Powering Drifter Buoys with Wave Energy and Rotating Mass Technology

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U.S. Department of Energy's Marine Energy Collegiate Competition

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Terminology

- CAGR – Compound Annual Growth Rate
- DOC – Department of Commerce
- DOE – Department of Energy
- DOD – Department of Defense
- GDP – Gross domestic product
- LCA – Life cycle analysis
- LDL – Lagrangian Drifter Laboratory
- MECC – Marine Energy Collegiate Competition
- MRE –Marine Renewable Energy
- WEC-sim – Wave energy converter Simulator
- WPTO – Water Power Technologies Office
- NOAA – National Oceanic and Atmospheric Administration
- NREL – National Renewable Energy Laboratory
- PTO – Power take-off
- RM – Rotating Mass
- RMT – Rotating Mass Technology
- SVP – Surface Velocity Program
- UNH – University of New Hampshire
- WEC – Wave energy converter

1. Executive Summary

Ocean surface drifters are instruments critical for climate modeling, weather prediction, and safe ocean navigation. At any given time, the National Oceanic and Atmospheric Association's (NOAA) Global Drifter Program deploys over 1,200 drifters to monitor the earth's oceans. However, despite their importance, two thirds of drifters fail due to battery issues before reaching their expected 18-month lifespan [8], contributing to marine debris and requiring constant replacement.

Drift-RMT is an ocean surface drifter equipped with Rotating Mass Technology (RMT), which uses the wave energy available in small surface waves to extend the device's lifespan from 18 months to 7-10 years. This design improves reliability and data transmission capabilities while reducing operational costs and device wastage. Our design saves NOAA significant costs, estimated at $3 million annually, while reducing marine waste and enhancing data accuracy for weather and climate predictions.

Our design stands out in the commercial ocean drifter market with its innovative Rotating Mass (RM) system, which generates renewable energy from the motion of small waves to power onboard sensors. By patenting this technology and enforcing design certifications, we ensure the uniqueness and protection of our product.

We've conducted extensive interviews with industry experts and stakeholders to gather insights for refining our product. Notably, Dr. Shaun Dolk from NOAA's Global Drifter Program as well as those from MetOcean Telematics provided valuable feedback and technical expertise. Our go-to-market strategy focuses on securing NOAA as our initial customer, capitalizing on our established relationship and their interest in our product. Despite facing research and development costs, which are currently supported by various grants, we anticipate profitability after the first year.

To expand, we will target new industries and grow our customer base. We will introduce new drifter types equipped with our Rotating Mass Technology for industries that currently use drifters such as oil spill protection, commercial fishing, and ocean safety. To finance our business, we're leveraging various sources such as non-dilutive government grants, loans, and business competitions to cover our startup and scaling costs. These funds will primarily fuel product development and patent acquisition while contributing to strengthening our government's drifter program. Drift-RMT represents not only a technological advancement but also a commitment to sustainability, innovation, and the preservation of our planet's marine ecosystems for generations to come.

Drift-RMT is designed as a sphere to maintain its primary function of tracking ocean currents. Its internal components incorporate a center shaft with a fixed eccentric mass, which rotates with changing pitch and roll of the drifter. A generator is in line with the shaft, and has a built gear ratio to step up the angular velocity of the center shaft. This generator will power a power management unit, which will then keep four lithium-ion rechargeable batteries full of charge. These batteries will then power the onboard sensors and can last for 23 days with no charging from the rotating mass PTO. This system has the potential to extend the lifetime of the drifters drastically which will save money and reduce ocean pollution.

In order to validate the concept and assess its practicality, two prototypes were constructed to replicate an ocean surface drifter buoy equipped with a rotating mass. These prototypes underwent a rigorous series of tests, including benchtop motor trials and wave tank tests, to evaluate the feasibility of Drift-RMT. The team meticulously gathered analytical data from these experiments and conducted a comprehensive evaluation to determine the viability and effectiveness of the proposed solution.

Business Challenge

2. Concept Overview

Ocean observation plays a crucial role in the Powering the Blue Economy initiative, aiming to collectively harness the immense potential of our oceans for the economic, social, and environmental progress of the United States and other nations. Drift-RMT focuses on developing and deploying a device to prolong the lifespan of existing ocean surface drifters and expand the global network of data acquisition buoys. Ocean surface drifters reduce the total global forecast error by approximately 3% [9]. Current drifters in the commercial and federal sectors rely on traditional batteries that ultimately fail before their potential is fully realized. Further, the buoys become untraceable marine debris after a mean of 450 days, contributing to global waste. To replace drifters, a team of professionals must embark on expensive sea voyages to restore the spatial functionality.

Drift-RMT is developing an ocean surface drifter with self-sustaining, Rotating Mass Technology (RMT) that allows for a significantly greater device lifespan of an estimated seven to ten years. The innovative design converts the kinetic energy from a drifter's pitch and roll created by small ocean waves to turn an electromechanical generator, creating a source of renewable energy and eliminating the need for a large array of batteries. This marine energy solution enhances the reliability of conventional drifter technology, enabling more resilient data transmission capabilities. By streamlining operational costs and minimizing device wastage associated with discontinued transmissions, Drift-RMT presents a sustainable solution for ocean data collection, benefiting both environmental conservation and operational efficiency.

Drift-RMT contains various sensor packages (barometric, salinity, conductivity, etc.). Within the drifter, the onboard global positioning system (GPS) signal pings once an hour, on the hour to provide the user with its position and relevant data. The energy required to transmit sensor readings every hour is calculated to be approximately 0.06-Watt hours [9], which Drift-RMT exceeds, averaging 0.7 Wh over that time to store excess power. The ultimate life span is increased from 450 days to 7-10 years which allows consumers to obtain more accurate data to serve their needs. The drifter may be fastened with a drogue that allows it to follow the currents deeper into the water column; if so, a gimbal system will be attached to ensure the ability of the buoy to rotate, while not comprising the drifter’s main function, an oceanic drifter. However, initial wave tank tests with a drogue attached indicated that the Drift-RMT may work with a standard drogue attachment.

Figure 1: Drift-RMT ocean observing buoy uses pitch and roll caused by small waves to maintain power to collect oceanic data for transmission

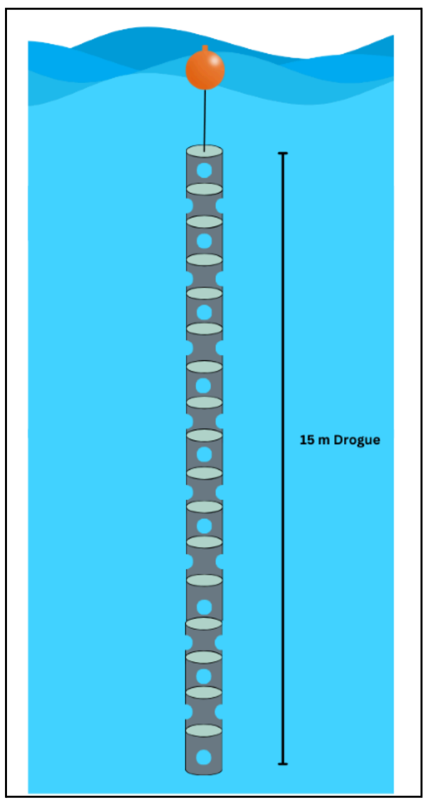

Figure 2: Drift-RMT will capture ocean currents with the drogue and continue to rotate from a combination of wave swell and wind forcing (15m drogue, subject to change via application)

The commercial market currently lacks a product that internally harnesses renewable energy to power ocean surface drifters. Drift-RMT fills this void by providing a reliable, marine energy drifter design. Our design negates the need for continual replacement of drifters within drifter programs. Drift-RMT offers increased reliability compared to traditional drifters, transmitting data for up to 120 months rather than 18. The rotating mass offers significant advantages compared to alternative renewable energy sources like solar, which could be vulnerable to salt buildup and icing.

Requiring approximately 400 drifter replacements annually, the extended lifespan of our drifters results in significant cost savings, estimated at $3 million per year for NOAA alone (See Appendix A). These savings can then be used for the implementation of our design, for a budget-neutral solution. After year 3, the amount of drifter replacements per year for NOAA are estimated to be below 100. This will give NOAA the opportunity to use their budget to expand their program, which they have expressed interest in. Beyond financial advantages, our drifter design improves the sustainability of drifter programs by minimizing marine waste resulting from drifter failures. Additionally, the increased reliability and longevity of our design enhances data accuracy for improved weather and climate predictions. This, in turn, aids in better preparing coastal communities for extreme weather and will improve our government's understanding of climate change.

3. Stakeholders

Those impacted by Drift-RMT are the organizations that require oceanic data for research and modeling in addition to the ultimate consumers of such. Further, as the buoy is unmoored, it may be encountered by fishers and the native populations in the ocean and near-shore.

Direct End Users:

Drift-RMT's raw data can be used for a myriad of applications which may include weather prediction, climate mapping, disaster preparedness, plotting shipping courses, fish population monitoring, and oil concentration detection. The increased lifespan and reliability of the buoy will enable longer-lasting missions; by saving on replacement costs, end users can purchase more buoys to increase their observation needs and thus have more accurate data.

Community Impact:

Combined with education and awareness, the increased observational data will allow coastal populations to be more informed of potential natural disasters and possible weather events, like flooding, due to improved forecasts from models that use the drifter buoy data. Disaster preparedness is only possible with meaningful data collected by reliable technology and organizations to disseminate the necessary warnings. Drift-RMT's ability to be deployed virtually anywhere in the world will benefit communities that may have had limited access to oceanic data previously. Further, we will use Drift-RMT to promote citizen science and public involvement through open data platforms and deployments with local schools.

Environmental Impact:

As discussed in more detail in the “Environmental Risk” section, the possible environmental impacts of Drift-RMT are minimal. The reduced number of batteries and near-elimination of "dead” buoys that become ocean debris support the strong elements of Drift-RMT's sustainable design. Our design incorporates four rechargeable Lithium-Ion batteries compared to the previous 30-50 D-cell Alkaline Batteries. An entire fleet of drifters previously required 76,000 disposable batteries a year, these batteries along with the rest of the drifter are destined to become marine debris with associated environmental repercussions.

4. Customer Discovery

Data acquisition buoys can be utilized by many industries. Drift-RMT appeals to a vast base of customers that may want many nodal points to create a holistic picture for their oceanographic research and ones who want to analyze very specific areas. Industry partners, oceanographers, engineering experts, and other end users were interviewed to gather insights for refining our product. Dr. Shaun Dolk, Manager of the Drifter Operations Center at the National Oceanic and Atmospheric Administration’s (NOAA) Global Drifter Program, expressed keen interest and provided valuable perspectives into the potential and applications of our product. Dr. Dolk emphasized the need for a more reliable solution to extend the battery life of the current drifter models. He noted that sensor longevity issues and drogue interference were the most prevalent factors that drained the D-Cell alkaline batteries.

MetOcean Telematics, a leading drifter manufacturing company, offered technical expertise to enhance our understanding of manufacturability. An interview with Lauren Bannerman-Maxwell unveiled detailed improvements that could be made to the current ocean surface drifters and how the rotating mass system could be integrated. Ultimately, they provided a wholesale quote including retail pricing on base-model drifters of $3600 per item. This information was key to determine Drift-RMT's pricing structure, profit margins, and other financial projections.

Peter Britz, the Director of Planning and Sustainability for the City of Portsmouth, NH, met with our team to discuss the recent floodings in January 2024 and how Drift-RMT's impact could help future disaster mitigation. The tidal forecast used by the city predicted a maximum high tide 4.1 feet below the actual observed heights. These tides, predicted to be below the flood table, inundated roadways and historical buildings. If better tidal predictions had been available, the city's Department of Public Works would have had time to deploy proactive flood deterrence protecting their infrastructure and raising awareness for local residents.

Other key organizations and individuals we've consulted include NERACOOS (Northeastern Regional Association of Coastal Ocean Observing Systems), NREL (National Renewable Energy Laboratory), Tom Coolbaug (Operations Manager at Ohmsett testing facility), Tom Lippmann (nearshore oceanographer affiliated with UNH), and Dr. Maithili Shroff (Licensing Manager of the Technology Transfer Office for Sciences and Engineering at UNH). Their input has been integral in guiding our decision-making, understanding industry needs, and shaping our technology and business plan.

5. Market Opportunity

5.1 Target Market

We plan on securing an initial customer in the National Oceanic and Atmospheric Administration (NOAA). NOAA plays a pivotal role in sustaining the global drifter program. We consulted with NOAA throughout our research and design process. NOAA's staff expressed a clear need for a more reliable design to reduce operational and replacement costs. NOAA has provided us support via drifter specifications and contact with their head engineers to help us pursue our design. We are currently continuing conversations with NOAA to discuss our engineering timeline and future collaboration between our two entities.

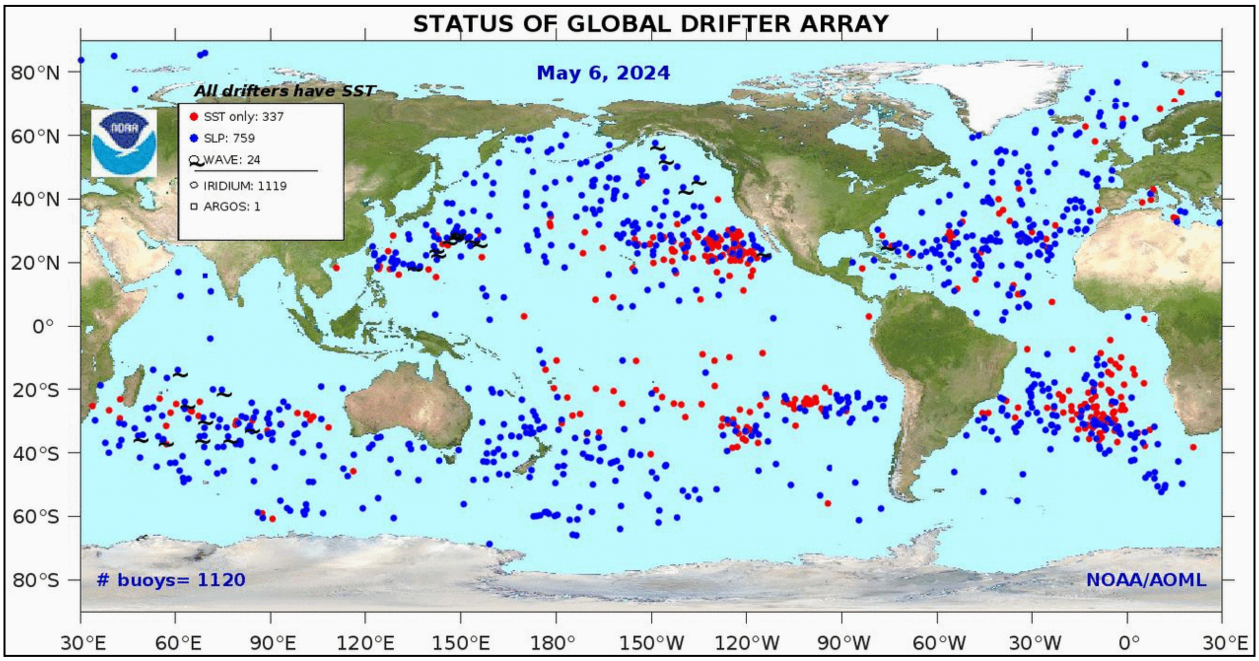

Figure 3: Live map of NOAA Global Drifter Program Buoys by sensor type [9]

Outside of NOAA, potential customers include shipping companies, commercial fishing, oil companies, foreign government organizations, and independent research facilities. Organizations within these respective industries across the globe currently use drifter technology to track marine populations, plot ideal shipping courses, find oil concentrations, and collect robust ocean data. The market will seek our innovative design to enhance the dependability of their ocean data collection endeavors, ultimately leading to long-term cost savings. We have engaged with potential customers such as the Coast Guard and potential users of the data, the town of Portsmouth, both of which have shown significant interest in our product. Through discussions with these organizations, it became evident that there is a pressing demand for robust weather prediction devices, particularly highlighted by recent flooding incidents in Portsmouth. The drifter market has witnessed a growing interest from organizations who aim to enhance data reliability by expanding their drifter matrices. The market for weather forecasting services in the US alone is over $6.6 billion with a predicted annual market growth rate of 2.9%. Based on available data, we've conservatively estimated the market size for drifters to be $150 million, but we can expect some upside to the market since there are many independent drifter users for which there is not available data.

5.2 Competition

Competition in the ocean surface drifter market is complex. As most programs are funded by governmental grants, the number of commercial designs is scarce. The for-profit businesses that benefit

from the technology are the manufacturers and the end users themselves, rather than drifter design producers. The Lagrangian Drifter Laboratory (LDL), based out of the Scripps Institute of Oceanography, University of San Diego, is a key player in the global network. As stated by Dr. Luca Centurioni, the director of the LDL, “The LDL is a research lab with a mission to provide research and instruments to science and is not a business.” Drift-RMT will be one of the first commercially available drifter designs and thus can be marketed to as many public, private, and federal organizations as possible.
Notable designs feature the Kinetic Energy Harvester Wave Energy Converter (KEH WEC) by Matias Carandell et al. [1], a designed and tested double-pendulum drifter WEC published in the Institute of Electrical and Electronics Engineers journal.

5.3 Barriers to Entry

Entering this market poses significant challenges due to the intricate technical nature of the product and the substantial costs associated with modeling, testing, and construction. Securing initial funding from investors becomes imperative to initiate the testing and design phases. Additionally, developing an efficient product capable of enduring prolonged periods while sustaining its power supply presents another formidable obstacle. Achieving sufficient efficiency with renewable energy sources to compete with non-renewable alternatives proves challenging. Despite the myriad challenges inherent in designing for harsh and unpredictable ocean conditions, wave energy stands out due to its high energy density. Consequently, assembling a team of seasoned engineers with diverse engineering backgrounds becomes essential to devise a comprehensive, efficient, and resilient design capable of competing in the market.

5.4 Other Possible Markets

Other possible markets we have considered targeting are the U.S. Coast Guard and arctic based research organizations. The coast guard serves as the first line of defense when preparing for extreme weather. Our drifter design will provide the coast guard with a reliable data collection source which will allow them to have better predictions of severe weather. This will allow them to be proactive when preparing for hurricanes and other extreme weather events. The coast guard is funded by the United States Department of Defense, opening Drift-RMT to be utilized by other branches of the United States military, like the Navy. In the arctic, batteries may drain even faster due to the cold temperatures. Renewable energy alternatives like wind and solar are impractical as brine and limited sunlight drastically affect those methods of energy production. Additionally, wave energy is five times more dense than solar and ten times denser than wind [4], which gives Drift-RMT an advantage in parts of the ocean known for intense wave activity. For comparison, the Sofar Spotter buoys are a similar size ocean data buoy that measures 3D surface displacements at 2.5 Hz. Spotters use five 2-Watt, 6-Volt solar panels along with lithium-ion batteries to power the buoy. In decreased sunlight areas, “Spotter’s solar panels naturally generate less power, reducing the lifespan of the device’s lithium-ion battery” [14].

6. Development and Operations

6.1 Decision matrix and design

During the initial design phase, a decision matrix was used to narrow down the various energy conversion technologies that would be suitable for this project. A decision matrix is a systematic tool used to evaluate and select the best alternative based on a set of desired criteria. The WEC systems evaluated include a rotating mass, point absorber, and an attenuator. These systems were evaluated based on the following set of criteria: power generation, capital cost, environmental impact, efficiency, size, lifespan/durability, simplicity, operational wave height, and energy transportation. The systems were given a score in each category from 0-10, with 0 being the worst and 10 being the best. The scores were based on the general characteristics of each system and analysis from experts in the field. The goal of this decision matrix was to help the team find a direction for their project. Review of the decision matrix concluded that a rotating mass wave energy converter would be the best technology for this project.

