DOE Wind Turbine: System Integration

UGRADS Presentation

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Sustainable Power Incorporating Nature

NORTHERN ARIZONA UNIVERSITY
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Overview

Project Introduction

Problem Formulation

Proposed Design

Prototype Fabrication

Testing and Results

Cost

Conclusion

Introduction

National Collegiate Wind Competition

- Established by the United States Department of Energy (DOE)
- Competition
    - Business plan
    - Design and test a micro wind turbine

Source: DOE

Clients

- Karin Wadsack
  - Lead Professional Investigator
- David Willy
  - Faculty Advisor
- Secondary Client
  - US Department of Energy

Needs Statement & Project Goal

- There is limited access to electricity from renewable energy sources after the occurrence of disasters.
- Develop a small wind turbine used to power small electronics for use in post disaster scenarios.

Objectives

Objective	**Measurement Basis**	**Units**
Maximum of 3 people to assemble	Ease of construction	People
Inexpensive	Cost to construct a single turbine	Dollars
Power Output	Power produced	Watts
Lightweight	Overall weight of turbine	Kg
Small Size	Amount of space turbine takes up	m^3
Reliability	How long the turbine will last	Years
Durable Tower	Tower strength	MPa

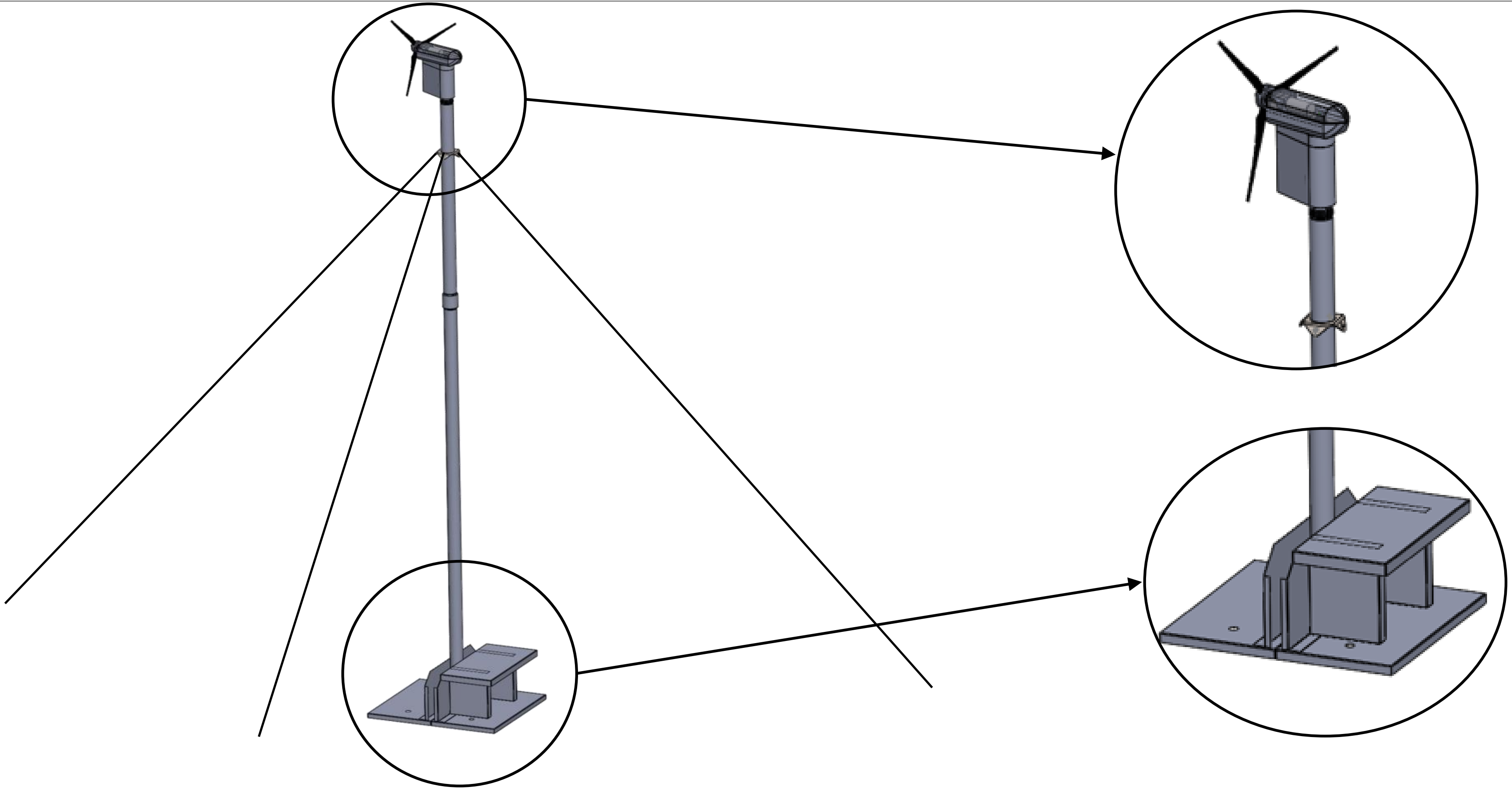
Constraints for Competition

- Turbine must produce a minimum of 10 W to power small electronics
- Rotor must fit within a 45cm x 45cm x 45cm volume
- Must use DOE provided generator (Great Planes Ammo GPMG 5225)
- Must be able to withstand fluctuating wind speeds up to 17m/s
- Rotor must be able to brake within 10% of rated rotor speed

Constraints for Business Model

- Must be able to be used in multiple different terrains for post-disaster scenarios
- Must be able to yaw into the wind
- Must be portable for transportation
- Be able to quickly assemble for emergency power supply
- Minimum tower height of 10ft

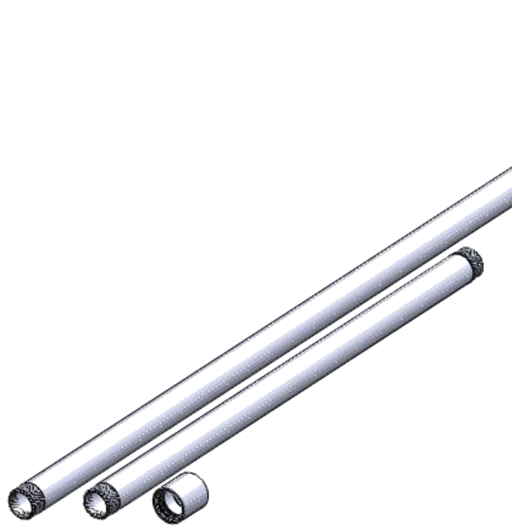
Assembly Design

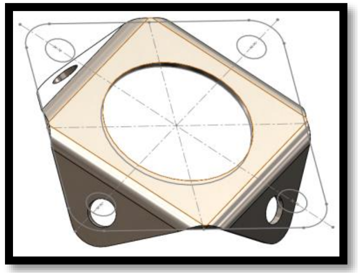


Selected Tower Design

McMaster Standard-Wall Aluminum Pipe	
Material	Aluminum
Pipe size (in)	1-1/2
Additional Specifications	Threaded on both ends

