

Comparative Study Of Velocity Deficit Calculation Methods For A Wind Farm In Vietnam

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Abstract: Vietnam is a country with good wind energy potential and can be exploited on a large scale to serve the economy. However, the current status of wind power development in Vietnam has not been as expected by many barriers from theory and practice, among them in which the problem of selecting methods and models to evaluate the wind energy potential suitable for Vietnam's conditions is very important. The WindFarm and WAsP softwares are very popular and commonly used in the assessment of potential and design of wind power projects in the world. These softwares have been fitted to a number of research institutes in the wind energy Vietnam to the application. This paper presents the results of the study comparing the calculation of the velocity deficit using WAsP and WindFarm softwares with experimental results by Fluid Engineering Laboratory, Division of Mechanical Engineering, Mie University, Japan to improve accuracy in the design of wind farms in Vietnam.

Keywords: Wind turbine, Wake effects, Velocity deficit, Wind tunnel experiment.

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I. INTRODUCTION

According to the Global Wind Energy Council (GWEC) [1], in 2016, which now comprises more than 90 countries, including 9 with more than 10,000 MW installed, and 29 which have now passed the 1,000 MW mark. Cumulative capacity grew by 12.6 % to reach a total of 486.8 GW [1]. The European Wind Energy Association (EWEA) has estimated that the world's electricity demand will be 25,800TWh by 2020, with wind energy able to meet 12% (3,000TWh) of consumption and can be reduced by 10.7million tons of CO₂ [2]. That means installing 1,245,030 MW of wind power. To achieve this goal requires all countries in the world to have specific development strategies and develop policies that are consistent with each country's potential.

In recent years, wind turbines are introduced in wind farms in which some wind turbines are concentrated. However, the quantity of electrical energy, really, produced by a wind farm is less than the summation of the power generated by each turbine, the power losses can be attributed to the wake effect. When wind turbines are built in contiguity with each other in wind farms, the flow passing through a wind turbine, which is called "Wake", may flow into other wind turbines (Figure 1, [4]). Wake is characterized by a large fluctuation of the wind speed and direction. Flow of wake into wind turbines causes decrease of power generation and increase of fatigue load on wind turbines (The wind farm output loss will be 10 to 20% for the entire wind farm). Therefore, in order to propose the best arrangement of wind turbines in wind farms, sufficient understanding of wake characteristics is required [3].

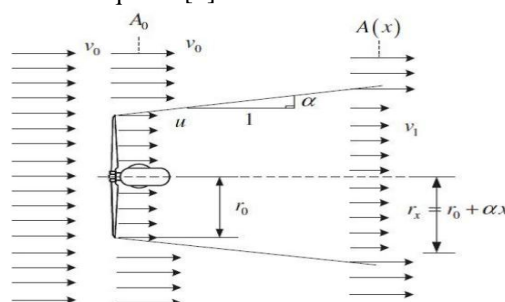


Figure 1: Schematic view of Wake description [4]

The different wake models have been developed to characterize the behavior of wind wake and evaluate the velocity deficit behind wind turbines. Generally the wake effect has two main impacts on wind farm: (i) reduction of wind speed which affects the energy captured by the turbine and may even stop some downstream turbines, hence it becomes useless (0 MW). (ii) The raise of turbulence intensity accelerates the fatigue and reduces the lifespan of wind turbines. Considered these two key in the design of wind farms can enhance the output of energy production and minimize the maintenance cost.

One of the oldest wake models is the model by N.O. Jensen (referred to as the Jensen model from now). It is quite a simple wake model, assuming a linearly expanding wake with a velocity deficit that is only dependent of the distance behind the rotor [4].

The Eddy Viscosity Wake Model (J.F. Ainslie, 1986) is based on the thin shear layer approximation of the Navier-Stokes equation. The approximation is based on the assumption of an axisymmetric, stationary, fully turbulent wake with zero circumferential velocity and negligible pressure gradients outside the wake region. The axisymmetric assumption allows a two-dimensional description of the wake. The model assumptions and equations as originally presented can be found in [5].

The model by G.C. Larsen (referred to as the Larsen model from now, but also known as the EWTSII model) is based on the Prandtl turbulent boundary layer equations and has closed form solutions for the width of the wake and the mean velocity profile in the wake. In order to obtain the closed form solutions a self-similar velocity profile is assumed and Prandtl's mixing length theory is used. The flow is further assumed to be incompressible and stationary and wind shear is neglected, hence the flow is axisymmetric. Larsen showed both a first-order and a second-order approximate solution to the boundary layer equations, of which the last one is capable of resolving the double dip in the velocity deficit profile of the near wake [6].

The analytical wake model developed by Ishihara [7-8] used wind tunnel data for a model of Mitsubishi wind turbine. The model takes into account the effect of turbulence on the wake recovery. It's not constant and depends on the Atmospheric and rotor generated turbulence, and the downstream distance from the wind turbine. The wake recovery is therefore more dependent on the turbine-generated turbulence. Ishihara is clearly shown that when thrust coefficient C_t (0.31, 0.82) is large, the rate of wake recovery increases. The same results are found either for ambient turbulence or mechanical generated turbulence. This model predicts the wake for any ambient turbulence and thrust coefficient.

The analytical wake model developed by Frandsen et al [9] is adopted in the Storpark Analytical Model (SAM), the aim of this model is to predict the wind speed deficit in large offshore wind farms using a rectangular site area and straight rows of wind turbines with equidistant spacing between wind turbines and rows. Frandsen considered a cylindrical control volume with constant cross-sectional area equal to the wake region, the shape can be presented by a rectangular distribution of the flow speed. Due to difficulty to identify in which distance the pressure regained the free flow. This model takes into account the initial wake expansion which is immediately expanded, this assumption is not treat in two previous wake models.

There are also models developed and perfected from the above models to better fit the reality. In that model developed by N.O. Jensen (1984) and later extended to actual wind farms by Kati et al (1986) was used in the WAsP software [10] and J.F. Ainslie model (1988) is developed and used in WindFarm software [11].

The use of software such as WAsP or WindFarm for evaluating wind potential and wind turbine layout for wind power projects is extremely necessary especially for projects with no experimental conditions. However, this application will inevitably overestimate or underestimate the reality in some special cases when the wind turbines are arranged in the range of 2 to 5 times the diameter of the wind turbine. Therefore, studies need to be conducted to adjust the evaluation results using WAsP or WindFarm software according to wind tunnel test results.

This paper will presents the results of calculating the velocity deficit after horizontal wind turbine in Co To island district, Quang Ninh province, Vietnam using WAsP, WindFarm softwares and comparison with experimental results of Mie University.

II. WAKE MODELS IN WAsP AND WINDFARM SOFTWARES

2.1. Wake model in WAsP (version 10.2)

The WAsP is a PC-program for the vertical and horizontal extrapolation of wind climate statistics. It contains several models to describe the wind flow over different terrains and close to sheltering obstacles.

The wind farm model, supporting mixed-turbine-type wind farms, is based on a mathematical model of the wake behind a wind turbine, developed by N.O. Jensen (1984) and later extended to actual wind farms by Kati et al. (1986) [10]. This model uses momentum-deficit theory to predict the flow field in a very simple way: the wake is assumed to expand linearly behind the rotor. Thus, the only variables are the initial velocity deficit at the start of the wake, evaluated from the thrust coefficient C_t of the turbine at actual wind speed, and the wake decay constant, which is the rate of expansion (break-down) of the wake.

