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Numerical Simulation for Optimization of Unsteady Rotating Wind Turbine

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Research Background

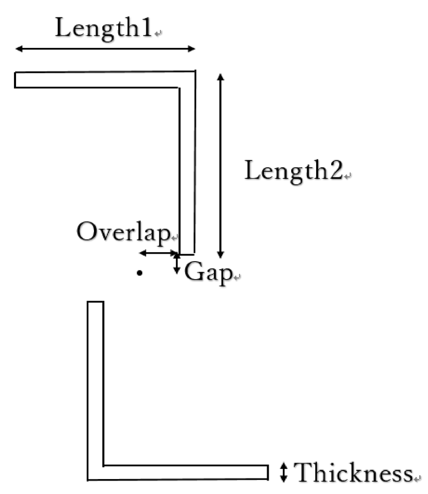
Research Objective

- **Problem**

  To find the optimum blade shape in the numerical simulations of the wind turbine
- **Focus on**

  To use a programming language (FORTRAN) to simulate 16 different wind turbines.
- **Research Objective**

Simulate:
Length1, Length2, Thickness, Overlap, Gap.
⇒ Power (torque)



Types of Wind Turbines

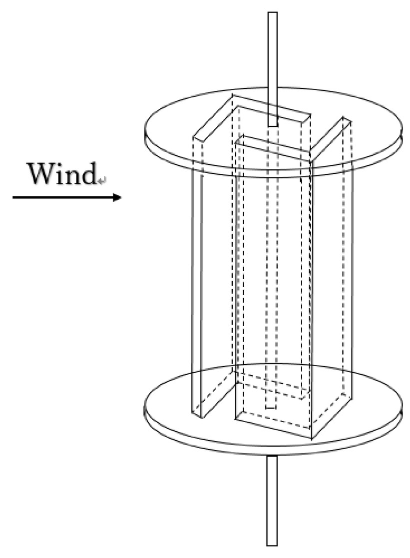
- **Horizontal axis**

Large three-bladed horizontal-axis wind turbines (HAWTs), with the blades upwind of the tower produce the overwhelming majority of wind power.

- **Vertical axis**

Vertical-axis wind turbines (VAWTs) have the main rotor shaft arranged vertically against wind. It can accept wind from any direction for the operation.

Vertical-Axis Wind Turbine



- **Equation of motion for wind turbines**

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

I : Moment of inertia(constant)

N : Torque received by wind turbines (Calculate from pressure)

B : Resistance of a wind turbine shaft to receive from a bearing (Proportional to angular velocity ω)

Calculation Method

Fundamental Equations of Fluid

- **Continuous expression**

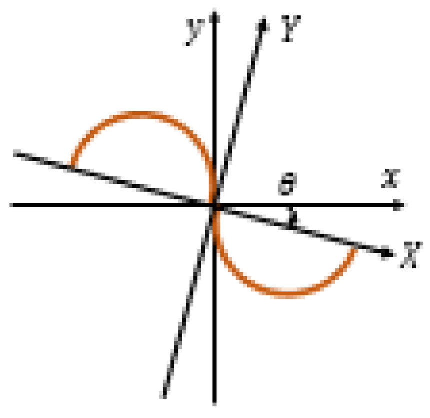
$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} + \frac{\partial W}{\partial Z} = 0$$

- **Equation of motion**

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

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

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



(X, Y, Z) : Position component in rotational coordinate system

(U, V, W) : Velocity component in rotational coordinate system

p : Pressure t : Time ω : Angular velocity of wind turbines

Re : Reynolds number based on wind turbine radius and uniform velocity ($= 10^5$)

Calculation Algorithm

- **Fractional step method**

$$U^* = U^n + \Delta t\left\{-U^n\frac{\partial U^n}{\partial X} - V^n\frac{\partial U^n}{\partial Y} - W^n\frac{\partial U^n}{\partial Z} + \omega^2 X - 2\omega V + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U^n}{\partial X^2} + \frac{\partial^2 U^n}{\partial Y^2} + \frac{\partial^2 U^n}{\partial Z^2}\right)\right\}$$

$$V^* = V^n + \Delta t\left\{-U^n\frac{\partial V^n}{\partial X} - V^n\frac{\partial V^n}{\partial Y} - W^n\frac{\partial V^n}{\partial Z} + \omega^2 Y + 2\omega U + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V^n}{\partial X^2} + \frac{\partial^2 V^n}{\partial Y^2} + \frac{\partial^2 V^n}{\partial Z^2}\right)\right\}$$

$$W^* = W^n + \Delta t\left\{-U^n\frac{\partial W^n}{\partial X} - V^n\frac{\partial W^n}{\partial Y} - W^n\frac{\partial W^n}{\partial Z} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 W^n}{\partial X^2} + \frac{\partial^2 W^n}{\partial Y^2} + \frac{\partial^2 W^n}{\partial Z^2}\right)\right\}$$

