Team 25: Taller Wind Turbine for Low Wind Speed Regions

Sponsor: Dr. Sungmoon Jung

Advisor: Dr. Kunihiko Taira

Authors:

Steven Blanchette (ME)

David Delie (ME)

Kimberly Martinson (CE)

Jeremiah McCallister (ME)

Abigail McCool (ME)

Theodore Meros (CE)

Project Overview

Current 80 meter wind turbines are not cost-effective for use in the Southeastern U.S. due to lower average wind speeds.

Horizontal Axis Wind Turbine

Current Specs:

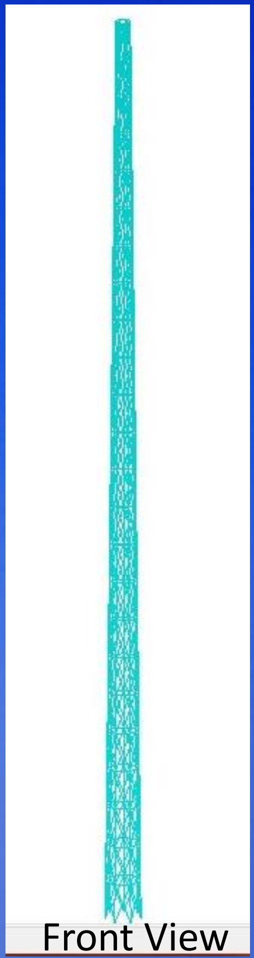
- 1-2 MW
- Avg. 80 m hub height
- Blades ~60 m long
- $72/MWh

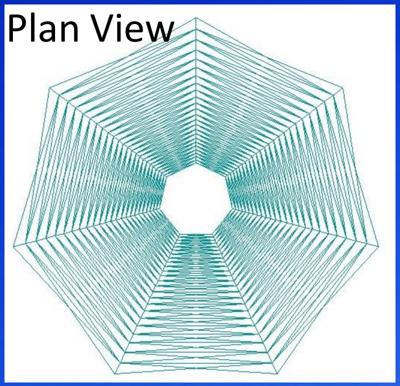
Project Specs:

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

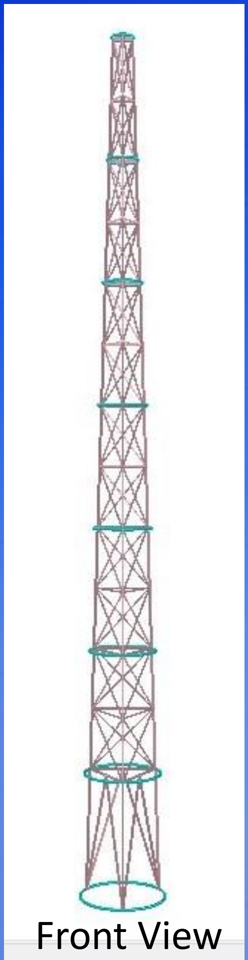
Preliminary Designs

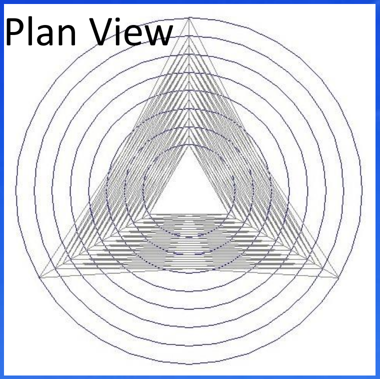
1. Heptagonal Lattice Tower





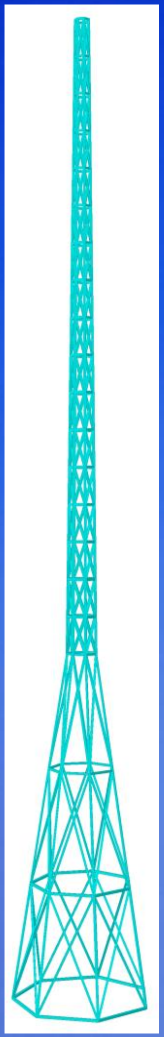
2. Triangular Lattice Tower



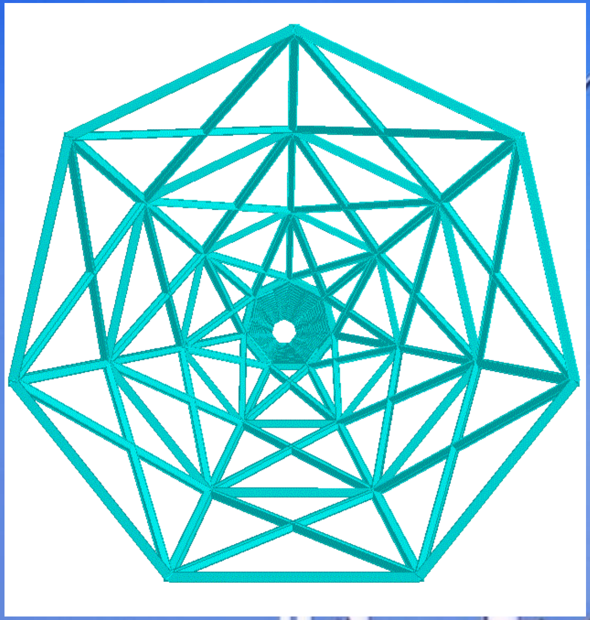


Final Design Layout

- Incorporates two previous designs
  - 7 sides allows for wider base, restricted by semi trailer size
  - Tubular rings increase ease of construction and curvature of exterior fabric
  - Requires only one application of field welding

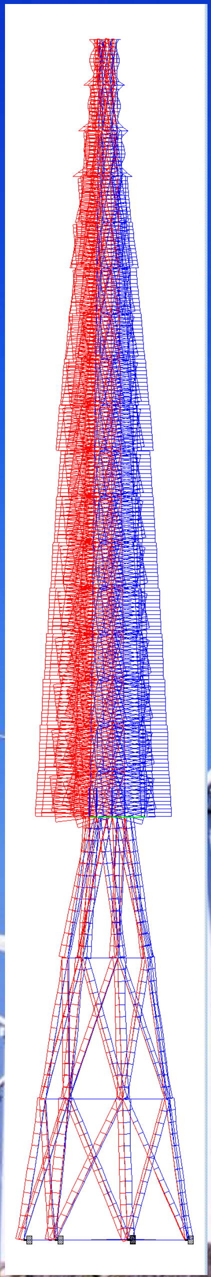


- 157.5 meter hub height
- Typical Bracing: HSST 12x12
- Typical Column: HSST 14x14
- Nacelle+Blades = 335 tons
- Steel Selfweight ~ 800 tons
- Total thrust: 144 kips
  - Designed 200 kips
- Earthquake load: 2.0 short term



Design Process

- Design in STAAD Pro V8i
  - Select optimization for 360°
  - Wider base: “shortens” moment arm
  - Fixity of members
  - Typical Sections: 20 spans, 7 sets
  - Application and magnitude of loading
  - Deflection 3’
  - No failed members; typical sections strength ratio range from 0.6-0.9
  - Modal Analysis



Blade Force Analysis

- Pressure

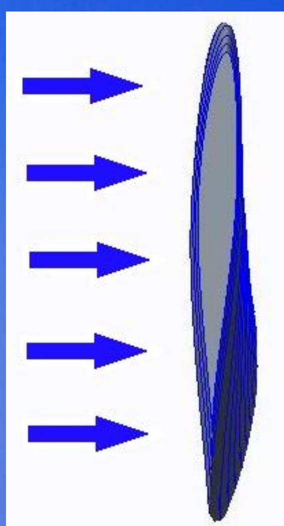
$$P = \rho_{air} c_d v^2$$
$$P = 500\ Pa$$