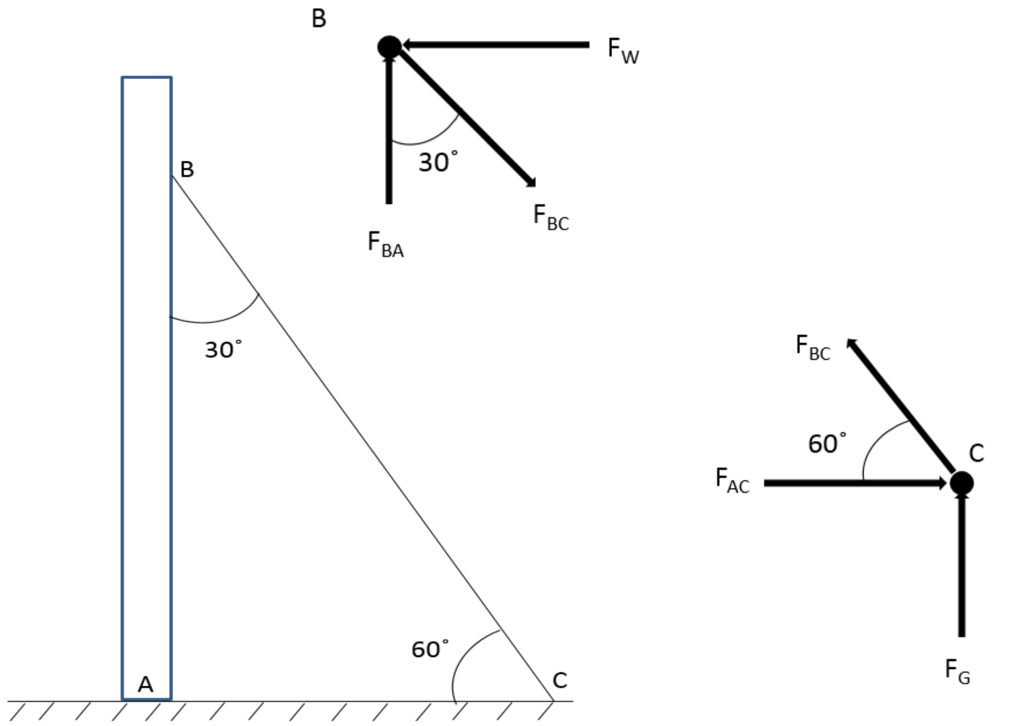
McMaster Type 304 Stainless Steel Wire Rope	
Material	Stainless steel
Size (in)	(1x 7) 1/16
Length (ft)	50
Breaking strength (lb)	500


Source: McMaster



Guy Wire Analysis

- Method of Joints
- Designed off 6m tower
- Horizontal load of 60N



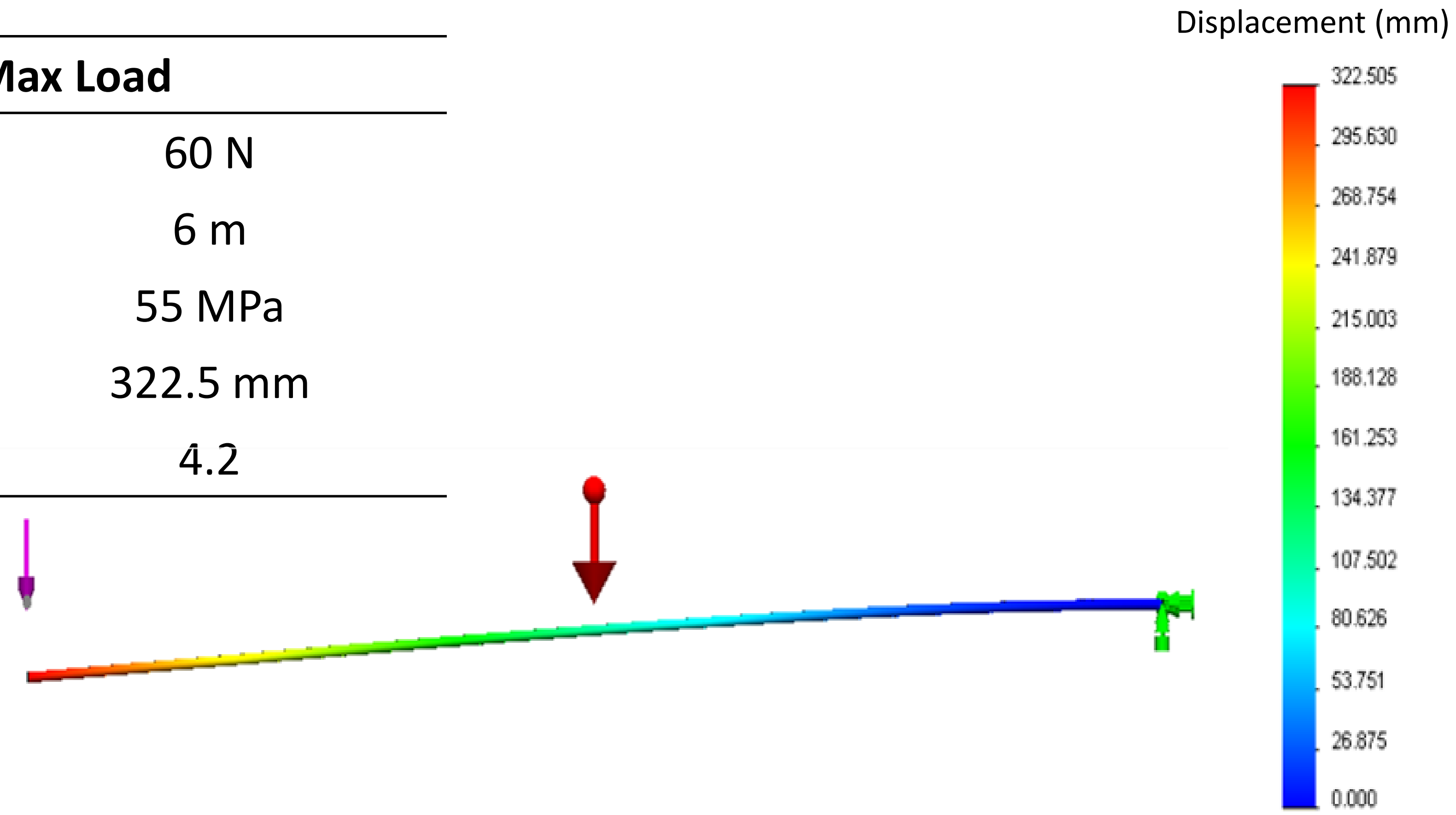
Guy Wire Results

Summary of Forces on Guy Wires	
F_{BC}	120 N
F_{BA}	104 N
F_{AC}	60 N
F_G	104 N

Survivability Wind Speed	
Air Density	1.2 kg/m^3
Area of Blades	0.16 m^2
Area of Tower	0.51 m^2
Velocity	61.79 m/s

