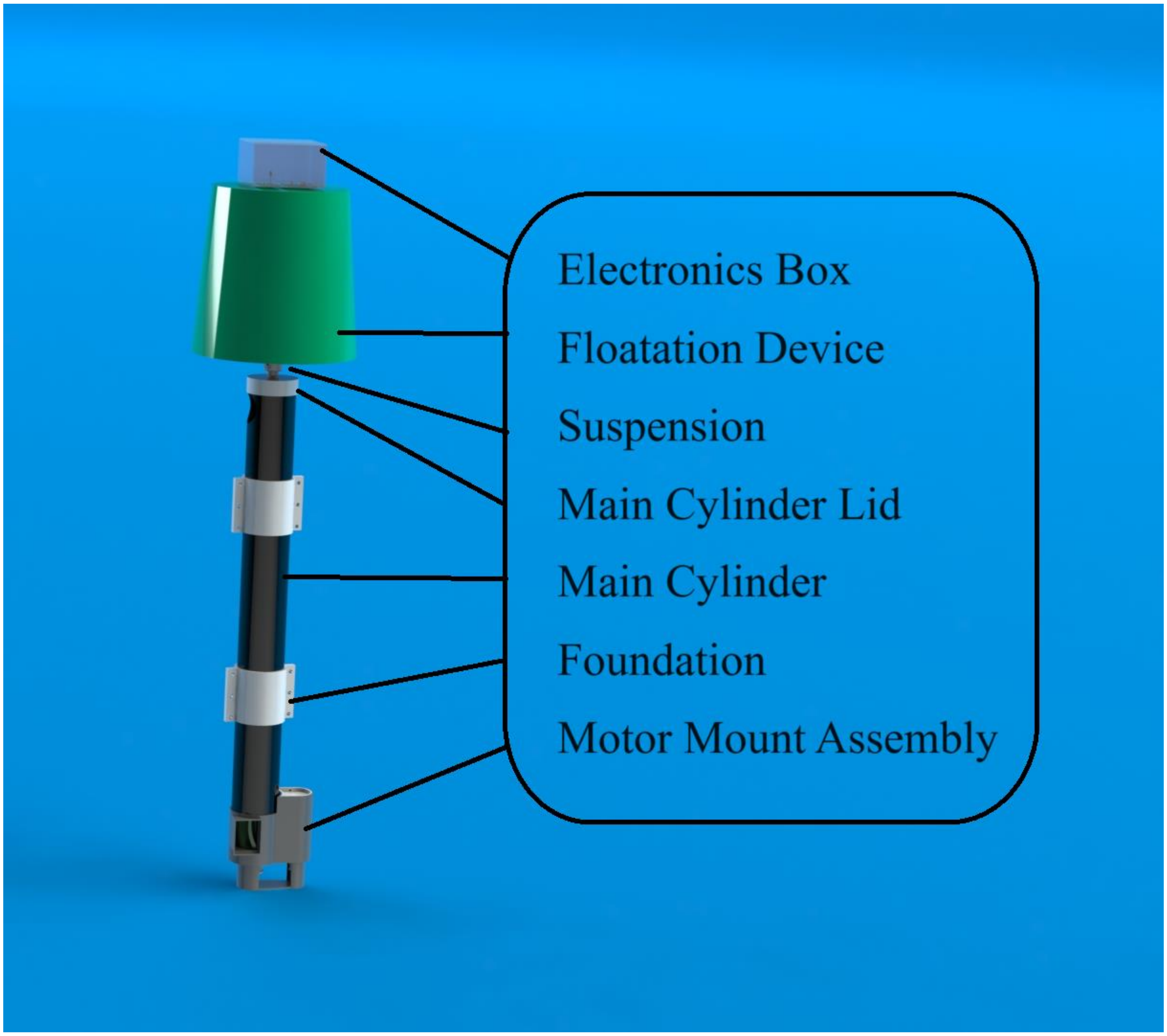
The power generated comes out as a DC voltage. This voltage is what would be used to power the desired device. For the prototype Duck Duck Goose used an Arduino uno to measure voltage and an LED to indicate that the V-MEPA was producing voltage at all. This electronics box sits on top of the floatation device in a waterproof container safe from any short circuits or water damage.

Overall, Duck Duck Goose designed a versatile and modular wave energy point absorber that can be used in a variety of applications. The design is compact and simple with modifications points in place to make changes for each environment easy and straight forward.

Maintenance

The overall design of the Wave Energy Converter is optimized to reduce the required frequency of maintenance thus reducing the cost. This is achieved using a simple yet robust design and choosing materials that resist corrosion.