The model assumes the centre-line of the expanding wake to follow the terrain, and the different hub heights and rotor diameters are taken into account by the overlapping fraction of a wake with a rotor plane of a downstream wind turbine. Due to the simplicity of the model the terrain must be relatively homogeneous in order to prevent large speed-up effects etc. The flow field and wind farm geometry used by the model to calculate wind turbine output is indicated below.

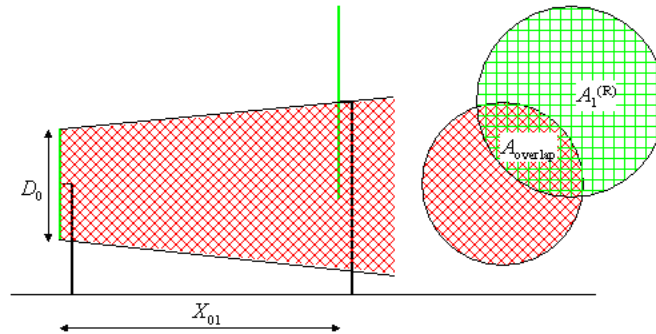


Figure 2: Schematic view of wake description in WASP [10]

The effective wind speed deficit at the down-wind wind turbine ("1") is calculated using the following equation:

$$\delta V_{01} = U_0 (1 - \sqrt{1 - C_t}) \left(\frac{D_0}{D_0 + 2kX_{01}} \right)^2 \frac{A_{overlap}}{A_1^{(R)}} \quad (1)$$

Where U_0 is the undisturbed wind speed at the upstream turbine ("0") with rotor diameter D_0 , C_t the thrust coefficient, X_{01} the downwind horizontal distance between the wind turbines and k is the wake decay constant (the default value is 0.075 used in all sectors. This is a reasonable value for on-shore wind farms, for off-shore wind farms the value could be about 0.050).

The thrust coefficient curve may be difficult to find in standard technical data, however, all wind turbine data files supplied with WASP includes thrust coefficient data. It can be computed by a rotor simulation program, estimated from data for similar wind turbines, or measured directly as tower bending moment. The thrust coefficient C_t is related to the thrust force F_T , ρ being the density of the air, as:

$$C_t = \frac{2F_T}{\rho \frac{\pi}{4} D_0^2 U_0^2} \quad (2)$$

The initial wind speed reduction from U_0 to V , when passing the rotor plane, is related to C_t by: $(1 - C_t) = (V/U_0)^2$.

2.2. Wake model in WindFarm Designer (Release 4)

WindFarm version 4.1.2.3 is program contains source code for wind flow in complex terrain from the Windows version of MS-Micro/3 by Zephyr North. The original DOS version of MS-Micro/3 was developed by scientists of the Meteorological Service of Canada and Zephyr North Ltd [11].

A wake model has been developed using the axi-symmetric method of Ainslie [5]. As devised the wake development depends upon the thrust coefficient, C_T , of the wind turbine, the ambient turbulence intensity, I , and the ratio of hub height to roughness length, (Z_H/Z_0) . This was simplified by using the relationship:

$$I = 1/\ln(Z_H/Z_0) \quad (3)$$

A table of maximum velocity deficit ratio was then created for various values of turbine thrust coefficient and ambient turbulence, at distances downstream up to 100 diameters in one-diameter steps. This is used as a straightforward look-up table, avoiding the need for specific wake calculations. The wake is assumed to have a Gaussian shape.

The wake velocity deficit model used in WASP/Park (linear wake width growth and rectangular wakes) and the power-law relationship in [12] (UPMPARK, 2 turbines in line) are also included as options. The latter gives the velocity deficit ratio as:

$$\text{Velocity deficit ratio} = 0.176 C_T^{0.83} [I^{0.63} (X/D)^{0.77}] \quad (4)$$

Where C_T is the thrust coefficient, I is the turbulence intensity and X/D is the distance downstream of the rotor plane in diameters.

The added turbulence due to the wake is calculated at the control points of the rotor disc when in the wake of upstream wind turbines by using the formulation of [13], which gives:

$$\text{added turbulence} = 1.31 C_T^{0.7} I^{0.68} (X/X_H)^{0.96} \quad (5)$$

Where X is the distance downstream of the rotor plane and X_n is the near wake length. The added turbulence is taken as constant at the calculated value over full wake width.

The added turbulence as formulated in [12] and [14] are also included as options. The first is termed the RISO method and is given in section 8 of the report as:

$$\text{added turbulence} = \sqrt{1.2C_T(X/D)^{-2}} \quad (6)$$

The second method, referred to as the Larsen Cookery Book method, is also reported in [15] and is given as:

$$\text{added turbulence} = 0.29(X/D)^{-1/3} \sqrt{(1 - \sqrt{(1 - C_T)})} \quad (7)$$

The effect of wake meandering as represented by Ainslie in [5] is also available as an option.

If a turbine is subject to multiple wakes, one of the following four wake combination methods is used:

1. Square root of the sum of squares of the velocity deficits:

$$(1 - U_i/U_w)^2 = \Sigma (1 - U_{ij}/U_i)^2 \quad (8)$$

2. Energy balance:

$$U_w^2 - U_i^2 = \Sigma (U_j^2 - U_{ij}^2) \quad (9)$$

3. Geometric superposition:

$$U_i/U_w = \pi * U_{ij}/U_j \quad (10)$$

4. Linear superposition:

$$(1 - U_i/U_w) = \Sigma (1 - U_{ij}/U_j) \quad (11)$$

These are applied when a point is within the wakes of two or more turbines. U_w is the wind velocity, U_i is the velocity at the i^{th} turbine, and U_{ij} is the velocity at the i^{th} turbine due to the wake of the j^{th} turbine. The summations are over the j turbines upstream of the i^{th} . Formulation 2 reduces to that of Smith [16], for the case of two in-line turbines when $U_w = U_1$. If a turbine is subject to multiple wakes, one of the four wake combination methods is used.

III. WAKE EFFECTS IN EXPERIMENT

The influence of wake effects for downstream turbine has been developed at Division of Mechanical Engineering, Mie University, by experimental study in wind tunnel [3]. Some results are summarized below.

In the experiment, the test wind turbine was operated under various turbulence intensities, and the velocity distribution of the wind turbine wake was measured. Turbulent flow incoming wind is produced by a active turbulence-grid devices as shown in Fig. 8 (a). Wind turbine is operated in no-yaw condition for inflow wind. The experiments were performed with varying turbulence intensity in the absence of wind shear, which are referred to as downstream wake velocity distribution measurement **I**. Also, the inflow wind condition was reproduced by changing the yaw angle of the wind turbine with no wind shear. The experiment is called the wake wind speed distribution measurement **II**. Wind shear was reproduced by the boundary layer grids with facing the wind turbine against the incoming wind. The experiment with changing wind shear is called as the wake wind velocity distribution measurement **III**.

