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Design of a Vertical Axis Wind Turbine for Urban Areas
Hidden In Plain Sight Wind Energy Conservation System (HIPS WECS)

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***Abstract*—The team at Roger Williams University is working with CBC LLC creating a new design for a horizontal axis wind turbine known as HIPS WECS as a senior capstone project. This new turbine is designed to fit into an urban environment where a traditional, horizontal axis wind turbine would not be possible. The team is conducting a number of tests using Solidworks® simulations and physical testing to the optimize design to meet the requirements. The goal of the project is to create specifically sized models to accommodate certain generators. The RWU housing structure will be used to power a 5 kilowatt generator. This design will give an advantage over other designs where lower winds speeds can start up the generator due to the fluid dynamics that accelerate the wind as it enters into the chamber.**

Keywords—Turbine, HIPS WECS, Vertical Axis, Simulation, SolidWorks®.

I. Introduction

The purpose of the Hidden In Plain Sight Wind Energy Conservation System or HIPS WECS is to create a vertical axis wind turbine that will generate the same amount of energy that a traditional horizontal wind turbine would produce. The main focus of this project will be creating a turbine that will be able to exist in an urban environment and, as the name suggests, be hidden in plain sight. This means that the turbine will blend in to the surroundings considerably more so than a traditional horizontal axis system. The height will only be fifteen feet tall. This makes placing the turbine on top of something like a New York City skyscraper, will be practically invisible. Also the design that the team at Roger Williams University is working on will make it look like a small house. This will also help blend it into the rooftops. The client had ideas of being able to incorporate trademark building designs into the roof in order to conserve the style of the building.

HIPS WECS will give these urban areas the capability to produce wind energy using a revolutionary enclosure which channels air into a chamber where fluid dynamics greatly increase wind speed. This increase in speed is generated by using eight wing shaped stationary stators that direct the air into the center of the 30 foot diameter housing structure. This 30 foot diameter is currently the maximum housing size that will be created and tested in order to power a 100 kilowatt generator that the client had asked we design our model for. After the air reaches the inside edge of the stators, it quickly comes in contact with either six or seven vanes that transfer the wind energy into torque as it rotates about a drum that is connected to the generator shaft. The shaft is connected to a generator that will harness the power from this torque and transfer the energy to a power source or battery. Below is a labeled cross section of a simplified, computer generated model of the turbine.

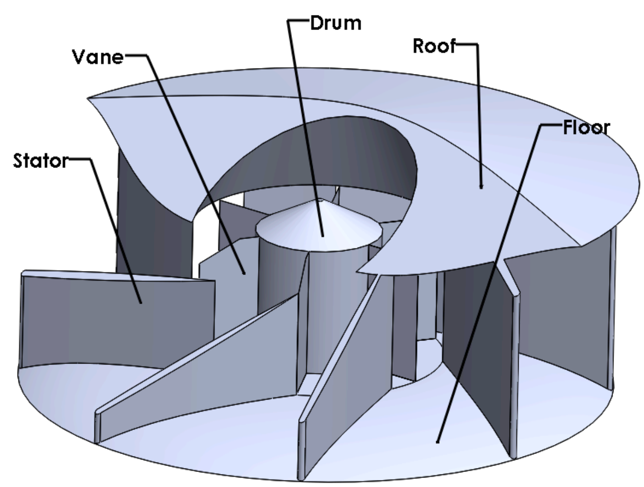

Figure 1: A labeled section view of a model of the turbine. This diagram shows the parts of the turbine and the titles referenced in this paper

II. Product Development and Testing

A. *Initial Design*

The initial design of the model consisted of four wing shaped stators placed inside of a similar housing structure. From the initial design what was observed was that the limited amount of inlets reduced the uniformity of the design with varying wind directions. The initial design is shown below:

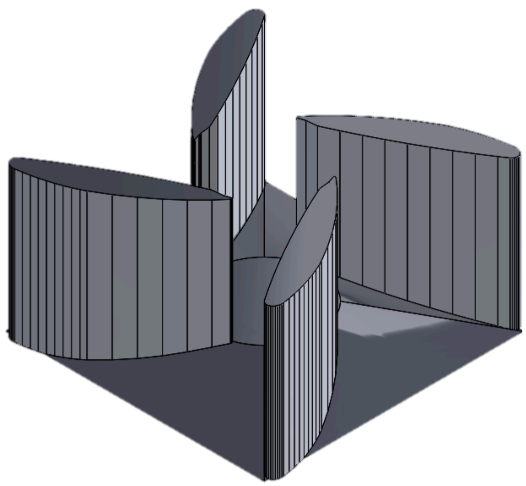

Figure 2: Initial design that CBC LLC presented to the team at the beginning of the project.

