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Comparative Study of Custom-constructed Wind Augmentation Shrouds on a Small-scale Wind Turbine (Work in Progress)

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My name is Marija Dimitrovska and I am from Skopje, Macedonia. I am a 20 year old graduate student at Texas A&M University-Kingsville. I received a Bachelors of Business Administration in Information Systems, graduating within 3 years from Texas A&M University-Kingsville. Currently I am working on my Masters of Science in Industrial Management. Being a tennis player, I was awarded a scholarship to come and play for Texas A&M University-Kingsville. I have been playing for the school for 4 years and next year I am going to be a graduate tennis assistant while I am finishing my Masters classes. I graduated with my Bachelors with a 4.0 GPA and was awarded with the President's List every semester. I also received the Undergraduate Distinguished Student Award for 2015, and was a part of the Honors College. Other than academic awards, I also received the Capital One Academic All-American Award, and ITA Scholar Athlete award, being a tennis player for Texas A&M University-Kingsville.

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Abstract

With the depleting resources of non-renewables more studies are focusing on the efficiency of the wind power generation. Previous work suggests that the wind shrouding devices have potential in improving the efficiency (Kosasih & Tondelli, 2012; Dakeev, 2011, 2014). However, various studies with different designed shrouds reported different results. The purpose of this study is to involve graduate students with different undergraduate majors to design, construct, identify the optimal design, analyze and compare previously reported work to the optimal wind shrouding device.

Wind shrouding experiments are conducted to investigate the influences of two custom-constructed wind augmentation devices: cone-shaped wind guide and a flanged diffuser shroud. A group of Industrial Technology students will develop both diffuser shrouds that will collect and accelerate the incoming wind. The tests will be carried out for three wind velocities (5 mph to 15 mph) in a laboratory setting to compare the influences of two shrouding devices on the power output. A small scale horizontal axis wind turbine will be used with 400 Watt power rating. The study will report the comparative measurements performed on an experimental small-scale wind turbine attached for both shrouding devices.

Introduction

Large scale wind shrouding devices are expensive to build and maintain, however, if used properly, the wind power is great source of renewable energy that gives the incentive to work on improving the technology (Foote, 2011). A recent study with a cone shaped wind guide system inside the shrouding resulted in more than 60% power outcome compared to a conventional bare wind turbine (Dakeev, 2014). Additionally, researchers reported that the wind augmentation device significantly influences power generation (Kosasih & Tondelli, 2012; Dakeev, 2011).

The Betz Law states that no wind turbine can capture more than 59.3% of the kinetic energy in wind (Betz, 1966). Utility scale wind turbines achieve approximately 75% to 80% of the Betz limit at their peak (Burton, 2001). Although Betz Law limits the wind turbines from producing no more than 59.3% Hansen (2000) reported that enclosing the wind turbine within the shroud can improve the power generation beyond the Betz limit (Hansen, 2000). The purpose of this study is to design and construct the optimal wind shrouding device to amplify the incoming wind velocity for more efficient power generation. The engineering students from different undergraduate backgrounds constructed four custom designed wind augmentation devices to investigate the potential wind increase. For example, one of the students with business background was involved in the 3D modeling and 3D printing, building the device in the laboratory, collecting the data, as well as data analysis using IBM's SPSS tool.

Literature Review

Constantly changing wind velocities require building a dynamic wind shroud with sensors to determine the optimal relationship between wind velocity and angle wind shrouding adjusts to for better power generation. However, determination of the optimal design of the wind augmentation device plays a crucial role on the efficiency of power generation. Ohya and Karasudari developed a collection-acceleration device for wind in 2010, which was a diffuser shroud equipped with brim, called wind – lens (Ohya & Karasudari, 2010). They tested two types of hollow-structure models; a nozzle, and a diffuser type. Their experiments revealed that the diffuser-shaped structure could accelerate the wind at the inlet. Another research in 2014 reported that the power generated by an experimental small-scale wind turbine increased more than 60% (Dakeev, 2014) when the shroud was introduced. The researcher tested and analyzed the wind shrouding to evaluate the performance of the wind turbine at various wind velocities. Dakeev and his team concluded that power generation significantly increased with the wind shrouding system (Dakeev, 2014; Dakeev & Mazumder, 2015). Additionally, Tondelli and Kosasih in 2012 approached the wind shrouding with a different design. They added a flange to the exit of the diffuser and suggested the brim design should be incorporated in the shroud designs (Kosiah & Tondelli, 2012). This paper discusses how various designs of the shrouds can affect the wind velocity at the inlet and the outlet of the wind augmentation devices.

Methodology

The study involves both testing and analyzing the custom designed wind augmentation devices (Figure 1) to evaluate the efficiency of air flow. Three students from mechanical engineering, civil engineering and business administration teamed up to develop the specified designs. For the phase one, the designs of three shrouds, 20^0, 25^0, and 30^0, were 3D printed to investigate the wind velocity change between inlet and the outlet. All three students developed the three dimensional models for 3D printing. Mechanical, and the civil engineering students constructed the remaining cylindrical shape from the sheet metal with the assistance of the thirds student with business background.

