Numerical Simulation for Optimization of Unsteady Rotating Wind Turbine

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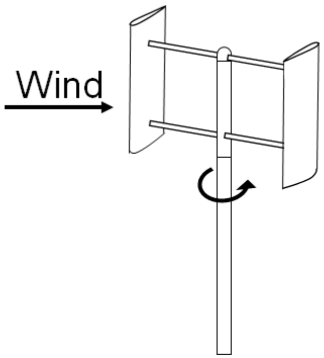
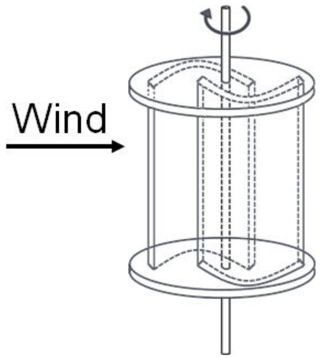
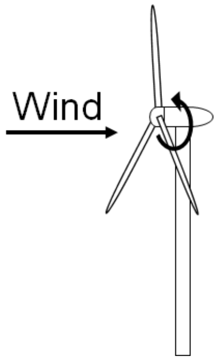
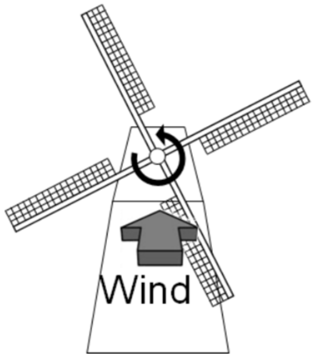
Outline

Types of wind turbines

Four Categories of Wind Turbines

	Rotated by Lift	Rotated by Drag
VAWT Vertical Axis Wind Turbine	① 	② 
HAWT Horizontal Axis Wind Turbine	③ 	④ 

①**Darrieus wind turbines**
They are not affected by wind direction.

②**Savonius wind turbines**
The wind direction is easy to change.

③**Propeller type wind turbines**
They have great power generation efficiency.

④**Dutch type wind turbines**
When rotating at a slow speed, the torque is also high.

Objective of This Research

Objective of this research

・In this study, we investigated the characteristics of rotating wind turbines and the time varying rotation in order to investigate the optimum wing shape.

・And I will change five parameters (blade length, wind turbine radius, overlap, gap, blade thickness) to find the optimum shape of wind turbines.

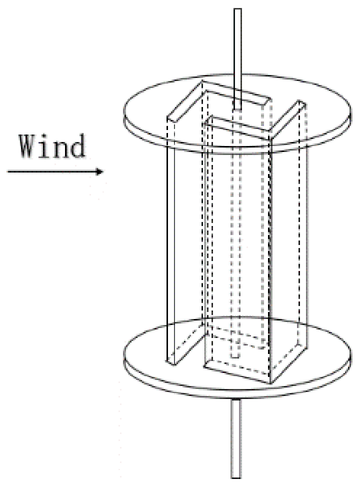


Fig.1. Drag-type vertical axis wind turbin

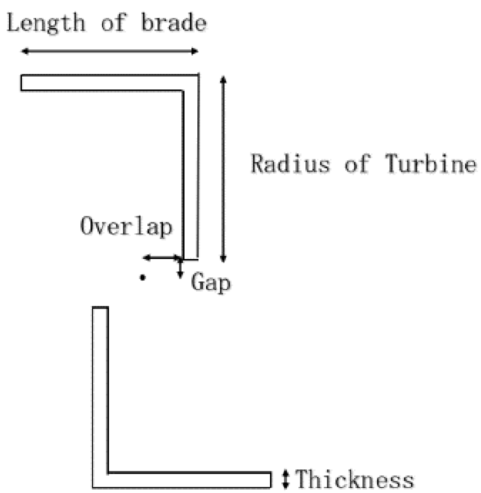


Fig.2. A cross-sectional view of Fig.1

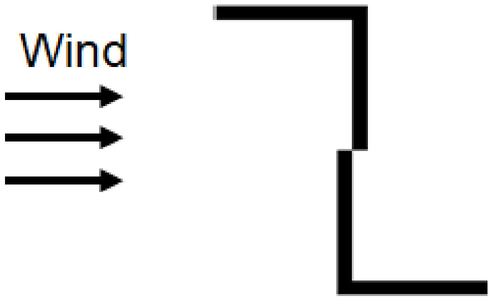
Parameter:
Length
Radius
Overlap
Gap
Thickness

