SMADWEC

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Abstract

In maritime emergencies, such as those occurring far from shore, access to electricity is crucial for vital functions like desalination and communication. However, the limited capacity of batteries on lifeboats poses challenges in ensuring sustained power supply. The University of Massachusetts Dartmouth is developing the Survival Maximal Asymmetric Drag Wave Energy Converter (SMADWEC) to address this issue. SMADWEC aims to harness wave energy to generate electricity for lifeboat inhabitants, extending survival capabilities and facilitating rescue operations. The project involves developing a commercialization strategy, identifying key stakeholders, and addressing challenges in funding and regulation. SMADWEC's value proposition lies in its ability to provide reliable power for essential functions, such as desalination, lighting, and communication, thereby enhancing resilience in maritime emergencies. Key activities include research, design refinement, and partnership development, with a focus on optimizing the technology's durability and integration into existing lifeboat systems. Through strategic partnerships and attractive pricing models, SMADWEC aims to capture a significant share of the market demand for renewable energy solutions in offshore emergency scenarios. Challenges such as environmental durability, deployment logistics, and technological optimization are being addressed to ensure SMADWEC's viability and effectiveness in real-world applications. The project's financial analysis projects revenue generation through device sales and potential upselling opportunities, supported by strategic pricing and market positioning. Overall, SMADWEC represents a promising innovation in maritime energy technology, with the potential to revolutionize emergency response capabilities and enhance safety at sea. The SMADWEC project itself is composed of three main components, a buoy which will follow the path of the waves, a Power Take-Off (PTO) which is seen in the electrical engineering portion of this report, and a ballast system which is seen in the mechanical engineering portion of this report. As the buoy will bob up and down with the motion of the waves, slack will be pulled from the PTO, which will turn the linear motion of the slack being pulled by the buoy into electrical energy. Similar to how a pull start on a lawnmower works. Tethered in series sitting below the PTO is the ballast system. The ballast system provides all the added mass and drag to the system, so while the slack from the PTO is being pulled out by the buoy, the ballast system will be there to stop the PTO from moving up, allowing the slack to be pulled more efficiently. This ballast system is also meant to produce as little drag as possible upon downstroke of the waves to allow the system to sink efficiently, hence the “AD” part of the acronym SMADWEC (Asymmetric Drag).

1 - Project Overview:

In the domain of emergency maritime scenarios, where vessels face isolation far from shore, the finite energy capacity of onboard batteries poses a critical challenge. Electricity serves as a vital resource, indispensable for essential functions like desalination, communication, and illumination. However, its scarcity demands meticulous management to ensure survival until rescue. SMADWEC intends to harness the power of ocean waves, providing a dependable electrical lifeline for lifeboat inhabitants.

1.1 - Problem Statement:

In the case of emergencies on large vessels far from shore, energy capacity is limited by the batteries included in the devices on board the lifeboat. Electricity is vital in these situations as it is used for desalination, communication, and lighting devices. Additional electricity could be used to power additional devices and lighting as needed.

However, the inherent limitation of battery capacity poses a challenge in such situations. The available energy must be managed judiciously to ensure it lasts until rescue or until the lifeboat reaches safety. This calls for prioritizing essential functions like desalination and communication while rationing electricity for other non-critical devices.

The ability to adapt and innovate in utilizing available resources effectively is essential for enhancing resilience and survivability in emergency maritime situations. Whether through optimizing existing technologies or integrating innovative solutions, ensuring adequate energy supply remains paramount for safeguarding lives and facilitating successful rescue operations far from shore.

1.2 - Project Description, Customers and Stakeholders:

The University of Massachusetts Dartmouth is developing a single-point wave energy conversion device with a projected goal of commercializing a modular and easily deployable system that will be used to convert wave energy into electrical power and supply electrical power to lifeboat inhabitants. The electrical engineering and mechanical engineering teams have continued development in the electrical generation and drag portions of SMADWEC. The business team has been tasked with implementing a commercialization strategy for SMADWEC.

Key considerations for the business team include evaluating the competitive landscape, identifying potential partners or investors, and establishing a roadmap for transitioning SMADWEC from research and development to commercial production. This involves navigating various challenges, such as securing funding, conducting market analysis, and addressing regulatory hurdles associated with deploying renewable energy devices in marine environments.

Moreover, the business team must consider factors such as cost-effectiveness, scalability, and sustainability in the commercialization strategy. They aim to position SMADWEC as a viable solution not only for supplying electrical power to lifeboat inhabitants.

2 - Business Logistics and Market Analysis

Our business model revolves around commercializing SMADWEC. The business teams' focus is on providing reliable power solutions for critical functions such as communication and desalination in maritime settings, particularly for lifeboats and offshore emergencies. We intend to engage closely with maritime stakeholders, utilize direct sales, partnerships, and online channels for distribution, and generate revenue through licensing agreements with lifeboat manufacturers. Key partners include the Office of Naval Research (ONR), UMass Dartmouth, and lifeboat manufacturers. Our vision is to deploy SMADWEC alongside lifeboats to enhance survival capabilities, offering industries such as government agencies, the shipping industry, cruise lines and oil/gas companies an advanced solution for exceeding safety standards.

2.1 - Business Model

Our business model is based on the commercialization of the Survival Maximal Asymmetric Drag Wave Energy Converter (SMADWEC). This innovative device utilizes ocean wave energy for various marine industry applications. The foundation of our work is dedicated to developing effective solutions for powering communication, desalination, and other demands in maritime settings. By miniaturizing the

SMADWEC device, our team aims to fulfill the market demand for dependable and renewable energy sources in crucial scenarios such as lifeboats, life rafts, and offshore emergencies.

2.1.1 - Value Proposition

In the event of a large vessel emergency, such as sinking, lifeboats play a vital role in ensuring the safety of survivors. Electricity is indispensable for necessary survival devices. SMADWEC would facilitate power generation post-deployment, thereby prolonging the operational life of these devices. Access to fresh drinking water is essential in such scenarios. However, current desalination methods for saltwater rely on battery power, leading to limited drinking water availability for survivors. SMADWEC would provide means to significantly extend survival time by enabling continuous drinking water production.

2.1.2 - Customer Relationships

Our customer relationships are based on the essential demands of maritime operators and emergency responders in offshore emergency situations. We engage with important marine industry stakeholders, including shipowners, offshore power providers, and maritime safety businesses. By working closely with individuals in the maritime industry, we can ensure that the SMADWEC device can adapt to the unique needs of offshore emergency scenarios, such as desalination and communication. We emphasize open communication channels and ongoing feedback to continuously improve our products and services and better serve our prospective partners.

2.1.3 - Channels

Our distribution methods will include direct sales to maritime operators, partnerships with maritime service providers, and collaborations with emergency response organizations. We will also use online channels and marketing initiatives to reach a larger audience and increase awareness of the SMADWEC device for offshore emergency applications. In addition, we will participate in industry conferences, trade shows, and networking events to promote this technology and establish beneficial partnerships in the maritime industry.

2.1.4 - Revenue Streams

Revenue generation for SMADWEC would be through a licensing model. With a lifeboat manufacturer on board, the SMADWEC technology and intellectual property would be licensed for manufacture distribution and sold by the third party. This model significantly lowers many risks that would be inherent in attempting to manufacture, distribute and sell the technology as its own item. Licensing also allows these third parties to integrate the technology more easily into their preexisting product lines and generate sales through add-ons.

2.1.5 - Key Partners

Key partners that we are working with include the Office of Naval Research (ONR), UMass Dartmouth, and lifeboat/life-raft manufacturers for academic and research collaboration as well as a look into the lifesaving appliance industry.

2.1.6 - Key Activities and Resources

Key Activities for the SMADWEC team involve finalizing research and design of the SMADWEC to be deployed from lifeboats. Continuing industry research through manufacturer/distributor interviews. Gaining industry partners interested in onboarding this technology and willing to work with the licensing model available.

2.1.7 - Cost Structure

During the manufacturing phase of SMADWEC, we'll partner with a contract manufacturer, with costs varying based on our chosen collaborator. Alongside manufacturing expenses, we anticipate annual expenditures of approximately $10,000 for marketing and research and development. For prototyping, we've allocated a budget of $5,000 per year. Legal fees, expected to be an average of $10,000 annually, will also factor into our budget considerations.

2.2 - Vision

In recent years, the focus of the SMADWEC team was in commercialization through the form of Autonomous Underwater Vehicles (AUVs). Focus has changed as this path was deemed unviable. Through industry research and outreach, the team has found that there is viability in the offshore lifesaving appliance industry. Deployment of SMADWEC on lifeboats would enable activities that improve survivability. Industries such as government agencies and other marine sectors are the most likely to invest in equipment that exceeds requirements such as the International Life-Saving Appliance Code. The team's vision is that SMADWEC would be purchased alongside lifeboats as an add-on. Deployment will take place alongside the deployment of the lifeboat anchor. Through integration with the lifeboat and other addons can then power de-salination machines, communication devices and lighting for survivors.

3 - Relevant Stakeholders

UMass Dartmouth leads the development of SMADWEC, engaging a diverse team to innovate marine energy solutions. Collaboration with industry leaders enriches research and enhances market readiness. Strategic conversations with life-saving appliance retailers and manufacturers drive commercialization efforts. Despite challenges, efforts persist to secure key partnerships. Targeting sectors like oil and gas and government agencies, SMADWEC aims to meet specific offshore emergency needs, ensuring compliance and operational efficiency.

3.1 - University of Massachusetts Dartmouth

The SMADWEC research and development team is led by UMass Dartmouth, under the direction of a dedicated group made up of students from different majors and faculty advisors with backgrounds in business and engineering. UMass Dartmouth is devoted to expanding the limits of marine energy technology innovation. SMADWEC technology can be advanced from concept to commercialization due to the university's strong academic foundation and research capabilities. UMass Dartmouth assists students in applying their knowledge and talents to real-world problems, advancing the creation of long-term solutions for offshore emergency situations.

3.2 - Industry Partners

Collaboration with industry partners is essential for turning the basic ideas of the SMADWEC device into useful, market-ready solutions. Industry stakeholders improve UMass Dartmouth's academic research with valuable information, resources, and useful insights. The SMADWEC project gains access to state-of-the-art technologies, production capabilities, and market networks by collaborating with leaders in the engineering, maritime technology, and renewable energy industries. These collaborations guarantee the SMADWEC device's applicability and influence in the marine energy industry by laying the foundation for its successful commercialization and deployment.

3.2.1 - Key Strategic Conversations

The most vital conversations to successfully commercialize the SMADWEC will be with retailers, manufacturers and distributors of life-saving appliances. Conversations with industry professionals have given the SMADWEC team the information that at an appropriate cost and with proper integration there are market subsets that will accept SMADWEC as a viable solution.

Conversations will also need to take place with manufacturers and retailers of desalination equipment for lifeboats to gain insight into our solution's viability. It will be necessary to understand the energy requirements for desalination equipment to know if SMADWEC can supply energy in a more robust and reliable manner than batteries.

3.3.2 - Potential Key Industry Partners

The successful commercialization of SMADWEC hinges on strategic partnerships with key industry players, particularly lifeboat manufacturers and distributors. Unfortunately, the SMADWEC team has encountered challenges in establishing long-term relationships with these pivotal partners. Given the limited number of manufacturers worldwide, securing these relationships presents a significant but crucial opportunity.

Despite proactive outreach efforts to all known manufacturers and distributors, the response regarding SMADWEC's technology has been limited. This lack of engagement underscores the need for targeted strategies to effectively communicate the value proposition of SMADWEC and foster collaboration within the industry.

Potential partners who helped the business team understand the industry are Breakwater International, John Verissimo and Switlik Survival Products. Partners who did not respond to requests or to questions are as follows at the time of writing: LRSE, SurvivalAtSea.com, Landfall Navigation, West Marine, Pilot John Int. Viking, Fisheries Supply, Mediterranean Shipping Company, CMA CGM, Evergreen Marine Corp, Grand Ocean Marine, Mass Maritime, Int. Chamber of Shipping, Palfinger, Lazilas and Textron Systems.

3.3 - End Users

In understanding the diverse landscape of end users, the SMADWEC project identifies critical sectors where its technology can make a significant impact in offshore emergency scenarios. By engaging with stakeholders across various industries, including oil and gas, government agencies, shipping, personnel involved in marine operations, and the military, the SMADWEC project recognizes the distinct challenges and requirements of each sector.

3.3.1 - Oil/Gas

Conversations with industry professionals within the oil and gas sector shed light on the unique dynamics of an industry known for its stringent safety standards and regulatory compliance. Oil and gas operations are conducted in environments that pose significant risks to personnel and assets. As a result, companies operating in this sector are acutely aware of the importance of robust safety measures and cutting-edge technologies to mitigate potential hazards.

One key insight gleaned from prior discussions is the industry's propensity to embrace technologies that surpass governmental regulation requirements. While governmental regulations set minimum standards for safety equipment and protocols, oil and gas companies often strive to go above and beyond these mandates to ensure the highest levels of safety and operational excellence making this sector particularly viable for SMADWEC.

3.3.2 - Government

Government agencies play a crucial role in maritime safety, environmental protection, and disaster response. During maritime emergencies, the SMADWEC device provides government agencies with a flexible way to power vital equipment such as desalination systems and communication networks. The SMADWEC device would work with government stakeholders to make sure the device complies with operating guidelines, regulations, and emergency response plans.

Governmental vessels, much like their counterparts in the oil and gas industry, operate in environments where safety is paramount and adherence to stringent regulations is essential. These vessels, whether they belong to coast guards, navies, or other government agencies, are tasked with a range of critical missions, including search and rescue operations, maritime law enforcement, border security, and environmental protection. SMADWEC could assist in an array of these operations in ensuring maximum opportunity where electrical energy is needed.

3.3.3 - Shipping

For ships to operate safely and efficiently, shipping companies depend on reliable power and communication systems. Given that the SMADWEC device offers a dependable source of power for vital systems onboard, shipping companies can improve their emergency preparation and response capabilities. Through partnerships with major companies in the shipping sector, the SMADWEC device can address the difficulties and demands of maritime operations, assuring maritime safety and resilience.

3.3.4 - Personnel

Personnel involved with marine operations, including researchers, divers, and offshore workers, depend on reliable power and communication systems to ensure their safety and well-being during fieldwork. By providing power to necessary equipment and communication devices, the SMADWEC device enhances situational awareness and response capabilities in difficult and remote locations. It is a small and transportable solution. Through collaboration with individuals from several marine industries, the SMADWEC project guarantees that the device satisfies the practical criteria and operational demands of frontline workers, allowing them to perform their responsibilities with efficiency and safety.

3.3.5 - Military

To maintain security and readiness at sea, the military must overcome unique challenges in a range of maritime environments. During maritime operations, the SMADWEC device offers the military a flexible energy source to power their communication, desalination, and surveillance devices. The SMADWEC project ensures that the device improves situational awareness, operational efficiency, and mission effectiveness in marine scenarios by working with military stakeholders to address the unique needs and operational requirements of defense forces. Through collaborating with the SMADWEC project, it improves maritime capabilities for defense and emergency response while also supporting national security initiatives.

4 - Market Opportunity

The market opportunity in the life-saving appliance industry, particularly concerning lifeboats and rafts, is centered around the critical need for reliable and sustainable power sources to support essential functions during maritime emergencies.

The existing challenges within the industry highlight the necessity for innovative solutions. Traditional power sources, such as diesel generators and batteries, have limitations that compromise their effectiveness during prolonged emergencies. Diesel generators can be reliable but pose logistical and environmental challenges. On the other hand, batteries, while more environmentally friendly, may lack the durability and energy density required for extended use.

However, emerging technologies, such as SMADWEC's renewable energy generation, present a unique market opportunity. By offering renewable energy solutions that minimize the need for frequent battery replacements, SMADWEC addresses the industry's need for reliable power sources. These solutions not only enhance the sustainability of life raft operations but also improve the efficiency and effectiveness of critical functions like distress signaling, GPS tracking, and communication with rescue teams.

Furthermore, the competition within the industry is driving technological innovation, leading to the development of energy solutions that are both efficient and environmentally sustainable. Energy storage technology is evolving to provide more dependable, compact, and eco-friendly options for powering vital maritime equipment.

4.1 - Lifeboats/rafts

The utilization of lifeboats during marine crises, be it shipwrecks or instances at sea, is pivotal for the safety and survival of those involved. These lifeboats serve as a refuge in dangerous waters, providing security. However, for these vessels to fulfill their critical function effectively, they require reliable power sources to operate essential communication, navigation systems and desalination equipment.

Conventional power solutions for lifeboats, often reliant on batteries, present significant limitations, particularly in prolonged emergencies. The finite capacity and duration of these batteries can jeopardize the effectiveness of distress signaling, GPS tracking, and communication with rescue teams over extended periods.

Moreover, SMADWEC's renewable energy generation minimizes the need for frequent battery replacements, reducing logistical challenges and enhancing the overall sustainability of lifeboat operations. Its compact form factor further facilitates easy integration into existing lifeboat designs without compromising valuable space or maneuverability.

4.2 - Industry Problems and Pains

One of the biggest issues facing the life-saving appliance industry is finding dependable power sources for essential operations like desalination. In an emergency, desalination is essential for turning saltwater into potable water, but it frequently requires outside power sources like batteries. However, particularly in long emergencies, these sources may be insufficient or prone to malfunction, endangering the hydration and general survival chances of survivors.

The industry's problems go beyond desalination to include other vital functions including lighting onboard life-saving devices and communication systems. To coordinate rescue operations and guarantee the safety of passengers and crew, effective communication is essential during emergencies. But since these technologies also rely on reliable power sources, the need for creative solutions to the problem of energy shortage at sea is even more urgent.

The industry faces a pressing need for reliable and sustainable power solutions to support critical functions in life-saving appliances. The sector can improve emergency response skills and ultimately save lives at sea by taking on this issue directly.

4.3 - Competition in Industry

The competition for energy producers in the life-saving appliance market is fueled by the necessity for dependable and effective power sources during maritime emergencies. Conventional energy sources, such as diesel fuel, have a track record of dependability but present logistical and environmental difficulties. In contrast, batteries offer a more environmentally friendly and sustainable option, but they might not have the durability and energy density required for emergencies. The competition among energy manufacturers to innovate and develop products that meet the strict requirements of the life-saving appliance business is intensifying as the demand for more sustainable and efficient energy solutions develops. Energy storage technology is developing because of this competition, providing more dependable, small, and eco-friendly options for powering vital maritime equipment.

In essence, the competition in the energy sector for life-saving appliances is pushing the boundaries of technological innovation, resulting in the development of energy solutions that are not only more efficient but also more environmentally sustainable, ultimately enhancing safety and resilience in maritime emergencies.

5 - Development and Operations

The potential shortcomings of SMADWEC technology encompass various aspects crucial for its viability in commercial applications. Primarily, concerns arise regarding its resilience in the oceanic environment, including challenges posed by saltwater corrosion, marine life interactions, and adverse weather conditions. Custom manufacturing may be necessary to enhance its durability and adaptability to specific deployment settings, ensuring compatibility with maritime safety protocols. Technologically, the system's efficiency in converting wave energy into usable power requires refinement to meet commercial standards. Environmental considerations emphasize the need for sustainable manufacturing practices and end-of-life strategies, advocating for modularity and repairability to minimize waste and promote resource conservation. Legal implications regarding liability loom large, necessitating thorough precautions to mitigate potential risks associated with SMADWEC deployment onboard lifeboats. Addressing these concerns through comprehensive research and strategic planning is essential to optimize SMADWEC's performance and ensure its seamless integration into maritime operations.

5.1 - Potential Shortcomings

Shortcomings for the SMADWEC technology will largely fall into its ability to withstand the ocean’s environment. Salt water, ocean life and difficult weather/terrain are all issues that will have to be considered in improving the overall reliability of SMADWEC for commercial sale.

