EML 4551 Design and Ethics Organization

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

GREEN ENERGY IN THE CARIBBEAN SEA
25% of the Final Report

William Rosado
Dominic L. Gayle
Francisco J. Molinares

Advisor: Andres Tremante

April 7, 2014

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of WILLIAM ROSADO, DOMINIC L. GAYLE, and FRANCISCO J. MOLINARES and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

William Rosado	Dominic L. Gayle	Francisco J. Molinares
Team Leader	Team Member	Team Member

Dr. Andres Tremante
Faculty Advisor

Table of Contents

Table of Figures

List of Tables

1. Abstract

The main objective of this project is to design the housing for a sea current turbine which will include a diffuser to improve the efficiency of our chosen blade geometry. We will also try to incorporate a wind turbine and a system in which we will be able to easily and regularly do maintenance and swap out turbine blades to help reduce the down time of the system as a whole and improve effective cost. The sea turbine will be moved mainly by the constant sea current but we will also try to incorporate a system of vanes along the circumference of the housing to allow for greater fluid and pressure build up. Both the water and air turbines will serve the purpose of converting their respective fluids kinetic energy into electricity. As a secondary objective we hope incorporate a system of fins which will help the turbines make minor adjustments due to the slight changes in sea current.

2. Introduction

Today's modern world is almost completely reliant on fossil fuels. Everything from out transportation to most of the electricity we receive in our homes comes from some type of nonrenewable energy source. The massive demand created by our society has caused many problems. From the ridiculous prices of crude oil to greenhouse gas accumulation in our atmosphere which is the main cause of the phenomenon known as "Global Warming". This very serious global phenomenon has sparked a sudden up rise in the interest of green technology. There is an imperative need for engineering solutions that can help tackle the issue of renewable energy technologies.

The geographical advantage of living in a state where the strongest under water ocean current is but a stepping stone away is too great to overlook. For this reason we decided to focus our efforts on harnessing arguably the largest untapped energy source available on our planet. According to the creators of the Evpod, the Gulf Stream around the coast of Florida at its peak moves on average 30 million cubic meters per second of ocean water at speeds in excess of 2 meters per second. These numbers can be roughly translated to 1 Gigawatt of electricity.

Introducing this technology would have a significant impact on the stranglehold that fossil fuels have on today's energy market. We plan to complete this project in the hopes of making a significant contribution to the alternative energy field and with the goal of one day applying our findings to the real world.

2.1 Problem Statement

Environmental pollution is one of the biggest issues in our current society. The extraction of fossil fuels is one of the most dangerous mechanical processes in the world. Not only is it a risk for the people who work on these rigs but it also has very severe secondary effects. For example fracking causes earthquakes, waterbed pollution and can lead to dangerous gas leaks. The consumption of these fossil fuels produces carbon dioxide which as well all know is the leading cause of Global Warming. If our carbon emissions aren't reduced in the next few decades we could face catastrophic global events.

Turbines along with other more modern technologies were created with the purpose of reducing the consumption of fossil fuels. This effectively would reduce our dependency and our carbon emissions. The US and other global powers have invested billions in the research and development of these so called "Green Technologies". It will take some time for these alternative energy sources to surpass the current cost benefits of fossil fuels, however, in the end this will be the only viable long term solution.

2.2 Motivation

After much deliberation we decided that we wanted to pursue and idea which, if enough time and money where to be invested, could change face of renewable energies. We wanted to work on an idea that both agreed with our mentality to help make a brighter tomorrow and which would help fuel our passion for innovation. Our proposed idea would not only improve the world but also leads the field in innovation.

Fossil fuels are a finite resource with only decades remaining. The use of these carbon based fuels has caused numerous changes in our planets' atmosphere and overall temperature. Within the next couple of decades if nothing changes some of the worlds' most prominent cities will disappear due to a rise in sea level and others will be destroyed due to the project super storms. We as humans have the obligation to prevent any further harm to our environment. To achieve this goal we must invest the time to find alternative sources of energy which we may use to replace fossil fuels altogether.