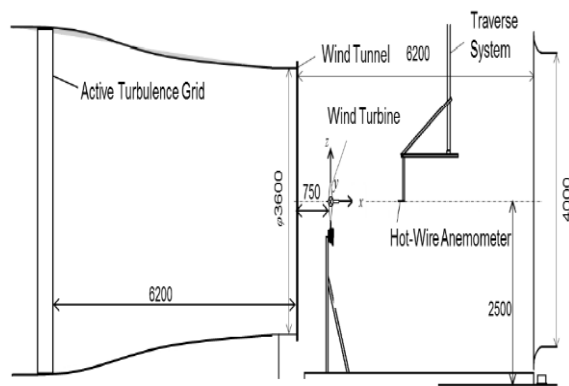


Figure 3: Experimental setup for experiment I and II [3]

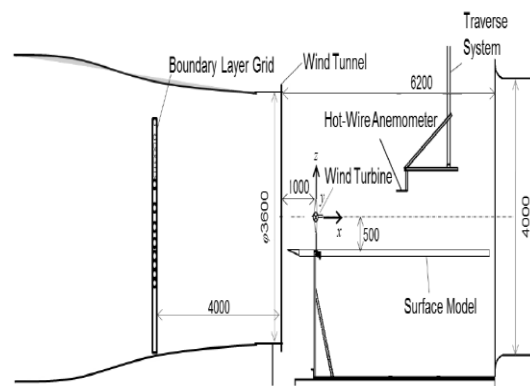


Figure 4: Experimental setup for experiment III [3]

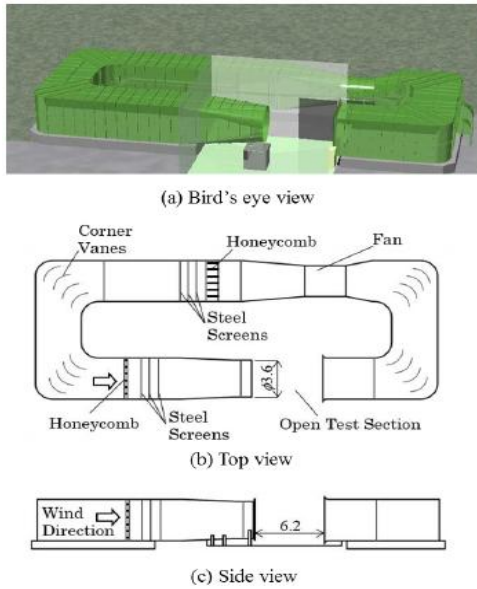


Figure 5: Wind tunnel [3]

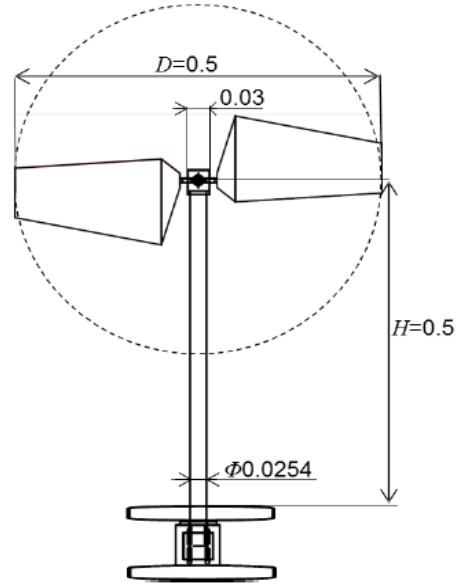


Figure 6: Test wind turbine [3]

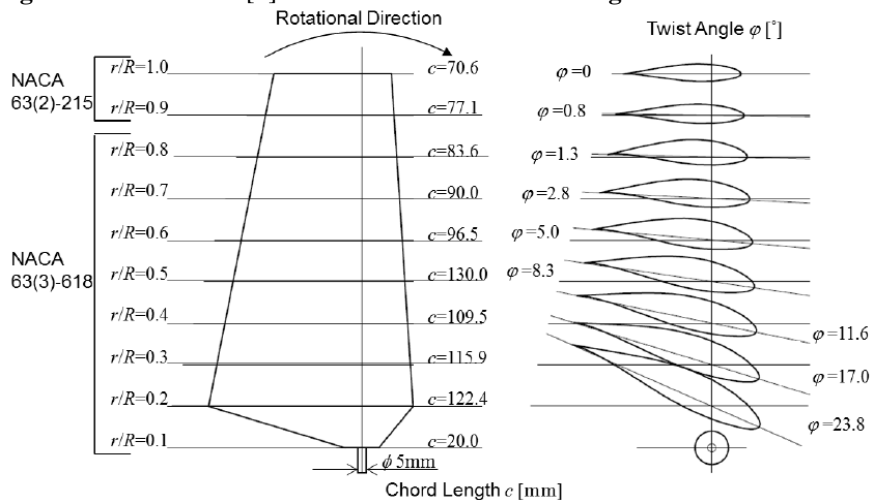
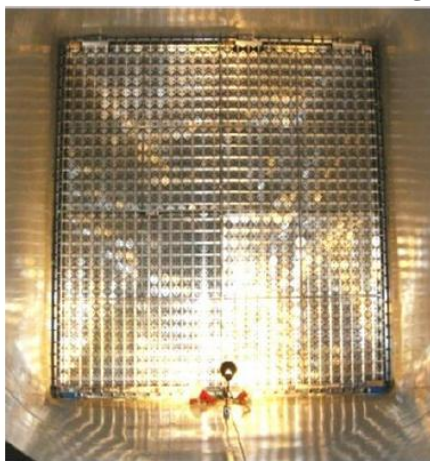
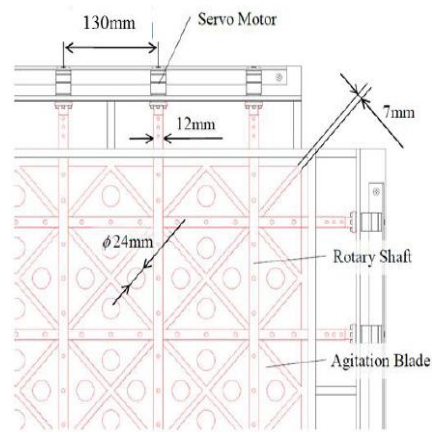


Figure 7: Test blade [3]



(a) Photograph



(b) Outline Drawing

Figure 8: Active turbulence grid [3]

- Experimental results: Shown in Figure 9-13 as follows.

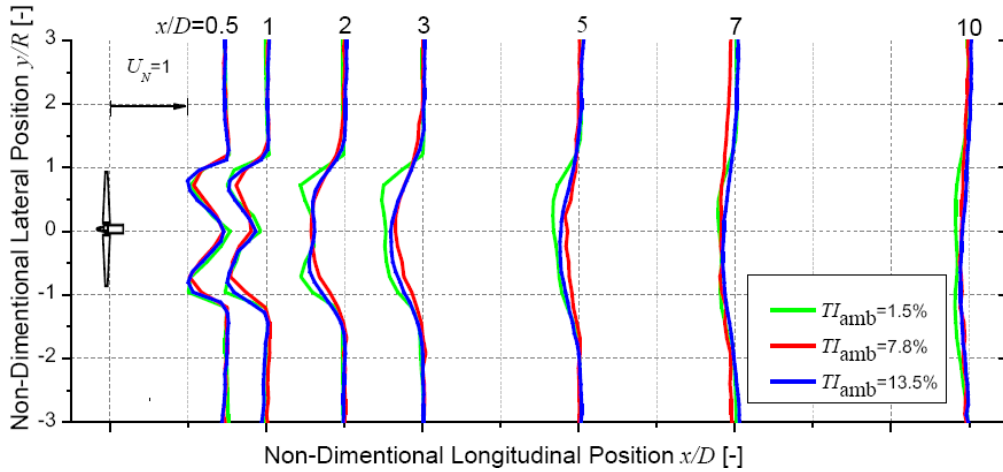


Figure 9: Wind velocity distribution in wake for various ambient turbulence intensities. ($\theta_{yaw}=0^\circ$, $\alpha=0$) The turbulence of inflow promoted the expansion of wake deficit area and recovery of wind speed with increasing TI_{amb} [3]

