Team 25: Taller Wind Turbine for Low Wind Speed Regions

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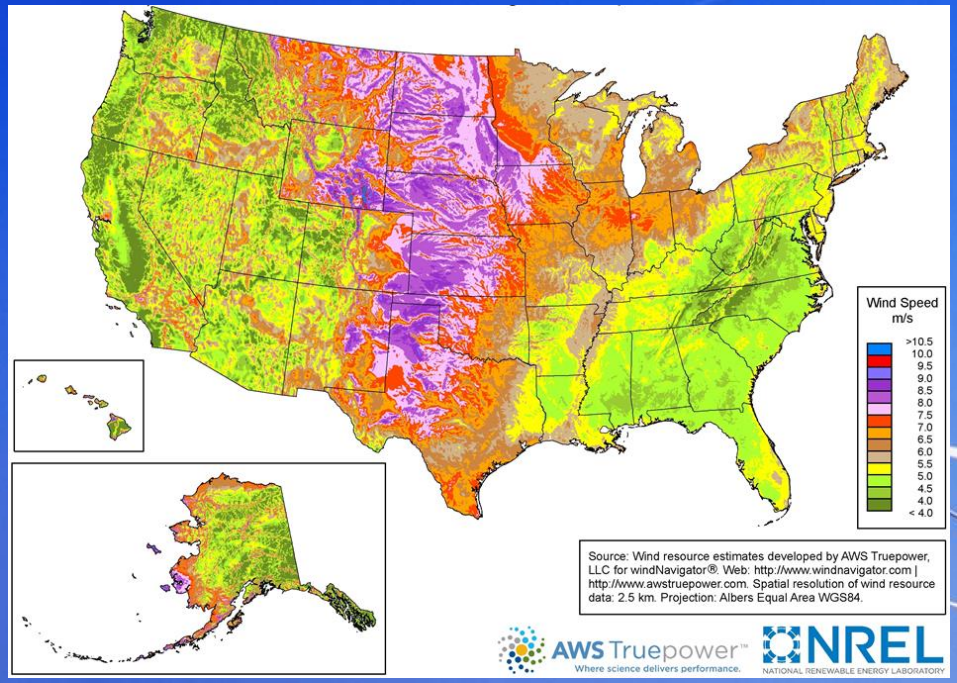
Problem Statement

"Traditional 80m wind turbines are not effective in the Southeastern U.S."



Project Goals

Horizontal Axis Wind Turbines

Current Specs:

- 1-2MW
- Avg. 80m hub height
- Avg. blade length 60m
- LCOE: $72/MWh

Project Specs:

- 5MW
- Taller structure (157.5m)
- Design lighter blades of same size
- Prototype budget: $2,000

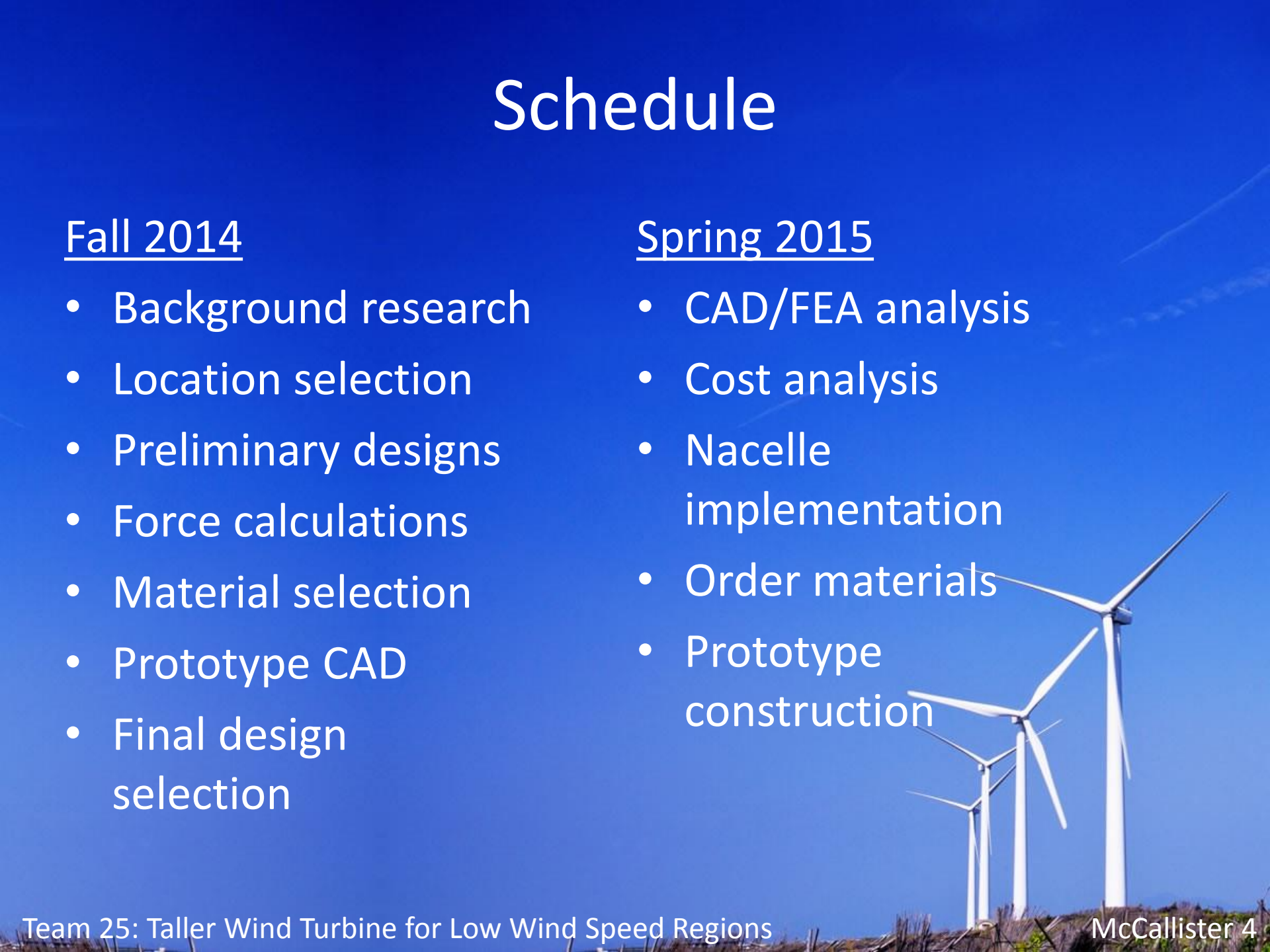
Schedule

<u>Fall 2014</u>

- Background research
- Location selection
- Preliminary designs
- Force calculations
- Material selection
- Prototype CAD
- Final design selection