⇨ Optimization

Objective of This Research

Steady rotation

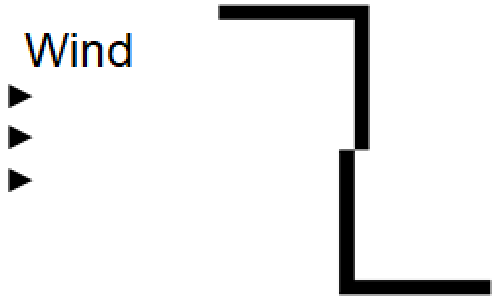
- Wind turbine rotates at constant angular velocity.
- Examining basic characteristics for the design of wind turbines.
- Many studies have been done this research.



Unsteady rotation

This researsh

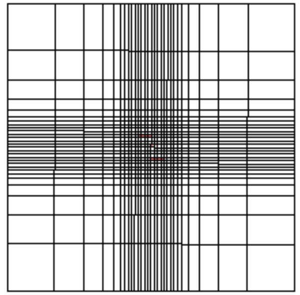
- The rotation speed of a wind turbine changes.
- A study on the response of wind speed.
- Examples are small but important.



Activation example

Numerical Methods

Incompressible Navier-Stokes equations.
Fixed on the rotating wind turbine.



Equation of continuity

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0$$

Centrifugal force

Coriolis force

Incompressible Navier-Stokes equations

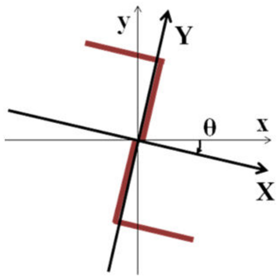
$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} - \omega^2 X + 2\omega V = -\frac{\partial p}{\partial X} + \frac{1}{\mathrm{Re}}\left\{\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right\}$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} - \omega^2 Y - 2\omega U = -\frac{\partial p}{\partial Y} + \frac{1}{\mathrm{Re}}\left\{\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right\}$$

In Rotational coordinate system

(X,Y) : Position

(U,V) : Velocity



p : Pressure

t : Time

ω : Angular velocity

Re : Reynolds number(=10^5)

Numerical Methods

Fractional-Step method:

$$\begin{cases} U^* = U^n + \Delta t\left\{-U^n \dfrac{\partial U^n}{\partial X} - V^n \dfrac{\partial U^n}{\partial Y} + \omega^2 X - 2\omega V + \dfrac{1}{\mathrm{Re}}\left(\dfrac{\partial^2 U^n}{\partial X^2} + \dfrac{\partial^2 U^n}{\partial Y^2}\right)\right\} \\ V^* = V^n + \Delta t\left\{-U^n \dfrac{\partial V^n}{\partial X} - V^n \dfrac{\partial V^n}{\partial Y} + \omega^2 Y + 2\omega U + \dfrac{1}{\mathrm{Re}}\left(\dfrac{\partial^2 V^n}{\partial X^2} + \dfrac{\partial^2 V^n}{\partial Y^2}\right)\right\} \end{cases}$$

$$\frac{\partial^2 p^{n+1}}{\partial X} + \frac{\partial^2 p^{n+1}}{\partial Y^2} = \frac{1}{\Delta t}\left(\frac{\partial U^*}{\partial X} + \frac{\partial V^*}{\partial Y}\right)$$

$$\begin{cases} U^{n+1} = U^* - \Delta t \dfrac{\partial p^{n+1}}{\partial X} \\ V^{n+1} = V^* - \Delta t \dfrac{\partial p^{n+1}}{\partial Y} \end{cases}$$