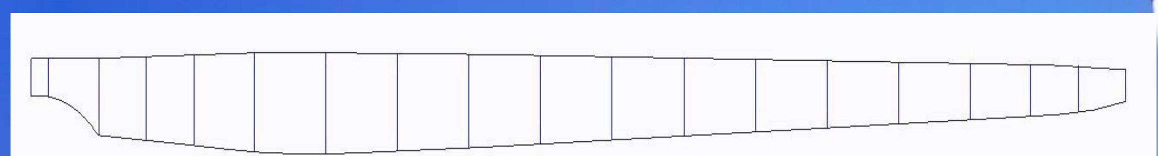
- Wind Load

$$\mathrm{F} = PA_s$$
$$F = 102\ kN$$

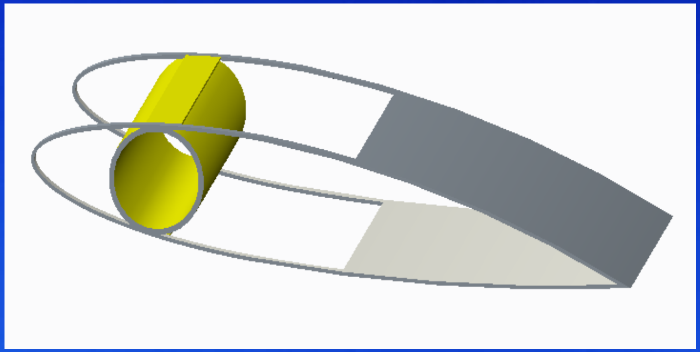
- Shape Factor

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



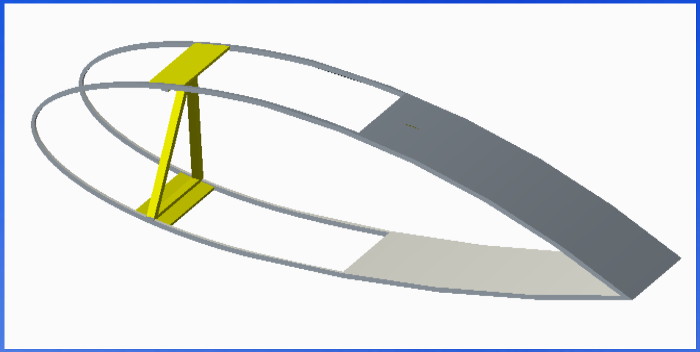


Initial Bracing Beams



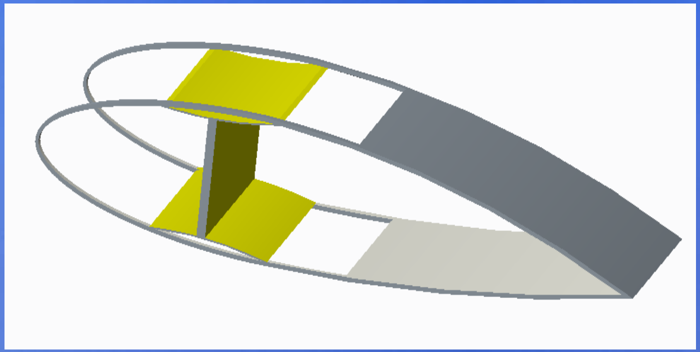
Internal Cylinder

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



Internal Truss

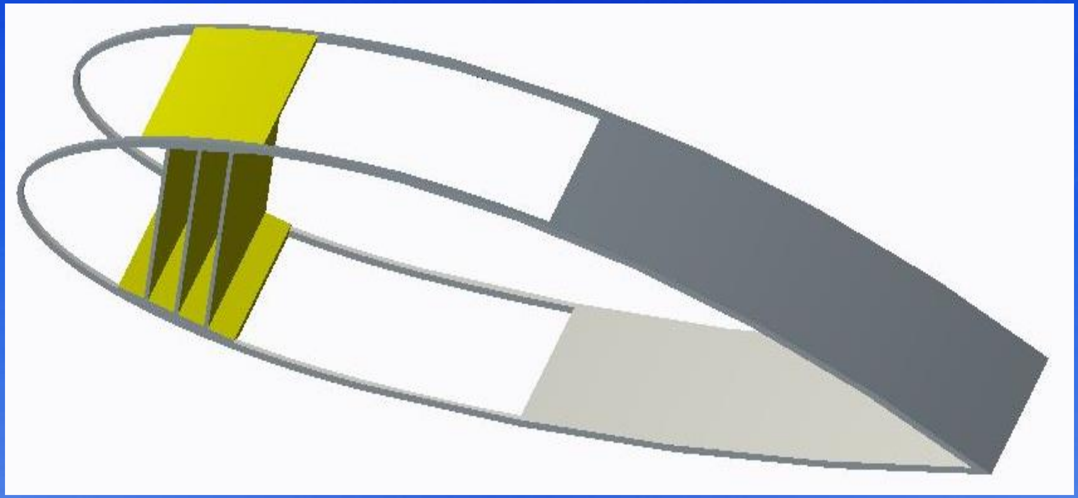
- $\varphi_B^e = 22.5$
- Many points of failure
- Complicated construction



