EML 4905 Senior Design Project

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BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

WIND TURBINE MODEL FOR POWER GENERATION AND HURRICANE WIND MITIGATION
25% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Marcos A. Balmaseda, Yoel Tanquero, and Yunior Licea 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.

Marcos A. Balmaseda Team Leader	Yoel Tanquero Team Member	Yunior Licea Team Member

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1. ABSTRACT

This project proposes the development of a horizontal wind turbine to be installed at the edge of a building's roof. The purpose of this device is to mitigate the effects of the pressure gradient produced by the flow of air over a roof at elevated speeds during a hurricane. Furthermore, this proposed design produces electricity by harvesting the kinetic energy carried by the fluid during the hurricane as well as under normal weather conditions.

The design phase of this revolutionary device considers variables such as diameter to length ratio, number of blades, shape of the blades, angle of twist, material used for prototype construction, and optimal location of the device relative to the structure's roof. Another aspect investigated is the shape of the roof. Various scenarios of roof shapes are considered during the design and optimization process. Computational Fluid Dynamic (CFD) studies are performed on the proposed design to investigate the viability of this system. In addition, an estimated power generation capacity of the model is assessed with the obtained pressure readings. After the CFD study is concluded, experimental trials of the turbine model are conducted in Florida International University's Wall of Wind to validate the results of this analysis.

2. INTRODUCTION

Hurricane season represents a very important phenomenon for South Florida due to its geographical location. Hurricanes come accompanied by severe rain as well as very strong winds. The destructive force of these winds is very high, especially for houses built using traditional construction methods. There is an imperative need for engineering solutions to improve the resistance of common houses to withstand the devastating forces of winds produced by a hurricane. Florida and the neighboring Caribbean countries are faced with the destructive and possibly fatal catastrophes caused by these natural disasters without innovative hurricane mitigation research and implementation.

Disasters produced by the devastating action of a hurricane’s powerful winds often involve high economic losses mainly due to buildings’ roofs lifting under the force of suction of the air. The tremendous pressure difference between the upstream and downstream conditions of the flow of air during a hurricane causes the lifting force that detaches the roof from the rest of the structure.

After the conclusion of this project, structures that have this proposed turbine installed would be able to withstand stronger forces and survive the passing of hurricanes. Furthermore, the physical and financial damage to society would be reduced after constructions becoming stronger and more resistant.

2.1 Problem Statement

There is a need for innovative engineering solutions to mitigate the destruction caused by hurricanes. The uplift effect caused by the pressure difference over the roof of a house is the main reason for roofs flying off during a hurricane. Thousands of homeowners lose their homes every year with the pass of major storms. After hurricane Andrews, Florida authorities and other entities started investigation and development of new technologies with the objective of preventing and reducing the destruction caused by such natural disasters.

On the other hand, power generation is extinguishing the planet’s limited resources. Issues like CO_2 emissions and global warming need to be addressed. For that reason, the development of new and inexhaustible green energy sources are of paramount importance for the immediate future.

This project aims at solving both problems by creating an innovative device that mitigates the uplift effect during a hurricane, and uses the kinetic energy of the wind to generate clean electricity. In addition, a system that allows the solution of both issues at the same time should have a significant impact on the area.

2.2 Motivation

The State of Florida like most of the Caribbean countries has always been under the scope of hurricanes. The geographic location of the sunshine state places it in a dangerous position during hurricane season. The losses and damages that Floridian houses have suffered under the action of windstorms represent the driving motive for engineers and contractors to look for ways and alternatives to improve strength and safety of houses. Nothing can be done to stop natural forces from happening; however, it is possible to work towards our preservation, comfort and security by improving aspects of life such as structural strength and safety of houses.

Economic sustainability is another reason to find new strengths and improvements in the field of wind and extreme weather mitigation. Hurricane disasters are the cause of significant economic losses in the Southeast region of the United States, especially in Florida, as well as in the Caribbean and some regions of South America every year. Major hurricanes such as Andrew, Ivan, Katrina and Wilma, have impacted Florida causing severe physical and economical losses. It is estimated that these losses will continue to increase as the population grows in the coastal areas. For that reason, it is necessary to improve engineering methods and practices to protect Floridians homes and also Floridians lives. As a result of improved engineering techniques to protect against climate contingencies, financial and social costs could be decreased when facing hurricane activity.

One of the primary concerns during a hurricane is the damage caused by the strong winds. Research shows that the roof of a house is very vulnerable due to large pressure differences produces by high speed winds. For that reason, this team decided to help diminish the losses resulting from a hurricane by building a turbine that can be installed in any house to serve as a wind mitigation device.