<u>Spring 2015</u>

- CAD/FEA analysis
- Cost analysis
- Nacelle implementation
- Order materials
- Prototype construction



Blade Force Analysis

- NACA64 Airfoil selected based on lift factor
- 61.5 meter blade selected based on transportation and deflection constraints

- **Pressure**

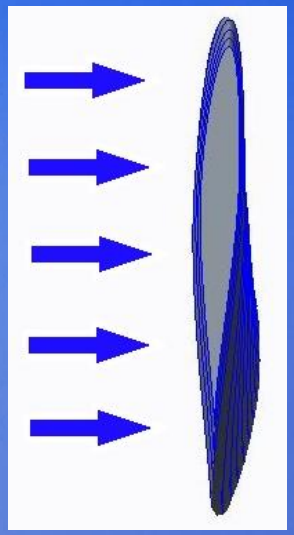
$$P = \rho_{air} c_d v^2$$
$$P = 500\ Pa$$

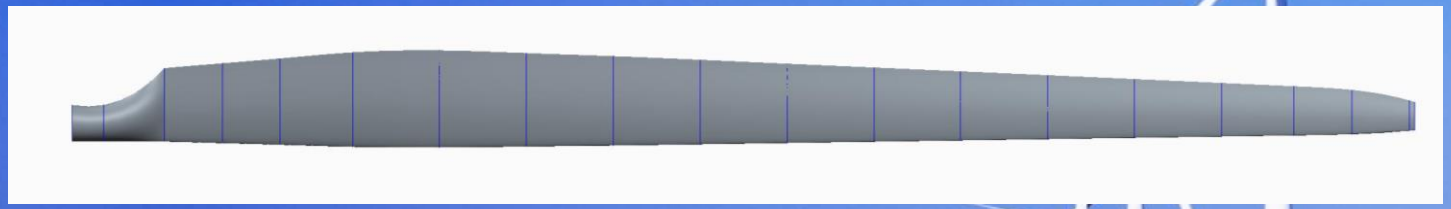
- **Wind Load**

$$\mathrm{F} = P A_s$$
$$F = 102\ kN$$

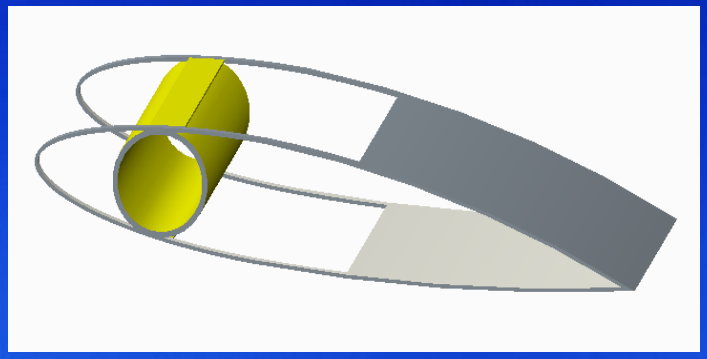
- **Shape Factor**

$$\varphi_B^e = \frac{12I}{A^2}$$



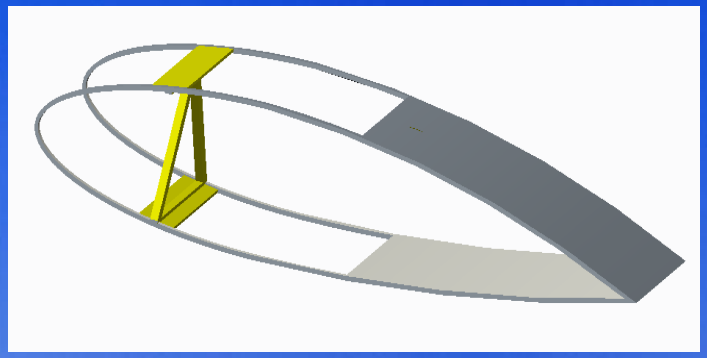


