Research on recycled carbon fiber reinforced thermoplastic for application on floating vertical axis wind turbine structures

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Paper Number:1247

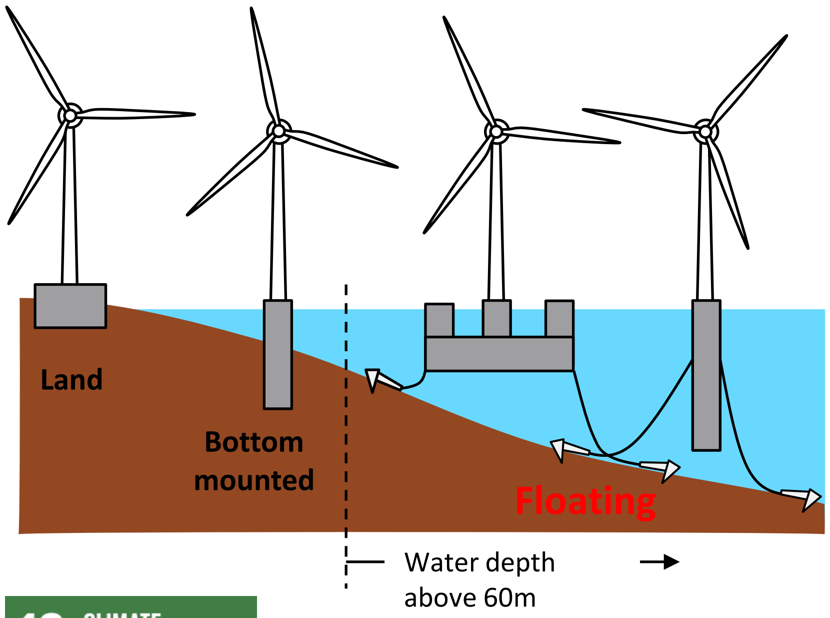
1. Research Background

2. Analytical Model

3. Numerical Study

4. Conclusions

Development of Deep Wind



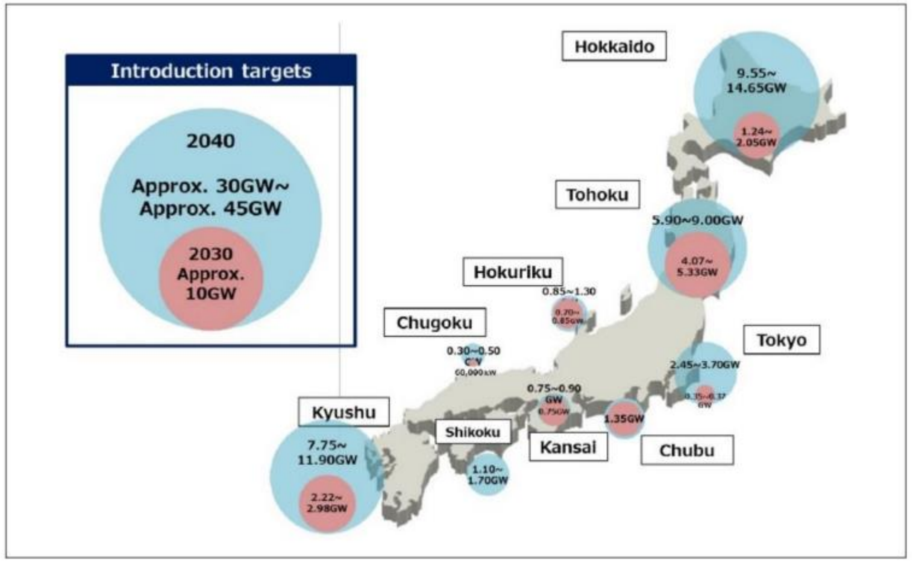


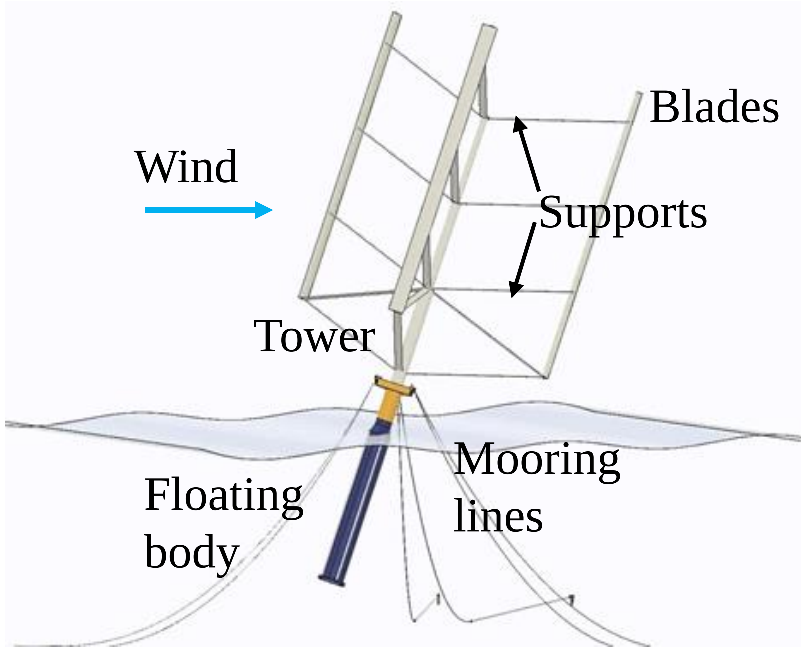
FIGURE 3. OFFSHORE WIND POWER GENERATION CAPACITY IN JAPAN [1]

Background

- Global Energy Crisis and Greenhouse Effect.
- Japan's onshore wind resources are scarce.
- The Oceans around Japan are deep, and there is not enough continental shelf.