Criteria	Point Absorber	Rotating Mass	Attenuator
Power Generation	8	7	6
Capital Cost	6	8	6
Environmental Impact	8	7	6
Efficiency	7	8	9
Size	7	6	4
Lifespan/Durability	8	9	7
Simplicity	6	8	7
Operational Wave Height	8	7	9
Energy Transportation	7	6	8
Totals	65	66	62

Table 1: WEC Decision Matrix

6.2 Final Design

After preliminary selection, optimizing the Rotating Mass Technology was the next step. The team analyzed the parameters of the NOAA drifters including size, weight, and desired power output. Given the variety of technologies that could be installed into a NOAA drifter it was important to create a rotating mass that could power several configurations under varying ocean conditions. With these factors in mind, the team utilized WEC-Sim, a numerical modeling software suite especially developed for WECs (reference!), with a custom rotating mass power-take off (PTO) module, to model the performance of the rotating mass under different wave conditions.

Following a series of simulations a preliminary design was constructed. This preliminary design was based on connecting the rotating mass system to an electro-mechanical motor. The benefit of a flywheel is its ability to convert angular velocity in both positive and negative directions, compared to a simple gear train which is only able to convert the motion in one direction. The team encountered technical issues when trying to design a flywheel which would fit around the scientific equipment of the buoy. The decision was made to alter the design and use a simple gear chain in the project's final design. This would meet the team's goal of taking advantage of a rotating mass system to power an electro-mechanical motor. The details of the design are presented in the Technical Design report.

7. Triple Bottom Line

The Triple Bottom Line (TBL) is a framework for analyzing business success in three dimensions: economic, social, and environmental [6]. The economic dimension is centered around traditional economic metrics such as profitability, production, and employment figures. The social dimension focuses on the impacts of business operations on people and their communities. Finally, the environmental dimension focuses on ecological impacts such as waste production and emissions. The TBL provides a framework that allows people and businesses to make balanced decisions, recognizing that there is more to consider than pure economics.

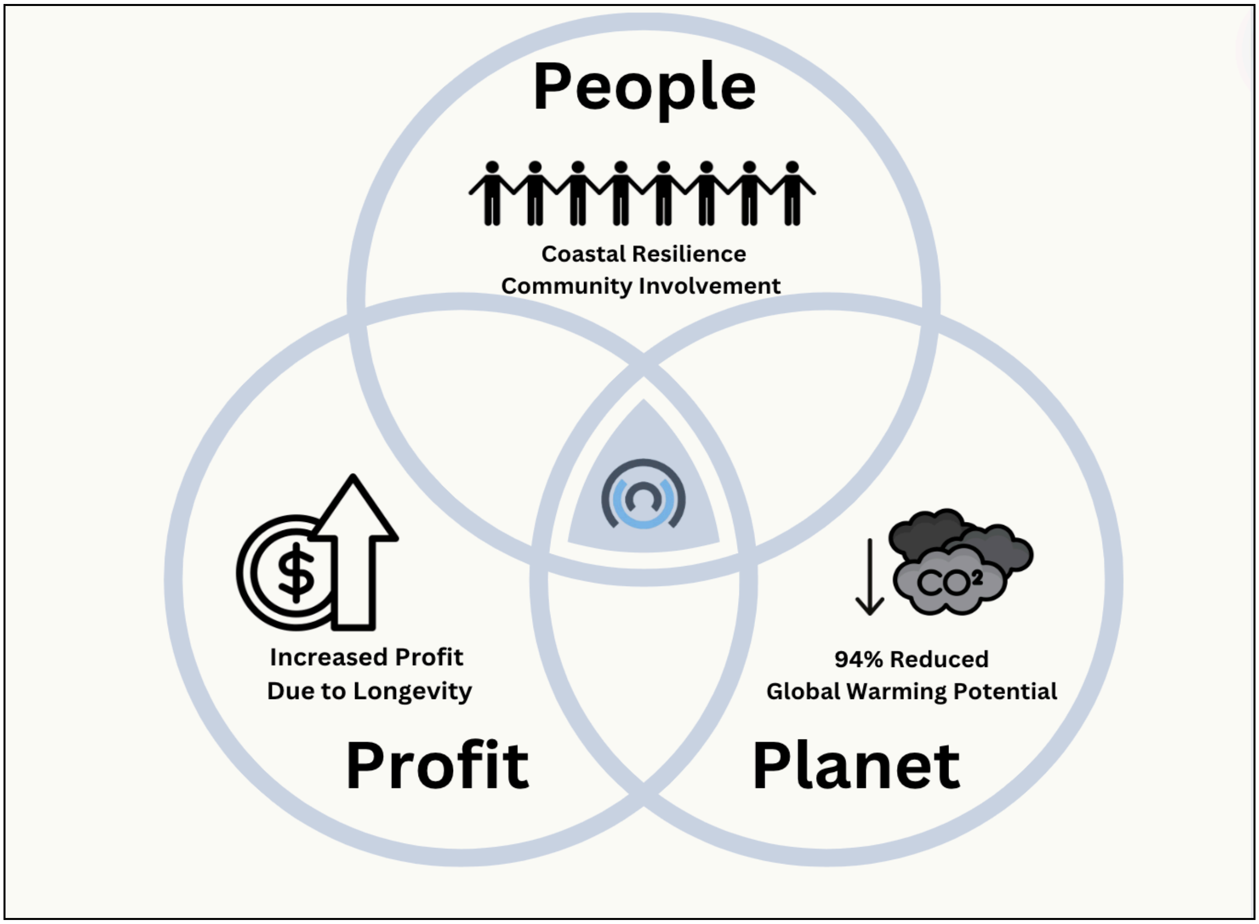

Figure 4: Triple Bottom line Venn Diagram comparing economic, environmental, and societal considerations

7.1 Environmental Risk

7.1.1 Overview

The goal of Drift-RMT is to extend the life of drifters. This would have several positive impacts in terms of the TBL. Environmentally, extending the life of NOAA drifters would mean less drifters would need to be produced and deployed each year. Drifter production has a relatively low environmental impact. The largest environmental impacts come from deployment, according to Dr. Dolk. Drifters need to be driven several miles offshore to ensure they will be captured by ocean currents and not washed ashore. This requires a voyage on a large vessel which increases the carbon footprint of the drifters. Furthermore, the end life of drifters is typically lost at sea, adding to the vast amounts of trash in our oceans. Drift-RMT seeks to remedy these issues by creating a product that can last longer at sea. Thus, lowering the footprint of manufacturing and deploying drifters and delaying their end-of-life impacts.

7.1.2 Ecosystem Considerations

The Drift-RMT buoy and NOAA drifter buoys have similar negligent impacts on ocean ecosystems. Both buoys have a nearly identical external design. The buoys themselves float at the surface of the ocean and pose little threat to any ocean life. The drogues connected to the buoys could potentially affect marine life in the direct vicinity. The drogues may create physical barriers or entanglement hazards for passing marine life. However, given the size of the drogues used for this project these risks are minimal. The biggest threat to the ocean ecosystem from these buoys is the potential to contribute to ocean debris. Following the death of these drifters they become marine litter. The Drift-RMT buoy mitigates this risk by extending the life of the drifters.

7.2 Biofouling

Biofouling on ocean surface structures poses a multifaceted challenge with implications for both performance and environmental sustainability. It begins with the settlement of microscopic organisms, gradually forming a biofilm that serves as a base for larger marine life like barnacles and mussels [15] This buildup increases drag, leading to higher battery consumption for Drift-RMT; due to the internally contained equipment, there will be no and reduced efficiency of such. Additionally, biofouling accelerates corrosion by trapping moisture and promoting localized corrosion cells, thereby compromising structural integrity and increasing maintenance costs. To combat these issues, various preventive measures are employed, including antifouling coatings that are not harmful to marine ecosystems. Ongoing research and innovative solutions are essential to effectively manage biofouling and mitigate its adverse impacts on ocean surface drifters and other structures.

7.3 Societal Considerations

The societal impact of drifters advances scientific research and our understanding of the ocean. They aid in predicting the effects of climate change and weather forecasting. In some cases, they can act as early warning systems for extreme weather events by measuring anomalies thus enhancing public safety with crucial information. Our product seeks to further build upon this mission and contribute to a project that achieves so much good.

7.3 Economic Considerations

Economically, Drift-RMT buoys are a cost-effective alternative to traditional NOAA buoys to extend drifter life and lower the costs of manufacturing and deployment. The Drift-RMT product has the potential to save NOAA millions of dollars. Furthermore, the production of new drifters could create more jobs and provide new business opportunities for manufacturers.

8. Operation and Maintenance

To maintain contact with the drifters, GPS satellite systems will continue to maintain a live network of all deployed units. Sensors to monitor the battery voltage and power supply will also be accessible from the repetitive drifter operation centers. As the drifter pitches and rolls, the rotating arm will spin providing resistance to the generator. In times of calm seas, there may be less than ample motion to produce power at that time. The four lithium-ion batteries can hold a charge and continue to transmit during these periods. If the batteries were ever to drain to zero, the owner can wait to see if sufficient motion resumes to recharge the buoy. If not, the buoy can be located based upon its previous trajectory mapped by the GPS onboard.

9. Financial Benefit and Analysis

9.1 Management

The basis of Drift-RMT is its ability to generate and maintain power for longer periods of time than traditional drifters. The mechanical system is internally located and thus less prone to the ocean's harsh conditions. We will provide our expertise in operation and maintenance to our customers as needed, in addition to educational training to our end users and manufacturing partners.

9.2 Permitting

Securing permits is a crucial preliminary step that needs attention before any manufacturing begins. Especially when deploying an untethered buoy offshore, the team acknowledges the necessity for a thorough investigation into permits and regulations to ensure the device's compliance before deployment in water.

By regulation of the Federal Energy Regulatory Commission, Drift-RMT will undergo the Hydrokinetic Pilot Project Licensing Process [5]. This is a mandatory step to ensure that this project is tailored to meet the needs of entities interested in testing our new technology while minimizing the risk of adverse environmental impacts.

9.3 Revenue/Pricing Models

Drift-RMT will employ a per-unit license fee model to generate revenue from our drifter design. Through contact with MetOcean, a leading drifter manufacturer, we plan to license our design to them, eliminating the need for Drift-RMT to have production and inventory costs. Organizations will be able to order drifters using our drifter design through MetOcean. We will take a fixed license fee from each item sold. The license fee will vary based on the specifications of the drifter type sold. There will be three main weather data drifter models (Basic, Middle, and High End) based on the instrumentation installed, and two other alternative drifter designs for oil spill tracking and marine life monitoring. At our recommended prices, MetOcean will see profit margins of over 25% on our products, 5% higher than the hardware industry standard. (See Tables 2 and 3 for pricing details & justification).

Drift-RMT Pricing & Manufacturing Costs	Base Model	Middle Sensor	High-End Sensor
Manufacturing Cost	$3,200	$5,200	$7,200
Fixed License Fee	$1,500	$1,800	$2,400
Total Manufacturing Cost	$4,700	$7,000	$9,600
Suggested Retail Price	$6,000	$9,000	$12,000
Manufacturer Profit (Per Drifter)	$1,300	$2,000	$2,400
Manufacturer Profit Margin (Industry avg:15-20 percent)	27.66%	28.57%	25%

Table 2: Drift-RMT manufacturing costs, suggested price, and manufacturer's profit. Fixed license fee considered.

Traditional Drifter Industry Statistics	Base Model	Middle Sensor	High-End Sensor
NOAA Unit Drifter Expense	$5,000	$7,000	$10,000

Table 3: NOAA traditional drifter costs.

9.4 Sales & Distribution

We are collaborating with NOAA and intend to secure them as our primary customer once our design sustains thorough testing. Given NOAA's status as a leader in global drifter deployment, our initial focus is on meeting their requirements. Utilizing our established rapport with NOAA, we will extend outreach to other government/independent drifter programs to introduce and promote our products. A sales team will be dedicated to reaching out to potential customers with our product offering and will serve as customer relations for our accounts. The manufacturing of our design will be entrusted to our current industry contact MetOcean, with distribution facilitated from their manufacturing center located in Oceanside, California. We chose MetOcean to distribute and manufacture our products because they are the leading manufacturer of drifters in the country, they have an established relationship with NOAA and other drifter programs. We have an existing relationship with them through communications associated with this project. MetOcean has provided us with quotes on pricing and industry costs and has confirmed our design's feasibility. MetOcean will have a sub-license to our design, and companies will be able to order our products directly through them. By outsourcing our manufacturing, we avoid start-up and sales costs, while simultaneously limiting the need for a large customer relations service.

9.5 Scaling

To expand our operations, we will focus on growing our customer base and developing new technologies to diversify into additional industries. Leveraging our reputation with NOAA, our team will target foreign governments, shipping companies, and independent research facilities for our version-one weather drifter, highlighting the long-term benefits of our design. There are programs across the globe that use drifters to collect data such as the European Union's Copernicus Marine Service drifter program. Drift-RMT will target the EU and other governmental entities to improve their existing drifter programs with our Rotating Mass Technology.

Besides weather data collection, we plan to introduce new drifter types equipped with our RM tech, catering to industries like commercial fishing, oil, and ocean safety. Our sales team will look to diversify our customer base by targeting these industries.

Additionally, NOAA has expressed interest in tightening their drifter grid to improve data accuracy. This would increase the number of active drifters in their matrix from 1200 to over 2000 (Appendix A). This presents an opportunity for the complete adoption of our technology within their expanded program. As our business expands, growth trajectories have been projected considering various scenarios (Appendix A). This figure takes into account the decreasing demand of drifters as NOAA's matrix adopts Drift-RMT and shows how we will scale around this. With increasing demand for our technology, we expect higher gross margins and lower costs of goods sold due to bulk manufacturing.

Another form of scaling we have considered is developing our own drifter grid. With an independent drift grid, Drift-RMT would be able to gather data that only we would own. We could then sell this data directly to end users who require it. This would provide an alternative stream of revenue for Drift-RMT.

9.6 Financing

To launch our business, we will rely on funding from government grants, loans, and business competitions to launch and scale our venture. We estimate a total startup cost of $100,000 dollars to finish the development of our first design and to implement our design within our manufacturer. Currently, we are funded by a DOE grant of $20,000 through the MECC (Marine Energy Collegiate Competition). This funding has gone toward the research and development of our product as well as travel for the competition. We are continuing our relationship with the DOE by applying for another grant of $60,000 to further fund the development of our technology. $30,000 dollars will go toward product development with the remaining $30,000 contributing to securing our patent and establishing a support team. In return, we will offer constant updates and reports on our project's progress and will contribute to strengthening the reliability of our government's drifter program. Through the MECC, we will have the opportunity to win up to $20,000 dollars to invest in the launch of our startup. We will seek additional funding from private investors when scaling our business.

9.7 Sales Forecast

Our sales forecast sees steady growth through the first five years of our business's launch. In year one we forecast unit sales of 250 drifters for a gross profit of $435,000. During year two we will introduce our oil and marine life drifters and expect sales to reach 600 drifters. Year three we will focus on expanding to other industries/governments, which will result in a gross profit of over $1.7 million. During year four, NOAA is expected to expand their drifter program, resulting in a demand for 800 new drifters. Year 5 will build upon this growth with an estimated 1900 total drifter sales across all industries and a net profit of $3.25 million. (See *Figure 5*.)

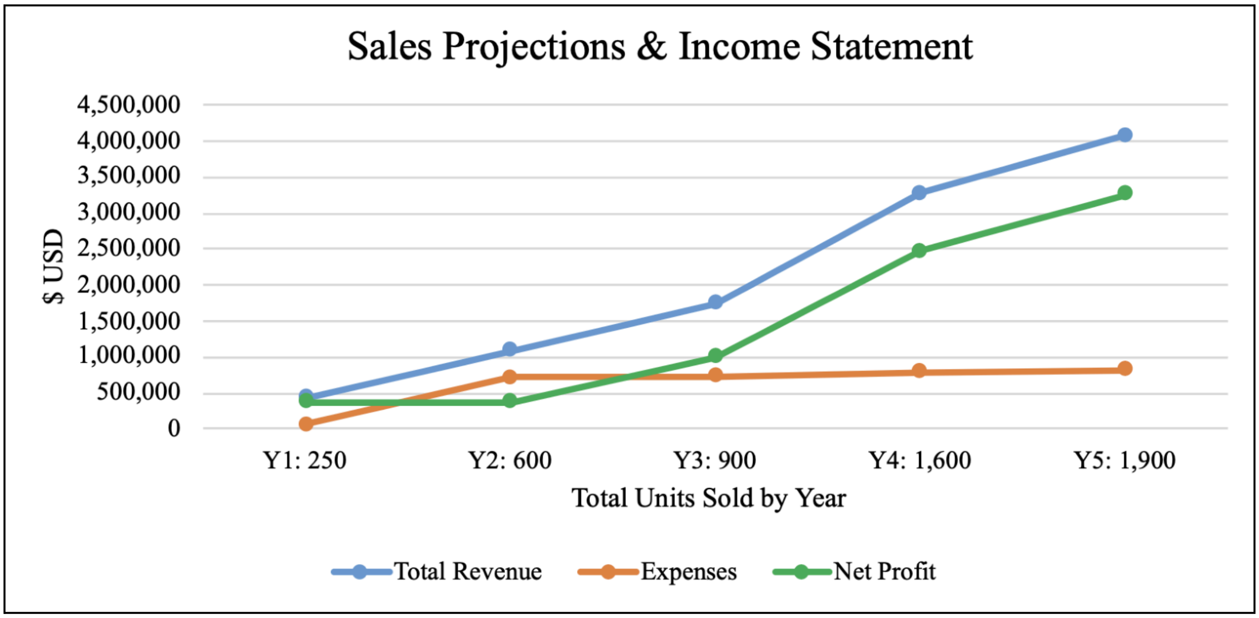

Figure 5: Sale Projections and Income Statements for years 1-5

9.7 Risk

The top risks our business faces regard technology adoption hesitance, proof of concept development, technical risk, and manufacturing. The biggest risk for our business initially is if NOAA decides they don't want to adopt our drifter design. This could be due to short-run financial costs, a lack of historical data on our technology, or a political policy limiting NOAA's budget. However, NOAA's expressed interest in our product and historical budget stability makes us confident in NOAA's willingness/ability to adopt our technology. If NOAA does not adopt our design, we will approach other entities with drifter programs such as the EU. Diversification between multiple industries will also mitigate risk.

A lack of real historical data to support our extended device lifetime claims could set our timeline back if companies require data before purchasing. Technical error within our technology would also pose a risk to the credibility of our design. To combat both issues, we will employ strenuous device testing, making sure that our technology lives up to its reliability claims. We will run a series of both ocean and lab testing, working to expose our tech to each potential environmental situation and assess the performance of our technology.

Another risk that may occur is poor manufacturing implementation. The manufacturing of our design will be a new process for MetOcean and without proper guidance, they may run into problems when manufacturing our product. To make sure manufacturing goes smoothly, we will create a certification program in which our manufacturer must meet a set of specifications and quality standards set by our engineers. To enforce this, we will send a team to help guide manufacturers through the initial building process to ensure device quality. If MetOcean cannot meet drifter demand, we will outsource to another drifter manufacturer such as Pacific Gyre.

10. University of New Hampshire's Paul J. Holloway Prize Business Competition

The Paul J. Holloway Prize competition is UNH's premier business plan competition for undergraduate and graduate students. It challenges students to develop products or services and present their plans to bring them to market. Students from across the University System of New Hampshire are invited to compete for cash prizes totaling $40,000. It is named in honor of Paul J. Holloway, an accomplished business leader and successful entrepreneur [13].

Four team members pursued this competition to refine the business section of our project. This competition has helped us structure the development of our business plan and pitch through various deadlines and feedback sessions. We have worked with business mentors and professionals that we've met through the competition to refine our business plan and develop our presentation.

In the Bud Albin Challenge Semi-Finals round on April 12th, 2024, 20 start-ups participated, and Drift-RMT placed 1st out of five teams in the Sustainability Category, automatically advancing to the final round. The Championship

Round will be held on May 8, 2024, where Drift-RMT competes against 6 other finalist teams.