Early Blade Designs



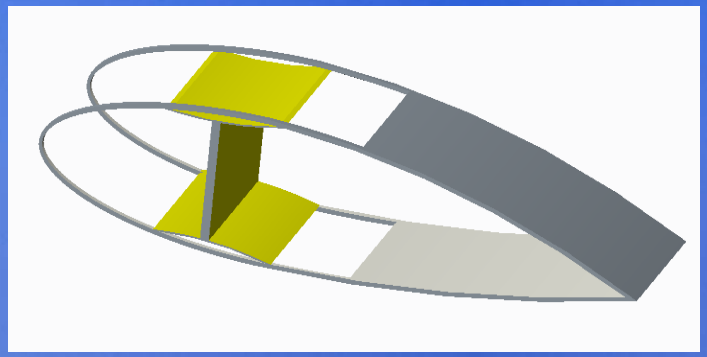
Internal Cylinder

- $\varphi_B^e = 8.5$
- Too heavy



Internal Truss

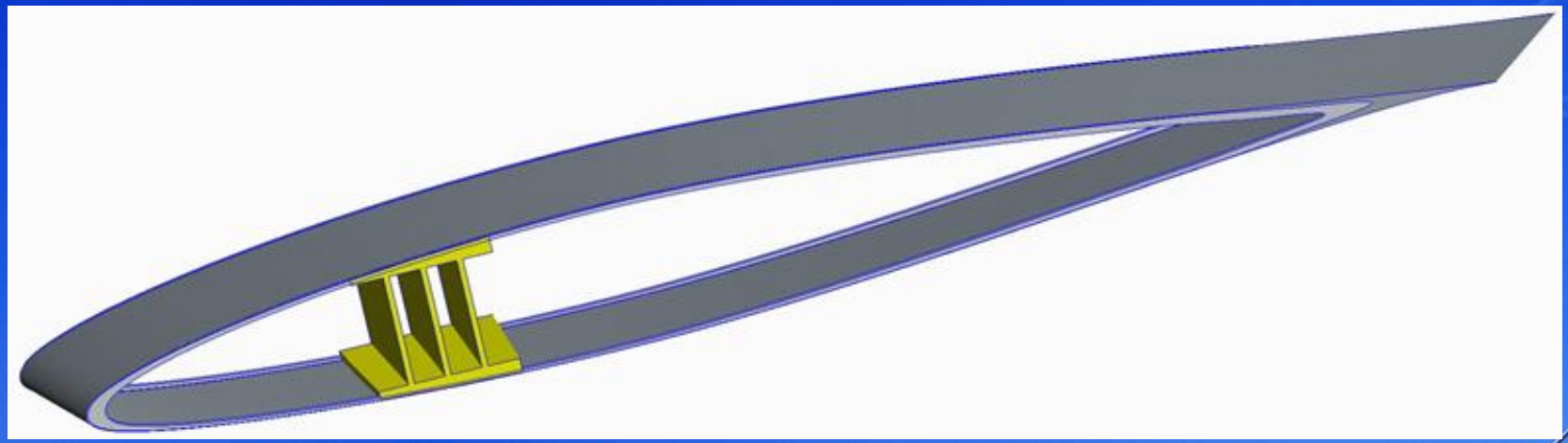
- $\varphi_B^e = 22.5$
- Many points of failure
- Complicated construction



Single Post

- $\varphi_B^e = 22.5$
- Curved surface
- Difficult fabrication

Blade Final Design

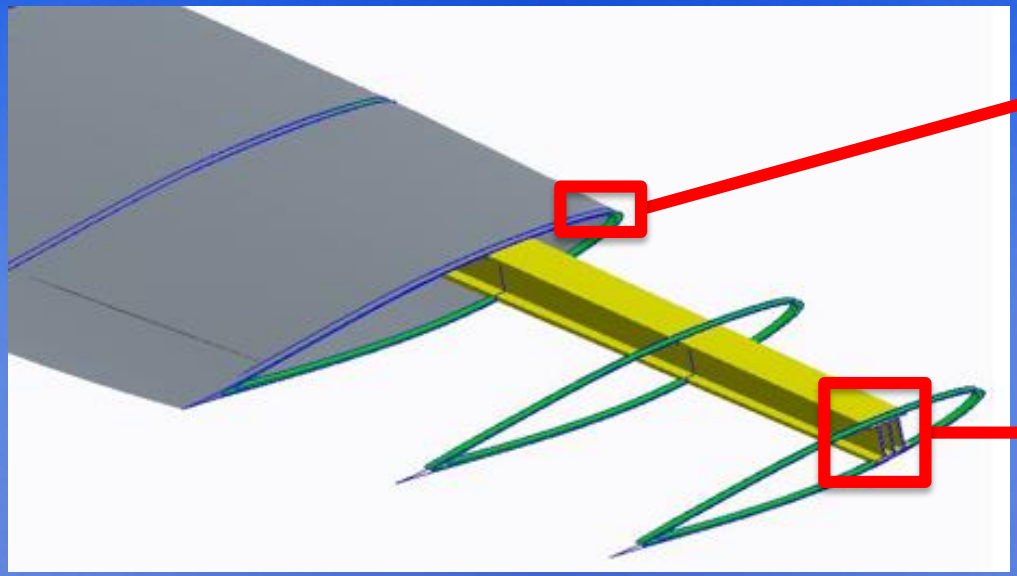


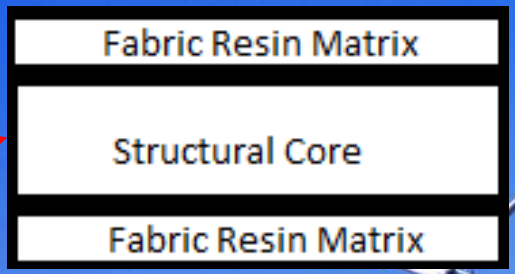
Triple I-Beam

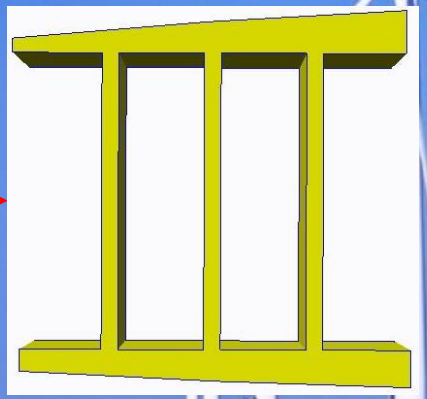
- $\varphi_B^e = 22.5$
- Good distribution of load
- Varying angle of twist
- Lightweight