Single Post

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

Selected Blade Interior



Triple I-Beam

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

Material for Bracing Beam

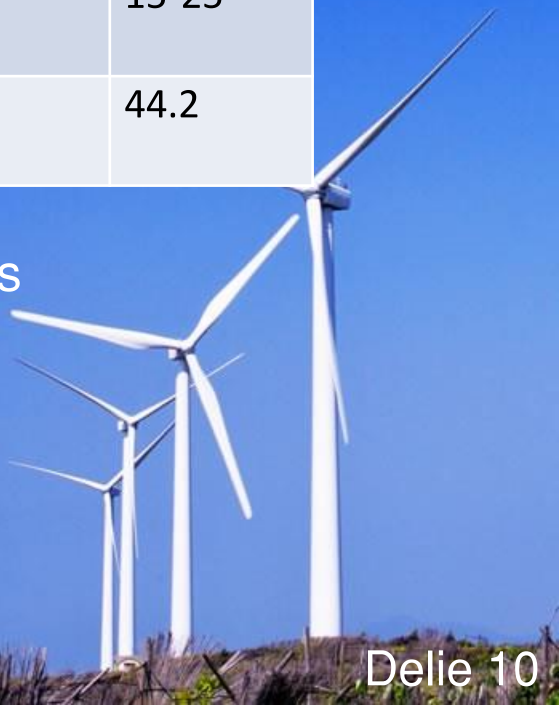
Materials	Average Young's Modulus (GPa)	Density $(\frac{kg}{m^3})$	Yield Strength (MPa)	Normalized Cost $(\frac{\$}{kg})$
Aluminum	75.0	2,700	287.0	1.60
Carbon Steel	208.0	7,850	322.5	0.67
Bamboo	17.5	700	40.0	1.80

Aluminum	Young's Modulus (GPa)	Density $(\frac{kg}{m^3})$	Yield Strength (MPa)	Cost $(\$)$
Aluminum 2024	73.1	2,780	324	16.38
Aluminum 7075	71.7	2,810	503	18.05
Aluminum 6061	68.9	2,700	276	6.37

Fabric Material Selection for Shell of Blades

Fabrics	Young's Modulus (GPa)	Density $(\frac{kg}{m^3})$	Failure Strain $(\%)$	Cost $(\frac{\$}{kg})$
E-glass	70-77	2.55-2.64	4.5-4.9	1.25-2.50
S-glass	86-90	2.46-2.49	5.4-5.8	15-25
R-glass	84-86	2.55	4.8	15-25
Carbon Fibers (12K)	220-240	1.7-1.8	0.7	44.2

The shell of the blades will be made mostly from E-glass with the use of carbon fiber in areas with high stresses.



Resin Selection for Shell of Blades

Resin	Weight (0.4)	Strength (0.2)	Stiffness (0.2)	Cost (0.2)	Total
Polyester	4	5	4	7	4.8
Vinyl Ester	5	6	6	6	5.6
Epoxy	7	8	8	4	6.8

Epoxy was selected for the resin.

Core Material Selection for Shell of Blades

- **End-Grain Balsa**- high strength and stiffness, inexpensive, more dense
- **Styrene Acrylonitrile (SAN) Foam**- good strength-stiffness to weight ratio, toughness
- **Poly Vinyl Chloride (PVC) Foam**- good strength-stiffness to weight ratio, not compatible with all materials
- **Polyethylene Terephalate (PET) Foam**- new technology, recyclable, made from abundant materials

SAN foam was selected
for the core.

Future Work

- Combined Modal/Fatigue Analysis
- Cost to Power Ratio
- Pricing for blade molds
- Ordering of material to construct blades
- Procurement of steel for tower
- Prototype construction

Summary

- Low wind speeds in southeast US inspired desire for taller wind turbine
- Final designs chosen for tower structure and blade design
- Currently getting quotes for purchasing.
- Next Steps
  - Obtaining materials
  - Building prototype

References

- http://www.aerospacemetals.com/contact-aerospace-metals.html
- http://www.onlinemetals.com/
- http://www.nrel.gov/docs/fy09osti/38060.pdf
- http://wind.nrel.gov/public/bjonkman/TestPage/FAST.pdf

Questions?