Final Presentation

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MAE 4272 Fluids and Heat Transfer Laboratory
Prof. Pepiot
411 - Group 2

Design Objectives

Design Variables

Given

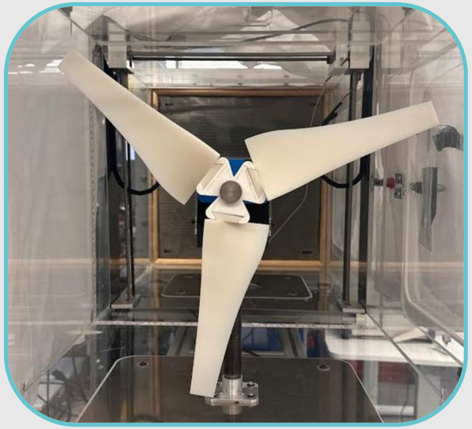
- Radius: ≤ 6” from root to tip
- Hub: 1” radius, dovetail shape

Chosen:

- Angular velocity: 1200 rpm
- Far-field wind velocity: 5 m/s
- NACA 4412

Optimization

Maximum power generation through aerodynamic efficiency



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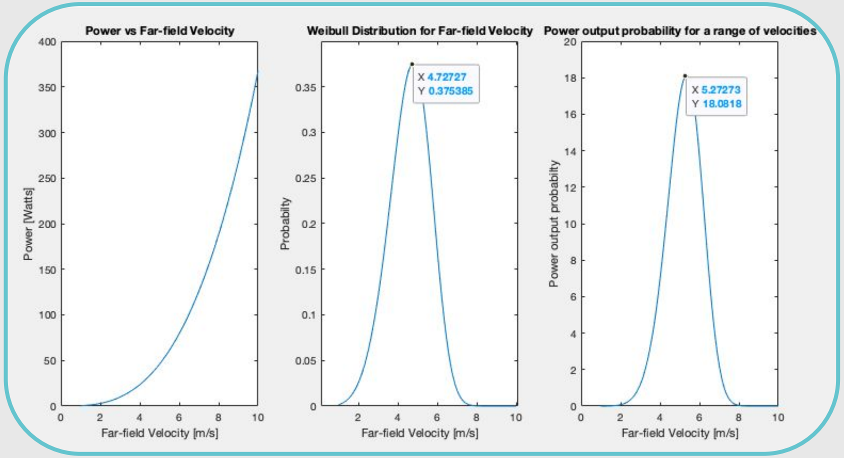
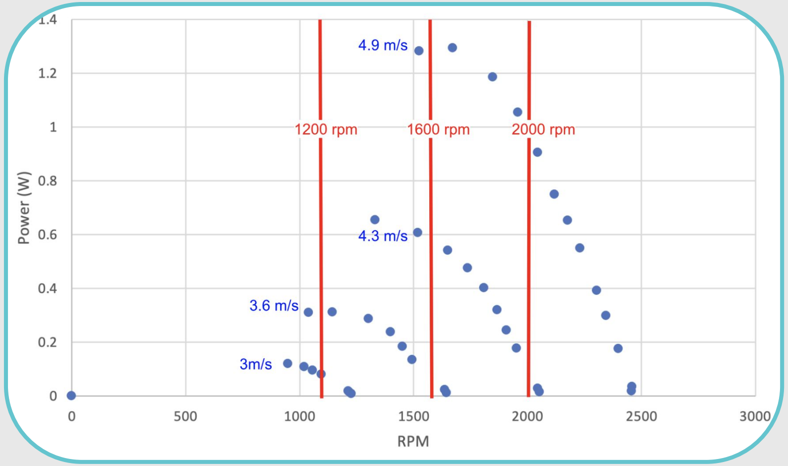
Design Approach