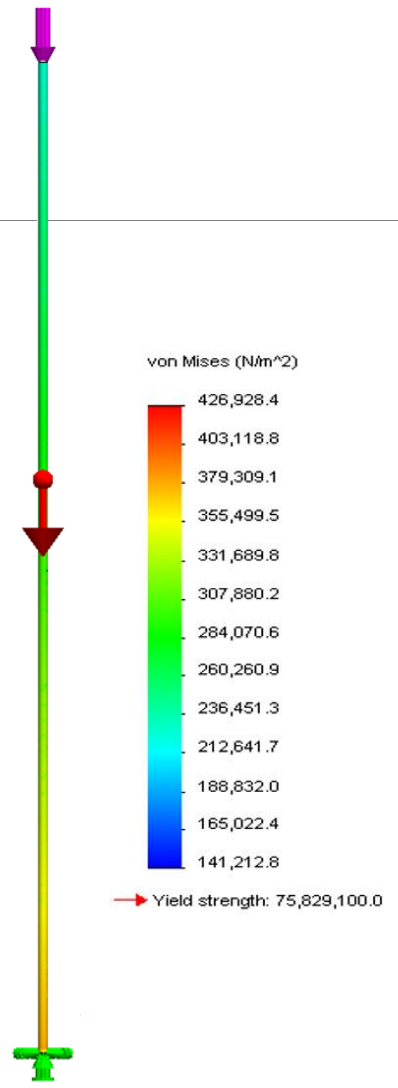
Tower Bending Analysis

Bending Analysis for Max Load	
Top Load from Turbine Weight	60 N
Tower Height	6 m
Maximum Bending Stress	55 MPa
Maximum Bending Displacement	322.5 mm
Bending Factor of Safety	4.2



Tower Buckling Analysis

Buckling Analysis With Guy Wire Supports for Max Load	
Top Load from Turbine Weight	60 N
Wind Load	100 N
Tower Height	6 m
Maximum Buckling Stress	0.4 MPa
Buckling Factor of Safety	180

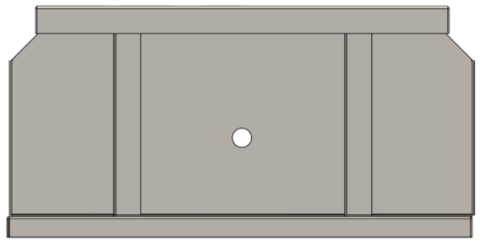


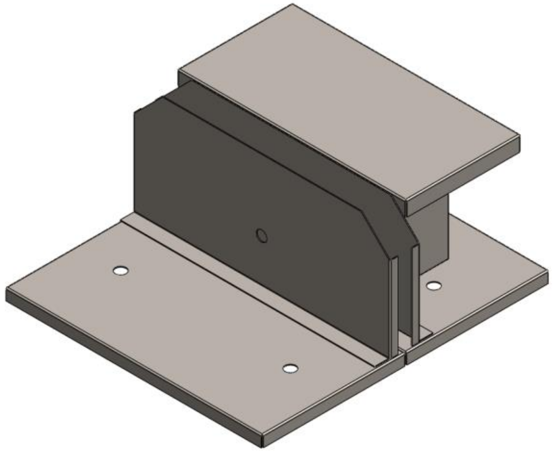
Tower Fabrication

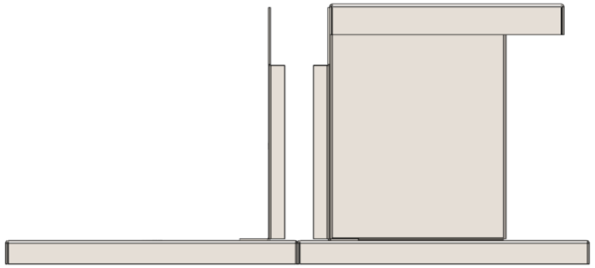
- Piping and coupling thread together
- Guy wire attachment piece milled and corners bent
- Guy wire crimped into place

Selected Base Design

- Withstands wind forces to keep wind turbine upright
- Base constructed out of 16 gauge sheet metal
- Acts as pivot point for tower
- Shelf to place small electronics while charging



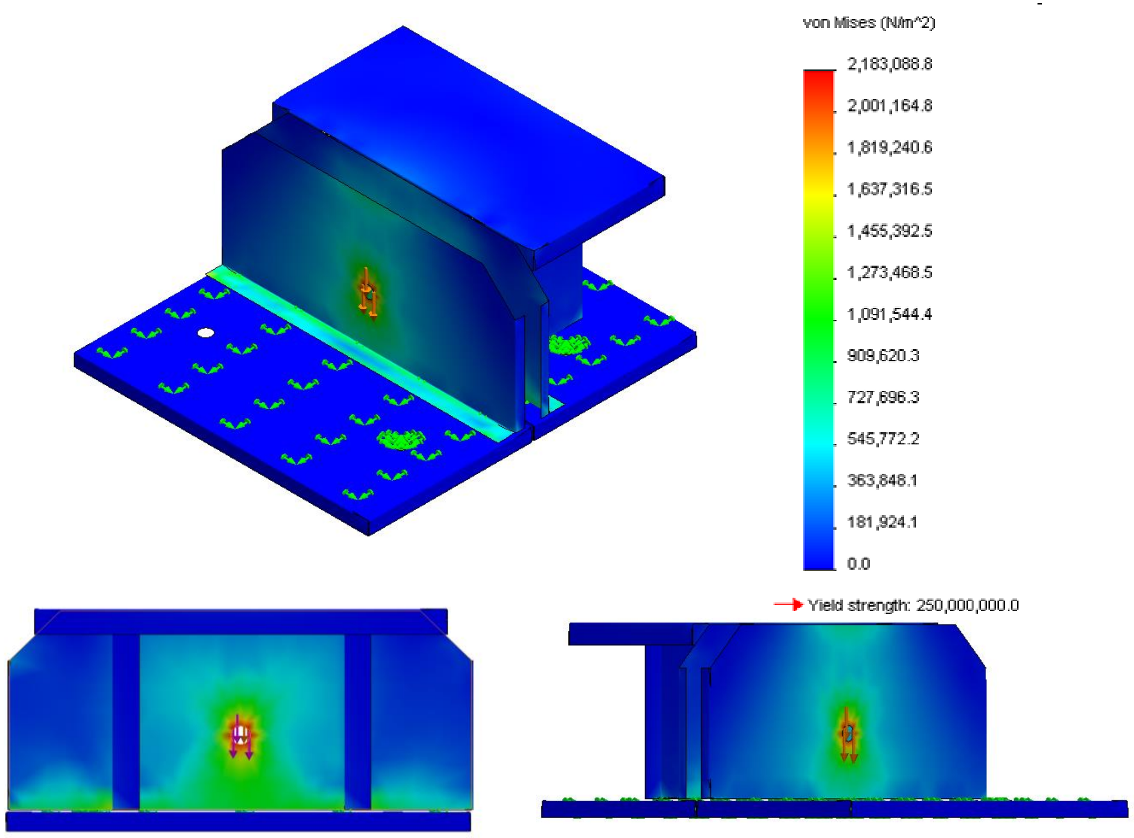




Base Von Mises Stress Analysis

FEA Analysis

- Factor of safety: 4
- Force applied at bolt location
- Largest stress: 2.18 MPa