Finally, there is another concern that has become increasingly important for humankind in the last few years: the burning of fossil fuels for electricity production. This is a very delicate situation because all the pollution produced is one of the main factors causing global warming and destroying the ozone layer. For that reason, there is an imperative need to find new sources of energy to use for electric power production. There is much research being done to find renewable sources such as water and wind to produce electricity; and these clean forms of energy are expected to eventually replace the traditional fuel burning methods used until now. Thus, the model proposed in this project is intended to be implemented nation and worldwide because it also provides a way to take advantage of wind energy under normal weather conditions and use it as a renewable and clean source to produce energy.

2.3 Literature Survey

2.3.1 Characteristics of Winds during a Hurricane

The force created by the wind during a hurricane generally produces significant damage. According to the National Hurricane Center, a category 5 hurricane is accompanied by winds with speeds of 150 miles per hour or higher, which most likely causes catastrophic damage to structures. This damage generally starts as a failure of the roof, and following destruction of the rest of the structure including walls and interiors.

One characteristic of hurricane winds that also contributes to the lifting of the roofs and destruction of the structures is the fluctuation of the flow field. If the speed and patterns of the flow were constant, it would be easier for the engineers to design a structure capable of enduring these forces. However, changing conditions produce fatigue in the different supporting elements that ultimately cause failure.

Another characteristic of a hurricane wind is the turbulence that accompanies the flow of wind. Turbulent flows carry much more energy than laminar flows, and this energy can be transferred into the structure causing the failure (Manwell.)

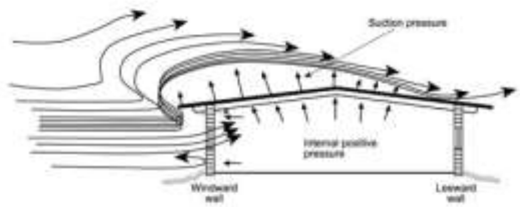

Figure 1. Wind behavior over a roof

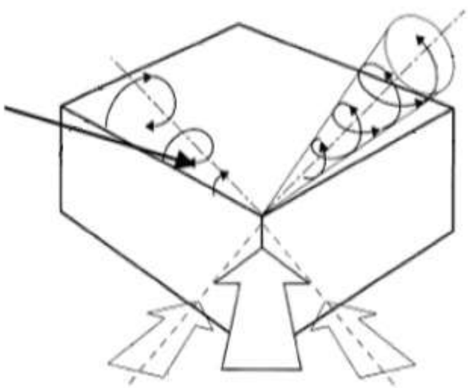

Figure 2. Wind corner vortices over a roof

The main concern of this project is the uplift effect cause by the strong winds. Figure 1 show what happens on the roof of a house when strong winds are acting upon it. The empty space that forms between the layers of air and the surface of the roof cause a vacuum effect that produces the uplift and ultimately the failure of the roof. Another risk presented by high hurricane winds happens when the direction of the wind is at an angle with the roof. Figure 2 shows the conical vortices formed when winds strike the house in the corners. These vortices increase the pressure difference that causes lift and produce a greater uplift effect (Lin 2008.)

2.3.2 Previous Wind Mitigation Devices

There has been extensive research dedicated to develop mitigation alternatives that can be easily retrofitted into existing structures. AEROEDGE™ Vortex Suppression Technology is an example of these kinds of mitigation devices. This technology was developed by RenaissanceRe group and tested in the 6-fan Wall of Wind at Florida International University. This technology has proven effective to reduce the pressure gradient on roofs during high winds, and experimental results confirm this (Lin 2008.) This type of static devices have been studied and improved over the years, with the aforementioned being one of the latest developments.

While research has found different sorts of static devices to fight wind, the model proposed in this project is a completely new approach that has been rarely studied before. The wind turbine developed in this thesis is a new kind of dynamic device that has a double purpose; it mitigates the force of strong winds while generating clean energy.

2.3.3 Types of Wind Turbines Available

Wind turbines are devices that convert the kinetic energy of the wind into useful energy that can be harvested such as mechanical energy. The main idea behind the basic operation of wind turbines is to use the force of the wind to rotate the blades. This way, the energy carried by the wind can be turned into mechanical energy which can be used to generate and store electrical energy. In modern wind turbines, the basic principle of lift produced by the wind is used to rotate the blades of the turbine and produce the torque necessary to move a shaft (Manwell 2). There are two main kinds of wind turbines: horizontal and vertical axis. Following is a brief description of them.

Horizontal Axis Wind Turbines (HAWT)

Figure 3. HAWT wind farm

These are the most commonly used wind turbines worldwide. Some of the leading manufacturers include General Electric, Urban Green Energy, and Northern Power Systems.

The main characteristic of these kinds of turbines is that their axis of rotation is parallel to the ground as shown in Figure 3. A HAWT consists of different parts such as the rotor and drive train.