5.1.1 - Manufacturing

The deployment environment of SMADWEC must be carefully considered during its design phase to ensure its survivability in salt water. While the prototype has been successfully assembled using entirely off-the-shelf components, a deployable version will likely necessitate some degree of custom manufacturing to adapt to specific environmental challenges. With manufacturing of any custom components, it is important that the team and partner can manufacture within any tolerances required to fully build the SMADWEC at scale and reduce failure rates.

5.3.2 - Deployment

The assumption has been made that there will not be significant difficulty integrating the SMADWEC with the normal deployment of lifeboats. This assumption has been marginally confirmed with industry experts but will require further research into if the SMADWEC is capable of being deployed alongside the lifeboats automatic deployment of the anchor or if the SMADWEC would require an entirely separate system for deployment.

Conducting further comprehensive research can help identify any potential challenges or limitations in integrating the SMADWEC with standard lifeboat deployment procedures. By addressing these issues early in the development process, stakeholders can ensure the seamless incorporation of the SMADWEC into maritime safety protocols, enhancing overall operational efficiency and emergency preparedness at sea.

5.3.3 - Technological

The most major potential shortcoming of SMADWEC is its ability to convert wave forces into reliable and usable energy. With current testing the SMADWEC can output up to 80 watts under normal operating conditions with a high level of ratio conversion in its rotational shaft meaning the current implementation would prove too weak for commercial sale. More innovation in the configuration will need to be completed to make the system more reliable and provide more energy from the same level of input.

5.3.5 - Environmental

The manufacturing process of SMADWEC would need to be optimized to extend its usable life and its ability to be reused or recycled at the end of its usable life. To minimize impact on the environment, a plan must be put in place to implement a cradle-to-cradle strategy, meaning that useful parts can be reused in future products. Parts that then are no longer serviceable are then reused or recycled to maximize the effective usefulness of the materials used in manufacturing.

Furthermore, designing the SMADWEC with modularity and repairability in mind can facilitate its maintenance and extend its service life. By incorporating interchangeable components and standardized interfaces, damaged or worn parts can be easily replaced or upgraded, thereby prolonging the overall lifespan of the structure. This approach not only reduces the frequency of disposal but also minimizes the demand for new materials, promoting resource conservation and circularity in the manufacturing process.

5.3.6 - Legal

A major concern when moving to a commercial scale will be the legal liability of the technology in the usage at which it will be sold. If there is an issue onboard a lifeboat that has been caused by the SMADWEC system, legal liability may play a major role in the future of SMADWEC if extensive precautions are not taken or if this liability is held by the distributors of SMADWEC. It is imperative to institute robust precautionary measures and establish clear lines of liability, whether they rest with the SMADWEC developers or its distributors. Proactive management of legal liabilities ensures not only the integrity of the technology but also safeguards its viability in the commercial realm, fostering trust and reliability among stakeholders.

6 - Financial and Benefits Analysis

The success of SMADWEC's commercialization hinges on several market assumptions due to limited cooperation from potential partners and industry stakeholders. Revenue projections are centered around the sale of SMADWEC units and potential upselling opportunities, aiming to tap into the market demand for renewable energy solutions in offshore emergency scenarios. As manufacturing scales up, revenue is anticipated to grow, leveraging economies of scale and expanding profit margins. The incorporation of upselling strategies, particularly with lifeboat integration, offers an additional revenue stream, enhancing the overall value proposition of the SMADWEC system and positioning it competitively in the maritime energy market.

6.1 - Market Assumptions

To effectively judge the potential success of commercialization of SMADWEC, multiple assumptions must be made on the market due to a lack of cooperation from potential partners and industry stakeholders. The SMADWEC team has assumed that at a cost of $1,500 to $2,000 would be a sufficient MSRP to attract customers and make a profit. At scale the SMADWEC system would provide the manufacturer with sufficient profit margins as well as additional opportunities to upsell consumers on additional devices like desalination systems.

6.2 - Expenses

Assumptions must be made on the market that there will not be significant economic shifts that would impact the supply chain needed to procure goods used in the manufacturing process. Operational expenses will take the shape of $10,000 not including an additional $5,000 for prototyping and research conducted by students of UMass Dartmouth. Also, marketing would partially fall on the SMADWEC team for successfully selling the technology to consumers with partners' help. Because this product would likely be best sold through direct selling techniques the only expenses would be on labor. If this labor is completed by students of UMass Dartmouth the expenses would be largely minimal or close to $0.

6.3 - Revenue

The revenue projections for the SMADWEC project are based on the anticipated sales of the SMADWEC device and the potential upselling of additional equipment. With an assumed retail MSRP ranging $1,500 to $2,000 per SMADWEC unit, the project aims to capture a significant share of the market demand for renewable energy solutions in offshore emergency scenarios. Revenue generation is expected to increase as manufacturing quantities grow, allowing for economies of scale and improved profit margins for manufacturers. Additionally, the potential for upselling products along with lifeboats offers an additional revenue stream and enhances the overall value proposition of the SMADWEC system. Through strategic pricing strategies and market positioning, the SMADWEC device aims to maximize revenue while providing customers with cost-effective and sustainable solutions for their maritime energy needs.

Technical Design Challenge

Introduction

The SMADWEC project is a multi-year blue energy project spearheaded by students at The University of Massachusetts Dartmouth with one goal; to create a portable, self-deploying ocean wave energy converter device for use in the open ocean which is capable of reliably producing electrical energy which can then be harnessed to charge electronics such as phones, scouting equipment, sonar equipment, emergency signals, and many more. SMADWEC stands for Survival Maximal Asymmetric Drag Wave Energy Converter and consists of three main components. Firstly, is the buoy, which bobs up and down following the motion of the waves. Secondly, is the PTO. The PTO is tethered to the buoy and as the buoy moves up and down with the waves, slack from the tether is pulled from the PTO which then converts the linear motion into electrical power. The PTO is being developed by a team of senior electrical engineering students at UMass Dartmouth. Finally, the third main component of SMADWEC is the ballast system, which is being developed by a team of senior mechanical engineering students at UMass Dartmouth. The ballast system is in charge of adding stability and added mass to the system. It will be tethered to the PTO and will be stationed underneath the PTO. The idea for the ballast system is that when the buoy rises up with the motion of a wave, the PTO will naturally want to move upwards with the buoy. The ballast system will anchor the PTO in place by providing added mass to overcome this upward force from the buoy, allowing the slack to be pulled from the PTO while the PTO itself will stay in place.

Electrical Engineering

Design Objective

Since the SMADWEC project has been ongoing in previous years, the sponsors have a strong understanding of what they would like the system to be capable of. The sponsors' needs can be summarized in the following statement: The SMADWEC needs a redesigned electrical system that can harvest and store energy using the existing mechanical design. It needs to improve efficiency, operate under different ocean conditions, be expanded in the future, and be environmentally friendly. During the team's meetings with the sponsors, the needs hierarchy shown in Figure ? was developed.

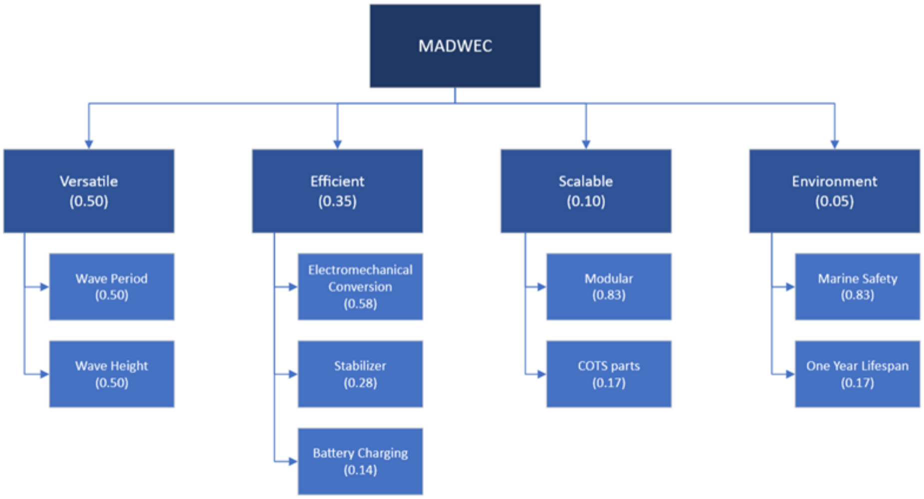


Figure 1.1: Needs Hierarchy

The first and highest priority category is versatility. The sponsors emphasized that the SMADWEC will be operating under nonideal ocean conditions where parameters like wave height and period are unpredictable and highly variable. Previous designs struggled to get consistent outputs with changes in these parameters, so the focus for this design project will be versatility. This will involve exploring alternative designs which have more consistent behavior with a change in the ocean environment.

The second most important category is efficiency. The sponsors mentioned that they would like to see a significant improvement in efficiency of the electrical system in the SMADWEC. The team’s task is to explore different designs in the subcategories of the EMECD, stabilizer, and battery charging circuitry to maximize the power output and minimize electrical losses. To sufficiently diagnose the efficiency of the system, several sensors will be needed to determine where power is being lost.

The next most important category is scalability. Since the SMADWEC project has been ongoing for several years and will continue in future years, the sponsors would like the electrical design to be scalable. To achieve this, the system should be broken down into several subsystems which can easily be disconnected from each other. This would allow future teams to replace entire subsystems with upgraded or improved versions if necessary. Additionally, to allow for easier acquisition of materials, commercially available off-the-shelf parts (COTS) should be preferred over any special-order items.

The final category of the needs hierarchy is the environment. The SMADWEC project is still in the development phase and will not be deployed in the ocean this year, but the team must still consider the environmental impacts. The team’s design should follow any applicable regulations in order to reduce the risk to the surrounding marine environment. Finally, the electrical system should be suited for typical marine conditions it may experience and have a lifespan of one year to make the design economically viable.

These needs were used to generate a list of specific engineering requirements for the new electrical system.

Table 1.1: Engineering Requirements

Engineering Requirement Number	Engineering Requirement Description	Test Method (IADT)
1.0	The electromechanical energy conversion device **SHALL** fit inside the existing chassis' dimensions of 8.23in x 7.25in x 7.00in.	Demonstration
2.0	The design **SHALL** abide by the Code of Federal Regulations Title 46 Chapter I Subchapter J-Electrical Engineering.	Inspection
2.1	The team **SHALL** abide by Occupational Safety and Health Administration Standard 1926 Subpart K-Electrical.	Inspection
3.0	The design **SHALL** convert the SMADWEC's mechanical rotational energy to electrical energy.	Testing Analysis
3.1	The design **SHALL** store the generated electrical energy in a battery with a voltage of *3.2V DC.	Testing Analysis
4.0	The design **SHALL** operate under the different ocean conditions (wave period, wave height, etc.) that can be simulated with the setup in the lab.	Testing Analysis
5.0	The design **SHALL** use modified commercially available off-the-shelf parts except when a custom printed circuit board (PCB) is required.	Inspection
6.0	The design **SHALL** be scalable and modular with three subsystems to allow for future expansion.	Inspection
7.0	The design **SHALL** improve the "GLOBAL Average Generator and Rectifier Efficiency" from last year's 28% to 50% when tested under the same conditions.	Testing Analysis
8.0	The system **SHALL** communicate with a computer to report diagnostic sensor data including RPM, torque, voltage, current, and battery status (i.e. charge level).	Analysis
8.1	A user interface **SHALL** display sensor data for RPM, torque, voltage, current, and battery status.	Inspection
9.0	The selected electrical components **SHALL** have a projected lifespan of one year.	Analysis

*Note: Initial Target voltage was 12V DC. Refer to Build and Test Report for more information.

Design: Overview

A winch is controlled to simulate the sinusoidal nature of ocean waves with varying heights and periods. The winch is connected to the SMADWEC's power take-off (PTO) system through a series of ropes and pulleys. The PTO system translates the rotational energy of the ocean waves into rotational energy with higher revolutions per min (RPM) at the expense of lower torque. This rotational energy is then converted to electrical energy by the electromechanical energy conversion device (EMECD). The electrical output of the EMECD is then connected to a battery to store the energy for use in electronic devices at sea. The design also incorporates several different sensors in order to characterize the behavior and efficiency of the system under the different wave conditions. These sensors measure things like RPM, torque, force, voltage, and current and report data to a laptop for storage and future processing.

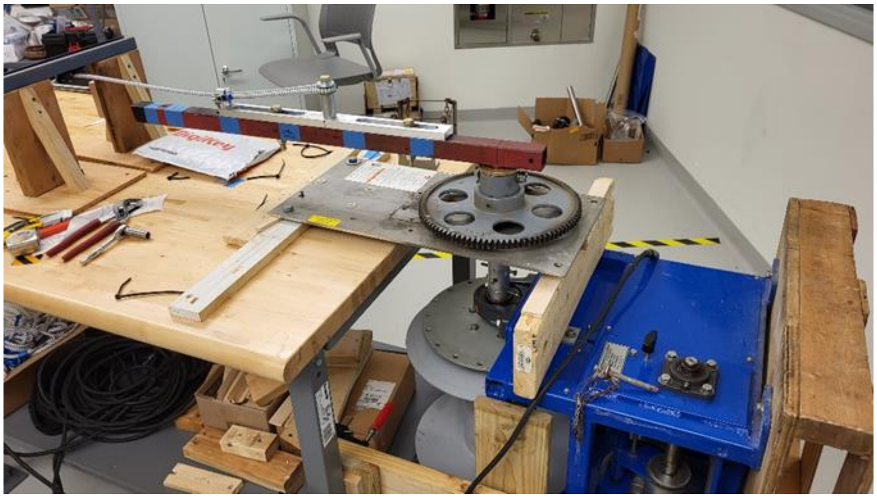


Figure 1.2: Winch Simulating Ocean Waves

The mechanical portion of the PTO was kept the same as last year and remained unchanged during the project this year. The reason for this is that the sponsors wanted the electrical engineering team to utilize the existing mechanical design and come up with an electrical system that properly interfaces and functions as desired. Then, based on the results of the electrical system, the future team could return to the mechanical system and make any necessary modifications.

Design: Electromechanical Conversion Device

The selected alternative to satisfy Engineering Requirement 3.0 for the electromechanical energy conversion device is an alternator. An alternator is capable of providing the versatility and efficiency that the SMADWEC project calls for.

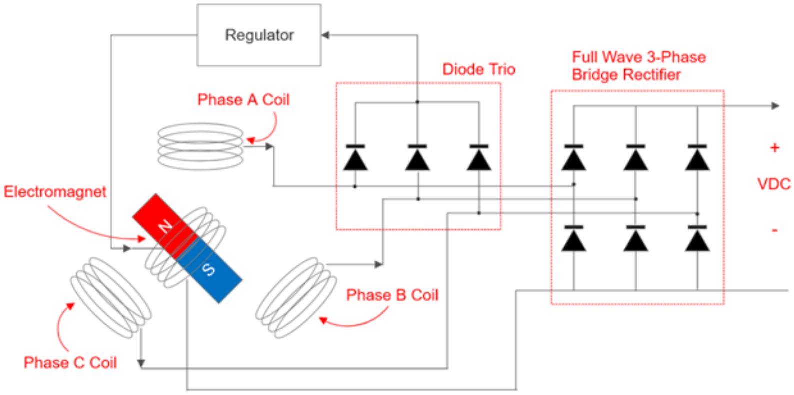


Figure 1.3: Typical Alternator System

The number one reason for the selection of the alternator over the generator is versatility. Car alternators are designed to provide a stable 12VDC – 14VDC output over a broad range of RPM. This is done by having an electromagnet instead of permanent magnets and using a feedback loop. Sending current to the coils in the rotor causes the electromagnet to produce a magnetic field. If the rotor is spinning slightly slower or faster than the ideal RPM, the output voltage would normally decrease, but by having a regulator in a feedback branch, some of the output current is sent back to the electromagnet to increase the magnetic field strength and keep the output voltage stable. This stable 12VDC output voltage is crucial because it means that a battery can be charged using a constant voltage which is mentioned in Engineering Requirement 3.1. The versatility of the design is the highest priority of the project because of the different parameters of the ocean waves like height and period simulated by the lab setup in Engineering Requirement 4.0. These parameters are converted to a wide range of RPM starting the cycle at 0 RPM and peaking around 700 RPM depending on the height and period. This RPM in the shaft of the existing SMADWEC system is what spins the electromechanical device, and the alternator handles this variability better than a generator could. The goal is that having a system that provides stable output over a wider operating range will also improve the total efficiency of the system, which is summarized in Engineering Requirement 7.0.

Another reason the alternator was selected is due to the size constraint of the SMADWEC system. The existing chassis that our design must fit inside of has specific dimensions of 8.23” x 7.25” x 7.00” mentioned in Engineering Requirement 1.0. Car alternators typically have dimensions of 5.00” x 6.00” x 6.60” which should fit nicely into the space provided in the chassis. A radial flux permanent magnet generator that works at the same output voltage is typically larger than this and an axial flux generator would need to be even larger than that. As mentioned before, most car alternators have an output voltage between 12VDC – 14VDC above 2500 RPM and up to 10,000 RPM. This range of RPM is higher than the range that is generated by the SMADWEC system, which is less than ideal, but research has shown that some modification to an off-the-shelf car alternator can decrease the operating range of RPM for wind and hydroelectric energy applications. This means that the alternator would satisfy Engineering Requirement 5.0 which calls for commercially available off-the-shelf parts with some modifications. Additionally, the use of an off-the-shelf car alternator should provide modularity to satisfy Engineering Requirement 6.0 because all the connection points will be standard. Also, car alternators typically have a lifespan of 5 – 7 years which will satisfy Engineering Requirement 9.0.

Design: Battery

The selected alternative to satisfy Engineering Requirement 3.1 for the storing of electrical energy was the Lithium Iron Phosphate battery. This LiFePO4 battery has a much more stable chemistry and greater lifespan that is crucial for the SMADWEC project.

The most important reason why the LiFePO4 battery was chosen was because of its safety protocols under unusual circumstances. Lithium-Ion batteries are very efficient, but they lack stability in their chemistry. If a lithium-ion battery is perforated or comes in contact with water, it will cause an explosion and a fire. The Lithium Iron Phosphate on the other hand reduces the risk of causing an explosion and fire due to its more stable chemistry. This translates to the battery not being able to overheat. Since the SMADWEC device will be submerged in water, this would be a great choice for the project and with its wide range of voltages it can be easily implemented. This means that the Lithium Iron Phosphate battery would satisfy both Engineering Requirements 3.1 and Engineering Requirements 2.1.

Another reason why the LiFePO4 battery was chosen was because of its efficiency. Once again, due to its greater chemistry stability, it is able to withstand more charging cycles than its lithium-ion counterpart (about 4-5 times longer). Compared to the lead-acid battery, the lithium iron phosphate battery has the advantage of having a much greater lifespan. Basically speaking, the lithium iron phosphate battery would have a greater lifespan (5-10 years) which would satisfy the Engineering Requirements 9.0. The LiFePO4 battery also has the capability of being partially charged and not getting damaged (lose efficiency) while the lead-acid battery requires it to be fully charged at all times, otherwise it will get damaged (lose efficiency) over time. Since the SMADWEC device won't be providing enough energy to fully charge the battery sometimes, the LiFePO4 is the better option.

Performance Analysis

Three important requirements from the customer were as follows: Convert mechanical energy to stored electrical energy, be versatile under different ocean conditions, and double the electrical efficiency. We believe that replacing the existing motor that's acting as a generator with an alternator would be the best way to appease these requirements for many reasons. SMADWEC will be taking in a wide range of RPM due to the unpredictable nature of the ocean, and an alternator can work with the widest range of RPM when taking into consideration all alternatives of electromechanical conversion devices. This will maximize the versatility of SMADWEC, which will certainly up the efficiency of the device. As far as storing the energy goes, a lithium iron phosphate battery was deemed the best of the explored alternatives. Lithium iron phosphate batteries have a higher charge density than lead acid batteries, which was another lead alternative explored. Lithium iron phosphate batteries can also support more charge-recharge cycles than the lead acid and most batteries. Another important factor was safety when analyzing batteries, and lithium iron phosphate batteries are relatively safe in comparison to other batteries such as lead acid. Both items are commercial off the shelf (COTS) parts, which was another requirement. RPM, Torque, Temperature, Voltage, and Current sensors are used to get efficiency values and data required for analysis to ensure the SMADWEC meets the requirements.