2.3 Literature Survey

Ocean current offers a clean, renewable source of energy. Similar to wind energy, this energy can be harvested through the use of turbines. Two major differences between the working fluids are: (1) water is 800 times as dense as air and (2) ocean currents are more persistent and predictable. As a result of the density differences, "the theoretical marine current power density per square meter of the blade-swept area is approximately 100 times greater than in wind…" [16]. It is for this reason that ocean current energy is a propitious prospect to aid in the worlds global energy needs. The table below demonstrates the advantages of ocean current energy compared to other popular energy sources.

Table 1: Energy Comparison

Energy type	Renewable source	Low capital cost	Low running cost	Minimal environmental impact	Predictability	Minimal visual impact	Modular
Fossil	X	√	X	X	√	X	X
Nuclear	X	√	X	X	√	X	X
Wind	√	X	√	√	X	X	√
Solar	√	X	√	√	X	X	√
Hydro	√	√	√	X	√	X	X
Wave	√	X	√	√	X	√	√
Current	√	X	√	√	√	√	√

Error! Bookmark not defined.

Locations that possess a steady, relatively fast-flowing current system are ideal to launch ocean current harvesting programs. The Gulf of Mexico is one such location. In particular, around Florida there is a well-developed portion of the Gulf Stream with current speeds of approximately 2 m/s [16].

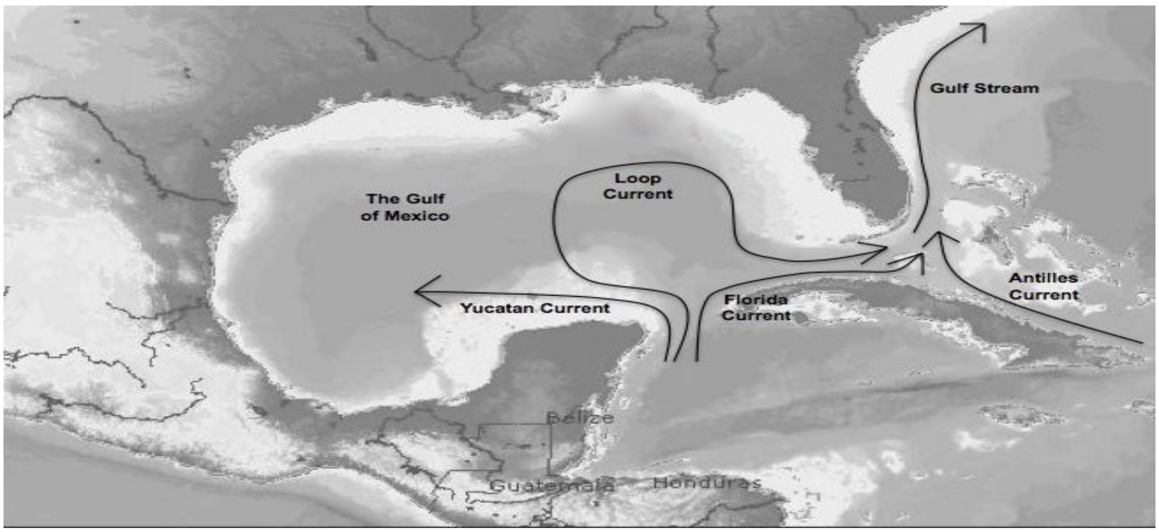

Figure 1:Current flow patterns in the Gulf of Mexico.