The rotor of a HAWT includes the blades and supporting hub of the device. The blades are the heart of a wind turbine because they are the elements directly interacting with the wind. These kinds of turbines use aerodynamically designed blades to take advantage of the forces generated by the wind. These blades, usually three of them, must be facing the wind according to their design specifications. In other words, the blades must be oriented perpendicular to the direction of the wind. It is because of this requirement that all HAWT must have a device to turn them and orient them correctly as the wind changes its direction. Usually these directional correctors are in the form of a wind-vane for small turbines while larger turbines use electronic devices and sensors to correct directional changes. Moreover, these blades are usually made of very light weight materials to facilitate transportation and installation as well as to increase efficiency in harvesting energy from the wind (Paraschivoiu 2002.)

The drive train of a HAWT consists of other rotating parts and components such as gears, bearings, and couplings. One of the main mechanisms of this drive train is the gearbox. The main function of this gearbox is to increase the velocity of rotation of the blades and transmit this power down through the shaft to the system that ultimately convert this rotational energy into useful electrical energy. It is very important to increase the rotational speed provided to the electric generator because the power generated by these machines is usually a function directly related to the speed of rotation of the shaft; therefore, the faster the shaft is rotating, the more electricity can be generated. However, there is an ideal value for this increase in speed that can be calculated because it is important to take into account the losses with each transformation. In summary, the perfect balance between rotational speed of the blades and output rotational speed of the shaft must be found in order to design the optimal gearbox and obtain the maximum possible efficiency from the wind turbine.

Vertical Axis Wind Turbines (VAWT)

Figure 4. VAWT, Savonius

Figure 5. VAWT, Darrieus

These kinds of wind turbines were studied extensively in the 1970s and 1980s particularly in the U.S. and Canada. The most important characteristic of these types of turbines is that they can accept wind coming from any direction, which is very advantageous and helps simplify the design and complexity of the mechanism. These kinds of turbine, like the HAWT, are composed of a rotor and a drivetrain.

The rotor of a VAWT serves the same purpose as the other kind of turbine explained before; the main difference here is that the blades generally have a shape that allows them to accept winds coming from any direction.

The drivetrain of a VAWT is similar to that of a HAWT; the only difference is that the shaft connected to the rotor is vertical instead of horizontal. In addition, the same gearbox idea must be use here for the same purpose.

Common examples of these vertical-axis wind turbines are the Savonius Rotor (Figure 4) and Darrieus turbines (Figure 5) (Paraschivoiu 2002.)

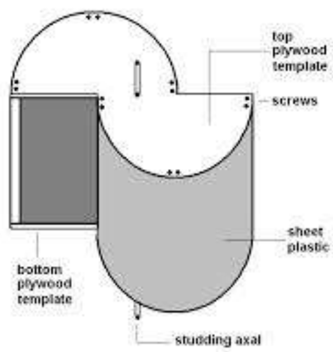

Figure 6. Double-blade Savonius

Savonius wind turbines have a characteristic cross sectional area as shown in Figure 6. These kinds of turbines may have two or more blades. Also, they can have a different configuration from the one shown in which the semi-cylinders do not cross each other in the center section. However, the most commonly seen Savonius turbines are similar to those shown in Figure 6, in which there is a space between the two “blades” that allows air to circulate.

Darrieus wind turbines are another kind of vertical axis wind turbines commonly seen nowadays. The first patent of this type of device was awarded in 1931 to the French engineer G.J.M. Darrieus by the U.S. Patent Office (Paraschivoiu 2002). These types of wind turbines are composed of curved blades mounted on a vertical axis that can accept winds coming from any direction as well.

In Summary, the two types explained above are the most commonly used nowadays. There are many patents that have improved on the initial designs. However, there are not many

2.3.4 Wind Turbines for Energy Production

The primary function of wind turbines nowadays is the production of electric power. There have been many efforts around the world to promote the use of renewable sources of energy such as the wind to produce electricity. In the United States, for example, the American Recovery and Re-investment Act of 2009 provide tax cuts to renewable energy decisions. Installed Wind Turbines qualify for up to 30% federal tax credit, which contributes to further develop and improve the existing designs and to encourage enterprises to implement these types of energy source.

There have been efforts all over the world to contribute to the development of new technologies that take advantage of this renewable source of “free” energy. According to information published by the National Renewable Energy Laboratory in its January 2012 Energy Update, the world’s total installed wind capacity increased from 50,000 MW in 2005 to around 216,000MW in 2012. The leading countries taking advantage of this renewable source are China, the U.S., Germany, Spain, and India. These facts clearly show a trace that can be easily interpreted as a new era in which a much cleaner energy is the main component.

