KNIGHT & CARVER

WIND BLADE DIVISION

# Sweep-Twist Adaptive Blade Design

## Project Overview

presented by Gary Kanaby

# KNIGHT & CARVER


- San Diego Bay– California
- 90,000 $ft^2$ Facility
- 15 Ton Overhead Cranes
- On-site Railroad access
- ISO 9001-2000 compliant
- 10 years in Blade Business
- Blade Repair Onsite/Offsite
- Blade Manufacturing for Retro-fit Market
- Blade Testing
- Engineering

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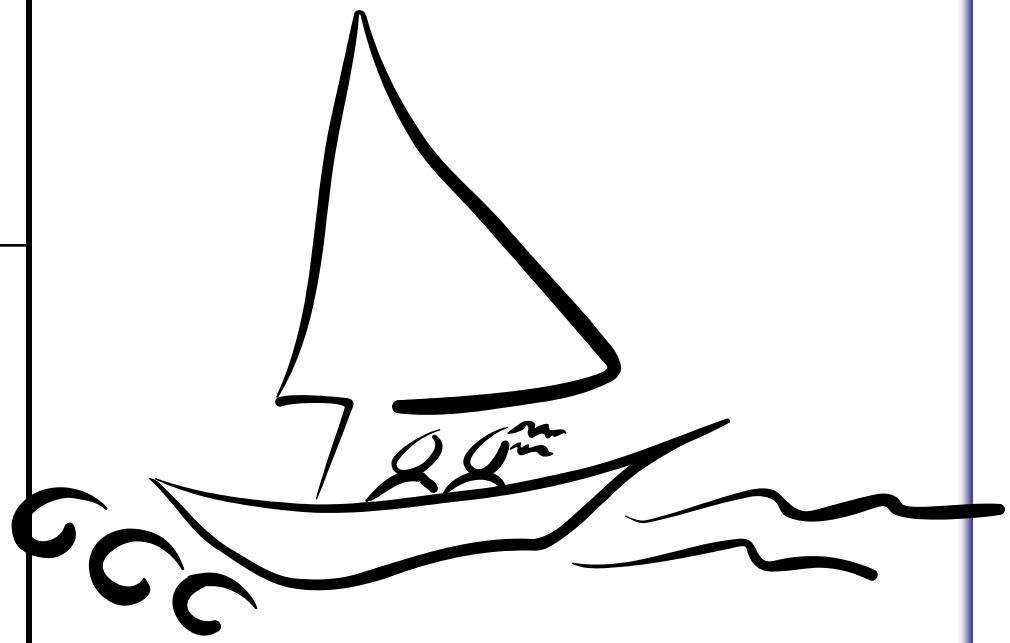
# LWST-PHASE II

| | |
|---|---|
| **In Response To** | Low Wind Speed Turbine Project – Phase II (Component RFP) |
| **Goal** | Reduce COE in Class 4 winds to 3 cents/kWh |

REEF THE SAILS!



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# DEVELOPMENT TEAM

| | | |
|---|---|---|
| **Gary Kanaby** | KNIGHT & CARVER | Project Leader |
| **Thomas Ashwill** | Sandia National Laboratories | Project Manager |
| **Rafay Navaid** | KNIGHT & CARVER | Manufacturing, Testing |
| **Dr. Kevin Jackson** | Dynamic Design | Principal Investigator |
| **Mike Zuteck** | MDZ Consulting | Originator of the Sweep Twist, Structures |
| **Scott Larwood** | UC Davis | Dynamics |
| **Dr. Case Van Dam** | UC Davis | Aerodynamics |
| **D.M. Hoyt** | NSE Composites | Finite Element Analysis |

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# DESIGN GOALS

- Enable the use of a larger, more productive rotor
- Reduce operating loads using outer blade sweep to create twist coupling without angled fiber
- Develop blade for existing turbine to validate concepts : Z-750
- Develop retro-fit product

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# Z-750 WIND TURBINE

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# Z-750 TURBINE SPECIFICATIONS

| | | |
|---|---|---|
| **Main Features** | Rotor Diameter | 48/50 [m] |
| | Rotor Hub Height | 65 [m] |
| | Rated Power | 750 [kW] |
| | Rated Rotor Speed | 32.3 [rpm] |
| **Rotor Hub** | Hub Design | Variable, Collective Pitch-to-feather |
| | Hub Radius | 0.816 [m] |
| **Drivetrain** | Design | Integrated gearbox |
| | Gearbox Ratio | 37.15 |
| | Generator type | Double-Fed Wound Rotor |
| | Synchronous Generator Speed | 1200 [rpm] |
| **Tower** | Tower Type | Steel Lattice with X-bracing or Tubular steel |