Figure 6: Pictured above are William Moore (top-left), Camerion Vose (top-right), Kara Wittmann (bottom-left), and Riley Desmarias (bottom-right) in the Bud Albin Challenge Semi-Finals round on April 12, 2024

Technical Design Challenge

11. Inspiration

Ocean surface drifters collect data that is critical for climate modeling, weather prediction, and safe ocean navigation. The National Oceanic and Atmospheric Association's (NOAA) Global Drifter Program maintains over 1,200 drifters to monitor the earth's oceans. However, two thirds of drifters fail due to battery issues before reaching their expected 18-month lifespan, contributing to marine debris and requiring constant replacement.

Drift-RMT is an ocean surface drifter equipped with Rotating Mass Technology (RMT), which uses the energy available in small surface waves known as wavelets, which could extend the device's lifespan from 18 months to 7-10 years. It does so by converting the energy in waves to electricity. This design improves reliability and data transmission capabilities while reducing operational costs and device wastage.

The ideas of the type of WEC and the target area of the Blue Economy came together in a team meeting in November. The initial inspiration for the rotating mass WEC and Power Take-Off (PTO) system came from the thought of automatic (self-winding) watches and a GIF of a rotating mass PTO. Similar to automatic watches, ocean-observing buoys (especially drifters) have a low power draw and experience frequency motion. Automatic watches produce an average of a few microwatts from natural wrist movements, and it was estimated that this could be scaled up to power ocean observation buoys using the surface wave motion.

The idea of a rotating mass PTO was particularly appealing because all moving parts of the PTO are enclosed in the hull of the buoy. All drifters have a spherical hull that is sealed. This leads to decreased maintenance, increased reliability, and less concern of corrosion even in the ocean environment. While rotating mass WEC PTOs are considered less efficient than other WEC PTOs [2], the rotating mass PTO is compatible with an ocean observing drifter's primary function and is able to provide sufficient energy to operate the drifter's sensors and data transmission.

12. Design Process

In order for the entire development and design of Drift-RMT to go as efficiently as possible, multiple processes had to take action in parallel. Aspects of the technical design agenda operated iteratively as subgroups and team members discovered more information to work off of. This is important to note because although this report is separated into sections they are not necessarily in chronological order. Preliminary theoretical modeling was done first to see if there was enough resource energy within such a small envelope. This progressed when more information on power demands surfaced and further calculations could be made and even further when SolidWorks modeling introduced size and weight limitations.

Multiple iterations of SolidWorks models arose from discoveries by the build and test team. This was because the design team used feedback on size restraints and rotation data to optimize the theoretical model. Environmental concerns regarding survival and end-of-life fate arose early in the process which helped guide the design team's decisions on battery selection and power management systems. These operations would not have moved as quickly as is necessary for the scope of this project if they did happen in process.

The most iterative part of the design process was the numerical simulation software, WEC-Sim. This required multiple inputs from different subgroups regarding wave resource, size, and weight considerations. Information became available throughout the year and the WEC-Sim team used it as it became available. A simple solidworks model was produced early in order to begin the initial steps on creating a functional simulation while wave resource data was investigated by other team members. Later, build and test input on mass distribution influenced simulation parameters. This allowed the team to seamlessly flow through design iterations and effectively communicate information to all facets of the team.

13. Design Overview

The shape of the ocean observing drifter is a sphere and its configuration with a drogue cannot be changed so the primary function of the drifter is maintained. The drifter's primary function is to act as a Lagrangian drifter in the ocean, meaning it is following the flow of the ocean water [7]. However, the drifter's internal components can be rearranged to allow for ocean instrumentation, a rotating mass PTO (power take-off) which converts some of the energy present in small waves, and rechargeable batteries for energy storage.

Figure 7 provides a CAD (Computer-Aided-Design) model of a Drift-RMT drifter with labeled components. The rotating mass PTO will feature a center shaft that is positioned vertically in the drifter's hull. The shaft will be connected, by a short arm, to a weighted mass that is located inside of the hull. Waves will rock the drifter, and the pitch and roll of the hull will create a moment, which will rotate the mass. The mass and shaft are connected so that when the weight rotates, both the weight and shaft will rotate about the yaw. The center shaft is connected in line with a DC electric motor generator. Preliminary calculations estimate that a gear ratio of 170:1 is a necessary specification for the generator. The estimate was made based on a desirable generator RPM for ideal power generation. The generator will be connected to a rechargeable battery pack that will provide power to the systems on board. In between the generator and the battery pack will be connected to an H-bridge or similar circuitry that will allow the battery charger to accept both rotational directions of the shaft and provide the appropriate polarity. Additionally, there will be a power management system that will regulate the power being supplied to the rechargeable batteries. The rechargeable batteries that power the sensors on board will store surplus power, which can be drawn during times of calm seas, when the buoy experiences minimal rotation.

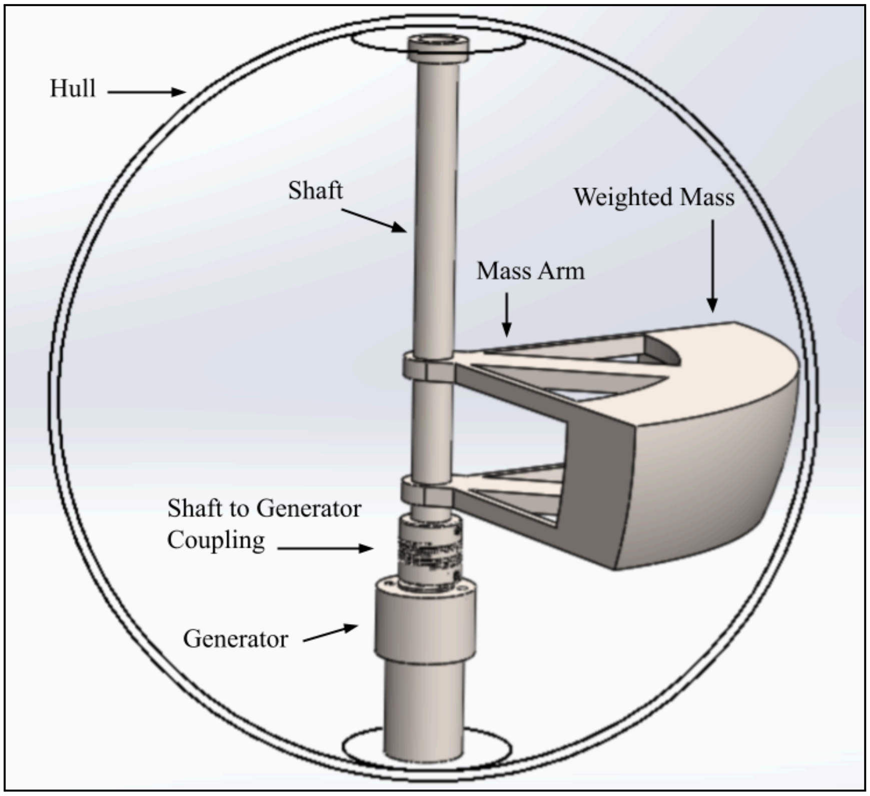

Figure 7: CAD Model with labeled components

The 30 D-cell Alkaline batteries from traditional drifters will be replaced with four 4.2V 2000mAh lithium-ion batteries. At full charge, the lithium-ion batteries will be able to power the drifter continuously for 23 days with calm seas and no charging.

The rotating mass mechanism will only occupy about 10 vertical centimeters in the spherical hull. Combined with the generator, circuity, and batteries, the rotating mass system will occupy less space than the previous 30 D-cell batteries. This ensures that there will be additional space for the sensors and transmitters for the drifter to perform its task of ocean observation and allow the drifter to store additional sensors if desired.

14. Advantages of a Rotating Mass Design

Drift-RMT selected a rotating mass design as its chosen form of WEC, due to numerous advantages over alternative WEC designs. By encapsulating the entire WEC system within the buoy, the risk of interference from ocean particles and concerns regarding corrosion are eliminated. Furthermore, the versatility of the rotating mass system enables a compact design, ideally suited for smaller buoys such as drifters.

A rotating mass PTO is traditionally less efficient than other types of WECs. Although this may seem a big issue, drifters only require a small amount of power to operate. Drift-RMT buoys do not aim to produce a large amount of power, because they do not need to. The focus of Drift-RMT buoys is meant to last as long as possible, which to the advantage of a rotating mass design.

A drifter powered by a rotating mass system proves more advantageous compared to a solar-powered alternative. Solar panels rely on sunlight availability, yet drifters, by their nature, are often submerged in water, reducing their exposure to sunlight. Moreover, accumulation of brine and algae on the solar panel may obstruct its full surface area from sunlight.

Deployed across diverse climates, drifters encounter harsh environments such as the Arctic and Southern Ocean, where sunlight duration is limited, resulting in reduced solar panel charging time. Additionally, extreme cold in these environments may lead to icing on the solar panel. In contrast, a rotating mass design is independent of sunlight and immune to icing issues since the entire mechanism is enclosed within the dry interior of the buoy.

15. Power Demands

The power demanded by sensors and the satellite communications devices can be difficult to compute due to the factors that affect the power draw of such devices. In an interview with Dr. Sean Dolk, the director of the drifter program at NOAA, he stated that he was unaware of the precise power consumption of the devices. The manufacturer of the device, MetOcean, would not inform the team of the power draw of the device, due to private business concerns. Research proved that pings from the ocean surface to satellite depended on distance between the device and satellite, amount of data being sent, and the type of transmission technology used.

It was up to our team to best estimate the power consumption of a typical drifter out at sea. Current drifters are equipped with an array of 30 D-cell Alkaline batteries. Each battery contains 18–27 Wh (Watt hours). Choosing the energy content that will lead to the highest power draw, each battery in a drifter was assumed to hold 27 Wh of energy. Multiplying this energy content times the 30 batteries in a drifter, the total energy content of the drifter is known. Using the simple equation below with the design time of the drifters, the average power draw and energy consumption per hour of a drifter can be determined. Each drifter is designed to last 18 months, which leads to an average power draw of 0.06 watts (0.06 Wh consumed every hour).

$$Power = \frac{Energy}{Time}$$

It is important to note that this is the average power draw of the drifter, but drifters measure and send data every hour on the hour. That means that every hour, the drifter consumes 0.06 Wh to read the sensors and then transmits the data to satellite. This is likely a high approximation of the power draw. Many drifters last longer than the design time, but also many fail prematurely due to excessive power draw. This excessive power draw can be caused by failed wiring, or the drifter trying to transmit data while being underwater [10]. The power consumption identified by the team is reassuring, as it suggests that the drifters possess low power requirements. This characteristic indicates compatibility with a compact and simple PTO system.

16. Theoretical Power Calculation & Desired Wave Conditions

To determine an expected power output from our rotating mass design, the team reviewed scientific research papers to explore similar designs. A paper written by H. Ming Chen and Donald R. DelBalzo titled "Circular-Slide Wave Energy Converter in Random Waves" investigates the power produced by a rotating mass design [2]. The paper features a rotating mass that is spun about the yaw along a frictionless track due to the force of random waves. *Figure 8* depicts the Circular-Slide Wave Energy Converter.

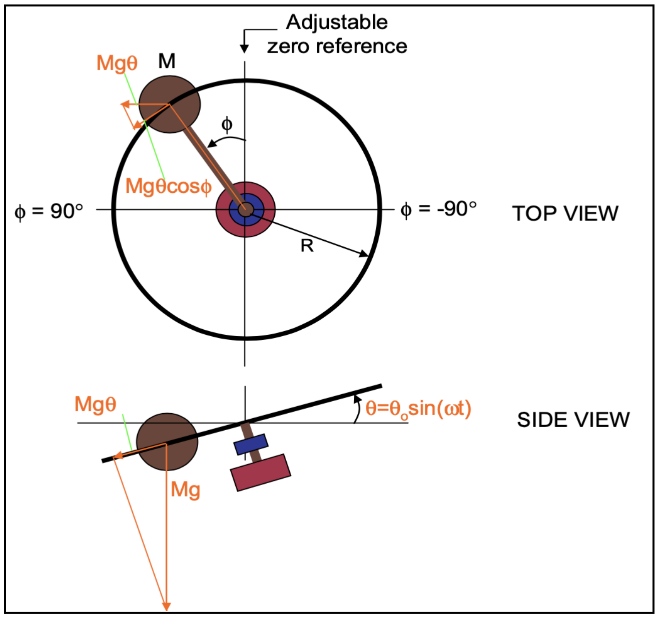

Figure 8: Top and Side views of Circular-slide Wave Energy Converter [2]

The paper derives the equation of motion of the Circular-slide WEC was derived to be:

$$M R^2 \frac{d^2\phi}{dt^2} + B \frac{d\phi}{dt} + K\phi = m\, g\, sin(\theta)\, cos(\phi)\, R$$

M = the weighted mass

R = the circular track radius

B = damping coefficient of friction and power

K = artificial torsional spring constant

g = gravitational constant

θ = the instantaneous incline angle

ϕ = sliding mass angular displacement on track

t = time

This equation can be further simplified to find power in the following equation:

$$P = \frac{1}{2} M\, g\, R\, \theta_0\, \omega\, \eta$$

P = power

ω = dominant wave frequency

η = system efficiency

θ_0 = buoy incline angle

The dominant wave frequency and buoy incline angle are dependent on the dominant wave period and the significant wave height. To understand what types of waves our rotating mass drifter would perform best in and produce the most power, we used MATLAB to perform power calculations over a given spectrum of wave heights and periods.

Since our system does not have a circular track, we substituted the radius of the center of the weighted mass for the radius of the circular track R. We assumed that the efficiency of the system would be .4 due to mechanical and circuitry losses. Mechanical inefficiencies include the nature of a rotating mass WEC, which does not efficiently harness the potential energy in waves. *Figure 9* provides a table of a power array produced from a wave height range of .1 meters to 3 meters and a wave period range of .5 seconds to 3.5 seconds. The x-axis is the dominant wave frequency, and the y-axis is the buoy incline angle.

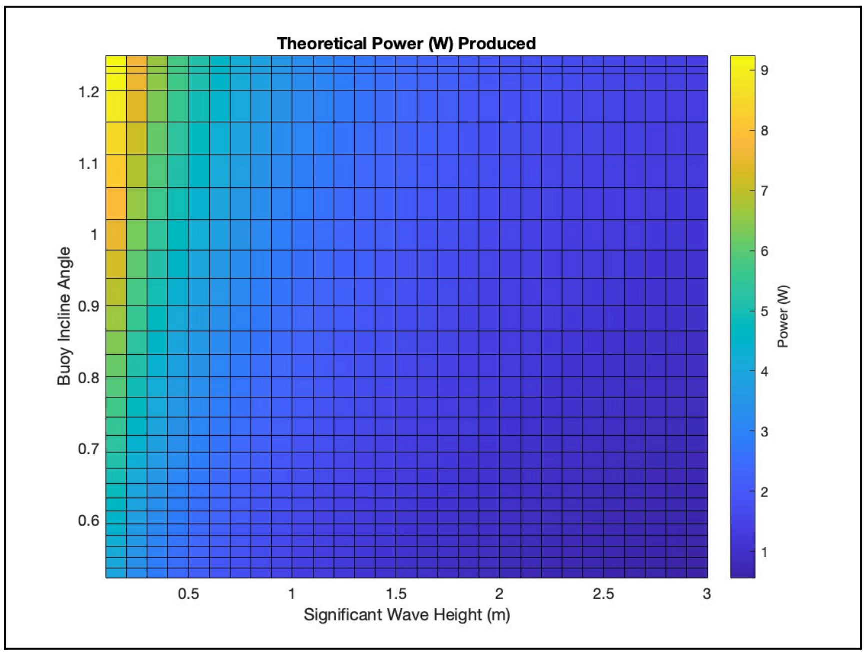

Figure 9: Theoretical Power Produced From a Range of Wave Heights and Periods

It is important to note that the equation assumes the rotating mass is in resonance with the waves, which is unrealistic. The drifter will constantly be subject to different wave heights and periods, and the rotating mass will not be completing full 360º rotations every time. What is important to note from this table is that the rotating mass drifter has a trend of producing more power in shorter, choppier waves. This is beneficial because these short and choppy waves are common wavelets that form from wind and can be on top of larger swells.

17. Energy Resource

Drift-RMT works best in small wavelets with small amplitudes and periods. These types of waves proved to be difficult to find raw data on, since observational buoys mainly track significant wave height and period. These smaller waves are ubiquitous in the ocean; however, they are not measured due to the large hull size of observational buoys. There are small buoys that might measure small waves (e.g. SOFAR Spotter Buoys), although they do not post the raw data which is then manipulated to retrieve the significant wave height and period [14].

In addition to finding minimal data on the waves that the team is after, there is also an added challenge from the fact that this device will be deployed all over the world. This device cannot be designed to one specific location. This is also a reason that our team chose a rotating mass PTO system, since it can harness power from small waves in a sealed and robust manner.

Thanks to Dr. Nathan Laxague of UNH, our team was able to access and use raw spotter buoy output data for our analyses. These buoys were deployed in November near and far off the coast of New Hampshire. From this spotter buoy data, we could perform a wave analysis and view the energy content of the waves that our device works best in. In the plot below, significant spectral density is compared with wave frequency and the height percentile. There is a significant spectral density in the small wave frequency range, indicating the presence of energy in waves with wavelengths on the order of meters or less.

The spotters were roughly 1 mile offshore, and the third data set is Jeffrey's ledge buoy, about 15 miles offshore. The data is colored by percentiles of significant wave height. All data sets show significant energy in small period / higher frequency waves (T < 2s, f > 0.5Hz).

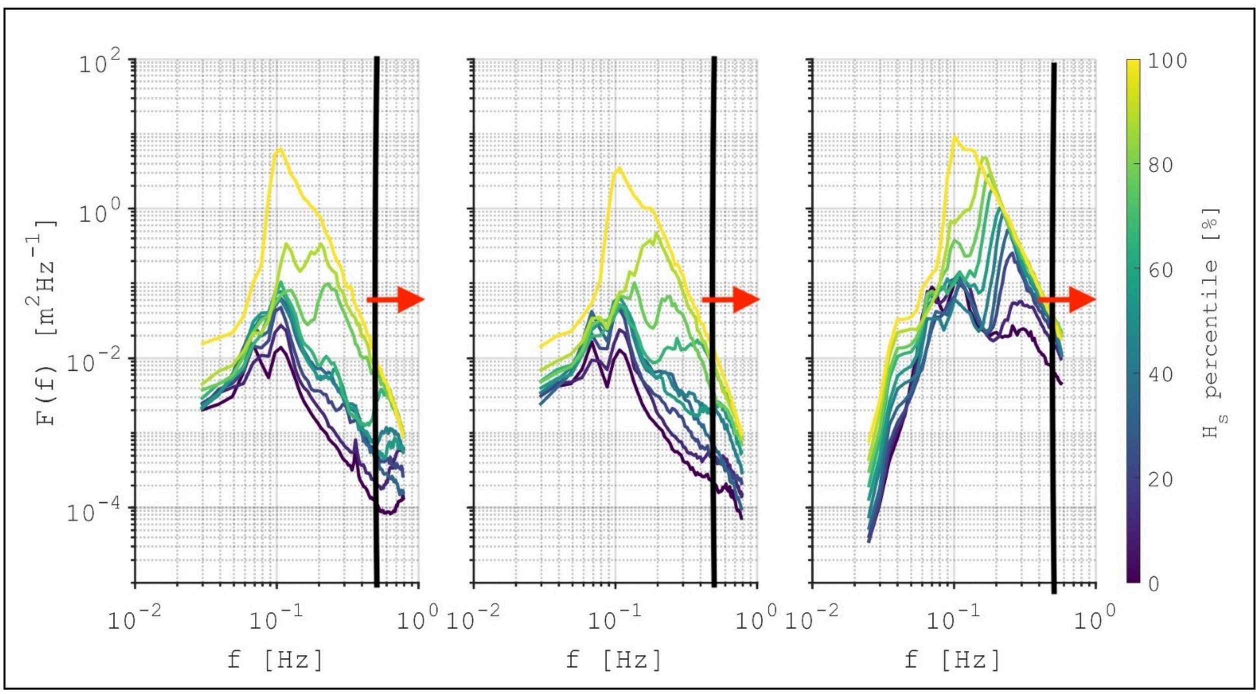

Figure 10. Significant Spectral Density of two near shore SOFAR Spotter buoys (~1 mile off-coast) and a further offshore buoy at Jeffrey's Ledge (right figure) off the coast of New Hampshire [Laxague].

