Principles of Wind Energy Production

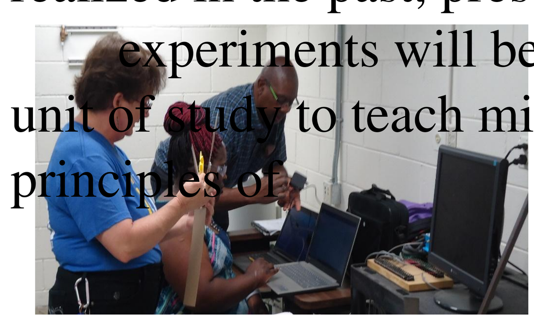
Willie Haynes, Dianne Lhotte, Johnetta Moore; *Valentin Soloui*[1], *Mosfequr Rahman*[2], *Relwinde Zongo*[3], *Timothy Chastain*[4],

1. Allen E. Paulson Distinguished Chair of Renewable Energy 2. Assistant Professor 3. Graduate Teaching Assistant 4. Undergraduate Student

NSF-RET (Award #1609524) , Georgia Southern University

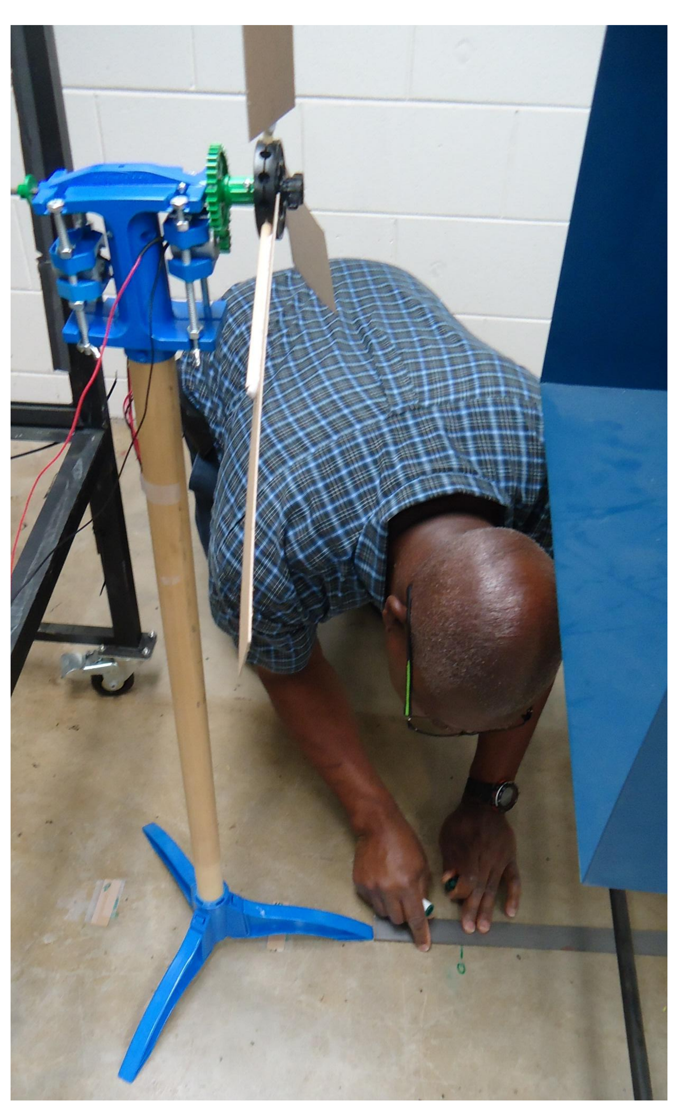
INTRODUCTION

Three public school teachers designed basic wind turbine energy production tests to help them teach wind energy principles to middle and high school students. Variables affecting wind turbine energy production were identified (distance from wind tunnel, blade design, angle of attack, and wind speed), and experiments were conducted to test each variable. This research aligns with Georgia DOE curriculum standard STEM-FET-3.7: Apply STEM knowledge and skills through hands-on research and lab experiments that are focused upon recreating the inventions and social solutions that were realized in the past, present, and possible future. These experiments will be a part of an instructional unit of study to teach middle and high school students the principles of wind turbine energy production.



