

# **Numerical Study on the Hydrodynamic Characteristics of Wind Energy Marine Unit**

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**ABSTRACT:** This paper discusses the influence of several important parameters on the hydrodynamic moment created by the rotating pontoon of a WEMU turbine, where the turbulent flow around pontoon under the double-model assumption is calculated by solving the Reynolds averaged continuity and momentum equations incorporated with the standard  $k-\varepsilon$  turbulence model. It is found the resulted hydrodynamic moment due to the rotational motion of pontoon has a power-law dependence on the period of rotation, while the power-law constant approaches to unity provided a sufficiently large incoming flow velocity is present.

**Keywords:** Moment, WEMU, Hydrodynamics

## **1. INTRODUCTION**

Currently, the wind energy is considered as one of the economic and clean means to solve problems of global power supply complicated by issues of global warming and waste utilization. Offshore wind power plants seem to be the most promising and quickly growing area in wind power engineering. They have obvious advantages over inland power plants, such as soft ecological demands, fast blade speed and high efficiency. Basic aims of wind energy unit design are to increase the allowable unit capacity, to operate safely under excessive wind loads, to have a wide wind speed range, to reduce wind energy cost, to eliminate noise emission and to avoid fatal injury of birds due to rotating turbine. In order to meet these requirements, an offshore wind

turbine system is proposed [1] and referred as the Wind Energy Marine Unit (WEMU), which consists of a large-scale floating rotor supported by a floating pontoon delivering required buoyancy, Fig. 1. The rotor rotates about a pile- or isle-based tower, where a generator system is located. One major advantage of the WEMU is the high aerodynamic efficiency even at a relatively low blade velocity. Its rated aerodynamic power capacity can reach tenths of MW [1]. After the related aerodynamic aspect of WEMU has been studied by our previous studies [1-4], another key issue for the WEMU design is the hydrodynamic characteristics of the pontoon, where an involuntary power loss due to hydrodynamic drag should be minimized. Recently, a preliminary study [5] on the hydrodynamic characteristics of pontoon has been

conducted, where seven different cases are calculated. The full understanding of the hydrodynamic behaviour for the floating pontoon is still far from complete. This paper is therefore aimed to more extensively investigate the hydrodynamic performance of pontoon via the calculation of turbulent flow about the pontoon in full scale under the double-model assumption, where the power loss due to viscous drag of water, and the influence of geometrical features on the power loss are quantitatively analyzed.

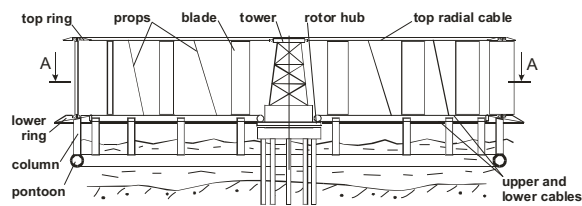


**Figure 1:** Layout of the WEMU turbine.

## 2. NUMERICAL MODEL

### 2.1 Governing Equations

The basic governing equations to describe the double-model turbulent flow around pontoon are the Reynolds-averaged continuity and Navier-Stokes equations:

$$\frac{\partial U_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial (U_i U_j)}{\partial x_i} = -\frac{1}{\rho} \frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_j} \left[ \nu \left( \frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) \right] - \frac{\partial (\overline{u'_i u'_j})}{\partial x_j} \quad (2)$$

where  $U_i$  denotes the velocity component in the direction of the Cartesian coordinate  $x_i$ ,  $P$  the pressure,  $\rho$  the fluid density,  $\nu$  the kinematic viscosity and  $\overline{u'_i u'_j}$  the Reynolds stress, which is defined as follows:

$$-\rho \overline{u'_i u'_j} = -\rho \frac{2}{3} k \delta_{ij} + \mu_t \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \quad (3)$$

where  $\delta_{ij}$  gives the value one only for  $i=j$ , otherwise zero and  $\mu_t$  represents the turbulent viscosity. In order to calculate the turbulent viscosity, a two-equation  $k$ - $\varepsilon$  model is adopted:

$$\frac{\partial (k U_j)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \left( \nu + \frac{\nu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + P_k - \varepsilon \quad (4)$$