[1] METI (2020), Public-Private Council 2nd Meeting Materials (https://www.meti.go.jp/shingikai/energy_environment/yojo_furyoku/002.html)

Floating Vertical Axis Wind Turbine



Floating **Vertical axis** wind turbine[1]

Floating **Horizontal axis** wind turbine[2]

Merits

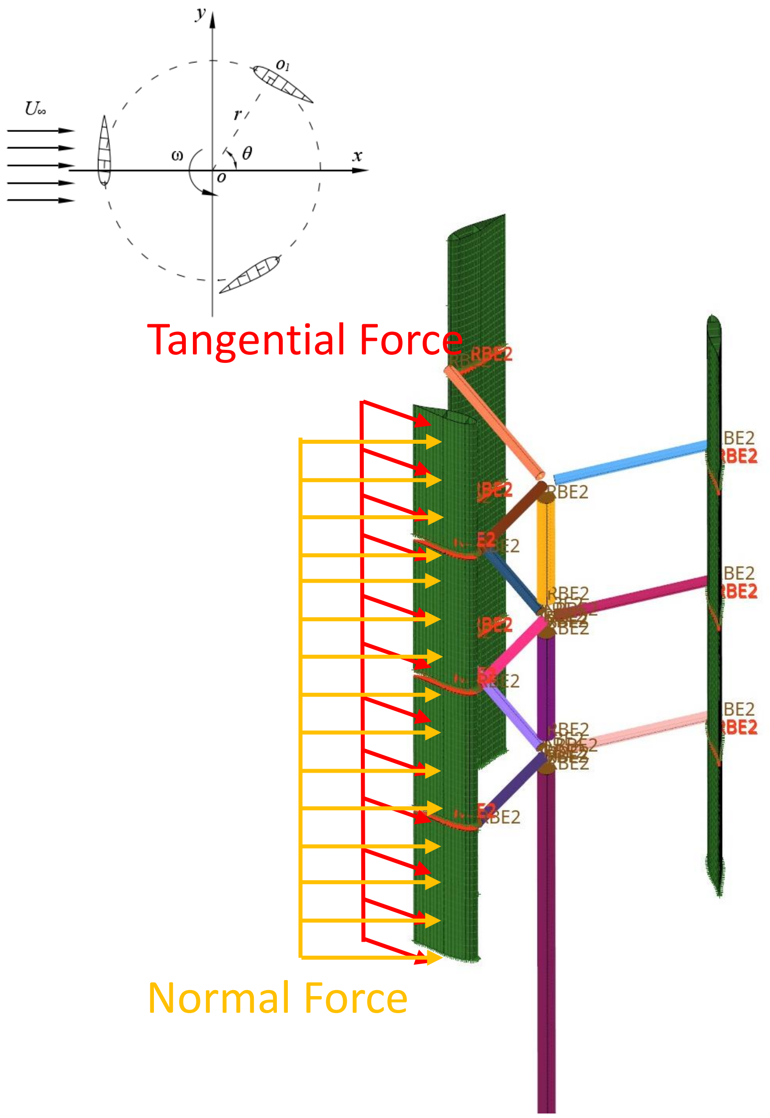
- No dynamic self-load, more potential to be large-scaled, more simple blade shape
- The low foundation costs are associated with a low center of gravity.

Primary problems:

- Balance of the structure weight and stability
- Practical design method considering the use of composite materials

[1] Albatross Technology (albatross-technology.com)
[2] CarbonTrust:Floating Offshore Wind（2015）:Market and Technology Review,18

Design Load Case

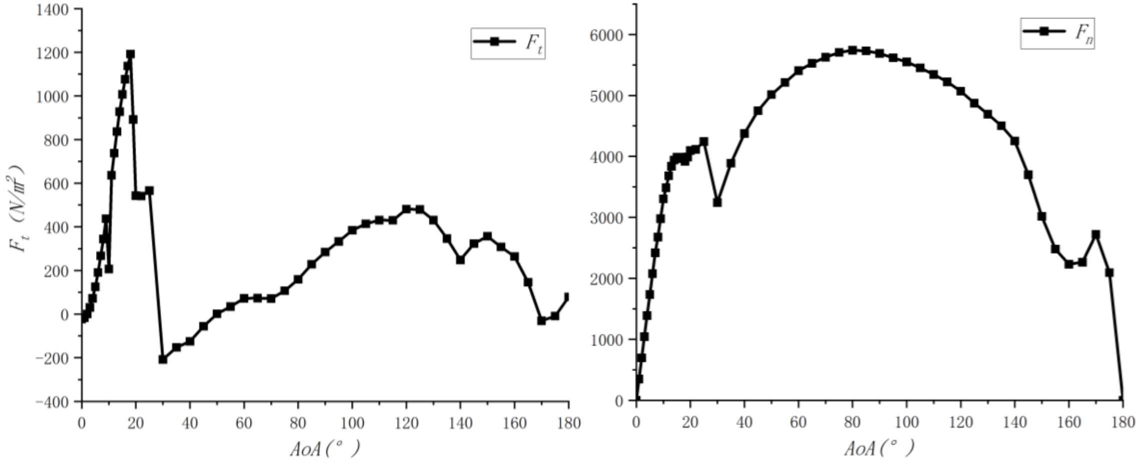


- **Extreme wind load (Design load cases 6.1)**

- The wind turbine class is I, so the reference 50-year return wind speed average over 10 min is **50m/s**, the **gust** value is **1.4** times of reference wind speed.