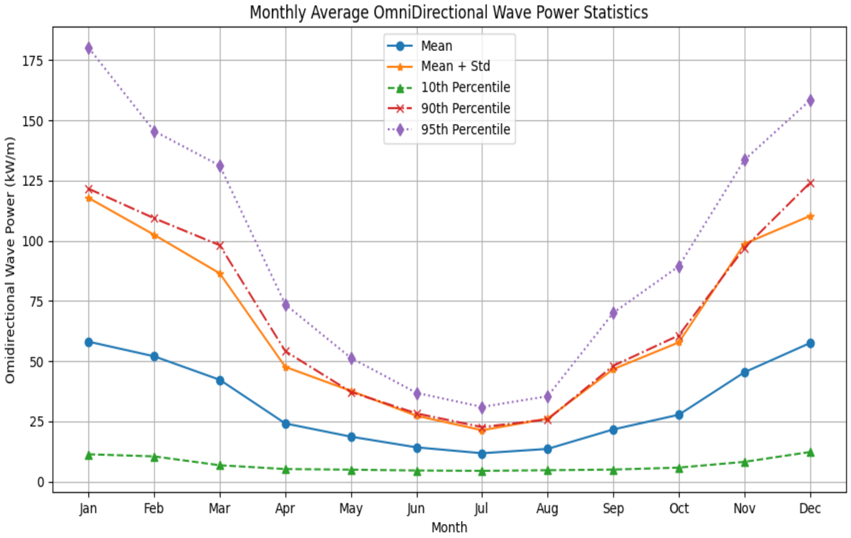
To prevent biofouling the surfaces would be sprayed with an anti-fouling spray. This would prevent the buildup of material and organisms building up on and in the V-MEPA.



Caption

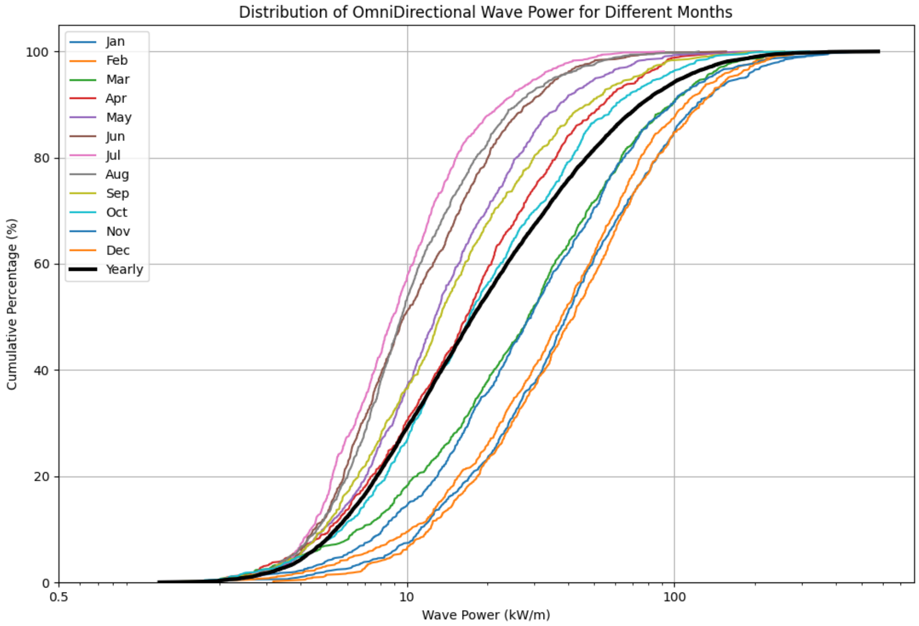
Performance Analysis

In order to evaluate the potential energy output of the V-MEPA the team had to evaluate the theoretical wave power resource in areas the V-MEPA could be deployed. The team found an IEC standard, IEC standard 62600-101, that we abided by to conduct a wave energy resource assessment for a location near Kitty Hawk, North Carolina, at 36.2578 N, 74.958 W and off the coast of the Aleutian Islands at 53.55374 N, 166.39017 W [8]. The Aleutian Islands location has a larger theoretical resource with 32.11 kW/m per year whereas the location near Kitty Hawk, North Carolina has a theoretical resource with 15.289 kW/m per year. In accordance with the standard the team created plots which display the monthly average omnidirectional power statistics; distribution of omnidirectional wave power for different months; and bivariate histograms for the deep-water wave power [8]. All data utilized to create these figures were collected using the MHK Atlas tool created by the National Renewable Energy Laboratory [12]. After obtaining the 32 years of data we used a MATLAB script to compile the data into csv files then used a Python script to generate the graphs with the first set of graphs being the set that was generated for the Aleutian Islands location.