On the other hand, even when there have been significant improvements in electricity generation utilizing wind power, most of this generation comes from wind farms. However, there is not much advance shown at the small scale. In other words, not much of the improvements and new technologies implemented in the last few years can be used by individuals to be installed in the houses and small constructions all over the country. For that reason, there is a wide field of research and exploration to be exploited, and this project is aimed at taking the first steps towards this initiative.

2.3.5 Electric Generators

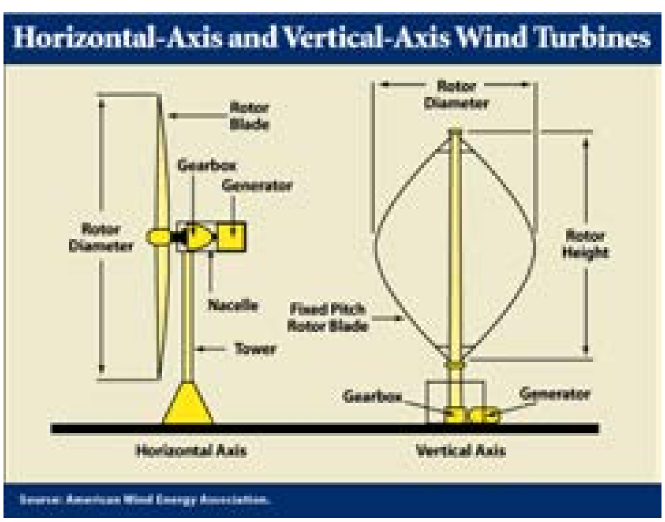

Figure 7. HAWT and VAWT schematic

The generation of electric energy on a horizontal axis wind turbine with a rotor diameter of up to 120 meters is up to 5 MW (Woodbank). The turbine is controlled to maintain a constant angular velocity for any wind speed. The angular velocity of the blades is in the range of 10 to 20 RPM. The rotor transmits the torque to a gear box that controls the number of RPM to a fix value, depending of the country to be installed. Usually, this value is 1200 RPM so that the frequency of the AC current is 60 Hz which is the used in the United States.

For vertical axis wind turbines the generation of energy occurs in a similar way. The main difference is that vertical axis wind turbines are mostly for domestic of small installations; therefore, the cost of the turbine is reduced by eliminating the speed controller that keeps the angular velocity of the rotor constant[1]. As a result, the frequency and amount of current produced changes with the changes in wind speed. Then the current produced by the turbine is adjusted and stored by a separate device. Subsequently, the energy stored can be used for different applications.

2.3.6 Wind Turbine for Hurricane Wind Mitigation

A great amount of information is available about the behavior of the winds during a hurricane. There are many articles explaining how hurricane winds impact different buildings and structures with different shapes. For example, the American Society of Civil Engineers (ASCE) Online Library contains several articles that analyze and characterize hurricane winds. Furthermore, several articles talk about the importance of improving the construction standards to make structures more resistant to wind forces produced by high speed winds. One example of the improvement that has been taking place in the last few years is the modifications that the Florida Building Code has experienced in the aftermath years of hurricanes Katrina and Wilma in 2005. A good example of these improvements is explained and visualized in a video recorded the inaugural day of the Wall of Wind Laboratory at the Florida International University (FIU). This video can be found in the website of the International Hurricane Research Center of FIU. The video shows two small houses, one built to the standards before these major hurricanes, and the other one built to the new improved standards. When these two houses are placed in a hurricane strength wind scenario, clearly the one that was built following the new code was more resistant.

Nevertheless, there is no indication of a device similar to the one proposed in this project that serves to mitigate the force of the winds during a hurricane. For that reason,

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[1] * Source: "*Window on State Government*" website

this project can serve as the initial steps towards a new era of hurricane mitigation devices that can also be used for other purposes such as energy generation using renewable sources.

3. PROJECT OBJECTIVES

The main objective pursuit on this paper is the design and optimization of a device that will generate electric power as well as mitigate the uplift effect generated by strong hurricane winds. The device by itself follows a new concept of dynamic wind mitigation. The power generation will follow the precedents established by horizontal and vertical axis wind turbines. Although this paper does not discuss all the details related to the implementation of the device, the same was designed taking into consideration the need for an aesthetically appealing product.

4. CONCEPTUAL DESIGN

The research showed that the use of wind turbines for hurricane wind mitigation is an innovative concept that has not been previously investigated. The main concept behind the design was to create a dynamic device to mitigate uplift forces instead of static mitigation device. This device had to be able to transform the energy of the wind into electric energy while redirecting the direction of the wind over the roof of the houses. As a result, the pressure difference between the wall and the roof of the house is reduced; therefore, the uplift effect is diminished and the integrity of the house is preserved.