Material Selection

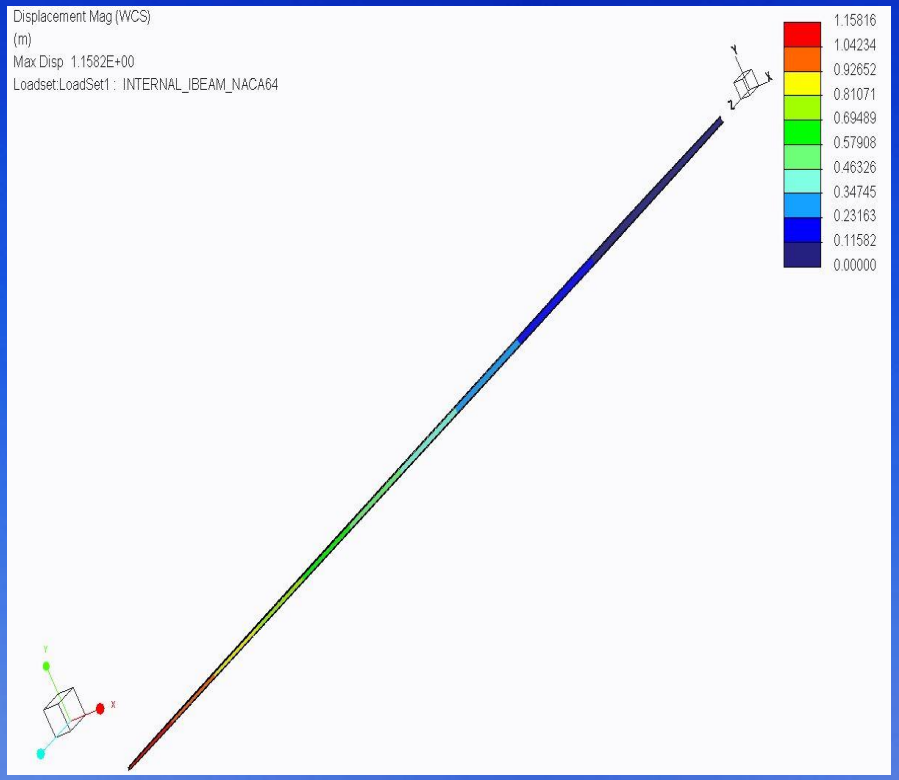
Blade Component	Material
Fabric Resin Matrix	E-Glass, Epoxy, Carbon Fiber
Structural Core	Styrene Acrylonitrile (SAN) Foam
Spar	Al6061

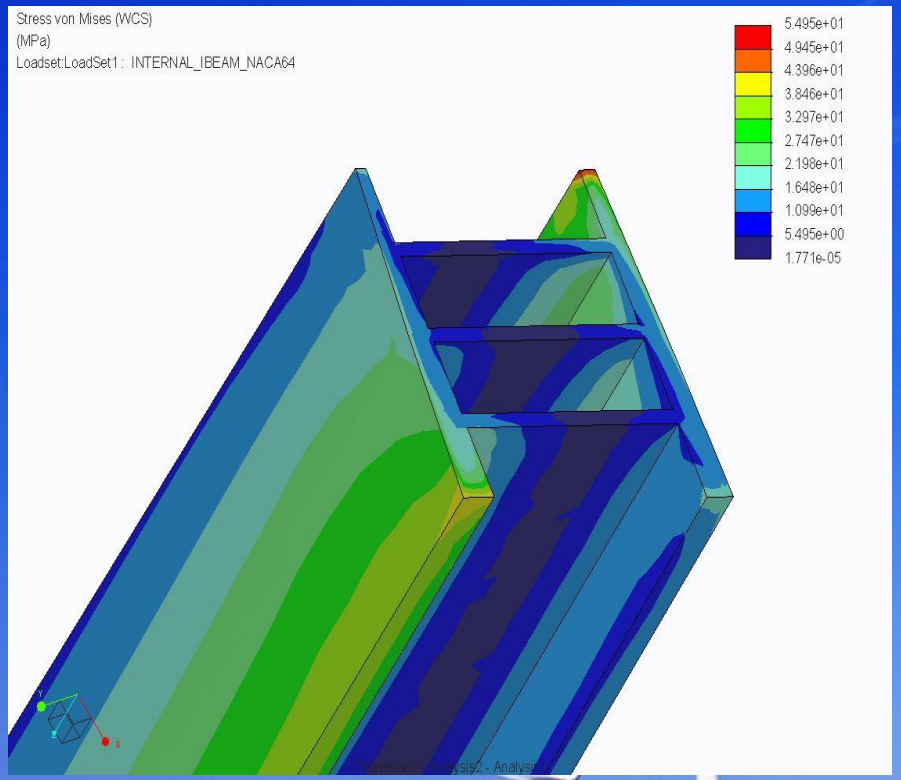






Blade Analysis





Blade Deflection: 1.15m

Max Stress in Spar: 55MPa

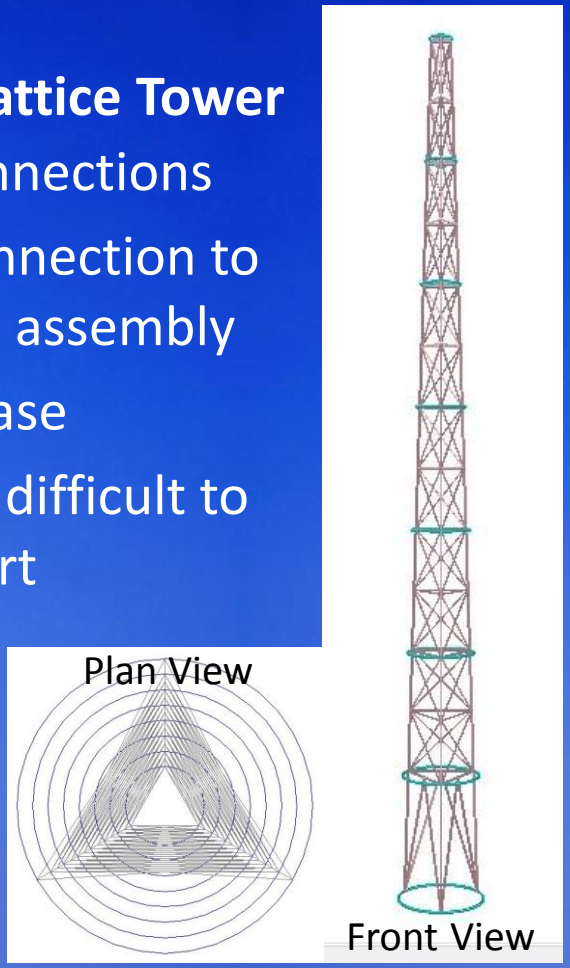
Early Designs: Tower

- Design Requirements
  - 150-200% height of typical tower
  - Comparable cost to typical tower
  - Ability to construct in Florida
- Alternatives
  - Steel or Concrete?
  - Shell or space frame?
  - 3-sided or 7-sided?