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# Z-750 BLADE SPECIFICATIONS

| | |
|---|---|
| **Blade Length** | 24.50 [m] |
| **Maximum Chord** | 2.40 [m] |
| **Thickness** | 18-40 [%] |
| **Twist** | 11.5 [deg] |
| **Blade Area** | 39.2 [$m^2$] |
| **Mass without Bolts** | 2200 [Kg] |
| **Design TSR** | 7.3 |

| | |
|---|---|
| **Nominal Tip Speed** | 75 [m/s] |
| **Rotor Diameter** | 50.0 [m] |
| **Material** | Glass/Epoxy |
| **Maximum Cp** | 0.50 |
| **Nominal Wind speed** | 10.9 [m/s] |
| **Airfoils** | EUROS+DU<br>NACA 64-618 |

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# DESIGN TARGETS

| | |
|---|---|
| **Axis Mass Moment** | 20,000 [Kg-m] |
| **Max Power Deflection** | 56 [inches] , 1422 [mm] |
| **Flatwise Frequency** | >3p |
| **Edgewise Frequency** | >4p |
| **Flatwise Loads** | Similar to Z-750 |
| **Pitch Moment** | Similar to Z-750 |
| **Materials** | Fiberglass Epoxy |

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# DESIGN PARAMETERS INVESTIGATED

- Rotor Speed (RPM)
- Blade Stiffness (EI)
- Spanwise Mass
- Chordwise Mass
- Total Blade Sweep
- Sweep Curve Exponent

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# FULLY INTEGRATED DESIGN—EVERYTHING IS A PARAMETER

- Blade Planform
- Airfoil Thickness vs Span
- Sweep Magnitude and Curve
- Spar Cap Position and Sizing
- Airfoil Panel Composition
- Materials and Process
- Root Forward Sweep

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# STAR BLADE SPECIFICATIONS

| | Z-750 | STAR |
|---|---|---|
| **Blade Length** | 24.50 [m] | 27.20 [m] |
| **Maximum Chord** | 2.40 [m] | 2.40 [m] |
| **Thickness** | 18-40 [%] | 16-40 [%] |
| **Twist** | 11.5 [deg] | 11.5 [deg] |
| **Blade Area** | 39.2 [$m^2$] | 46.3 [$m^2$] |
| **Mass without Bolts** | 2200 [Kg] | 2245 [Kg] |
| **Design TSR** | 7.3 | 8.0 |
| **Nominal Tip Speed** | 75 [m/s] | 92 [m/s] |
| **Rotor Diameter** | 50.0 [m] | 56 [m] |
| **Material** | Glass/Epoxy | Glass/Epoxy |
| **Nominal Wind speed** | 10.9 [m/s] | 10.0 [m/s] |
| **Airfoils** | EUROS+DU, NACA 64-618 | EUROS+DU, STAR Series |