Wind Speed



Speed of most common power output using Weibull distribution

Rotating Rate



Power graph from Lab #6 showing optimal power generation at 1200 rpm

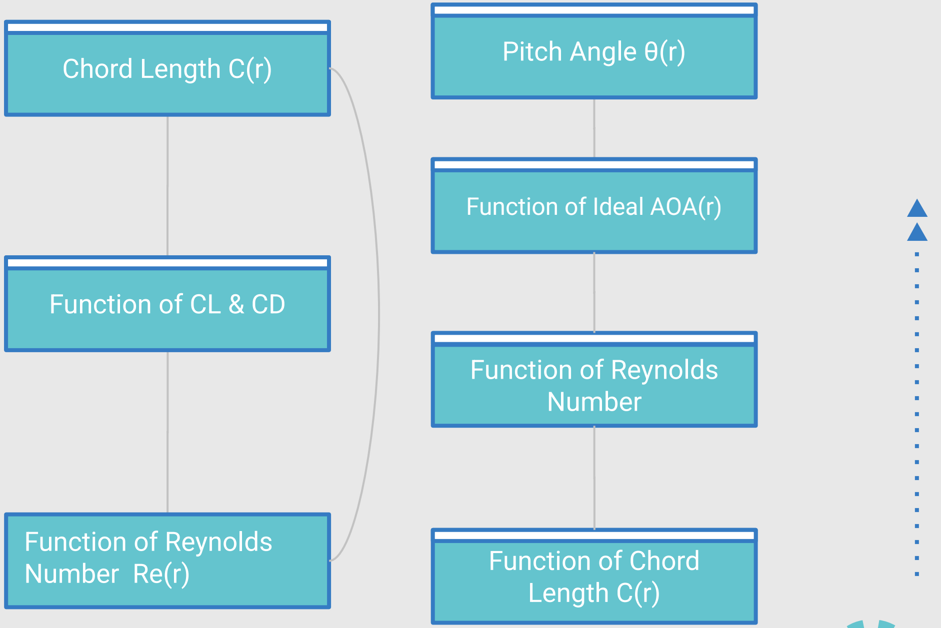
Design Process: The Circular Problem

-In Lab 5, a constant Reynolds number of 100,000 was assumed. This influenced decisions to use constant values for

AOA for our pitch angle calculations
CL & CD for our chord length calculations

-That correspond to maximum CL/CD for the aforementioned Reynolds number.

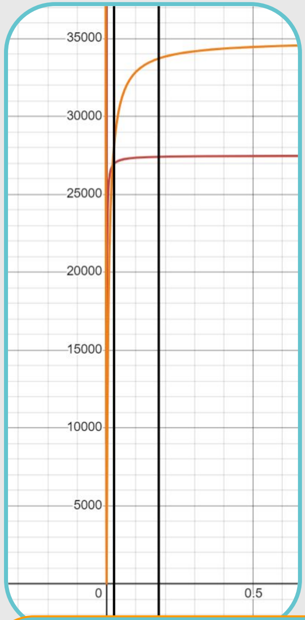
-BUT… Reynolds number is not constant for a given cross section some radial distance r from the hub.



Optimizing Chord Length: An Iterative Process

- Begin by assuming C_L and C_D based on the initial Reynolds number 100,000.
- Use these values to find $C(r)_1$ and thus $Re(C(r))_1 = Re(r)_1$. Then took the average of this finding Re_{avg} which was 27300.
- Find the values of C_L and C_D corresponding to this Reynolds number and plug them into a new chord length function $C(r)_2$

2nd Chord Length (Orange) versus First Chord Length (Red) in inches as a function of radial distance in meters

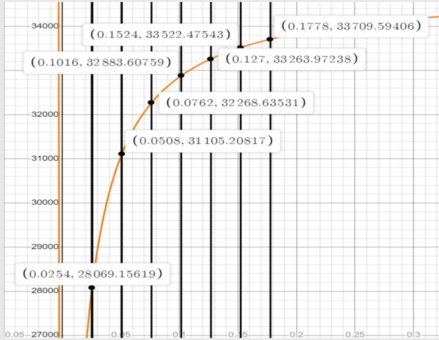


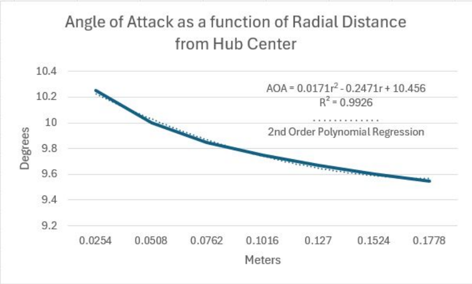
2nd Reynolds Number (Orange) versus 1st Reynolds Number (Red) as functions of radial distance in meters