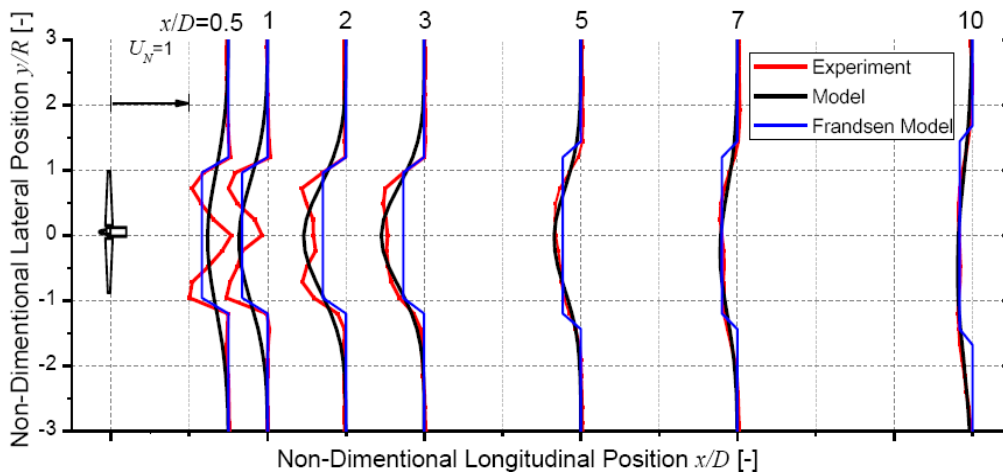


Figure 10: Comparison between experimental results and model ($TI_{amb}=1.5\%$, $\theta_{yaw}=0^\circ$, $\alpha=0$). Wake model agreed well to experimental results in $x/D \geq 5$ where wind distribution has the single peak shape (Basic data under low turbulence)

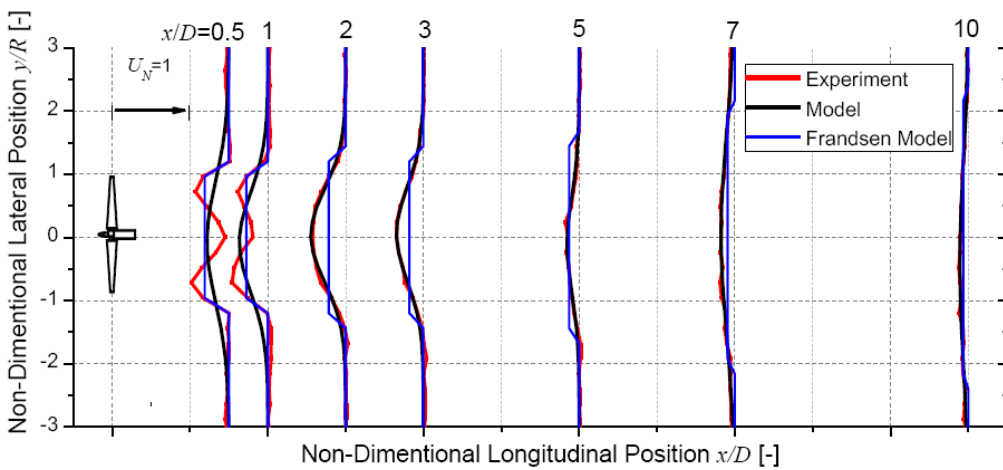


Figure 11: Comparison between experimental results and model ($TI_{amb}=13.5\%$, $\theta_{yaw}=0^\circ$, $\alpha=0$). Wake model agreed well to experimental results in $x/D \geq 2$ where wind distribution has the single peak shape (Application for high turbulence), [3]

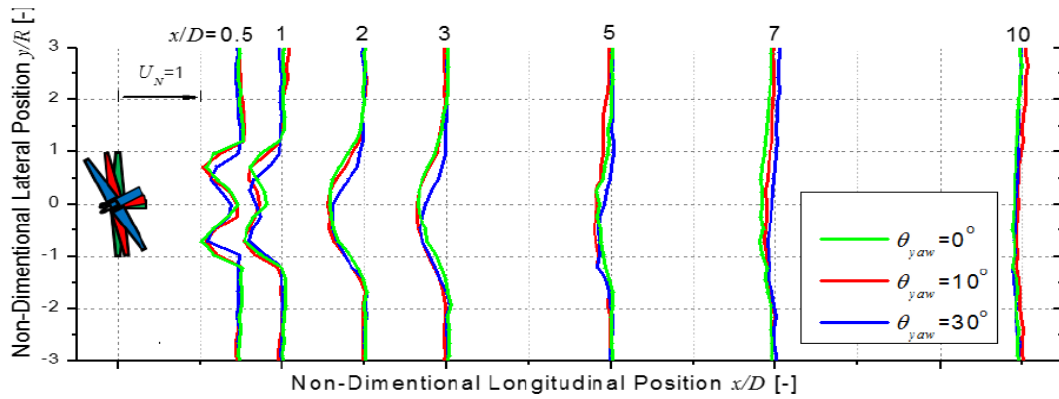


Figure 12: Wind velocity distribution in wake for various yawed inflow condition ($Tl_{amb}=13.5\%$). The yawed inflow influenced that the wake deficit area moves to $-y$ direction and magnitude of wake deficit velocity is reduced with increasing θ_{yaw} , [3]

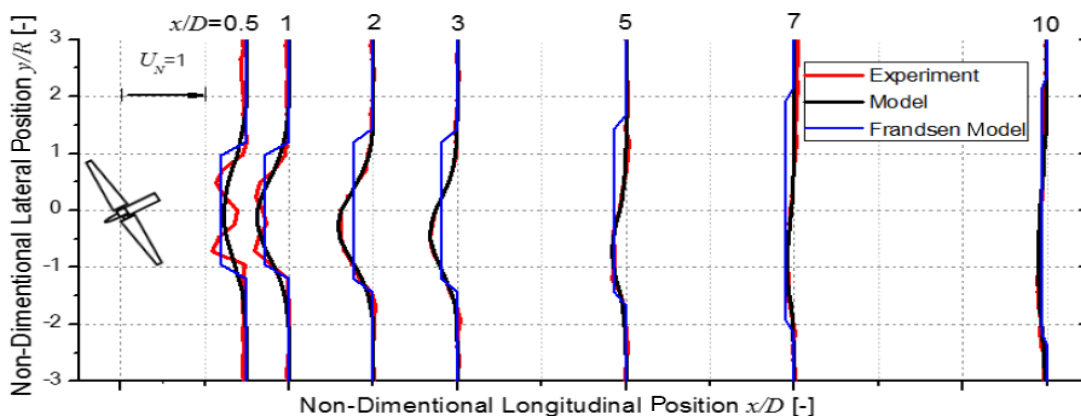


Figure 13: Comparison between experimental results and model ($Tl_{amb}=13.5\%$, $\theta_{yaw}=30^\circ$). Wake model agreed well to experimental results in $x/D \geq 2$ where wind distribution has the single peak shape, [3]