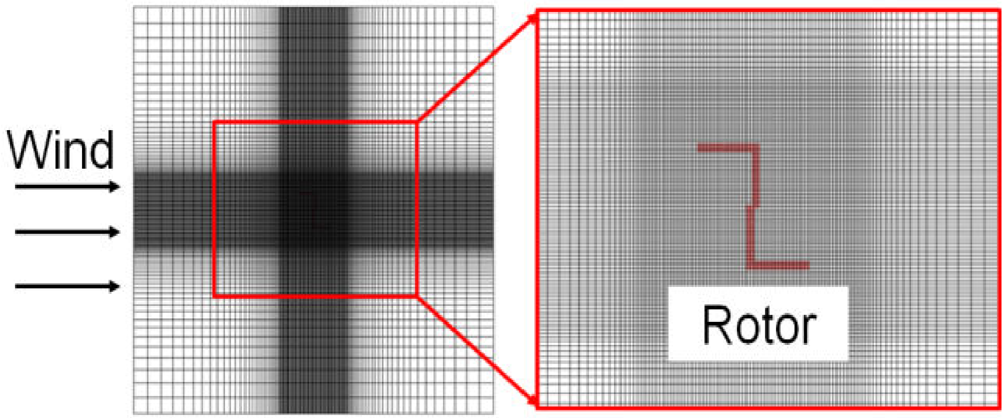
Advection term => Third order upwind difference

$$f\frac{\partial u}{\partial x}\Big|_{x=x_i} = f\frac{-u_{i+2}+8(u_{i+1}-u_{i-1})+u_{i-2}}{12\Delta x} + \frac{|f|\Delta x^3}{12}\frac{u_{i+2}-4u_{i+1}+6u_i-4u_{i-1}+u_{i-2}}{\Delta x^4}$$

→Numerical stability for non-linear terms

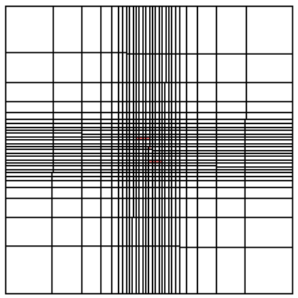
Numerical Methods

Grid points: 141x141



External side:
Uniform flow

On the blade:
No-slip



Grid rotates with
the wind turbine

Boundary condition

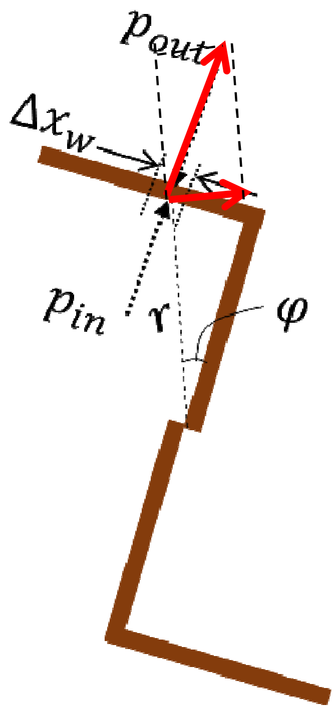
	Distant boundary	Wind turbine blade
speed	u=0.1 v=0.0	u=0.0 v=0.0
pressure	$\frac{\partial p}{\partial x} = \frac{\partial p}{\partial y} = 0$	Average pressure value near the point

Table.1 Boundary condition

Numerical Methods

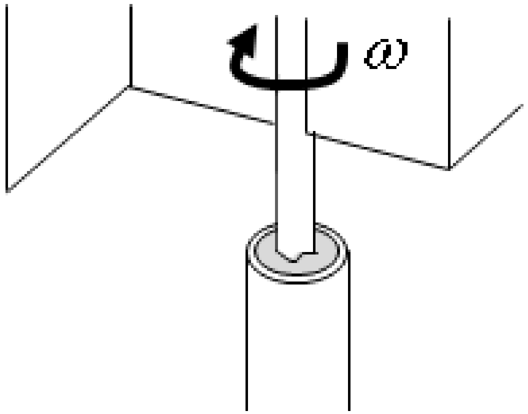
Torque: the force that rotates the rotor