Another characteristic of the device is that it was designed to be installed close to the house and along the edge of the roof; therefore, it shares the physical characteristics of a horizontal axis wind turbine. However, there are many differences between the device proposed in this project and a horizontal axis wind turbine (HAWT.) First, a HAWT uses rotor blades that require the wind flowing normal to the turbine; thus, they are usually accompanied by a device that constantly positions the turbine facing the wind. Nonetheless, this characteristic does not meet the design intended. Second, HAWT are big in diameter and small in length like a fan, with the objective of maximizing power generation. Nevertheless, the device designed had to minimize the uplift effect and to do that, some of its power generation capacity had to be compromised.

Simultaneously, vertical axis wind turbines have rotor blades that allow them to generate energy by harnessing the air flowing in different directions. This principle was implemented on the design of the device proposed in this project. However, the rotor blades are considerably smaller than those used on a HAWT, and they have an optimized shape that maximizes the energy generation. While the mitigation device designed need to be optimized to minimize the uplift effect during a hurricane, the same has characteristics of both horizontal and vertical axis wind turbines. Some of the most important design alternatives being considered are discussed below.

4.1 Design Alternative 1

Figure 8. Design alternative 1

The first design alternative is shown in Figure 8. The alternative meets the required horizontal axis and proposes an array of straight blades with a triangular shape and a rectangular corner. The perpendicular corner array could be a way of maximizing the pressure difference. Although this device can be less efficient than expected with winds flowing perpendicularly, it was taken into consideration for its efficiency with winds flowing along the axis.

The dimensions used for modeling were estimations selected based on previous studied designs and they are not based on design calculations. However, the design followed the principles that were found during the literature survey and some of the most important design considerations. Overall, creating an assembly of simple similar parts instead of a full helical feature considerably reduces the complexity and cost of the turbine, but it also increases the amount of material used which may contribute to a considerably augment in the weight of the device. Future final element analysis (FEA) and computational fluid dynamics (CFD) analysis of this turbine are required.

4.2 Design Alternative 2

Figure 9 Design alternative 2

The second design alternative idea began with a concept found during the research phase. The turbine, with three blades in torsion all along the shaft, has the capability of allowing the wind to flow through the turbine and create a rotation that is then converted into useful electric power (see Figure 9.) At the same time, if this device is placed really close to a roof the expected result can be achieved. Although this type of device is really efficient in the presence of wind flowing normal to the axis of rotation, it may be to a certain degree inefficient under winds flowing along its axis.

The high cost could add against the final proposal of this type of design for a big device, small turbines can be manufactured on 3D printers and their cost remains similar to the previously proposed design. Additionally, the multidisciplinary design optimization (MDO) doubtlessly reduces the material used; therefore, the cost of the turbine and the simplicity of the assembly are also reduced.

From a design stand point, this alternative should provide a higher efficiency than the first design alternative because the blades on torsion generate a better flow through the turbine increasing the output. Additionally, the flow acting perpendicular to the wall is the main concern and this design is more much efficient than Design Alternative 1. Future final element analysis (FEA) and computational fluid dynamics (CFD) analysis of the turbine are required.

4.3 Design Alternative 3

The third design alternative is shown in Figure 10. Unlike the first two alternatives, this turbine provides a helical blade fully independent from the shaft. This design contains features that appear on the Darrieus wind turbines as the helical blade separated from the axis of rotation. The blade is connected to two rotors that then keep

Figure 10. Design alternative 3

the device in place and generate the electric output, which then is transmitted and accumulated on a separate device.

This device presents possible issues that need to be studied deeply such as the strength of the assembly and the position of the generators. Since the main purpose of the device is to mitigate the uplift effect of high speed winds, structural analysis is required to ensure the integrity of the same. Other variations of this alternative are the addition of more blades, the change in the blade angle, shape and angle of twist. Additional CFD is required in order to define the optimal values for the aforementioned parameters.

4.4 Design Alternative 4

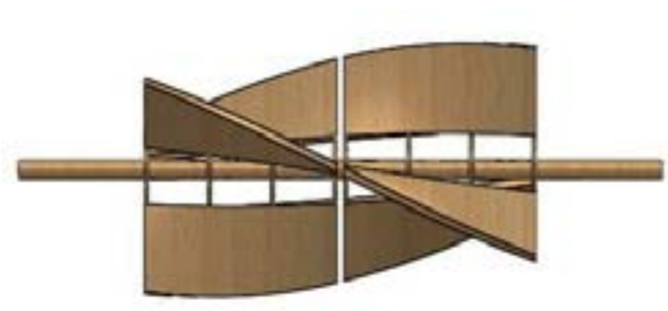

Figure 11. Design alternative 4

The fourth design alternative is shown in Figure 11. This alternative combine some of the most important features found in horizontal and vertical axis wind turbines, as well as in the previous 3 design alternatives. It is composed of three blades equally separated by an angle of 120 degrees. The blade profile is rectangular in order to maximize the simplicity and reduce the cost of the prototype. The total twist angle on the blade is 90 degrees. However, since the blades are not continuous, the actual angle of torsion becomes 45 degrees with a small separation in the center and then other three blades continue in the same path with an additional twist of 45 degrees. Moreover, there are rectangular spaces between the blades and the shaft that improve the flow through the device, reduce the amount of material used, reduce the weight of the turbine, and reduce the final cost of the prototype.