Figure 1: Construction of wind augmentation devices (Civil Engineering Student)

A miniature blower, with the outlet diameter of 7 inches, was utilized to produce an artificial wind in a closed environment as shown in Figure 1. A total number of 90 readings from the anemometer were collected in the laboratory setting for all three designs as illustrated in Figure 2 below. The Industrial Technology students, from various undergraduate backgrounds, collected the wind speed readings to transfer the collected data to IBM's SPSS for One Way ANOVA test.

Figure 2: Wind Speed Data collection (students with Civil and Mechanical Engineering backgrounds)

The phase two compared a custom constructed wind shroud with a flange at the exit of the device with the most optimal design previously designed. In other words, the researchers identified the most optimal design for the wind shroud during the phase one and added a flange to the same shroud to collect wind data (Figure 3). Collected data was sent to SPSS for t-Test analysis to compare the flange design wind readings with the proven design from phase one. For the phases 1 and 2, the students with different undergraduate backgrounds needed to learn SPSS. As they learned t-Test or One Way ANOVA analyses, they discussed as a team to report the interpretations of the collected data.

Figure 3: Wind Speed Data collection

Figure 4 below illustrates the comparison of average wind velocities with and without the use of custom constructed wind shrouds. Additionally the Figure 4 compares the average wind velocity output of the flanged shroud with the rest of the designs. The 30 observations for each of the designs, with wind velocity ranging from 18 mph to 33 mph is also presented in Figure 4.

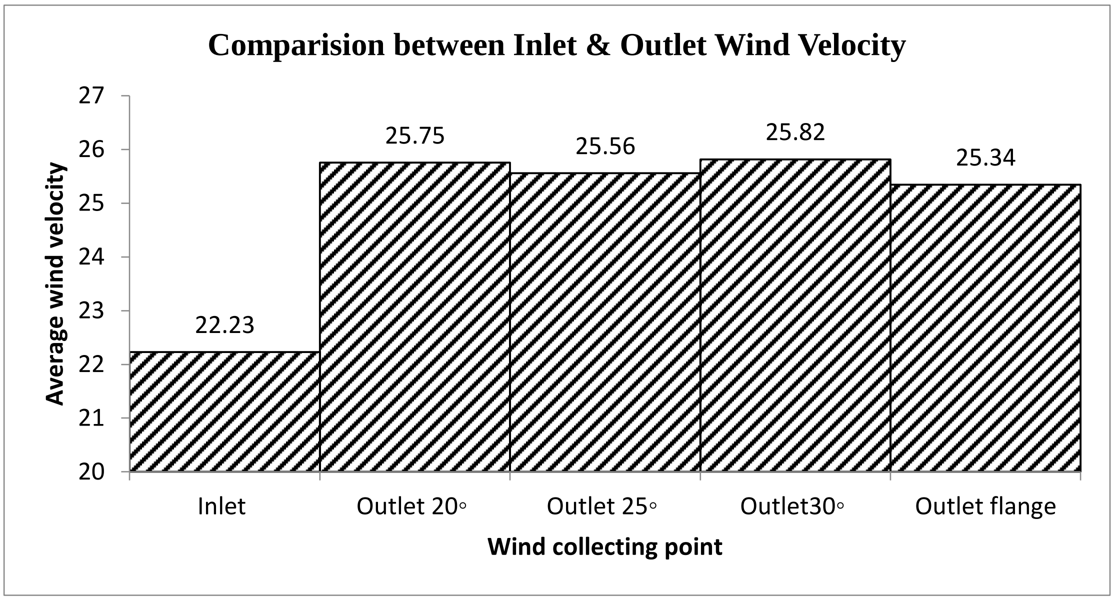

Figure 4: Average Wind Velocity Comparison for various experimental setup

Data Analysis

Collected wind velocity data was analyzed using IBM's SPSS software for One Way ANOVA and the t-Test for phases one and two respectively. The independent variable, the inlet velocity, was compared with the outlet wind speeds for all three designs 20^0, 25^0, and 30^0 as well as the flanged shrouding design.

The descriptive statistics in the Table 1 below shows that the mean values of the output velocities were higher for the shroud with 30 degrees (N=30, Mean=25.81) than the other shrouds (20^0: N=30, Mean=25.75, $25^{0:}$ N=30, Mean= 25.55), which means the 30^0 shroud has successfully achieved the max efficiency in producing a higher output wind flow.

Table 1: Descriptive Statistics, Incoming vs Outgoing Wind Velocity

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Intake speed	30	22.2273	1.90539	.34787	21.5158	22.9388	17.77	27.42
outlet 20degrees	30	25.7513	1.87303	.34197	25.0519	26.4507	21.87	30.82
outlet 25 degrees	30	25.5557	1.90782	.34832	24.8433	26.2681	21.49	31.67
outlet 30 degrees	30	25.8160	1.90855	.34845	25.1033	26.5287	22.30	33.37
Total	120	24.8376	2.41120	.22011	24.4017	25.2734	17.77	33.37

Table 2 illustrates the One Way ANOVA test results from SPSS for three custom constructed wind shrouds. The statistical analysis was conducted to observe whether there is any significant difference in the output wind velocities for different angled shrouds when the inlet velocity was constant. The statistical test shows that there is a significant difference ($p=0.00<0.05$) between 20, 25, and 30 degrees of shrouds.