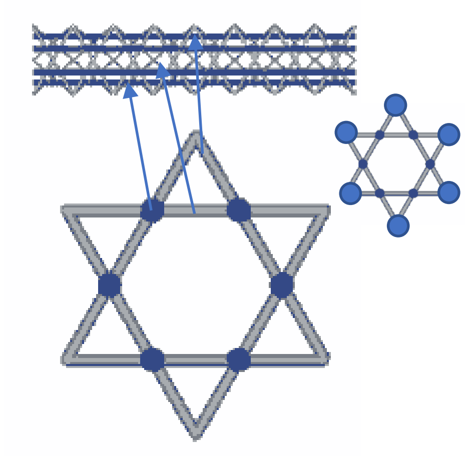
- IEC specifies a load safety factor of 1.35.

- Safety factor for composite material 2.205.



Normal force and tangential force for blade with different AoA (Angle of attack)

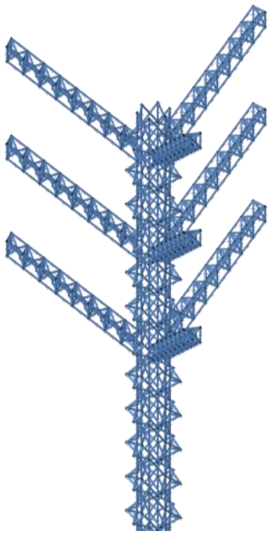
Predefined Structure Type & Design parameters



6 nodes Truss section [1]

Truss Wind turbine structure[2]

[1] https://www.compositesworld.com/news/isotruss-carbon-fiber-cell-towers-support-global-demand-for-5g-telecom-rollout
[2] https://www.windpowermonthly.com/article/1823639/suzlon-wins-200mw-plus-wind-turbine-order-india

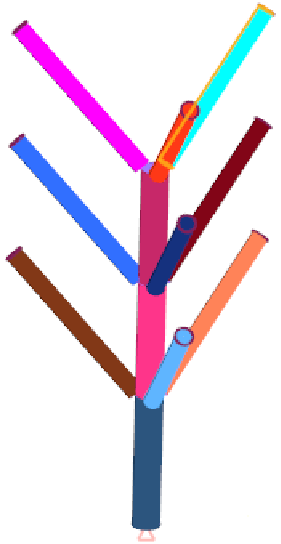


Truss wind turbine structure model

Design parameters

7 structure parameters for the Isotruss structure to be decided; **5 parameters** for the Cylinder structure:

1. Degree of the support arms
2. Inner radius of the tower
3. Outer radius of the tower
4. Height of the support truss
5. Height of the link truss
6. Height of the support arm element
7. Width of the support arm element



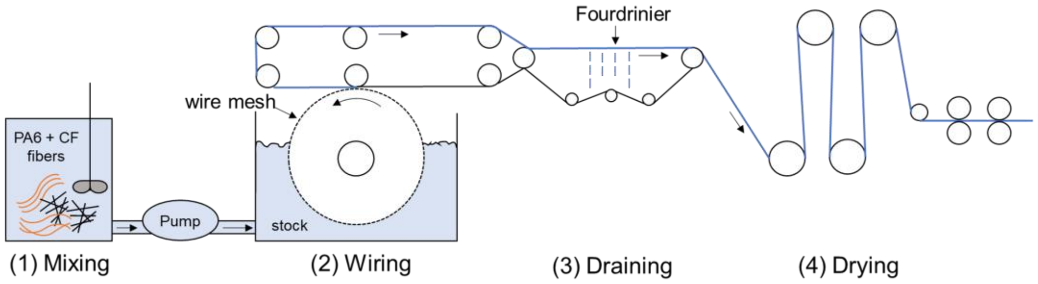
Cylinder wind turbine structure model

2. Analytical model

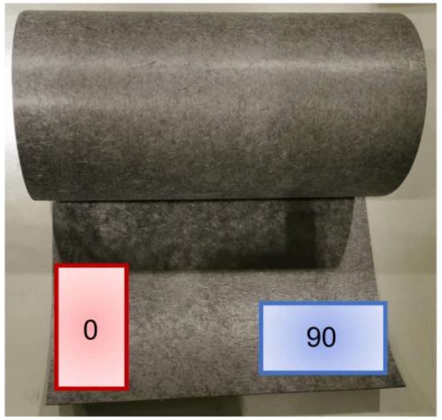
Materials applied to the model & Design parameters

Composite material for Iso truss structure (beam elements):

Composite material for Cylinder structure (shell elements):