Design Process: Chord Length to Pitch

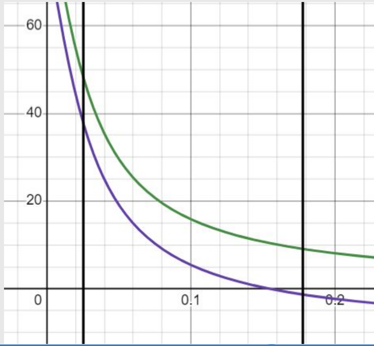
- Iteratively updated chord length equation $c(r)_2$ factored into our Reynolds number equation $Re(c(r)_2)_2 = Re(r)_2$
- At radial intervals, find the approximate Reynolds numbers and interpolate to find the corresponding angles of attack
- Make a plot for the angle of attacks wrt to r from the hub and perform a regression obtaining angle of attack as a function of r - AOA(r).
- This leads to more accurate pitch angle calculation where not only phi but AOA depends on r

Reynolds Numbers Charted (iteration 2) at various radial locations (meters) using $Re(r)_2$





Angle of attack for Max CL/CD for the corresponding Reynolds number as a function of radial distance



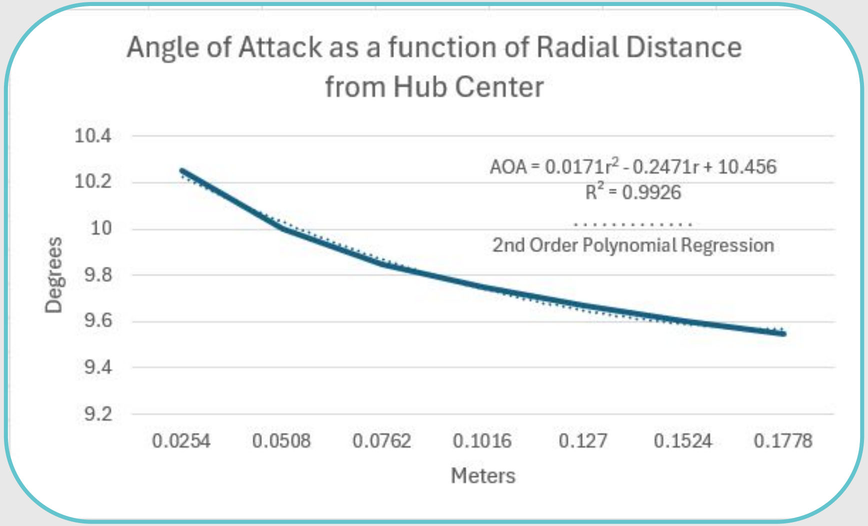
phi in green and pitch angle in purple in degrees as a function of radial distance meters

Design Process: Chord Length to Pitch

Incorporating the chord equation:

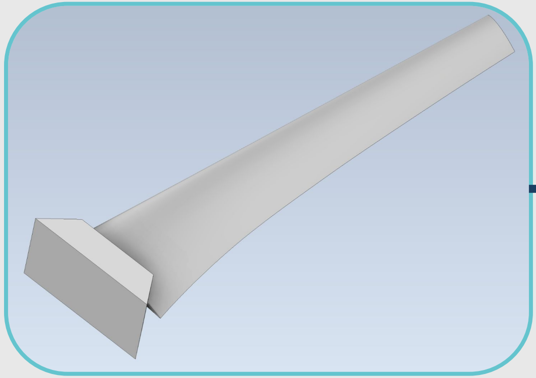
- Found:
  - Angles of attack where C_L/C_D is maximized
  - Angle of attack as a function of radius

- **More accurate pitch angle calculation** that takes into account radial distance and phi