METHODS

Four straight, untwisted turbine blade designs were tested for energy output. Researchers designed three blade shapes and kept one blade unaltered as a control, resulting in four different blade profiles (images 1-4). Using a commercial wind turbine testing kit manufactured by KidWind, wind tunnel tests of all four blades were conducted using a hub with three equidistantly spaced blades at a constant wind speed of 3 meters squared (tested and verified by anemometer) for all tests, with three trials for each blade. A variable motor resistance on a potentiometer in this circuit of nine ohms was set and maintained for all blade tests. Four angles of attack (10 degrees, 15 degrees, 30 degrees and 60 degrees of blade tilt) were tested for each blade, at three distances from the wind tunnel opening (10 inches, 20 inches, and 30 inches). Data was collected using a Vernier Energy Sensor and Logger Pro 3 software. The same setup was also used for the testing of the four experimental blades at a wind speed of 4 meters squared, verified by hand-held anemometer readings. Circuit resistance settings varied for each blade, but were consistent through all three trials for each individual blade. Blade 1 was tested at 30-32 ohms, blade 2 and blade 3 were tested at 28-29 ohms of resistance.



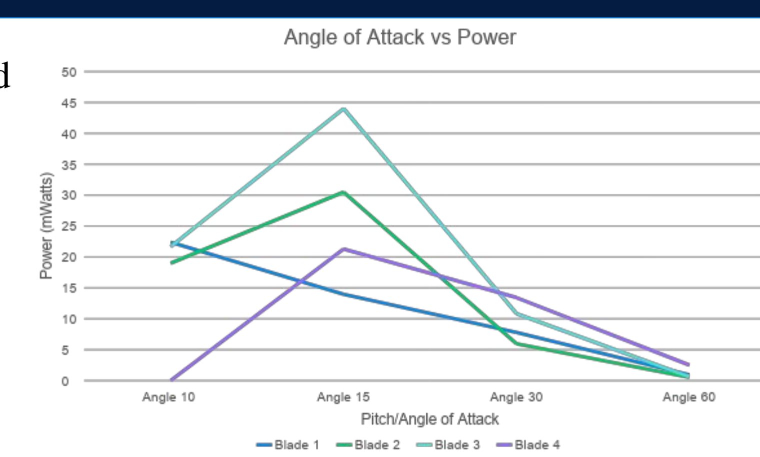
FIGURES OR TABLES

Research Question 1: Overall, the collected data showed that turbine setup distance from the wind turbine did not significantly affect the power output. At the same pitch, all four blades registered consistent power output regardless of the distance of the setup from the wind tunnel, with a few outlier readings that were discounted for vagaries in the equipment.

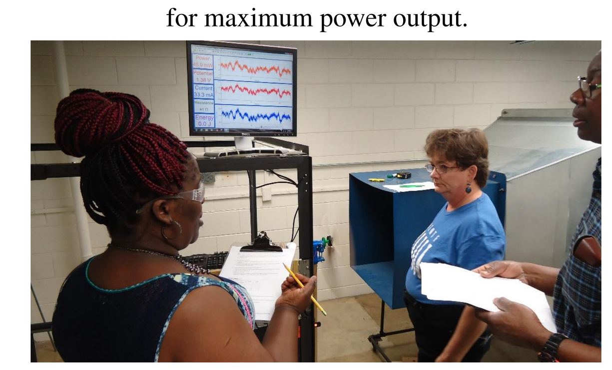
Research Question 2. For the second research question, the collected data showed that blade design did have a significant effect on energy output. The control blade 3 (which had the greatest area) recorded the largest energy output readings of all four experimental blade designs, with output readings falling as blades with smaller surface areas were tested. Blade 4, with the smallest surface area, recorded the smallest energy output readings of all experimental blades at comparative blade pitch settings.