Furthermore, the design must fit inside the existing chassis, use modified or off-the-shelf parts, and have a projected lifespan of at least one year. The parts for the design have all been selected with these requirements in mind. All parts are off-the-shelf, sized to fit within the mechanical chassis, and have a projected lifespan of one year or more. In addition, for future modification and expansion, the design must have three modular subsystems: the energy conversion system, the battery charging circuit, and the battery. With the current design, it should be trivial to swap out or modify parts within these systems. Finally, the design must interface with a computer to take and record measurements of torque, RPM, voltage, current, and battery status. The current system includes many sensors for those measurements, which connect to a data acquisition device (DAQ). The DAQ then communicates with LabVIEW, which presents and records the information in an easy-to-read format.

The design's ability to convert mechanical energy to electrical energy can be proven by measuring the power output of the system when given mechanical input, using the DAQ and LabVIEW. Similarly, we can prove that the system can store electrical energy by measuring the charge of the battery while the system is running. This charging will be done with and without a load on the battery. The system will pass the test if the battery gains charge while a mechanical input is applied, and does not lose substantial charge over time when there is no mechanical input.

The versatility of the system will be evaluated using measurement with LabVIEW at a variety of wave periods and amplitudes, then performing analysis on the measured data to determine the effective range of the system. Waves are simulated using a winch that has a steel bar attached to it. The cable can be connected at various radii from the center of the winch, and the winch can be operated at various speeds. This allows a large variety of ocean conditions to be simulated in a lab environment.

The global average generator and rectifier efficiency must be improved from last year's 28% to 50%. To test this, the SMADWEC system will be tested under identical conditions to last year's design. Measurements of the mechanical input torque and RPM, and the output voltage and current will be taken using the DAQ, and the data will be analyzed to determine the efficiency. The device will pass the test if the efficiency is 50% or more.

The design is also required to fit within the existing SMADWEC chassis, use modified or off-the-shelf parts, and have modular subsystems. The design's ability to fit inside the SMADWEC chassis will be proven by demonstration. The device uses only modified or off-the-shelf parts, and this can be proven by inspection. The team can provide receipts for all electrical parts. Similarly, the modularity of the design will be proven by inspection.

The design's ability to communicate with a computer and report diagnostic sensor data can be proven through data analysis. Furthermore, the presence of sensor data for RPM, torque, voltage, current, and battery status can be proven through data analysis. The presence of the sensors in the design, and the DAQ's ability to interpret the sensor data will be proven by presenting data that was measured using the sensors and the DAQ. All parts used in the design have a projected lifespan of at least one year, and that is reflected in the documentation of said parts given by the manufacturer. By running the SMADWEC for at least a month, data analysis can be done on the condition of the parts and if they will last for a year without maintenance to prove that the design has a projected lifespan of at least one year.

The functional block diagram for the proposed design is shown below.

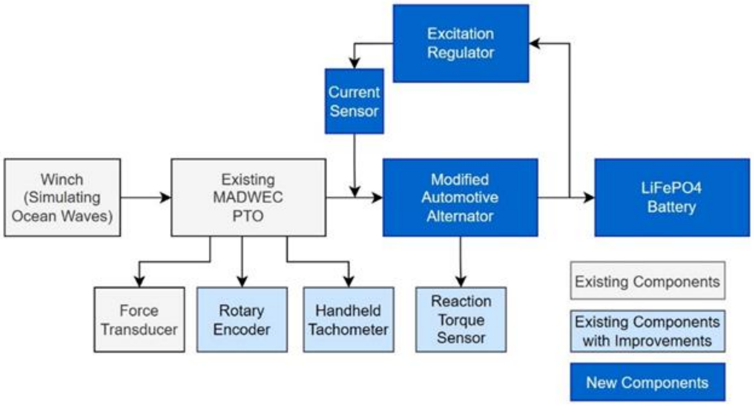
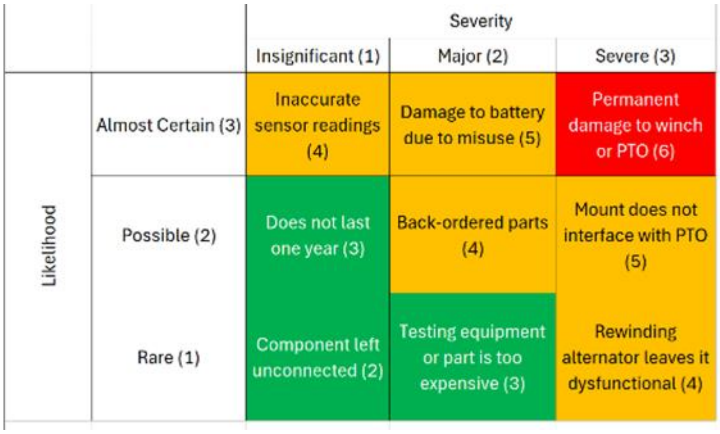


Figure 1.4: SMADWEC Block Diagram

Risk Analysis

There are several risks that must be considered when trying to complete this project including performance, lack of experience, cost, and schedule.



		Severity		
		Insignificant (1)	Major (2)	Severe (3)
Likelihood	Almost Certain (3)	Inaccurate sensor readings (4)	Damage to battery due to misuse (5)	Permanent damage to winch or PTO (6)
	Possible (2)	Does not last one year (3)	Back-ordered parts (4)	Mount does not interface with PTO (5)
	Rare (1)	Component left unconnected (2)	Testing equipment or part is too expensive (3)	Rewinding alternator leaves it dysfunctional (4)

Figure 1.5: Risk Fever Chart

The largest performance risk associated with the SMADWEC is the ocean wave simulating setup in the SMAST lab. This is categorized as a severe risk because with the current setup in the lab, if the winch were to get caught on the rope, the winch could be overloaded and destroyed or the or the SMADWEC PTO's mechanical system could be significantly damaged. This could also lead to over-working the gear box in the mechanical system. The 15:1 gearbox includes lots of gears and is prone to failure. Putting too much strain on the gearbox could cause damage and delay the project. These risks were mitigated by ensuring there were several people (2+) in the lab when operating the setup and following test conditions that were known to be safe for previous teams.

A major risk for the project was the lack of mechanical experience on the electrical team. This was mitigated by using the university's resources and consulting the technicians in the mechanical engineering department for assistance. The team took an ambitious approach in rewinding an automotive alternator which can be tedious and difficult with no experience. To mitigate this the team referenced different sources that document the process well and have shown the method to be successful. The other part to the mechanical side of the project is the mounting of the new alternator into the chassis of the SMADWEC PTO. This was mitigated by having a mechanical technician perform all the measurements, modifications, and manufacturing of the new mount.

Cost is not a large risk for this project because the budget was given as $5,000 and the parts were commercial off the shelf (COTS). To perform individual testing of the alternator, the team needed a repeatable and accurate way of spinning it at various RPM. Purchasing a motor capable of this would be a substantial cost so the team used a drill press available in the mechanical engineering shop as a variable RPM motor to test the alternator.

Scheduling was a moderate risk for this project as it was crucial to set up and meet deadlines for the sponsor. The obvious scheduling risk is purchasing parts and not having them come in on time. As a direct result of this, this could cause delays in prototyping and testing that would occur weeks later or even months later, making the team fall behind on their required deadlines.

A risk associated with the lithium iron phosphate battery is that if mis-handled, it can combust into flames because of its ability to store a large amount of charge in a small area. Also, it can release hydrogen gas, which is very flammable and can ignite very easily.

Mechanical Engineering Team

Design Objective – Alternative Use Cases

When the mechanical engineering team was first approached with this project at the start of the academic year it was proposed that the SMADWEC project be used for military applications. With the intentions being that it would be used to help prolong operations such as naval surveillance missions. Due to this the design for the ballast system would have to be self-deployable from a type-A sonobuoy typically used by the military. This is why both the mechanical engineering design challenge and build & test challenge reference a need to fit and be deployed from a sonobuoy. As this project evolved so did its use cases, with a new commercial lifeboat use coming to fruition which is covered in the business plan. Due to the size constraints of this ballast system resulting from the sonobuoy, it allows for the ballast system to still function perfectly within the lifeboat use case due to its compact size, weight, and ease of deployment. When reading these mechanical engineering sections please keep this in mind as it is essential to understand why values/needs outlined in things like the PDS chart, customer needs, etc. are so specific. Along with this, the dual usage that the SMADWEC can be used for (Miliary applications & lifeboats) allows for more versatility of the device and overall increases the marketability of the device which will in turn help to increase usage of the SMADWEC once a production model is available.

Design Objective – Support

Ocean wave energy conversion involves capturing energy from ocean waves. For the Survival Maximal Asymmetric Drag Wave Energy Converter (SMADWEC) project, a ballast system is needed to create drag allowing for the generation of electrical energy. The ballast system needs to fit within a class A sonobuoy along with all other SMADWEC components and should be capable of outlasting current battery powered alternatives. It is required that the system be self-deployable and capable of producing the maximum added mass with the given constraints. It was found that the system would need to expand beyond the diameter of the sonobuoy to meet the added mass requirements. The finalized design resembles an upside-down umbrella which expands upon deployment which best fits the requirements based upon the predetermined evaluation criteria. The finalized design fully utilizes the reduced size allocations to produce the highest added mass possible with the smallest displacement relative to the sonobuoy. This is achieved through multiple design features such as twice collapsible spring-loaded support members that are released by a fully mechanical key mechanism that is tension driven. Through this key release, the design can remain hydrodynamic until it reaches its operating depth, where it expands and locks into place for rapid deployment. Following the manufacture of a prototype of the finalized design, computational analysis and experimental analysis were completed in MATLAB and the SMAST testing facility respectively. The results from said testing and data driven analysis have shown a fully collapsible and rapidly deployable design that can achieve substantial added mass numbers for reliable power generation.

Engineering Constraints and requirements from PDS Chart

Stemming from the created PDS (product design specifications chart) and deliverables document for the ballast system (Full tables can be seen in the appendix) are a list of constraints either directly stated by the sponsors of this project or were found during background research for this project, these constraints are broken down into categories with each constraint being its own subcategory.

The first of these categories is integration into the SMADWEC platform and there are two different constraints that come with this category. The first constraint being that the design needs to be able to attach to already existing interfaces on the PTO. This will be done by tethering the ballast to the PTO, but it needs to be done so no extra holes or attachment points are created on the PTO. The second constraint is that this design needs to be easily scalable. While the sonobuoy that the SMADWEC will be packaged in is quite small, in the future if this functions as effectively as intended, more industrialized larger scale applications of this design may be adopted. In that case the designs need to be easily scalable to fit any application.

The second category is in regard to the material selection for the ballast system. Since this ballast system will be functioning within a marine environment, first and foremost the materials chosen must be ocean safe, meaning no components that may harm the ecosystem of a marine environment. Secondly, since the ballast is operating in saltwater, the materials chosen must have a high corrosion resistance as unwanted corrosion can hinder the effectiveness or result in failure of the SMADWEC. Finally, the materials chosen must sink if anything happens to the SMADWEC that causes it to have catastrophic failure. The system should then sink to the ocean floor and function as what could be described as a “artificial reef” and not pose any detriment to marine life. While this occurrence is assumed to be remote, it is still something that needs to be considered when selecting materials.

Since this ballast system and the entire SMADWEC device needs to be packaged into a type-A sonobuoy, there are strict size constraints that need to be followed. The interior dimensions of this type of sonobuoy are roughly 4 7/8 inches in diameter and 36 inches in length. The ballast system has been allocated one third of the interior volume of the sonobuoy.

Along with the size requirements are some weight requirements that come with the sonobuoy packaging. The total weight of a type-A sonobuoy is limited to 39 lbs. Half of this allocation is given to the ballast system. This requirement isn’t as demanding compared to the size requirements, as durable and lightweight marine grade components are readily available.

Due to the operating conditions that this ballast system will be functioning in, the design must perform under ocean temperatures and ocean pressures. For a generous estimate of these parameters, the properties of the ocean environment were evaluated at around 200 meters (about 656.17 ft) of depth. This depth should well exceed the functional depth of the ballast system. At the specified depth, the ballast system must function at a temperature of 3° C and a pressure of 291 Psi.

Due to the systems projected operation in a marine environment, additional codes and standards may apply. These codes and standards mainly stem from the United States Department of Defense and OSHA, and can be found below in part B.

Next, the ballast system must provide maximum drag during upstroke and the minimum drag during downstroke. This will result in the maximum power being generated from the SMADWEC as the ballast will resist upward movement but will sink during the downstroke to keep tension on the tether.

The next requirement is the lifecycle. This design needs to effectively replace what a sonobuoy filled with a charged battery bank would be able to achieve and for that reason, having a life span of as long as possible (days to weeks) would justify the reasoning to deploy this SMADWEC device over that of a charged battery bank design.

Finally, the last requirement is that one functional ballast system is to be created. Since this is effectively a prototype. Only one ballast system is needed to establish proof of concept and its functionality. Following the manufacture of the prototype, the system will be re-designed for ease of manufacturing once more units are needed for production.

How Design Meets PDS Requirements

Below is a list of PDS (from **Figure 2.1**) along with comprehensive analysis corresponding to all aspects of the finalized design and testing.

Provide maximum drag during upstroke of the SMADWEC – The final design utilizes the full allocated geometry of the sonobuoy interior and expands beyond the interior diameter of the sonobuoy through the use of twice collapsible support mechanisms. The added mass testing yielding a peak added mass of 570.95kg and an average added mass of 373.94kg, further solidifies the design's ability to meet this requirement.

Provide minimum drag during downstroke of the SMADWEC - The design rapidly sinks due to its high density and geometry of its partially collapsed spring-loaded arm mechanisms, a phenomenon that was seen in the deployment testing. The small-scale terminal velocity testing yielding 1.29m/s, further solidifies the design's ability to meet this requirement.

Design allows for scalability for possible future larger scale applications – The designs feature many components that make for easy scaling in all dimensions to allow for simple redesign for varying customer requirements. Furthermore, modifications to size requirements have been appeased though scaling of said components. Thus, preventing major re-designs.

Ballast system is tethered to PTO - The designs will be tethered to the PTO with the same cable used to tether the PTO to the sonobuoy.

Material selection must not result in pollution of the environment, disruption of the ecosystem, or harm to wildlife – The design features a full metal construction with a combination of marine grade aluminum and stainless-steel structural components along with highly resistant neoprene as the dynamic components, which are designed to be safe for a marine environment.

Corrosion must not inhibit the operational components in the design as well as not cause failures to any structural components - The designs feature a combination of marine grade aluminum, stainless-steel, and neoprene components which are designed to withstand the harsh conditions of a marine environment. In addition, marine grade anti-seize compound was applied to all wear points for increased longevity.

If discarded in ocean, it should not disrupt ecosystem or harm wildlife, and should sink to the ocean floor - The design features marine grade materials that are denser than water and will sink upon their disconnection from the sonobuoy.

Collapsable design that fits into sonobuoy but expands upon deployment – The finalized design features twice expanding arm mechanisms that activate upon deployment, which are small enough when collapsed to fit comfortably within the size allocation of the sonobuoy. Upon deployment testing, the collapsibility and fitment of the design in the Sonobuoy was validated.

Once released from a sonobuoy, the ballast system will deploy on its own - The finalized design deploys instantaneously through a fully mechanical key release mechanism which activates upon the first instance of tension supplied from the PTO tether. With no external equipment needed. From deployment testing, the design's ability to expand into its operating position was validated.

If exceeds needed lifespan system can be used for larger and more lengthy applications – The design features a full metal construction of high tensile strength and marine grade resistant materials along with a high wear resistant neoprene dynamic material which serves to extend the lifecycle of the design. Furthermore, marine grade anti-seize compound was applied to all wear points acting as a high-performance lubricant.

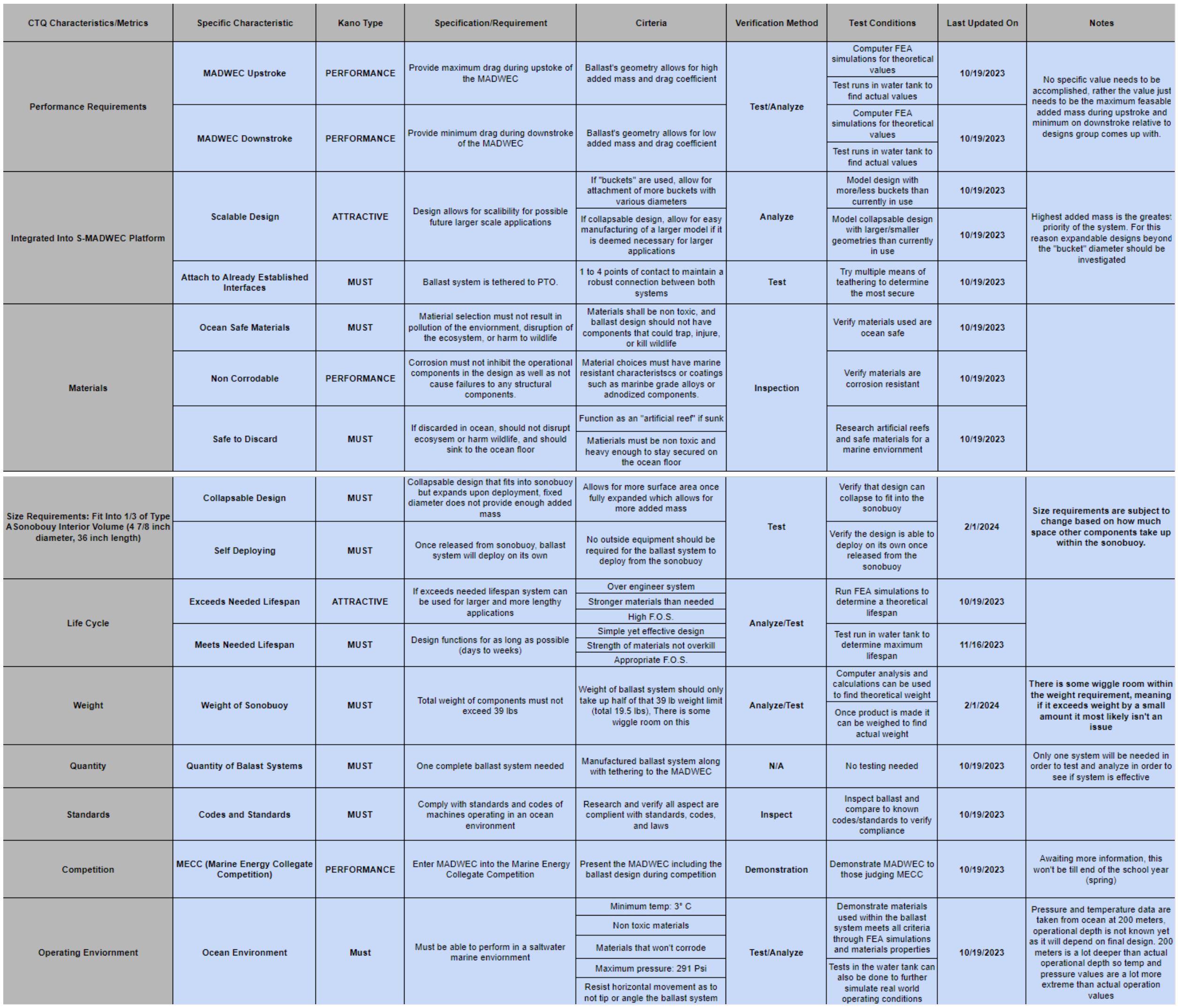
Design functions for as long as possible (days to weeks) - See previous Requirement.