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

$$U^{n+1} = U^* - \Delta t\frac{\partial p^{n+1}}{\partial X}$$

$$V^{n+1} = V^* - \Delta t\frac{\partial p^{n+1}}{\partial Y}$$

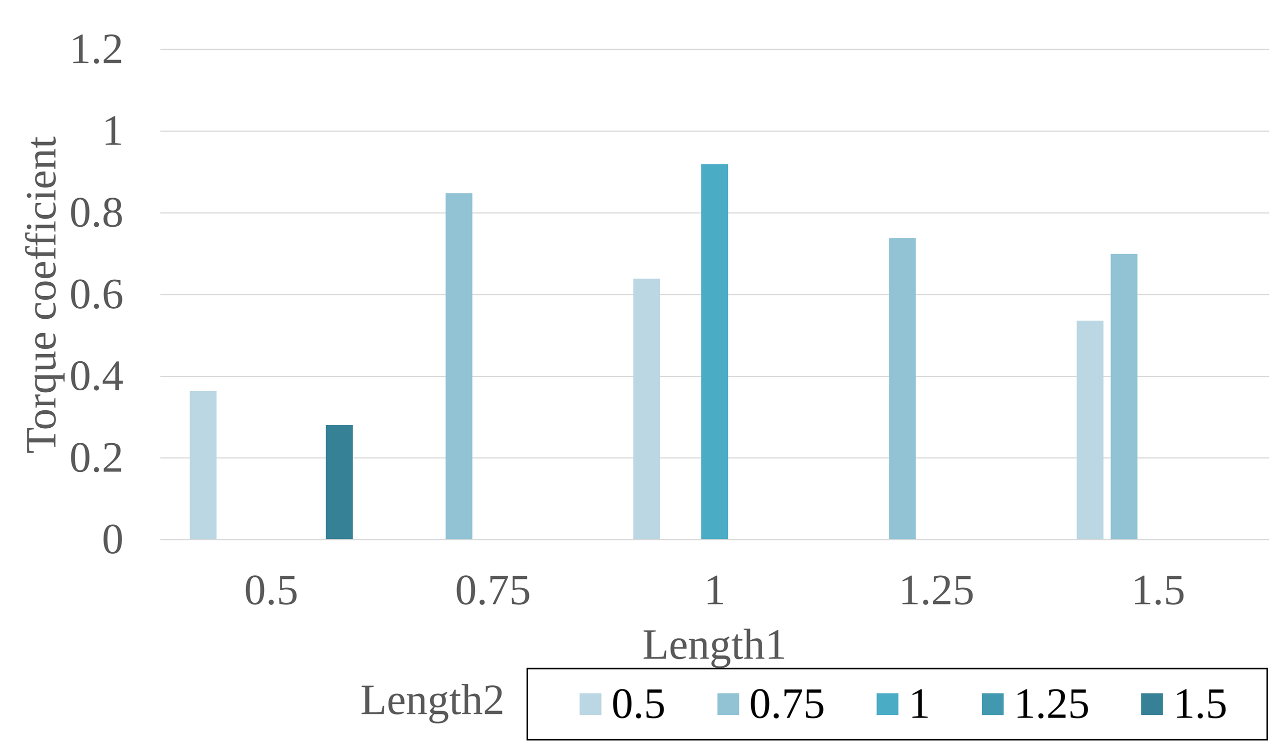
$$W^{n+1} = W^* - \Delta t\frac{\partial p^{n+1}}{\partial Z}$$