Early Designs: Tower

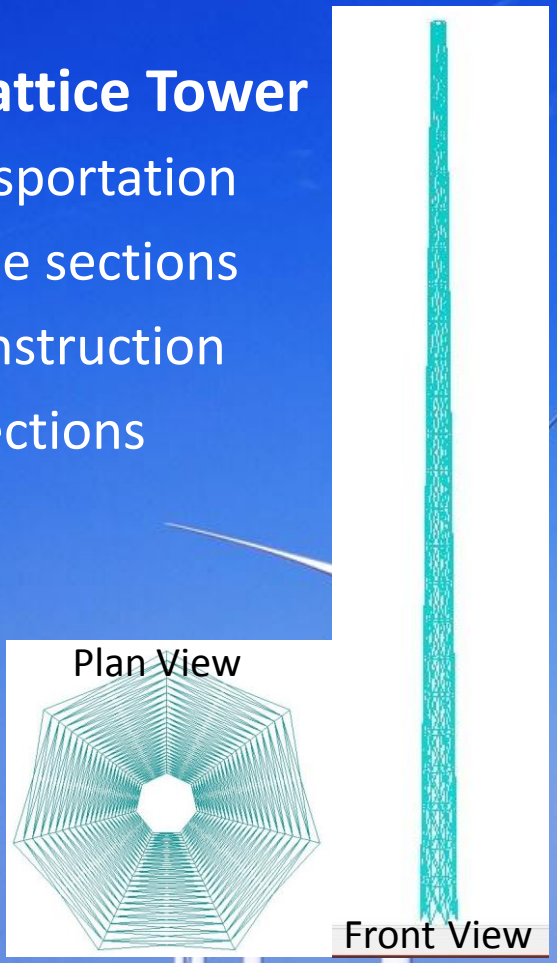
Triangular Lattice Tower

- Few connections
- Ring connection to assist in assembly
- Large base
- May be difficult to transport



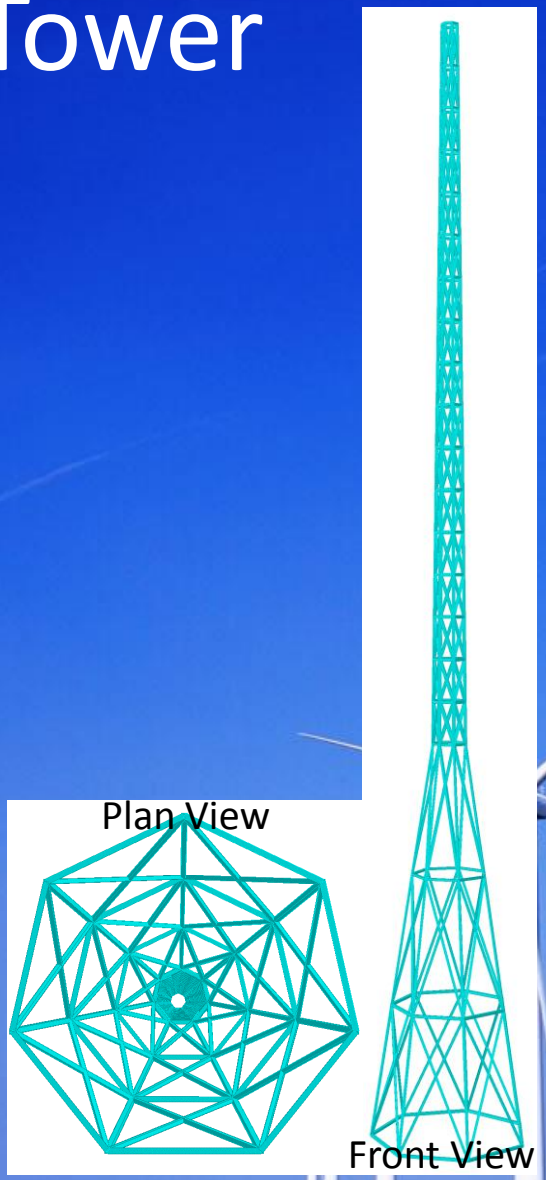
Heptagonal Lattice Tower

- Ease of transportation
- Pre-assemble sections
- Modular construction
- Many connections



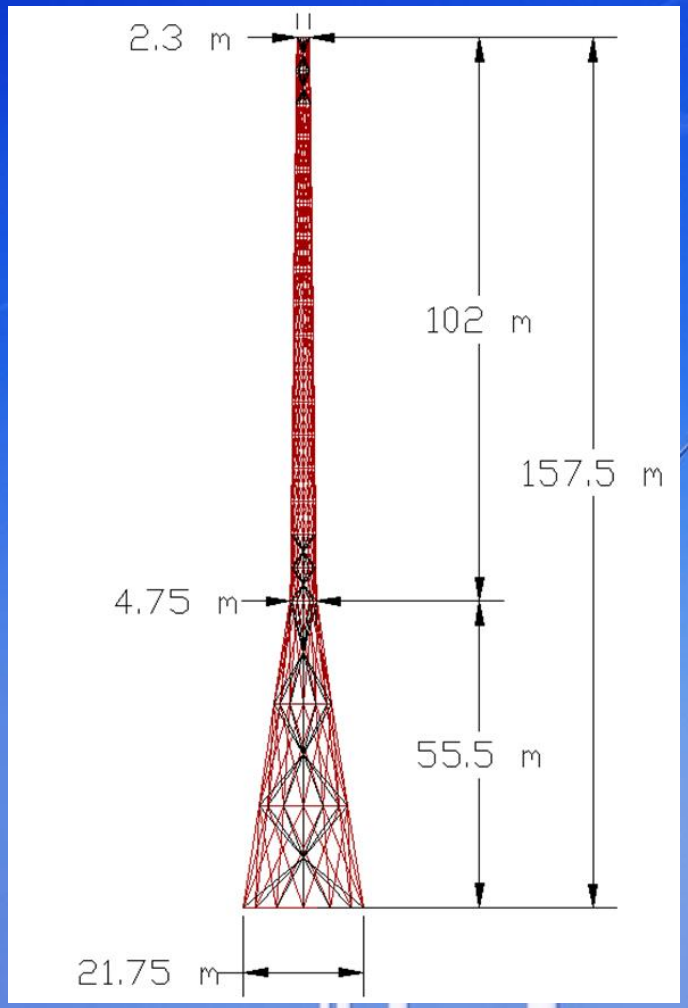
Final Design: Tower

- Features
  - Heptagonal lattice tower
  - Hub height: 157.5m
  - 20 sections
  - Insulated with architectural fabric
  - Material: Hollow Structural Steel (HSS)
- Innovations
  - Widened base
  - Internal bracing
  - Two separate construction methods
  - Male/Female connections