Total weight of components must not exceed 39 lbs. - While featuring a full metal construction, due to their size, the design does not come close to the weight restrictions. Due to the other components that will be packaged within the sonobuoy, the ballast system has been allocated half of the total weight (19.5lbs.) with a little bit of wiggle room. The structural components have been mass studied at under 7lbs which is well within the given requirements. Furthermore, after the design final assembly, it was weighed in at just over 10lbs, which is well with the requirement.

One complete ballast system needed – As this process is designing a possible prototype to then be used in real world applications, only one ballast system is needed for this project. Thus, the singular completed prototype of the final design meets this requirement.
Comply with standards and codes of mechanical systems operating within an ocean environment - The designs comply with the codes and standards of the marine environment proving to be environmentally safe.

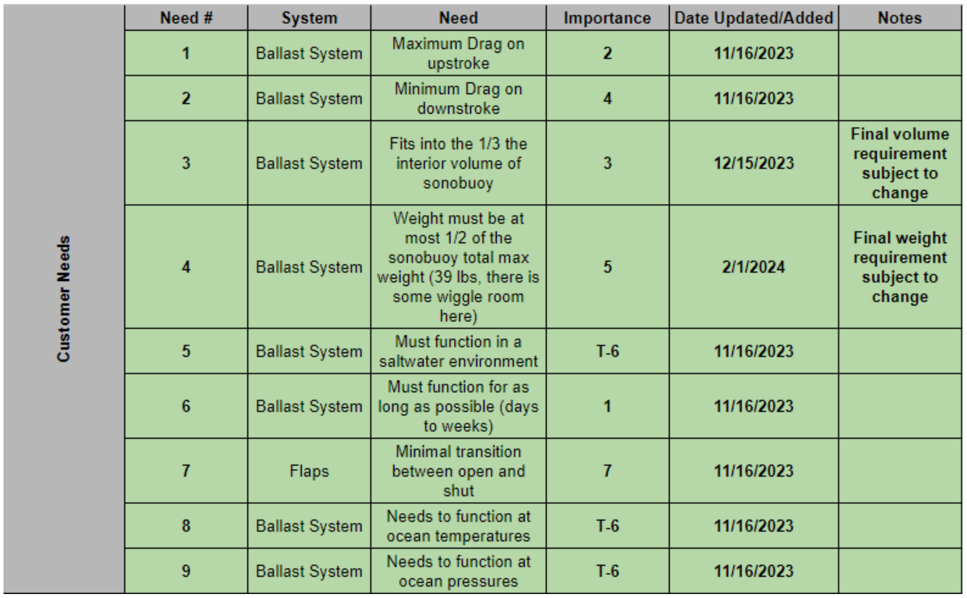
Enter SMADWEC into the Marine Energy Colligate Competition – The finalized design has been entered into the MECC competition.

Must be able to perform in a saltwater marine environment - The designs feature marine grade material construction as outlined previously which are rated to resist corrosion and rust from the saltwater environment, (in addition to protective anti-seize compounds and thread locker).



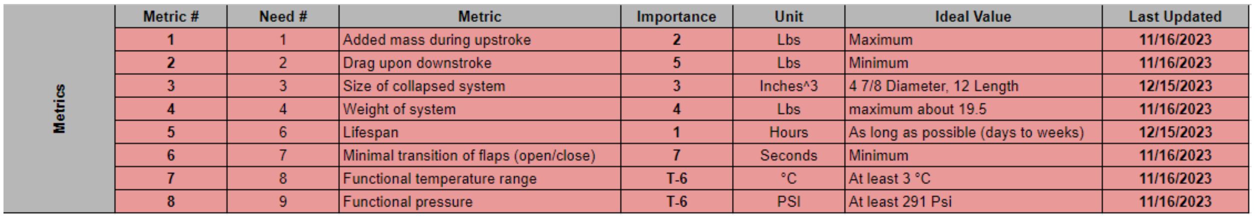
CTQ Characteristics/Metrics	Specific Characteristic	Kano Type	Specification/Requirement	Cirteria	Verification Method	Test Conditions	Last Updated On	Notes
Performance Requirements	MADWEC Upstroke	PERFORMANCE	Provide maximum drag during upstoke of the MADWEC	Ballast's geometry allows for high added mass and drag coefficient	Test/Analyze	Computer FEA simulations for theoretical values Test runs in water tank to find actual values	10/19/2023	No specific value needs to be accomplished, rather the value just needs to be the maximum feasable added mass during upstroke and minimum on downstroke relative to designs group comes up with.
	MADWEC Downstroke	PERFORMANCE	Provide minimum drag during downstroke of the MADWEC	Ballast's geometry allows for low added mass and drag coefficient		Computer FEA simulations for theoretical values Test runs in water tank to find actual values	10/19/2023	
Integrated Into S-MADWEC Platform	Scalable Design	ATTRACTIVE	Design allows for scalibility for possible future larger scale applications	If "buckets" are used, allow for attachment of more buckets with various diameters If collapsable design, allow for easy manufacturing of a larger model if it is deemed necessary for larger applications	Analyze	Model design with more/less buckets than currently in use Model collapsable design with larger/smaller geometries than currently in use	10/19/2023 10/19/2023	Highest added mass is the greates priority of the system. For this reason expandable designs beyond the "bucket" diameter should be investigated
	Attach to Already Established Interfaces	MUST	Ballast system is tethered to PTO.	1 to 4 points of contact to maintain a robust connection between both systems	Test	Try multiple means of teathering to determine the most secure	10/19/2023	
Materials	Ocean Safe Materials	MUST	Matierial selection must not result in pollution of the enviornment, disruption of the ecosystem, or harm to wildlife	Materials shall be non toxic, and ballast design should not have components that could trap, injure, or kill wildlife	Inspection	Verify materials used are ocean safe	10/19/2023	
	Non Corrodable	PERFORMANCE	Corrosion must not inhibit the operational components in the design as well as not cause failures to any structural components.	Material choices must have marine resistant characteristscs or coatings such as marinbe grade alloys or adnodized components.		Verify materials are corrosion resistant	10/19/2023	
	Safe to Discard	MUST	If discarded in ocean, should not disrupt ecosysem or harm wildlife, and should sink to the ocean floor	Function as an "artificial reef" if sunk Matierials must be non toxic and heavy enough to stay secured on the ocean floor		Research artificial reefs and safe materials for a marine enviornment	10/19/2023	
Size Requirements: Fit Into 1/3 of Type A Sonobouy Interior Volume (4 7/8 inch diameter, 36 inch length)	Collapsable Design	MUST	Collapsable design that fits into sonobuoy but expands upon deployment, fixed diameter does not provide enough added mass	Allows for more surface area once fully expanded which allows for more added mass	Test	Verify that design can collapse to fit into the sonobuoy	2/1/2024	**Size requirements are subject to change based on how much space other components take up within the sonobuoy.**
	Self Deploying	MUST	Once released from sonobuoy, ballast system will deploy on its own	No outside equipment should be required for the ballast system to deploy from the sonobuoy		Verify the design is able to deploy on its own once released from the sonobuoy		
Life Cycle	Exceeds Needed Lifespan	ATTRACTIVE	If exceeds needed lifespan system can be used for larger and more lengthy applications	Over engineer system Stronger materials than needed High F.O.S.	Analyze/Test	Run FEA simulations to determine a theoretical lifespan	10/19/2023	
	Meets Needed Lifespan	MUST	Design functions for as long as possible (days to weeks)	Simple yet effective design Strength of materials not overkill Appropriate F.O.S.		Test run in water tank to determine maximum lifespan	11/16/2023	
Weight	Weight of Sonobuoy	MUST	Total weight of components must not exceed 39 lbs	Weight of ballast system should only take up half of that 39 lb weight limit (total 19.5 lbs), There is some wiggle room on this	Analyze/Test	Computer analysis and calculations can be used to find theoretical weight Once product is made it can be weighed to find actual weight	2/1/2024	**There is some wiggle room within the weight requirement, meaning if it exceeds weight by a small amount it most likely isn't an issue**
Quantity	Quantity of Balast Systems	MUST	One complete ballast system needed	Manufactured ballast system along with tethering to the MADWEC	N/A	No testing needed	10/19/2023	Only one system will be needed in order to test and analyze in order to see if system is effective
Standards	Codes and Standards	MUST	Comply with standards and codes of machines operating in an ocean environment	Research and verify all aspect are complient with standards, codes, and laws	Inspect	Inspect ballast and compare to known codes/standards to verify compliance	10/19/2023	
Competition	MECC (Marine Energy Collegate Competition)	PERFORMANCE	Enter MADWEC into the Marine Energy Collegate Competition	Present the MADWEC including the ballast design during competition	Demonstration	Demonstrate MADWEC to those judging MECC	10/19/2023	Awaiting more information, this won't be till end of the school year (spring)
Operating Enviornment	Ocean Environment	Must	Must be able to perform in a saltwater marine enviornment	Minimum temp: 3° C Non toxic materials Materials that won't corrode Maximum pressure: 291 Psi Resist horizontal movement as to not tip or angle the ballast system	Test/Analyze	Demonstrate materials used within the ballast system meets all criteria through FEA simulations and materials properties Tests in the water tank can also be done to further simulate real world operating conditions	10/19/2023	Pressure and temperature data are taken from ocean at 200 meters, operational depth is not known yet as it will depend on final design. 200 meters is a lot deeper than actual operational depth so temp and pressure values are a lot more extreme than actual operation values

Figure 2.1: Full PDS Chart



	Need #	System	Need	Importance	Date Updated/Added	Notes
Customer Needs	1	Ballast System	Maximum Drag on upstroke	2	11/16/2023	
	2	Ballast System	Minimum Drag on downstroke	4	11/16/2023	
	3	Ballast System	Fits into the 1/3 the interior volume of sonobuoy	3	12/15/2023	Final volume requirement subject to change
	4	Ballast System	Weight must be at most 1/2 of the sonobuoy total max weight (39 lbs, there is some wiggle room here)	5	2/1/2024	Final weight requirement subject to change
	5	Ballast System	Must function in a saltwater environment	T-6	11/16/2023	
	6	Ballast System	Must function for as long as possible (days to weeks)	1	11/16/2023	
	7	Flaps	Minimal transition between open and shut	7	11/16/2023	
	8	Ballast System	Needs to function at ocean temperatures	T-6	11/16/2023	
	9	Ballast System	Needs to function at ocean pressures	T-6	11/16/2023	

Figure 2.2: Customer needs document.



	Metric #	Need #	Metric	Importance	Unit	Ideal Value	Last Updated
Metrics	1	1	Added mass during upstroke	2	Lbs	Maximum	11/16/2023
	2	2	Drag upon downstroke	5	Lbs	Minimum	11/16/2023
	3	3	Size of collapsed system	3	Inches^3	4 7/8 Diameter, 12 Length	12/15/2023
	4	4	Weight of system	4	Lbs	maximum about 19.5	11/16/2023
	5	6	Lifespan	1	Hours	As long as possible (days to weeks)	12/15/2023
	6	7	Minimal transition of flaps (open/close)	7	Seconds	Minimum	11/16/2023
	7	8	Functional temperature range	T-6	°C	At least 3 °C	11/16/2023
	8	9	Functional pressure	T-6	PSI	At least 291 Psi	11/16/2023

Figure 2.3: Metrics document.

Performance Analysis

After extensive testing, we have conclusively established that our ballast design yields a peak added mass of 570 kilograms and an average added mass of 370 kilograms. It's important to note that while we have not yet finalized the theoretical power output due to pending completion of the PTO testing and determination of efficiencies, preliminary assessments suggest promising results. The anticipated drag generated by the ballast design should provide ample energy for the PTO system, potentially enabling it to generate sufficient power to effectively operate a communications buoy. Furthermore, it's worth highlighting that our ballast system exhibits minimal drag during the downstroke of the wave, contributing to its overall efficiency. This characteristic is particularly noteworthy as it ensures that the system operates with optimal effectiveness, even during varying wave conditions. Additionally, our thorough testing has revealed that the ballast system attains a terminal velocity of 1.3 meters per second, further underscoring its capacity to navigate through water currents with exceptional stability and control.

When considering the project objectives outlined at the beginning of the semester as well as the results produced by the SMADWEC team, it is reasonable to conclude that the produced ballast system was a success. It is capable of collapsing into and deploying from the allotted sonobuoy volume. The design also performs well in terms of added mass achieved on wave upstrokes from our peak added mass figure being 571Kg from testing as compared to our theoretical figure 783Kg. Additionally, the team remained on schedule and within budget. It should be noted however that this design was started from scratch and that it should only serve as a first iteration to be further refined and finalized for large scale production and deployment.

Looking towards the future for further project development, the next steps would include adjusting and simplifying the design to improve manufacturability, assembly, and performance. The most important change that needs to be implemented is the replacement of the flexible material with one that is more capable of folding up more compactly. This is because the current rubber being used is difficult to fold and has difficulty falling away from the sonobuoy due to friction with the tube interior. Silicone lubricant addressed this issue for testing, but a more suitable material can be selected for future use. Otherwise, it is recommended that the arms be redesigned to integrate the hinges as a single component, which would streamline assembly and increase the compactness of the design. These recommendations in addition to the cumulative work achieved during the project should allow for future teams to further refine the design.

Force Calculations - Mechanical Loading

Using a MATLAB code provided by Dr. MacDonald, a hypothetical wave period and height that would correspond to represent an ultimate limit for vertical velocity and acceleration. These parameters would then be used to evaluate the maximum stresses that the ballast system would be under during operation and allow for a generous safety factor to be considered. The wave parameters chosen were 5 meters high with a 2-second period. Inputting these values into the MATLAB code results in a maximum peak power of 105515 W, as shown below in **Figure 2.5.** This code takes into account a 1 by 1 meter section (1 m^2) of a given wave, to fully evaluate the design of the ballast, the force will have to be multiplied by the area of the ballast system. This area will be taken as if a flat plate was placed on top of the ballast system rather than the contact area between the ballast in the water, as the area needs to be in relation to the wave.

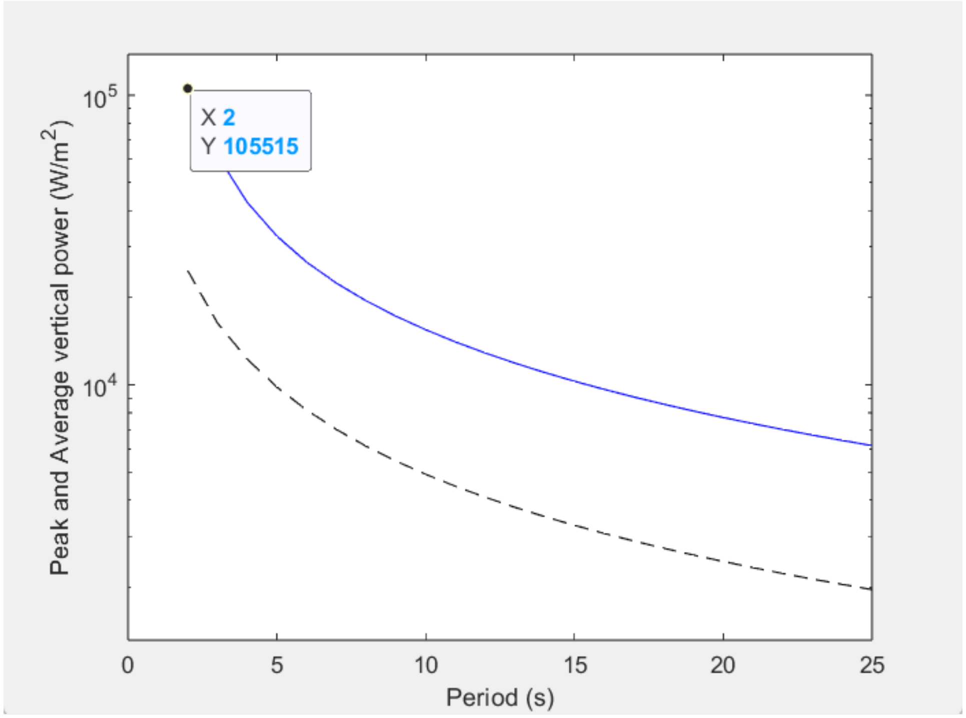
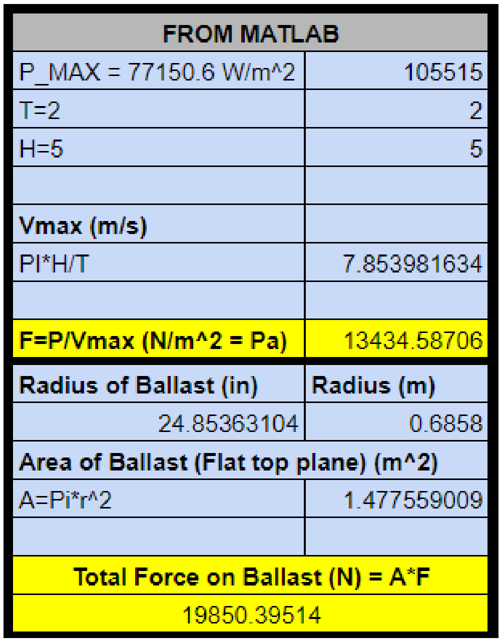


Figure 2.5: Maximum peak wave power available to a point absorber given a wave height of 5 m.

Using these parameters from MATLAB (Power, height, and period) simple calculations can be done to find the maximum force the ballast will be under. Firstly, the formula Vmax = PI*H/T is used to find the maximum velocity that the ballast system could possibly be undergoing with a wave of that size. Then using this value and plugging it into the force equation of F=P/Vmax, a value of 13434.6 Pa (1.9485 Psi) is found. However, since this is still per unit area of the wave, this value must be multiplied by the area of the ballast system in order to find the total force. Using the ballast x direction radius of 24.85 inches and converting to 0.6858 m, it results in an area of about 1.4776 m^2. Which, when multiplied by the force value shown before, results in a total force of 19584.4 N. These calculations can be seen below.



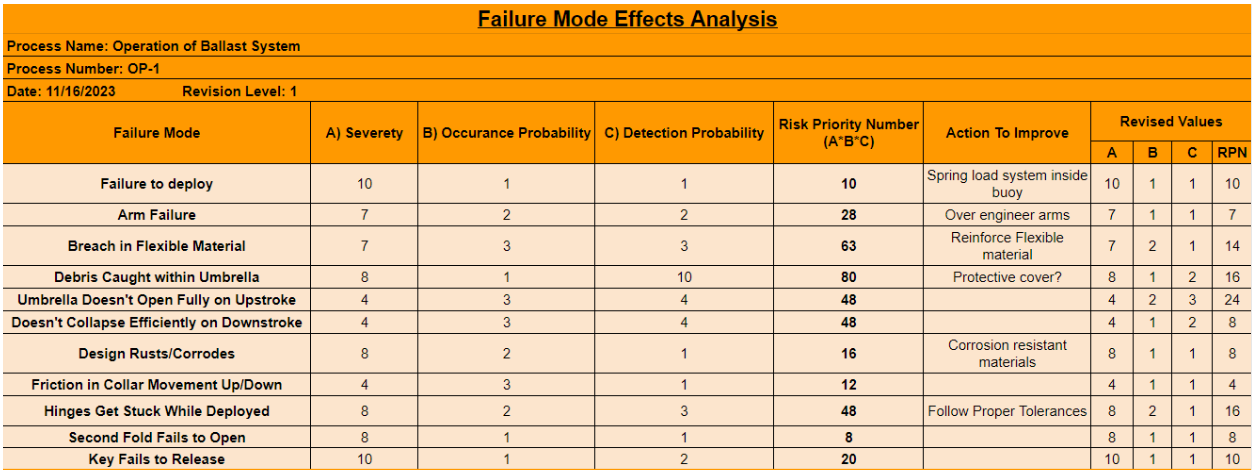
FROM MATLAB	
P_MAX = 77150.6 W/m^2	105515
T=2	2
H=5	5
Vmax (m/s)	
PI*H/T	7.853981634
F=P/Vmax (N/m^2 = Pa)	13434.58706
Radius of Ballast (in)	**Radius (m)**
24.85363104	0.6858
Area of Ballast (Flat top plane) (m^2)	
A=Pi*r^2	1.477559009
Total Force on Ballast (N) = A*F	
19850.39514	

Figure 2.6: Calculations of the total force on the ballast system.