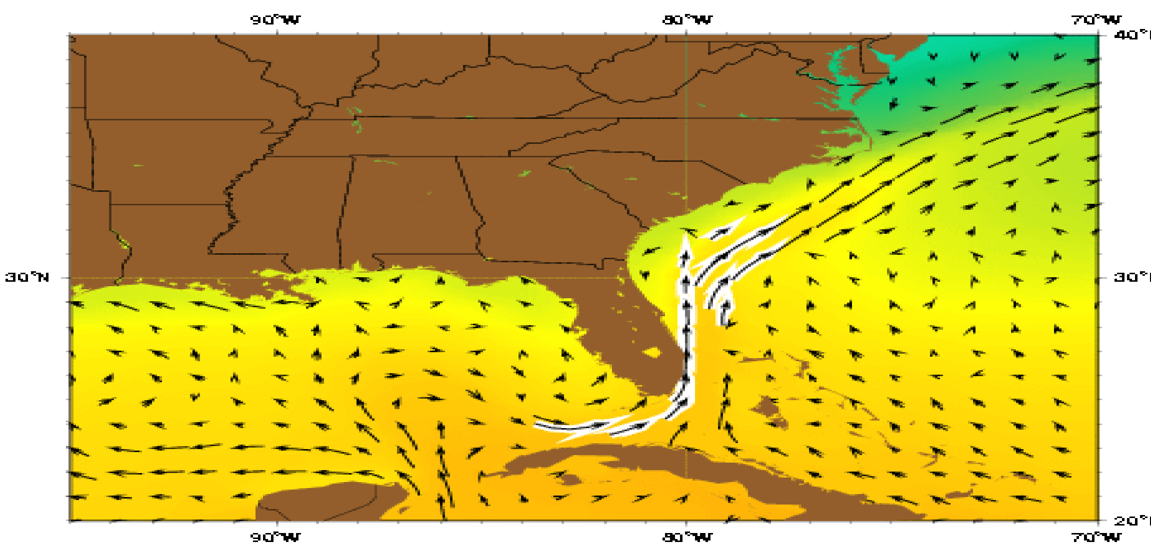

Figure 2: Ocean current flow patterns around Florida coast.

Currently, analysis of current energy is performed similar to that of wind energy. As such, the maximum current power, P, available from a stream of water, assuming there is no significant change in elevation, is given by the following equation:

$$P = 0.5(\rho A v^3 C_p)$$

Equation 1: Max Current Power

where ρ is the density of water, A is the cross-sectional area, v is the undisturbed fluid speed and C_p is the power coefficient, which is accepted to be between 0.4-0.5 [17]. Similar to wind turbines, the most prevalent issue is blade design. Research is continuously being conducted to enhance the efficiency of turbines. The figure below illustrates several turbine designs and their corresponding efficiencies.

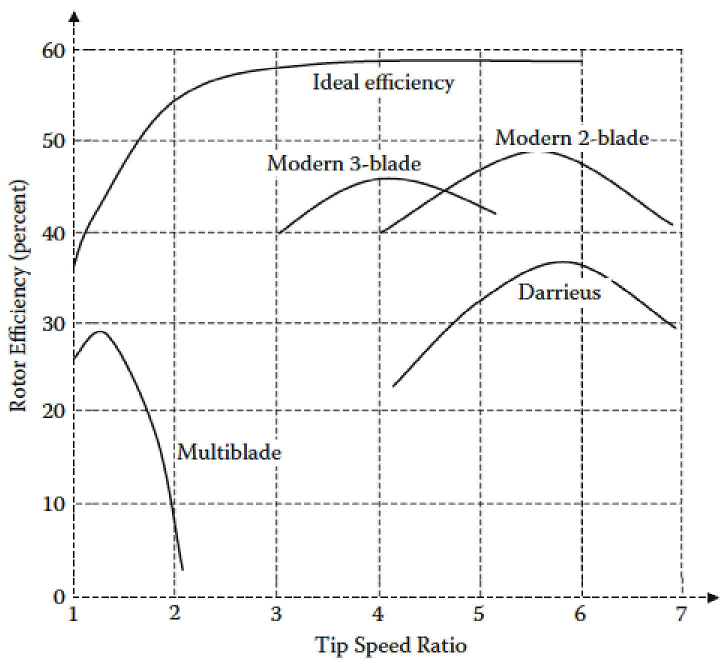

Figure 3: Efficiency of turbine designs.