Base Fabrication

Processes

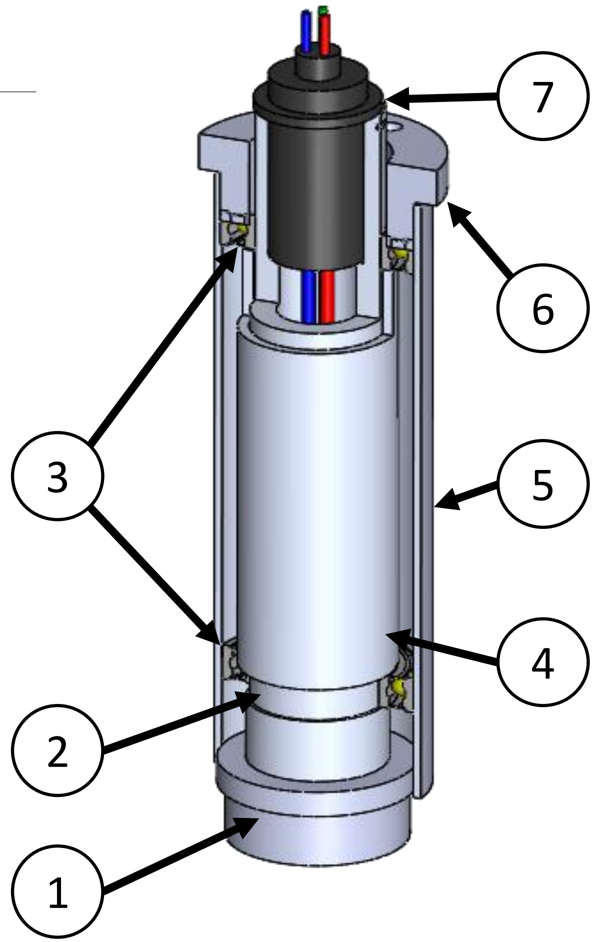
- Layout for cuts and bends
- Floor shear and angle shear for cuts
- Bend and Brake for bends
- Hydraulic press for holes
- Welded individual pieces together

Completed Base Design

- Sheet metal parts cut to specs
- All pieces welded together
- Components coated with galvanizing spray and primer

Selected Yaw System

- Components:
  1. Base plug
  2. Aluminum yaw shaft
  3. Two deep groove ball bearings
  4. Bearing spacers
  5. Aluminum yaw sleeve
  6. Mainframe yaw plug
  7. Slip ring



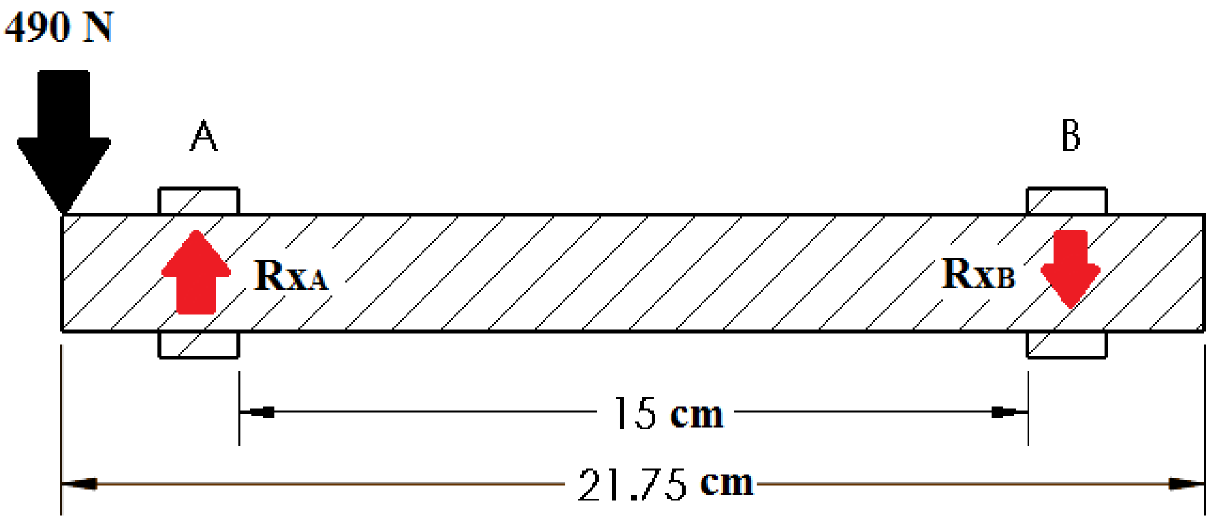
Selected Slip Ring

- Three electric leads
- Maximum current rating of 30 amps
- Maximum voltage rate of 400VDC/VAC
- Diameter of 22 mm

Source: Senring Electronics

Bearing Analysis

- Maximum resultant load of 646 N on bearing A
- Results in a dynamic load (C10) of 12kN
- Two single row, deep groove ball bearings

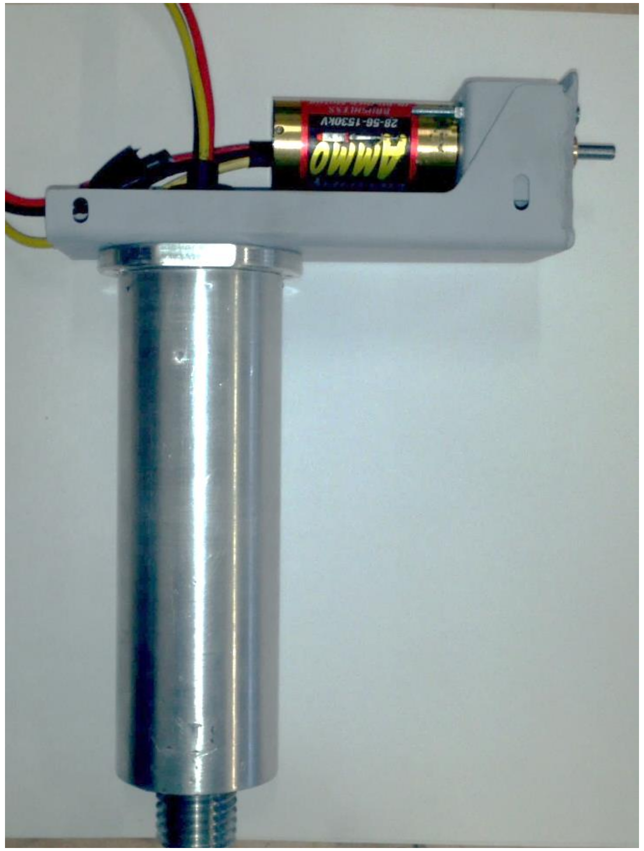


Yawing Mechanism Fabrication

- Base plug threaded and press fit into top of tower
- Aluminum shaft turned down and bored with lathe
- Main frame yaw plug press fit into yaw sleeve and bolted to main frame
- Other components cut with band saw