- **Finite difference of advection term: Third order upwind difference**

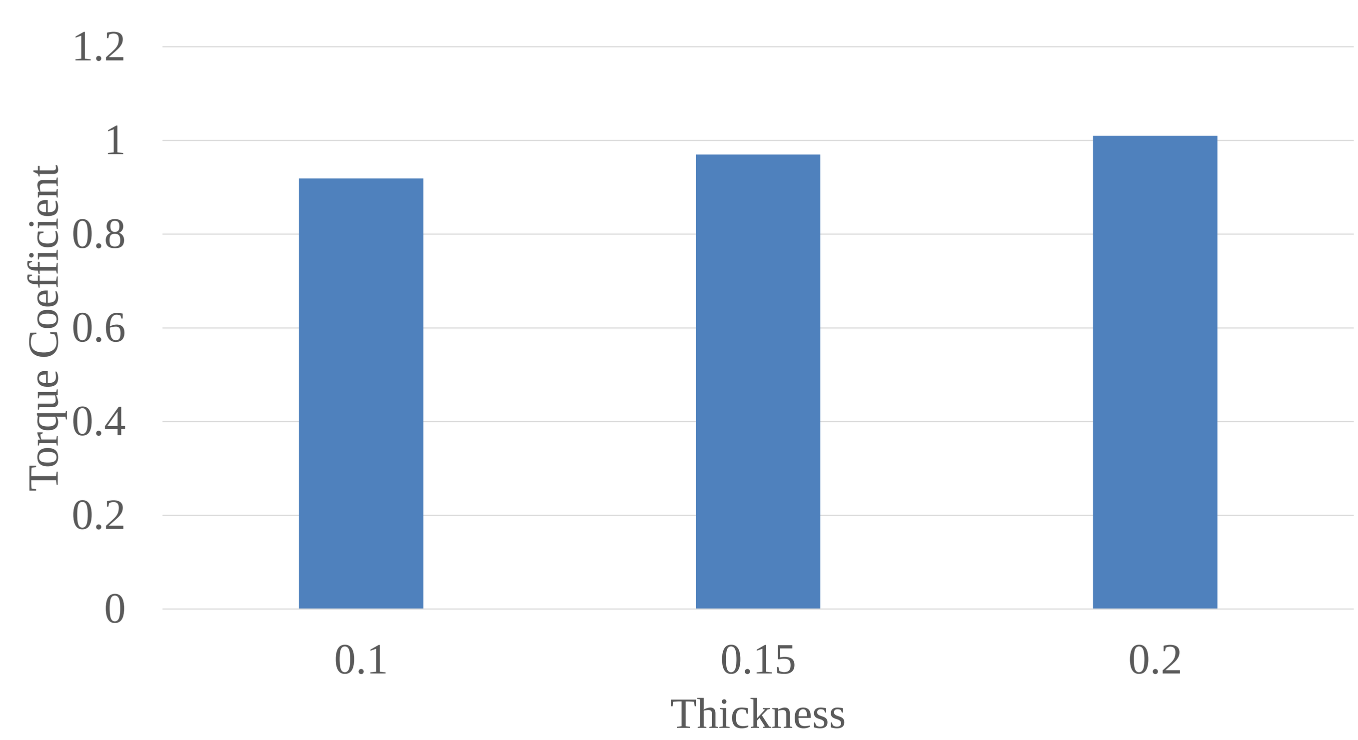
$$f\frac{\partial u}{\partial x} \sim f\frac{-u_{i+2} + 8(u_{i+1} - u_{i-1}) + u_{i-2}}{12\Delta x} + \frac{|f|\Delta x^3}{12}\frac{u_{i+2} - 4u_{i+1} + 6u_i - 4u_{i-1} + u_{i-2}}{\Delta x^4}$$