(a) Papermaking method



(b) CPT prepreg roles

Pultrusion CFRP

Steel rod

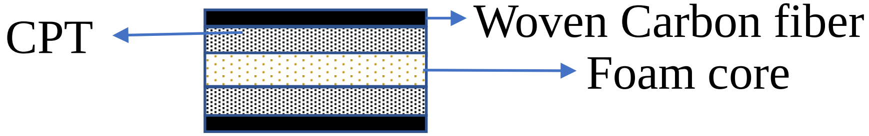
→ **Truss structure**

Recycled CFRP laminate

Roll steel columns

→ **Cylinder structure**

Carbon fiber **paper-reinforced** thermoplastics

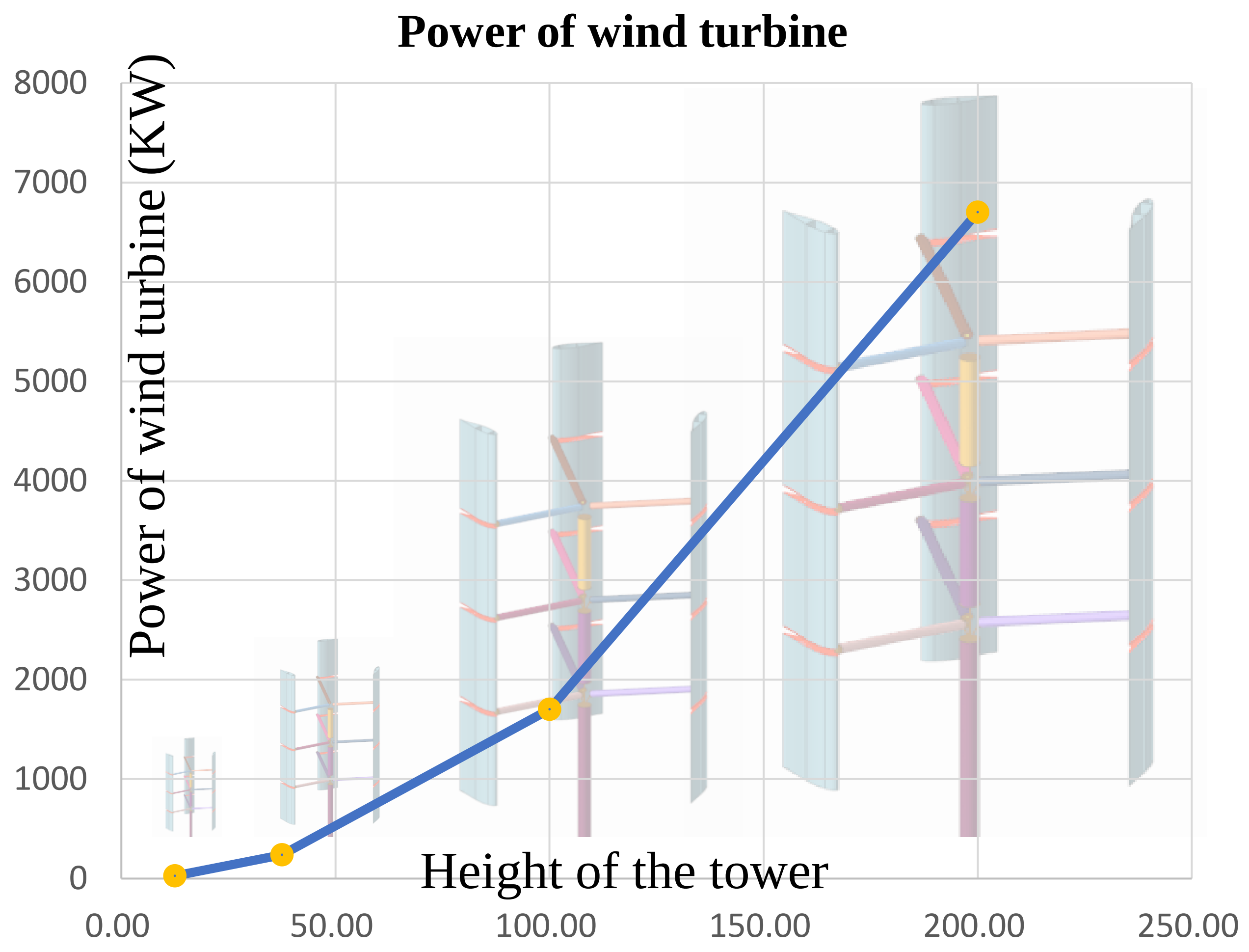


Design parameters: Thickness of plies/tubes

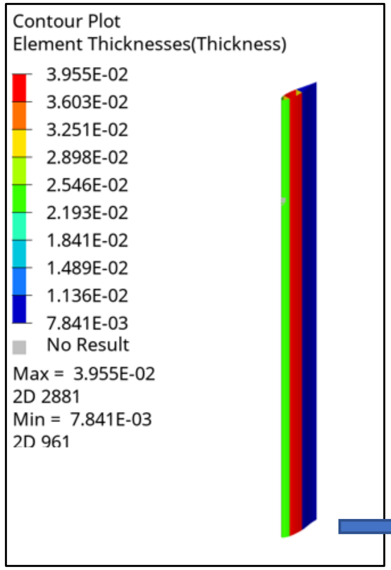
Structure Optimization: Different Structure size

Parameters	Structural Size			
Blade height	10	30	80	160
Blade Chord	1	3	8	16
Blade load ft (n/m^2)	159	159	159	159
Blade load fn (n/m^2)	5740	5740	5740	5740
Rotor Diameter	8	25	67	133
Tower Height	12.5	37.5	100	200
Design wind speed	12	12	12	12
Extreme wind Speed	70	70	70	70
Power of Wind Turbine	25KW	238KW	1.7MW	6.7MW
Tip Speed Ratio	7	7	7	7

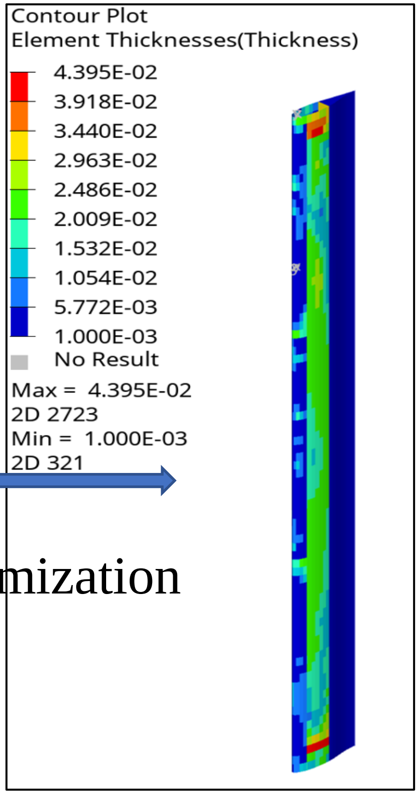
Parameters for different size wind turbine



Blade Weight estimation: optimization for composite materials blades



Free size optimization



Optimized CFRP blade laminate thickness

- Find a set of suitable thicknesses for every ply;
- Under the most dangerous AOA wind load