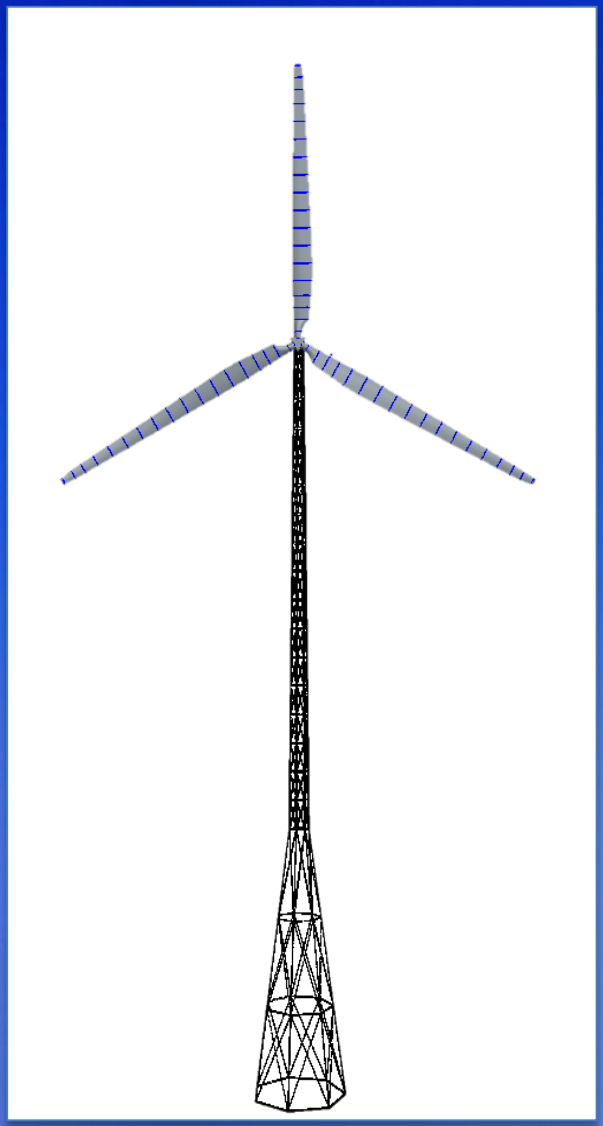


Tower Analysis

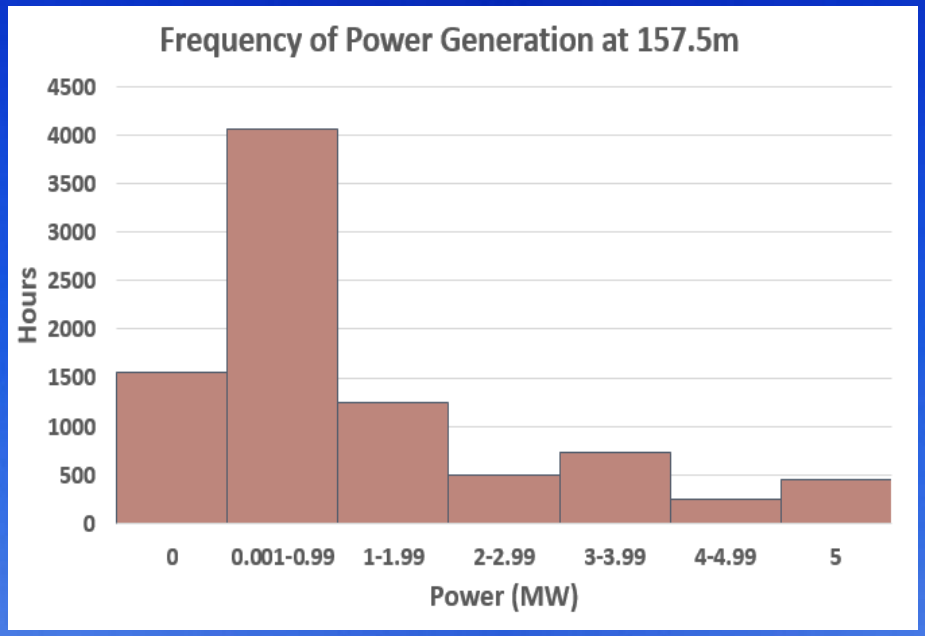
- STAAD Pro V8i and AutoCAD Civil 3D
  - Iteration of design at early stages
  - Issues of strength
  - Connections
  - Modal Analysis
- Optimization
  - By weight
  - By deflection
- Compared to typical 5MW 90m tower
  - 175% taller
  - 10% heavier



Final Design



Power and Cost

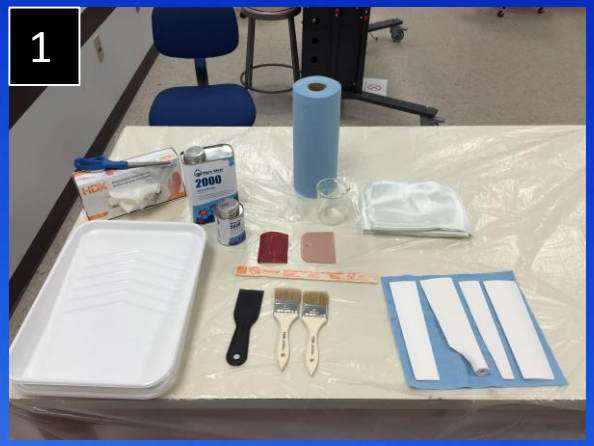


ITEM	COST ($)
Blades	1,091,130
Tower/Foundation	1,178,000
Additional Components	5,101,990
Soft Costs	815,000
Lease	250,000
Operation & Maintenance	3,400,000
Total	13,646,119