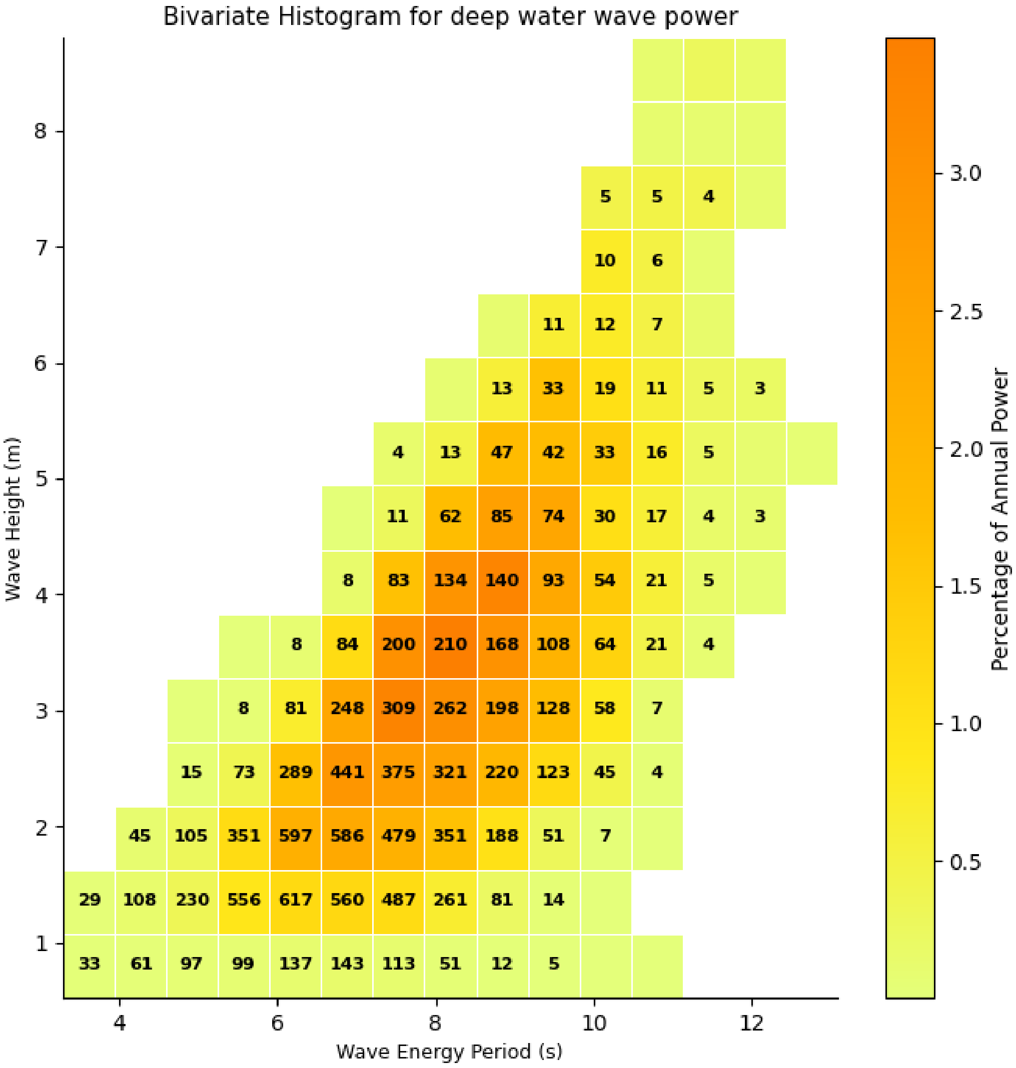
Plot of Monthly Variation of Omnidirectional Wave Power at the location off the coast of the Aleutian Islands accordance with IEC Standard 62600-101 with Data from MHK Atlas [8], [12].

The plot above displays the monthly variation of the theoretical wave energy resource across a year. The key information which can be derived from this graph is what times of the year the wave energy is at its highest, with that being the fall and winter months. The next figure further builds on these conclusions by providing the power distribution.



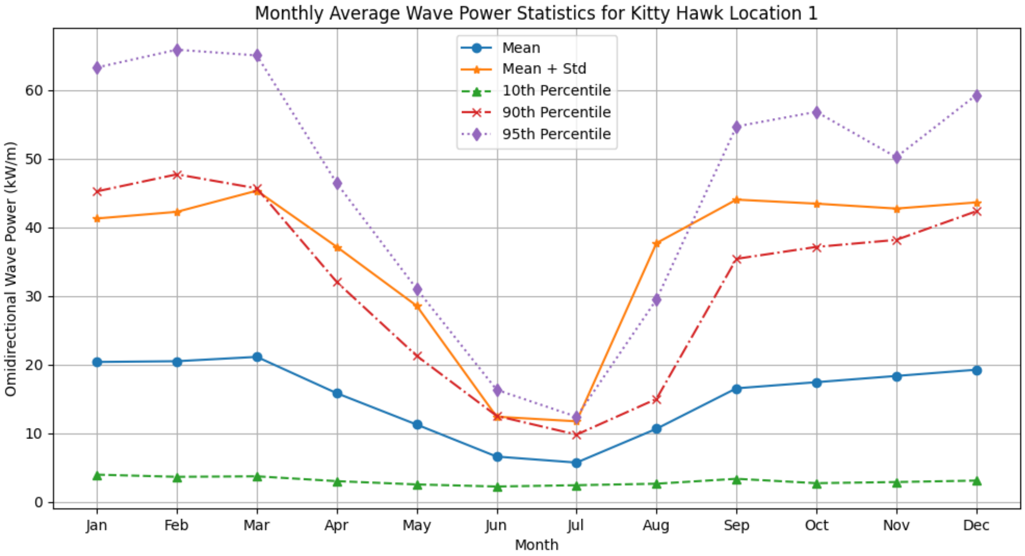
Plot of the Distribution of Omnidirectional Wave Power for the Location off the coast of the Aleutian Islands in accordance with IEC Standard 62600-101 with Data from MHK Atlas [8], [12].