From the design in figure 2 the team learned that more stators were needed in order to optimize the design. The newer design still incorporated the wing shaped stators but the number was changed in order to find the most optimal number. The shape of the stators were initially designed as double wedged air foils in order to make changing the model simpler. SolidWorks® was used to test the new designs in order to find the most optimal design.

B. *SolidWorks® Testing*

Much of the testing that occurred during this project was done by creating and using computational fluid dynamic (CFD) analysis on models using SolidWorks®. These tests have optimized the design to generate the maximum torque on the vanes attached to the rotating center drum based by maximizing the mass flow rate. The drum and vanes at the center of the turbine will be attached to a generator which will generate power from the turbine. The results that the team has generated are:

- The average wind speed of the wind inside of the chamber.
- The average wind speed for the inlets and outlets in order to determine turbine efficiency.
- The total mass flow rate inside a section of the chamber.
- The torque on the drum through hand calculations to determine the needed shaft rotation rate.

This data will show the team which of the designs will generate the most torque on the vanes as the vanes start directly after the end of the stators. Each of these tests is run at a constant 15 miles per hour or 6.7065 meters per second ambient wind speed or the speed of the air before it contacts the housing structure.

This method of testing allows the team to make changes to the design easily based on the results from the analysis. The design table function in SolidWorks® was used to optimize the designs of the roof, floor, stator and drum radius in order maximize the designs performance. Also, SolidWorks® gives very quick and clear results so that it is possible to make these changes and not have a long lead time. By using SolidWorks®, the team was able to test a large number of models with micro and macro modifications and see the differences in the mass flow rate and torque based off of the average wind speed. The image below illustrates two cut plots, one taken before entering the chamber and one midway through the chamber.

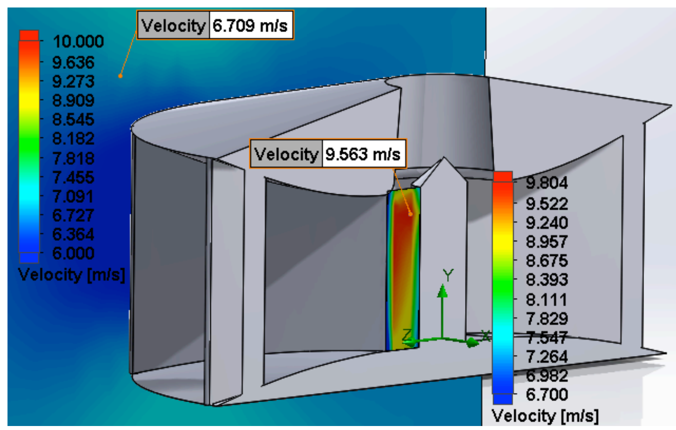

Figure 3: SolidWorks® CFD cut plots showing the average wind velocities before entering the housing structure and midway through the chamber.

The following table is an example of the results that the team generated using SolidWorks® to measure the average wind speed.

Table 1: Table of results from a batch of simulations run using SolidWorks®. Each of the cells represents a maximum wind velocity of a different model. The velocities given are in meters per second.

	G	H	I
1	10.456	9.350	9.229
2	10.462	9.526	9.325
3	10.449	9.945	9.416
4	10.436	10.364	9.862
5	10.384	10.577	9.845
6	10.488	10.692	9.843
7	10.485	10.350	9.898
8	10.402	10.559	10.089
9	10.447	10.717	9.782

Table 1 was the basis for a majority of the design process where models were assigned names like "G1" in order to optimize the design. The function of this table was to specify a tolerance to the model which related to different aspects of measurements. In the first set of models the numbers 1-9 were assigned based off the stator angle and thickness. Each number corresponds to the combination of the two in respects to their tolerance. The letters G, H, and I represented the drum diameter that was used during the test. This process was very effective in quickly finding the most optimal model. Once the most optimal model was found, in this case above "H6", then a smaller tolerance was tested around the measurements used in that specific model. A number was attached to the front of these designs which corresponded to the number of stators. In most cases the 8 stator model was the most effective. A table in the appendix shows all of the model results. 81 models were initially created and from these models the best 5 were chosen for further analysis. From these tests we were able to narrow down the most optimal model. Using the information from all of these simulations, the team has been able to create a working design that will be created using a 3D printer and tested using a wind tunnel and torque transducer to measure the rotation rate.