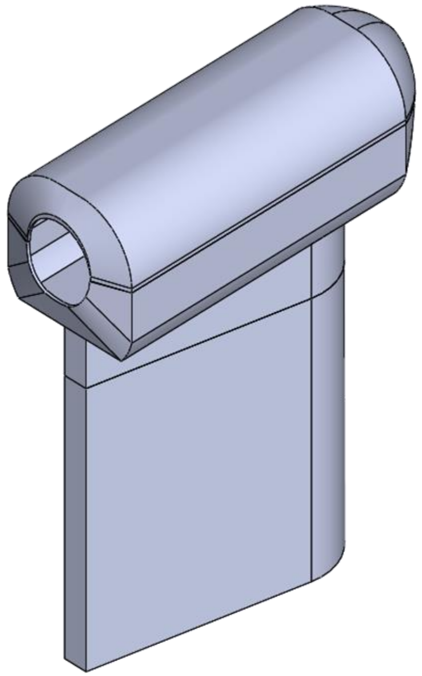
Final Yaw Assembly

- Yaw system threaded into tower
- Main frame bolted to top of sleeve
- Slip ring wires run through system and to generator
- System encased by nacelle

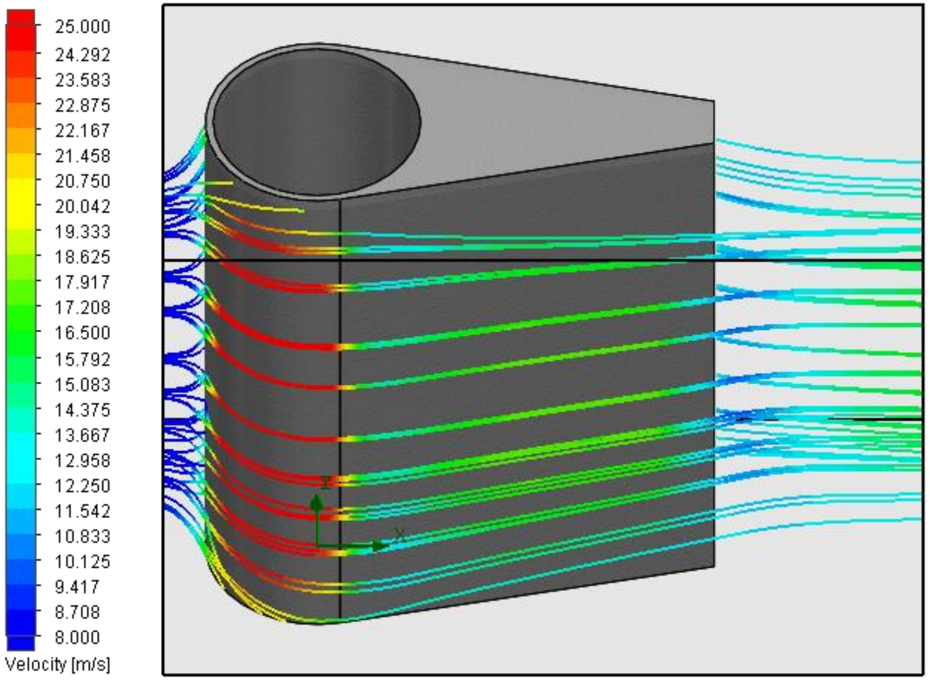


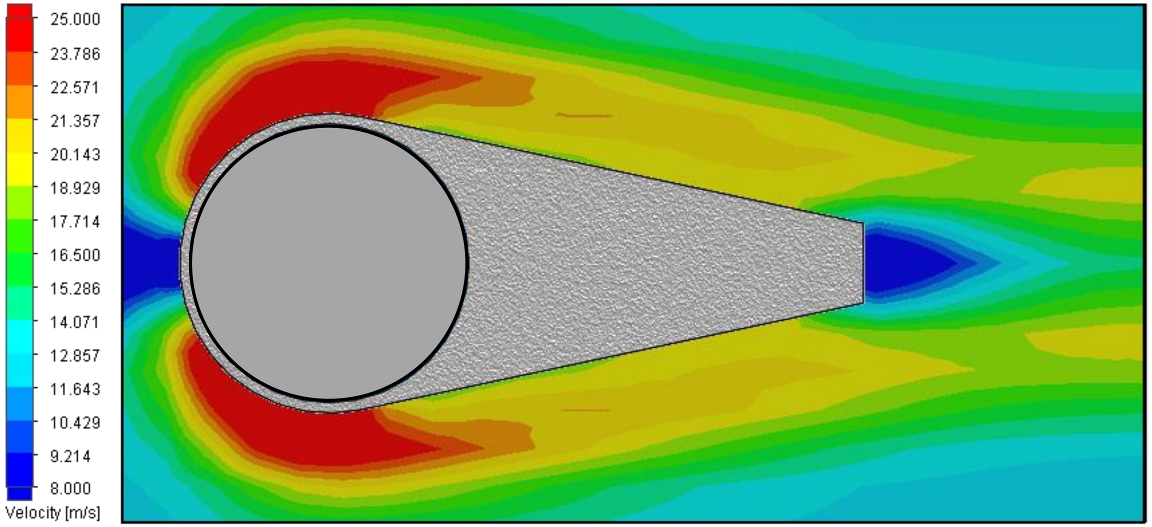
Selected Nacelle Design

- Downwind turbine design chosen
- Integrated with faired tower
- Encases main frame
- Protects electrical components from environment
- Rapid prototyped



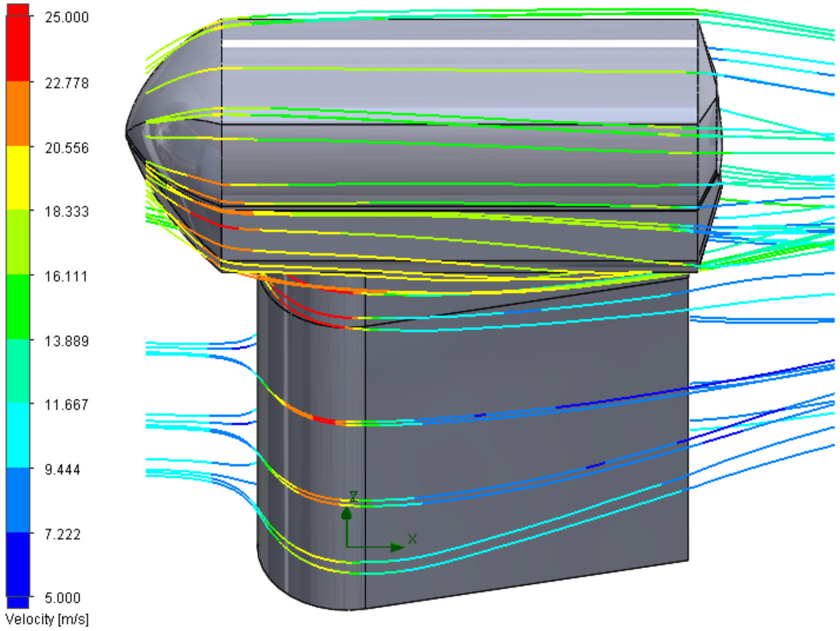
Flow Analysis (Faired Tower Section)