The plot above as mentioned previously is the distribution of power across a year in teams of wave power and the cumulative percentage of power across the year. As stated earlier this graph supports the conclusion that the optimal time to collect energy during the year is the fall and winter months. The next plot is a bivariate histogram which displays the types of waves the resource comprises.



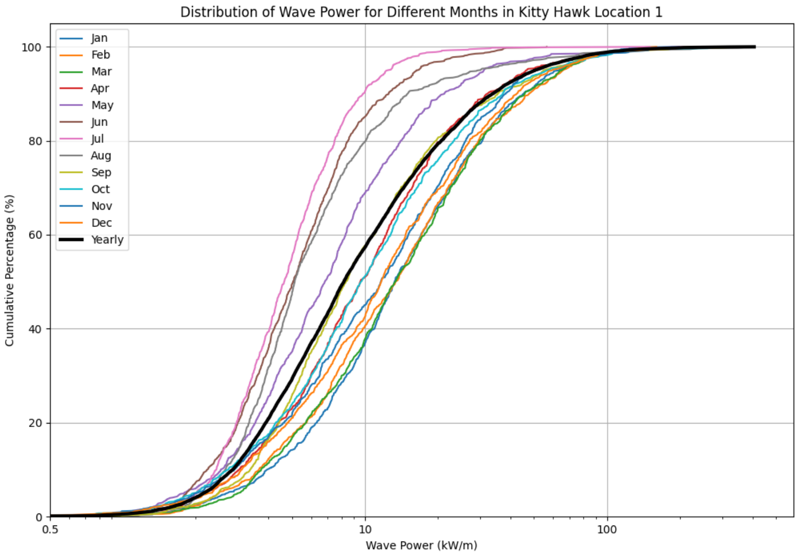
Bivariate histogram of Significant Wave Height and Mean Absolute Period at the location off the coast of the Aleutian Islands in accordance with IEC Standard 62600-101 with Data from MHK Atlas [8], [12].

As stated previously the plot above is a bivariate histogram that displays the types of waves the make up the wave energy resource. The type of wave which makes up the majority of wave energy resource can be derived from this histogram and these numbers will be used in the calculations for power output. The next set of figures is the graphs used to analyze the location near Kitty Hawk.



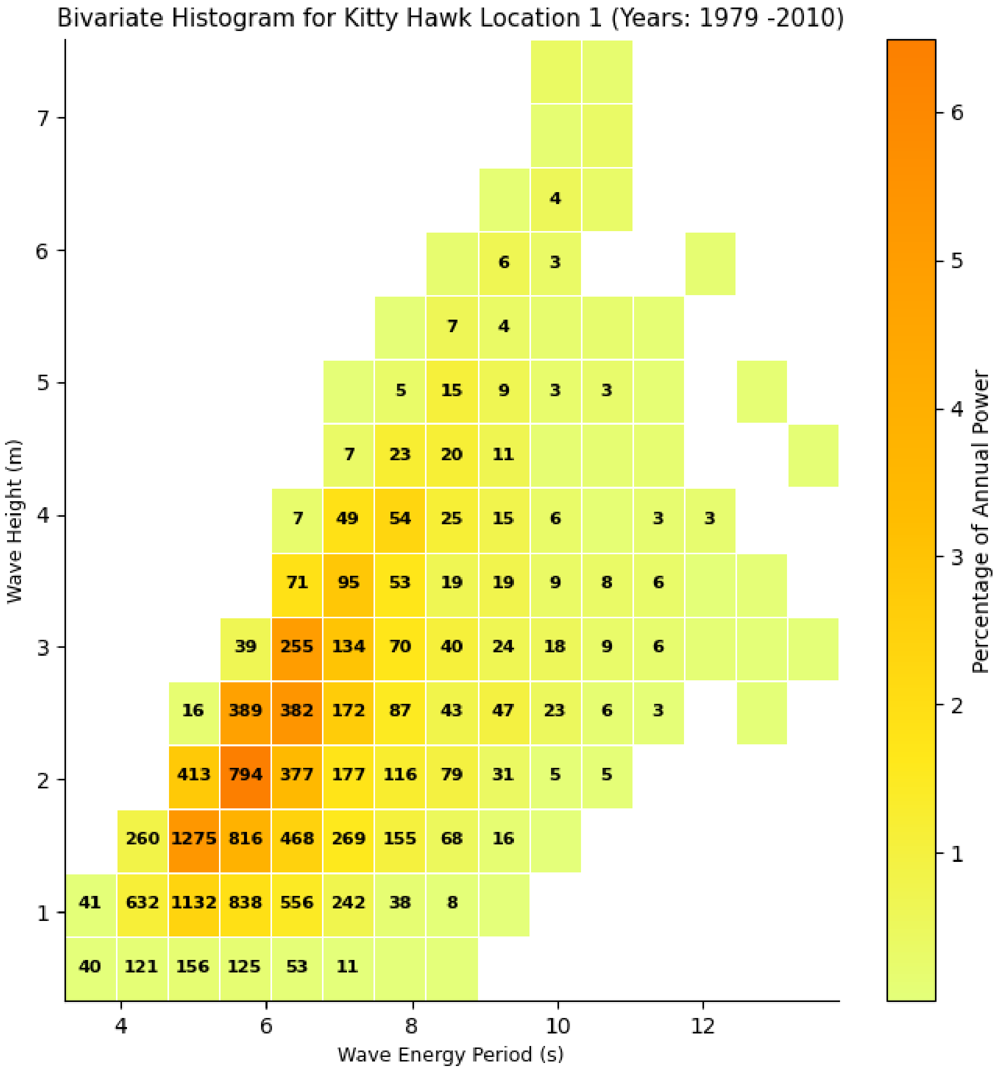
Plot of Monthly Variation of Omnidirectional Wave Power at a location near Kitty Hawk, NC in accordance with IEC standard 62600-101 with Data from MHK Atlas [8], [12].