This plot highlights that to the right of 0.5 Hz frequency (2s period), there is still a significant amount of spectral density for both near and far shore, meaning a significant amount of energy is present. It should be noted that the smallest wave period that a spotter buoy can detect is a 0.7 Hz frequency (~1.42 second period), and our device will likely perform in waves with even shorter periods.

18. WEC-Sim

WEC-Sim was used in parallel with the initial design calculations and mechanical design of our device. The main purpose of WEC-Sim is to facilitate the design, optimization, and performance assessment of WEC devices by providing a computational platform for simulating their behavior in different wave conditions. Users can simulate the dynamics of WEC devices, including their buoyancy, power generation, and response to wave forces, to evaluate factors such as power output, efficiency, and structural integrity. WEC-Sim is an open-source tool developed by the National Renewable Energy Laboratory (NREL) in collaboration with other research institutions. It is widely used in the wave energy research community to advance the understanding of wave energy conversion technology and support the development of commercially viable WEC devices [17].

WEC-Sim was paramount in helping the technical design team test theories and concepts with detailed results and visual help. Initially, there was a great deal of confusion and misunderstanding with the software, but with practice we managed to get reasonable results from it and use it to our advantage. As an overview for the approach to modeling the Drift-RMT device into WEC-Sim, the hull of the drifter was treated as a hydrodynamic body while the rotating mass mechanism was treated as a non-hydrodynamic body attached to the hull with a rotational PTO.

A simplified model of the drifter hull with the PTO inside was used to reduce computation times. The hull of the drifter (solid sphere of 38cm diameter) was designed in SolidWorks and brought into BEM Rosetta to transform the triangular STL file into a quadrilateral STL file. Also in BEM Rosetta, the exported file only contained the nodes and faces that were below the water line. This was necessary for Capytaine to perform the hydrodynamic calculations on the hull. Capytaine produced the necessary .nc file, which then could be run by WEC-Sim's BEMIO function to generate the hydrodynamic coefficients and export it into a .h5 file.

With the .h5 file, the Simulink model was then created to represent the drifter hull with the rotating mass PTO. A 6 DOF was used for the hull and a rotational PTO (about the yaw axis) connected the hull to the non-hydrodynamic rotating mass system. The damping of the PTO was 0.01 Nm/s. In the mechanics explorer, the hull of the drifter was made transparent so the team could view the rotating mass mechanism inside of the drifter.

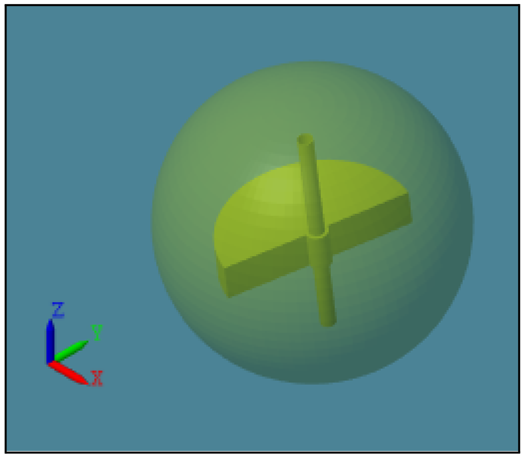

Figure 11. Model of Drift-RMT in WEC-Sim Mechanics Explorer

After initial testing in WEC-Sim, it was clear that with the hull shape and size, Drift-RMT works best in "wavelets". These waves are generally small in amplitude (< 1 meter) and have quick periods (< 2 seconds). The wavelets are steep, which is essential in pitching and rolling our device. Below is an instantaneous power plot of the device. It is noted that the power generation of this device is highly variable and somewhat random depending on the wave characteristics and the location of the mass within the hull.

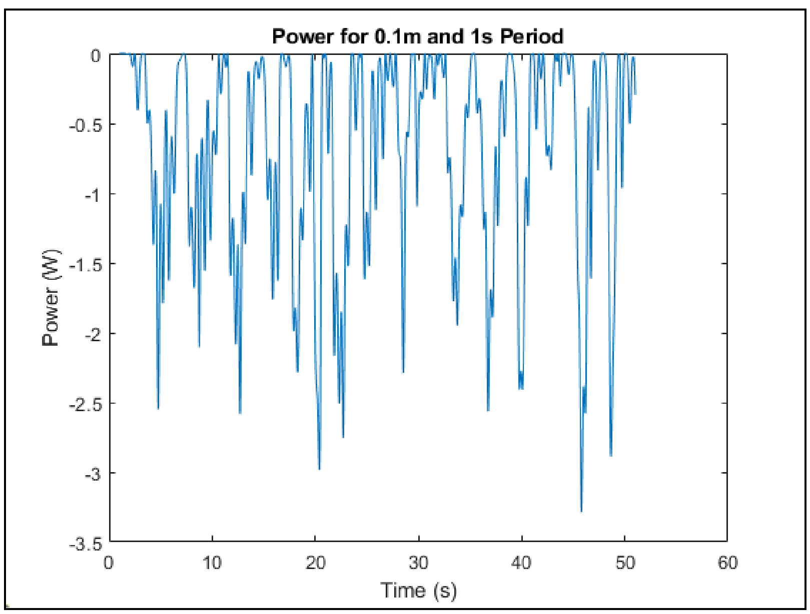

Figure 12. Instantaneous Power for a wave height of 0.1 meters and 1 second period. The average power of these wave conditions is 0.7 watts. The negative power is just a WEC-Sim sign convention.

The results from WEC-Sim proved that this device could produce more than enough power when in the correct wave conditions. In the plot above, for such small wave conditions, the model produced over ten times the required power. This power is of course an over assumption because there will be power losses through gears, friction, and circuitry. Combining multiple runs of this model with different wave conditions led to a rudimentary power matrix of the device. This is depicted below in Table 4. Power is in Watts.

		Wave Period (s)					
		0.5	**1**	**1.5**	**2**	**2.5**	**3**
Wave Height (m)	**0.05**	0.01	0.02	0.18	0.01	0.01	0
	0.1	0.02	0.7	0.35	0.03	0.01	0
	0.15	0.05	1.81	1.26	0.09	0.03	0.01
	0.2	0.12	2.98	N/A	0.16	0.05	0.02
	0.25	0.24	N/A	N/A	0.28	0.12	0.04
	0.3	0.51	N/A	N/A	0.35	0.21	0.07

Table 4. Power Matrix of WEC-Sim model through various wave conditions. Power in Watts.

In the table, there are quite a few sets of wave conditions that far exceed the power demand of the drifters. The N/A boxes represent a set of wave conditions that caused the model to flip over in the initial WEC-Sim runs, which led to instability in the simulation and caused the code to "blow up". In the ocean, this device will either not tip over due to the drogue being present or will tip itself back over quickly due to the center of gravity having shifted to the top of the hull. It is expected that the power generated in the N/A boxes is relatively large compared with the other boxes compared to the overall trend.

In addition to the simple mass shown above, a more complex rotating mass mechanism was tested in WEC-Sim. It was thought by the team that a mechanism with more rotational inertia would yield more power and better efficiency, although the hull is not there to support the greater center of gravity radius of the mass. In the visual, it could be seen that the redesigned mass would simply tilt the hull too much and the sphere did not have the wiring abilities to tip back up. Below is the model with the redesigned rotating mass mechanism. Generally, the spherical hull shape is not ideal for a WEC PTO, although we decided to stick with the form factor of traditional drifters due to a competitive business advantage. To assist in the self-righting abilities of the hull, it needs to have a low center of gravity, which can be achieve by appropriate mass distribution

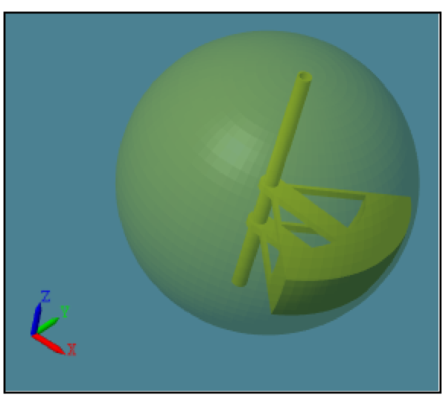

Figure 13. WEC-Sim Model with Redesigned Mass

19. Drogue Considerations

For drifters to “drift” along with the current, they are deployed with a drogue. A drogue is a 15-20 meter long “sock” which is weighed down by a sandbag and attached to the bottom of the drifter’s hull [10]. The drogue catches near-surface currents, thus moving the drifter along with it. This helps make the drifter a true Lagrangian ocean drifter, as it becomes less impacted by winds at the surface. *Figure 14* depicts a drifter at the ocean surface, with a 15-meter drogue attached that extends downward.

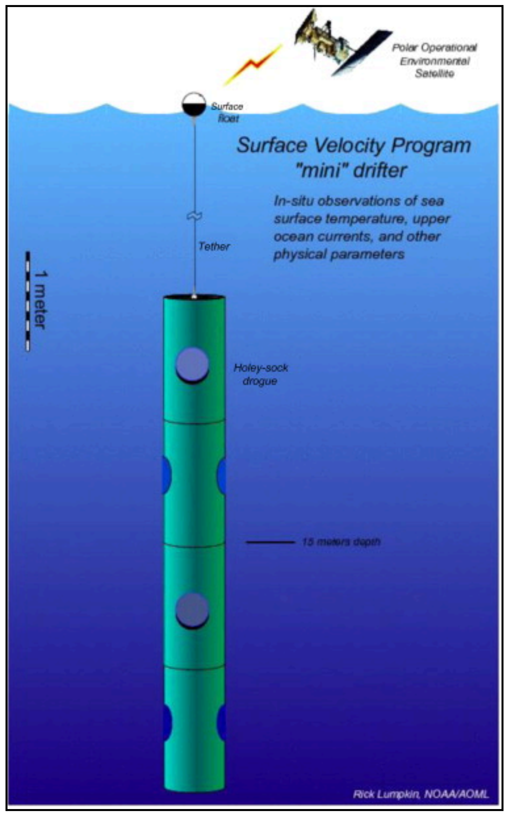

Figure 14: Drogue Attached to Drifter [10]

Design and operational concerns regarding the drogue and rotating mass system arose, particularly concerning whether the rotating mass system might hinder the buoy's movement with the current. An additional concern was if the downward force exerted by the drogue on the drifter could also limit the electrical generation.

When considering the buoy's motion in line with the current, the rotating mass system would exert minimal influence. This is primarily due to the intended function of the drogue and the dynamics of ocean currents. The drifter is designed to track near-surface currents, which permeate depths up to 100 meters in the ocean, rather than solely those at the surface level [12]. With the drogue extending down 15-20 meters, it will continue to propel the drifter along these near-surface currents. The force generated by the rotating mass system will have little to no effect altering the buoy's movement.

To address the concern of power generation, the team attempted to model a drogue in WEC-Sim and re-run a power take-off test. To model the drogue, a mass further down in the water column was created as a non-hydrodynamic body and attached to the bottom of the hull. The mass was selected to be 5kg and 3 meters below the surface. The results showed minimal to no pitch and roll of the rotating mass drifter, which was expected. However, it's important to note that this representation doesn't explicitly match a real drogue, which is a complex hydrodynamic structure with uneven mass distribution. For a more accurate model, the drogue would need to undergo analysis via a BEM solver and be treated as a hydrodynamic entity. If the more precise model reveals that the drogue does in fact restrict the device's pitch and roll, then relocating the rotating mass mechanism to the top of the hull might prove beneficial. Additionally, the team could redesign how the drogue is attached to the drifter. A gimbal system between the drogue and the drifter would allow the drifter to rotate without the drogue inhibiting the pitch and roll of the buoy. The adjustment could potentially enhance the device's instability, inducing more pronounced pitching and rolling, provided that the drogue maintains the system's upright position.

20. Design Specifications & Material Study

To design our rotating mass drifter, the team decided to improve the existing hull design of a traditional drifter. While traditional rotating mass WEC's are designed with an unbalanced hull, Drift-RMT has maintained a spherical shape to leverage a competitive edge in the market, maximize design simplicity, and uphold its established position within the industry. The team has decided to use injection molded ABS plastic for the buoy's hull to maintain aspects of the current drifter design that have proven to be durable and weather resistant. Currently, the drifters are also using nylon drogue connected to the bottom of the hull with impregnated stainless steel. However, since the drogue is critical to buoy's ability to follow ocean currents, a shortened drogue was considered for wave tank tests.

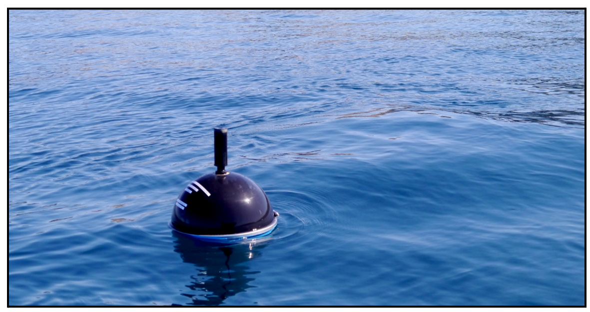

Figure 15: NOAA SVP drifter

The center shaft will be made of corrosion resistant 316 stainless steel. This material was chosen to maximize longevity and cost efficiency of the buoy. The mass that drives the rotation of the shaft will be attached with an arm made of machined steel. This will extend almost to the edge of the hull interior with 1 kilogram of tungsten attached at the farthest point from the shaft. Tungsten, although expensive, is a dense metal that will be beneficial to space maximization in the drifter's compact design. A 2 kilogram mass produced proficient power output in WEC-Sim with cost and optimization determining the final design. Since the shaft will be fixed with two bearings on either end and the buoy will be designed for a roll angle between 0° and 35°, a fatigue analysis of the center shaft was necessary to determine proper materials. First, a centripetal force calculation assuming the 2 kilograms is positioned at the farthest point from the shaft. Using:

$$Fc = mr\omega_{max}^2$$

where *m* is the mass *r* is the radius and *ω* is the maximum angular velocity that the shaft will experience and the following estimates for shaft dimensions:

Inner diameter = 0.96 centimeters

Outer diameter = 1.27 centimeters

Length = 38 centimeters

Radius = 25 cm

It is likely that these assumptions are exaggerated but will only provide extra security against failure. The centripetal force with these parameters was calculated to be approximately 395 kN (kilonewton). To calculate stress in the moment induced in the shaft must be calculated with the following equation:

$$M = \frac{2F(\pi r_o^{\ 2} - \pi r_i^{\ 2})}{L^3}$$

This equation coupled with the equation for bending stress:

$$\sigma_b = \frac{64M}{\pi(d_o^{\ 2} - d_i^{\ 2})}$$

Gives the equation:

$$\sigma_b = \frac{128F(\pi r_o^{\ 2} - \pi r_i^{\ 2})}{\pi L^3(d_0^{\ 2} - d_i^{\ 2})}$$

From which the bending stress of a hollow pipe under centripetal forces was calculated to be approximately 2.8 MPa. According to a material study done by Bo Chen, Koenraad Janssens, and Fionn Dunne on 316L stainless steel, this is well below the endurance limit of the material.

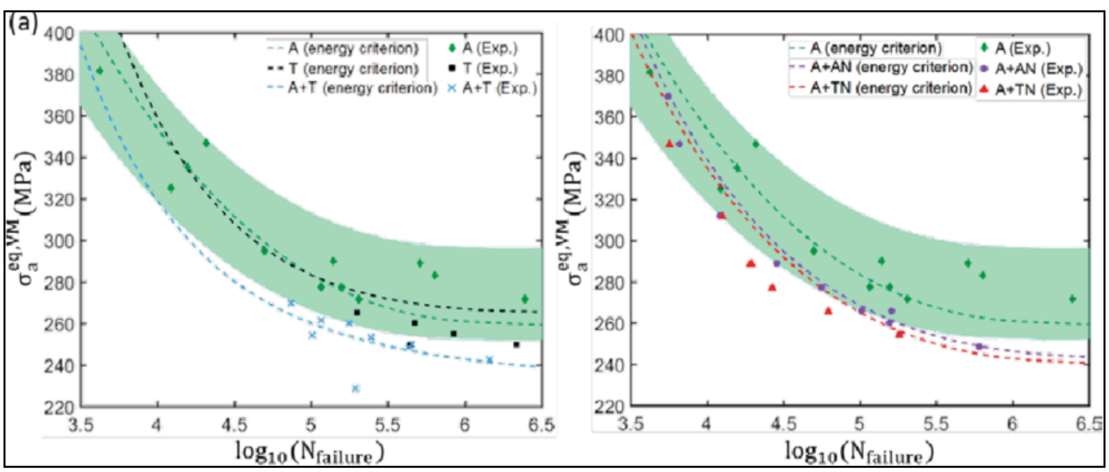

Figure 16: SN Curve of 316L Stainless Steel

The drifter's completely sealed design will prevent any water from entering the buoy, ensuring the electrical and metal components will not be compromised. The shaft will be connected to an electric-mechanical motor to produce electricity. The team chose a 12V metal gear motor. This specific motor was chosen because it has a 1:150 gear ratio, close to what was estimated initially. The large gear ratio is needed to gear up the rotation because the weighted mass and shaft will not be spinning quickly, and often changing direction.

The motor will be connected to a rectifier circuit, which will produce the absolute value of the input voltage. This is needed because the mass will rotate both clockwise and counterclockwise about the center shaft, and will spin the motor both ways, producing both positive and negative voltage. In series with the rectifier circuit will be a power management system, to regulate the voltage being transmitted to the 4 rechargeable lithium-ion batteries. The four lithium-ion 4.2V 2000mAh batteries will power the sensors on board. The sensors on board of each drifter are up to the customer, including GPS, a barometer, a thermistor, a salinity sensor, and a sonic anemometer. Like traditional drifters, Drift-RMT drifters transmit data hourly to a satellite.

The rotating mass system, including the shaft, weighted mass, motor, power management system, drogue, and 4 rechargeable lithium-ion batteries, has a total weight of about 15 kilograms. This is just under the current drifter design weight in part due to the removal of the 30 D-cell batteries. With this substitution, the drifter is saving 2.5 to 5 kilograms of weight, which would allow for additional sensors to be added.

21. Sustainability Overview

21.1 Overview

By harnessing the power of waves, Drift-RMT provides a sustainable method for collecting ocean data with considerably reduced environmental impacts compared to traditional drifters. NOAA has reported that 63% of drifters fail due to a “quit transmitting” error. After discussions with the manager of the global drifter program, it was revealed that NOAA infers "quit transmitting" to signify battery failure. This battery failure is attributed to the drogue pulling the drifter underwater as it attempts to transmit data packets, which significantly drains the battery. Without a power source, these drifters are unable to update their locations, becoming marine debris. Throughout the lifetime of the global drifter program, over 8900 drifters have “quit transmitting”, a consequential portion of which are not retrieved and contribute to marine pollution. The current power source of the drifters is 30-50 D-cell Alkaline batteries. These batteries are bulky and material intensive.

Concern within the public has been raised over a drifter's possible impact on marine animals. However, drifters are not known to harm marine wildlife and often house crustaceans which attract larger species forming a micro-habitat. Another concern was marine disturbance through noise pollution, so the design is tailored for silent ball bearings and insulation to self-contain any noise. Marine toxicity due to the chemical composition of the Lithium-Ion batteries is addressed by using encapsulated batteries that are leakproof. Finally, the prevention of marine debris will be actualized with GPS tracking through Iridium to enable the location and retrieval of any device as well as monitoring the electrical component health.

21.2 Life Cycle Analysis

A life cycle analysis (LCA) is an analysis of the environmental impacts of a product or process over its entire life. The analysis accounts for the materials, production, distribution, use, and disposal of the product or process. For this project's purposes, a lifecycle comparison of the Drift-RMT's WEC system was compared to the alkaline battery pack used in current drifters. The rest of the sensors and materials associated with the drifters were omitted as they would be the same no matter which powertrain is utilized. The LCA was performed on SimaPro, and the kilograms of carbon dioxide equivalence from each stage of the two powertrains' life cycles were compiled graphically, as shown in *Figure 17*.