$$\Delta N = \Delta x_w (p_{in} - p_{out}) r$$



Equation of motion of a wind turbine

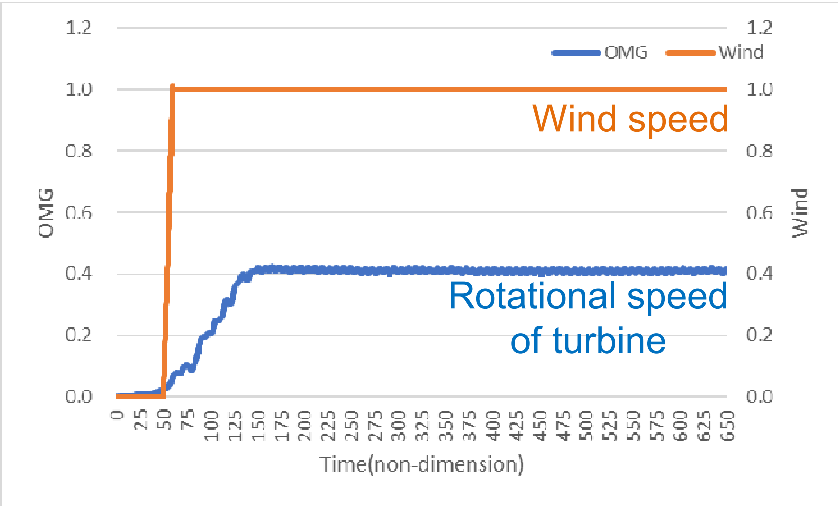
$$I \frac{\partial \omega}{\partial t} = N - B$$

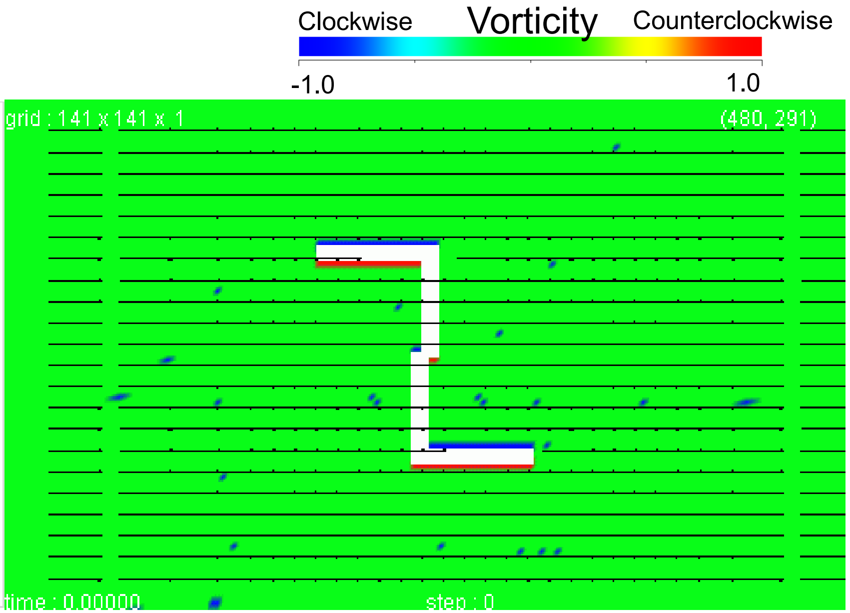


I: the Moment of inertia
N: Torque
B : Friction from rotation axis

Numerical Methods

Starting Characteristics





- Initial condition: No wind, turbine is in stationary state
- Wind start to blow →turbine starts to rotate with a delay
- Constant wind speed, the turbine continues to rotate at a constant speed

Simulation results

Vertical axis： torque coefficient (power of the wind turbine) （The bigger the Length1 & Length2 is, the bigger the torque is.）