These force values come with a few caveats. Firstly, this is a very unrealistic wave profile that is being used, so true operational values will be much lower than the values shown. Secondly, this is assuming that the PTO is fixed in relation to the buoy (no energy consumption). Under these wave conditions, it is much more likely that the ballast system would pull the PTO and buoy underwater than it is to have the ballast system pulled up at such a high velocity. Finally, it is unknown the true operating conditions for the ballast, and how the components of the SMADWEC will all work together as SMADWEC is under continuous development by different engineering teams. Finally, the maximal wave conditions provide a very broad estimate of what the maximum operating force could possibly be. Actual operational values will be far lower than this.

Risk Analysis/FMEA

Failure Mode Effects Analysis (FMEA) is a way to identify and address potential problems and their effects on the system. For this ballast system there are three main processes that the FMEA is split into. Those being operation of the ballast system (OP-1), manufacturing of the ballast system (MFG-1), and the assembly of the ballast system (ASM-1). Below are the FMEA tables created by the group and preliminary risk ratings assigned for A) Severity of failure, B) probability for failure to occur, and C) probability this issue will be detected before deployment.



Failure Mode Effects Analysis

Process Name: Operation of Ballast System

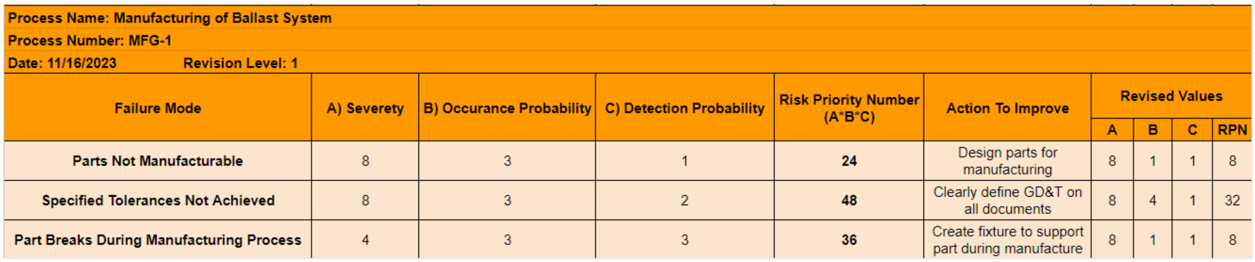
Process Number: OP-1

Date: 11/16/2023 **Revision Level: 1**

Failure Mode	A) Severety	B) Occurance Probability	C) Detection Probability	Risk Priority Number (A*B*C)	Action To Improve	Revised Values			
						A	B	C	RPN
Failure to deploy	10	1	1	**10**	Spring load system inside buoy	10	1	1	10
Arm Failure	7	2	2	**28**	Over engineer arms	7	1	1	7
Breach in Flexible Material	7	3	3	**63**	Reinforce Flexible material	7	2	1	14
Debris Caught within Umbrella	8	1	10	**80**	Protective cover?	8	1	2	16
Umbrella Doesn't Open Fully on Upstroke	4	3	4	**48**		4	2	3	24
Doesn't Collapse Efficiently on Downstroke	4	3	4	**48**		4	1	2	8
Design Rusts/Corrodes	8	2	1	**16**	Corrosion resistant materials	8	1	1	8
Friction in Collar Movement Up/Down	4	3	1	**12**		4	1	1	4
Hinges Get Stuck While Deployed	8	2	3	**48**	Follow Proper Tolerances	8	2	1	16
Second Fold Fails to Open	8	1	1	**8**		8	1	1	8
Key Fails to Release	10	1	2	**20**		10	1	1	10

Figure 2.7: FMEA for OP-1, operation of ballast system.

As shown above in **Figure 2.7** the possible failure modes for OP-1 are listed in the left most column. These include failure to deploy, arm failure, breach in the flexible material, umbrella mechanism not opening/closing effectively, corrosion in the design, friction in the collar, and hinges getting stuck. While a majority of these failure points can be detected through proper force calculations and testing, there is one failure mode which has an exceptionally low probability but has not been considered in our testing due to its difficulty of simulating. This failure mode is ocean debris getting caught within the ballast system. While there is an exceptionally low chance of this occurring, as most ocean debris either floats on the surface or sinks to the bottom it is still an unpredictable occurrence which would hinder the effectiveness of the ballast. Finally, there are a couple modes of failure stemming from the deployment of the ballast system, these being the second arm fold failing to unfold, and the key failing to release. The second arm failing to fold has been evaluated in the deployment testing. As far as the key failing to deploy, this comes down to applying proper tolerances so that there is a small bit of interference, but not enough to keep the key wedged in the ballast once enough tension is applied by the tether.



Process Name: Manufacturing of Ballast System

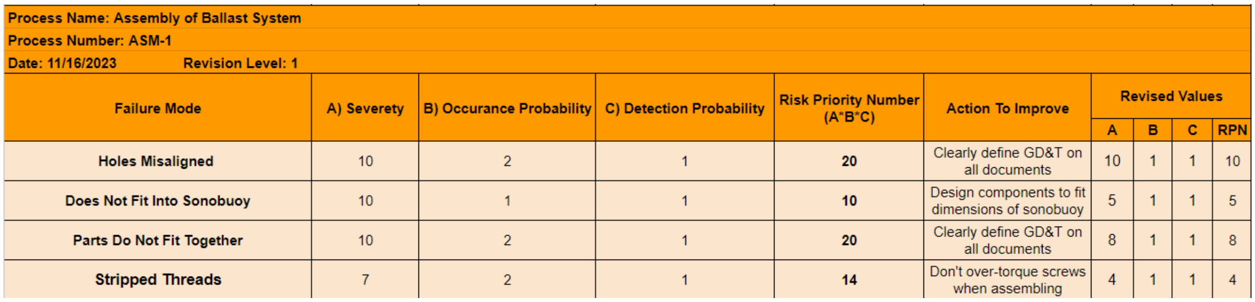
Process Number: MFG-1

Date: 11/16/2023 **Revision Level: 1**

Failure Mode	A) Severety	B) Occurance Probability	C) Detection Probability	Risk Priority Number (A*B*C)	Action To Improve	Revised Values			
						A	B	C	RPN
Parts Not Manufacturable	8	3	1	**24**	Design parts for manufacturing	8	1	1	8
Specified Tolerances Not Achieved	8	3	2	**48**	Clearly define GD&T on all documents	8	4	1	32
Part Breaks During Manufacturing Process	4	3	3	**36**	Create fixture to support part during manufacture	8	1	1	8

Figure 2.8: FMEA of MFG-1, manufacturing of ballast system.

As shown above in **Figure 2.8** during the manufacturing process there are only a few possible failure modes. The parts in the design are not manufacturable, the specific tolerances and dimensions are not achieved, and the part breaks during the manufacturing process. All of these can be mitigated by designing for manufacturing. This will help to achieve specified tolerances, ensuring that proper geometric dimensioning and tolerances are clearly stated on all supporting CAD files and draft documentation. Finally, there is a small possibility that a part breaks during manufacturing, this can be mitigated by using proper manufacturing processes, cutting tools, cutting speeds, etc. As well as supporting the workpiece to make sure no unwanted movement happens that may cause the part to break or be cut incorrectly.



Process Name: Assembly of Ballast System
Process Number: ASM-1
Date: 11/16/2023 **Revision Level: 1**

Failure Mode	A) Severety	B) Occurance Probability	C) Detection Probability	Risk Priority Number (A*B*C)	Action To Improve	Revised Values			
						A	B	C	RPN
Holes Misaligned	10	2	1	20	Clearly define GD&T on all documents	10	1	1	10
Does Not Fit Into Sonobuoy	10	1	1	10	Design components to fit dimensions of sonobuoy	5	1	1	5
Parts Do Not Fit Together	10	2	1	20	Clearly define GD&T on all documents	8	1	1	8
Stripped Threads	7	2	1	14	Don't over-torque screws when assembling	4	1	1	4

Figure 2.9: FMEA of ASM-1, assembly of ballast system.

For this final process there are four main failure modes that can occur as seen in **Figure 2.9**. These stem from misaligned holes, the assembled product not fitting into the sonobuoy, parts not meshing properly, and stripped threads during the assembly process. Holes being misaligned and parts not fitting together can be solved by practicing proper geometrical dimensioning and tolerancing when creating the CAD files. Evaluating fitment into the sonobuoy stems from the deployment testing as well as measurements taken when assembling the design as dimensions of the sonobuoy need to be taken priority in order to have a correct fitment. Finally stripped threads are easy to mitigate by not over torquing screws when assembling.

