Bioinspired Wind Turbine Blades

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New Flight Albatross Energy

Mission

Objective: Develop and validate bio-inspired airfoil designs based on albatross bird for wind turbine blades.

Goals:
- Increase torque output.
- Reduce mechanical stress.
- Enhance energy capture for residential and commercial use.

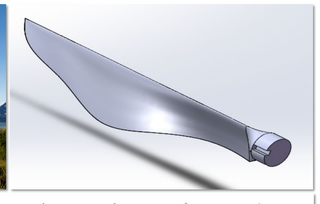
Methods:
- Test albatross airfoil blades via wind tunnel testing.
- Additive manufacture of blades for full-scale testing and validation
- Compare performance with simulation data.

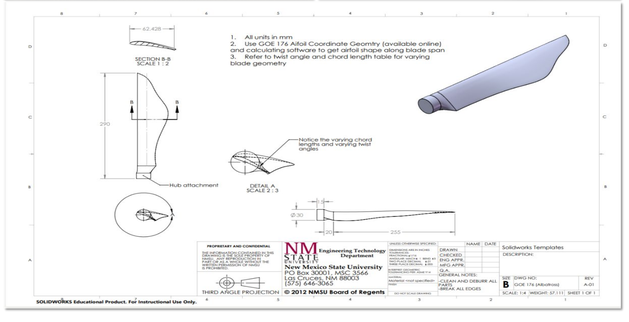
Outcome: Demonstrate how bio-inspired designs can lead to more efficient wind energy systems.

Research

Preliminary Research
- Explored multiple ways to improve adaptiveness surface texture, and geometry of wind turbine blades.
- Used university resource articles and client guidance from previous bio-inspired airfoil simulations.
- Albatross airfoil selected for favorable aerodynamic performance, aligning with the client's findings.

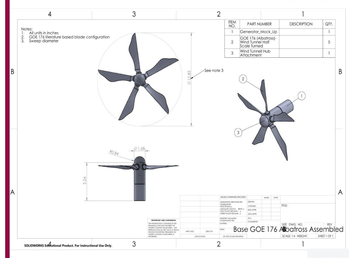
Our Research Focus:
- Focus is to improve aerodynamic efficiency in small scale wind turbines for residential and commercial buildings.
- Research was done through simulation validation, additive manufacturing of complex geometries, wind tunnel testing, and full-scale testing.



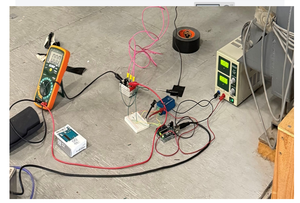


Final Design

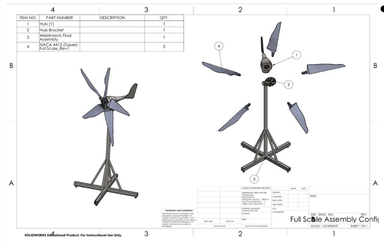
Wind Tunnel



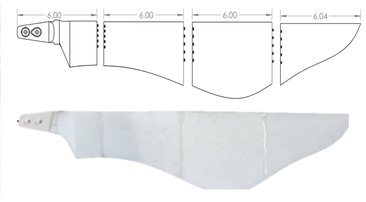
- Scaled sweep diameter sized to avoid wind tunnel blockage.
- Wire setup configured to torque sensor and generator for data log.

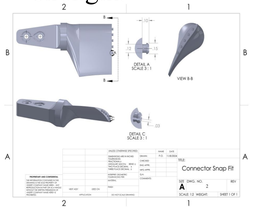


Full Scale

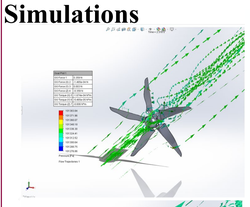


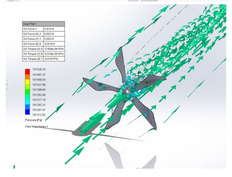
- Full-scale assembly uses manufactured stand, off-the-shelf generator, and SLS-printed blade sections snap-fitted and epoxied for strength.





Simulations



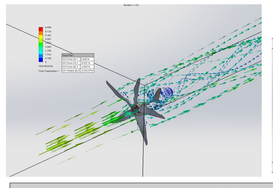


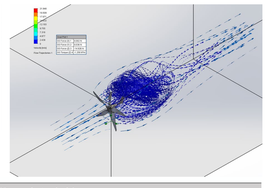
Static	RPM = 0		
V = 4 m/s	NACA 4412	Albatross	Tapered
Force (N)	0.22	0.23	0.225
Torque (Nm)	0.005	0.005	0.005

V = 8 m/s	NACA 4412	Albatross	Tapered
Force (N)	0.881	0.919	0.902
Torque (Nm)	0.019	0.019	0.019

Rotational	RPM = 300		
V = 4 m/s	NACA 4412	Albatross	Tapered
Force (N)	0.359	0.383	0.358
Torque (Nm)	0.008	0.008	0.008