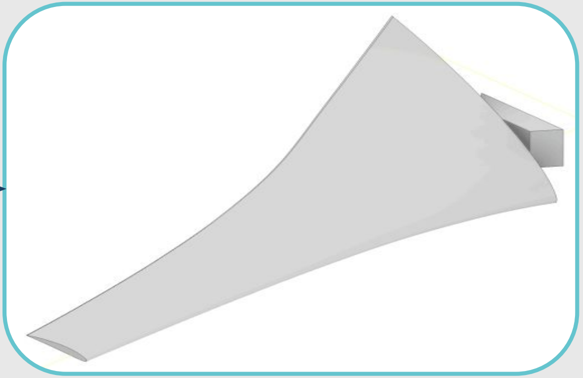


Design Process: CAD

Initial Design

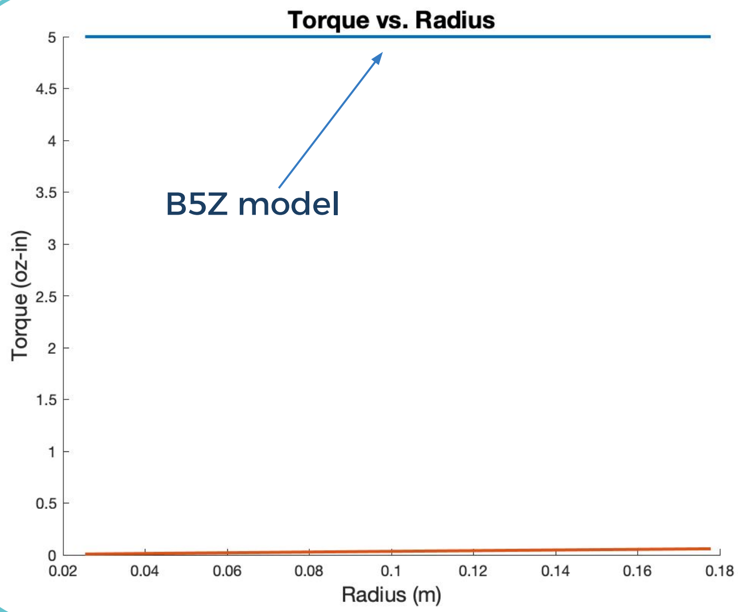


Final Design



- Utilize Chord Length and Pitch Angle calculations as f(radius)
- Establish Work Planes at regular cross sections
- Constrain sketches based on Airfoil Geometry, Pitch Angle, and Chord Length using global variables
  - Enable rapid design iteration
  - Adaptable to changes in circumstances and recovering from errors
- Loft across sketches to create smooth, continuous surface

Constraints

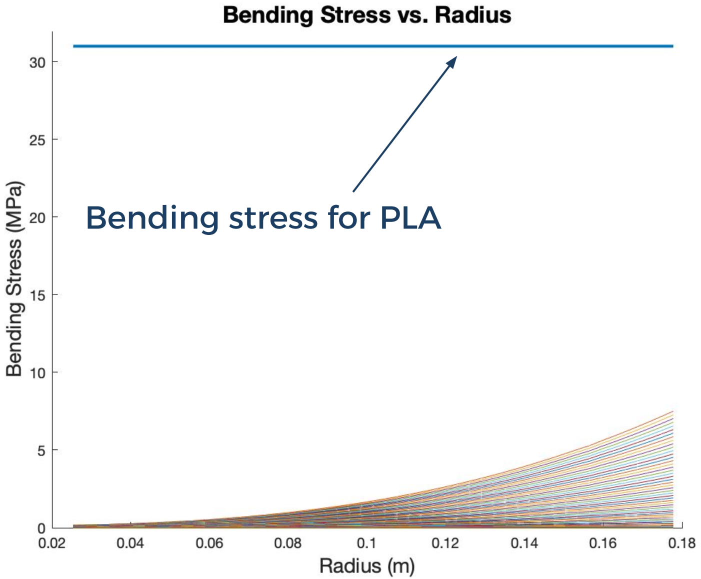


Blade Max Torque: 0.0588 oz-in

B5Z Max Torque allowed: 5 oz-in

Catastrophic failure? No!