$$\frac{\partial (\varepsilon U_j)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \left( \nu + \frac{\nu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + c_1 \frac{\varepsilon}{k} P_k - c_2 \frac{\varepsilon^2}{k} \quad (5)$$

$$P_k = \nu_t \left( \frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) \frac{\partial U_i}{\partial x_j} \quad (6)$$

$$\nu_t = C_\mu \frac{k^2}{\varepsilon} \quad (7)$$

where  $k$  denotes the turbulent kinetic energy,  $\varepsilon$  the dissipation rate of  $k$ ,  $\nu_t$  the turbulent viscosity ( $=\mu_t/\rho$ ),  $P_k$  the energy production term. The constant appearing in the employed turbulence model is given as follows:  $c_1=1.44$ ,  $c_2=1.92$ ,  $C_\mu=0.09$ ,  $\sigma_k=1.0$  and  $\sigma_\varepsilon=1.3$ .

### 2.2 Numerical Scheme

The governing equations are discretized by a second-order finite-volume method, where the SIMPLE algorithm [6] is adopted to separate the velocity and pressure coupling. The numerical scheme has been implemented in the software Comet [7], which is adopted in this study to investigate the turbulent flow around pontoon.

### 2.3 Grid and Computational Domain

A body fitted grid system is applied to discretized the computational domain given in Fig. 2, where  $L$  denotes the radial distance from the cross-section centre of the pontoon to the outer boundary,  $R$  the radial distance from the cross-section centre of the pontoon pointing to the location of its rotational axis,  $h$  the water depth to sea bed,  $d$  the cross-section diameter of pontoon,  $h_p$  the submergence depth of pontoon. Because the flow problem is axis-symmetrical, a domain discretizing only part of the pontoon ( $5^\circ$  along the tangential direction) is employed for the numerical computation instead of using the complete one. A grid-dependence test of several successively refined grid levels with cell number ( $N$ ) ranging from 5,000 and 30,000 shows the discretization error of predicted moment  $M$  is smaller than 0.1% for the typical grid density of 20,000 cells, Fig. 3. After a sensitivity test, the value defining the outer boundary location

of the employed computational domain ( $L$ ,  $R$ ,  $h$ ) is given by (50 m, 50 m, 50 m).

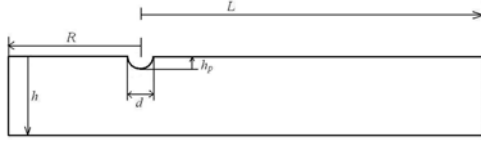


**Figure 2:** Computational domain for the calculation of flow around pontoon.

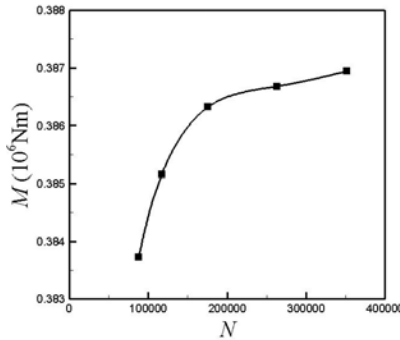


**Figure 3:** Grid-dependence test.

### 3. NUMERICAL RESULTS

#### 3.1 Geometrical Definition of Pontoon

After removing the structure above the pontoon, the investigated pontoon can be regarded as a toroid floating in the sea, where the radial distance from the cross-section centre to the rotational axis is fixed as 100m. The most important parameter influencing the hydrodynamic moment due to hydrodynamic drag is the rotational speed of pontoon, which is characterized by the corresponding period  $T_p$ . The influence of three different parameter groups, e.g. ( $T_p$ ,  $d$ ), ( $T_p$ ,  $h_p$ ) and ( $T_p$ ,  $V$ ), on the hydrodynamic moment is systematically discussed, where  $V$  denotes the incoming flow speed.