V = 8 m/s	NACA 4412	Albatross	Tapered
Force (N)	1.047	1.107	1.053
Torque (Nm)	0.024	0.024	0.023





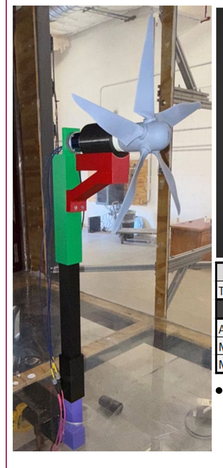
Rotating Forces (Dynamic Analysis)			
	NACA 4412	GOE 176 (Taper)	GOE 176 (Research Paper)
Force Z (N)	-14.296	-14.177	-14.425
Torque Z (Nm)	-1.256	-1.088	-1.008
Surface Force (N)			-2.738

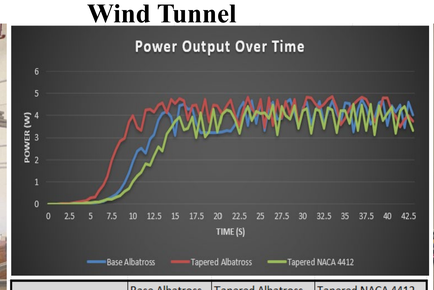
Static Results			
	NACA 4412	GOE 176 (Taper)	GOE 176 (Research Paper)
Force Z (N)	-3.543	-3.627	-3.794
Torque Z (Nm)	-0.332	-0.3	-0.306

- Flow simulations visualize aerodynamic efficiency, showing wake dynamics and velocity. Differences in flow patterns highlight blade performance and the resulting torque and thrust can be compared

Test and Results

Wind Tunnel

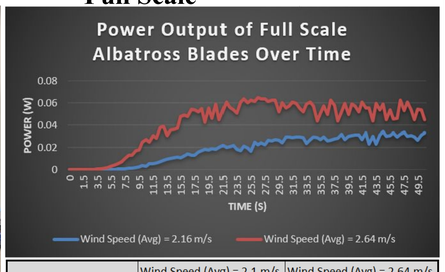




	Base Albatross	Tapered Albatross	Tapered NACA 4412
Time to Develop (s)	13	9.5	15
Onced Developed			
Average Power (W)	4.03619216	4.267517241	3.968456145
Maximum Power (W)	4.740871081	4.873994604	4.549460425
Minimum Power (W)	3.1031361	3.320736525	3.01311027

- Tapered Albatross generates highest average and max power, with faster power development.

Full Scale



	Wind Speed (Avg) = 2.1 m/s	Wind Speed (Avg) = 2.64 m/s
Time to Develop (s)	30	17
Onced Developed		
Average Power (W)	0.030	0.055
Maximum Power (W)	0.035	0.065
Minimum Power (W)	0.023	0.042

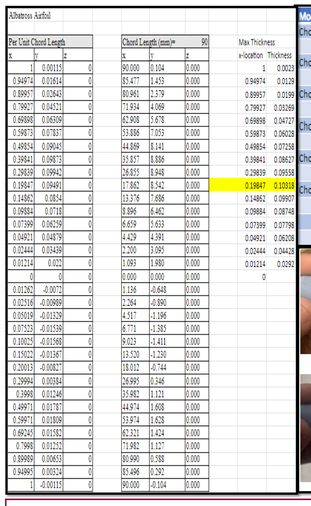
- High resistance resulted in low power. Low wind speed differences create relatively large increases in output.

Concept Development

Initial Concept:
- Began with adaptive wind turbine blades but shifted focus after evaluating feasibility.
- Moved to bioinspired designs, specifically the albatross, due to its ability to glide long distances with minimal energy.

Albatross-Inspired Design:
- The albatross wing was chosen for its aerodynamic efficiency, making it ideal for wind turbine applications. Three blade types were developed:
  - Base albatross blade: Modeled directly based on literature from our client.
  - NACA 4412 tapered blade: A standard airfoil shape and turbine taper for comparison.
  - Albatross-inspired blade: Modeled with a similar taper for fair comparison of airfoil geometries.

Modeling and Comparison:
- Focused on matching surface areas between the NACA 4412 and albatross-inspired blades to enable an accurate comparison of aerodynamic performance.