Despite the many similarities between wind turbines and ocean current turbines, the latter presents several unique challenges that must be addressed in order for them to be viable sources of energy. These challenges arise as a result of the density differences between the two fluids, the slower flow rate of ocean currents and cavitation. Therefore, the "structural designs will need to take into account the marine environment and the complex dynamic loadings that are present due to wave/structure interactions…"[17]. Additionally, debris and other objects carried by ocean currents could cause significant damage to turbine blade and structure. It is also crucial that the necessary steps be taken at the design stage to simplify and/or reduce maintenance of turbines [19]. Finally, special consideration must be taken depending on where the system is to be launched. For example, the Gulf of Mexico the region experiences seasonal extremes in the form of hurricanes and tropical storms. The turbines and their structure must be capable of withstanding these extreme conditions and not fail.

Aside from blade optimization, another route that is widely studied to achieve greater power generation from turbines is the use of diffusers. Diffusers are mechanical devices that are used in a system to alter fluid flow. In particular, diffusers decrease the fluid velocity, which then causes an increase in fluid pressure. Diffusers can greatly increase the power density, which makes them much more economically feasible sources [20].

As is expected, it is not possible to extract 100% of the power from a free stream. This is because the turbine affects the flow field. The turbine creates a pressure difference upstream as it extracts power from the fluid. This causes fluid to divert from the turbine. The Betz limit, determined using the Betz theory, states that it is fundamentally impossible to extract more than 60% of the power from the flowing fluid [20].

$$\eta = \frac{W}{W_\infty} = \frac{1}{2}\left[1 - \left(\frac{u_w}{u_\infty}\right)^2\right]\left[1 + \frac{u_w}{u_\infty}\right]$$

Equation 2 Efficiency based on Betz Theory

where η is efficiency; W is power produced by turbine; W_∞ is the power in undisturbed stream; u_w is the wake velocity; and u_∞ is undisturbed stream velocity. As seen in Figure 3, the ideal efficiency for conventional turbines is within the 55-60% region. However, ducted, or diffuser augmented turbines (DATs) are capable of exceeding that threshold. The power generated by DATs depends on the pressure drop that can be created by the duct, which is dependent on its design. Research conducted on the topic has concluded that it is theoretically possible to achieve power extraction up to 3 times greater than the Betz limit through the use of a diffuser [21].

In spite of the immense potential ocean current energy has and the technological know-how to utilize these ocean currents, the subject is still in its infancy. Several countries such as China, Canada and the United Kingdom are at the forefront of this field, constantly pushing the envelope. In the UK, it is believed that ocean current energy could deliver up to 220TWh per year. Marine Current Turbine Company, a company based out of the UK, installed a 300-kW current turbine 1km offshore of a county named Devon in the UK [16]. Ocean current turbines, in concurrence with other renewable sources of energy, have tremendous potential to meet the world's ever-growing energy demand.

3. Project Objectives

The main objective of this project is to design an underwater diffuser augmented turbine which would improve the efficiency of the system by creating a pressure difference which would create more torque which in turn would generate more electricity. Based on studies; the Gulfstream is the most powerful water current available on planet earth. In this investigation it will be necessary to determine the appropriate depth at which our devised would be deployed to help with the design considerations. We plan on optimizing the cross section of our diffuser and turbine blades to hopefully achieve the best efficiency we can. As a secondary objective we will design a system in which both an underwater turbine and a wind turbine coexist as an example of what we envision the real world design to be.

4. Conceptual Design

Our research showed us that the use of underwater currents to harness electricity is a very uncommon practice. The only concept that we could find that was related to our idea was the use of tidal currents to generate electricity. This idea is similar in nature to our idea but it differs in the sense that our current is unidirectional and always constant which is a major advantage for the design aspect and the electricity generation aspect of our project. Our design would need to sustain pressure depending on the depth at which it will operate. The design must also be composed of environmentally friendly materials, must not corrode, and must not cause harm to the local ecosystem.

The main objective is to design a system which would be able to harness the sea current near the coast of Florida. The idea is to maximize the output of the system while keeping costs at a reasonable level. We want a design which will require little effort to repair or replace if damage where to occur. The specific blades chosen will depend on the actual depth and cross section which our turbine will be exposed to. Due to the lack of information available we will focus on only 2 different alternatives. These will be discussed below.