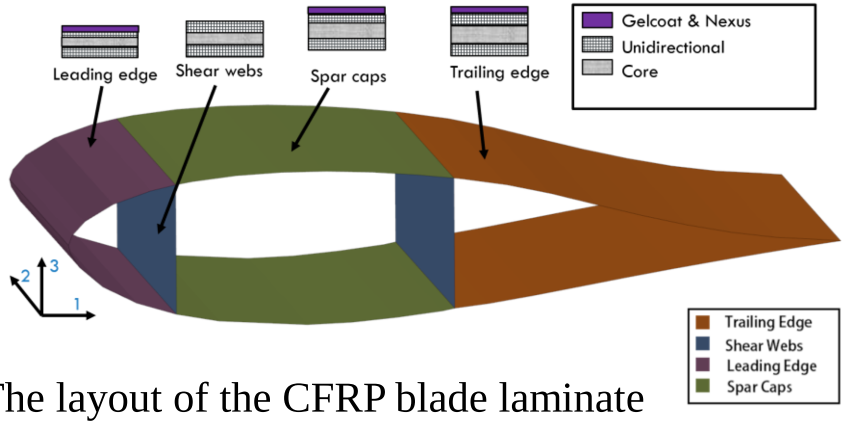
Mass=14538.5kg
（Blade length=80m）

Design variables:
The thickness of each layer

Constraints:
Displacement and stress of blades

Objective function:
Minimize blade mass

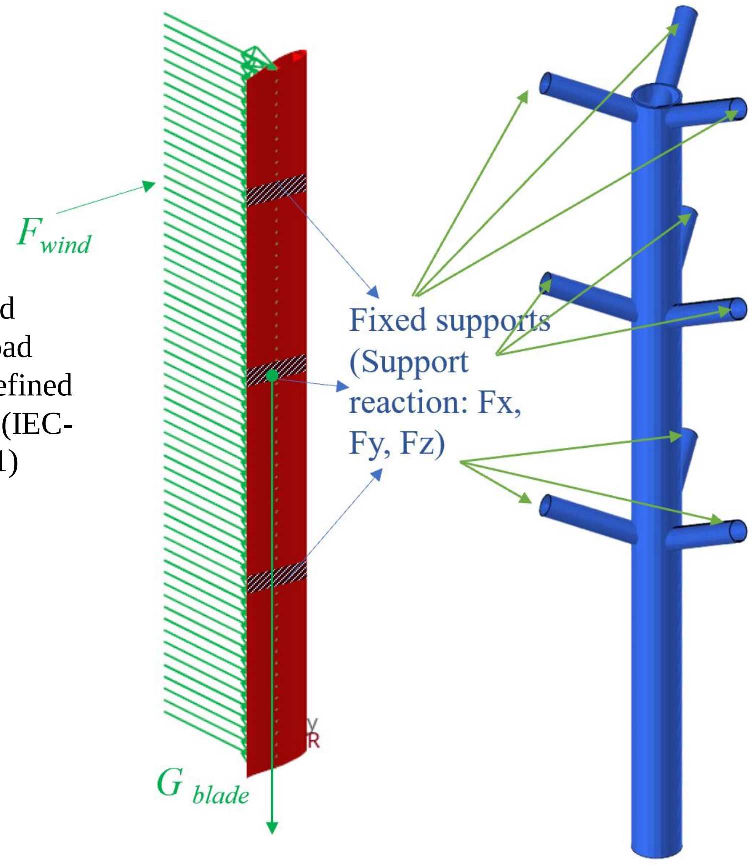
FEM optimization solver (HyperWorks OptiStruct)

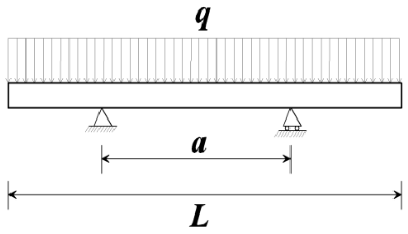


The layout of the CFRP blade laminate

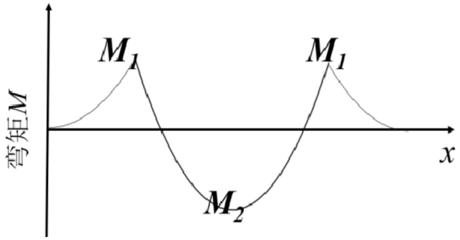
Blade Weight estimation: the influence of support arms