Drift-RMT replaces the D-Cell batteries with 4 Lithium-Ion batteries and a rotating mass WEC would reduce the global warming potential of these drifters by 94% in terms of kg of CO2 equivalence. Although Li-ion batteries require precious metals gathered with invasive mining not seen in Alkaline batteries, the reduction of overall required energy storage leads to environmental benefit. D-cell Alkaline batteries use 160g of material while our Li-ion batteries are almost the size of an AA battery and only use about 45g of material. Not only is the base design of the drifter more environmental in energy storage, but when we factor in the 5x extended lifetime and retrievable nature of our design it is by far the more environmentally advantageous solution. An extended lifetime also reduces operating and maintenance which will help eliminate the emissions from vessels having to redeploy drifters annually.

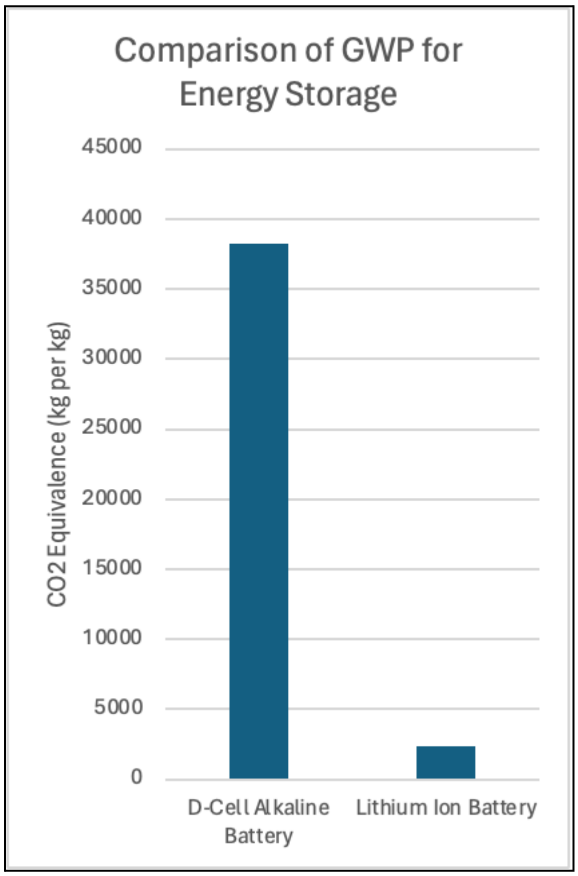

Figure 17: LCA D-Cell Alkaline Battery vs. 4.2 V Lithium Ion Battery

Build and Test Challenge

22. Introduction

The build and test team took a systematic approach throughout the testing process, allowing isolation of each subsystem of the prototype. By separating the rotating mass, motor, and drogue tests, the team developed a complete understanding of how each individual subsystem operates and how they react when interacting with each other. This approach allows the team to predict how a prototype will perform before building it, optimizing the complete system's performance. Going forward, the team plans on testing additional variables that would affect the performance of the drifter including the size and shape of the rotating mass, the size and location of the stabilizing mass inside the drifter, and different power storage loads.

23. Scaling

Froude scaling is a method used in hydrodynamics to ensure that the behavior of a scaled-down model in a wave tank test accurately represents the behavior of the full-scale object in real-world conditions. The principle behind Froude scaling is based on the concept of similarity between two systems. In this case, the similarity is between the model being tested in the wave tank and the full-scale object it represents.

The key parameter in Froude scaling is the Froude number, denoted as Fr. It's defined as the ratio of the inertial forces to gravitational forces and is expressed as:

$$Fr = \frac{V}{\sqrt{gL}}$$

Where V is the velocity of the fluid or the buoy, g is the acceleration due to gravity, and L is a characteristic length (buoy diameter). In Froude scaling, the Froude number in model tests is matched to the Froude number of the full-scale system. This ensures that the dominant forces, such as gravitational and inertial forces, are accurately scaled between the model and the full-scale object [18].

For the Drift-RMT build and test team, the buoy we modeled and tested in the wave tank was to scale. In this specific case, no Froude scaling was necessary, however, it is important to note that the team considered such when deciding how to test the ocean surface drifter. Going forward, if we were to test a buoy with a full-length drogue, we would have to create a smaller scale drifter and consider Froude scaling as discussed above.

24. Testing Methods

All pieces of the first prototype that were able to be created using a 3D printer were designed and printed using the UNH Makerspace to save on assembly cost. All other parts were purchased through various online retailers. As the necessary parts became available, the Build and Test team assembled the first prototype. The 3D printing, purchase, and assembly of parts took place over the last few weeks of January and the first prototype was completed on February 1, 2024.

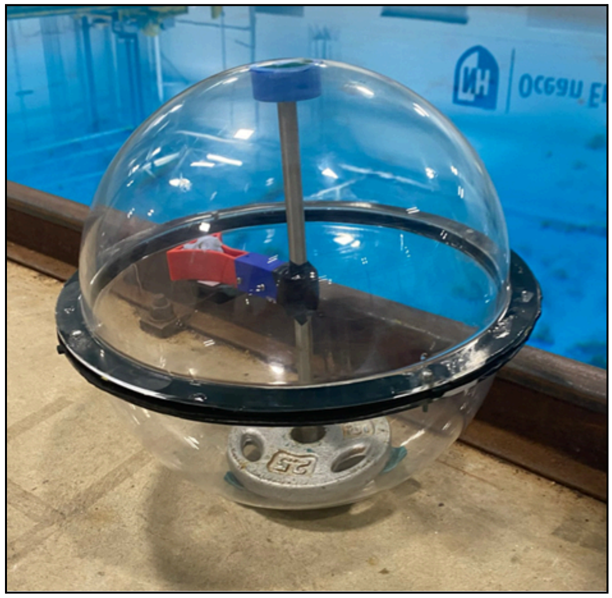

Figure 18: First prototype of Drift-RMT

The initial tests of the first prototype took place on February 22, 2024 in the University of New Hampshire's (UNH) Chase Ocean Engineering wave tank. During these tests, the Build and Test team took video of how the rotating mass reacted to waves with several different wave height and period characteristics. Originally, the team planned on using video analysis software with these recordings to gather angular velocity and acceleration data. Poor video quality caused inefficient analysis and inaccurate data. The team decided a more accurate, efficient method for collecting data was needed.

The second set of wave tests took place on March 26, 2024 in the UNH wave tank. The tests were similar to the first tests with the addition of an accelerometer that was attached to the rotating mass arm. The accelerometer, connected to a computer wirelessly, measured angular position, velocity, and acceleration and the drifter was tested under twelve unique wave conditions. The angular velocity data for each of these tests was plotted as a function of time using MATLAB software. These data sets were given a best fit line that was plotted over the raw data. These best fit lines help filter the raw data and eliminate noise caused by equipment or environment limitations.

To support this data for the drifter without a drogue, the team conducted tests to explore how attaching a drogue would affect the angular velocity of the rotating mass enclosed in the drifter. The drogue prototype was built out of a nylon laundry basket and a 5 lb. weight attached to the bottom. Due to the depth limitations of the wave tank the drogue was scaled down to approximately 10% of the size of an actual drogue. Since drifters typically have portions of their lifetime both with a drogue attached and without, the team felt it was important to prove the rotating mass system had the tendency to rotate under both conditions.

A critical step in determining the necessary gear ratio connecting the shaft of the rotating mass to the electro-mechanical motor is knowing the average angular velocity under each wave condition. The accelerometer measures clockwise rotations as having positive angular velocity and counterclockwise rotations as having negative angular velocity. Since the system has the same tendency to rotate in either direction, averaging the data set would result in 0 rad/sec. The absolute value of the data set was averaged to find the average angular velocity of the rotating mass disregarding the direction of motion.

The team conducted lab tests on three different sized electro-mechanical motors to determine each's operating range. These tests were conducted on April 16, 2024 using the UNH Makerspace. It was assumed that the voltage supplied to the motor, generating a specific angular velocity, would be the same voltage produced by the motor given the same angular velocity supplied to the motor.

Motors were chosen based on the premise that the torque required for operation at their maximum operating range would not impact the angular displacement of the rotating mass system. Only motors with less than one ounce-inch of torque were considered. The three motors tested consisted of a six-volt motor the team took from a hand crank provided by KidWind for a community connections activity, a six-volt motor purchased from DigiKey (1), and a twelve-volt motor purchased from DigiKey (2).

The three motors were connected to a direct current power supply. For these experiments the power supply was set to limited voltage. The voltage across each motor was gradually increased until the motor shaft started to rotate. Once the minimum voltage required to overcome the static friction of the shaft was discovered, the team measured its angular velocity at increasing voltage increments. The team tested each motor up to the voltage it was rated for.

After analyzing this data, the team determined the optimal gear ratio each motor needed to take advantage of the rotating mass system under the tested wave conditions. Determining which motor to use depends largely on the load the electro-mechanical motor is supplying power to. This means that final battery and power management systems will determine the generator selected.

Using the angular velocity data of the rotating mass system, the team used the gear ratios to determine the corresponding angular velocity of the motor shaft when connected to the system. Having the predicted angular velocity of the motor at any given time allows the team to predict the theoretical voltage produced by the motor using the data collected during the lab tests.

The team was able to build a second prototype combining the motor provided by the KidWind kit with the rotating mass system. The second prototype was built using a suboptimal gear ratio due to time constraints and available materials.

Figure 19: Second prototype with gears

Despite not producing the optimal voltage the team was able to predict the accuracy of the methods in which they predict output voltage from the motor. Lab tests were conducted on April 23, 2024 in which data for both the angular velocity of the rotating mass and voltage produced by the motor were collected. The angular velocity of the rotating mass was manipulated using the methods outlined above to predict a theoretical voltage produced. These numbers were then compared to the results collected of the actual voltage produced by the motor.

A timeline of the build and test progress can be found below in *Figure 20.*

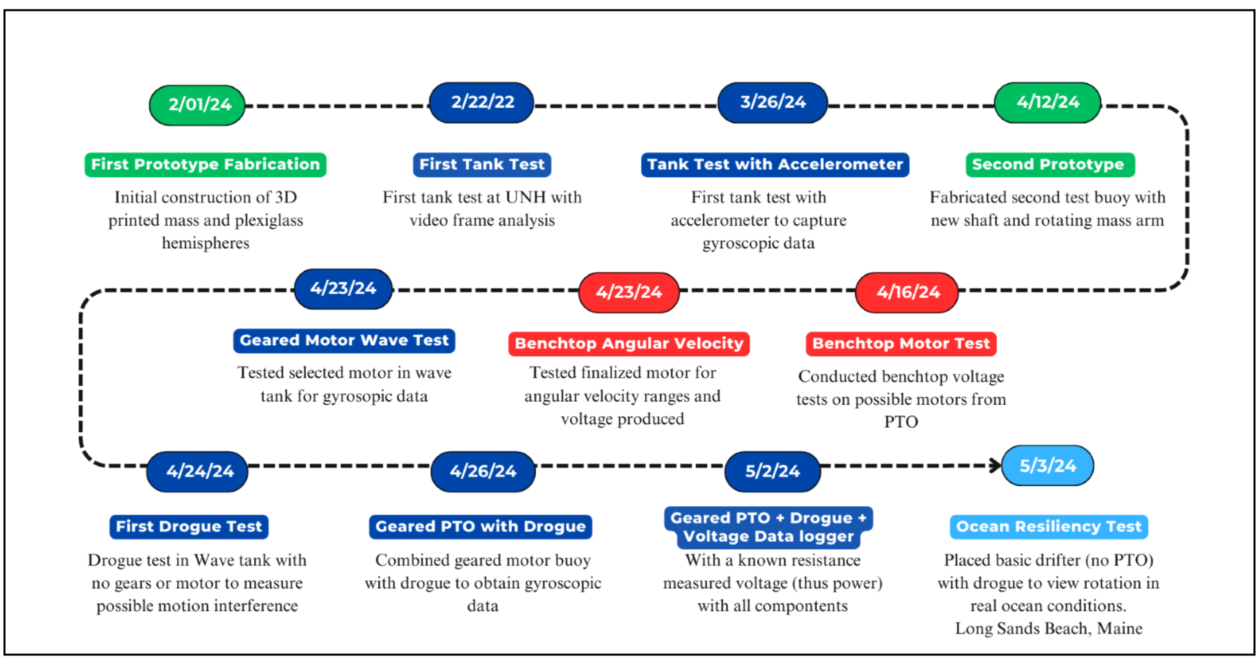

Figure 20: Timeline of Build and Test progress. Prototype construction, wave tank testing, benchtop testing, and ocean test.

25. Results and Analysis

Although no raw data was collected from the first set of tests on February 22, they still proved to serve as proof of concept for the rotating mass system. Through video analysis, the team estimated an approximate maximum angular velocity of eighty rotations per minute and an average angular velocity of around thirty rotations per minute.

The data collected during the March 26 tests proved to be much more useful for technical analysis. *Figure 21* below shows the data collected from the accelerometer. The raw data was filtered to find a best fit line that eliminates a significant amount of the signal noise. The plots of raw data with the best fit line for all twelve wave conditions can be found in Appendix B.

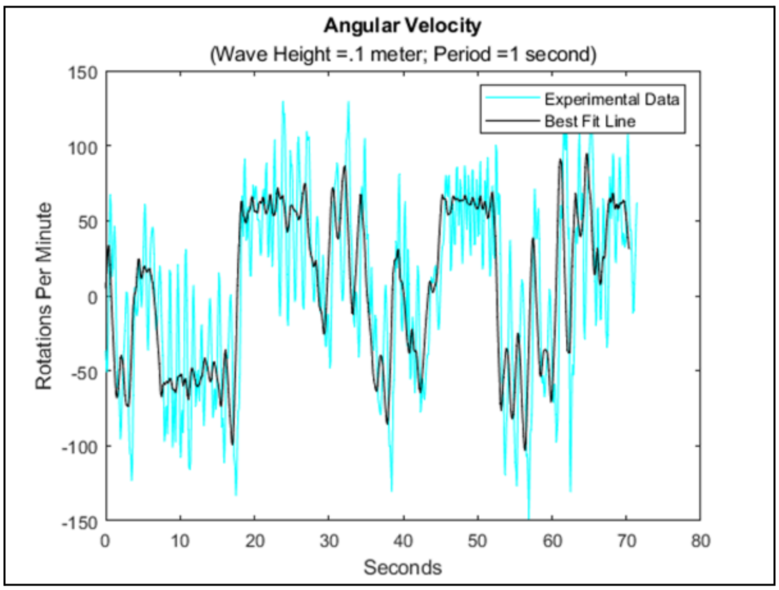

Figure 21: Angular Velocity test

As mentioned in the testing methods section of this report, the absolute value of this data was averaged to find the average angular velocity of the rotating mass regardless of the direction of motion. The average angular velocity of the rotating mass under each wave condition can be found in the tables below.

0.05 meter waves		
Wave Period (seconds)	**Maximum Angular Velocity (RPM)**	**Average Angular Velocity (RPM)**
1	81.33	40.92
1.1	24.62	3.04
1.2	13.80	1.84

Table 5: Wave tank tests 0.05 meter waves

0.1 meter waves		
Wave Period(s)	**Maximum Angular Velocity (RPM)**	**Average Angular Velocity (RPM)**
1	103.44	46.7
1.05	97.47	46.28
1.1	89.59	43.6
1.2	38.06	5.66

Table 6: Wave tank tests 0.1 meter waves

0.15 meter waves		
Wave Period(s)	**Maximum Angular Velocity (RPM)**	**Average Angular Velocity (RPM)**
1	83.41	43.56
1.05	88.8	43.12
1.1	94.29	42.18
1.15	96.92	38.62
1.2	88.4	34.44

Table 7: Wave tank tests 0.15 meter waves

The data from *Table 5*, *Table 6*, and *Table 7* are plotted to give a visual representation of the relationship between angular velocity and wave period given a constant wave height. These plots can be found below.

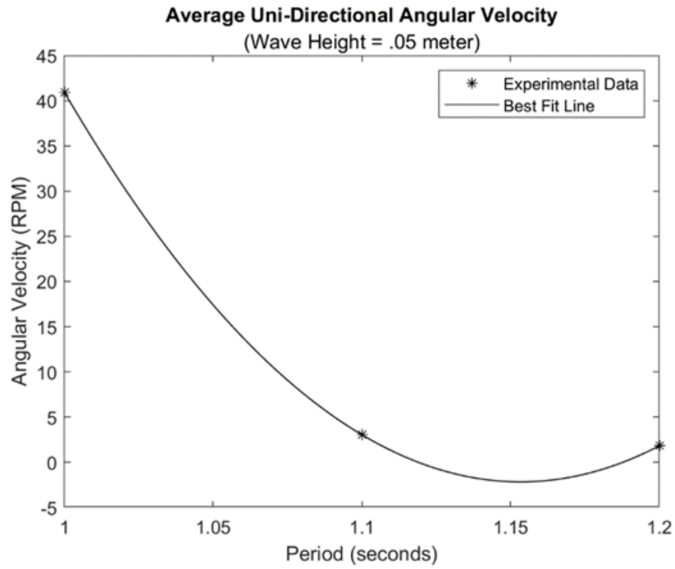

Figure 22: Average angular velocity with wave height 0.05m

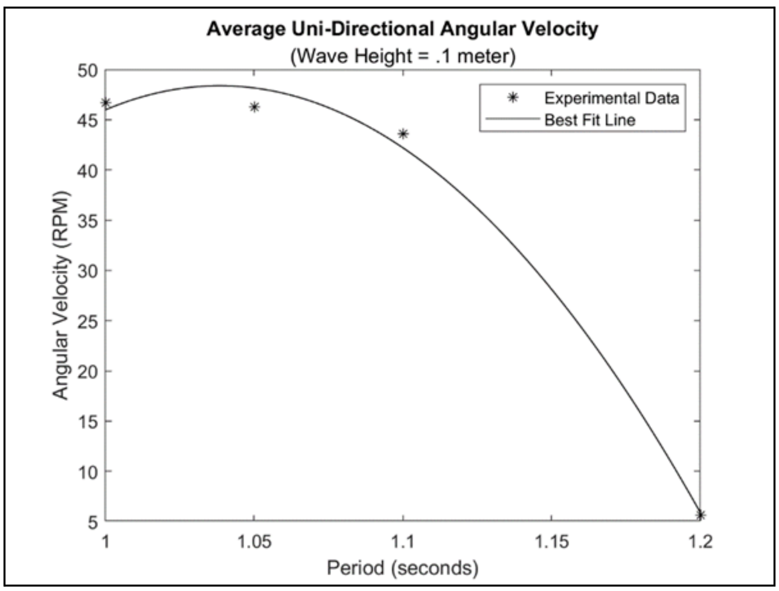

Figure 23: Average angular velocity with wave height 0.1m

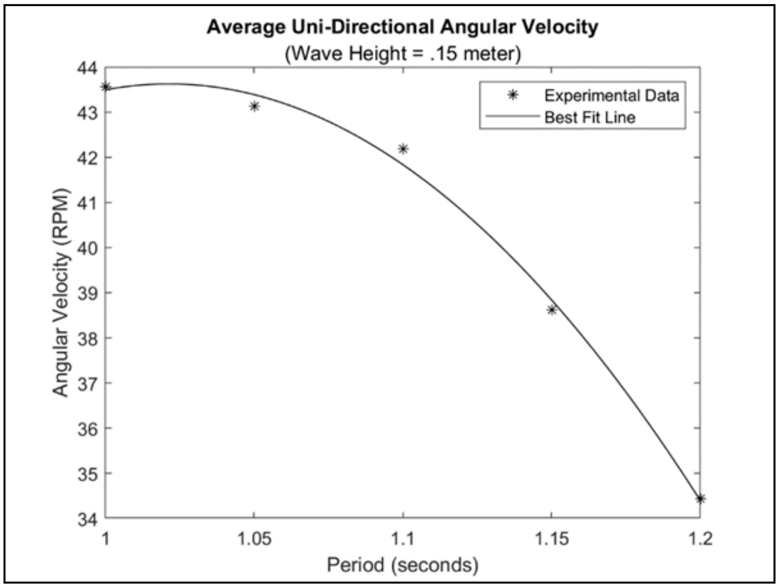

Figure 24: Average angular velocity with wave height 0.15m

Figures 23 and *24* show a clear second order relationship between period and angular velocity. It is believed that this relationship will continue until the average angular velocity reaches zero at which point it will flatline and stay at zero. *Figure 22* shows a second order relationship the team believes to be inaccurate. It is believed that the angular velocity by waves that have a 1.1 second period and 0.05 meter wave height has already flatlined. A likely explanation is that an insufficient amount of data points were collected for waves with periods between 1 second and 1.1 seconds. The team predicts that if more measurements had been taken between these points the relationship between wave period and angular velocity would look like that of *Figures 23* and *24*.