Nacelle Flow Analysis

- Analyzed for rated wind speed of 12 m/s
- Adequately allows wind flow to turbine blades
- Estimated effects from boundary layer on blades



Nacelle Fabrication

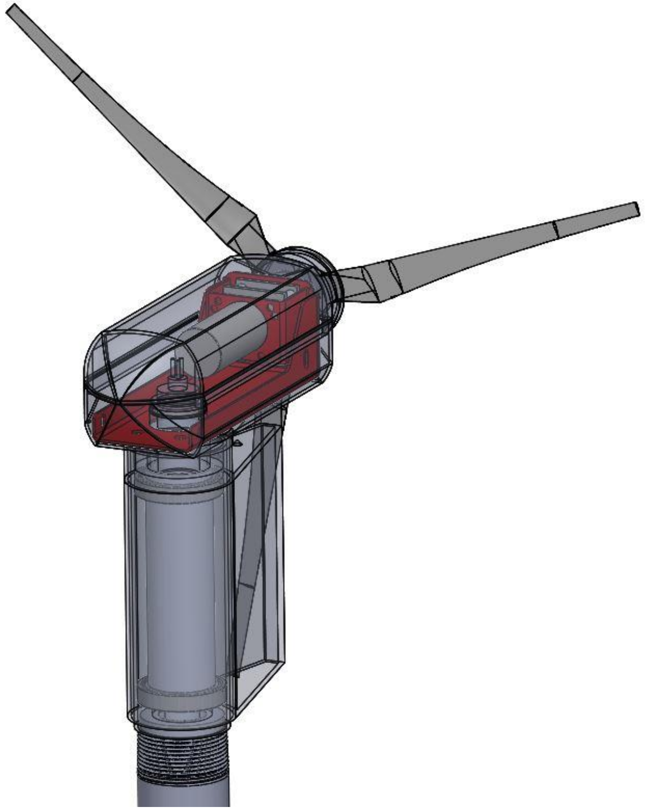
- Rapid prototyped in 3 pieces
- Nacelle and faired tower section permanently connected with epoxy
- Nacelle attaches to main frame by fasteners
- Top half also attaches by fasteners
- Painted blue for aesthetics

Final Nacelle Assembly

- No tail is needed, and faired tower section helps efficiency of blades
- Faired tower section reduces vortices shed from the trailing edge of the tower
  - Integrated into nacelle

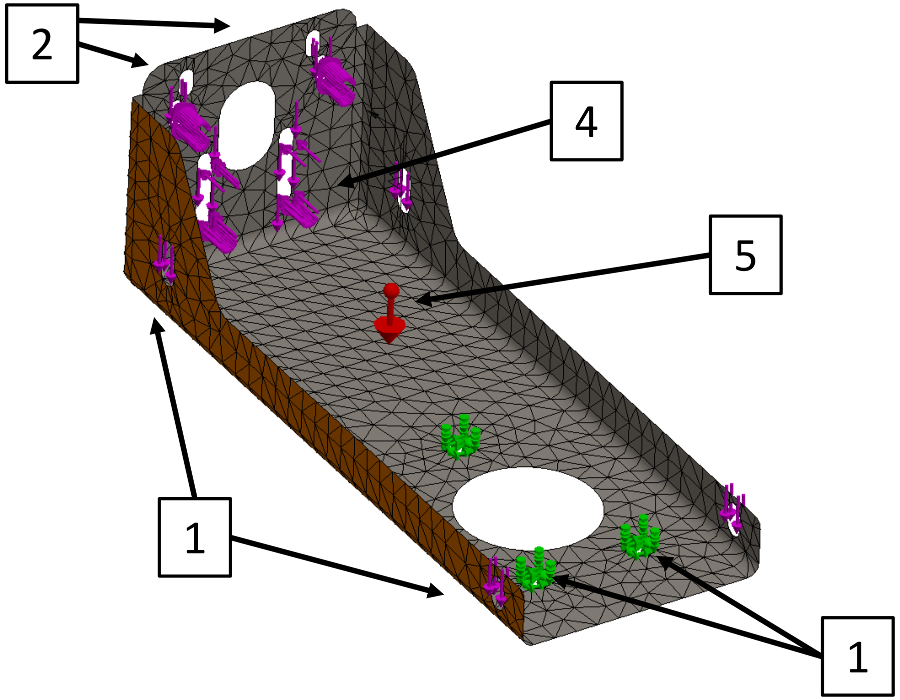
Selected Main Frame

- Main structural member of the turbine
- Built as two main parts
  - Main frame structure
  - Generator mounting bracket
- 16 gauge steel
  - Galvanized coating
- Connects components such as:
  - Generator
  - Gearbox
  - Nacelle
  - Yaw system