IV. SIMULATION RESULT

4.1. Calculation diagram

To compare the results of the Wake effects calculated by the WindFarm and WAsP softwares with the experimental results at Mie University, Division of Mechanical Engineering, Fluid Engineering Laboratory, we compared based on the same conditions follows:

- Calculation for single Wake effects with the diagrams in Figure 14:

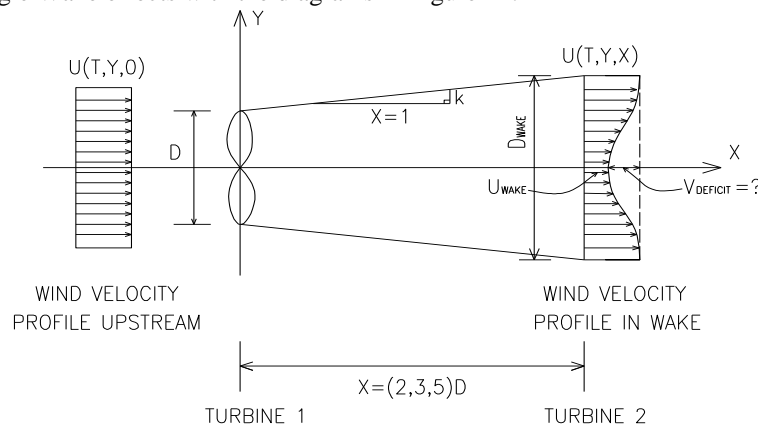


Figure 14: Calculation diagram wake single [9]

- Wind condition: wind only one direction along the axis of the turbine 1 and 2, with the same turbulence intensity in the experiment (Figure 10): $Tl_{amb} = 13.5\%$, $U_0 = 6.012$ m/s;
- Calculation cases: $X = 2D$, $X = 3D$, $X = 5D$;

- Determine: $U_{wake}=?$ $D_{wake}=?$

where D is the rotor diameter, X is the downstream distance, U_0 is the undisturbed wind speed, U_{wake} is wind velocity in wake area, D_{wake} is wake diameter and TI_{amb} is turbulence intensity [%].

4.2. Input data for calculation

- Location: Co To island district, Quang Ninh province, Vietnam (20°56'50"N 107°41'53"E).
- Wind condition ([17],[18]) (Measurement time: from 10/8/2008 to 05/01/2010; 10 minutes/time):

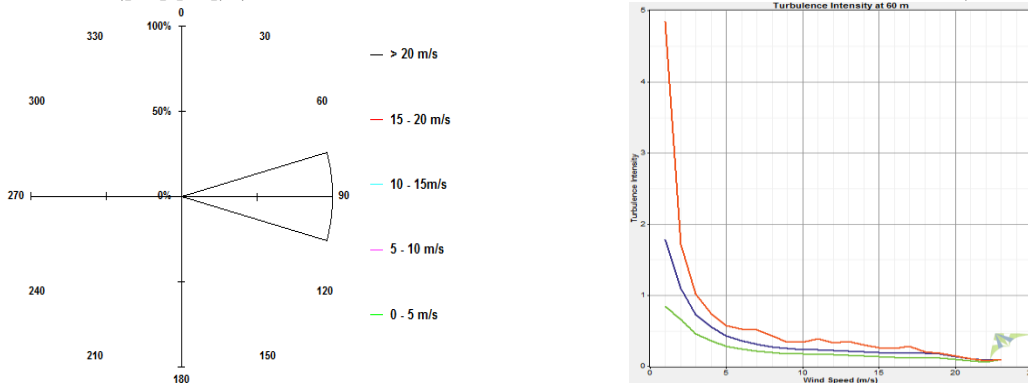


Figure 15: Wind direction at the height of 60m, $TI_{amb}=13.5\%$, $U_{Hub=60m} = 6.012$ m/s [17-18]

- Technical characteristics of the turbine (Manufacturer: Bonus)

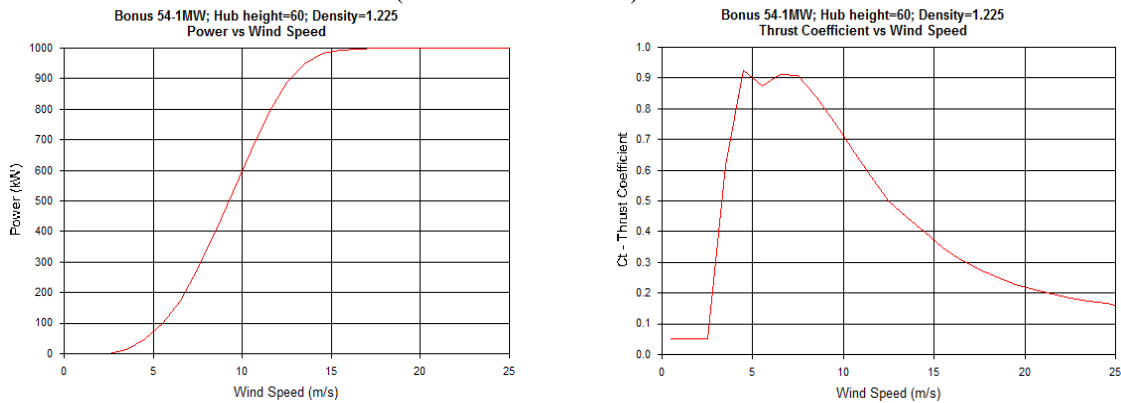


Figure 16: The technical characteristics of the turbine

- The location of the anemometer and turbine layout (based on topographic map, scale 1:25.000, [17-18]):

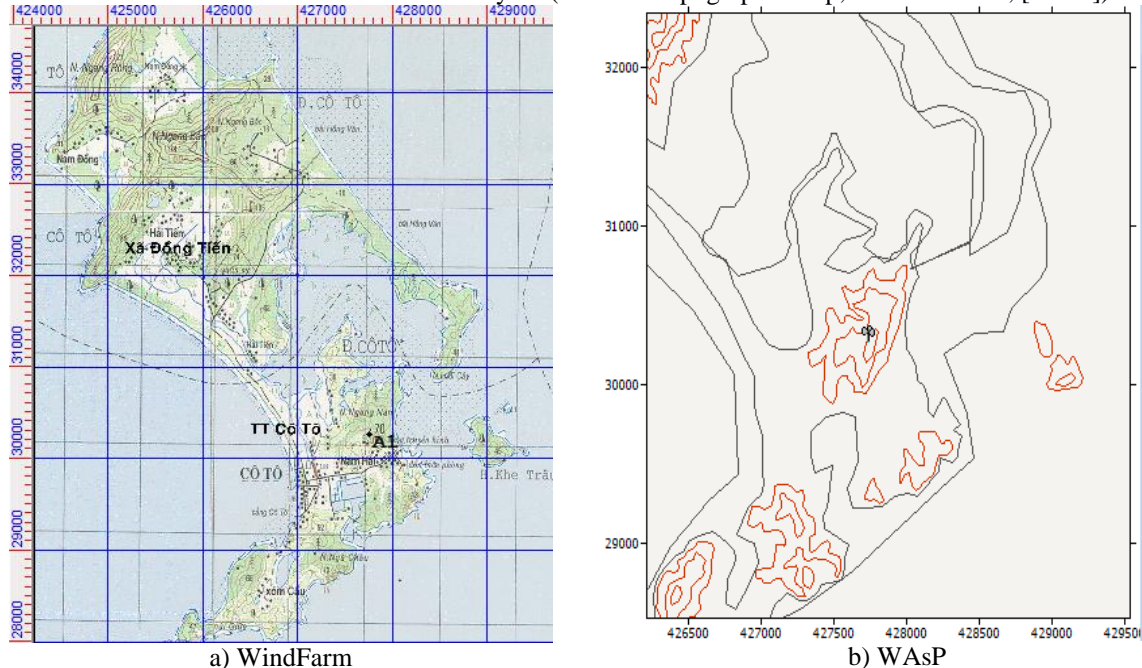


Figure 17: Location of anemometer A1 ($X=427753$, $Y= 30273$)