Research Question 3. The third question identified an optimal angle of attack, or pitch, for each blade that varied depending on experimental blade, from 10 to 15 degrees, not supporting the expected result that higher angles of attack would result in lower energy output readings. However, pitch settings in excess of 15 degrees did result in significantly lower energy output readings, confirming an inverse ratio of energy production with increased angles of attack.

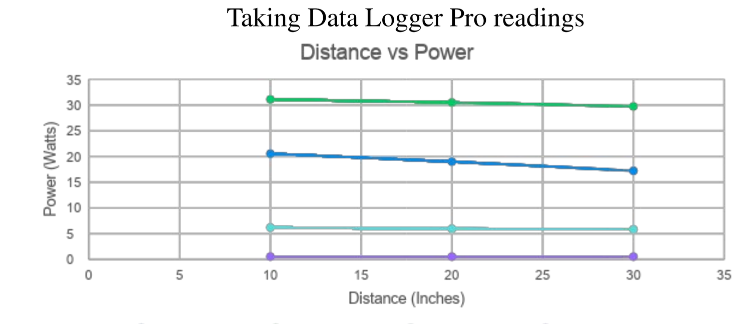
Research Question 4. For research question four, tested energy output readings supported the expected outcome of increased energy production at greater wind speed, even at a blade pitch that proved less optimal at lower wind speed.



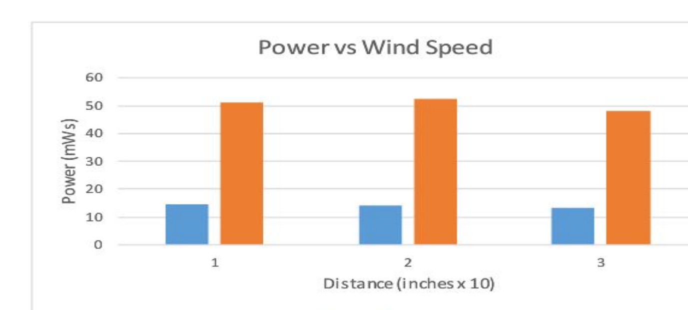
Data on all four test blades indicating optimal angle of attack (15°) for maximum power output.



Taking Data Logger Pro readings



Data on all four test blades, showing equivalent power output regardless of distance from wind tunnel.



Power comparisons: 3M2 and 4M2

Blade #1-Designer Willie Haynes

Distance (inches)	Blade Angle (degrees)				Power (mWs)Avg, windspeed 3m/s 10	15	30	60
10	10	15	30	60	23.584	14.374	8.23	.991
20	10	15	30	60	22.374	13.959	7.777	.9589
30	10	15	30	60	22.98	13.318	7.257	.984

Blade #2- Designer Johnetta D. Moore

Distance (inches)	Blade Angle (degrees)				Power (mWs)			
10	10	15	30	60	20.558	31.122	6.195	0.535
20	10	15	30	60	18.999	30.505	5.951	0.531
30	10	15	30	60	17.223	29.752	5.846	0.529

Blade #3-CONTROL (Control- no design at all remained the same)

Distance (inches)	Blade Angle (degrees)				Power (mWs)Avg 10	15	30	60
10	10	15	30	60	70.367	43.830	11.643	0.632
20	10	15	30	60	21.654	44.019	10.838	0.637
30	10	15	30	60	54.685	84.230	12.103	0.619

Blade #4- Designer Dianne Lhotte

Distance (inches)	Blade Angle (degrees)				Power (mWs)Avg 10	15	30	60
10	10	15	30	60	N/A	33.560	13.562	2.278
20	10	15	30	60	N/A	21.292	13.424	2.529
30	10	15	30	60	N/A	21.154	11.464	1.185

Energy output per blade at varying distances and angles of attack at 3M2 wind speed.

Blade 1 – Measurements were 11 inches long, 2.5 inches at the base, and 5/8 inch at the tip. Blade 1 proved the optimum blade of all for the experiment.

Blade 2 - Measurements were 11 long, ~2.5 inches at the base, and 1 inch at the tip

Blade 3 – The control blade: nothing was done to alter the blade from its original design. The measurements were 11 inches long, by 3 inches (width).