Main Frame Analysis

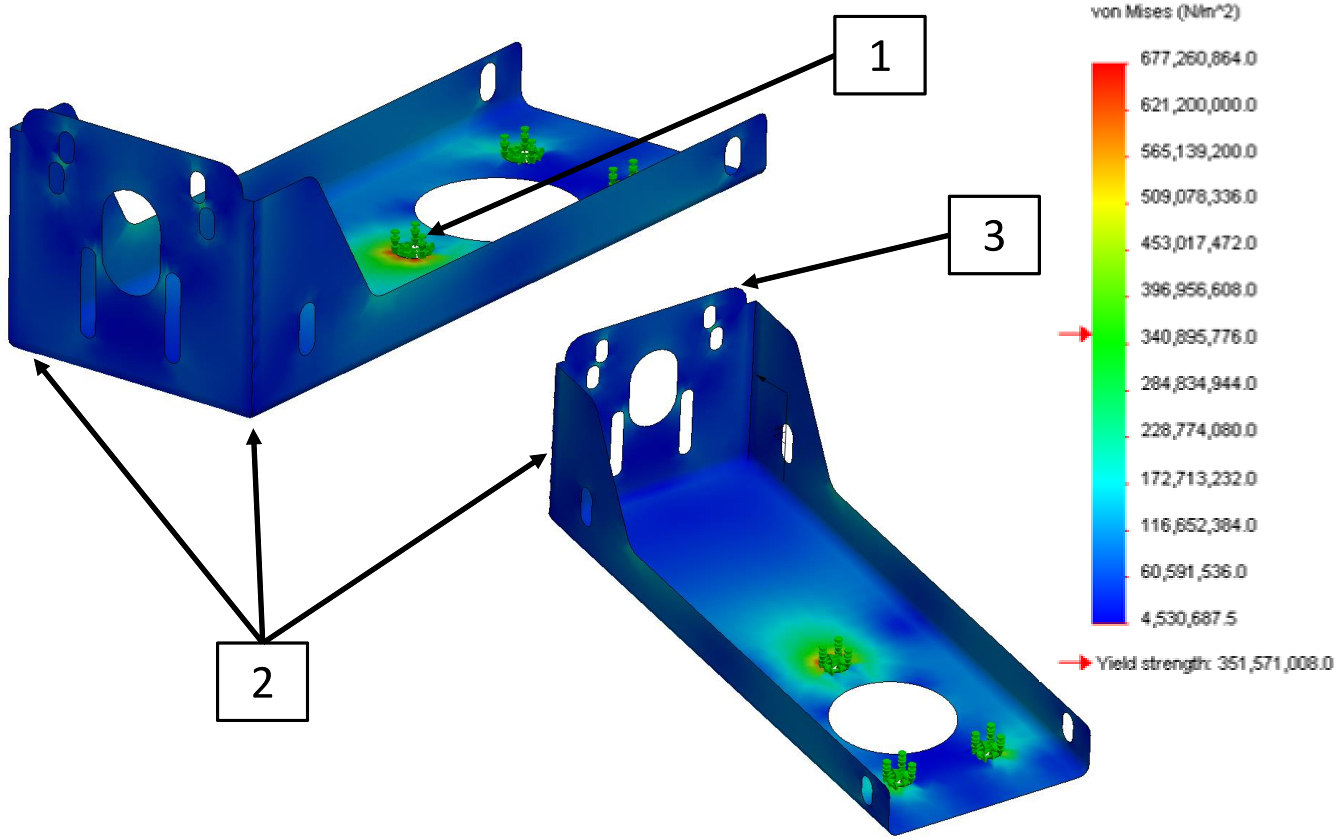
Static Structural Loading Conditions	
Boundary Conditions (1)	Fixed
Thrust Load (2)	30 N
Nacelle Weight (3)	20 N
Electronics Weight (4)	30 N
Gravitational Effect (5)	9.81 m/s^2



Main Frame Analysis Cont.

Maximum von-Mises Stress	
Critical Stress (1)	677 Mpa
Stress at Location of Interest (2)	172 MPa
Factor of Safety at (2)	2.03

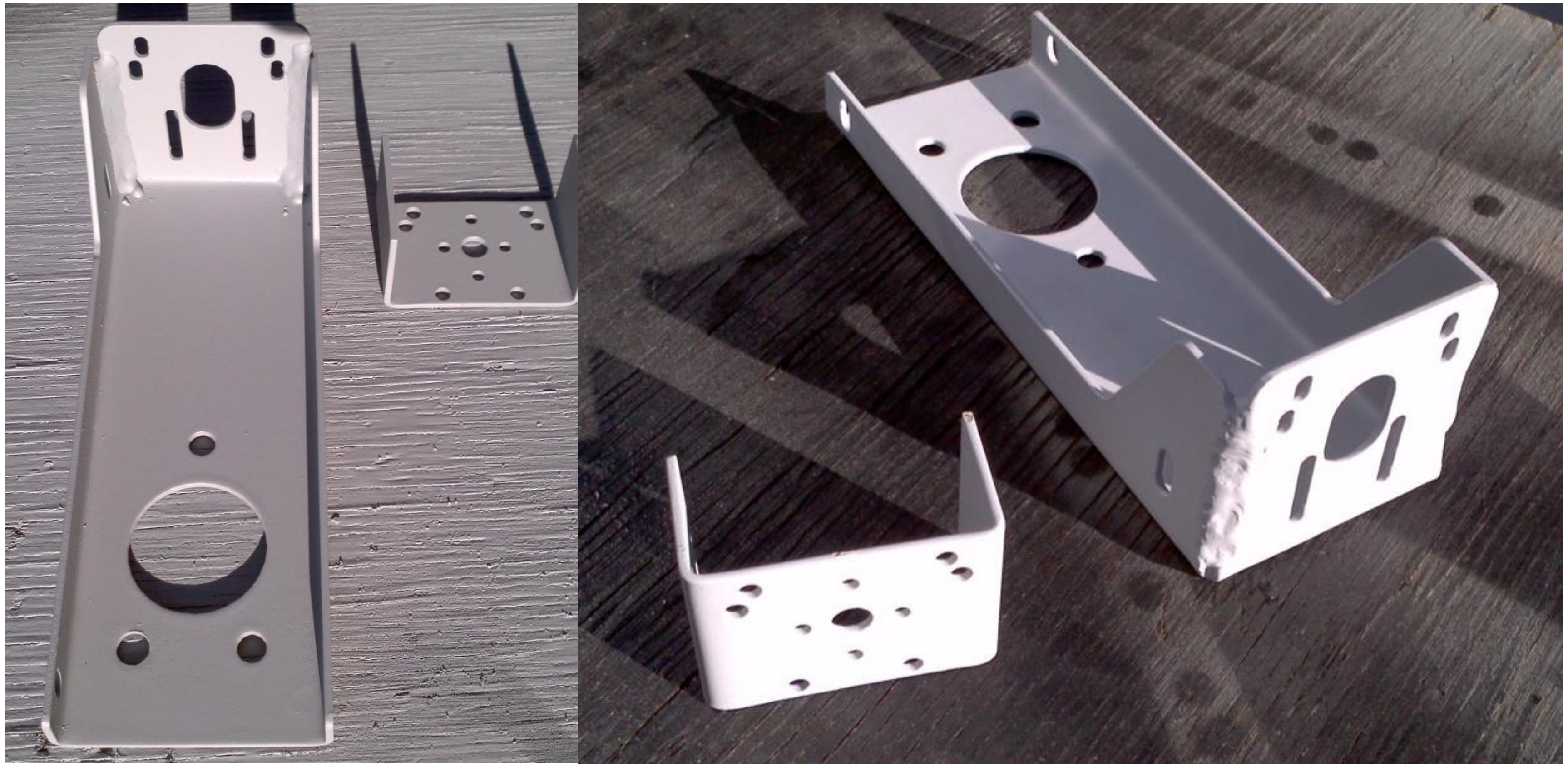
Deflection of Main Frame when Loaded	
Maximum Deflection (3)	1.63 mm



Main Frame Fabrication

- Machined with Tormach CNC
- Milled out as one piece
- Bent into final shape
- Corners welded for structural rigidity
- Machined out of 16 gauge sheet metal