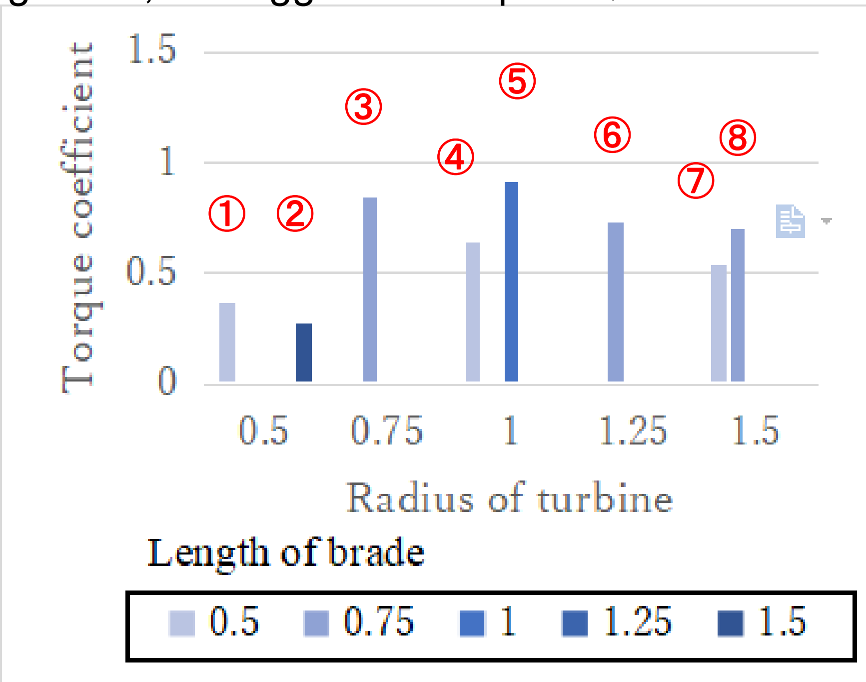
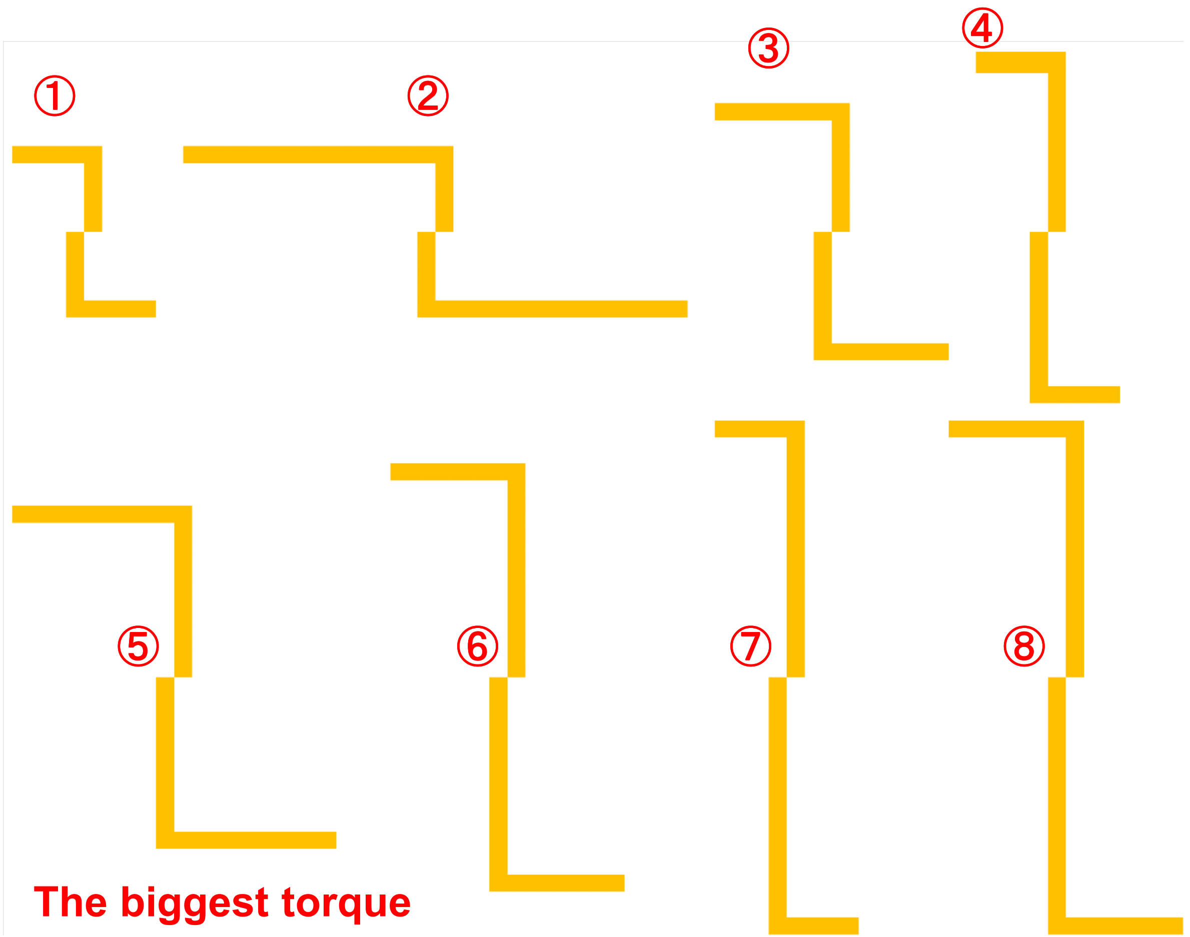