Constraints



Blade Bending Stress: 7.51 MPa

PLA Bending Stress: 31 MPa

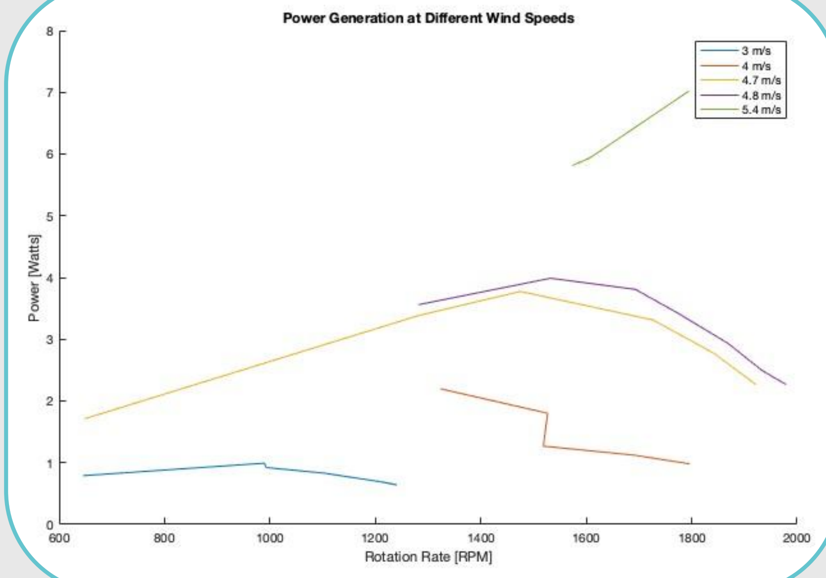
Catastrophic failure? No!

Data Collection Process

1. Slot #1: Delayed start due to setup issues
2. Set wind speed to ~4.8 m/s and perform RPM Sweep*
3. Slot #2: Set wind speed to ~4 m/s and perform RPM Sweep
4. Set wind speed to ~4.7 m/s and perform RPM Sweep
5. Set wind speed to ~5.4 m/s and perform RPM Sweep
6. Analyze data and identify trends
7. Set wind speed to ~3 m/s and perform RPM Sweep

RPM Sweep*: We started at the highest value of rotational rate and incrementally increased torque brake power, collecting data points in between steps. This continued until the rotational rate reached zero.

Actual vs. Theoretical Values for Power



Theoretical

- Max power generation at 4.7 m/s
- Optimal speed for power generation is 1200 RPM

Actual

- Max power generation of **3.98 W** at **4.8 m/s**
- Optimal speed for power generation is around **1570 RPM**
- Due to speed limits with the turbine, 5.4 m/s data set was cut short (greater power gen.)