4.1 Design Alternative 1

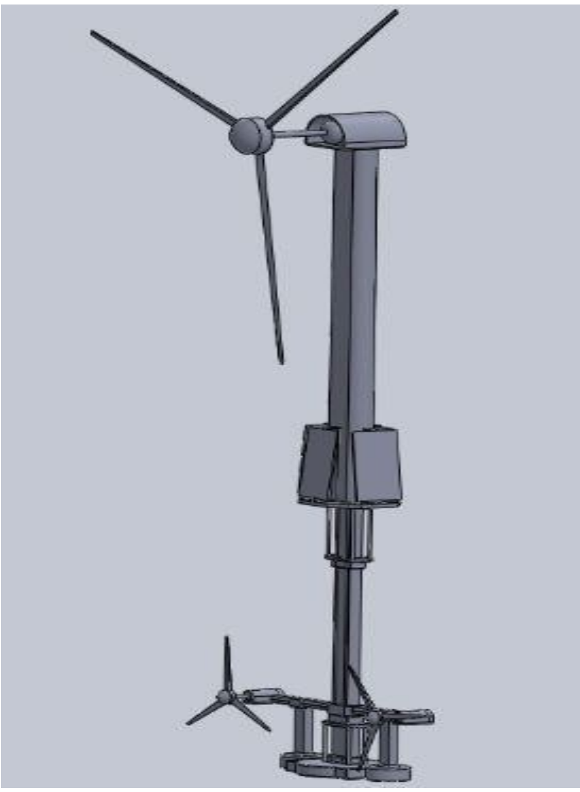

Figure 4: Design 1

The first design alternative is shown in Figure 4. This alternative meets our requirement of being a water turbine which isn't difficult to replace or repair. It meets our secondary objective which is to make a system that also incorporates a wind turbine. The issue with the design is that it lacks innovation and more could be done to improve the efficiency, which is our primary goal. There are two different alternatives. These are; uncovered blades like in this design and blades with a housing like in the second alternative.

The dimensions were estimates based designs we studied during our research. The blades on this design are not of any value as they were just illustrated to make a point, however, we intended them to be either Kaplan or Cross flow blades. Of course no matter what we choose we will still run the design through a finite element analysis (FEA) and a computational fluid dynamics (CFD) analysis to optimize all aspects of the design.

4.2 Design Alternative 2

The second and final design alternative is shown in figure 5, 6, and 7. The idea for this design came from applying the concepts we aquired in classes about propulsion and of concepts that were applied to wind turbines to improve the torque output. This specific design makes replacing blades a trivial task. The blades are enclosed in in a ring which can be pulled out with out any hassle. The blades are enclosed in a housing which takes the shape of a diffuser. The outside of the housing has vanes which act like smaller diffusers to allow any flow outside of the housing to enter through those points. All this was designed with the intent to great a pressure difference from the inside to the outside of the housing which would cause a “lift” effect like on the airfoil of a plane but instead of using this force to fly we use it to create more torque which in turn increases the power output.