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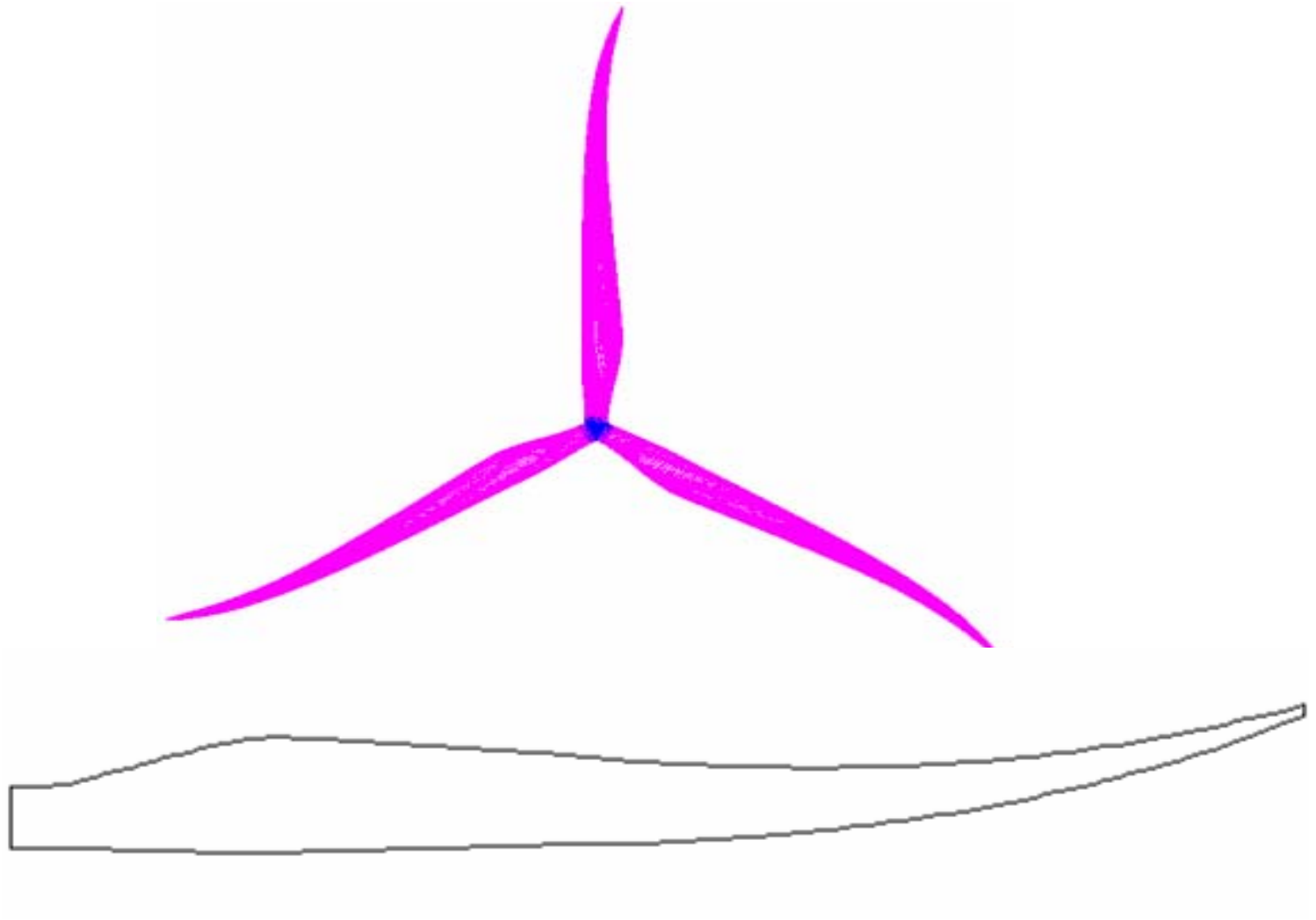
# STAR ROTOR AND BLADE



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# DESIGN RESULTS

| | TARGET | STAR |
|---|---|---|
| **Axis Mass Moment** | 20,000 [Kg-m] | 19,661 [Kg-m] |
| **Max Power Deflection** | 56 [inches],1422 [mm] | 56.6 [inches],1438[mm] |
| **Flatwise Frequency** | >3p | 3.75p |
| **Edgewise Frequency** | >4p | 4.57p |
| **Flatwise Loads** | Similar to Z-750 | Similar to Z-750 |
| **Pitch Moment** | Similar to Z-750 | Similar to Z-750 |
| **Materials** | Fiberglass Epoxy | Fiberglass Epoxy |

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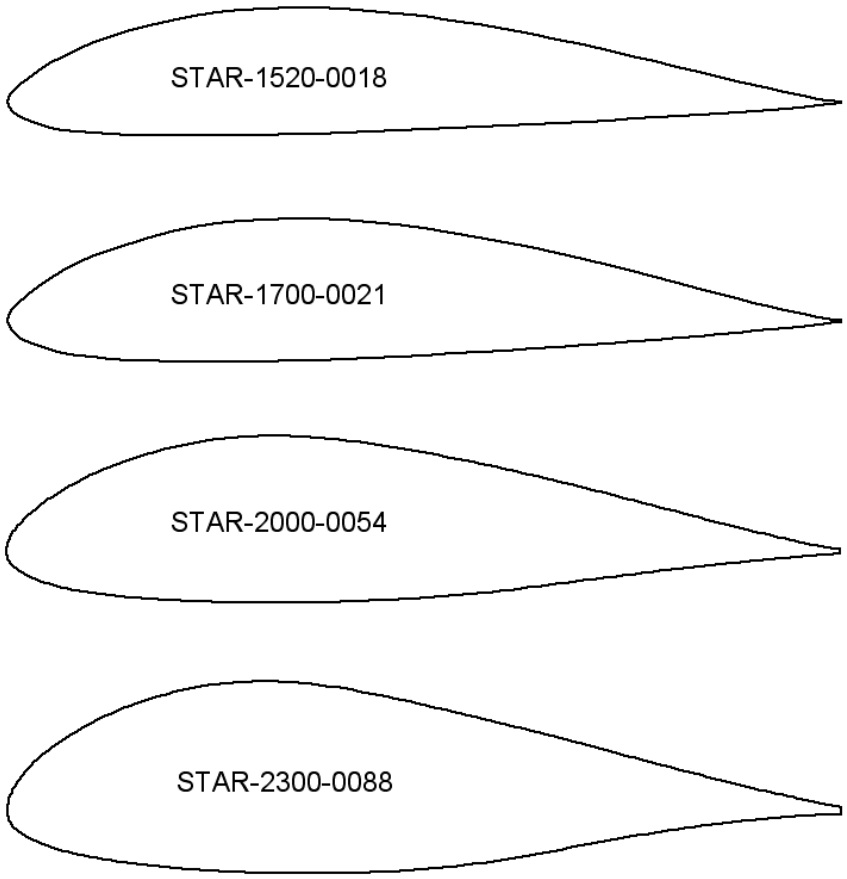
# STAR AIRFOILS-SAMPLES