4.5 Feasibility Assessment

All four design alternatives can be built. However, there are some issues in the building and implementation of the alternatives that need to be considered. For design alternative 1, the amount of blades increases the complexity of the prototype considerably. Moreover, the analytical analysis of this type of device may introduce a number of errors that may then alter the final results. Similarly, attaching the blades to the shaft may require welding and the number and size of the blades creates a bottleneck during production. For the design alternative 2, the system is relatively simple, but the construction of a blade in torsion welded or molded into the shaft increase its complexity considerably. Consequently, the blades in design alternative 3 represent by themselves an issue. Not only the helical shape fully separated from the shaft may be unstable in the presence of high velocity winds, but also they are extremely hard to manufacture which makes this alternative unfeasible at the time of this study. On the other hand, the design alternative 4 is simple and efficient. Although ideally all these prototypes should be built and studied, the lack of funds could considerably reduce the number and quality of the prototypes. As a result, the four alternatives are extensively studied using CFD and other computational methods to reduce the total cost of the research.

4.6 Proposed Design

Even though all four alternatives can be built, the proposed design corresponds to alternative 4. This alternative constitutes a balance between reduction of the uplift effect and energy generation. Simultaneously, it is simple enough and serves as a generic model to further study other design alternatives. For instance, the number of blades, the shape of the blades and the angle of rotation can be changed in relation to the results found with this device. Furthermore, the symmetry of the alternative helps to reduce the axial forces created during the rotation of the device. The separation of the blades from the shaft eliminates the vortices that are generated in the corners of a house.

This alternative should have the power generation, air flow output, and size required. Nevertheless, the validation of the proposed design is not completed yet and still requires CFD analysis. This proposed design takes into account the future accommodation of the electric generator, as well as the frame to fix the device in the proximity of the roof.