Albatross Airfoil

Per Unit Chord Length			Chord Length (mm)=	90		Max Thickness	
x	Y	z	x	Y	z	x-location	Thickness
1	0.00115	0	90.000	0.104	0.000	1	0.0023
0.94974	0.01614	0	85.477	1.453	0.000	0.94974	0.0129
0.89957	0.02645	0	80.961	2.379	0.000	0.89957	0.0139
0.79927	0.04321	0	71.934	3.889	0.000	0.79927	0.03269
0.69898	0.06069	0	62.908	5.678	0.000	0.69898	0.04721
0.59873	0.07837	0	53.886	7.053	0.000	0.59873	0.06018
0.49854	0.09045	0	44.869	8.141	0.000	0.49854	0.07158
0.39841	0.09873	0	35.857	8.886	0.000	0.39841	0.08637
0.29839	0.09942	0	26.855	8.948	0.000	0.29839	0.09558
0.19847	0.09491	0	17.862	8.542	0.000	0.19847	0.10318
0.14862	0.0854	0	13.376	7.686	0.000	0.14862	0.09909
0.09884	0.0718	0	8.896	6.462	0.000	0.09884	0.08748
0.07399	0.06259	0	6.659	5.633	0.000	0.07399	0.07786
0.04921	0.04879	0	4.429	4.391	0.000	0.04921	0.06208
0.02444	0.03439	0	2.200	3.095	0.000	0.02444	0.04428
0.01214	0.022	0	1.093	1.980	0.000	0.01214	0.0295
0	0	0	0.000	0.000	0.000	0	
0.01262	-0.0072	0	1.136	-0.648	0.000		
0.02216	-0.00989	0	2.264	-0.890	0.000		
0.05019	-0.01529	0	4.517	-1.198	0.000		
0.07523	-0.01939	0	6.771	-1.385	0.000		
0.10025	-0.01988	0	9.023	-1.411	0.000		
0.15022	-0.01367	0	13.520	-1.230	0.000		
0.20013	-0.00827	0	18.012	-0.744	0.000		
0.29994	0.00384	0	26.995	0.346	0.000		
0.3998	0.01246	0	35.982	1.121	0.000		
0.49971	0.01787	0	44.974	1.608	0.000		
0.59971	0.01809	0	53.974	1.628	0.000		
0.69245	0.01582	0	62.321	1.424	0.000		
0.7998	0.01252	0	71.982	1.127	0.000		
0.89969	0.00653	0	80.990	0.588	0.000		
0.94995	0.00324	0	85.496	0.292	0.000		
1	-0.00115	0	90.000	-0.104	0.000		

Modeling Parameters	GOE 706 (Research Paper)	NACA 4412	GOE 706 (Taper)
Chord length @ 0% [mm]	90	140	140
twist angle	30	30	30
Chord length @ 20% [mm]	90	120	120
twist angle	30	30	30
Chord length @ 40% [mm]	110	110	110
twist angle	15	15	15
Chord length @ 60% [mm]	130	90	90
twist angle	9	9	9
Chord length @ 80% [mm]	80	60	60
twist angle	5	5	5
Chord length @ 100% [mm]	20	20	20
twist angle	2	2	2
Avg Chord	86.66666667	90	90
Surface Areas (mm^2)	48896	48188	47088

Resin Printed Albatross Blade – Unsanded

Resin Printed Albatross Blade - Sanded

References

1. Yossri, W., Ben Ayed, S., & Abdelkefi, A. (2023). Evaluation of the efficiency of bioinspired blade designs for low-speed small-scale wind turbines with the presence of inflow turbulence effects. *Energy*, 273, 127210. Yossrietal-2023.pdf
2. YouTube. (2023, October 3). Wind tunnel blockage ratio explained. YouTube. https://www.youtube.com/watch?v=gope2XIBwA4
3. Bešlagić, E., Lemeš, S., & Hadžikadunić, F. (1970, January 1). Procedure for determining the wind tunnel blockage correction factor. SpringerLink. https://link.springer.com/chapter/10.1007/978-3-030-46817-0_38
4. Bai, J., Zhang, L., Yang, K., Zhao, D., & Xu, J. (2023b, January 16). Interactive effects of wind tunnel sidewalls on flow structures around 2D airfoil model - journal of thermal science. SpringerLink. https://link.springer.com/article/10.1007/s11630-023-1753-7
5. Bai, J., Zhang, L., Yang, K., Zhao, D., & Xu, J. (2023a, January 16). Interactive effects of wind tunnel sidewalls on flow structures around 2D airfoil model - journal of thermal science. SpringerLink. https://link.springer.com/article/10.1007/s11630-023-1753-7
6. Lu, D., Lu, Z., Han, Z., Xu, X., & Huang, Y. (2022c, October 10). Numerical investigation on the effect of blockage on the icing of airfoils. MDPI. https://www.mdpi.com/2226-4310/9/10/587
7. Lu, D., Lu, Z., Han, Z., Xu, X., & Huang, Y. (2022b, October 10). Numerical investigation on the effect of blockage on the icing of airfoils. MDPI. https://www.mdpi.com/2226-4310/9/10/587
8. Lu, D., Lu, Z., Han, Z., Xu, X., & Huang, Y. (2022a, October 10). Numerical investigation on the effect of blockage on the icing of airfoils. MDPI. https://www.mdpi.com/2226-4310/9/10/587
9. SimScale. (2024). *CFD Modeling, Analysis, and Online Simulation For Beginners*. Retrieved from CFD Analysis, Modeling & Simulation For Beginners | SimScale
10. NACA 4412 (NACA4412-IL). (n.d.). NACA 4412 (naca4412-il) (airfoiltools.com)