Results and Analysis

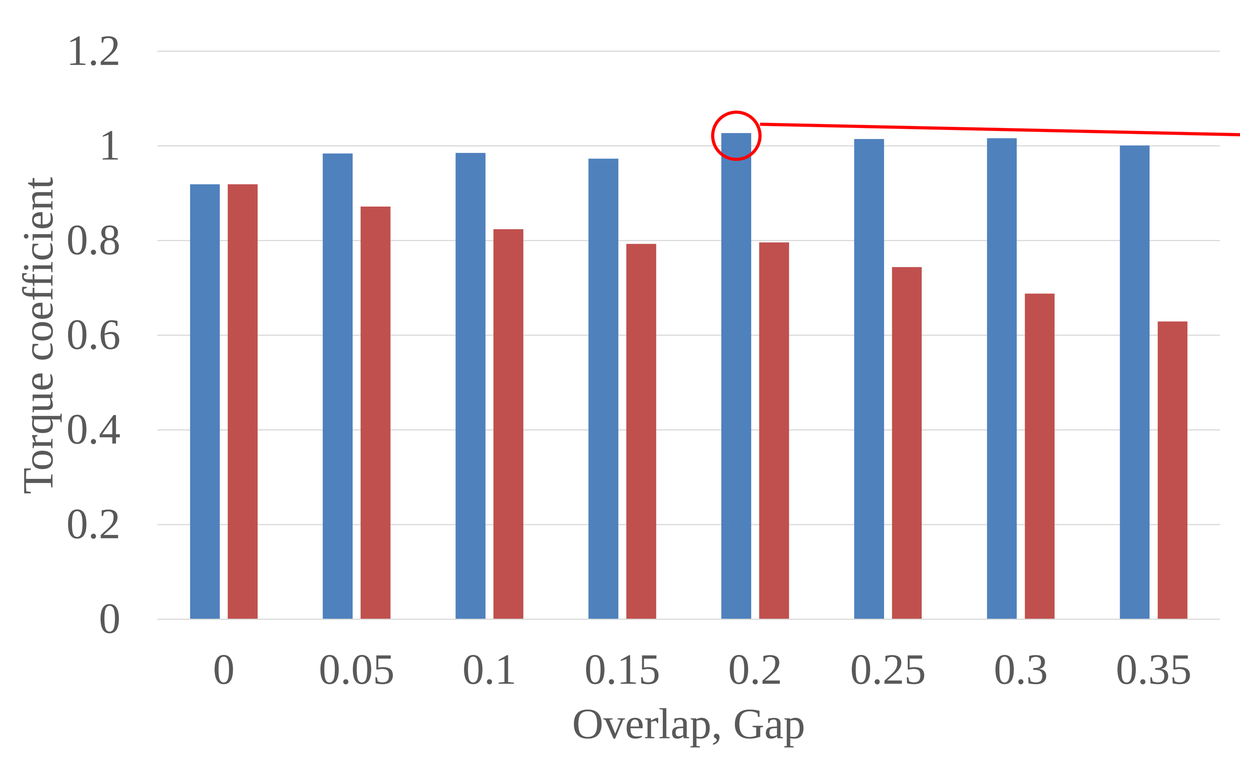
- **Analysis for Length1 & Length2**
- **(Thickness=0.2, Overlap=Gap=0.0 are fixed)**



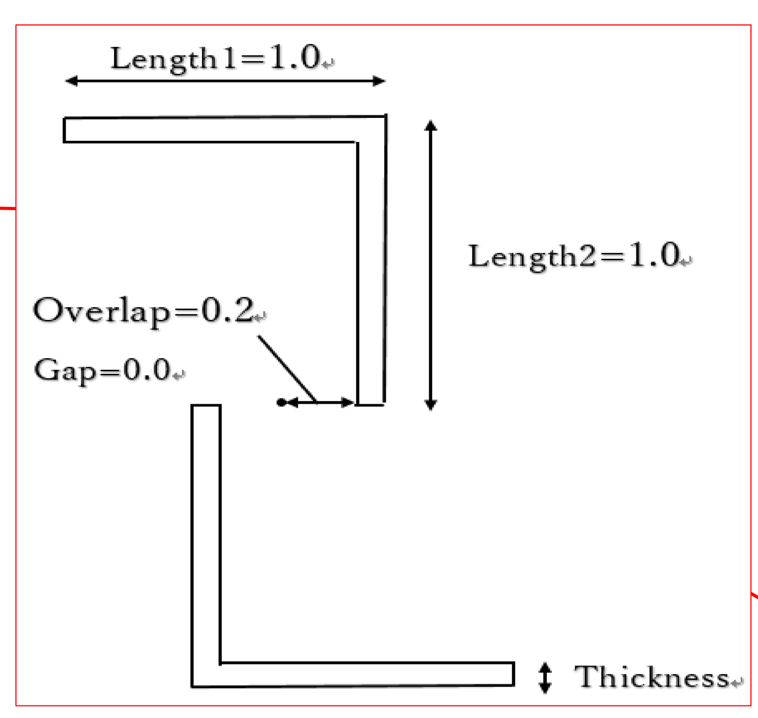
- **Analysis for Thickness**
- **(Length1=Length2=1.0, Overlap=Gap=1.0 are fixed)**



- **Analysis for Overlap & Gap**
- **(Length1=Length2=1.0, Thickness=0.1 are fixed)**



Conclusion



When the gap is large, the torque coefficient is bad.

The highest torque coefficient.