Use the reaction of blade support as a load of support structures

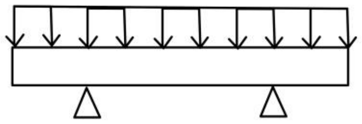




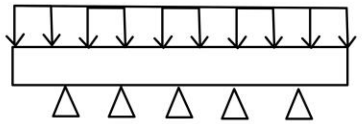
Force diagram of the blade



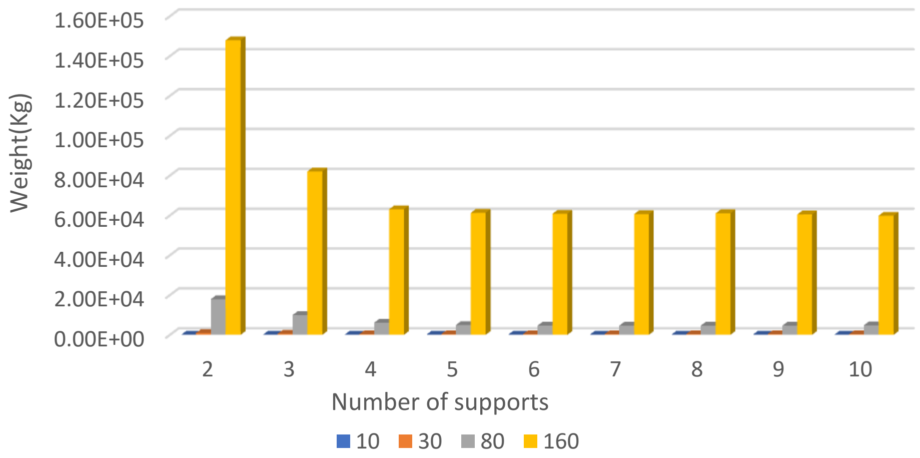
Moment of the blade



Number of supports = 2



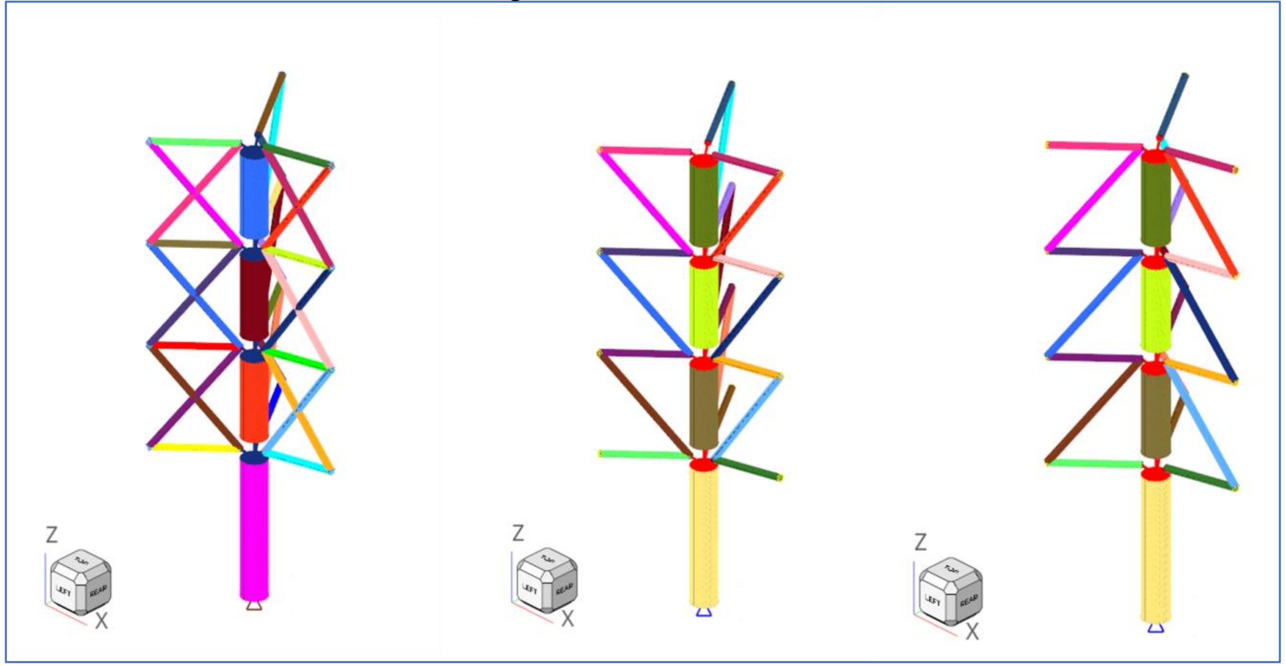
Number of supports = 5



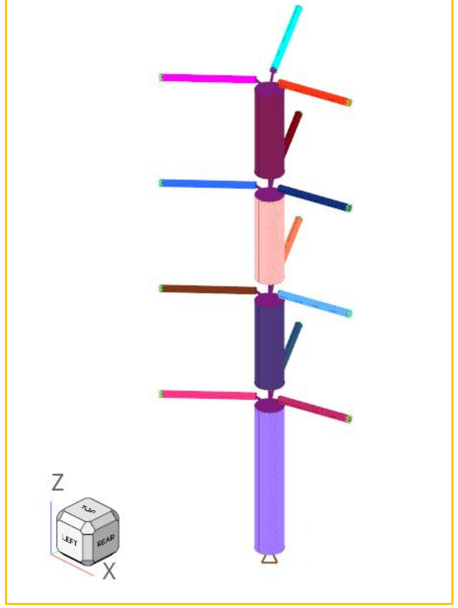
The optimized blade weight with different support numbers and different blade length