- Belle Glade, FL (2014): Power ≈ 10,570MWh
- That's enough electricity to power 970 homes
- Generates useable power 82.3% during 1 year
- **Levelized Cost of Energy (LCOE): $65/MWh**

Prototype Blade Assembly

1



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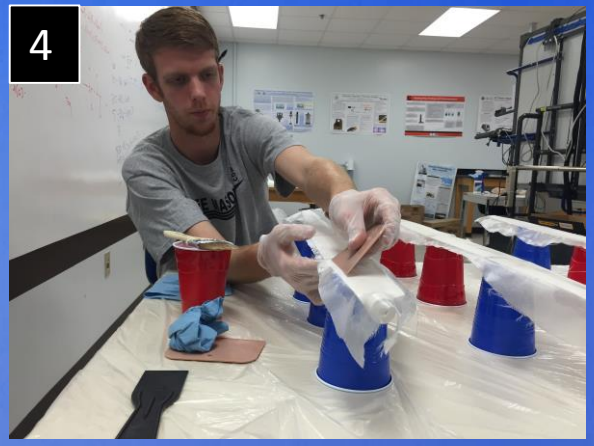

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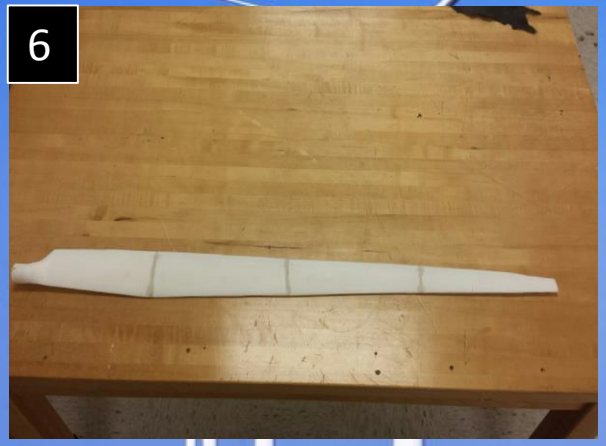
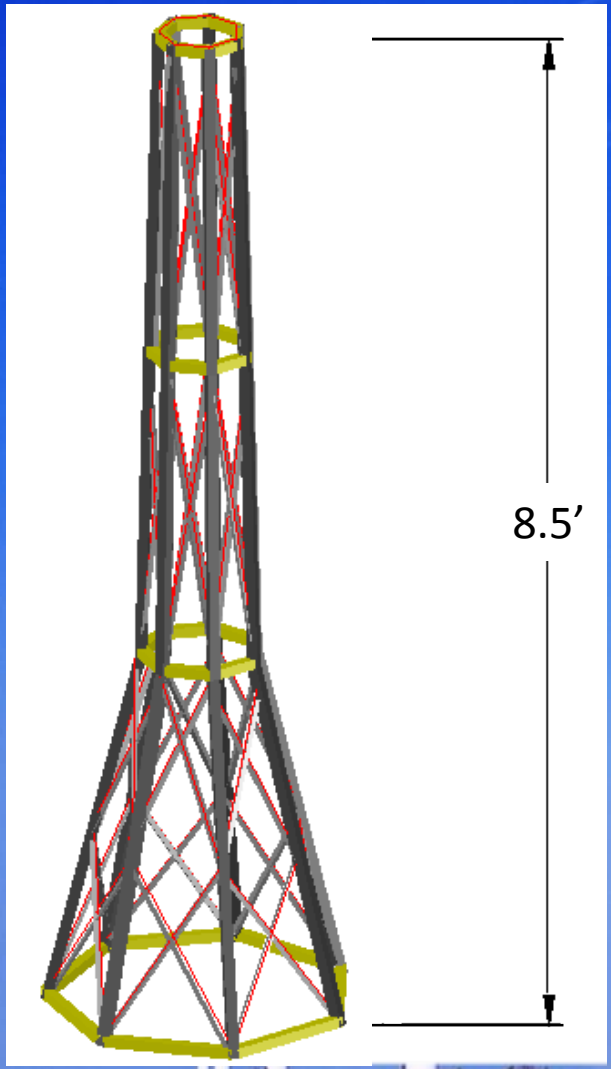
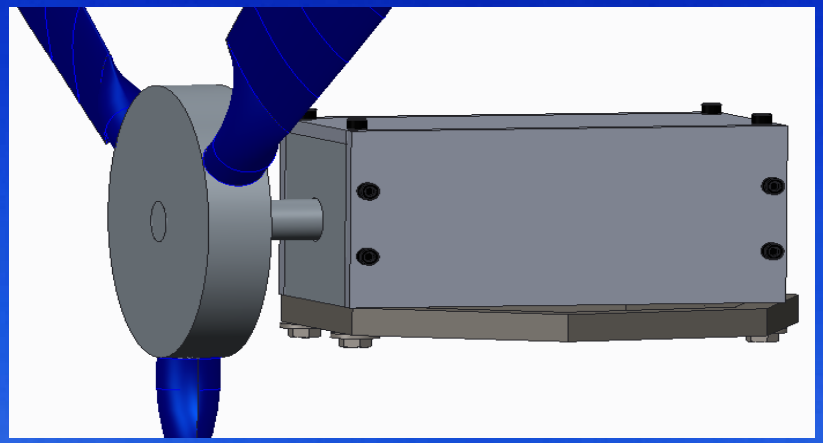