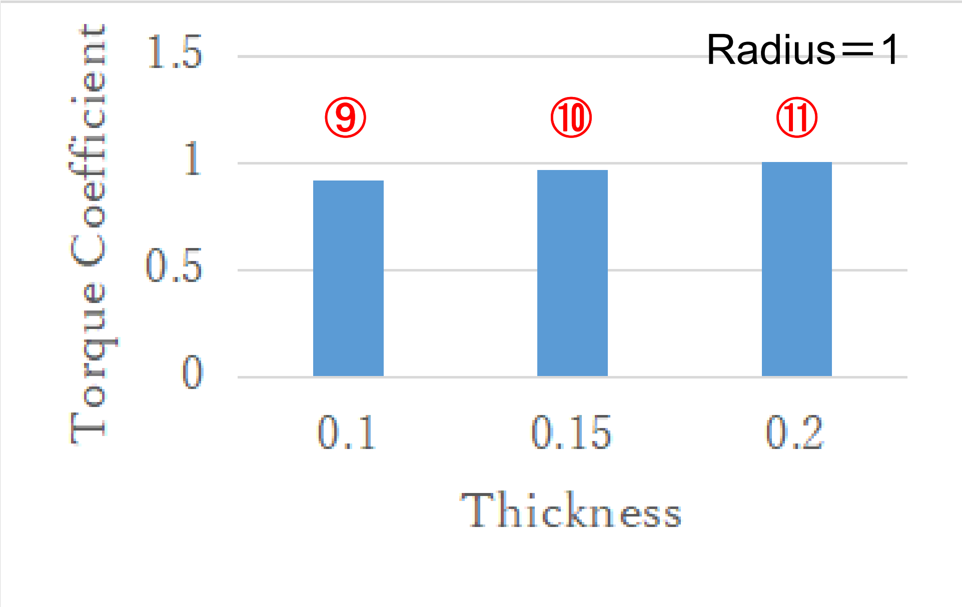