Engineering diagrams of all mechanical components

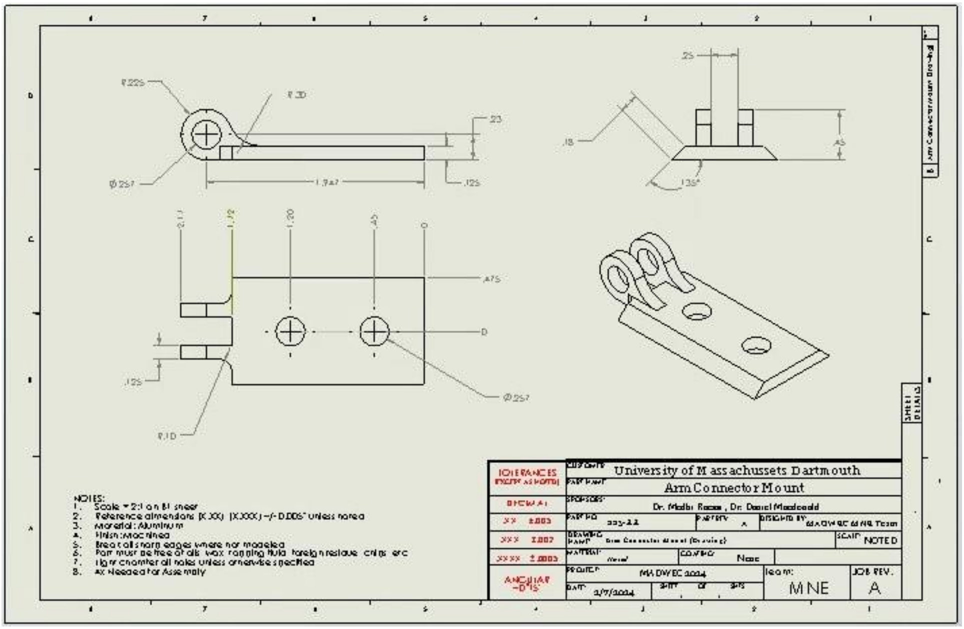


Figure 2.10: Arm Connector Mount Drawing

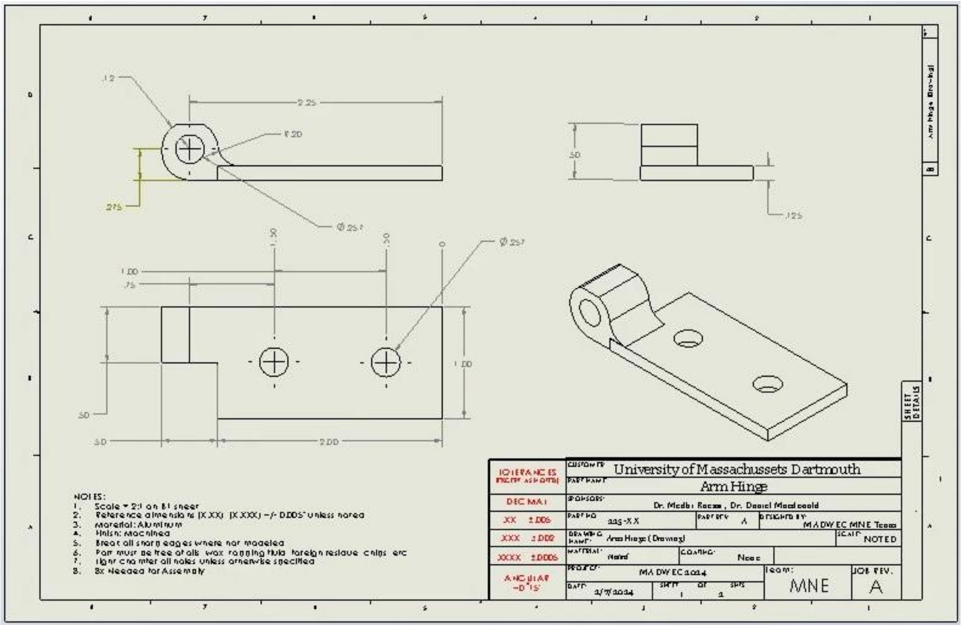


Figure 2.11: Arm Hinge Drawing

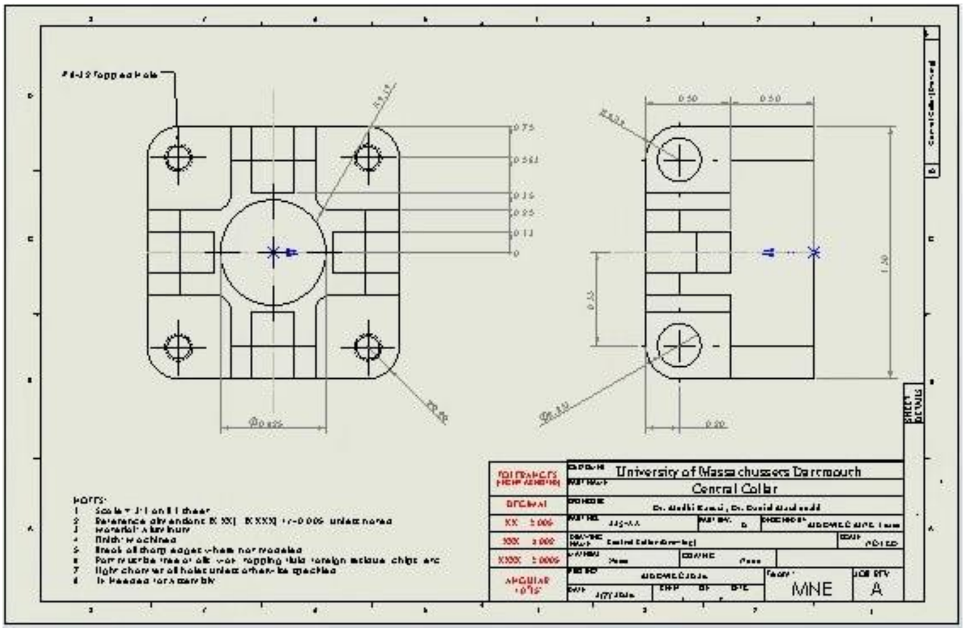


Figure 2.12: Central Collar Drawing

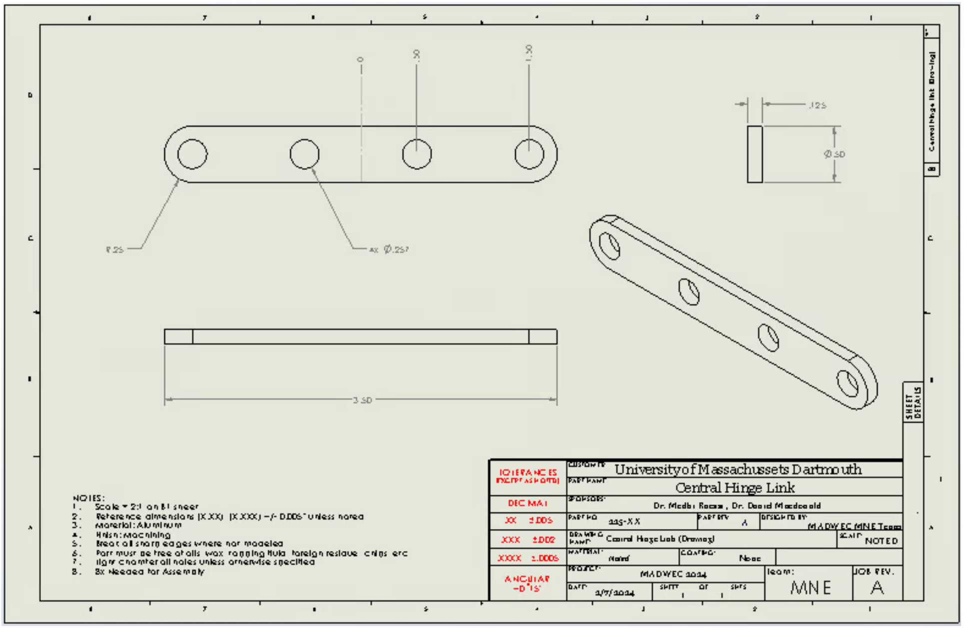


Figure 2.13: Central Hinge Link Drawing

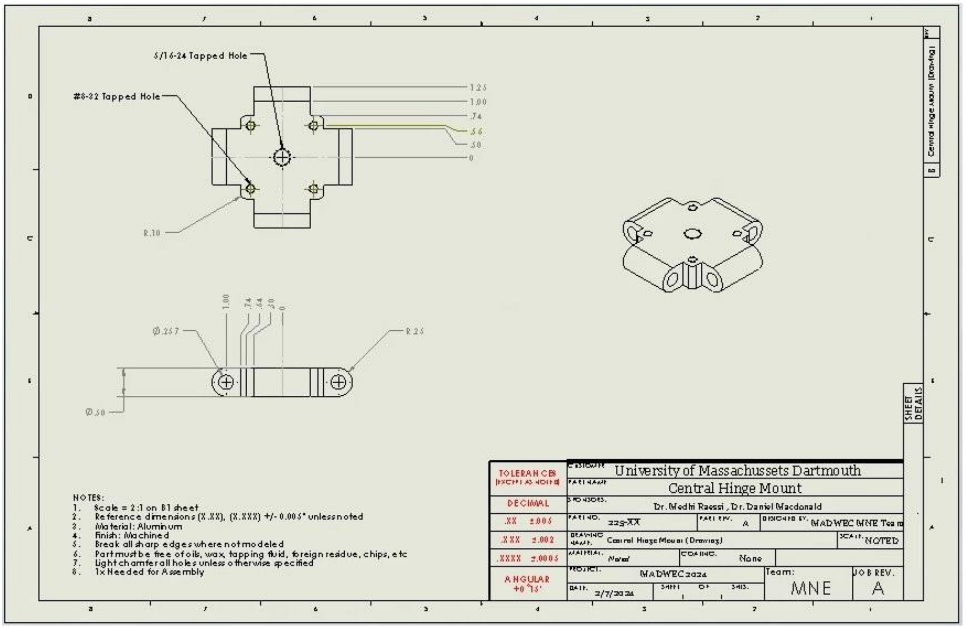


Figure 2.14: Central Hinge Mount Drawing

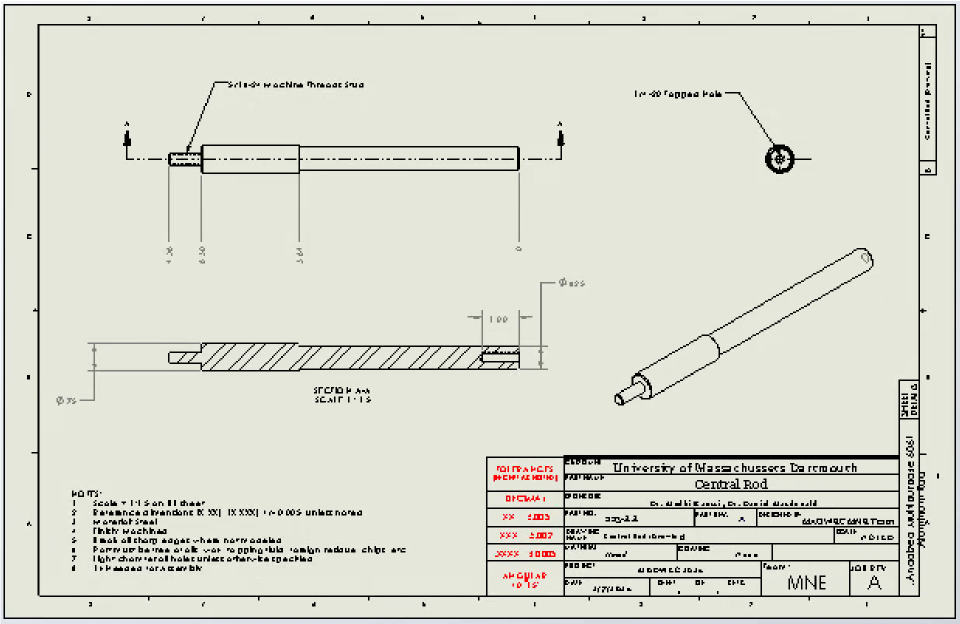


Figure 2.15: Central Rod Drawing

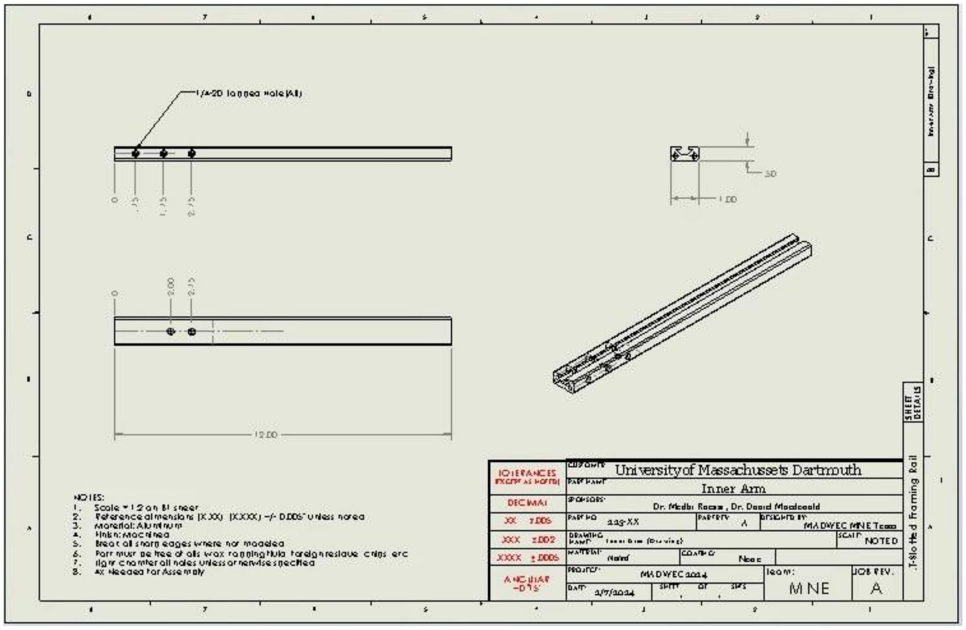


Figure 2.16: Inner Arm Drawing

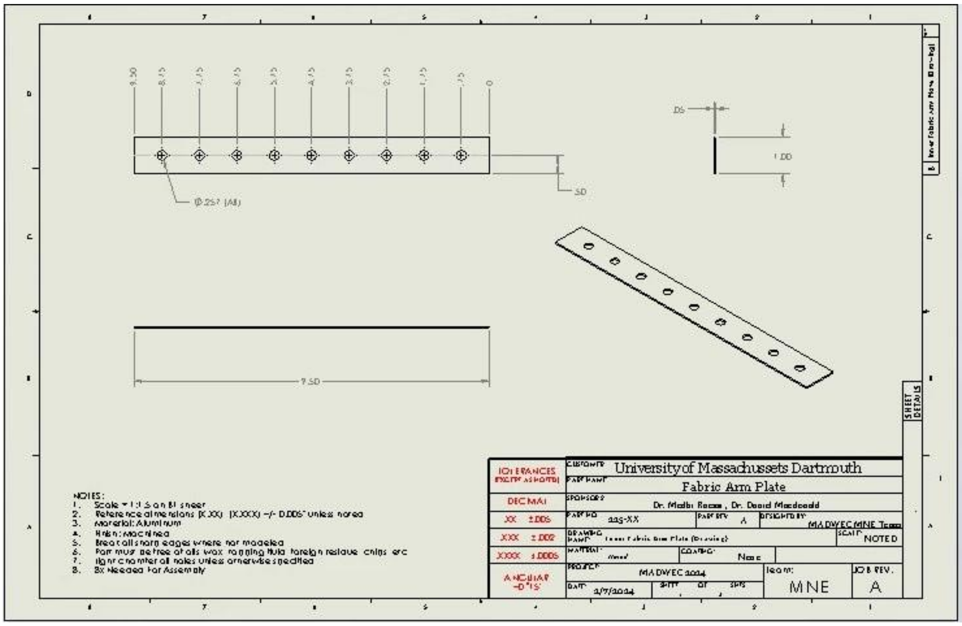


Figure 2.17: Fabric Arm Plate Drawing

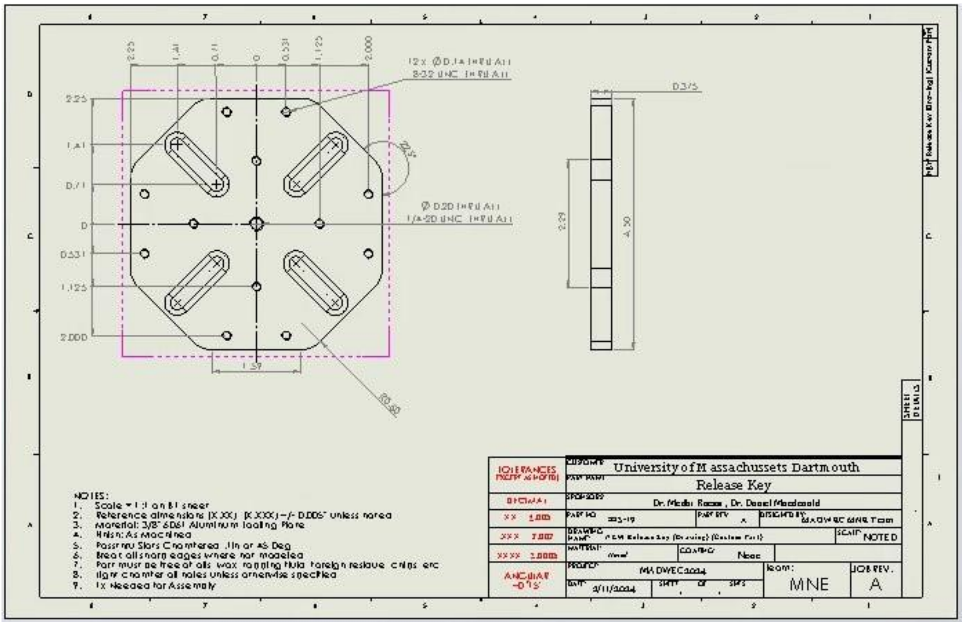


Figure 2.18: Release Key Drawing

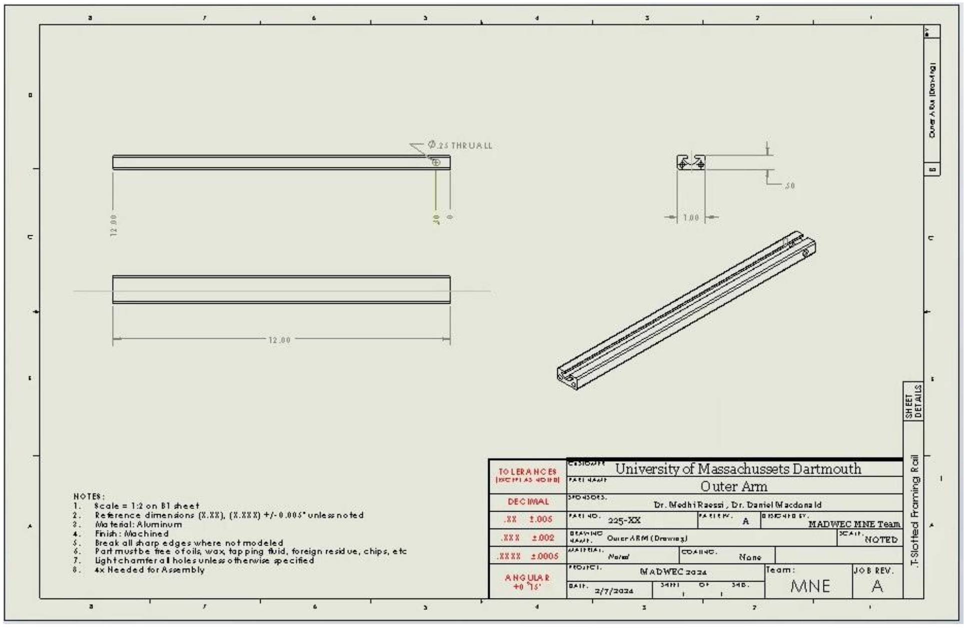


Figure 2.19: Outer Arm Drawing

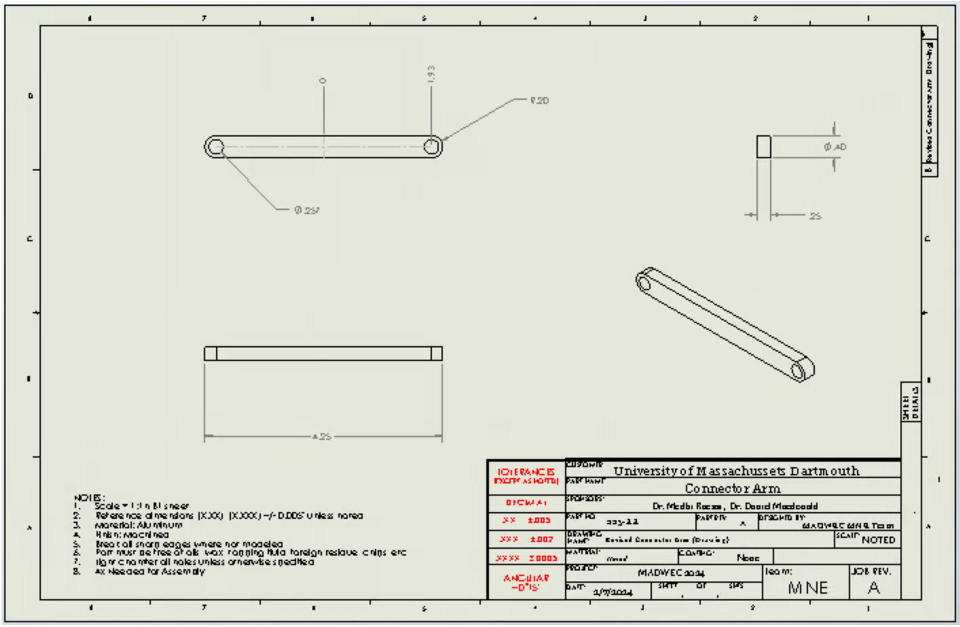


Figure 2.20: Connector Arm Drawing

Build and Test Challenge

Electrical Engineering

Final Design

The SMADWEC consists of the ocean wave simulation setup, the mechanical PTO, a set of sensors, and the new electrical system designed by the ECE team. The new electrical system can be divided into three major subsystems: the alternator, the regulator, and the battery.

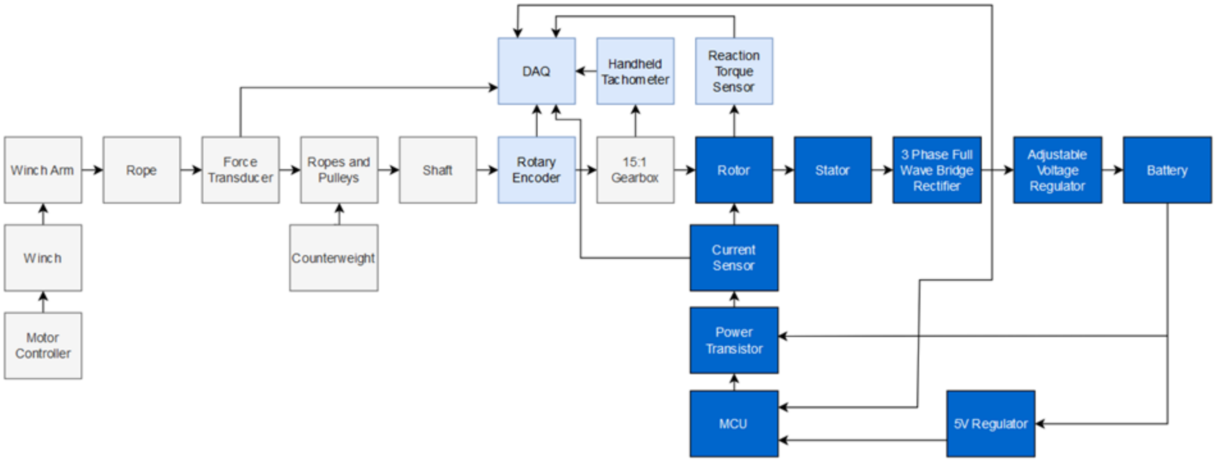


Figure 3.1: Detailed System Diagram

The electromechanical energy conversion device is a modified automotive alternator. Automotive alternators typically generate 12-15V at RPM above 2500. To use an alternator for this low RPM application, a significant modification is required. Using the principle of Faraday's Law, the output voltage is proportional to the excitation current and the number of windings in the stator coils. The team's approach involves using an externally regulated alternator with increased excitation current to the rotor and rewinding the stator coils of the alternator. The equation for the required number of turns per pole is given below:

$$N_{ph} = \frac{E_{RMS}}{\left[\frac{\sqrt{2}}{poles} * \frac{\pi}{60} * \frac{4\mu_0}{\pi g} * 2lr\right]\left[n_s k_w k_f N_f I_f\right]}$$

- N_{ph} is the number of turns per pole
- E_{RMS} is the target output voltage in RMS
- Poles is the number of poles per phase in the stator coils
- n_s is the target RPM
- I_f is the rotor excitation current
- The other variables are properties of the rotor and stator's physical dimensions and properties

The team performed measurements and testing of the alternator before rewinding to determine the values of the other variables in the equation. The target voltage was selected to be $12V_{pk}$ or $8.484V_{RMS}$ because that was the original goal of the project. The target RPM was selected as 100 RPM because the team's characterization of the SMADWEC indicates that it consistently reaches this level under different wave conditions. The number of poles remained at 14, same as the original stator.

After performing this calculation with various excitation currents, it was determined that the desired output voltage would not be achievable at the SMADWEC's operating RPM, so the team fit the maximum number turns inside the stator using a wire gauge rated for 3A of current. The team communicated this with the sponsors and came to the decision to target 3.2V instead of the original 12V as a proof of concept for the alternator design.

The major benefit of the alternator design is that it is capable of maintaining a stable output voltage for a varying range of RPM by utilizing the feedback mechanism and changing excitation current to keep output voltage fixed for a given change in RPM. For SMADWEC this means keeping the output voltage constant to charge the battery when the RPM from the PTO changes during the wave cycle.

The alternator chosen for the project is externally regulated which means that with a few small modifications, a custom feedback network can be connected to provide excitation; this is the job of the Regulator Subsystem.

The Regulator Subsystem is the feedback network that controls the alternator output. It does this through use of a microcontroller (MCU) and power transistor. A MCU circuit was selected because it , which allows for adjustability of the target output voltage. A custom circuit using ICs. may have a faster response time but does not allow for tuning which the unique behavior of the SMADWEC calls for. The MCU has a 10-bit analog to digital converter (ADC). The ADC is connected to the alternator output through a resistive sense divider, which limits the voltage on the ADC pin from ever exceeding the MCU's maximum safe level of 5V. The MCU then uses the sensed output voltage to calculate an 8-bit pulse-width modulation (PWM) value. This PWM value is used to control the gate of the power transistor to change the amount of current flowing from drain to source. In the system implementation, the drain of the transistor would be connected in series with the rotor to the alternator output, but since the output voltage does not allow self-excitation, the circuit was powered by an external power supply for the proof-of-concept build. The source of the transistor was grounded to complete the loop.

The alternator and regulator circuit is shown below.

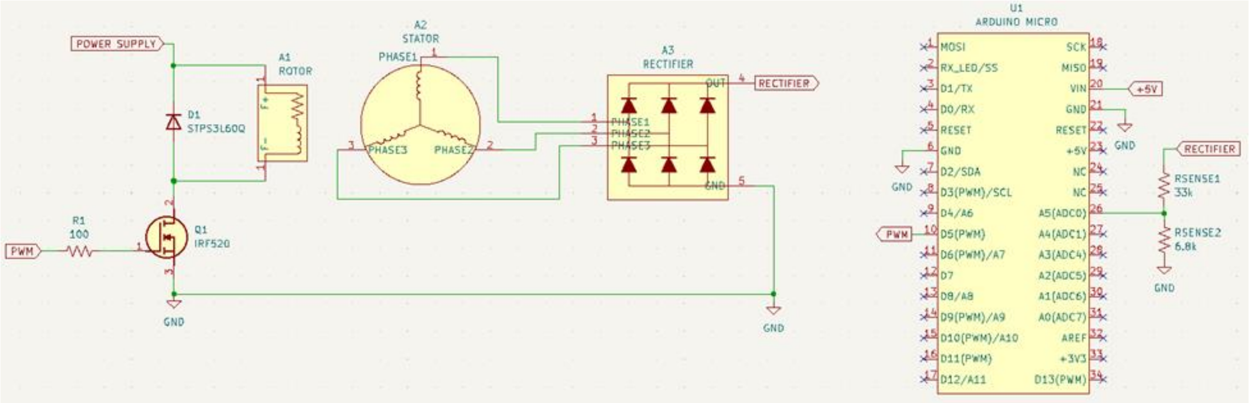


Figure 3.2: Alternator and Regulator Circuit

The MCU algorithm used is as follows:

$$error = target - sense$$

$$pwm = 255(0.5 + \frac{error}{2})$$

Future innovations could include changes to this simple algorithm for more accuracy, the introduction of a digital filter for smoothing of the sensed voltage, or the replacement of the sense divider to improve ADC resolution.

The output power from the alternator is directed to an adjustable battery regulator (2.5-9V Step-Up/Step-Down regulator). This ensures that the voltage generated by the alternator does not exceed the battery's ideal charging voltage (3.65V) and allows to step-up the voltage output in case the alternator under delivers. An additional safety measure is a 3.6V Zener diode in parallel to ensure the regulator output does not exceed a safe level. The regulator then is connected directly to a fuse as a safety precaution. This ensures that the battery does not receive excess current which could lead to damage or combustion. Finally, the fuse is then connected to the LiFePO4 3.2V battery which can then be charged safely. The battery circuit is shown below:

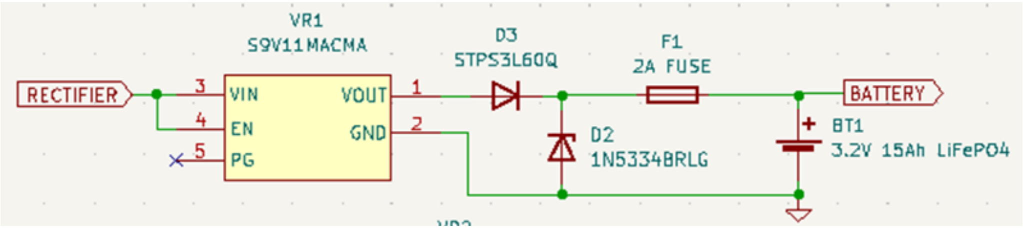


Figure 3.3: Battery Circuit

Building the Prototype

Building and implementing the prototype for the electrical system required a substantial amount of mechanical as well as electrical work. The team began by disassembling an automotive alternator into the individual components that make the complete assembly. Having direct access to the rotor allowed for precise measurement of the physical dimensions using calipers as shown below.