#### 3.2 Parameter Group ( $T_p$ , $d$ )

First, the dependence of hydrodynamic moment  $M$  on the parameter group ( $T_p$ ,  $d$ ) is studied. Figure 4 shows the comparison of  $M$  for different rotational speed among several pontoon sizes, where the water submergence is equal to the radius of cross section. The hydrodynamic moment clearly

shows a power-law dependence on the period of rotation, where  $M$  increases with the rotational speed and the diameter  $d$ . In order to compare the hydrodynamic moment delivered at different conditions, the dimensionless moment  $M^*$  can be further defined by the following equations:

$$M^* = M/M_0 \quad (8)$$

$$M_0 = \rho_w V_p S_p / T_p^2 \quad (9)$$

where  $\rho_w$  denotes the water density,  $V_p$  the volume of pontoon submerged in water,  $S_p$  the wetted surface of pontoon. From Fig. 5, it is apparently that the dimensionless  $M^*$  increases with the rotation period, while a critical point occurs at  $T_p = 20$  min. This phenomenon might be due to the transition of flow from turbulent to laminar flow regime. The dimensionless  $M^*$  has the following dependence on  $T_p$  (in min) within the investigated range:

$$M^* = e^{A+Bd} T_p^C \quad (10)$$

where the constant set ( $A$ ,  $B$ ,  $C$ ) is equal to (6.1, -1.4, 0.121) for  $T_p < 20$  min and (5.377, -1.363, 0.347) for  $T_p > 20$  min.

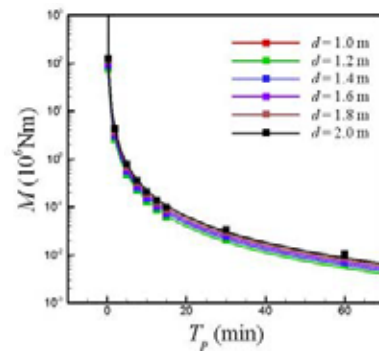


**Figure 4:** Dependence of  $M$  on  $T_p$  and  $d$ .

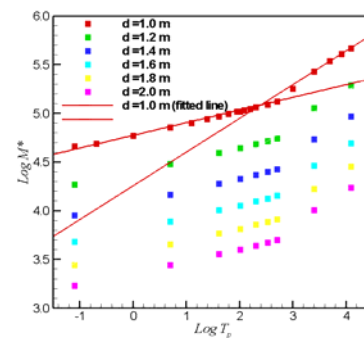


**Figure 5:** Dependence of  $M^*$  on  $T_p$  and  $d$ .

### 3.3 Parameter Group ( $T_p$ , $h_p$ )

Second, the dependence of hydrodynamic moment  $M$  on the parameter group ( $T_p$ ,  $h_p$ ) is studied. Figure 6 shows the comparison of  $M$  for different rotational speed among several submergence depths, where the radius of cross section is fixed as 1 m. The hydrodynamic moment also shows a power-law dependence on the period of rotation, where  $M$  increases with the rotational speed and the submergence depth  $h_p$ . It can be found that the hydrodynamic moment varies little when all the pontoon is under the water surface when the wave induced effects are neglected.

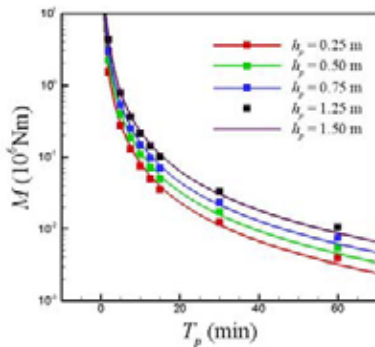


**Figure 6:** Dependence of  $M$  on  $T_p$  and  $h_p$ .

### 3.4 Parameter Group ( $T_p$ , $V$ )

At last, the dependence of hydrodynamic moment  $M$  on the parameter group ( $T_p$ ,  $V$ ) is studied. Different from the previous sections, the flow problem becomes no more axis-symmetrical provided the incoming flow velocity is taken into account. Therefore, a full computational domain is adopted in the numerical calculations to account for the influence of incoming velocity, Fig. 7, where  $L$  is taken as 400 m. Similar to the previous calculations, the wave effect is neglected for the sake of simplicity. Figure 8 shows the comparison of  $M$  for different rotational speed among several incoming velocities, where the submergence depth and the radius of cross section are chosen as 0.5 m and 1 m, respectively. The hydrodynamic moment still gives a power-law dependence on the period of rotation, where  $M$  increases with the rotational and incoming speed.