Analysis of the data for wave heights of .15 meters and .1 meters brought the team to a few interesting conclusions. The first is that shorter periods lead to higher angular velocities. This makes sense because the motion of the internal mass depends on the change of the buoy's angle with respect to vertical. As the drifter rides the inclination of a wave, gravity settles the mass to the lowest point. Once it changes to riding the wave's declination, the rotating mass rotates to the other side of the drifter, now the lowest point until it rides the inclination again. Shorter periods result in a more frequent change of angle. It can also be seen that waves with a larger wave height tend to maintain a wider range of significant average angular velocities. The rotating mass manages to spin at an average angular velocity of 17.22 rotations per minute at a 1.2 second period and 0.15 meter wave height while it reduces to 2.83 rotations per minute at the same period for waves with a wave height of .1 meters. This observation supports the team's belief that the relationship for *Figure 22* is incorrect because there are not enough data points between 1 second and 1.1 seconds.

In general, all three of these wave conditions are relatively small and short. These wave conditions exist when larger, longer waves are present in the ocean. The build and test team refers to these waves as "chop". Data investigating the larger and longer "carrier waves" is far more prevalent than data on ocean chop. The choppy waves are caused by local wind gusts or marine traffic. Although there is less data on these smaller waves, the team believes that these conditions are often present in the ocean.

On April 24 the team conducted tank tests on the drifter with a drogue attached. The tests were conducted with the intent to explore how a drogue attached to the bottom of the drifter would affect rotation. Five tests were conducted under wave conditions with .15 meter heights and varying wave periods. The raw data was processed and analyzed with the same procedure as the data from the March 26 tests. The figure below shows that data collected under wave conditions of .15 meter wave height and 1.00 second wave period. The other four plots can be found in Appendix C.

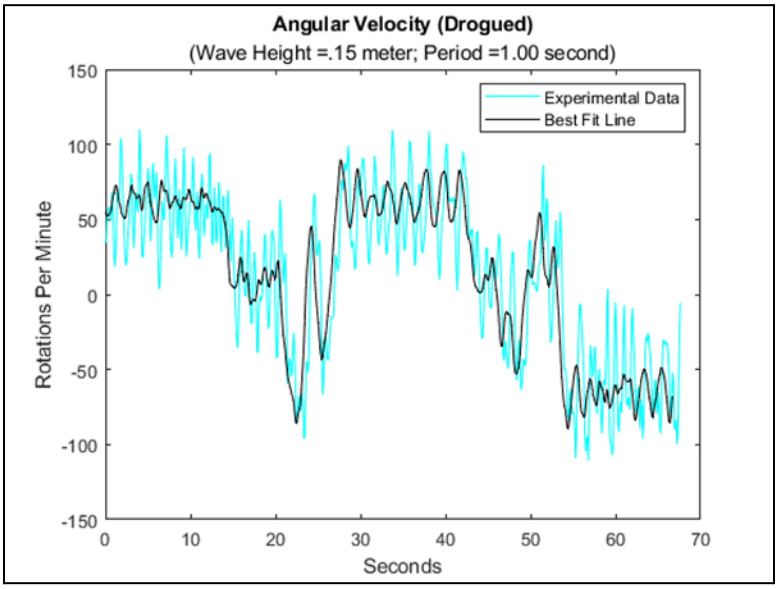

Figure 25: Average angular velocity with drogue

Initially, the team predicted that the drogue attachment would slightly dampen the average angular velocity of the rotating mass because the drogue would act as a stabilizing force for the entire system. Through visual observations of the tests and the data analysis, the team determined this initial prediction was incorrect. The rotating mass maintained a higher, more consistent angular velocity in these tests than it did when the drifter was tested without a drogue attached to the bottom. The drogue appeared to act as a stabilizing force only for itself while still allowing waves to affect the buoy’s angle with respect to vertical. The dampening of the rotation of the drifter hull, while not affecting that of the rotating mass, increased the relative angular displacement between the two. Though this motion was dampened, the ball bearings at either end of the shaft permitted the mass to rotate even with a lower inclination angle. The team believes that the increase in average angular velocity arises from the drogue’s impact on motion regulation. The drogue allowed the rotating mass to reach a resonant frequency more often since the motion was less chaotic.

In the table below the average and maximum angular velocity of the rotating mass in the drifter with a drogue attached under each wave condition can be found using the same analysis technique used on the data from Tables 5-7. Also included are the maximum and average angular velocities of the rotating mass in the drifter without a drogue attached for comparison.

0.15 Meter Waves				
Wave Period (s)	**Maximum Angular Velocity (Drogued) (RPM)**	**Maximum Angular Velocity (Un-Drogued) (RPM)**	**Average Angular Velocity (Drogued) (RPM)**	**Average Angular Velocity (Un-Drogued) (RPM)**
1.00	89.85	83.41	49.28	43.56
1.05	86.98	88.8	59.02	43.12
1.10	92.09	94.29	53.41	42.18
1.15	82.57	96.92	47.31	38.62
1.20	35.40	88.4	4.73	34.44

Table 8: Angular mass with(out) drogue for 0.15 meter waves

As can be seen from the data in table 8, the average angular velocity of the rotating mass in the drogued drifter is approximately 10 RPM higher than in the un-drogued drifter. Although this increase in average angular velocity may seem insignificant, once the rotating mass system is connected to an electromechanical motor through a gear train, the potential power created will increase by around 20% depending on the gear ratio and motor used.

Combining the data obtained through visual analysis, along with comparing the plots from Appendix C to the plots in Appendix B under the same wave conditions, the team noticed that the rotating mass rotates more directionally consistent when a drogue is attached compared to when it is not. This information is important because the team believes that the erratic behavior of the rotating mass in the un-drogued drifter may result in lower efficiency when generating power. Less erratic behavior also decreases the time it takes for some parts in the system to fail mechanically.

Although the drogued drifter provides higher average angular velocity than the un-drogued drifter, the data for the latter were used for the analysis throughout the rest of this paper. The un-drogued drifter data was used in this analysis because the drogue typically detaches early in a drifter's lifetime. Using the un-drogued drifter data allows the team to get more realistic expectations of what the drifter will experience for the majority of its lifetime.

The motor tests on April 16 provided useful data on motor specifications essential to predicting the power produced under each wave condition. Each motor was tested between the lowest voltage supplied that allowed the motor to overcome the static friction of the shaft and the highest voltage it was rated for. The results for each of the six-volt, twelve-volt, and twenty-four-volt motors are displayed in the plot below.

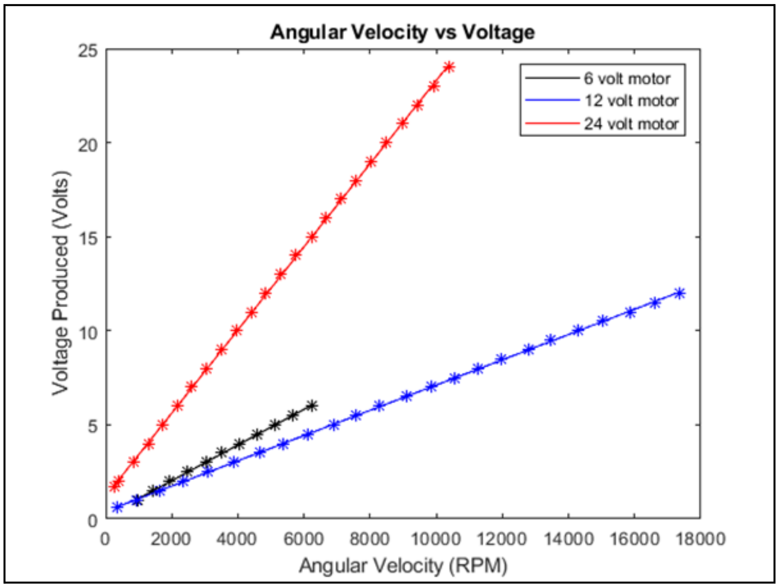

Figure 26: Average angular velocity vs voltage

As expected, the motors rotated faster the more voltage supplied but each had different operating ranges and rates of change. The six-volt motor had an operating range of 980 to 6,240 rotations per minute. The twelve-volt motor had an operating range of 365 to 17,350 rotations per minute. The twenty-four-volt motor had an operating range of 276 to 10,390 rotations per minute.

To determine the appropriate gear ratio for each motor in the wave conditions tested, the team decided it was best to match the maximum angular velocity of the rotating mass in the drifter without a drogue attached, 97.47 rotations per minute, with the maximum operating range of each motor. Under different wave conditions there may be different maximum angular velocities for the rotating mass, so the gear ratio would need to be adjusted appropriately. To determine the appropriate gear ratio the following relationship was used, where ω represents angular velocity and GR represents the gear ratio.

$$GR = \frac{\omega_{motor}}{\omega_{mass}}$$

Using this relationship the appropriate gear ratios were determined to be 64:1 for the six-volt motor, 178:1 for the twelve-volt motor, and 106:1 for the twenty-four-volt motor under these wave conditions. Ultimately, the electrical components within the drifter will determine the motor and therefore gear ratio necessary for optimal performance.

For the reasons described in the “Testing Methods” section of this report, the team used a sub-optimal gear ratio with the motor provided to us from KidWind. The gears available to the team had a ratio of 40:1. Despite providing sub-optimal voltage, the team tested the accuracy of their motor voltage predictions against actual voltage generated.

The team conducted lab tests where the drifter was rocked back and forth, mimicking the motion of the drifter in choppy seas. Data from the accelerometer measuring the angular velocity of the rotating mass was manipulated to develop the predicted voltage produced by the motor for each test. The data for the experimental voltage produced by the motor was collected using a digital oscilloscope. The results for each of the three tests can be seen in the figures below.

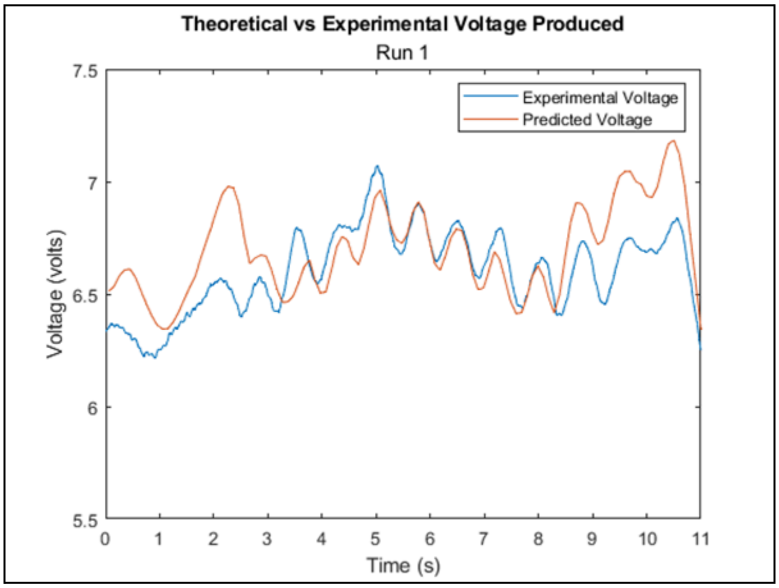

Figure 27: Theoretical versus experimental voltage produced, run 1

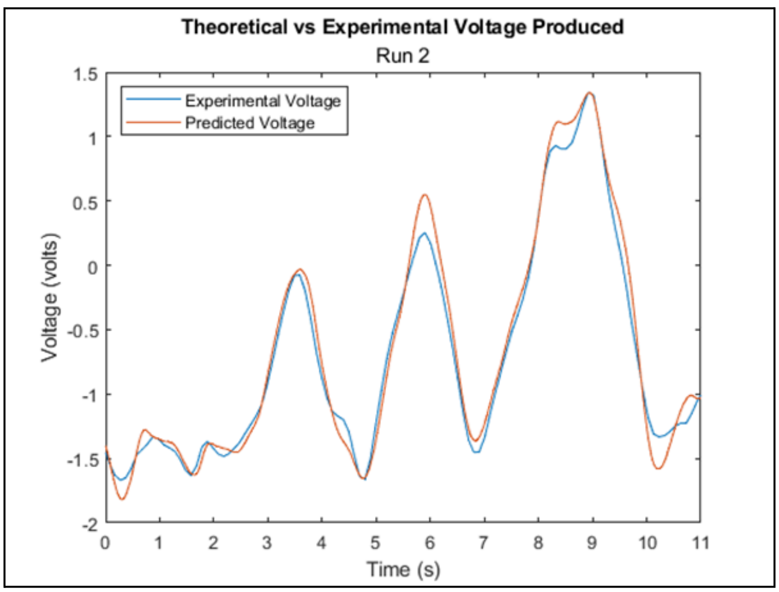

Figure 28: Theoretical versus experimental voltage produced, run 2

As can be seen from *Figures* 27 and *28*, the method used to predict theoretical voltages matched well with the experimental voltages measured with the oscilloscope. The average difference between predicted and experimental voltages is 0.16 volts for run one and 0.09 volts for run two. When compared to the range of voltages for which the motor was operating under these differences are approximately 2.23% and 3% respectively. This confirms the team's process of predicting voltage output. The team can now confidently forecast the voltage output for these systems using isolated motor and angular velocity data without having to build the physical prototype that combines each combination of rotating mass system and motor. This will simplify future tests if proper measures are taken to ensure this relationship is maintained.

26. Future Testing

Going forward, the team plans on attaching a load to the motor to see how it affects the performance of the system. Having a process that allows the team to predict the voltage output displays the electric potential energy of the system, but the power output also depends on the load. Although the team is still conducting these tests and analyzing the data, initial observations can help us predict the system's power output.

The rechargeable batteries Drift-RMT plans on using have approximately 0.1-1 Ohm resistance depending on how much they are charged. The lower charge they have, the higher resistance they provide to the system. The results from the load tests conducted so far show that batteries of this size, when attached to a rotating mass system described above and under the wave conditions described above, slow down the rotating mass 5-20%. This percentage depends on the charge level of the battery, motor size, and specific wave conditions.

There are several other experiments the team plans on completing in the future to measure how they affect the system. Some tests include changing the size and shape of the rotating mass, changing the size and location of the drifter's stabilizing weight, and seeing how the static friction of a larger motor affects the performance of the system. These tests will all help inform the team on how to optimize the power take off system.

27. Materials List

The table below shows the materials purchased by the build and test team to build the prototypes that came out of the budget set aside for the team. Some materials used to build the prototype are not included in the table that were provided to the team through the UNH Maker's Space 3D printing shop and metal workshop free of charge.

Item	Unit Price	Quantity	Total
High-Pressure Natural Rubber	$49.54	1	$49.54
Pack of 50 Stainless Steel Hex Head Screw	$8.46	1	$8.46
Pack of 100 Locknuts	$8.57	1	$8.57
Softened Temper Copper Sheet	$15.15	1	$15.15
12 Volt Mini Gearmotor	$156.97	1	$156.97
Digital Accelerometer	$43.90	1	$43.90
12 Volt 14400 RPM DC Motor	$6.04	1	$6.04
24 Volt 8100 RPM DC Motor	$6.99	1	$6.99
12" Acrylic Hemisphere	$46	4	$184.00
20 1/2" Ball Bearings	$12	1	$12.00
Clay Kit	$24.99	1	$24.99
			$516.61

Table 9: Materials list of Build and Test

28. Lessons Learned

The team learned several valuable lessons through the testing process. We learned that paying attention to small details while preparing for experiments is critical for seamless execution of those tests. There were several tests that had to be cut short or postponed all together because of problems like data acquisition equipment not being charged, the drifter prototype being assembled incorrectly, or having an incorrect understanding of how to operate test equipment. Taking care of the small details before the tests saves frustration and valuable testing time. Another valuable lesson the team took away from the testing process is having a clear plan prior to, during, and after testing. There were a few times the lack of a clear plan led to confusion in the direction the team was taking.

The non-technical lessons learned by the team were just as valuable as the technical ones. The appreciation of working amongst a team was strengthened throughout the process. Realizing how to take advantage of a member's strengths and weaknesses was an important lesson learned by the team. By the time the final set of tests were concluded, all members understood that the team was truly stronger than the sum of its parts.

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Appendix A

Drift-RMT
Financial Projections
Key Assumptions

Model Start Date	1/1/2025			
Sales	**Year 1**	**Year 2**	**Year 3**	**Year 4**
#1 Units Sold Weather Drifter Base	150	300	400	600
#2 Units Sold Weather Drifter Mid	50	100	150	250
#3 Units Sold Weather Drifter High	50	100	150	250
#4 Units Sold Oil Drifter	0	50	100	250
#5 Units Sold Marine Life Drifter	0	50	100	250
#1 Base Sales Price	$1,500.0	$1,575.0	$1,653.8	$1,736.4
#2 Base Sales Price	$1,800.0	$1,890.0	$1,984.5	$2,083.7
#3 Base Sales Price	$2,400.0	$2,520.0	$2,646.0	$2,778.3
#4 Base Sales Price	$1,500.0	$1,575.0	$1,653.8	$1,736.4
#5 Base Sales Price	$2,000.0	$2,100.0	$2,205.0	$2,315.3
Annual Price Increase	5.0%	5.0%	5.0%	5.0%
Maintenance Revenue (% of Hardware Revenue)	0.0%	0.0%	0.0%	0.0%
Shipping ($/ unit)	$0	$0	$0	$0
Other Revenue	$0	$0	$0	$0
Cost of Sales	**Year 1**	**Year 2**	**Year 3**	**Year 4**
#1 Units Sold		$0.00	$0.00	$0.00
#2 Units Sold		$0.00	$0.00	$0.00
#3 Units Sold		$0.00	$0.00	$0.00
#4 Units Sold		$0.00	$0.00	$0.00
#5 Units Sold		$0.00	$0.00	$0.00
Other Cost of Goods Sold	$0	$0.0	$0.0	$0.0
Unit Price (cost component build up)	$0	$0	$0	$0
Annual Component Cost Increase	3.0%	3.0%	3.0%	3.0%
Maintenance Cost (% of Maintenance Revenue)	0.0%			
Shipping Cost ($/ unit)	$0			
Operating Expenses	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Employees	4	6	6	6
Average Salary	$0	$80,000	$80,000	$80,000
Payroll expenses	$0	$480,000	$480,000	$480,000
Outside services	$2,000	$2,000	$2,000	$2,000
Supplies	$4,000	$5,000	$5,000	$5,000
Repairs and maintenance	$500	$1,000	$1,500	$2,000
Advertising	$0	$10,000	$10,000	$20,000
Travel & Entertainment	$5,000	$5,000	$5,000	$5,000
Accounting and legal	$10,000	$15,000	$15,000	$20,000
Rent	$14,400	$14,600	$14,800	$15,000
Telephone	$600	$600	$600	$600
Utilities	$4,800	$4,800	$4,800	$4,800
Insurance	$1,000	$1,000	$1,000	$1,000