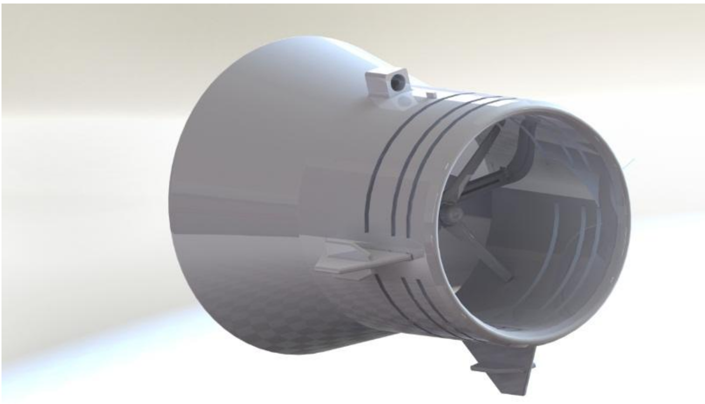

Figure 6: Design 2

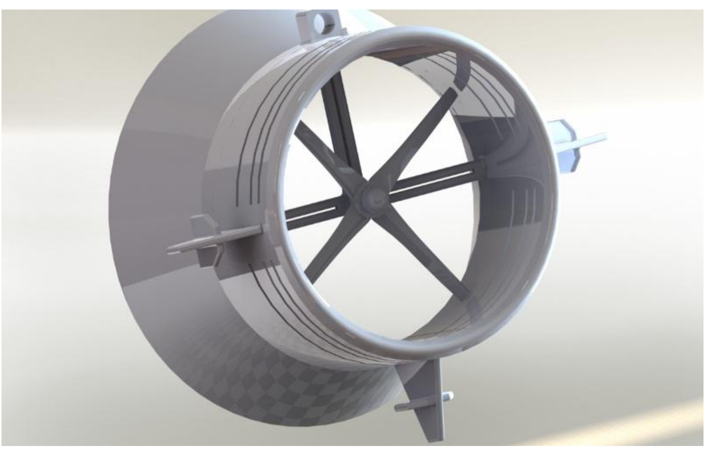

Figure 5: Design 2; view from rear

The dimensions were estimates based designs we studied during our research. The blades on this design are not of any value as they were just illustrated to make a point, however, we intended them to be Kaplan blades. Of course no matter what we choose we will still run the design through a finite element analysis (FEA) and a computational fluid dynamics (CFD) analysis to optimize all aspects of the design.

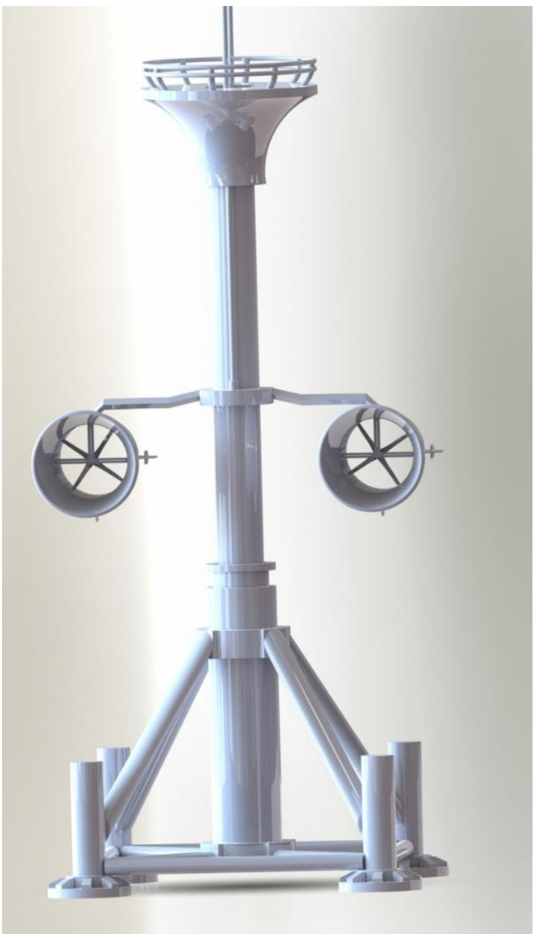

Figure 7: Hypothetical Assembly Design

4.3 Proposed Design.

Both designs can be manufactured but the second design is the one we believe will prove to be more efficient. This alternative is what is considered a Diffuser Augmented Turbine (DAT). Based on our research this approach will improve the efficiency of the design considerably. The design considerations we have taken will make maintenance extremely simple which is always desirable. Everything from the geometry of the diffuser to the inlet angles of the vanes and the cross section of the blades will have to be optimized using FEA and CFD programs. This design should prove to meet all of the necessary criteria stated earlier as well as produce results which we expect to exceed anything previously seen. This proposed design also takes into account the future system which is comprised of a wind turbine and a platform to which boats may access for maintenance.

5. Timeline and Responsibilities

Table 2: Work Timeline

MONTH	MAR	APR	MAY	SEPT	OCT	NOV	DEC
Research							
Preliminary Designs							
Equipment Selection							
Assembly							
Testing							
Modeling							

Considering the difficulty of the project and the amount of time we expect to spend while completing the project we have decided to share the work load as evenly as possible while focusing on our individual areas of expertise.

William Rosado: Lead Designer, Researcher.