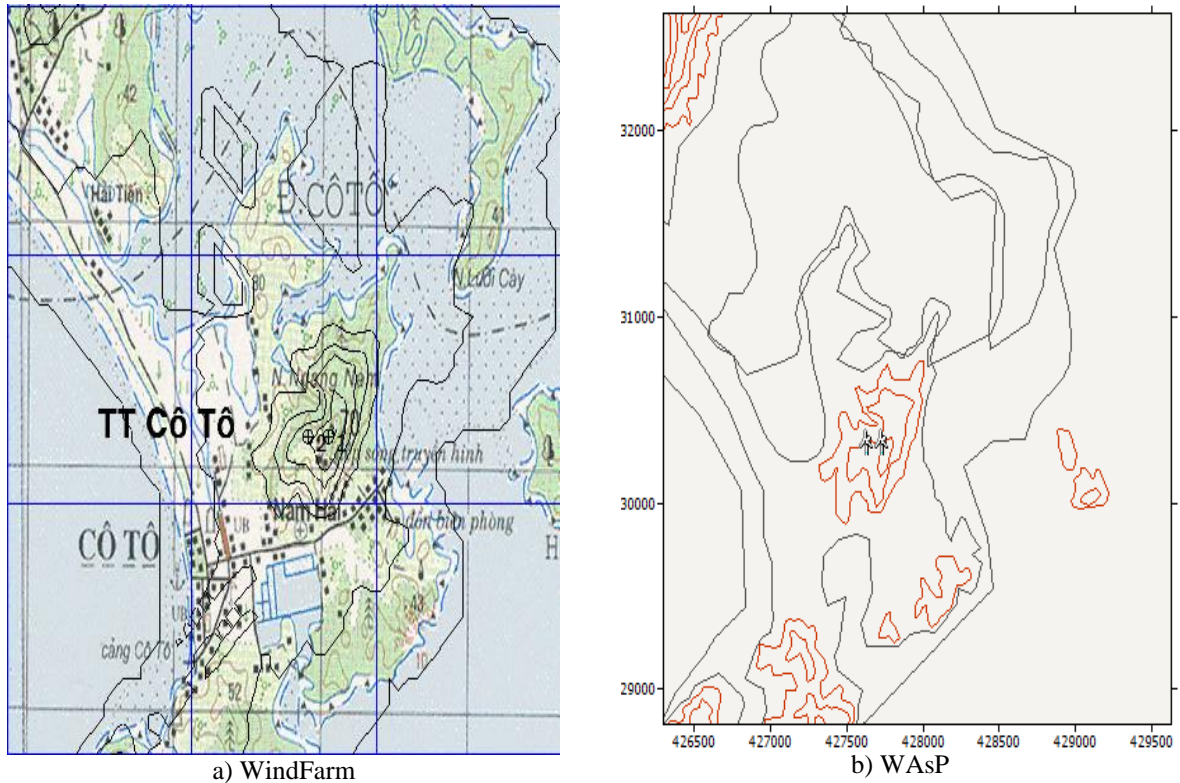


Figure 18: Case 1, X=2D, Turbines layout T1 (X=427743, Y=30273), T2 (X=427634, Y=30273)

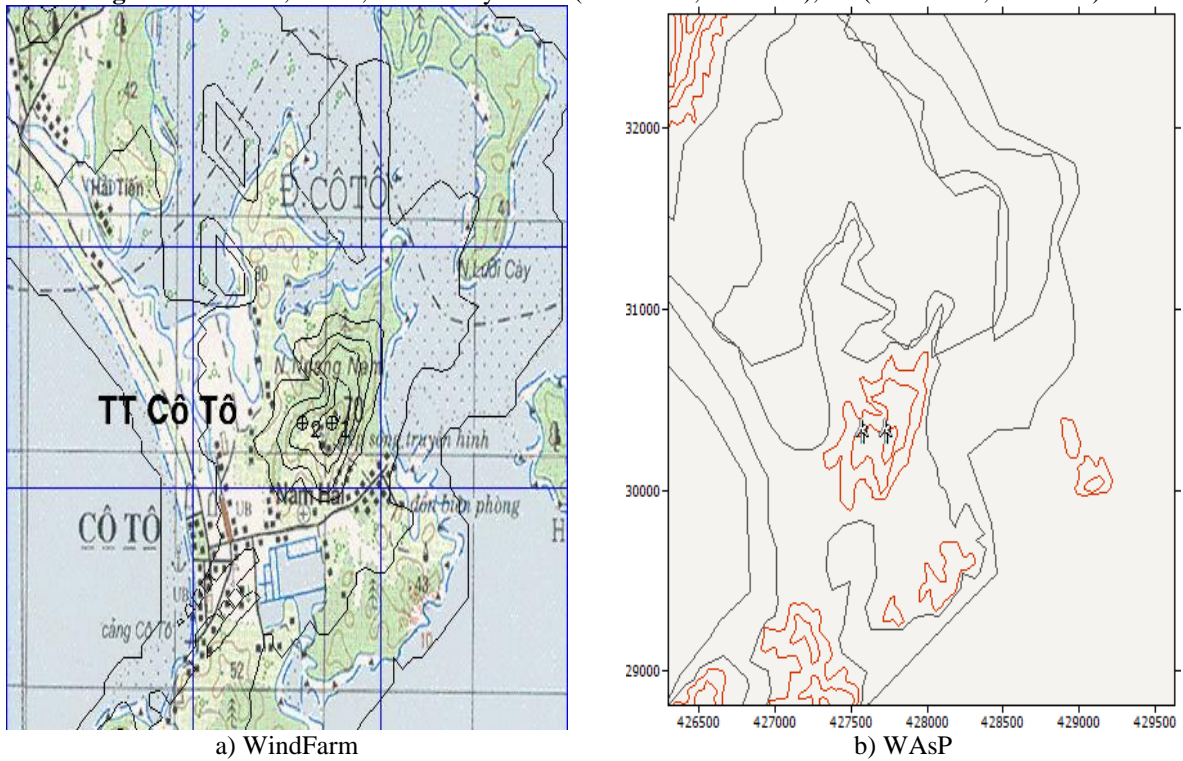


Figure 19: Case 2, X=3D, Turbines layout T1 (X=427743, Y=30273), T2 (X=427580, Y=30273)