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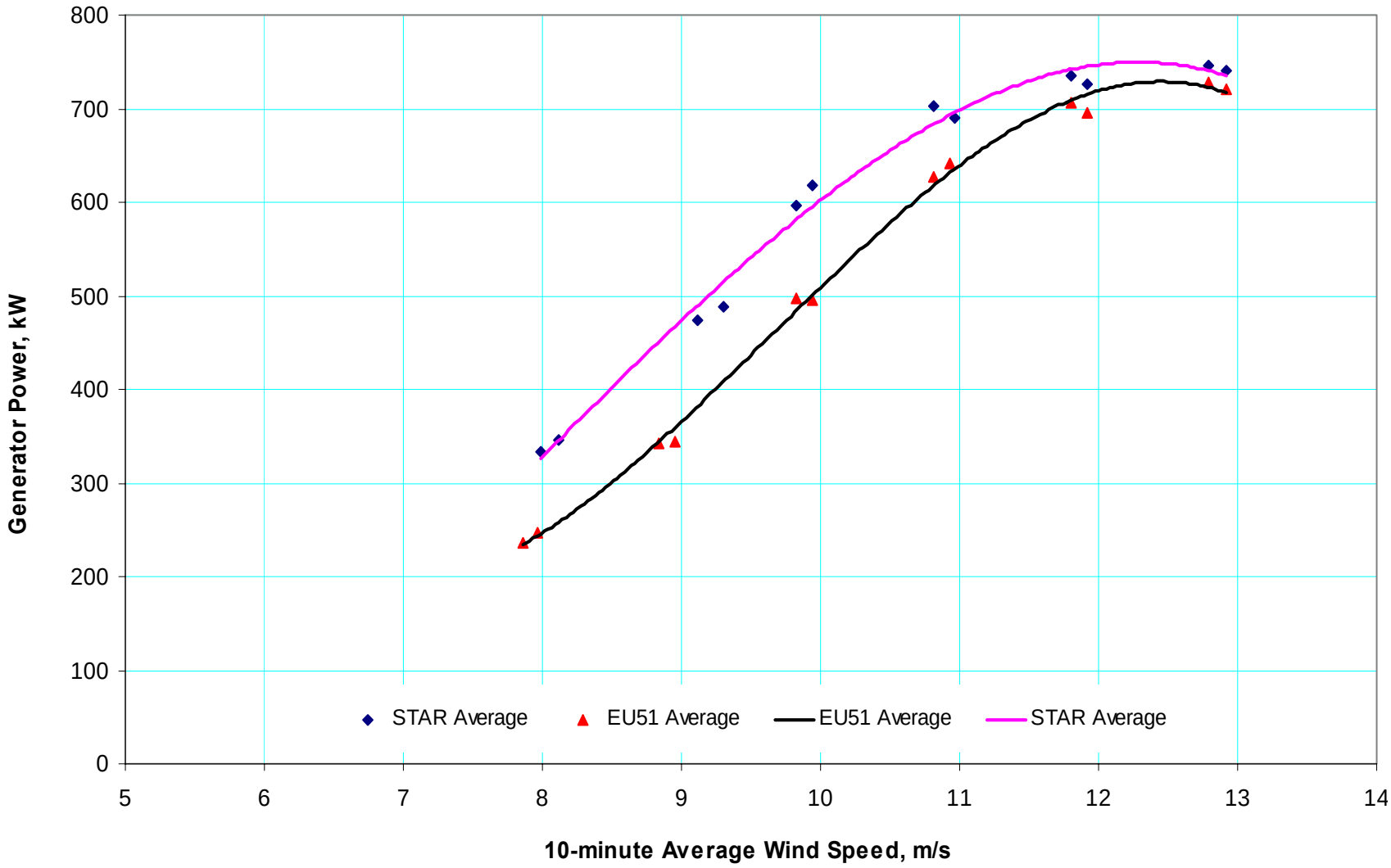
# PREDICTED-POWER CURVE