C. Physical Testing

After the optimized housing structure was selected, which consisted of the roof, floor and the stators, it was decided upon by the team to create a 3D model at a 1/20th scale of the full-scale design. Some challenges faced during this process will be how to print such a large model using a printer with a small printable area. This problem was solved by dividing the model into 3 pieces that can be printed individually and then assembled after. The base will be split up into four quarters in an effort to create a clean area for the center shaft and drum to be located. The attachment of the stators also poses a problem. The stators need to be recessed in to the base to give them strength when testing, but sufficient material must be left in the base to prevent issues. To solve this, extra material will be printed first to give the entire model a base layer. The housing structure will be able to be pieced and fastened together so that it is structurally sound when completed. The methods for connecting the shaft and drum are unclear at this time but the model needs to incorporate places for bearings and the center shaft. Below are the 3 components that will be printed in the correct quantity in order to fully assemble the model.

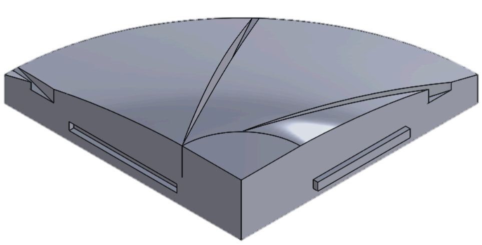

Figure 3: SolidWorks® floor component to be printed 4 times in order to create the floor.

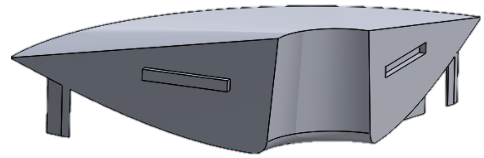

Figure 4: SolidWorks® roof component to be printed 4 times in order to create the roof.

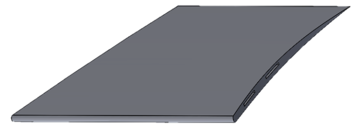

Figure 5: SolidWorks® stator component to be printed 8 times.

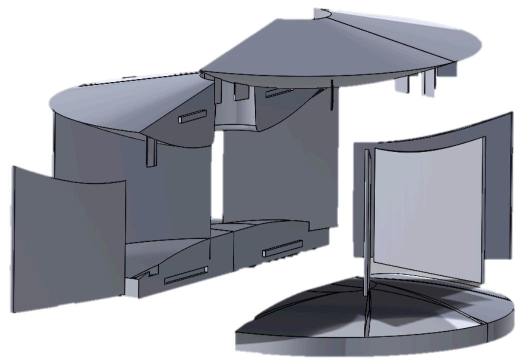

Figure 6: Exploded view of assembly of components. The roof and floor will be permanently secured together using contact cement and the stators will be able to be removed in order for the model to be taken apart if changes are needed to be made.

Along with the housing structure, a number of designs for the drum and vane configurations will also be 3D printed. These drums will have the capability of being removed from the rest of the housing structure in such a way that they will be able to spin freely and simulate the full-scale model. Each of these full turbine assemblies will be tested in a wind tunnel at the fifteen miles per hour. This will allow the team to be able to measure the torque on the physical model and compare it to the expected values from the simulations. The test will be conducted with a torque transducer attached to the drum that will measure the torque that is generated as the shaft is spun by turbine.

The team will also be conducting smoke testing to observe how each design allows for the air to flow through the whole structure. The team will use a fog generator to create and push the fog in through the stators as the wind would. The team will be able to observe the fog as it travels through the structure, looking for potential change that could not be seen in the SolidWorks® CFD analysis.

Using the torque measurements and observations from the smoke testing, the team will be able to make a decision on which of the vane and drum configurations is the best for generating the greatest amount of power. The conclusion of this testing will allow the team to have a fully optimized model that will be presented to the client in order begin full scale production.

D. Full Scale Modeling

The client proposed that this 3D printing stage only be taken as a small step in moving forward. When considering the effects due to small scale modeling where the Reynolds number would not be the same, he proposed that we move towards the full scale as soon as possible. Currently the team is deriving an equation which can be applied to any model that requires a specifically sized generator. The goal of this derivation is to be able to use SolidWorks® to find the scale from the 100 kilowatt that will accommodate any smaller generator. The dimensions of the smaller housing structure for a 5 kilowatt generator are currently unknown but once the equations for determining the factors which effect the power output of a model is found then SolidWorks® will be used to find the exact dimensions that will best suit a 5 kilowatt generator. The advantage of creating different sized housing structures is that it will allow more consumers to be included in the scope of application. Being able to create a range of models for different sized generators will allow potential consumers to apply a specific model to whatever the see is best suited for their needs.