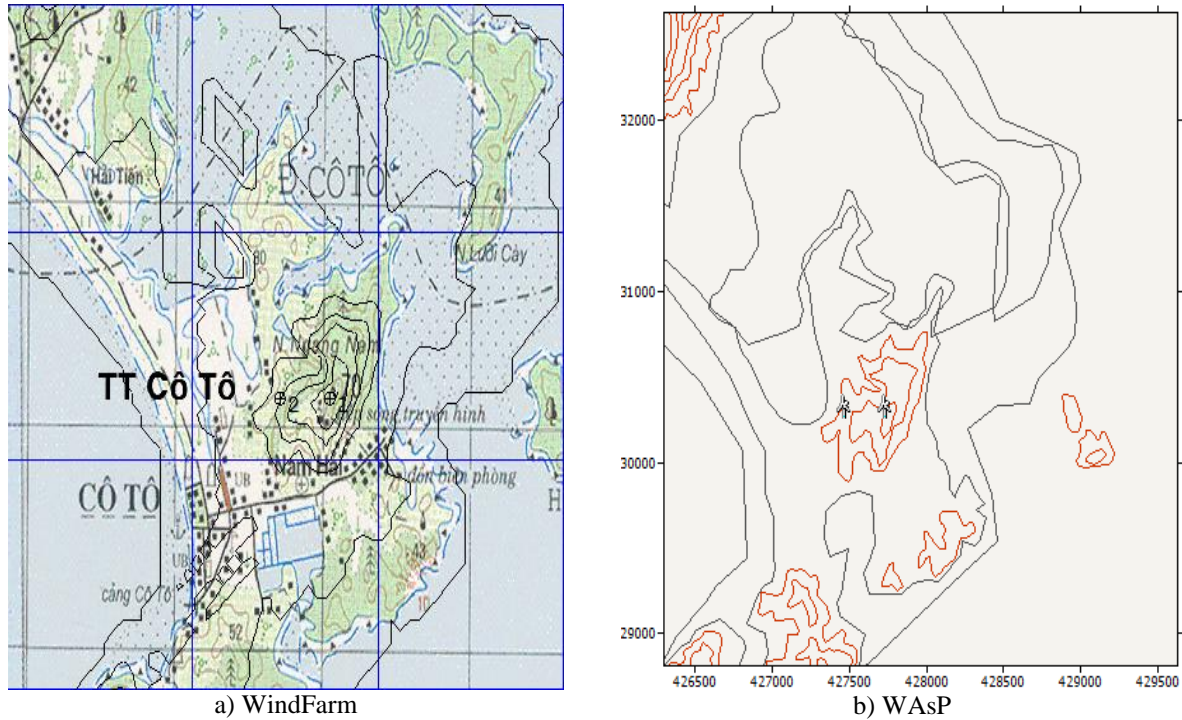


Figure 20: Case 3, X=5D, Turbines layout T1(X=427743, Y=30273), T2(X=427471, Y=30273)

4.3. Calculated results of wind speed at turbines downstream

Table 1: Wind speed at downstream turbine by WindFarm

a) Case 1: X=2D=108.40m		b) Case 2: X=3D=216.80m		c) Case 3: X=5D=271.00m	
T1 (X=427743, Y=30273)		T1(X=427743, Y=30273)		T1(X=427743, Y=30273)	
T2 (X=427634, Y=30273)		T2(X=427580, Y=30273)		T2(X=427471, Y=30273)	
Turbine Identifier	Mean Wind Speed	Turbine Identifier	Mean Wind Speed	Turbine Identifier	Mean Wind Speed
1	6.012	1	6.012	1	6.012
2	4.334	2	4.929	2	5.465
$U_0=6.012\text{m/s}, U(X)_{\text{wake}}=4.334\text{m/s}$		$U_0=6.012\text{m/s}, U(X)_{\text{wake}}=4.929\text{m/s}$		$U_0=6.012\text{m/s}, U(X)_{\text{wake}}=5.465\text{m/s}$	
$\frac{U_{\text{wake}}}{U_0} = 0.721$		$\frac{U_{\text{wake}}}{U_0} = 0.820$		$\frac{U_{\text{wake}}}{U_0} = 0.909$	

Table 2: Wind speed at downstream turbine by WAsP

a) Case 1: X=2D=108.40m		b) Case 2: X=3D=216.80m		c) Case 3: X=5D=271.00m	
T1 (X=427743, Y=30273)		T1(X=427743, Y=30273)		T1(X=427743, Y=30273)	
T2 (X=427634, Y=30273)		T2(X=427580, Y=30273)		T2(X=427471, Y=30273)	
Site description	Speed [m/s]	Site description	U [m/s]	Site description	U [m/s]
Turbine site 002	4.32	Turbine site 001	6.01	Turbine site 001	6.01
Turbine site 001	6.01	Turbine site 002	4.84	Turbine site 002	5.42
$U_0=6.012\text{m/s}, U(X)_{\text{wake}}=4.3320\text{m/s}$		$U_0=6.012\text{m/s}, U(X)_{\text{wake}}=4.840\text{m/s}$		$U_0=6.012\text{m/s}, U(X)_{\text{wake}}=5.420\text{m/s}$	
$\frac{U_{\text{wake}}}{U_0} = 0.719$		$\frac{U_{\text{wake}}}{U_0} = 0.805$		$\frac{U_{\text{wake}}}{U_0} = 0.902$	

The results indicate that wind speeds in Wake at downstream turbines using WindFarm and WAsP softwares are nearly equal (Case 1, X=2D: the difference is 0.05%; Case 2, X=3D: the difference is 1.80%; Case 3, X=5D: the difference is 0.82%). Thus, the WAsP or WindFarm software used to calculate wind speed in wake will have similar results.

4.4. Experimental result and discussion

Based on the results of wind tunnel experiments at Mie University (Figure 11), calculate the wind speed at downstream for turbine 1MW to compare with the results of WindFarm and WAsP as follows:

$$U_{\text{wake}} = (U_{\text{wake}}/U_0)_{y/D=0, \text{experiment}} * U_0 \tag{12}$$

Where: $(U_{wake}/U)_{y/R=0,experiment}$ is ratio at $y/D=0$ determined from Figure 10, $U_0=6.012\text{m/s}$ is the wind speed upstream turbine at H_{hub} . The results are determined as follows:

Table 3: Calculated wind speed downstream of the turbine ($H_{hub}=60\text{m}$, $U_0=6.012\text{m/s}$) based on the experimental results ($TI_{amb}=13.5\%$, $X/D=2,3,5$)

y/R	X/D=2		X/D=3		X/D=5	
	U_{wake}/U_0	U_{wake} (m/s)	U_{wake}/U_0	U_{wake} (m/s)	U_{wake}/U_0	U_{wake} (m/s)
-2.00	1.000	6.012	1.000	6.012	1.000	6.012
-1.50	0.950	5.711	0.999	5.711	0.950	5.711
-1.25	0.915	5.500	0.988	5.500	0.915	5.500
-1.00	0.839	5.041	0.899	5.041	0.839	5.041
-0.75	0.733	4.407	0.823	4.407	0.733	4.407
-0.50	0.649	3.901	0.724	3.901	0.649	3.901
-0.25	0.588	3.533	0.675	3.533	0.588	3.533
0	0.567	3.406	0.653	3.406	0.567	3.406
0.25	0.588	3.533	0.675	3.533	0.588	3.533
0.50	0.649	3.901	0.724	3.901	0.649	3.901
0.75	0.733	4.407	0.823	4.407	0.733	4.407
1.00	0.839	5.041	0.899	5.041	0.839	5.041
1.25	0.915	5.500	0.988	5.500	0.915	5.500
1.50	0.950	5.711	0.999	5.711	0.950	5.711
2.00	1.000	6.012	1.000	6.012	1.000	6.012