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# PERFORMANCE SUMMARY

- **STAR is predicted to shed 20% of the root moment via tip twist of nearly 3 degrees**
- **Preliminary design estimates indicate STAR will yield 5-10% greater energy capture in IEC class III winds than baseline**
- **Steady-State bending moment similar to that of baseline rotor**
- **Stiffness driven design→Very long fatigue life**

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# DESIGN FOR PRACTICALITY

- 2.4m Sweep -> 3 Blades on Trailer
- Sweep Curve Eases Skin Curvature
- Exotic/Expensive Materials Avoided
- Match Moments to Existing Blades
- Onsite impregnation of laminates acheives composites equal to pre-preg and pultrusions.

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# BLADE MANUFACTURING

- Resin Impregnator used to create ‘Prepreg’ material for lamination
- Spar Cap fabricated using uni-directional fibers similar to Pultrusion process
- Complete blade structure vacuum bagged and post cured
- Superior quality fabrication
- Manufacturing ISO compliant
- Manufacturing GL certified

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# TIP PLUG UNDER CONSTRUCTION

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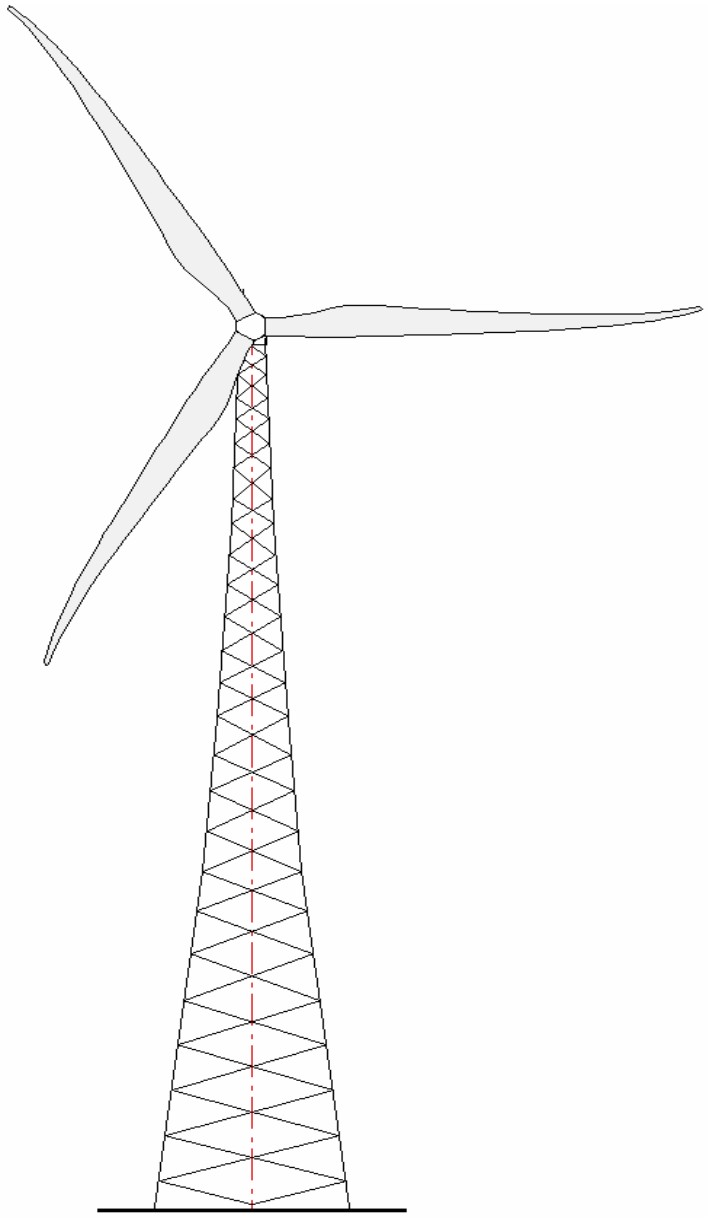

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