5. TIMELINE AND RESPONSIBILITIES

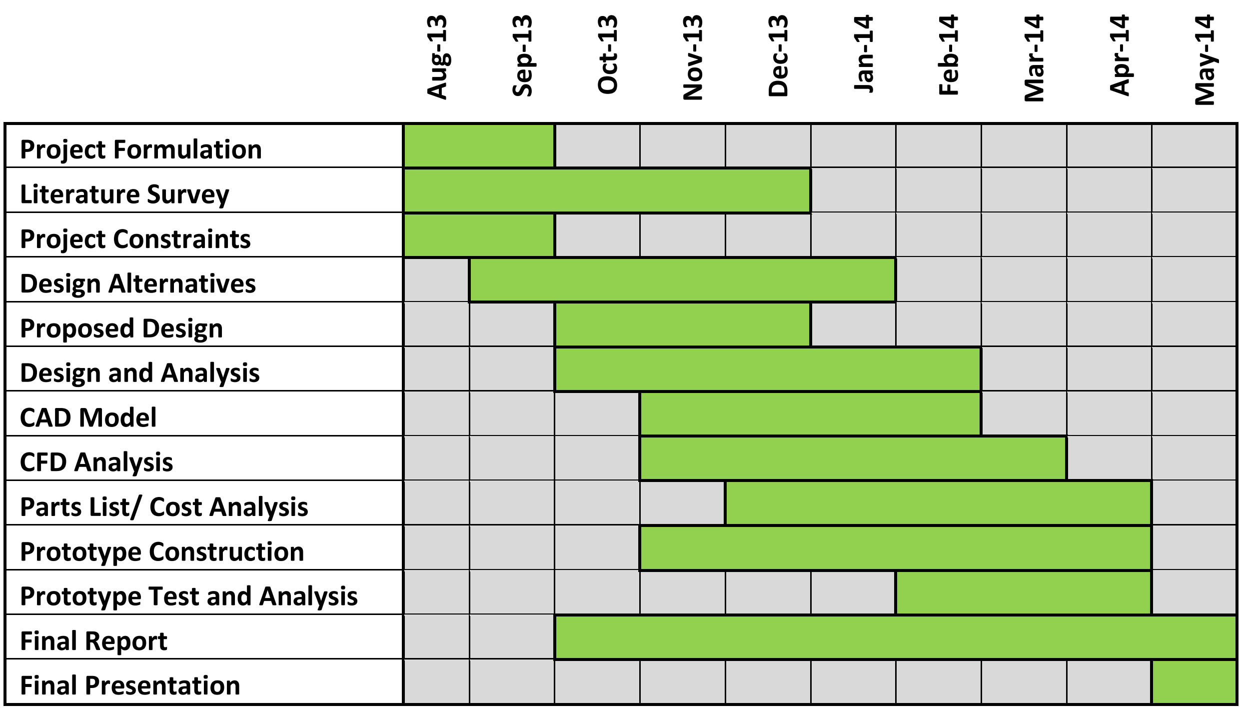

Figure 12. Timeline

	Team Member(s) Responsible
Project Formulation	Yoel
Literature Survey	Marcos
Project Constraints	Marcos, Yoel, Yunior
Design Alternatives	Yoel, Yunior
Proposed Design	Yoel,Yunior
Design and Analysis	Marcos, Yoel, Yunior
CAD Model	Yunior
CFD Analysis	Marcos, Yoel, Yunior
Parts List/ Cost Analysis	Marcos, Yunior
Prototype Construction	Yunior, Yoel
Prototype Test and Analysis	Marcos, Yoel, Yunior
Final Report	Marcos, Yoel, Yunior
Final Presentation	Marcos, Yoel, Yunior

Figure 13. Team responsibilities

6. ANALYTICAL ANALYSIS

This section includes some of the equations used for analytical considerations of the proposed design. Two main aspects should be mentioned in this section. The first analytic analysis relates to the function of this design to mitigate the uplift forces of hurricane winds; and the second one relates to the power generation.

The analysis pertaining to the wind mitigation and structural integrity of the design is still pending for future investigation. The reason this analysis has not been performed is because of the lack of literature in this field of research. As it has been mentioned throughout this report, the revolutionary concept being developed in this project has not been studied before. Since this new concept is still in its initial stage, the main concern up to this point has been to verify the possibility of a device that works. In other words, this phase of the concept involves starting with a simple design that has proven effective, and make sure it works for the purposes described in this project. Once it is verified that a simple device is functional, the next step is to optimize its design.

Another aspect of the present concept that has been analytically considered is its power generation capability. Although the device designed is not a vertical axis wind turbine, the physical characteristics and functionalities are very similar. From the analytical perspective, it is important to determine the maximum power carried by the fluid and the maximum theoretical power that can be harvested by the turbine. Therefore, the kinetic energy contained in the air with uniform speed and unidirectional motion is considered, and it is given by:

$$E = \frac{1}{2} m V_1^2$$

Where: E – Kinetic Energy

m – Mass of the fluid

V – Velocity of the fluid

The mass flow rate $\dot{m}$, with the density ρ through a stationary control surface of frontal section A, it can be expressed as:

$$\dot{m} = \rho A V_1$$

The wind stream power through A is given by:

$$P_{Air} = \frac{1}{2}\rho A V_1^3$$

The Continuity Equation can be expressed as:

$$\dot{m} = \dot{m}_{in} = \dot{m}_{out}$$

The power coefficient on a wind turbine can be calculated by a non-dimensional thrust coefficient. This coefficient is defined as:

$$C_p = \frac{P_{rotor}}{P_{air}}$$

Where P_{rotor} correspond to the power generated by the rotor and can be defined, without including the losses on the rotor as:

$$P_{rotor} = \tau\Omega$$

Where: τ – Average Torque

Ω – Angular Velocity

* All equations above can be found in the paper "*Optimización Aerodinámica y Estructural de un Generador Eólico de Eje Vertical"* by Jorge E. Tamayo (See References)

7. FIRST PROTOTYPE

7.1 Prototype System Description

The first prototype was built very early in the design stage for competition purposes. This prototype was presented in the RenaissanceRe Shark Tank College Competition during the 2013 FLASH Annual Conference in Orlando Florida on November 21st.

Figure 14. First built prototype

Figure 14 shows an image of the first built prototype. It is a very simple model that considers the vortex characteristics of wind over roofs as explained previously.

The dimensions of this prototype are shown in Appendix A. The material chosen for construction was balsa wood. Several considerations were evaluated when choosing this material for construction. First of all balsa wood is inexpensive, which made it an excellent candidate when compared to other materials such as harder woods, metals, or composites. Secondly, balsa wood is very soft and flexible which made the construction very simple. Finally, even though balsa is a soft material, it provided the strength needed to fulfill the purpose of this first prototype. When all the components were attached in place, the entire turbine was strong enough to safely withstand winds of up to 20 m/s, which was the range of winds used for demonstration during the competition at the FLASH Conference.

7.2 Prototype Cost Analysis

Table 1 shows the cost analysis for the construction of the first prototype. One of the major expenses that any enterprise has is labor. Therefore, the person-hours for the total cost of this first prototype were considered and accounted for. The average salary paid to the team members was assumed to be $30 per hour. The hourly wage was adopted for consulting services utilized. By doing this, a better estimation of the final cost can be obtained, and a more accurate decision can be made if this project reaches construction for commercialization stage.