Blade 4 - Measurements were 11 inches long, 1.5 inches at the base, and 1/8 inch at the tip.

RESULTS

The results of experiemnts on basic wind principles supported researchers' expectations. These replications of historic experiments were determined to be necessary for students to recreate to understand how wind turbines work. These principles and experiments will be incorporated into future instructional strategies for students.

DISCUSSION

Analysis of data support expected outcomes, which recreate previous historical research on basic wind turbine function. This research supports the Georgia DOE curriculum standard for replicating previous research to validate reliability of results.

CONCLUSIONS

Data determined that distance from the wind tunnel for experimental turbine setup did not have an appreciable effect upon the recorded energy output of a straight, non-twisted turbine blade design at any blade pitch.

Data demonstrated that blade design did have a significant effect on energy production. Blades with greater surface area generated greater energy production. Depending on blade design, blade angle of attack (or pitch), did have a significant effect on recorded energy output of experimental turbine setup. The optimal angle of attack that was tested was shown to be 15 degrees of pitch.

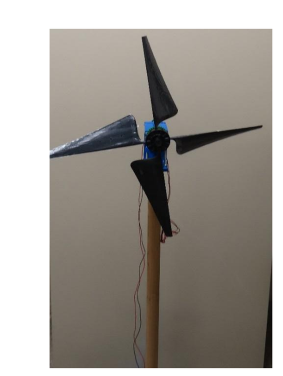
Additionally, data determined that blade energy output increased at higher wind speeds, this effect proving to be consistent over all tests.

FUTURE RESEARCH DIRECTION

Future testing on the effect of additional or fewer blades since all tests were conducted with three blades (see C, D) on energy production would be suggested, as well as testing energy production using blade designs in a vertical axis configuration (see A, B) since all tests were conducted with horizontal axis configuration).

A

B



C

D

REFERENCES

Chamorro, Leonardo P.; Porte-Agel, Fernando. (23 April 2009). A Wind tunnel Investigation of Wind-Turbine Wakes: Boundary-Layer Turbulence Effects. Boundary-Layer Meterology July 2009, 132:1, pp. 129-149.

Lei, Ma; Shiyan, Luan; Chuanwen, Jiang; Honliong, Liu; Zhang, Yan. (May 2009). A Review on the Forecasting of Wind Speed & Generated Power. *Renewable and Sustainable Energy Reviews*, 13:4, pp 915-920. doi.org/10.1016/j.reser.2008.02.002

Jeffrey, Roy D.; Krough, Carmen; Horner, Brett. (May 2013). Adverse Health Effects of Industrial Wind Turbines. Canadian Family Physician, 59:5, pp. 473-475. PMCID: PMC3653647

Shen, Zin; Yang, Hong; Chen, Jinge; Zhu, Xiaocheng; Du, Zhaohui. (July 2016). Aerodynamic Shape Optimization of non-Straight Small Wind Turbine Blades. *Energy Conservation & Management*, 119:1, pp. 266-278. doi.org/10.1016/j.enconman.2016.04.008

Thumthae, Chalothorn; Chitsomboon, Tawit. (20 November 2008). Optimal Angle of Attack for Untwisted Blade Wind Turbine. *Renewable Energy* 34:2009 pp. 1279-1284. Retrieved from https://www.deepdyve.com/lp/elsevier/optimal-angle-of-attack-for-untwisted-blade-wind-turbine-4SDuOXVGjy

Walford, Christopher A. (March, 2006). Wind Turbine Reliability: Understanding and Minimizing Wind Turbine Operation and Maintenance Costs. Global Energy Concepts. Retrieved from prod.sandia.gov/techlib/access-control.cgi/2006/061100.pdf

Yurdusev, M.A.; Ata, R.; Cetin, N.S. (September 2006). Assessment of Optimum Tip Speed Ratio in Wind Turbines Using Artificial Neural Networks. Energy, 31:12, pp. 2153-2161. doi.org/101016/j.energy.2005.09.007