III. Looking Forward

The team plans on giving back to the Roger Williams University community by transferring the power generated by the wind turbine to the electric car charging stations on campus or by transferring the power generated to power the lights for the parking garage and lot below. The team feels that it is important to support the Roger Williams University community.

A. Materials

The entire housing structure of the wind turbine in the final model, including the stationary stators, will be made out of fiber glass. The goal was to have a lightweight and cheap material that is also very strong and readily available. Fiber glass is typically low in brittleness which is also a deciding factor since pitting can occur on the stationary stators over time. Fiber glass will also allow for easy repairs if the housing structure is ever damaged by outside debris that may come into contact with the unit. With fiber glass being lightweight and easily molded; production and maintenance will be simple. The drum that is connected to the generator and holds the stators is to be made of carbon fiber. Carbon fiber is lighter and stronger than steel making it the ideal material for the team to use for the rotating region of the turbine. While somewhat more expensive it would require less material due to its strength and would make balancing the drum less difficult.

However, for the first coming prototypes the client had suggested making the models out of a sheet metal in order to save time and money. The client believes that the model that we present him with will only be a prototype and there will most likely be minor changes that are made in order to accommodate any changes that will optimize the model more.

B. Physical and Elemental Loads

The overall weight of the wind turbine will affect the placement on the RWU Campus. Not only will the overall weight of the wind turbine be taken into account but also the live and dead loads created by snow and wind conditions on the campus. These loads will be calculated as the design is finalized.

C. Placement

The optimal spot for placement of the wind turbine on campus is the top deck of the parking garage on the north end of the campus. The turbine will sit on a covered truss-like structure in order to help reduce many complications with attaching structures to roofs. The structure will reduce the vibrations transferred to the garage and eliminate the need to directly attach the turbine to the roof. This deck will create a watertight seal around the base which will help benefit the attachment of this unit to any roof. The cite selection will allow the most access for students and faculty to see and conduct any experiments, testing, and data collection. Having the turbine in a public area will also provide great access for potential clients who wish to see the wind turbine design and its functionality. This spot selection was also selected based off of the prevailing winds at RWU. Most wind comes from the north and south in this location and the parking structure will allow for undisturbed airflow as wind passes over the parking structure

Acknowledgement

Thanks to Dr. Thomas and Dr. Gupta for their support throughout the project. They were an essential component in our success. They were able to aid the team in making the correct decisions prior to being made. Also a thanks to Dr. Ruocco for helping manage the side portions of the project. With his help we were able to direct our paper and poster in the right direction. Finally a special thanks to Rob Baxter and Bill Gardner of CBC LLC for supporting this project financially. Their input and ideas helped guide the team in the right direction to best meet their specifications. Without their help the team would not have been able to complete this much of the project. Rob Baxter and Bill Gardner have been very open to helping the team as much as possible and it has greatly helped the team in the process of achieving our goal.

CBC LLC

APPENDIX

Table 2: CFD results from initial model testing. The colors represent the value of the wind speed compared to all models. This table was used in order to select the most optimal models. From this we were able to retest these models with different tolerances in the measurements.

	Velocity Results(mph) Ambient Wind Speed 15mph								
	8 Stator								
	1	2	3	4	5	6	7	8	9
G	21.678	24.594	22.459	22.312	22.801	22.331	21.328	22.919	22.245
H	22.005	22.223	22.640	21.972	22.049	23.055	23.655	22.818	22.417
I	21.602	22.805	22.590	21.845	22.841	22.710	21.827	22.774	22.675
	10 Stator								
	1	2	3	4	5	6	7	8	9
G	21.634	21.149	20.174	22.002	21.206	19.963	21.829	21.049	19.898
H	22.733	21.408	20.202	22.330	21.488	19.773	22.474	20.143	20.120
I	20.038	24.544	19.983	20.564	20.246	19.700	19.993	20.269	20.118
	12 Stator								
	1	2	3	4	5	6	7	8	9
G	23.652	22.813	21.012	23.751	22.846	20.897	23.061	21.980	20.791
H	22.160	22.579	23.188	22.452	22.295	21.675	23.263	22.657	22.218
I	20.259	20.654	20.076	20.273	20.336	19.977	20.895	21.265	20.245