Structure model: Hypostatically indeterminate / Statically indeterminate

Statically indeterminate



Statically determinate



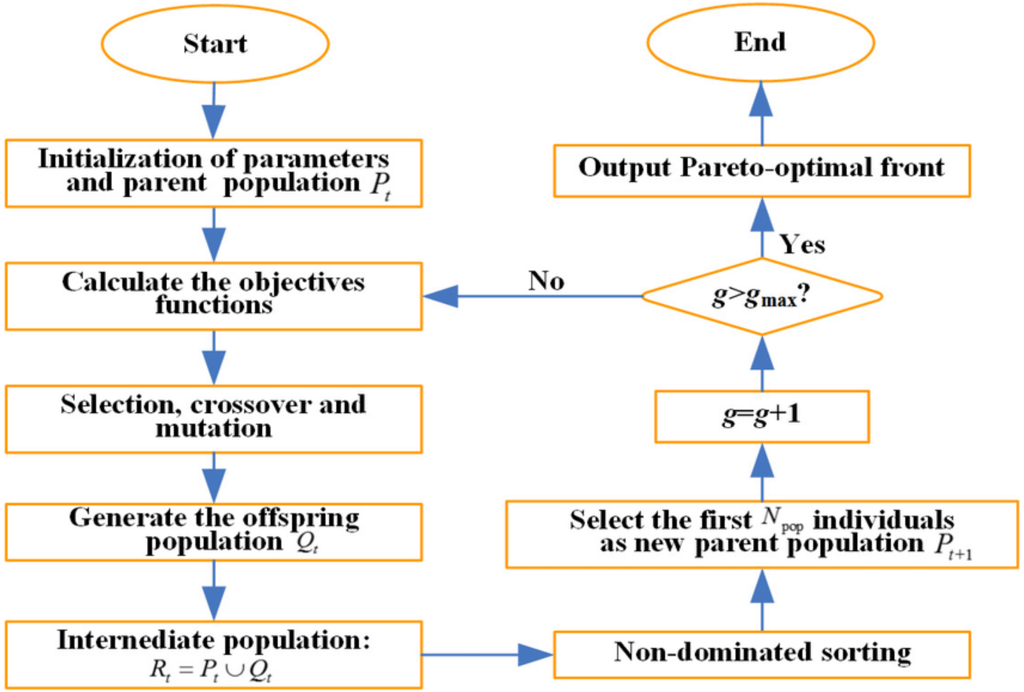
h (Hyperstatic) = 2

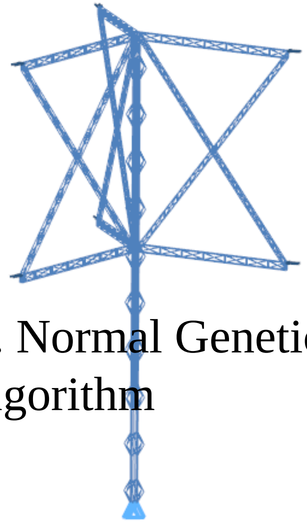
h = 1

h = 1

h = 0

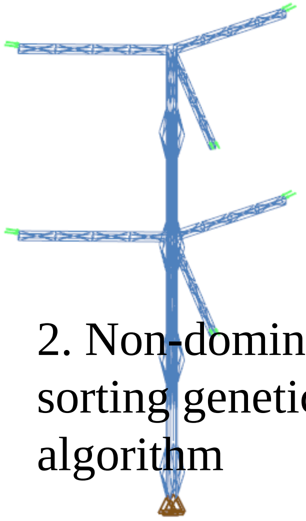
Optimization Strategy flow chart





1. Normal Genetic algorithm

Mass:6060kg
Node:543



2. Non-dominated sorting genetic algorithm

Mass:6231kg
Node:132

Mass ↑ 3%; Node ↓ 75%

Design variables:
[hyperstatic parameter, number of supports, structure parameters, material parameters]

Constraints:
Parameter range limits; Displacement of nodes; Stress of elements

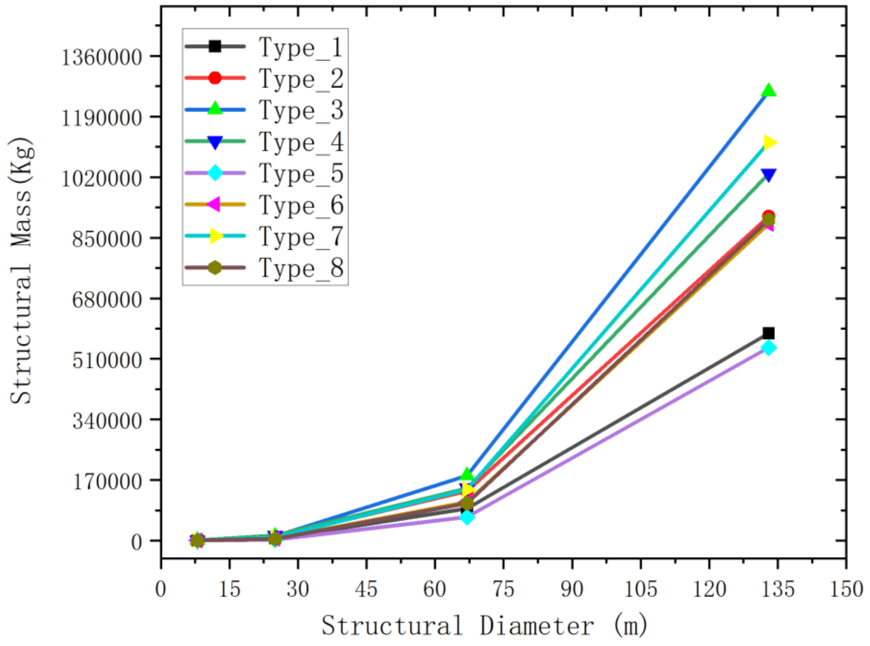
Genetic algorithm & FEM solver (HyperWorks OptiStruct)

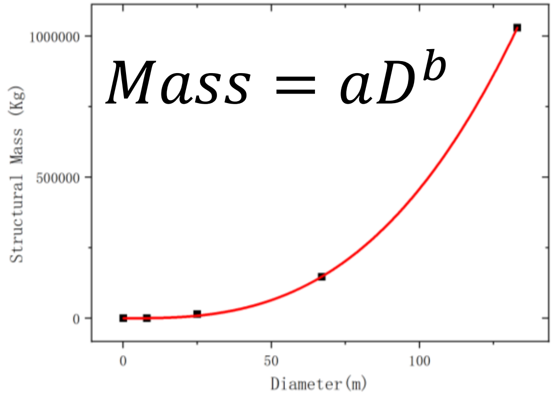
Objective function:
Minimize structure mass

3. Numerical study

Optimization Result: Influence of Size & Material

Structure type	Support arms type	Support arms material	Tower material	a	b
1	Cylinder structure	CFRP laminate	CFRP laminate	0.95	2.73
2			Steel cylinder	1.42	2.73
3		Steel cylinder	Steel cylinder	1.30	2.82
4			CFRP laminate	0.99	2.83
5	Truss structure	Pultrusion CFRP	Pultrusion CFRP	0.17	3.07
6			Steel tube	0.27	3.07
7		Steel tube	Steel tube	0.49	2.99
8			Pultrusion CFRP	0.20	3.14