Taxes (real estate, etc.)	$1,000	$1,000	$1,000	$1,000
Interest	$0	$0	$0	$0
Depreciation	$4,000	$6,000	$6,000	$6,000
Patents	$20,000	$20,000	$15,000	$15,000
Research and Development	$10,000	$15,000	$15,000	$15,000
Misc. (unspecified)	$1,000	$1,000	$1,000	$1,000
Fringe (Taxes, Benefits, etc)	25.0%			
Annual Cost Increase	3.0%			
Capital Expenditures				
Computers	$0	$0	$0	$0
Furnature	$0	$0	$0	$0
Office Supplies	$0	$0	$0	$0
Software Development	$20,000	$10,000	$0	$0
Total Capital Expenditures	$20,000	$10,000	$0	$0
Depreciable Life (in years)	5.0			
Balance Sheet Items				
AR Outstanding (in days)	30			
AP Outstanding (in days)	30			
Inventory on hand (future unit sales in months)	4	months		
Bad Debt Assumption (% of Revenue)	1.0%			
Financing Assumptions				
Initital Funding (Opening Cash Balance)	$100,000			
Equity Funding	$0	$100,000	$0	$0
Debt Funding	$0	$0	$0	$0
Debt Interest Rate	7.0%			
Repayment Term (in years)	5.0			

Debt Repayment Profile	Year	Beg Bal	Interest	Principal
	1	$0	$0	$0
	2	$0	$0	$0
	3	$0	$0	$0
	4	$0	$0	$0
	5	$0	$0	$0
	6	$0	$0	$0
	7	$0	$0	$0
	8	$0	$0	$0
	9	$0	$0	$0
	10	$0	$0	$0

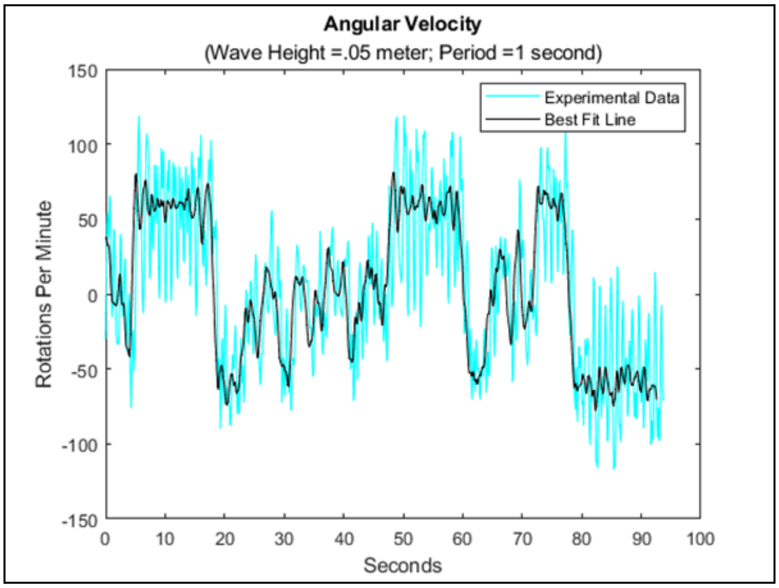
Drift-RMT

Drift-RMT Cash Flows	Pre-Startup EST	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25	Oct-25	Nov-25	Dec-25	Year 1	Year 2	Year 3	Year 4	Year 5
Capital purchase (Patent)	0	1,667	1,667	1,667	1,667	1,667	1,667	1,667	1,667	1,667	1,667	1,667	1,667	20,000	10,000	0	0	0
Other startup costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reserve and/or Escrow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Owners' Withdrawal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CASH PAID OUT	0	2,583	6,192	6,192	6,192	6,192	6,192	6,917	6,917	6,917	6,917	6,917	6,917	75,042	717,253	735,331	789,307	820,931
Cash Position (end of month)	0	-2,583	-8,775	-14,967	-21,158	-27,350	-33,542	-40,458	25,125	90,708	156,292	221,875	287,458	287,458	749,771	1,643,011	3,943,935	7,005,280
ESSENTIAL OPERATING D																		
Sales Volume (dollars)		0	0	0	0	0	0	72,500	72,500	72,500	72,500	72,500	72,500	435,000	1,097,250	1,741,950	3,270,291	4,084,101
Accounts Receivable		0	0	0	0	0	0	72,500	72,500	72,500	72,500	72,500	72,500	72,500	90,185	143,174	268,791	335,680
Bad Debt (end of month)	0	0	0	0	0	0	0	725	1,450	2,175	2,900	3,625	4,350	4,350	10,973	17,420	32,703	40,841
Units Built	0	0	0	0	42	42	42	83	42	42	75	42	42	450	700	1,133	1,700	1,900
Inventory on hand (eom) (units)	0	0	0	0	42	83	125	167	167	167	200	200	200	200	300	533	633	633
Inventory on hand (eom) ($)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accounts Payable (eom)	0	4,525	4,525	4,525	4,525	4,525	4,525	4,525	4,525	4,525	4,525	4,525	4,525	4,525	6,434	6,688	8,299	8,612
Depreciation		333	333	333	333	333	333	333	333	333	333	333	333	4,000	6,000	6,000	6,000	6,000

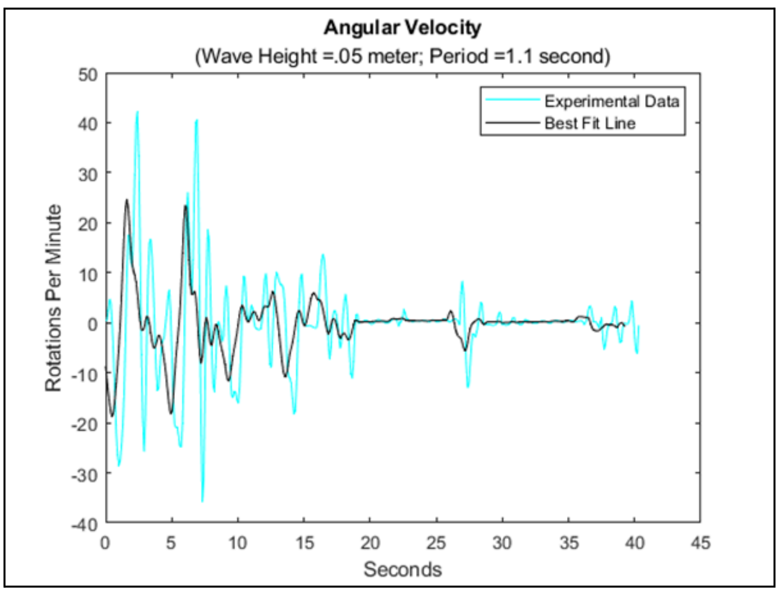
Expenses																					
Payroll expenses	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	494,400	45.1%	509,232	29.2%	524,509	16.0%	540,244	13.2%
Fringe (Taxes, Benefits, etc)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	123,600	11.3%	127,308	7.3%	131,127	4.0%	135,061	3.3%
Outside services	167	167	167	167	167	167	167	167	167	167	167	167	2,000	0.5%	2,060	0.2%	2,122	0.1%	2,185	0.1%	2,251	0.1%
Supplies	333	333	333	333	333	333	333	333	333	333	333	333	4,000	0.9%	5,150	0.5%	5,305	0.3%	5,464	0.2%	5,628	0.1%
Repairs and maintenance	42	42	42	42	42	42	42	42	42	42	42	42	500	0.1%	1,030	0.1%	1,591	0.1%	2,185	0.1%	2,814	0.1%
Advertising	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	10,300	0.9%	10,609	0.6%	21,855	0.7%	22,510	0.6%
Travel & Entertainment	417	417	417	417	417	417	417	417	417	417	417	417	5,000	1.1%	5,150	0.5%	5,305	0.3%	5,464	0.2%	5,628	0.1%
Accounting and legal	833	833	833	833	833	833	833	833	833	833	833	833	10,000	2.3%	15,450	1.4%	15,914	0.9%	21,855	0.7%	22,510	0.6%
Rent	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	14,400	3.3%	15,038	1.4%	15,701	0.9%	16,391	0.5%	17,108	0.4%
Telephone	50	50	50	50	50	50	50	50	50	50	50	50	600	0.1%	618	0.1%	637	0.0%	656	0.0%	675	0.0%
Utilities	400	400	400	400	400	400	400	400	400	400	400	400	4,800	1.1%	4,944	0.5%	5,092	0.3%	5,245	0.2%	5,402	0.1%
Insurance	83	83	83	83	83	83	83	83	83	83	83	83	1,000	0.2%	1,030	0.1%	1,061	0.1%	1,093	0.0%	1,126	0.0%
Taxes (real estate, etc.)	83	83	83	83	83	83	83	83	83	83	83	83	1,000	0.2%	1,030	0.1%	1,061	0.1%	1,093	0.0%	1,126	0.0%
Interest	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Depreciation	333	333	333	333	333	333	333	333	333	333	333	333	4,000	0.9%	6,000	0.5%	6,000	0.3%	6,000	0.2%	6,000	0.1%
Bad Debt Expense	0	0	0	0	0	0	725	725	725	725	725	725	4,350	1.0%	10,973	1.0%	17,420	1.0%	32,703	1.0%	40,841	1.0%
Research and Development	833	833	833	833	833	833	833	833	833	833	833	833	10,000	2.3%	15,450	1.4%	15,914	0.9%	16,391	0.5%	16,883	0.4%
Misc. (unspecified)	83	83	83	83	83	83	83	83	83	83	83	83	1,000	0.2%	1,030	0.1%	1,061	0.1%	1,093	0.0%	1,126	0.0%
Total Expenses	4,858	4,858	4,858	4,858	4,858	4,858	5,583	5,583	5,583	5,583	5,583	5,583	62,650	14.4%	713,253	65.0%	741,331	42.6%	795,307	24.3%	826,931	20.2%
Net Profit	-4,858	-4,858	-4,858	-4,858	-4,858	-4,858	66,917	66,917	66,917	66,917	66,917	66,917	372,350	85.6%	383,998	35.0%	1,000,619	57.4%	2,474,984	75.7%	3,257,170	79.8%

Drift-RMT Profit and loss projection	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25	Oct-25	Nov-25	Dec-25	Year 1	%	Year 2	%	Year 3	%	Year 4	%	Year 5	%
#1 Units Sold Weather Drifter Base	0	0	0	0	0	0	25	25	25	25	25	25	150	60%	300	50%	400	44%	600	38%	700	37%
#2 Units Sold Weather Drifter Mid	0	0	0	0	0	0	8	8	8	8	8	8	50	20%	100	17%	150	17%	250	16%	300	16%
#3 Units Sold Weather Drifter High	0	0	0	0	0	0	8	8	8	8	8	8	50	20%	100	17%	150	17%	250	16%	300	16%
#4 Units Sold Oil Drifter	0	0	0	0	0	0	0	0	0	0	0	0	0	0%	50	8%	100	11%	250	16%	300	16%
#5 Units Sold Marine Life Drifter	0	0	0	0	0	0	0	0	0	0	0	0	0	0%	50	8%	100	11%	250	16%	300	16%
Units Sold	0	0	0	0	0	0	42	42	42	42	42	42	250	100%	600	100%	900	100%	1,600	100%	1,900	100%
Revenue (Sales)																						
#1 Units Sold Weather Drifter Base	$0	$0	$0	$0	$0	$0	$37,500	$37,500	$37,500	$37,500	$37,500	$37,500	$225,000	51.7%	$472,500	43.1%	$661,500	38.0%	$1,041,863	31.9%	$1,276,282	31.3%
#2 Units Sold Weather Drifter Mid	0	0	0	0	0	0	15,000	15,000	15,000	15,000	15,000	15,000	90,000	20.7%	189,000	17.2%	297,675	17.1%	520,931	15.9%	656,373	16.1%
#3 Units Sold Weather Drifter High	0	0	0	0	0	0	20,000	20,000	20,000	20,000	20,000	20,000	120,000	27.6%	252,000	23.0%	396,900	22.8%	694,575	21.2%	875,165	21.4%
#4 Units Sold Oil Drifter	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	78,750	7.2%	165,375	9.5%	434,109	13.3%	546,978	13.4%
#5 Units Sold Marine Life Drifter	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	105,000	9.6%	220,500	12.7%	578,813	17.7%	729,304	17.9%
Maintenance/Support	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Shipping/ Handling	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Other Revenue	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total Revenue (Sales)	$0	$0	$0	$0	$0	$0	$72,500	$72,500	$72,500	$72,500	$72,500	$72,500	$435,000	100.0%	$1,097,250	100.0%	$1,741,950	100.0%	$3,270,291	100.0%	$4,084,101	100.0%
Cost of Sales																						
#1 Units Sold	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	0.0%	$0	0.0%	$0	0.0%	$0	0.0%	$0	0.0%
#2 Units Sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
#3 Units Sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
#4 Units Sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
#5 Units Sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Other Cost of Goods Sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total Cost of Sales	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	0.0%	$0	0.0%	$0	0.0%	$0	0.0%	$0	0.0%
Gross Profit	0	0	0	0	0	0	72,500	72,500	72,500	72,500	72,500	72,500	435,000	100.0%	1,097,250	100.0%	1,741,950	100.0%	3,270,291	100.0%	4,084,101	100.0%

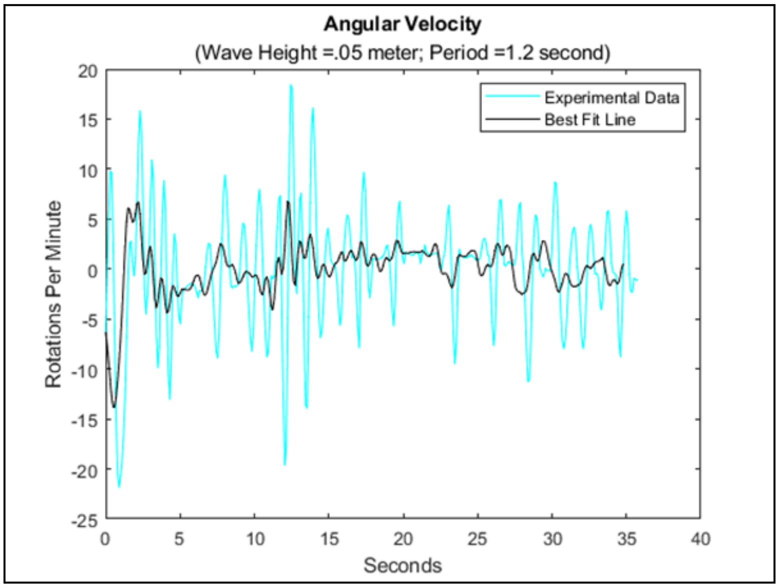
Appendix B



Angular Velocity
(Wave Height =.05 meter; Period =1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
80
90
100



Angular Velocity
(Wave Height =.05 meter; Period =1.1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
50
40
30
20
10
0
-10
-20
-30
-40
0
5
10
15
20
25
30
35
40
45


Angular Velocity
(Wave Height =.05 meter; Period =1.2 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
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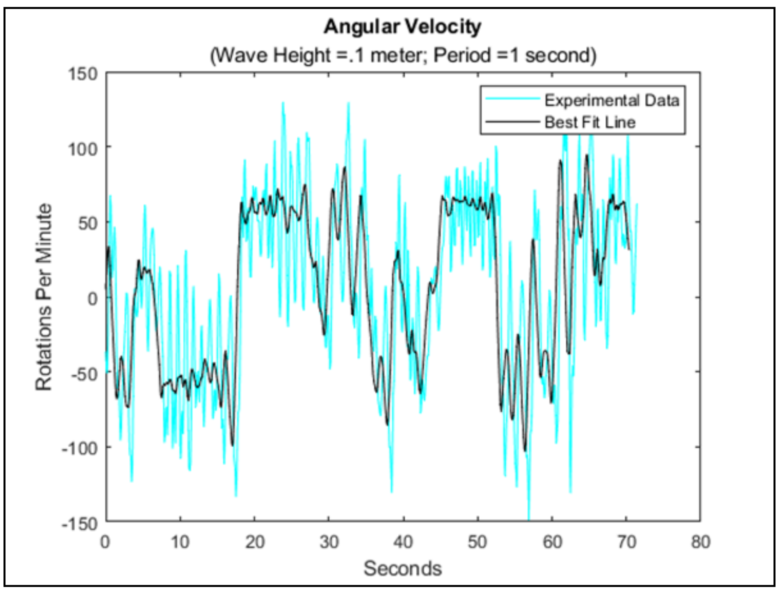
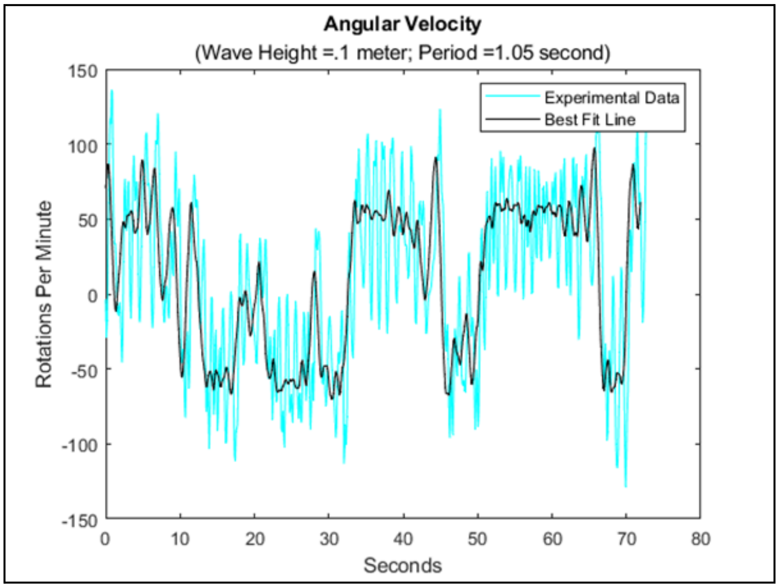
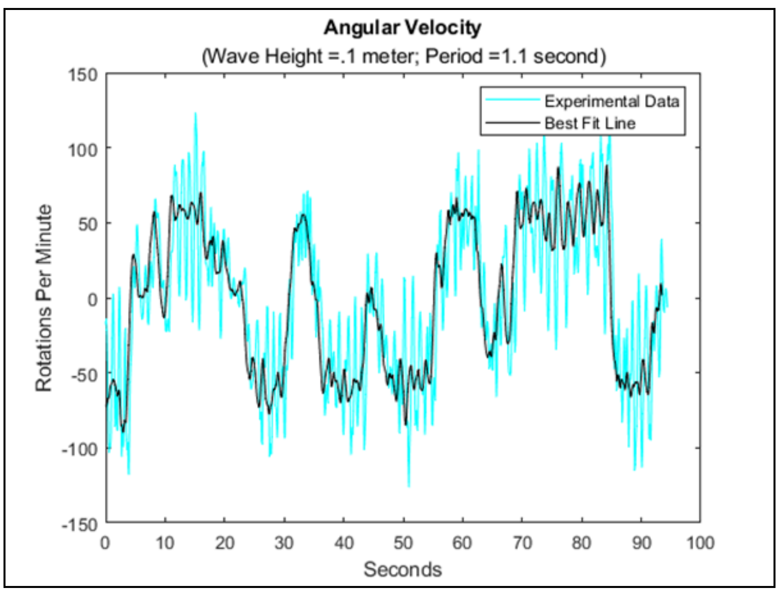
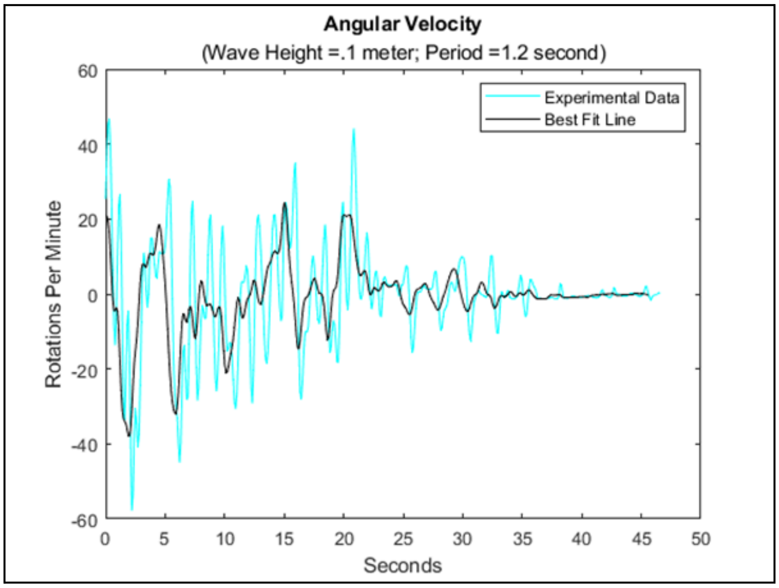
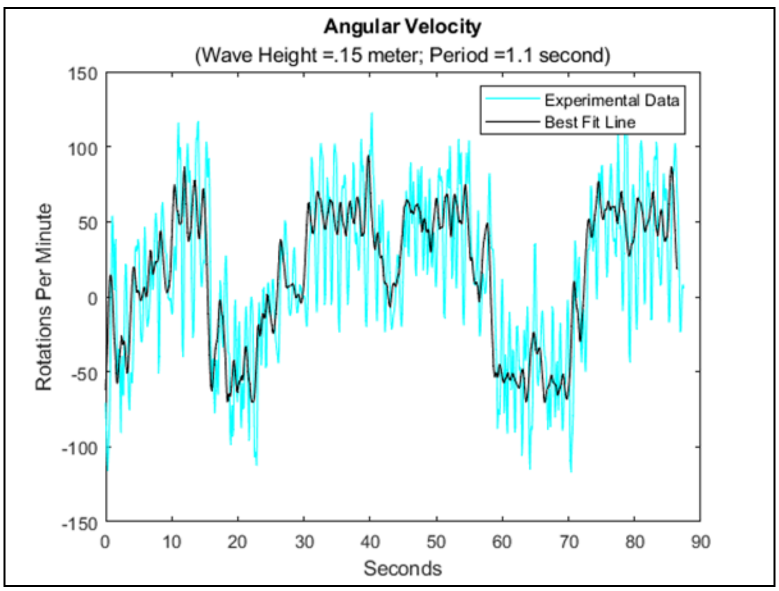
15
10
5
0
-5
-10
-15
-20
-25
0
5
10
15
20
25
30
35
40