Dominic Gayle: Lead Researcher.

Francisco Molinares: Team Leader, Design Tester.

6. Analytical Analysis

As given by Equation 1, the maximum power that can be extracted from a stream of fluid is given by:

$$P = 0.5(\rho A v^3)$$

However, as given by the Betz limit, it is impossible to extract more than 60% of the power from this stream. As such, each turbine design has a power coefficient associated with it. This power coefficient, C_p, can be determined through use of the following equation:

$$C_p = \frac{P_s}{P}$$

The shaft power, P_s, is given by:

$$P_s = T\omega$$

where T is the torque produced by the rotor and ω is angular velocity of the rotor. Another important concept in determining blade performance is the Tip-Speed Ratio, TSR. TSR is determined using the following equation:

$$TSR = \lambda = \frac{Tip\ speed\ of\ blade}{Speed\ of\ incoming\ fluid}$$

Further, an optimal value for a specific turbine design is given by the following relationship:

$$\lambda_{opt} = \frac{4\pi}{n}$$

where n is the number of blades in the design.

Water current turbines may also experience extreme operating conditions. Considering the density difference between air and water, water current turbines will encounter much greater forces and as such the structure needs to be capable of withstanding these forces. The maximum thrust force a turbine must be capable of withstanding is given by the following equation:

$$T_{max} = 0.5(\rho A C_T V^2)$$

where C_T, is the thrust coefficient.

Once a prototype has been constructed, it is through these equations that the effectiveness of a diffuser augmented water turbine will be evaluated.

7. Major Components

The major components of this design are the diffuser, the turbine and the platform that will support the structure. The diffuser is the housing that will enclose the turbine and is the primary focus of the project. Figure 8 is an example of a wind turbine with an incorporated diffuser.

Figure 8: Diffuser Augmented Turbine

The turbine will be housed within the diffuser and will be connected to a shaft. The shaft is then connected to a generator above water level on a platform that supports the entire system. An example of this set up can be seen in the figure below.

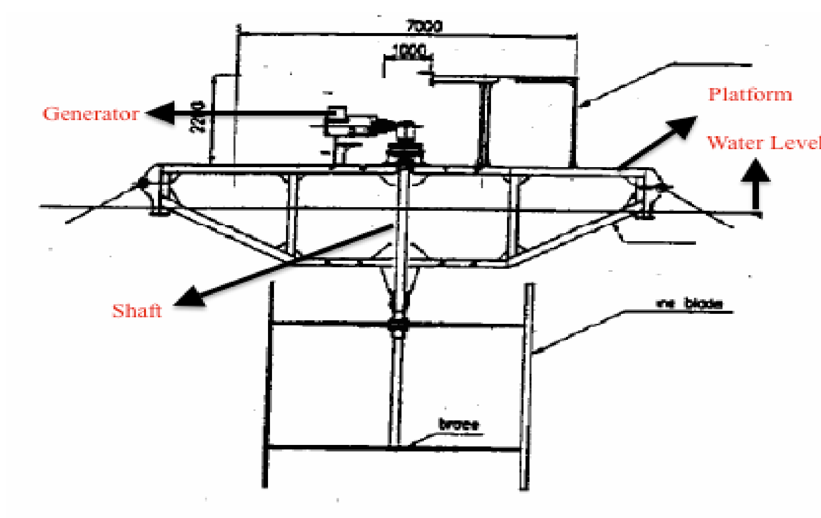

Figure 9: Schematic of Water Current Turbine

8. Prototype and cost

8.1 Prototype Description

Our Prototype design has not been finalized. So far our design is comprised of a Kaplan turbine with a housing designed to include a diffuser and vanes. The diffuser and vanes should cause a pressure difference inside the housing which will allow us to take advantage of the physical implications which arise from that scenario. The cross section of our diffuser should resemble the cross section of an airfoil. The specific geometry of the blades will be determined using FEA and CFD analysis. The turbine should also be able to change its angle of attack thanks to the fins on the housing which act like routers directing the blades as perpendicular to the flow as possible. The blades will be a part of a removable ring which seals the unit but when needed can be extracted with very little effort. Further specifications will be available once the design is finalized.