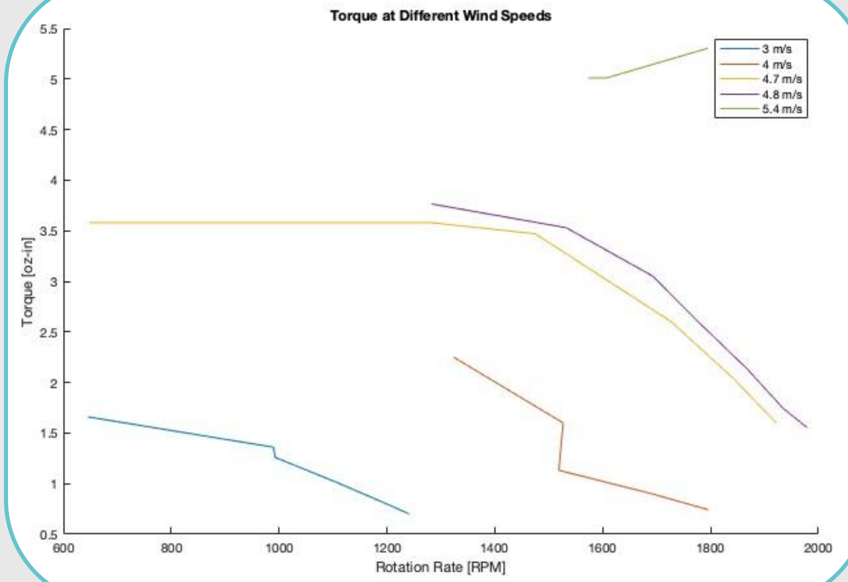
Actual vs Theoretical Values for Torque

Theoretical

- Max torque: 0.0588 oz-in at 5 m/s

Actual

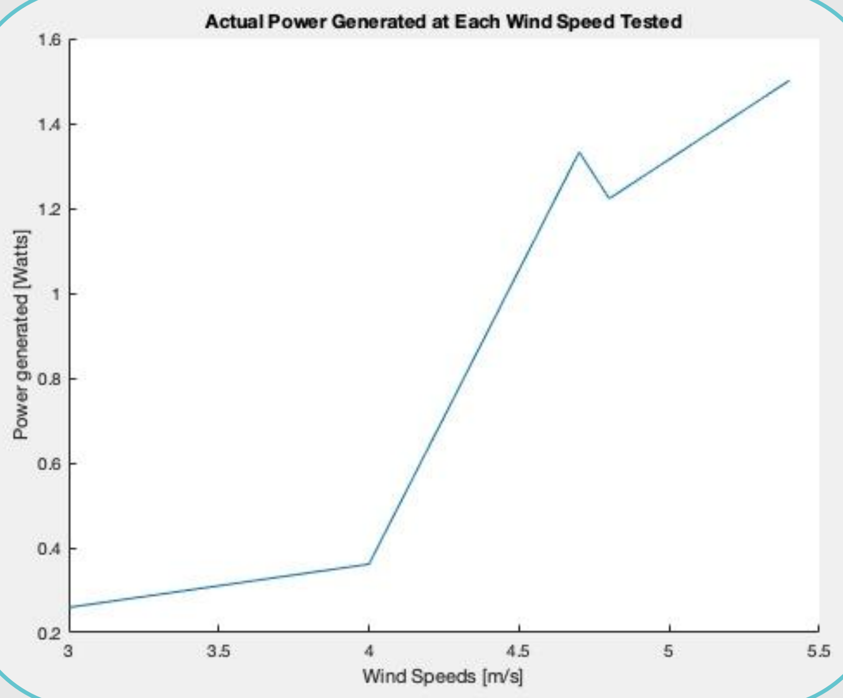
- Max torque: 3.6 oz-in 4.8 m/s
- RPM limited data set for 5.4 m/s
- Discrepancies due to model simplifications in theoretical calculations