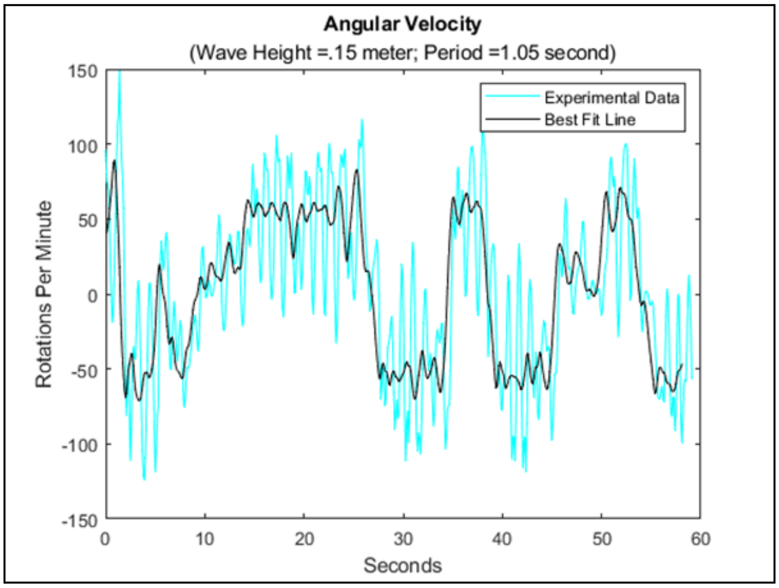

Angular Velocity
(Wave Height =.1 meter; Period =1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
80

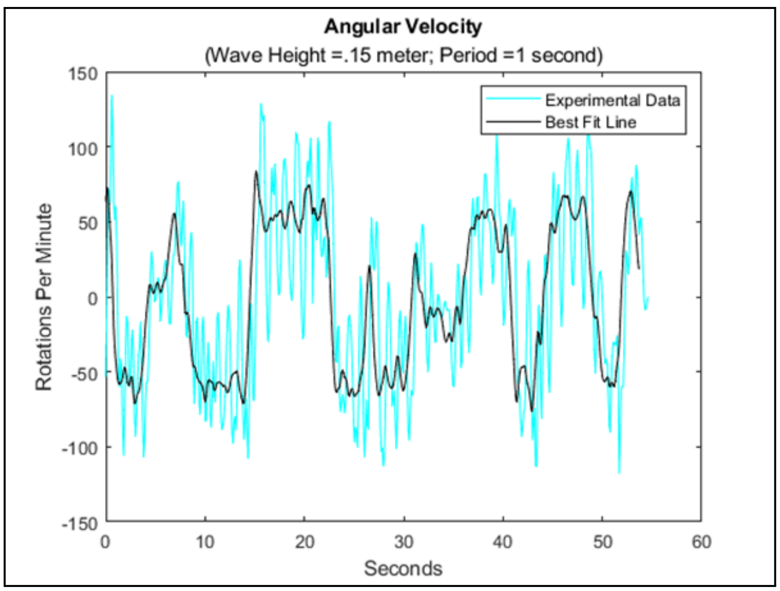

Angular Velocity
(Wave Height =.1 meter; Period =1.05 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
80

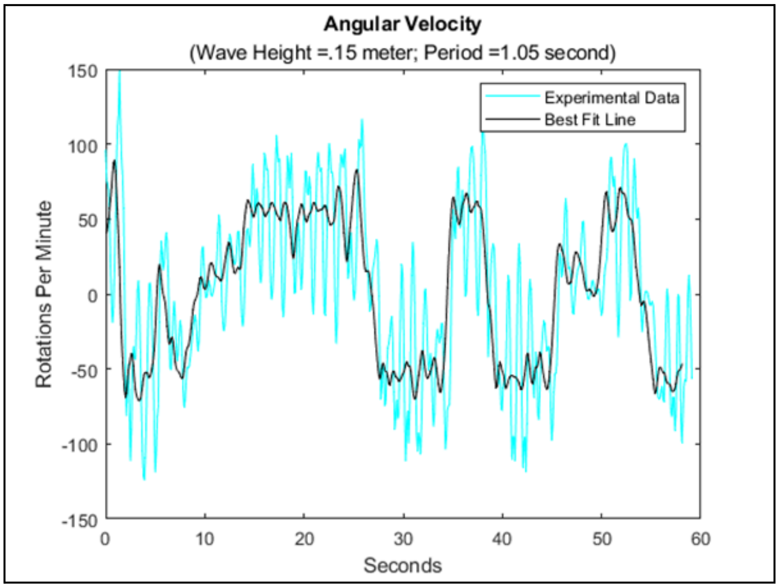

Angular Velocity
(Wave Height =.1 meter; Period =1.1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
80
90
100

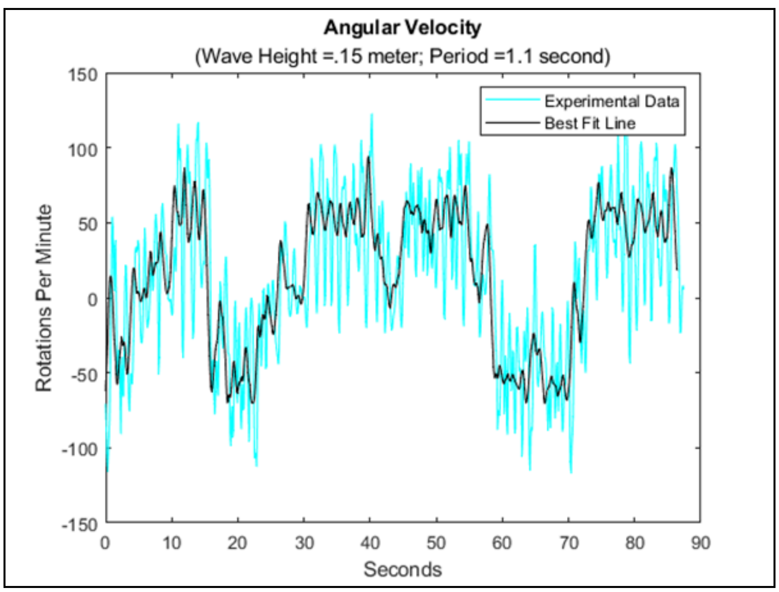

Angular Velocity
(Wave Height =.1 meter; Period =1.2 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
60
40
20
0
-20
-40
-60
0
5
10
15
20
25
30
35
40
45
50

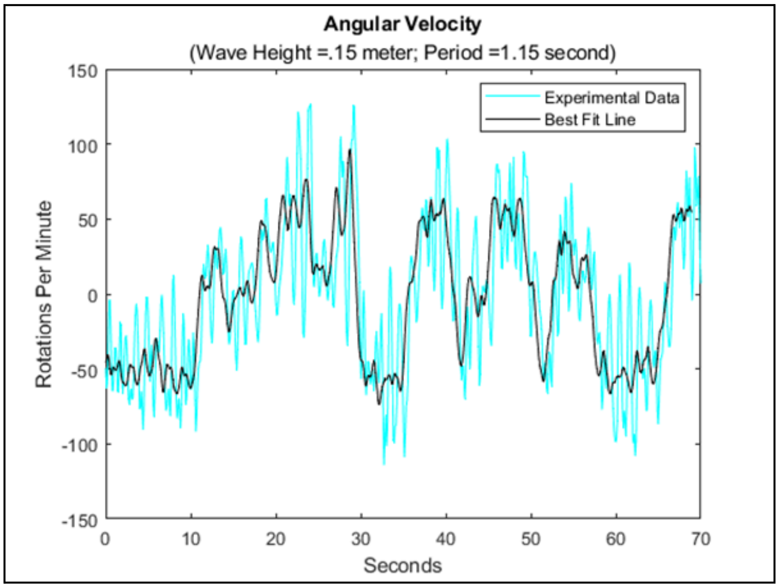

Angular Velocity
(Wave Height =.15 meter; Period =1.1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
80
90

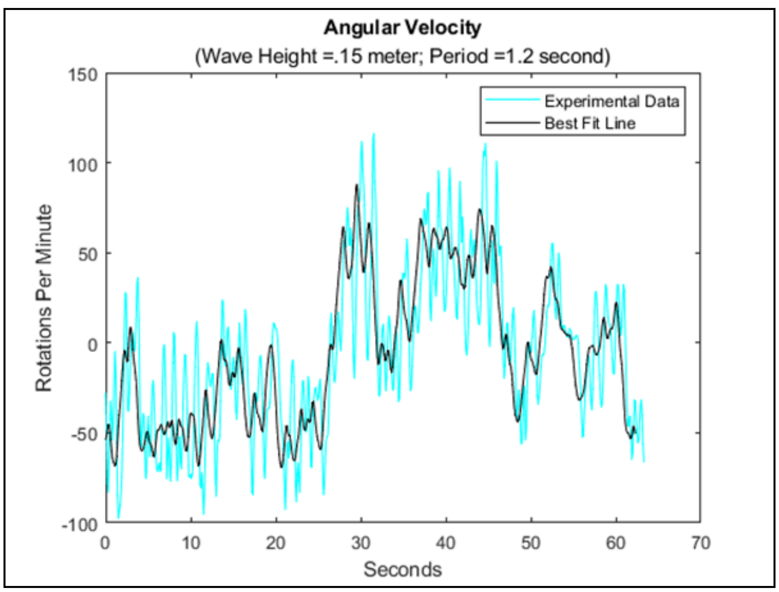

Angular Velocity
(Wave Height =.15 meter; Period =1.05 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60


Angular Velocity
(Wave Height =.15 meter; Period =1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60

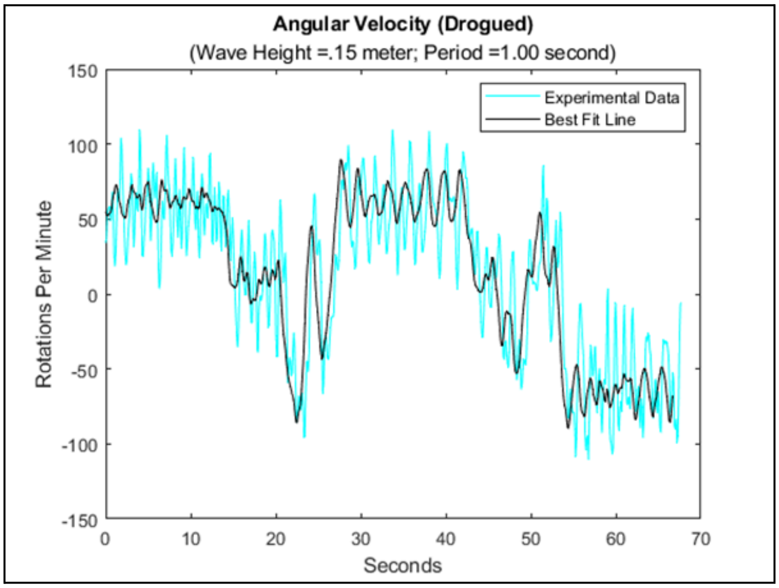

Angular Velocity
(Wave Height =.15 meter; Period =1.05 second)
Experimental Data
Best Fit Line
Rotations Per Minute
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
Seconds


Angular Velocity
(Wave Height =.15 meter; Period =1.1 second)
Experimental Data
Best Fit Line
Rotations Per Minute
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
80
90
Seconds

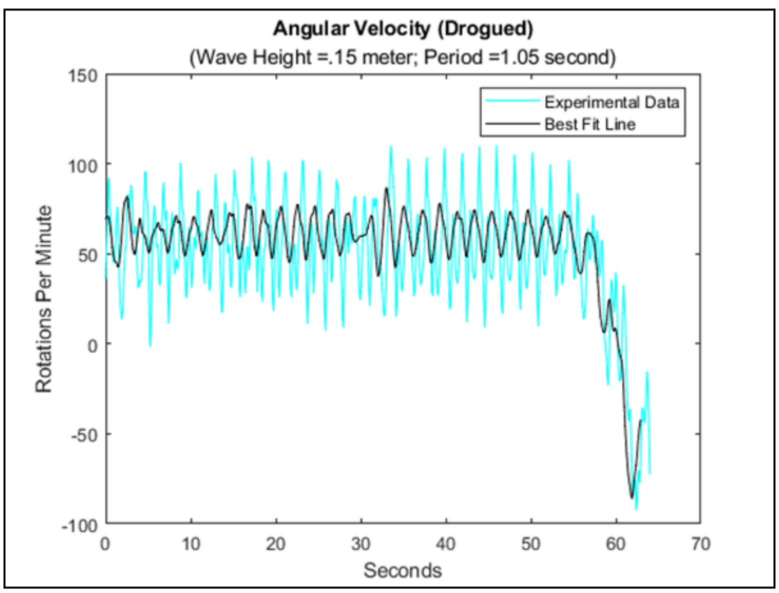

Angular Velocity
(Wave Height =.15 meter; Period =1.15 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70


Angular Velocity
(Wave Height =.15 meter; Period =1.2 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
0
10
20
30
40
50
60
70

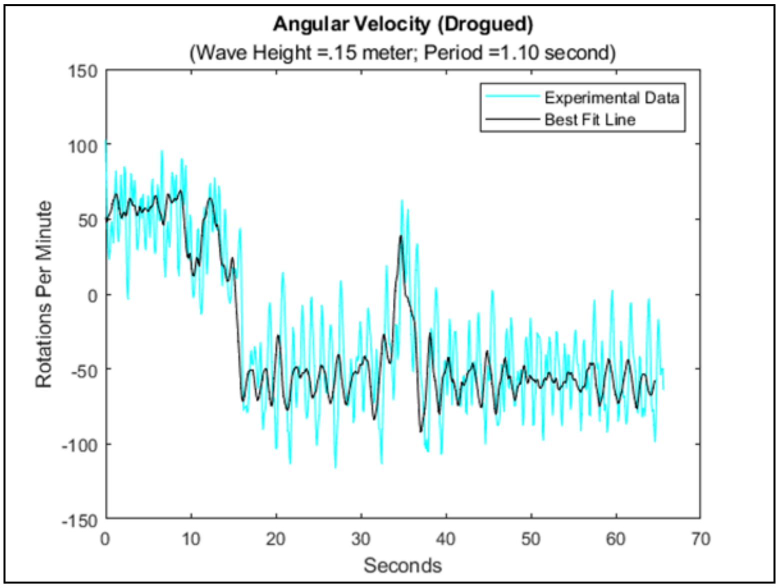
Appendix C

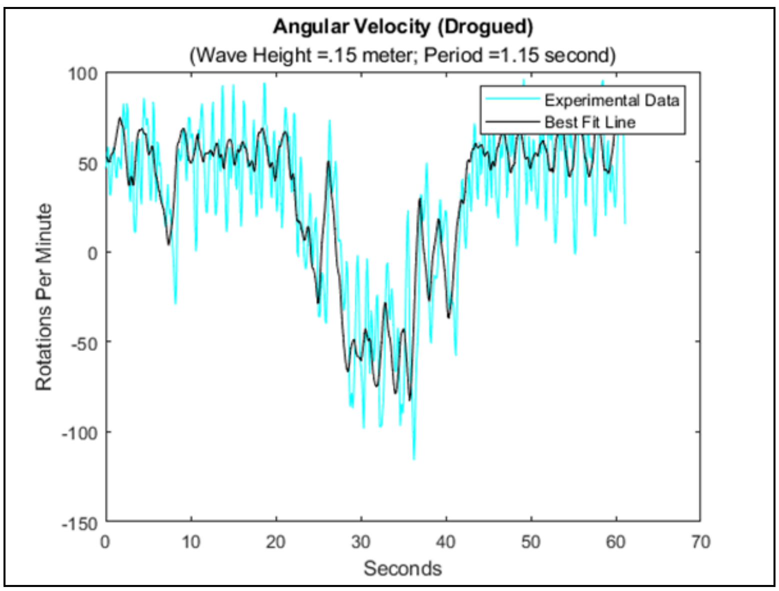


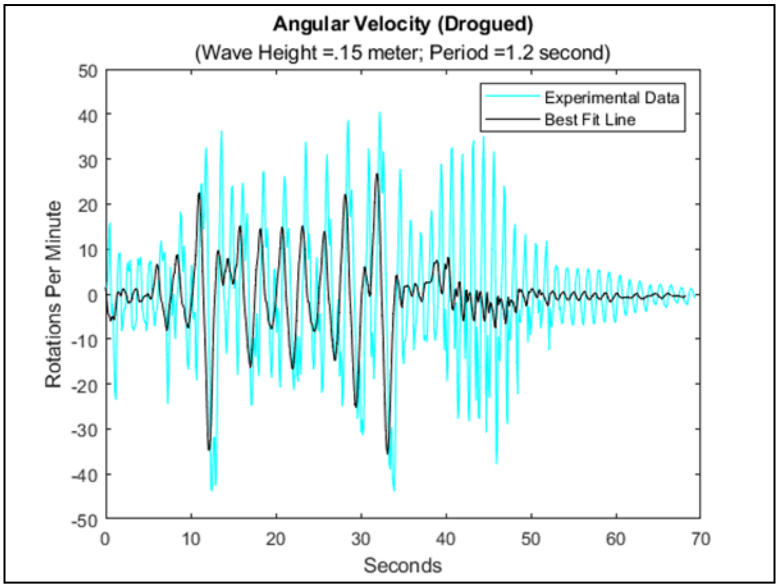
Angular Velocity (Drogued)
(Wave Height =.15 meter; Period =1.00 second)
Experimental Data
Best Fit Line
Rotations Per Minute
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70
Seconds



Angular Velocity (Drogued)
(Wave Height =.15 meter; Period =1.05 second)
Experimental Data
Best Fit Line
Rotations Per Minute
150
100
50
0
-50
-100
0
10
20
30
40
50
60
70
Seconds


Angular Velocity (Drogued)
(Wave Height =.15 meter; Period =1.10 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70


Angular Velocity (Drogued)
(Wave Height =.15 meter; Period =1.15 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
70


Angular Velocity (Drogued)
(Wave Height =.15 meter; Period =1.2 second)
Experimental Data
Best Fit Line
Rotations Per Minute
Seconds
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
50
60
70