Table 1. Prototype cost analysis

Title of Project WIND TURBINE MODEL FOR POWER GENERATION AND HURRICANE WIND MITIGATION			
			Cost
A. Team members			
	Name	Person-hrs	
1.	Marcos A. Balmaseda	20	$600.00
2.	Yoel Tanquero	20	$600.00
3.	Yunior Licea	20	$600.00
4.	Subtotal		$1,800.00
F. Consultant Services			
	Name	Person-hrs	
1.	Javier Palencia, Ph.D Student FIU	15	$450.00
2.			
3.			
Subtotal			$450.00

D. Miscellaneous Costs		
1. Materials and supplies		$98.00
balsa wood sheets	$60.00	
1/4" rod	$8.00	
glue	$5.00	
bearings	$15.00	
other	$10.00	
3. Other		$0.00
4.		
Subtotal		$98.00
E. Total Prototype Cost		$2,348.00

7.3 Experimental Testing and Results of Prototype

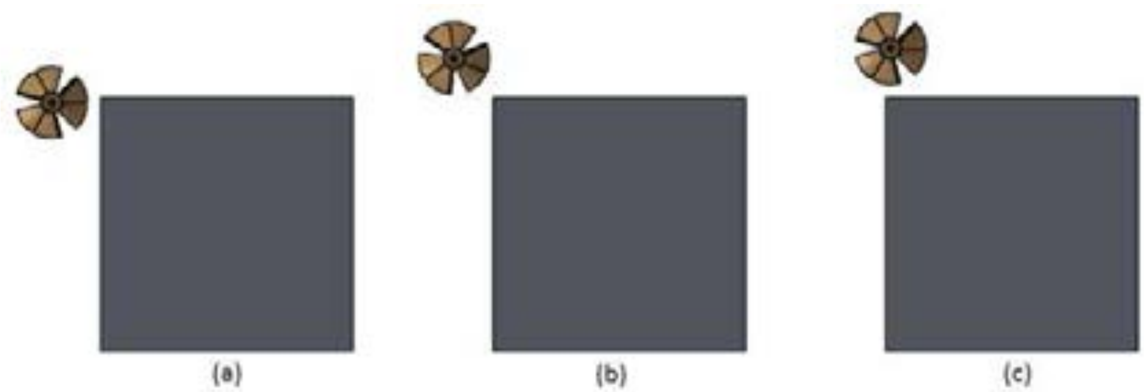

Figure 15. (a) horizontal (b) 45 degree (c) 90 degree

Several experimental tests were already performed on the prototype. For this preliminary testing stage a flat roof square house was used. One important variable considered was the position of the device relative to the roof. Three different alternatives were considered and they are shown in Figure 15. The first alternative was to place the device horizontally parallel to the edge of the roof. The second alternative was to place the device at a 45 degree angle to the edge of the roof. Finally, the last alternative studied was with the device placed at a 90 degree angle to the edge of the roof.

Figure 16. (a) experiment without device (b) experiment with device

To evaluate the efficacy of the system, the flat roof was covered with light weight gravel, and a fan delivering winds between 5 and 10 m/s was aimed normal to the turbine and along the surface of the roof. The purpose of this experiment was to discover if this prototype was effective in reducing the pressure difference over the roof. To evaluate this, the scouring of the gravel was examined. Experiments suggested that the third alternative was the most effective in reducing the scouring of the gravel. Figure 16 shows the experimental results mentioned above. As the image suggest, there was a significant reduction of scouring in the gravel with the device.

Figure 17. Corner winds prototype test

Another experiment conducted using this prototype is shown in Figure 17. For this experiment, the fan (shown in blue in the picture) was placed at a 45 degree angle with the roof. The purpose of this experiment was to be able to observe the difference of the scouring with and without the device in one single shot. As the picture suggests, the gravel on the side of the roof without the device was almost whipped out completely, while the edge of the roof with the turbine was almost intact. These results demonstrate that the system works, which was the main purpose of all experimentation up to this point.

7.4 Plan for Tests on Prototype

Future prototype experimentation plans involve determining wind mitigation as well as power generation capability of the prototype. For this pressure and velocity difference before and after the turbine must be measured.

The Florida International University Wall of Wind facility plays an important role to further test the prototype that was built as well as future ones. It is important to find the optimum values for all the variables involved in the design phase. Some of these variables such as the number of blades, angle of attack of the blades, and angle of twist of the turbine. Furthermore, variables such as shape of the roofs and optimal location of the turbine relative to the edge of the roofs are also to be considered during prototype testing.

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9. APPENDICES

Appendix A: Engineering Drawings for First Prototype