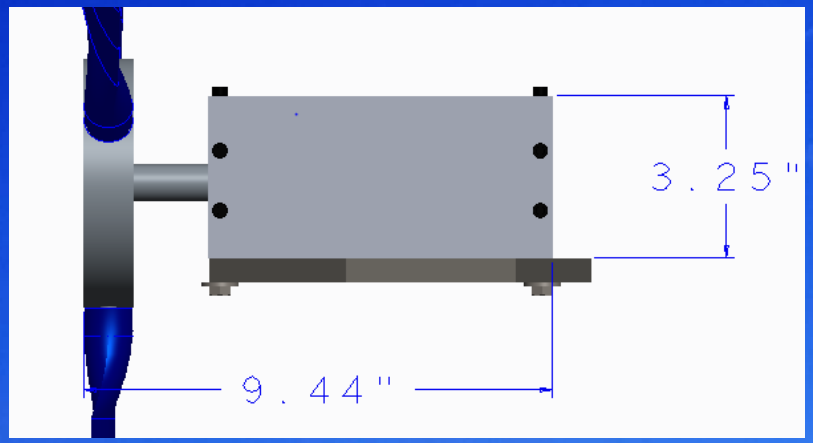
Tower Prototype

- 8.5-ft Steel Tower
  - 3 typical sections
  - General geometry will be properly scaled
- Connections
  - Custom design
  - Heptagonal rings between sections
- Wrap tower in fabric

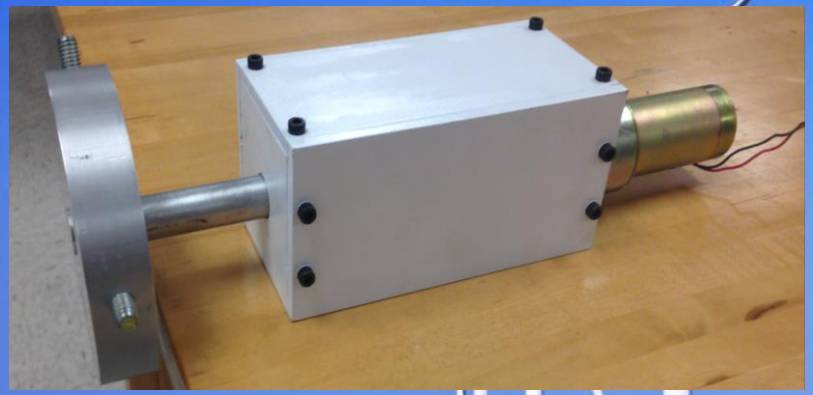


Nacelle Prototype

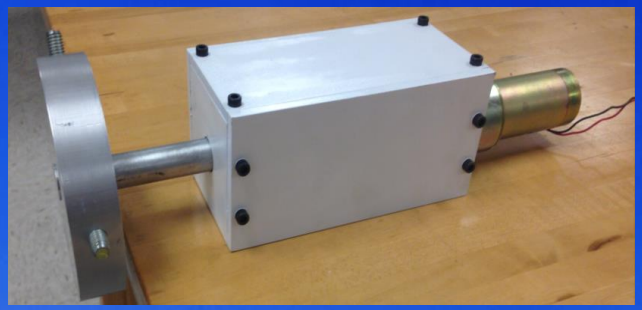


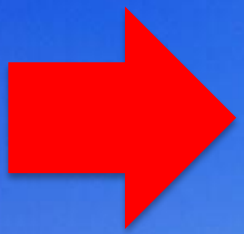


- Machined at COE
- Coupled motor for power generation

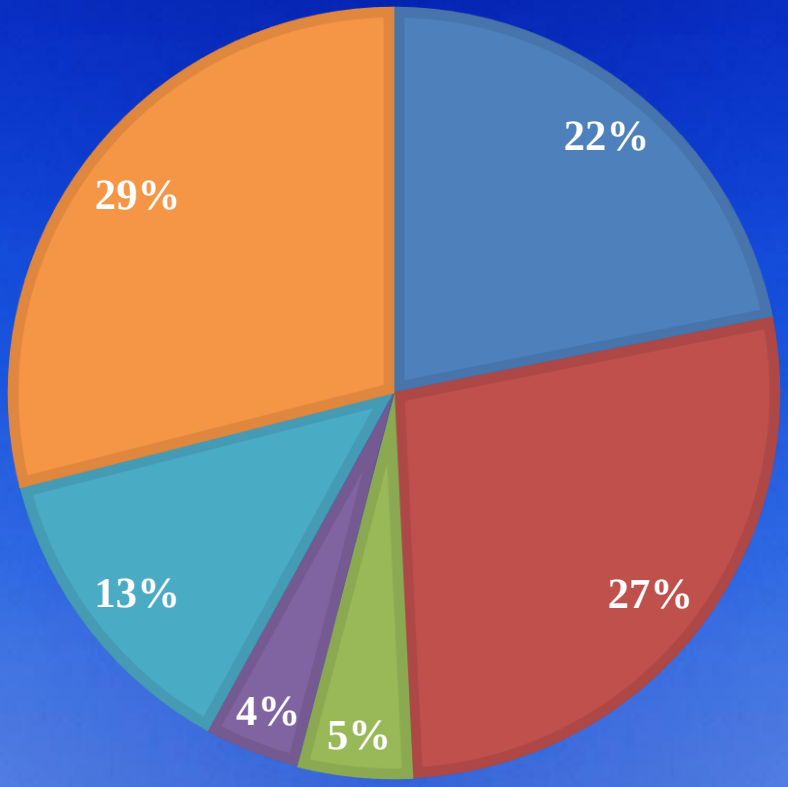


Complete Prototype





Prototype Budget



Material	Cost ($)
Steel	437.58
Blades	547.20
E-glass & Epoxy	95.50
Fabric	80.14
Additional Parts	260.33
Remaining	**579.25**

$579.25 (29%) of the initial $2000 remaining at the completion of the project

What We Learned

- Wind power is a growing industry that can be used in new areas with proper innovative design
- Uncertainties are common in design
- Must account for tolerances in design
- Time management and communication are key to a successful project

Conclusions

- Team 25 has completed feasibility study of taller wind turbine for Southeastern U.S.
- Prototype constructed showing key design components
- Innovative ideas allowed for design of an improved tower and lighter blades
- Reduced LCOE by approx. 10%

References

- http://www.nrel.gov/docs/fy09osti/38060.pdf
- http://wind.nrel.gov/public/bjonkman/TestPage/FAST.pdf
- http://www.gettyimages.com/detail/news-photo/aerial-view-of-field-taken-from-goodyear-blimp-above-news-photo/457716040
- http://www.ncdc.noaa.gov
- http://www.nrel.gov/midc/nwtc_m2/

Questions?