The plot for the monthly variation of omnidirectional wave power seen above is for the Kitty Hawk Location, and further corroborates the conclusion that the optimal time for wave energy production is during the fall and winter months. The power distribution curve follows the same pattern as discussed previously.



Plot of the Distribution of Omnidirectional Wave Power for the Location near Kitty Hawk, NC in accordance with IEC Standard 62600-101 with Data from MHK Atlas [8], [12].

The power distribution plot for the Kitty Hawk location as stated previously confirms the conclusion of when it is best to utilize wave energy production throughout the year. The bivariate histogram shows the breakdown of the types of waves which comprise the wave energy resource at the Kitty Hawk location.



Bivariate histogram of Significant Wave Height and Mean Absolute Period at the location near Kitty Hawk, NC in accordance with IEC Standard 62600-101 with Data from MHK Atlas [8], [12].

As seen in the plot above, the ideal wave height and period that the V-MEPA would have to be constructed for would be different. This further highlights the benefit of the modular design of the V-MEPA because different locations will have different wave heights which the column of the V-MEPA can easily be adapted to thus the simplistic design is ideal.

From these plots we can see the seasonal variability of the theoretical wave energy resource and the type of waves which make up the majority of the theoretical wave energy resource at these locations. From the data the ideal times of the year to operate the V-MEPA are during the fall and winter months. Furthermore, the calculated rpm value is based on the wave height and period which commonly occurs and creates the most power at the Aleutian Islands locations with these values being 4 meters and 9 seconds [12].

With a wave height of 4 meters, a period of 9 seconds, and a diameter of 0.2 meters the velocity of the water through the turbine can be obtained by the equation:

$$V = \frac{\dot{V}}{\nu \cdot \rho \cdot A}$$

Which finds the velocity by using the volumetric flow rate divided by the product of the area of the inlet, fluid density, and specific volume. The volumetric flowrate is found by finding the volume and dividing it by half the period. After which the velocity comes out to be 0.74 meters per second. The velocity can then be used to find the angular velocity by assuming the water hits halfway through the radius (average). Angular velocity is calculated by dividing the velocity by the distance to the point of rotation. When calculation is done the angular velocity equals about 15 rad/s or about 141 RPM. When put through the 3to1 gear ration the motor experiences about 424 RPM. The torque created from the water is needed to calculate power, and the torque is calculated by multiplying the average distance, half the radius, by the force. The force is calculated by finding the average acceleration and multiplying it by the mass of the water that is performing work then dividing the product by the constant p.55. The volume found in-between two fins of a 0.2 diameter turbine multiplied by the density of water gives a mass of .042 kg. The acceleration is found by assuming the turbine starts at rest and reaches peak velocity at half the period (peak to peak) dividing the velocity by time. The acceleration calculates to .00691 m/s^2 and the power comes out to 25 Watts per meter. This Wattage is theoretical and without any imperfections.

Calculating the Flexural and Shear Stress on the Suspension

The suspension will have to sustain transverse loading from the heave and surge forces of the waves. In order to ensure the suspension was designed to sustain this loading, calculations were performed to determine the maximum load that could be applied to the floating assembly. The suspension was designed from PVC pipe with an outer diameter of 0.84” and an inner diameter of 0.5”.