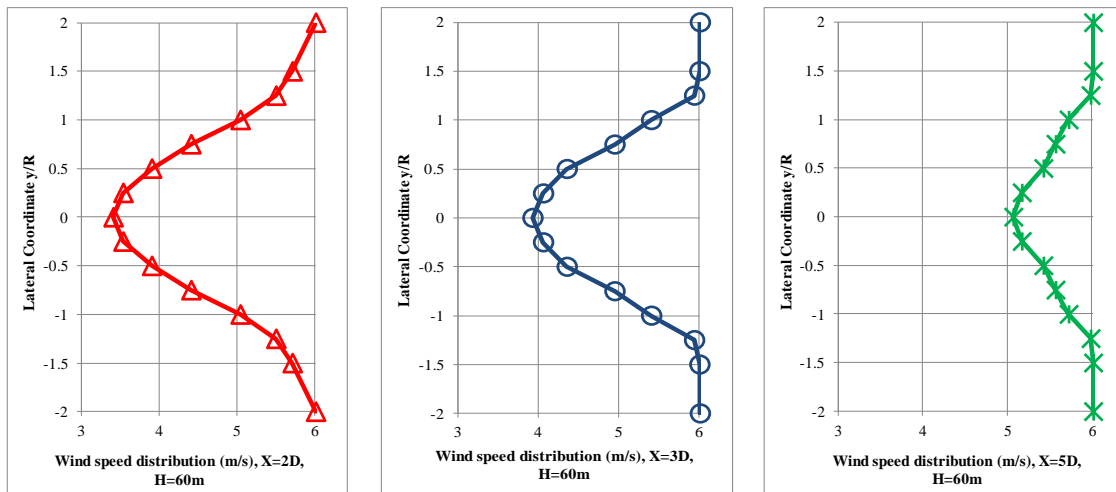


Figure 21: Wind speed distribution at downstream turbine

Table 4: Comparison of coefficients U_{wake} / U_0 between experiment and calculations by the WindFarm and WAsP softwares

X/D	y/R	TI(%)	U_{wake}/U_0 by WindFarm	U_{wake}/U_0 by WAsP	U_{wake}/U_0 by Experiment	D(m)	D_w (m) by WindFarm	D_w (m) by WAsP	D_w (m) by experiment	$k_{WindFarm}$	k_{WAsP}	$k_{experiment}$
2	0	13.5	0.721	0.719	0.567	54.2	62.3	62.3	72.3	0.075	0.075	0.167
3	0	13.5	0.82	0.805	0.653	54.2	66.4	66.4	81.4	0.075	0.075	0.167
5	0	13.5	0.909	0.902	0.843	54.2	74.5	74.5	99.5	0.075	0.075	0.167

If: $\frac{U_{w-MieU}}{U_{w-WindFarm}} = f(X/D)$ where U_{w-MieU} , $U_{w-WindFarm}$ are wind speeds in wake at downstream turbine

which are determined from experiments and WindFarm software, then we have the following relationship:

Table 5: Comparison between experimental results and WindFarm software ($TI_{amb}=13.5\%$)

X/D	2	3	5
$\frac{U_{w-MieU}}{U_{w-WindFarm}} = f(X/D)$	0.79	0.80	0.93

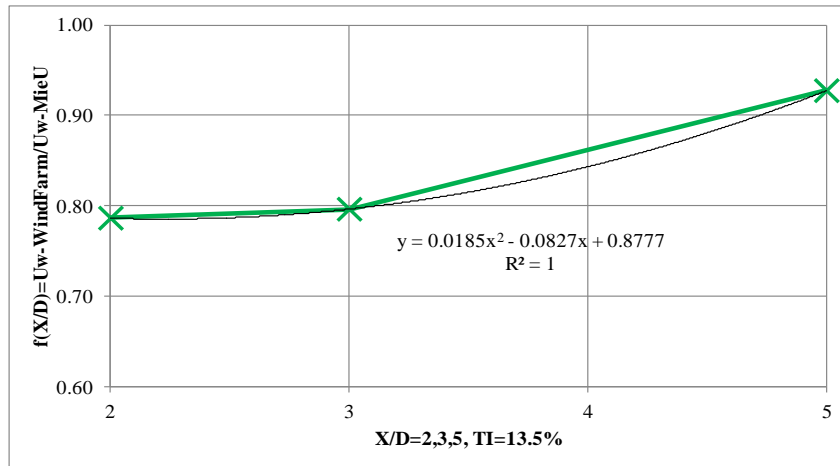


Figure 22: Function shows the relationship between experimental results and WindFarm software ($TI_{amb}=13.5\%$)
Based on Figure 22 we obtain:

$$f(X/D) = \frac{U_{w-MieU}}{U_{w-WindFarm}} = 0.0185(X/D)^2 - 0.08279(X/D) + 0.8777 \quad (\text{with } X/D=2\div 5).$$

From the above results, we draw the following conclusions:

- The results calculated by the WAsP and WindFarm was similar in the same input condition;
- If the axial distance X is greater than $5D$, the results calculated by WindFarm or WAsP is not too different from the experiment results. So we can use the results from these softwares without the need to calibrate.
- If the distance $X=(2.0-5.0)D$, the results calculated by the WindFarm or WAsP is relatively different compared to the experimental results, so it is necessary to adjust the calculation.
- The results of experiments by wind tunnel at Mie University can be considered to suit the wind condition of Vietnam where the terrain condition is similar. In the case of single Wake ($X/D=2.0-5.0$ and $TI_{amb}=13.5\%$ is characterized with wind condition of Vietnam), the formula adjustment proposals as follows:

$$U_{w-final} = U_{w-calc} [0.0185(X/D)^2 - 0.08279(X/D) + 0.8777] \quad (13)$$

$$U_{deficit-final} = U_{deficit-calc} [0.0185(X/D)^2 - 0.08279(X/D) + 0.8777] \quad (14)$$

Where:

+ $U_{w-final}$ and $U_{deficit-final}$ are wind speed and wind speed deficit in wake at downstream;

+ U_{w-calc} and $U_{deficit-calc}$ are wind speed and wind speed deficit in wake at downstream calculated by WindFarm or WAsP.

V. CONCLUSION AND RECOMMENDATION

This paper presents models for calculating the wind velocity deficit in Wake by WAsP and Windfarm softwares and the experimental results of wind tunnel about wake effects at Mie University, Japan. The calculation results for the Co To island in Quang Ninh province with a wind measurement time of more than 1 year at a height of 60m by WAsP and Windfarm softwares showed that within $X=(2.0-5.0)D$ (rotor diameter) then the velocity deficit computed by these software are similar but larger than the results of the experiment. Therefore, for the assessment of wind potential with WAsP and WindFarm to be consistent with the realities of near wake ($X=(2.0-5.0)D$), it is necessary to adjust the results calculated according to the results experimental of wind tunnel by Eqs. (13) and (14). Thus, the accuracy of the design of wind farms in Vietnam will be improved.

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