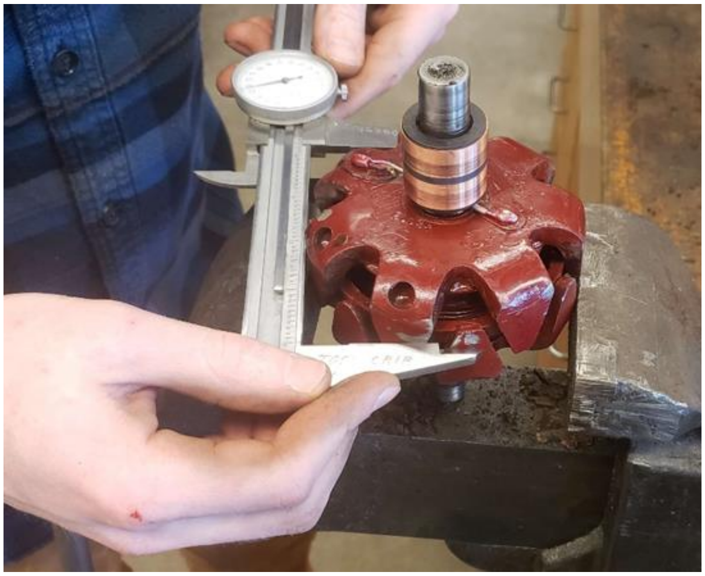


Figure 3.4: Rotor Measurements

This also allowed the team to remove the existing coils in the core of the stator and implement the proposed design. Electrically insulating fish paper was added to the slots of the stator to ensure the magnet wire did not become shorted to the core and cause a loss in output.

Figure 3.5: Stator Core Insulation

The team replaced the 3 to 4 turns of 14AWG copper wire per pole with 14 turns of insulated 22AWG magnet wire. The 22AWG magnet wire was selected because it is designed for this purpose and allows the stator to fit more turns per pole while also being able to deliver up to 3A of continuous current while operating at 155°C. A vice was used to hold the stator and c-clamps were used to keep the coils in placed and give repeatable size to each pole of the stator.

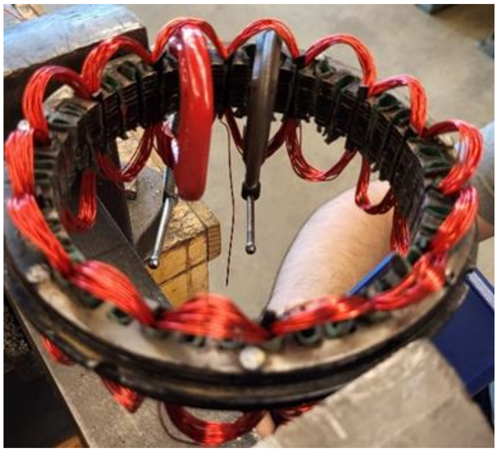


Figure 3.6: Rewinding One Phase of the Stator

After the first phase of the stator had been rewound, the team reassembled the alternator to the assembly level, but kept the output from the coils connected from the rectifier. This would allow the team to measure the AC output from the first phase of coils and determine that the winding had been done correctly. The results of this intermediate testing are shown below.

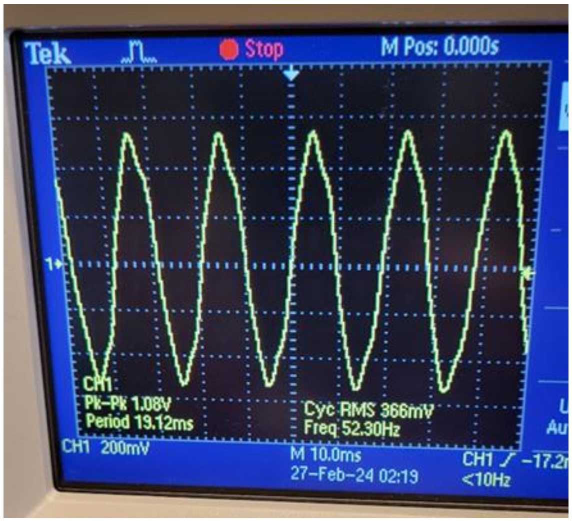


Figure 3.7: First Phase Verification Testing

After verification of the first phase, the team finished rewinding the other two phases of the stator and performed another verification test, this time to ensure that each phase is 120° apart to have complete coverage of the 360° period. The alternator was reassembled, spun with a drill, and provided excitation. The output of each set of coils was connected to one channel of a four-channel oscilloscope. The results of this test shown below indicate the proper phase separation between set of coils.

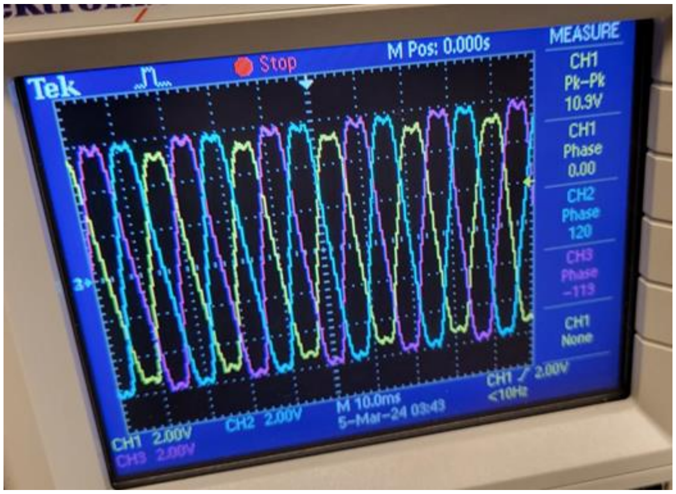


Figure 3.8: Three Phase Verification Testing

The coils were then coated with insulating varnish to further ensure that the wires did not short to each other or the stator core. The finished stator is shown below.

Figure 3.9: Rewound Stator

The regulator and battery circuits were implemented on breadboards to allow for quick swapping of components and the possibility for expansion in the future. The breadboarding process including programming the MCU, excitation via power supply, and measurement via multimeters and oscilloscope is illustrated in the figure below.

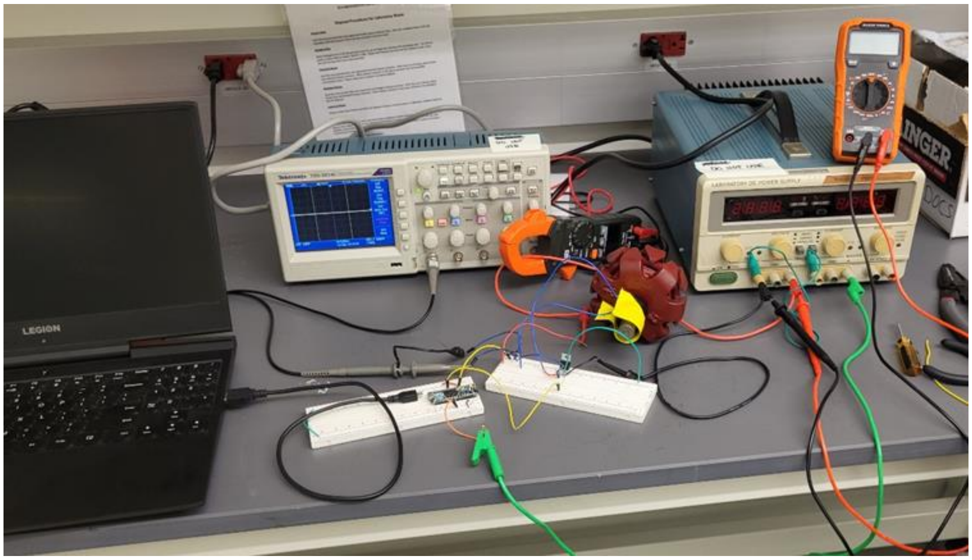


Figure 3.10: Regulator Breadboarding

Once the prototyping at the subsystem level was complete, the team approached the technicians in the mechanical engineering lab to get their assistance with modifying the existing PTO mount to properly adapt to the alternator. The technicians created a tapered bushing to connect the alternator shaft to the existing coupler and added two rods to mount the alternator to the existing octagonal mounting plate. The completed mount is shown below.

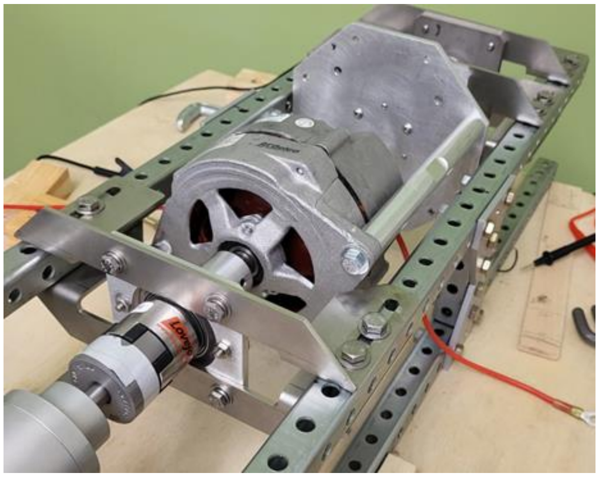


Figure 3.11: Alternator Mounted in PTO

After mounting the alternator, the team was ready to move on to testing.

Testing and Results

Table 3.1: Verification Cross Reference Matrix

Engineering Requirement	Verification Method			
	Inspection	Analysis	Demonstration	Test
1.0			D-1	
2.0	I-1			
2.1	I-1			
3.0		A-1		T-1
3.1		A-2		T-2
4.0		A-2		T-2
5.0	I-2			
6.0	I-2			
7.0		A-1		T-1
8.0		A-3		
8.1	I-3			
9.0		A-4		T-3

Requirement 3.0 was tested by supplying an input of mechanical rotational energy to the system via a winch with a metal arm attached. The winch simulates the action of a wave pulling a buoy upwards in the water, which pulls on a cable, generating torque which is applied to the alternator. The electrical output of the alternator was then measured using sensors attached to a data acquisition system (DAQ). The device was given a 25Ω load, and a 0.5A excitation current for all tests. Mechanical input was found to result in voltage and current output from the alternator, thus the SMADWEC was found to be effective in converting mechanical rotational energy in the form of RPM and torque to electrical energy in the form of voltage and current.

Requirement 4.0 was tested in much the same way as requirement 3.0. However, in testing requirement 4.0, the team varied the period and amplitude of the simulated wave input. This was accomplished by varying the speed at which the winch turned, and varying the position at which the rope was attached to the winch arm, respectively. As with requirement 3.0, the output of the alternator was measured with the DAQ. The device was found to produce electrical power under all tested variations of input period and amplitude. The results of two tests of two different wave amplitudes and periods are shown in the figures. It is noteworthy that the team was severely limited by the physical capabilities of the winch and the 15:1 gearbox. The team could not test all desired amplitudes and periods with the desired excitation current and electrical loads, because the winch would quickly become overloaded.

Requirement 3.1 stipulates that the device must store the generated electrical energy in a 3.2V battery. This requirement was not met. During the performance of load testing, the winch began to shake, and the overload indicator lit up. Following the failure of the winch and gearbox, the team decided to cease testing to prevent further damage to the system. The team had scheduled battery prototyping and testing after the load testing but felt that it was best to refrain from using the winch any further.

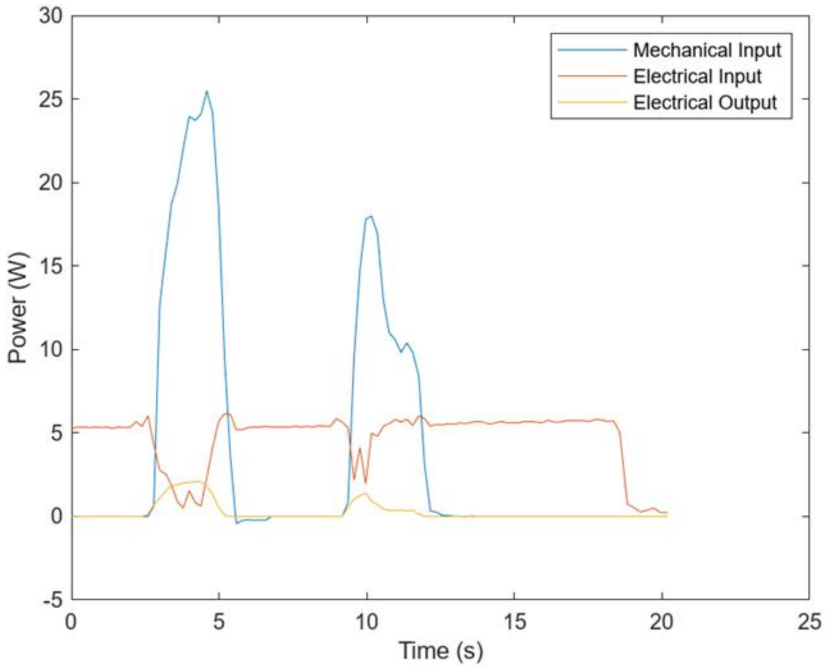


Figure 3.12: Data Indicating Winch Or Gearbox Failure

Requirement 7.0 requires that the device have a global average generator rectifier efficiency of 50%, as compared to the previous SMADWEC design's 28%. The requirement was tested by supplying a mechanical input with the winch as with requirements 3.0 and 4.0. The input torque and RPM of the alternator, as well as the rectified electrical output were recorded using the DAQ. The recorded data was then analyzed and processed in MATLAB to calculate the efficiency. Based on the measurements taken during testing, the team calculated the best-case efficiency of the device was only 39%, which is approaching 50%, but it should be noted that this is the best-case result under the most ideal conditions.

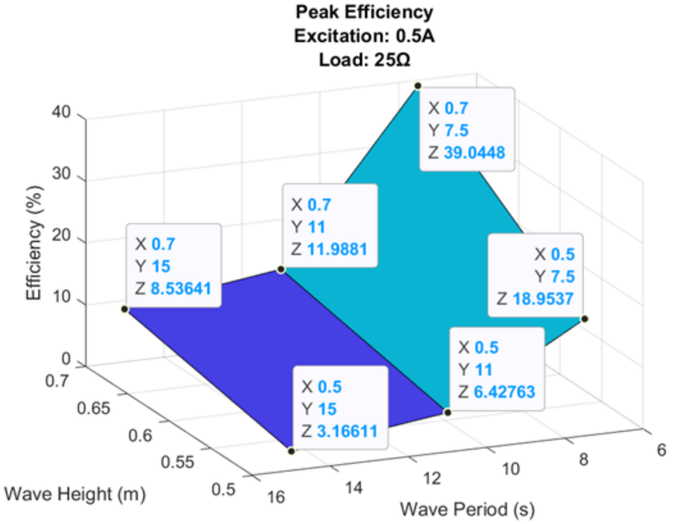


Figure 3.13: Peak Efficiency of the System with 0.5A Excitation and 25Ω Load

It is noteworthy that the team was unable to test the device with all wave heights and wave periods when providing an excitation current of 1A, as the winch became overloaded. The design was tested with periods of 7.5s, 11s, and 15s for a wave height of 0.5m and 11s and 15s for the height of 0.7m. The completed results are shown below.

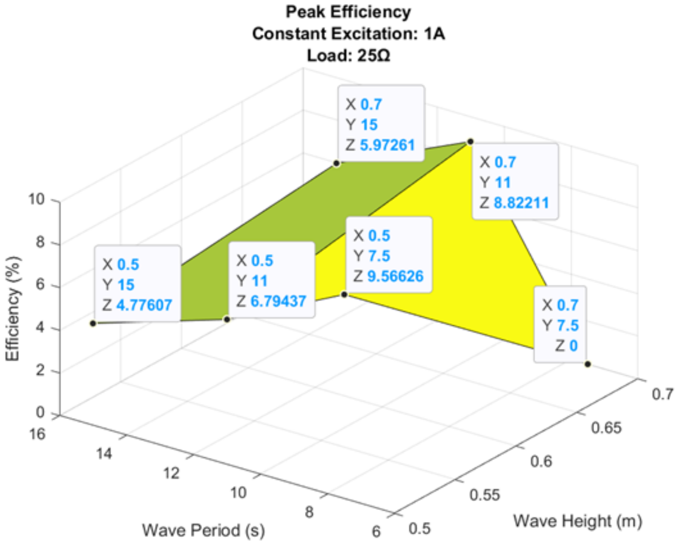


Figure 3.14: Peak Efficiency of the System with 1A Excitation and 25Ω Load

Once the regulator was implemented and tested, the team discovered that under most wave conditions, the electrical power input required for excitation to reach the target output voltage exceeded the output power delivered to the 25Ω load at the output voltage. This leads the team to believe that more testing with a variety of resistive loads or even the use a DC electronic load to draw continuous voltage (CV) or continuous current (CC) to simulate and electronic load from some device may provide better insight to the capabilities of the design. Unfortunately, the timeline did not allow for this extensive testing and requires that it be done by future teams.

The important thing to show is that the alternator and regulator design functioned as intended and the output voltage was properly stabilized to the target voltage of 3.6V (charging voltage for 3.2V battery) under a variety of wave conditions. This is shown in the figure below.

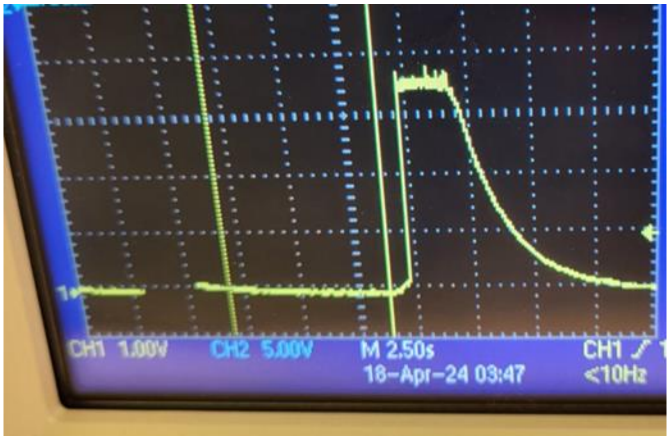


Figure 3.15: Alternator and Regulator Functionality

Lessons Learned

This year's SMADWEC project took an ambitious approach to solve the problem that the sponsors presented. The result was a functional prototype of the design featuring a modified alternator and custom feedback regulator. It provides insight into the unique application of energy conversion that is SMADWEC and demonstrates a creative solution to the problem. The design may not have achieved the desired output voltage and efficiency of power conversion, but the core functionality of a stable output voltage of a varying range of RPM was achieved. This provides the sponsors with building blocks for future teams to make improvements to or implement their own innovations where they see fit. The ambitious approach that was taken may not be the final solution, but the team believes that further testing should be performed to determine the capability of the design.

The constraint of using commercial off-the-shelf parts limited the team to using a stock electromechanical conversion but the team believes that the unique behavior of SMADWEC lends itself to the creation of a custom-made electromechanical conversion machine. The maximal asymmetric drag one-way clutch puts a large constraint on the electrical system and the type of battery that is used so the team believes that some mechanical changes such as a flywheel could be made to the PTO to keep the shaft spinning during the resetting of the buoy. The 15:1 gearbox contains a complicated arrangement of several different gears and the experience of testing the PTO indicates that the gearbox is the major chokepoint in the design and alternative solutions should be explored. Finally, the team believes that future improvements to the ocean wave simulating setup should include replacement of the winch, possibly the creation of a custom PCB or wiring harness to simplify sensor connections to the DAQ, and the replacement or recalibration of the sensors in use.