Additionally, the presence of incoming velocity results in the increase of the constant  $C$  in the Eq. 10, which approaches to 1.0 when the incoming velocity is sufficiently large. It indicates that the in the studied case, the incoming velocity has substantial influence on the hydrodynamic moment.

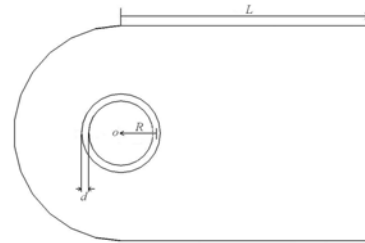


**Figure 7:** Computational domain for the calculation of flow around pontoon with incoming flow velocity.

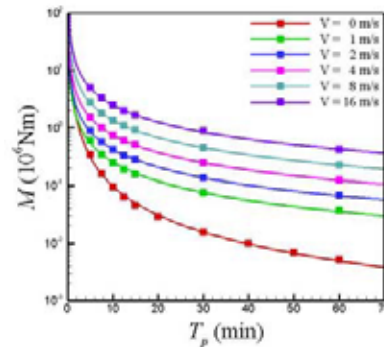


**Figure 8:** Dependence of  $M$  on  $T_p$  and  $V$ .

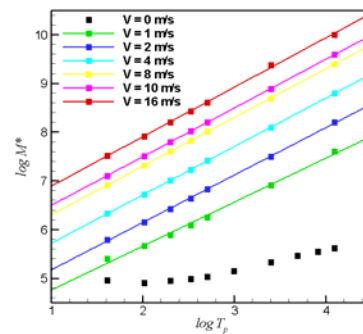


**Figure 9:** Dependence of  $M^*$  on  $T_p$  and  $V$ .

## 4. CONCLUSION

This paper discusses the influence of several parameters on the hydrodynamic moment created by the pontoon of a WEMU

turbine, where the turbulent flow around pontoon under the double-model assumption is calculated by solving the Reynolds averaged continuity and momentum equations incorporated with the standard  $k-\varepsilon$  turbulence model. The influence of three different parameter groups, e.g.  $(T_p, d)$ ,  $(T_p, h_p)$  and  $(T_p, V)$ , on the hydrodynamic moment is extensively discussed. It is found the resulted hydrodynamic moment due to the rotational motion of pontoon has a power-law dependence on the period of rotation, while the power-law constant approaches to unity provided a sufficiently large incoming flow velocity is present.

## ACKNOWLEDGEMENT

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## REFERENCES

- [1]Cheboxarov, VV, Cheboxarov, VV, Bekker, AT, Anokhin, PV. 2002. A Novel Turbine for Offshore Wind Energy: Design and Energy Conversion. Proc of the 12<sup>th</sup> Int Offshore and Polar Eng Conf. Vol 1. pp700-706.
- [2]Cheboxarov, VV, Cheboxarov, VV. (2002). WEMU: Development of Novel Water Supported Wind Power Plant. Proc of the World Wind Conf.
- [3]Cheboxarov, VV, Cheboxarov, VV, Bekker, AT. (2004). Numerical Analysis of Large-Scale Offshore Vertical Axis Wind Turbine. Int J of Offshore and Polar Eng. Vol 14. No 3. pp 233-238.
- [4]Cheboxarov, VV, Cheboxarov, VV. 2006. Analysis of Air Flow and Deformations of Large-Scale Floating Wind Turbine. Proc of Int Conf "Renewable Energy-2006". pp759-762.
- [5]Cheboxarov, VV, Cheboxarov, VV, Kouh, JS, Chau, SW, Chen, YJ. 2008. Numerical Simulation of Water Flow about Rotary Pontoon of Floating Wind Turbine. Proc. of the 4<sup>th</sup> Asia-Pacific Workshop on Marine Hydrodynamics.
- [6]Pantankar, SV. 1980. Numerical Heat Transfer and Fluid Flow. Hemisphere Publishing.
- [7]Comet User's Manual. 2002.