Table 2: SPSS ANOVA Output, Inlet vs Outlet Wind Velocity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	273.639	3	91.213	25.300	.000
Within Groups	418.211	116	3.605		
Total	691.850	119			

The Tukey analysis drew further conclusions to determine the shroud with the maximum significant difference in the means of inlet and outlet wind data. Table 3 below shows that there is a maximum mean difference (MD=3.58) in wind speeds for the 30^0 shroud and the intake, meaning that 30^0 design achieved the maximum efficiency and could produce higher output wind flow.

Table 3: Tukey HSD Multiple Comparison

POST HOC TEST

Multiple Comparisons

Dependent Variable: velocities

Tukey HSD

(I) inlet outlet		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intake speed	outlet 20degrees	-3.52400*	.49026	.000	-4.8019	-2.2461
	outlet 25 degrees	-3.32833*	.49026	.000	-4.6063	-2.0504
	outlet 30 degrees	-3.58867*	.49026	.000	-4.8666	-2.3107
outlet 20degrees	Intake speed	3.52400*	.49026	.000	2.2461	4.8019
	outlet 25 degrees	.19567	.49026	.978	-1.0823	1.4736
	outlet 30 degrees	-.06467	.49026	.999	-1.3426	1.2133
outlet 25 degrees	Intake speed	3.32833*	.49026	.000	2.0504	4.6063
	outlet 20degrees	-.19567	.49026	.978	-1.4736	1.0823
	outlet 30 degrees	-.26033	.49026	.951	-1.5383	1.0176
outlet 30 degrees	Intake speed	3.58867*	.49026	.000	2.3107	4.8666
	outlet 20degrees	.06467	.49026	.999	-1.2133	1.3426
	outlet 25 degrees	.26033	.49026	.951	-1.0176	1.5383

*. The mean difference is significant at the 0.05 level.

The second phase of the analysis was to introduce the flange to the custom wind shrouding (Figure 3). Twenty degree shroud was selected to compare the wind speed outcomes between the flanged design and without flange. Since the researchers already had 20^0 design wind data, the flange was constructed on top of the 20^0 design shroud. Constant intake wind velocity experiment was repeated 30 times to collect readings from the flanged diffuser.

Table 4: Descriptive Statistics for Flange and Without Flange Diffusers

Group Statistics

Shroud Type		N	Mean	Std. Deviation	Std. Error Mean
Wind Velocity	Without Flange	30	25.81	1.90	.34
	With Flange	30	25.34	2.53	.46

Table 5: Independent Sample t-Test for Flanged and Without Flange

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Wind Velocity	Equal variances assumed	4.46	.039	.817	58	.417	.47	.57	-.68	1.63
	Equal variances not assumed			.817	53.84	.417	.47	.57	-.68	1.63

A t-Test comparative analysis (Table 5) revealed that there is no significant difference between the wind velocity data at the exit of the shrouds ($p=0.417>0.05$ alpha level). The descriptive statistics in Table 4 shows that outgoing wind velocity means are very close to each other (Mean without Flange=25.81, Mean with Flange=25.34). Therefore the phase 2 of this study did not reveal any significant difference between the wind velocity output means when the flange introduced.

Conclusion

The purpose of this study was to investigate the optimal design for wind augmentation devices. The researcher developed three designs with various inlet angles for comparison reasons. Additionally a flange was introduced to a diffuser to investigate if there was a significant difference when the flange had been introduced. One way ANOVA test resulted that the 30^0 angled shroud was increasing wind velocity significantly differently compared to the inlet wind velocity. Moreover, the 30 degree shroud was the most efficient with the highest mean values of wind speeds at the exit of the shroud. However, all of the designs (20, 25, and 30) were capable of increasing the wind velocity significantly. On the other hand, the flanged diffuser did not reveal significant difference in mean wind speeds when compared to a regular 20^0 degree design. This study was beneficial to the involved students with different undergraduate majors (mechanical, civil and business). The masters' students in Industrial Management learned a 3D modeling tool, 3D printed the designed products, and collected the data. Additionally, the students learned how to accurately interpret the statistically analyzed data and present it in both written and oral forms. The leading faculty believes that presenting the outcomes of this study in ASEE 2016 the students will gain further interest and motivation for the research.

Future work

The analyses of various shroud designs revealed important information on the future construction of the shroud. Although the abstract initially said a wind turbine would be included to investigate the power generation with the shrouds the custom constructed designs were too small to test with the 400W rating wind turbine. The researchers will be developing a custom shroud with 30^0 angle to investigate the power generation by a small scale wind turbine. The next phase of the study will include constructing a bigger scale wind shroud with 45-50 diameter outlet for 400W to 1.2kW wind turbine. The outcomes of the next study will be reported in various conferences/publications.

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