Mechanical Engineering

Final Design: CAD, Detailed Design Documentation, Advantages & Disadvantages.

After significant brainstorming and planning, a finalized design throughout the fall semester and part of winter break was completed in SolidWorks and was subsequently submitted to MECC for entry into the competition. Planning for this finalized design has included varying aspects outlined by our sponsors resulting in various design changes presenting new challenges. Initially, there were two draft designs that were made from the evaluation of the initial conceptual designs based upon team derived weighted criteria as well as sponsor feedback. The two draft designs were made with the intent to both be suitable candidates for the final design. From additional sponsor meetings which outlined unforeseen requirements and changes to pre-existing parameters, it has been decided that these draft designs are no longer suitable for the final design process. Thus, a redesign was needed to better suit the new customer requirements.

Our first major requirement change was that of the size allocation of the ballast system within the sonobuoy. This requirement was changed from half the interior volume of the sonobuoy, to roughly 1/3 the interior volume of the sonobuoy in order to provide more space for the electrical components. The targeted lifespan also increased. Originally, we were informed of a very lenient lifespan being only about 8 hours which is the total lifespan of current battery powered systems. This parameter has changed to as long as possible from which we as a group determined to be 1 to 2 months, as this would make the system more competitive against the traditional battery designs.

The planning of the final design has been heavily influenced by the space allocation parameter change mentioned previously, due to the fact that both draft designs incorporate features which extend past this new parameter. From further investigation with sponsors, there were two possible draft choices to move further in the final design process. The first option is to utilize the full length of the original parameter being ½ of the interior volume of the sonobuoy, which is about 18in. However, with this option, space needs to be allocated for the PTO in the center of the ballast system. The second option is to utilize the full space and height of the new parameter being 1/3 the volume of the sonobuoy which is about 12in in height and 4 and 7/8 inches in diameter. This would include the use of a new two-piece support member that allows for an expandable diameter during deployment of twice the height of the ballast system. This would mean an expandable diameter of about 48 inches as opposed to the approximate 39in, (twice the 18in height plus the diameter of the shell), proposed in the first design. This would mean that this second choice would have the highest added mass. However, there are multiple reasons both of these designs were still considered at that point despite the added mass advantage of the design that extends twice. First, the second design presents new design and manufacturing challenges to produce a two-piece arm that fully expands and is secured in place upon deployment as opposed to the more simplistic and guaranteed deployment of the one-piece arm mechanism found in the first design. Secondly, from further theoretical calculations, it has been determined that both designs would produce sufficient added mass.

Ultimately, the decision was made to develop the latter design option utilizing the two-piece support member to allow for the ballast system to extend twice and achieve the greatest added mass possible within the size constraints. Whenever possible, premade components from McMaster-Carr were used in the design, though it was necessary to make multiple custom components. These components were also kept as simple as possible to ensure that the manufacturing process was achievable and cost effective. An assembly of the ballast structure was created in SolidWorks which contained all components aside from the fabric itself and the necessary tether cables and is shown in **Figure 4.1.**

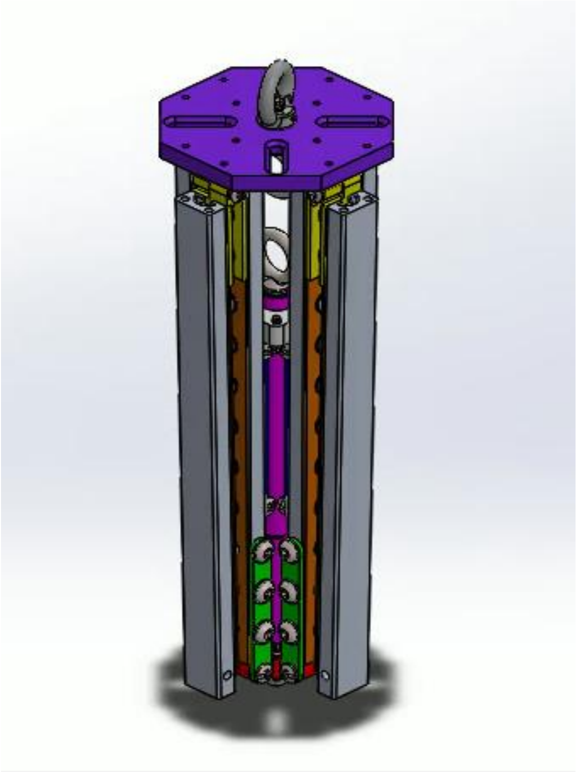


Figure 4.1: SolidWorks assembly of folded final design

Building the Prototype

Shortly after the design had been finalized, parts were ordered and arrived, and all machining of custom parts was started and completed. Once all the components had arrived and were manufactured, the assembly was started. This build phase consisted of two main parts, an initial build where the metal frame of the ballast was constructed to ensure clearances and that all of the parts meshed together properly. A few slight issues came up due to incorrect clearances and tool pathing of the CNC, mainly in the hinges and center collar. However, since all the affected parts were oversized slightly and led to this interference, it was a very easy issue to fix. Simply filing down the points of contact resolved the issue and all parts fit together seamlessly. After this initial build of the frame, it was time to complete the full build including the flexible rubber material. The frame was fully built, lubricated, and all screws were fastened with Loctite. The next step was to add the tethers from the center column and arms up into the key to allow for the arms to fold out when deployed. Once the frame had its final build and the tethers were attached, the arms were fully extended and traced with the flexible material to form a template. This template was traced, and four sections were subsequently cut out, and holes were punched in them where screws would fasten them into the ballast frame.

All metal components are made from 6061 aluminum except for the center column, which is made from 304 stainless steel, this is done to prevent galling in the center column and collar. The flexible material selected is an ultra-strength neoprene rubber which is 1/32nd inch thick, and the dynamic flaps are made from an ultra-strength neoprene which is 1/64th inch thick. While the 13434.6 Pa worst conditions possible maximum force sounds like a lot at first. However, this force is only 1.9485 psi and the aluminum parts are rated for 35,000 psi, the stainless steel is rated for 30,000 psi, and the neoprene is rated for 2,500 psi.

Testing Procedure - Testing of the Prototype

The first initial real-life test was being done during construction, which was ensuring that the ballast system would fit into the acrylic tube which was a stand-in for the sonobuoy as seen in **Figure 4.2**. This was done by periodically fully folding up the sonobuoy and seeing how it deployed, this was done with the frame, the frame with the material attached, and the frame with the flexible materials. A prescribed force was placed on top of the ballast to simulate the weight of the other components of the SMADWEC, and the bottom of the tube was left open for the ballast to deploy from. This has been achieved multiple times with great success. Having the ballast slip out of the tube with no help besides the prescribed load, and fully deploy on its own once tension was achieved in the key and arms.

For the primary water deployment testing, silicone-based lubricant was used for its ability to not evaporate out of the sonobuoy, (silicone is a common lubricant in marine based applications).

Figure 4.2: Ballast System Collapsed in Mock Sonobuoy

Once it was established that the ballast system was fully built and would deploy on its own, it was time to test the ballast's performance in the water tank at SMAST (University of Massachusetts Dartmouth's School for Marine Science and Technology) seen in **Figure 4.3**. Three tests were conducted. Firstly, the goal was to complete the testing outlined in section IV part F, using a pressure sensor along with a force cell, and simulating the motion of a wave with a winch and pulley system. The data from which will be processed in a MATLAB code. Secondly, it was decided that it was also important to do a terminal velocity test, to make sure the ballast system sank efficiently upon downstroke. This test was only done with the pressure sensor, the ballast would be tied to the tether, given lots of slack, and dropped to see how the ballast would behave when trying to sink as fast as possible. The pressure sensor is only necessary for this as using the positional data along with the time can provide a velocity graph by taking the derivative of the displacement (depth) graph. Finally, the third test outlined in section IV was completed to evaluate the ability of the ballast system to deploy from a class-A sonobuoy in a marine environment.

Once data has been gathered from testing it is time to process the results, the main bulk of which is done in a MATLAB code as previously mentioned. Compiling the acceleration and force curves, it was noticed that there was roughly a 2 second lag in the data from one sensor to another, so after this offset was accounted for, data processing could begin.

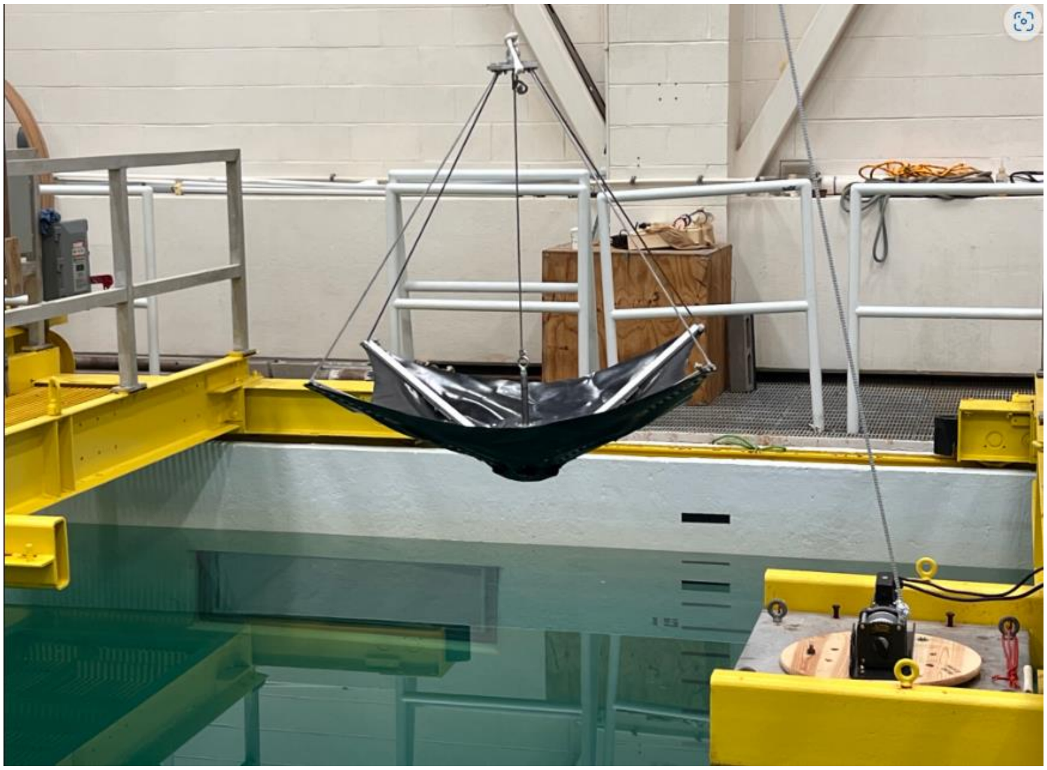


Figure 4.3: Ballast System Over Test Tank.

Data Processing/Results

The main focus of the data processing from Test 1 is a large step in force seen at the start of the upstroke due to this being the area of highest acceleration. Velocity graphs were used to calculate an acceleration value for the large step up, as it was found that there was too much noise in the acceleration graphs to get any meaningful data. Using the force cell, data points for average and peak force were harvested for each upstroke. An example of harvesting data from one upstroke from velocity graphs and for the big step up in force can be seen below, note while the times on the graphs are roughly 2 seconds off, once the offset is applied the data lines up. This process was repeated for each upstroke (12 in total). Force and acceleration values were then plotted against each other, and a line of best fit was formed, the slope of which is the added mass value from the ballast system. Where it was found that the ballast system was creating a peak force of **590.74 kg** and an average force of **373.94 kg**. This graph can also be seen below. Due to the peak force happening only for a brief moment, it is believed that the average force is a more accurate depiction of what the added mass would be during continued operation, while the peak force can be seen as a maximum possible value that the ballast is capable of producing.

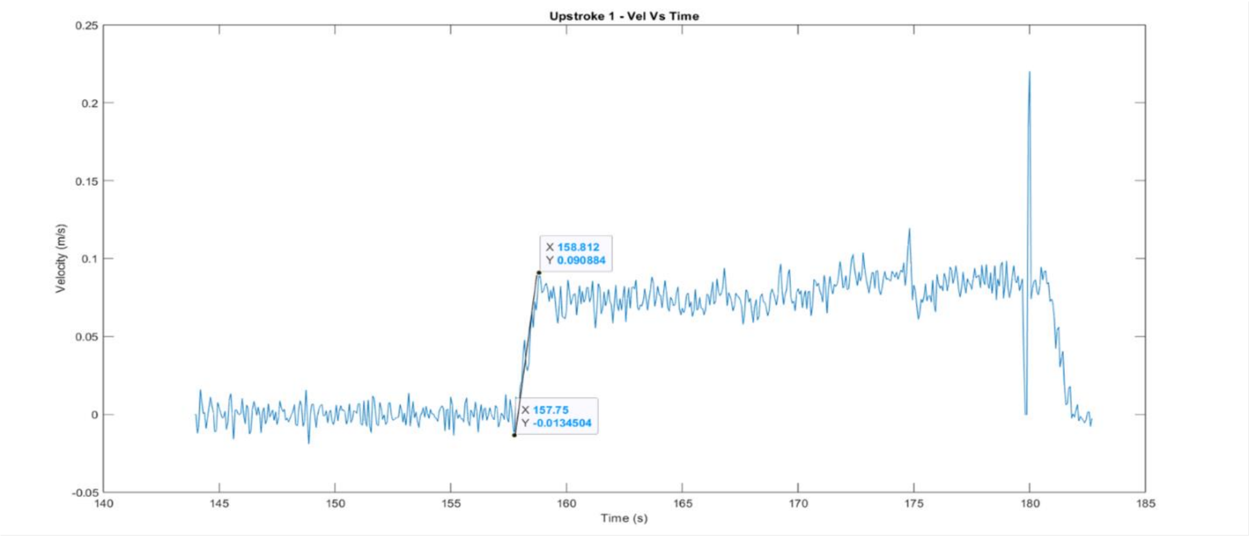


Figure 4.4: Harvesting an acceleration value from the step up in velocity.

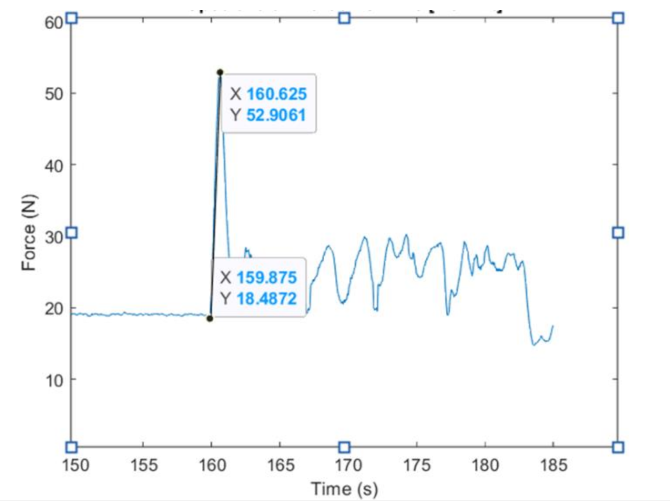


Figure 4.5: Harvesting values from the large step up in force.

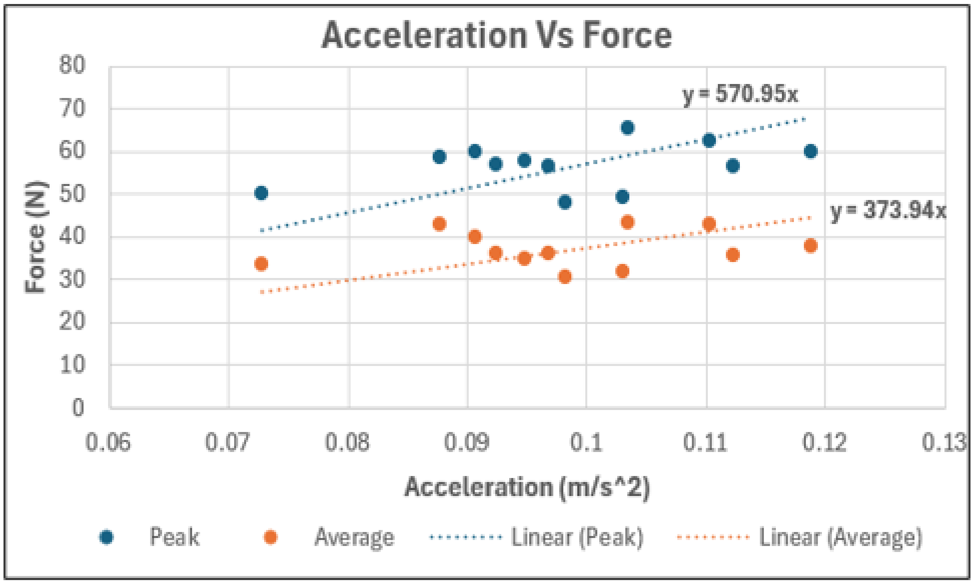


Figure 4.6: Plotted acceleration vs force graph, slope of trendline is average mass. (peak in blue, average in orange).

For Test 2, the pressure sensor was used again to create a velocity graph in which the highest values were harvested from and averaged out to get a terminal velocity. Results of this test can be seen below in **Figure 4.7**. Where the terminal velocity comes out to be roughly 1.29 m/s. There is a small caveat to this being that these tests were limited to the depth of the tank at the SMAST facility which is only a few meters deep. Further testing should be done in a deeper tank as there is a chance that terminal velocity may be higher than the found value.

Trial	Peak V (m/s)
1	1.22
2	1.27
3	1.30
4	1.34
5	1.33
Average	1.29m/s
	4.24 ft/s

Figure 4.7: Terminal velocity values.

Comparing the results in **Figure 4.6** to the calculated added mass value calculated theoretically, there is a large disparity between the theoretical and found values. With the theoretical added mass value of 782.03 kg compared to the 570.95 kg peak added mass and 373.94 kg average added mass value. This is due to a few reasons, firstly when assembling the ballast, chunks of material needed to be taken out from each panel of the flexible material in order to allow the ballast to fit comfortably into the sonobuoy. Removing this material reduces the ballast's surface area, which reduces the added mass potential. Secondly, it was found that there were slight leaks in certain parts of the ballast where sections of the dynamic rubber overlap. These small leaks, while not detrimental to the function of the design, have a role to play in reducing the total overall added mass. In the future, further research should be put into flexible materials, specifically ones that could fold up to be more compact than the rubber used for this build. Research should also be done into finding a way to seal the leaks near the hinges as well. This would help to increase the added mass of the ballast system slightly. It is still believed that the current values obtained by this design are more than sufficient for what the SMADWEC needs in terms of added mass. Looking at the results from test 2, it is shown that the ballast is capable of rapid descent as needed upon downstroke and could possibly have an even faster terminal velocity value if the trials are repeated in a deeper tank where the ballast has more time to accelerate to terminal velocity.

Conclusion - Lessons Learned

SMADWEC is an energy conversion platform that takes the kinetic energy from ocean waves and turns it into electrical power that can be used in multiple applications. The ballast system must be able to create sufficient drag on the upstroke while creating minimal drag on the downstroke. Throughout the first half of the engineering process, we applied our knowledge of physics, fluid mechanics, and design engineering to develop a ballast system that optimizes drag based on the wave cycle. During the design process, we were met with many challenges. Since this project has many aspects being engineered by other teams of engineers simultaneously with our team, many challenges of the integration of each of the subsystems becomes apparent. Things such as design parameter changes due to the updated volume allocation of the interior of the sonobuoy to our subsystem due to the updated constraints produced by the simultaneous engineering of other subsystems by other teams of engineers. This presented many challenges such as setting back our final design process in that our draft designs needed to be re-evaluated. Additionally, throughout our sponsor meetings, we were presented with new design ideas and pre-existing design change suggestions which heavily impacted on our design process. However, there are many takeaways from this experience and these challenges. We have learned to work effectively as a group and have learned to adapt to and predict possible design parameter changes and failure points.

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