Final Main Frame Assembly



Final Assembly

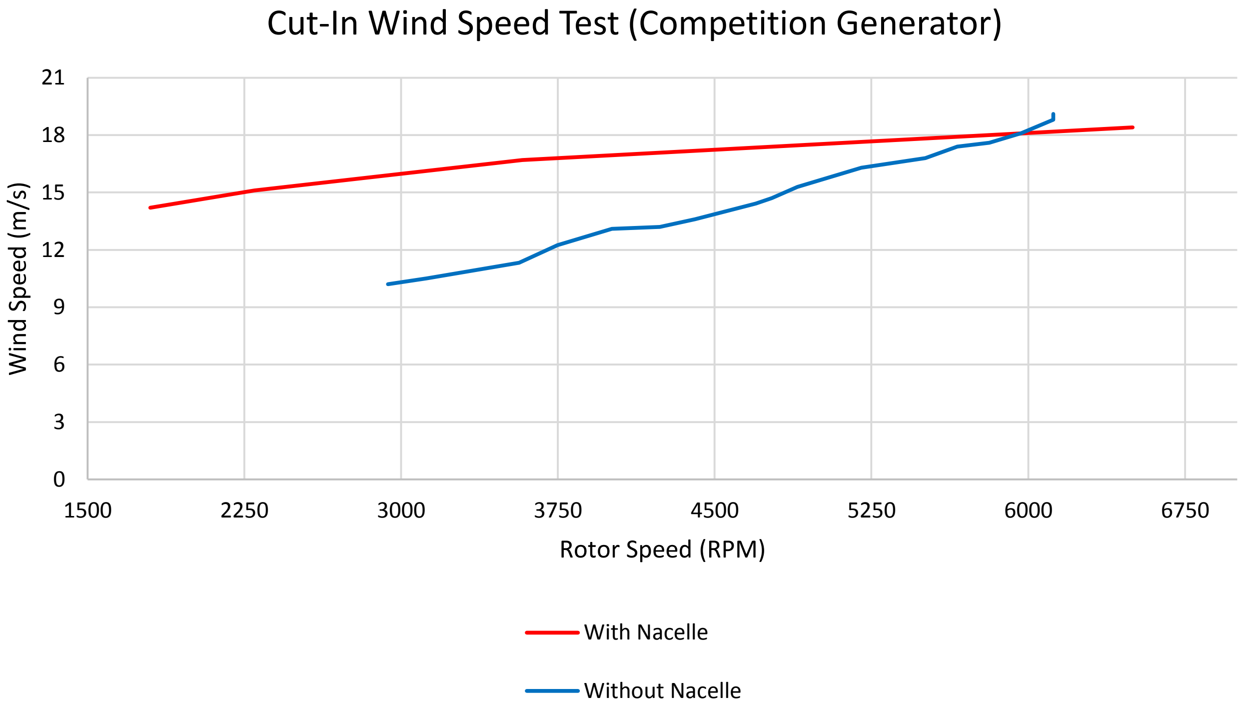
Testing

System testing consisted of:

- Cut-In Wind Speed
- Cut-Out Wind Speed
- Rated RPM
- Ability to yaw

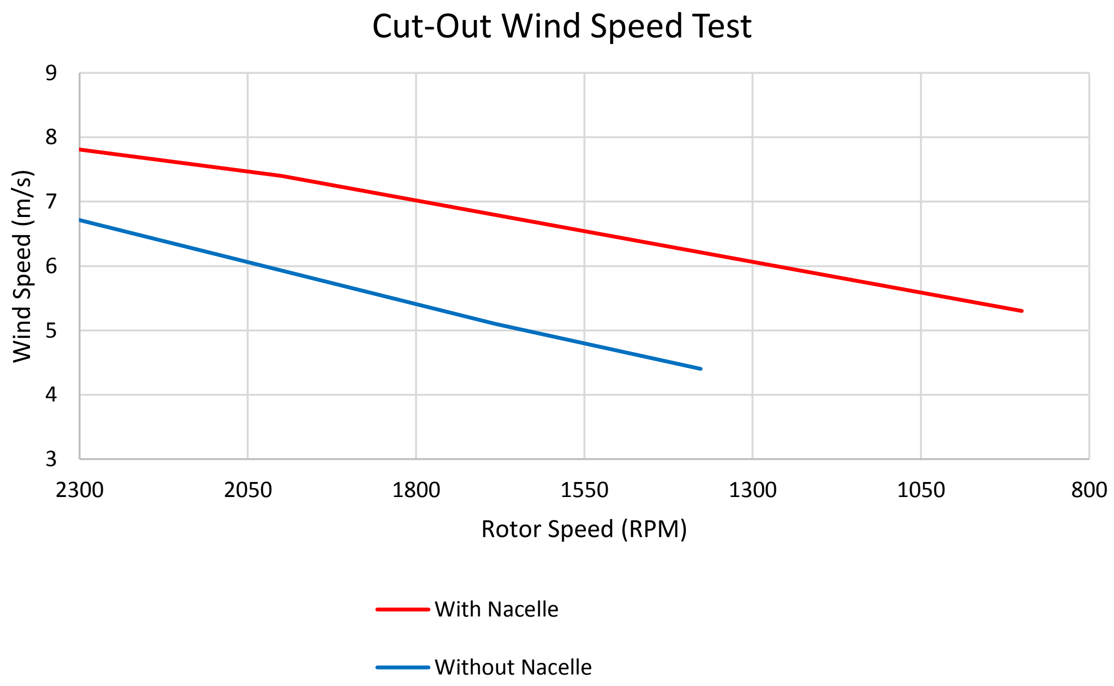
Cut-In Wind Speed/Rated Rotor RPM

Test	With Nacelle	Without Nacelle
Cut-In Wind Speed	14.2 m/s	10.2 m/s
Maximum Rotor Speed (17 m/s)	6500 RPM	6120 RPM



Cut-Out Wind Speed/Ability to Yaw

	Cut-Out Wind Speed (m/s)	Ability to Yaw
With Nacelle	5.2	Yes
Without Nacelle	4.4	Yes



Cost Analysis

	Material	Manufacturing
Tower	$413.00	$45.00
Base	$38.50	$180.00
Main Frame	$1.50	$22.50
Yaw System	$133.00	$112.50
Nacelle	N/A	$100.00
Total	$586.00	$430.00

Cost of main frame assembly	$369.00
Full cost including tower and base	$1067.00
Total project cost	$365.00

Conclusion

- Integrated systems for the DOE Collegiate Wind Competition
- Successfully developed the following components for a small wind turbine:
    - 21 ft. Tower
    - Steel Base
    - Functioning Yawing System
    - Weather Resistant Nacelle
    - Structurally Sound Main Frame

Conclusion

- Testing reveals the nacelle:
  - Helps with the rated rotor RPM
  - Cuts in and out at higher wind speeds
- Competing in the DOE Collegiate Wind Competition
  - May 5th- May 7th, 2014
  - Las Vegas, Nevada

Acknowledgements

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Questions?

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