8.2 Labor and Cost

Table 3: Hours Worked

Team Member	Assignment	Time Spent (Hours)
William Rosado	Solid Works Design	23
	Research	5
	PowerPoint Presentations	2
	Poster Board	3
	10% Report	5
Dominic Gayle	Research	15
	10% Report	5
	25% Report	10
	PowerPoint Presentations	5
Francisco Molinares	10% Report	10
	25% Report	15
	Research	2
	PowerPoint Presentations	5
	Overall	105

At this time we have not finalized the prototype design so we cannot say with certainty how much it would cost to manufacture.

8.3 Plans for Testing

Using the water tunnel available at Florida International University, several tests will be conducted on the water current turbine prototype. The prototype's design either will allow for the turbine to be removed from the diffuser housing or a separate stand-alone turbine will be manufactured. The stand-alone prototype will be tested and its performance data used as a baseline against which to measure the diffuser augmented turbine.

Testing will be done to determine the torque and angular velocity of the turbine as water flows over it. This will be done with and without the diffuser at varying flow velocities. With this data it will be possible to calculate C_p associated with the turbine. Additionally, the wake velocity of the DAT and turbine will be determined. The efficiency can be calculated with this information. The two configurations can then be compared to determine how significant of an impact the diffuser has on the performance of the turbine. Based on the assumption that the DAT will outperform the normal turbine, further testing will then be performed to optimize the diffuser.

Figure 10: FIU Water Tunnel

9. Conclusion

After our initial research we concluded that there exist a need to improve upon existing current harvesting systems. The main objective of this project was to study and design the functionality of an entire system which relied on sea currents as its main source of kinetic energy. The final design was able to record the basics system requirements including geometric parameters and functionality of the system. Based on the time line the team was able to accomplish all the project objectives and them provide all the required information for the investigation accomplished. There was multiple alternative designs presented which give an idea of how the design could change while maintaining functionality of the system. This project could represent a reference for future development and could be taken into account for mass production.

10. References

1 http://www.marineturbines.com/

2 http://www.boem.gov/Renewable-Energy-Program/Renewable-Energy-Guide/Ocean-Current-Energy.aspx

3 http://voith.com/ca-fr/Voith_Ocean_Current_Technologies.pdf

4 http://www.energy.siemens.com/hq/en/renewable-energy/hydro-power/ocean-power.htm

5 http://www.ge-energy.com/wind

6 http://www.alternative-energy-news.info/technology/wind-power/wind-turbines/

7 http://environment.nationalgeographic.com/environment/global-warming/wind-power-profile/

8 http://www.windturbine.net/products.htm

9 http://www.endurancewindpower.com/

10 http://www.ceoe.udel.edu/lewesturbine/index.shtml

11 http://www.solarworld-usa.com/

12 http://wilderness.org/blog/10-facts-you-probably-didnt-know-about-solar-energy?gclid=COiJj_HYhr0CFWuhOgodSH8Ahw

13 http://www.seasolarpower.com/

14 http://www.westfield.ma.edu/news/solar-panels-a-sea-of-green/

15 http://www.conserve-energy-future.com/AlternativeEnergySources.php

16 Mukund, P. R., 2012. Shipboard Propulsion, Power Electronics, and Ocean Energy. CRC Press

17 Bahaj, A. S., 2011. Renewable and Sustainable Energy Reviews. Elsevier, 15, 3399-4516.

18 Wang, S., Yuan, P., Li, D., Jiao, Y., 2011. An Overview of Ocean Renewable Energy in China. Elsevier, 15, 91-111.

19 Ponta, F. L., Jacovskis, P.M., 2008. Marine-current power generation by diffuser augmented floating hydro-turbines. Elsevier, 33, 665-673.

20 Gaden, D., Bibeau, E., 2010. A numerical investigation into the effect of diffusers on the performance of hydro kinetic turbines using a validated momentum source turbine model. Elsevier, 35, 1152-1158.

21 Kirke, B., 2003. Developments in ducted water current turbines. Cyberiad.net.