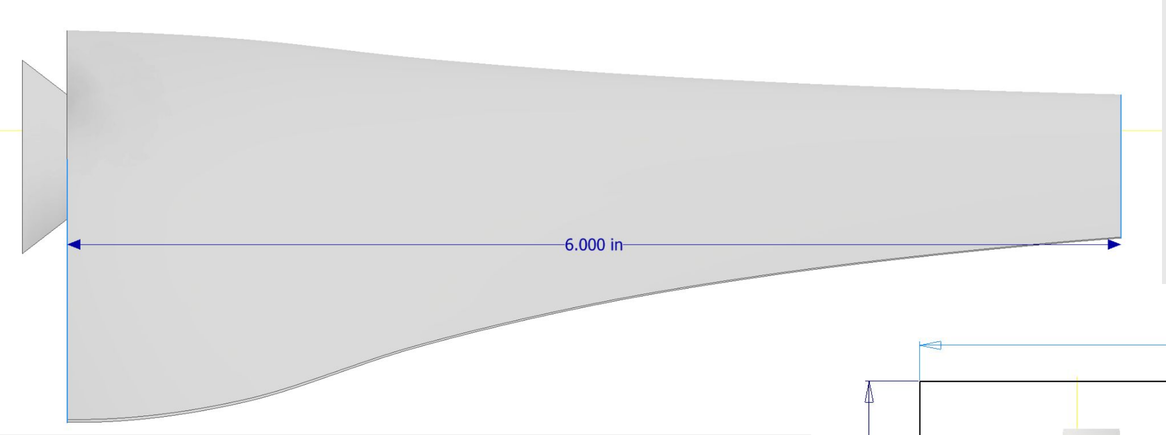
Design Actualization

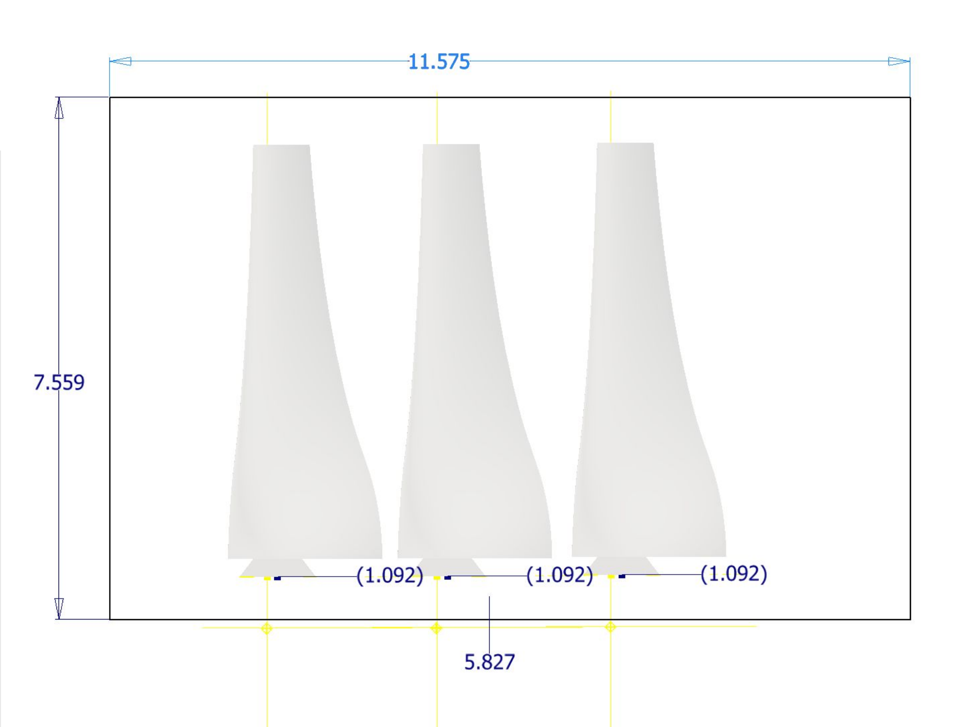
Operating Rotation Rate

- For each wind speed:
    - Range: 600-1800 RPM
- Wind speeds:
    - 3, 4, 4.7, 4.8 and 5.4 m/s
- Max Power Output
    - ~1.4 W at 4.7 m/s