Section Properties:

$$I_{cylinder} = \frac{\pi}{64}(D^4 - d^4)$$

$$= \frac{\pi}{64}(0.84^4 - 0.5^4) = 0.02137 in^4$$

$$A_{cylinder} = \frac{\pi}{4}(D^2 - d^2)$$

$$= \frac{\pi}{4}(0.84^2 - 0.5^2) = 0.3578in^2$$

$$length = 24\, inches$$

$$\sigma_Y = 14500psi$$

Flexural Stress:

$$\sigma_Y \geq \frac{My}{I}$$

$$M = F_{surge} * length$$

$$F_{surge} \leq \frac{\sigma_Y * I}{y * length} = \frac{14500 * .02137}{0.42 * 24} \geq 30.741\, lb_f$$

$$\tau = \frac{V}{A}$$

$$\tau = 8330psi$$

$$\tau * A = V$$

$$= 8330 * 0.3578 = 2980.474\, lb_f$$

Calculating Buoyancy Force on the Floating Assembly

In order to determine if the floating assembly will oscillate with the ocean waves, calculations were performed to determine the force of buoyancy acting on the assembly. The buoyancy force and the force of gravity were used to determine the net force acting on the cylinder at the peak of a wave.

$$Weight_{FA} = 12lb_f$$

$$\Sigma F_y = F_{buoyancy} - F_{gravity} = 0$$

$$\rho = 2\, \frac{lb}{ft^3}$$

$$g = 32.2\, \frac{ft}{s^2}$$

$$V = 0.7\, ft^3$$

$$F_{buoyancy} = -\rho g V = 2 * 32.2 * 0.7 = 45.08lb_f$$

The net force acts on the anchored assembly at the top of a wave and must be counteracted with the anchoring systems. The foundation is structured as two sleeves secured to the cylinder with six bolts.

$$F_{net} = F_{buoyancy} - F_g = 45.08\, lb_f - 12\, lb_f = 33.08\, lb_f$$

$$F_{Fs} = \mu_s * F_N$$

$$\mu_{s\, ABS\, Plastic\, on\, PLA} = 0.42$$

$$\frac{F_{Fs}}{\mu_s} = F_N = \frac{33.08}{0.42} = 78.762\, lb_f$$

$$\frac{78.762\, lb_f}{6\, bolts} = 13.127\, lb_f\, per\, bolt$$

In order to ensure the cylinder is properly secured against the oscillating forces of the waves, the bolts will be tightened to 15 lb-ft of torque.

Future Considerations

A number of design modifications were identified during the design and build phase that would improve the efficiency of the design and reduce cost.

Linear Induction Coil

In addition to generating power using a rotating generator powered by a turbine, the Wave Energy Converter could take advantage of the linear oscillation of the floating assembly and use a linear induction coil placed around the cylinder along with a magnet attached to the piston to generate electrical energy.

Improved Turbine Design

The Wave energy converter went through several iterations of the Turbine design with earlier designs resembling the low-pressure axial turbine of a gas turbine. Later iterations reflected Kaplan style turbines which are common in run-of-the-river hydroelectric dams. A key issue with using axial flow turbines is the oscillation of the water which causes the turbine to change direction. This creates issues with power generation and decreases the efficiency of the generator as the rotational speed of the turbine decreases at the peaks of the waves. The solution to this problem was to create a turbine that combines elements of the Kaplan turbine and the Francis turbine in which water enters the cylinder tangent to the direction of rotation and is expelled from the cylinder axially which creates a unidirectional rotation. This optimized the design for power generation, but the turbine design still had a number of inefficiencies.

Improved Stability for Adverse Conditions

The linear actuating design of the WEC is effective for driving a turbine but is at risk of sustaining damage during rough conditions. The floating assembly is designed to be constrained laterally which requires the anchoring system to resist the surging of the waves. Future designs should either be built with more bracing to resist this damage or should allow for lateral translation of the floating assembly.

Build-Test Overview

Objectives

The objective of the build-test plan is to create a prototype that accurately reflects the design elements of the Wave Energy Converter and to effectively demonstrate the converter's ability to generate power and operate safely in marine environments.

Design Process

Early Concepts

When first considering collocation of offshore wind and wave energy the team decided on a point absorber that used a vacuum to suction water but there were few ideas on how to proceed. One of the first few designs was a one-way inlet and outlet design that would use two turbines to spin a generator. Another option was to use a floating oscillation water column. Our last concept is what turned into the V-MEPA, using a single turbine and a bidirectional inlet/outlet. When considering which option to choose the team decided that simplicity or manufacturing and low cost would be the most important variables, while originality and maintenance would still be considered. To decide on which option the team used a decision matrix depicted below.

Table 1: Early Deciding on Design Concept

WEC Decision Matrix	Simplicity 40%	Cost of Materials 40%	Originality 10%	Longevity and Maintenance 10%	Final Score
2 Turbine	2	1	4	2	1.8
Oscillating Water Column	3	3	2	4	3
Single Turbine	5	4	2	3	4.1

In this decision matrix the single turbine concept is determined to be the best option. The simplicity is so heavy weighted due to manufacturing within the timeframe given being a large variable this competition. Duck Duck Goose acknowledged that they were a rookie team that did not have access to every tool they would need to manufacture a large metal project, and the simpler the project the more they could learn about the fundamentals of energy production and manufacturing a prototype. Another benefit of having a simple project is having less failure points. In the design chosen, when something inevitably goes wrong diagnoses of the problem and a solution to fix it could come faster.