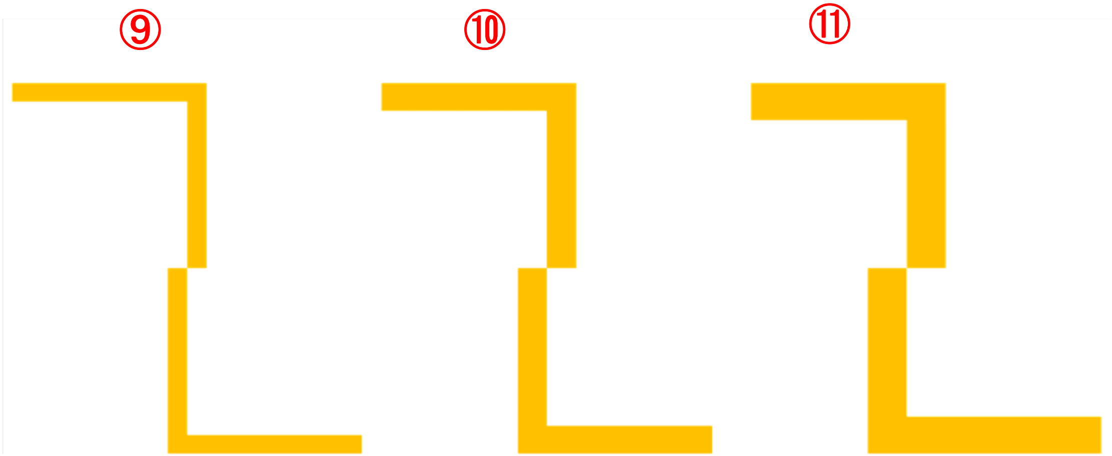
Fig.3. Analysis for Length1 & Length2 （Thickness=0.2, Overlap=Gap=0.0）