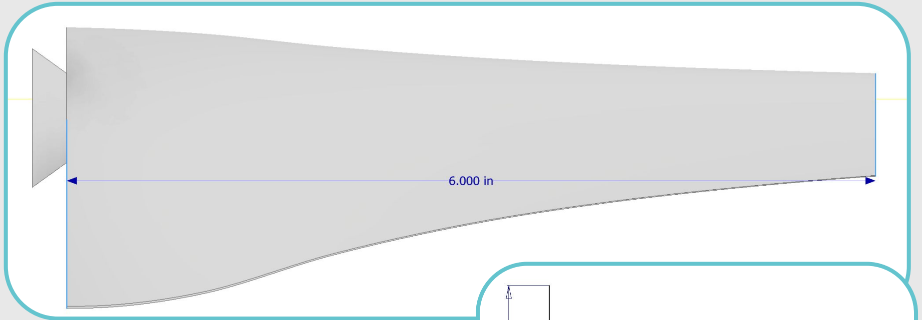


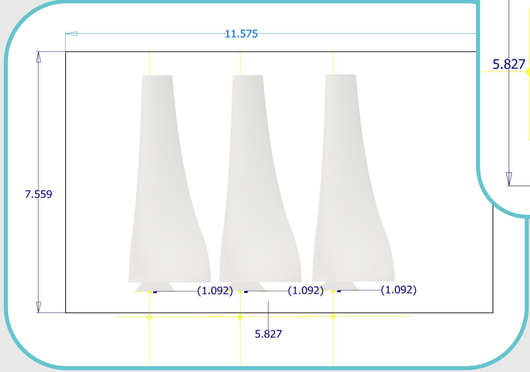
Blade Dimensions

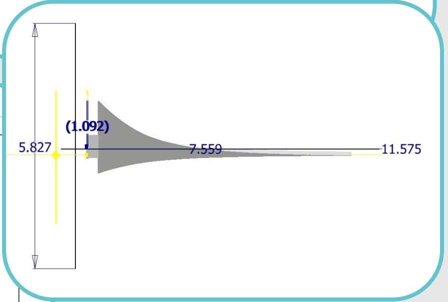

6.000 in

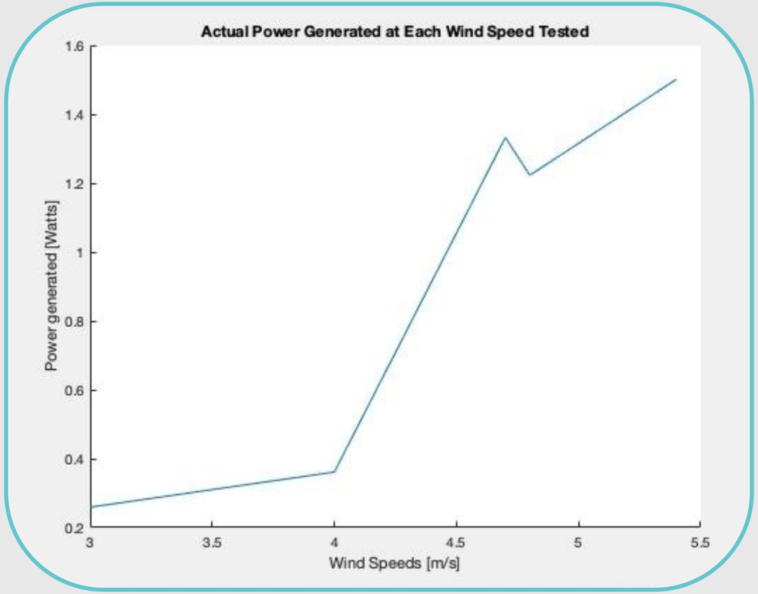

11.575
7.559
(1.092)
(1.092)
(1.092)
5.827

Final Slide: Group 411-2









- For each wind speed:
  - Range: 600-1800 RPM
- Wind speeds:
  - 3, 4, 4.7, 4.8 and 5.4 m/s

Thank you for your time!

Questions?

Appendix

$$R_1 = \frac{(1.18)(U)(c_1)}{1.6\left(10^{-5}\right)}$$

$$R_2 = \frac{(1.18)(U)(c_2)}{1.6\left(10^{-5}\right)}$$

$$c_1 = \frac{F^2(4)(a)(1-a)\pi r}{3\left(\frac{1}{2}L_1U^2\cos(\phi) + \frac{1}{2}D_1U^2\sin(\phi)\right)}$$

$$c_2 = \frac{F^2(4)(a)(1-a)\pi r}{3\left(\frac{1}{2}L_2U^2\cos(\phi) + \frac{1}{2}D_2U^2\sin(\phi)\right)}$$

$F = 5.36$

$$U = \sqrt{\left((1-a)F\right)^2 + \left(rw(1+A)\right)^2}$$

$w = 125.663$

$A = 0$

$a = \frac{1}{3}$

$L_1 = 1.14250$

$D_1 = 0.01990$

$$\phi_{phiorpitchangleplusangleofattack} = \tan^{-1}\left(\frac{(1-a)F}{rw(1+A)}\right)$$

$$\phi = \arctan\left(\frac{(1-a)(F)}{rw(1+A)}\right) - \left(0.017r^2 - 0.247r + 10.456\right)$$

$L_2 = 0.9$

$D_2 = 0.195$

$x = 1(0.0254)$

$x = 7(0.0254)$