During design and construction, the team would get together weekly for a design review and go over what tweaks needed or had already been made. During this process multiple parts were changed and innovated.

Flotation Device

Initially the floatation device would be made up of a heavy center, to have weight when the wave went down, and a flotation ring made of a similar material to inflatable life rafts. However, in research the use of boat foam, polyurethane, was found and showed it had potential for our application. The use of boat foam meant all the floatation device had been a sealable container large enough to fit enough foam for positive buoyancy. The boat foam was the team's final decision.

Suspension

The suspension is one of the few parts that would mechanically change from consumer size to industrial size. In smaller sizes the team made use of a small diameter PVC pipe to be the suspension. In larger wave heights the team has designed a multi-beam structure that would prevent torsion and keep the suspension straight.

Piston Head

The design of the piston head started as just a tall cylinder, so it could be easily manufactured. However, after further thinking the team thought the cylinder wall would rub against the main cylinder and cause too much friction. The next thought was to decrease the height of the cylinder, similar to the shape of an air hockey puck. This design would cause less friction but would introduce the problem of rolling along the axis perpendicular to the oscillation and getting stuck if the suspension flexed at all. The team then looked at motor vehicle piston heads and determined a design similar would work best. The first section of the piston head, before the first groove, would act as the hockey puck, and the longer structure after the grooves would guide the piston and prevent rolling.

Motor Mount

When designing the motor mount, the part only had one point of contact for the axils and did not guide the direction of the water into the turbine. In testing this design proved to be problematic because the axils were able to move a few degrees, causing the turbine to rub on the wall and create lots of friction. A second part was made to counteract this effect, a spacer that kept the two axils at the correct distance, but this did not solve the issue. The team then designed a motor mount that included two points of contact that fixed the axils where they should be, except for axial rotation of course while also guiding the water properly into the turbine. See the figure below for a before and after.

Figure 15: Previous (Left) and Current (Right) Motor Mounts

<u>Turbine</u>

The turbine was originally meant to have a design similar to a plane propeller. This design allowed the water to flow through it axially and it allowed for stacking multiple propellers on one axial, producing more torque on the same input. After a few iterations, the design was made to be symmetrical in an attempt to get the same efficiency in both directions. The problem with this design was that it was not efficient in water and the directions of flow would flip the direction of current. That means the electrical part of the project would be more complicated needing an active bridge to flip the direction current with the flow of water. Finally, Duck Duck Goose decided on a modified horizontal turbine that would spin water flowing over it from the side or from the top. This design spun the same direction no matter the flow and was theoretically more efficient in the horizontal direction than the flat propeller design.

Figure 16: Turbine Iterations Over Time

Fabrication

Floating Assembly

The floatation device was fabricated by using a five-gallon bucket and filling it with boat foam. This process dealt with possibly dangerous materials, so the proper precautions were takin. Using cloves when near contact with it and wearing a filtering gas mask to protect against fumes. That boat foam and the painting process were both done in well-ventilated locations.

Figure 17: Fabrication of Boat Foam

The rest of the floating assembly, bucket to suspension, suspension and piston head, were all made to size. The only manufacturing needed was to drill 6 holes, four into the bucket and 2 into the PVC suspension. After which they were all bolted together, no force needed.

Anchored Assembly

The main cylinder was bought out of a five-foot ABS pipe for plumbing. It was then cut down to size. After achieving the desired size, the cylinder had two 2.25-inch circular holes drilled into it; one at the top and one at the bottom. The lid, foundation, motor mount and turbine were all 3D printed to size and did not need manufacturing. The axils were bought then cut to size, and all the shaft collars, bearings and the motor used were bought and used directly.

Test Plan

For the protype V-MEPA a plan was put in place at the midyear submission. Unfortunately, due to poor planning and unforeseen problems during manufacturing the plan could not be followed. Over the course of the competition testing was being done alongside manufacturing to speed up the timeline. In subsystem testing the floatation device was tested by simply allowing it to float the whole device, in case the anchored assembly foundation fails it will not sink to the bottom of the ocean. The turbine to motor subsystem was tested by using a 20-volt power supply to spin the axial attached to the turbine. The voltage output from the generator was measured to level off at 14.98 volts for a 75% efficiency. The seal created by the piston head was initially tested by dropping the piston head through the main cylinder with no escape for the air except through the piston head. The time it took to go through the length of the tube was compared to the time it took to drop while air was able to escape out the bottom, free fall, and it was found that the seal caused the piston to fall five times slower than the piston in free fall. After which the water seal was tested pushing and pulling the piston through a waterlogged main cylinder and observing the water shoot out of the inlet/outlet holes. The turbine was tested by flowing water through the turbine, undamped but assembled, and observing the rotation of the axile. The V-MEPA was then brought to the coast and was put into the ocean to test the actuation of the whole prototype without the motor and electronics, depicted below. In this test the prototype actuated with the heave and ho of the waves.