Simulation results

Vertical axis： torque coefficient (power of the wind turbine) （The bigger the thickness is, the bigger the torque is.）



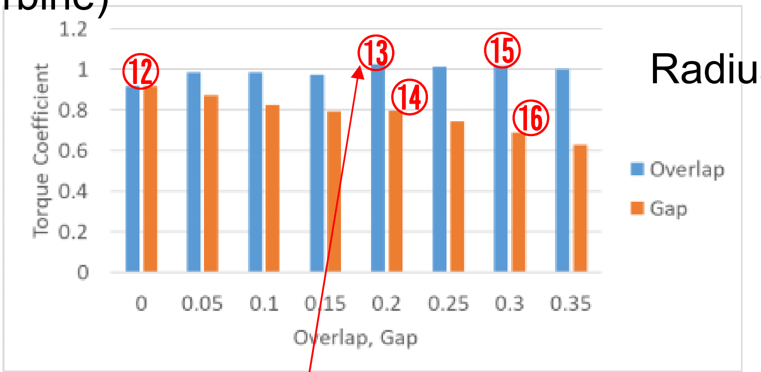


The biggest torque

Fig.4. Analysis for thickness

Simulation results

Vertical axis： torque coefficient (power of the wind turbine)



Radius＝1

Fig.5. Analysis for Overlap & Gap

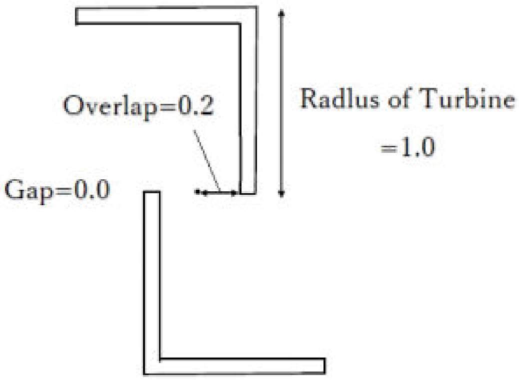
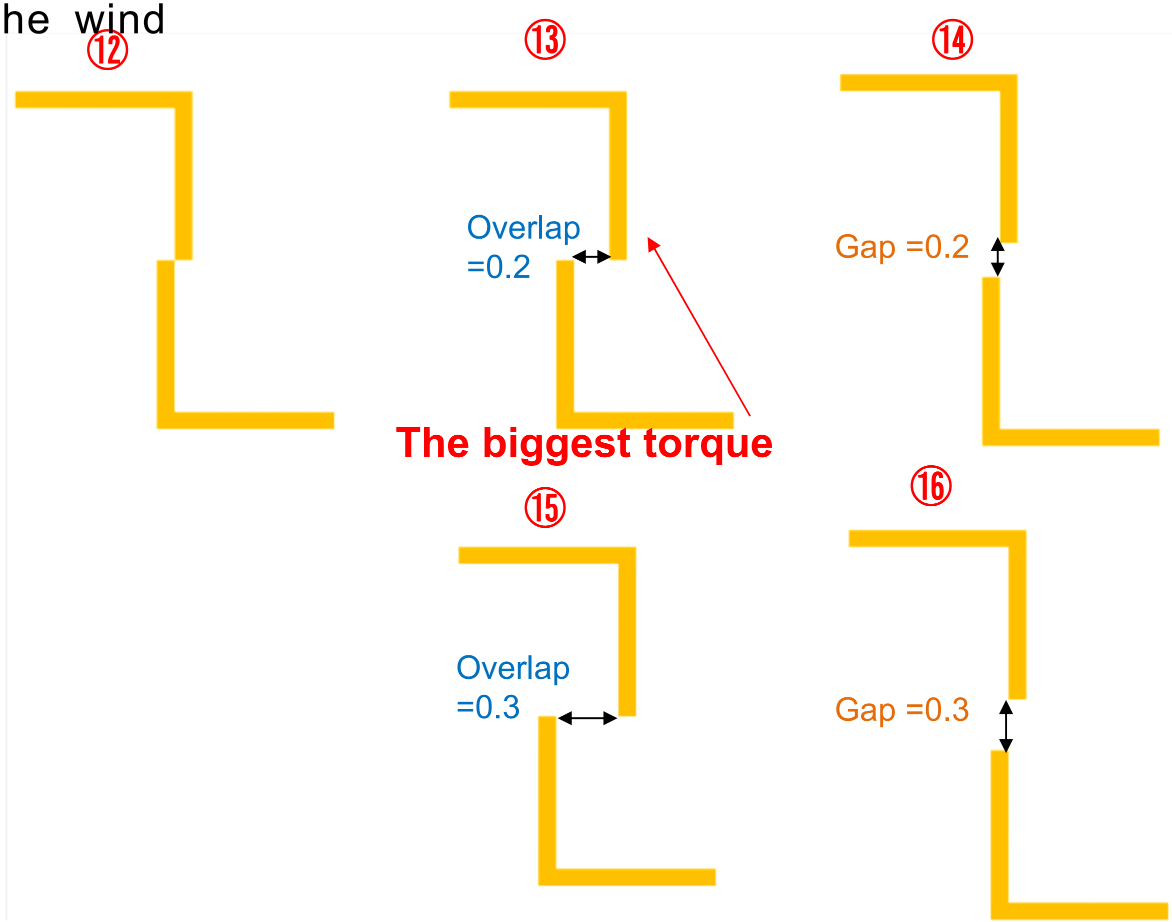


Fig.6. The biggest torque of ①～⑯



Summary

- In this study, we investigated the characteristics of rotating wind turbines and investigated the time varying rotation in order to investigate the optimum wing shape.
- Five parameters (blade length, wind turbine radius, overlap, gap, blade thickness) were changed, and optimum shape was obtained.
- The tendency of simulation results qualitatively agreed with the experimental results for steady rotating wind turbines.

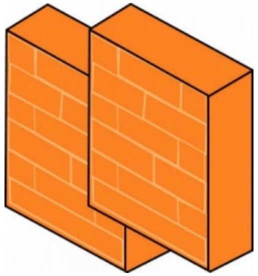
Summary

Future research

In order to improve the efficiency of wind turbines, the simulation is carried out in the case where multiple wind turbines are installed close.

Chinese Proverbs

When the wind changes, some people builds a wall, and others make a wind turbine.



Don't be afraid of change!

That means, when the environment changes, different people have different attitudes, some people have a passive attitude, refusing all challenges, and some people adapt to the situation.