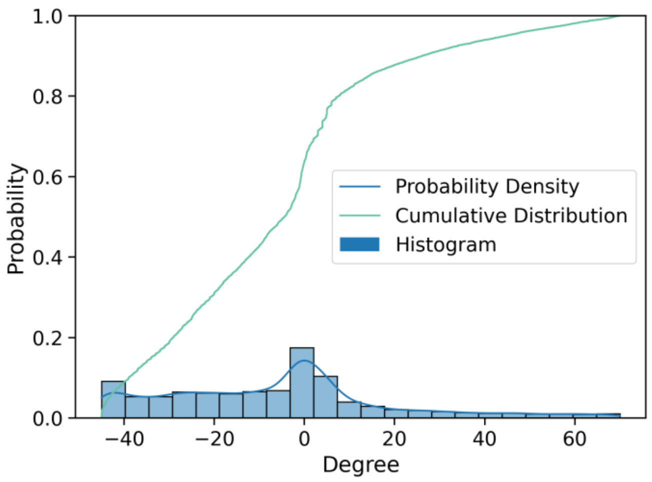




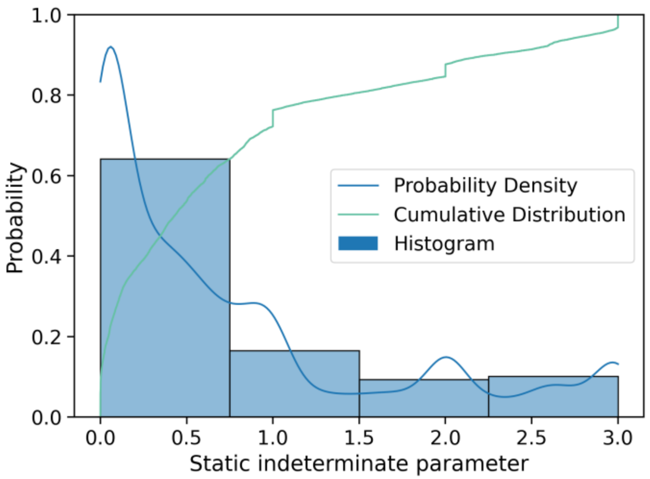
- The weight of CFRP structures can be less than half of the steel structures.
- Applying CFRP on support arms rather than on the tower can better reduce the weight of the structure.
- Truss structures are more sensitive to the scale of the wind turbines.

Optimization Result: Distribution of structure parameters

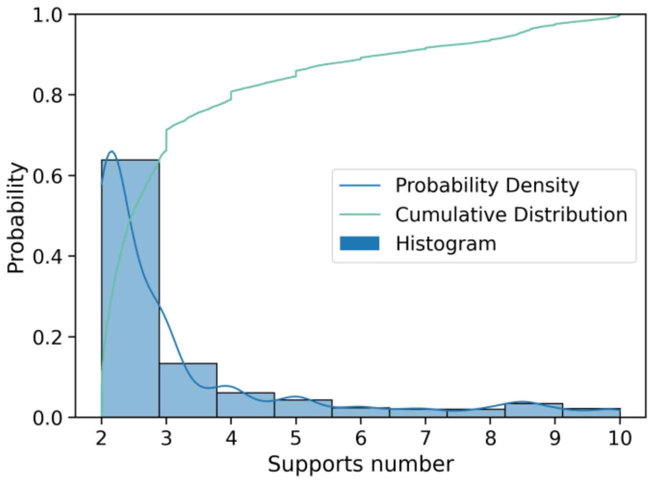
Degree of the support arms



Hyperstatic parameters



Number of the support arms



- Optimal range for the degree of support arms is [-5°,15°]
- Optimal range for the hyperstatic parameters is [0,1]
- Optimal range for the number of support arms is [2,3]

Summary of the structure optimization

- NSGA or GA method combined with FEM can solve the problem of floating vertical axis wind turbine structure optimization, especially for discrete parameters.
- Applying CFRP materials on the wind turbine structure, especially the support arms can effectively reduce the structural mass.
- The optimal value range for the wind turbine can be decided based on the optimizations.

Future task:

- Verify the dynamic and other performance of the wind turbine designs
- Develop more detailed optimization models for blades using recycled CFRP
- Experiments to prove the reliability of the optimization method

Thank you for Your Attention!

Acknowledgment:

This work was supported by JST SPRING, Grant Number JPMJSP2108. The authors would like to express sincere thanks to the members who have provided valuable information and useful discussions.

Presentations from Takahashi-Wan lab

Name	Date	Venue	Room	Title
Qian GAO	Wed	Recycling and sustainability - S3	1B	Prediction of strength and its variation of carbon fiber mat reinforced thermoplastics using Monte-Carlo method
Weizhao HUANG	Thu	Structural health monitoring - S1	Arc	Inversing spatial modulus distribution of cfrtp by a vibrational method and its hydrothermal aging application
Peng XUE	Mon	Structural analysis and optimization - S2	3B	Optimization of floating vertical axis wind turbine structures using recycled carbon fiber reinforced thermoplastic
Xiaohang TONG	Tue	Mechanics of composites - S2	3A	The influence of tape geometry on the mechanical performance of bolted CFRTP-SMC joints
Zihao ZHAO	Tue	Liquid composites moulding - S2	2A	Simulation of fiber orientation during compression molding process of CFRTP-SMC
Ruochen XU	Wed	Multiscale modelling - S5	Studio	Morphology analysis and shape optimal of CFRTP-SMC based on Monte-Carlo simulation
Zhiyu WANG	Mon	Process modelling - S1	Studio	A state-based peridynamic model for progressive damage analysis of CFRTP-SMC base