Figure 18: Testing in Ocean

All these tests showed each subsystem working as designed with promising observable results. The last step of this process was to attempt full systems test with the motor and electronics to find out if the water pulled in from the suction turned the turbine and motor. Unfortunately, this did not happen.

Raw Data

From the test results the prototype showed potential for working, however more work and time is needed to prove viability. The data we did obtain however shows that with more troubleshooting and refining this prototype can be a working model. The subsystem testing all shows positive results with each part of the prototype working separately. In short, the prototype has the potential to be a viable strategy of energy harvesting but is not finished.

Lessons Learned

From the fabrication and testing process Duck Duck Goose learned so much. The team experienced fabrication of designed parts and bringing them into reality. This came with understanding how to design a part that can be fabricated, fastened and withstand the forces it would experience in a non-ideal world. From this competition the team learned how to produce energy and how to determine what methods will be efficient.

The team also learned the hard way how setbacks with design and late part shipments can affect a testing timeline. Next year the team will already be established and will have more time to work on the actual project rather than forming enough members and a team identity. Next year a schedule will be put in place to start earlier and allow for things to go wrong.

Works Cited

[1]	Coastal Wiki. 2023. *Wave energy converters.* December 3. Accessed 2024. https://www.coastalwiki.org/wiki/Wave_energy_converters#cite_note-32.
[2]	Cornett, Andrew. 2008. "A Global Wave Energy Resource Assessment." *International Offshore and Polar Engineering Conference.* Vancover.
[3]	European Marine Energy Centre. 2024. *CEFOW: CLEAN ENERGY FROM OCEAN WAVES.* Accessed 2024. https://www.emec.org.uk/about-us/wave-clients/wello-oy/cefow-clean-energy-from-ocean-waves/.
[4]	European Commission. 2020. *Horizon 2020.* Accessed 2024. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en.
[5]	Falcão, António F. de O. 2010. "Wave energy utilization: A review of the technologies." *Renewable and Sustainable Energy Reviews* 899-918.
[6]	Grand View Research. 2023. *Renewable Energy Market Size, Share & Trends Analysis Report By Product (Bioenergy, Hydropower, Wind Power, Solar Energy), By Application (Industrial, Residential, Commercial), By Region (Europe, Asia Pacific), And Segment Forecasts, 2024 - 2030.* Market Research, Grand View Research.
[7]	Gunnar Mørk, Steve Barstow, Alina K. Kabuth, M. Teresa Pontes. 2010. "Assessing the Global Wave Energy Potential." *29th International Conference on Ocean, Offshore Mechanics and Arctic Engineering.* Shanghai.
[8]	Hosna Titah-Benbouzid, Mohamed Benbouzid. 2015. "An Up-to-Date Technologies Review and Evaluation of Wave Energy Converters." HAL Open Science, May 20.
[9]	International Electrotechnical Commission. 2015. "Marine energy – Wave, tidal and other water current converters ." Geneva: International Electrotechnical Commission.
[10]	International Maritime Organization. 2019. *IMO and its role in protecting the world's oceans.* Accessed 2024.
[11]	International Renewable Energy Agency. 2015. *Renewable Power Generation Costs in 2014.* Market Research, International Renewable Energy Agency.
[12]	Michael Barnett, Irene Henriques, Bryan W. Husted. 2019. "Beyond Good Intentions: Designing CSR Initiatives for Greater Social Impact." *Journal of Environmental Management.*

[13]	National Renewable Energy Laboratory. 2024. *Marine Energy Atlas.* https://maps.nrel.gov/marine-energy-atlas/?vL=OmnidirectionalWavePowerMerged.
[14]	Ocean Energy Systems. 2019. *Annual Report An Overview of Ocean Energy Activities in 2019.* Annual Report, Ocean Energy Systems.
[15]	Roger Samsó, Júlia Crespin, Antonio García-Olivares, and Jordi Solé. 2023. "Examining the Potential of Marine Renewable Energy: A Net Energy Perspective."
[16]	Ryan G. Coe, Yi-Hisang Yu, and Jennifwe van Rij. 2017. "A Survey of WEC Reliability, Survival and Design Practices." NREL.
[17]	Saurabh Dixit, Rutuja Danekar, and Eswara Prasad. 2020. *Wave Energy Market Size, Share, Competitive Landscape and Trend Analysis Report by Technology, Location and Application : Global Opportunity Analysis and Industry Forecast, 2020-2027.* Market Research, Allied Market Research.
[18]	Thomas, Will. 2012. "Economic Analysis of Wave Energy Extraction." Stanford University, December 13.
[19]	Wave Energy Scotland. 2016. *Structural Forces and Stresses for Wave Energy Devices.* Final Report, Wave Energy Scotland.
[20]	World Energy Council. 2013. *World Energy Resources: Marine Energy.* Market Reseach, World Energy Council.
[21]	Wu, Tin Lok. 2023. "The Pros and Cons of Wave Energy." *Global Commons*, October 12.