TURBULENCE AND ITS EFFECTS ON THE THRUST AND WAKE OF A POROUS DISC ROTOR SIMULATOR

Tom Blackmore and AbuBakr S Bahaj
Energy and Climate Change Division, Sustainable Energy Research Group
University of Southampton, Southampton SO17 1BJ, UK, (www.energy.soton.ac.uk)

Marine current turbines are still in their infancy with many devices at the development stage. Studies are often carried out using small scale laboratory experiments in flumes, towing tanks and numerical simulations to investigate the wakes and performance of scale marine current turbines. However, the characteristics of the inflow turbulence used in such studies is often not fully considered. Tidal flows are highly turbulent with a broad range of eddy sizes and intensities. So differences are expected when predictions of array energy yields are made from towing tanks studies with zero turbulence. This work considers the effects of turbulent eddy size on the thrust and wake behind a porous disc rotor simulator commonly used to represent marine current turbines in small scale experiments. The results show an increase in thrust coefficient with increasing length scale and a corresponding reduction in velocity deficit in the wake. These findings have implications to array special planning and hence energy yields.

Keywords: Marine Energy, Tidal, Marine Currents, Turbulence, Turbines

INTRODUCTION

Marine current turbines are still in the initial development stage with only single demonstration devices in deployment [1-3]. To progress the development, further research has been highlighted in the design of multiple device arrays and the turbulent conditions in which the turbines operate [1-3]. However, the turbulence inflow conditions used in small scale experiments is often poorly reported, or not considered. In comparison the turbulence in marine currents is very high with a broad range of length scales and intensities of around 10% [4,5].

It has been shown that the inflow turbulence characteristics used in experiments with porous disc rotor simulators has a significant effect on the measured thrust coefficient [6]. Overall variations in thrust coefficient of over 20% were recorded, demonstrating the need to consider the specific turbulence characteristics for accurate predictions to be made.

This work builds on this previous work to consider the variations in thrust with different turbulent inflows to explain how the near wake characteristics are changed. An increase in thrust on the porous disc will be a result of a greater decrease in velocity across the disc. However, in a high turbulence flow the wake is likely to recover more quickly. The implications of this are to array special planning and the associated energy yield, which are discussed in this paper.

METHOD AND DATA REDUCTION

The experimental method is first described, before the data analysis and reduction described.

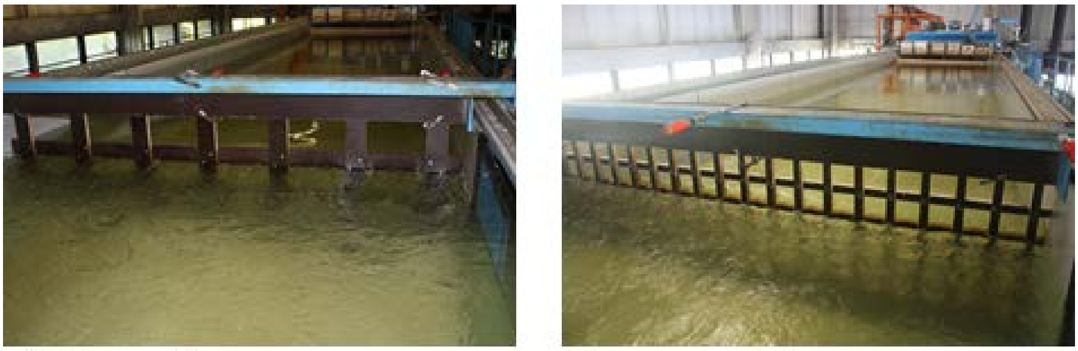
Experimental Method

Experiments were performed in a gravity fed flume at the Technical University of Braunschweig, Germany. The flume is 2m wide, 0.6m deep and 36m long and set to achieve uniform flow conditions along the length of the flume, such that constant depth and velocity profile was achieved. Flow straighteners were installed at the inlet and grids were installed 8m downstream to generate turbulence with different length scales, or eddy sizes. Figure 1 shows the 300mm and 100mm grids used for this study. It can be seen in Figure 1 that the upstream surface (top of the photo) is smooth and uniform, downstream (bottom of the photo) of the grids the turbulent structures generated by the grids can be seen in the surface. Full details of the experimental procedure can be found in [6].

A 150mm diameter, 0.6 porosity disc rotor simulator was then installed in the turbulent flow and the thrust coefficient measured using two load cells. Velocity measurements were made with two Nortec Vectrino+ Acoustic Doppler Velocimeter’s (ADV’s). Figure 2 shows the porous disc rotor simulator and ADV installed in the flume.

Data Reduction

The measured thrust forces are presented as non-dimensional thrust coefficients,



a) 300mm grid in flume. b) 100mm grid in flume.

Figure 1. 300mm and 100mm grids installed in flume – Note turbulent structures seen in the downstream surface (bottom of photo), and smooth upstread flow (top of photo).

Figure 2. 150mm porous disc rotor simulator and ADV velocity probe to the left.

$$C_T = \frac{T}{\frac{1}{2}\rho U_\infty{}^2 A} \quad (1)$$

Where C_T is the thrust coefficient, T is the thrust, ρ is the density, U_∞ is the freestream velocity and A is the frontal area of the porous disc. The velocities are presented as velocity deficits,

$$U_D = 1 - \frac{U}{U_\infty} \quad (2)$$

Where U_D is the velocity deficit and U the axial velocity. The turbulent flow was described as a stream wise turbulence intensity and integral length scale,

$$I = \frac{u'}{U} \quad (3)$$

Where I is the turbulence intensity and u' is the RMS of axial velocity fluctuations. The integral length scale was calculated using Taylors Hypothesis as,

$$\ell_x = U \int_0^\infty \frac{R(s)}{R(0)} ds \quad (4)$$

Where ℓ_x is the integral length scale, R() is the autocovarience and s is the time lag [7].

RESULTS AND DISCUSSION

Thrust coefficients

The thrust coefficients recorded are shown in Table 1. Case 1 is the low turbulence case in the flume without the grid turbulence generators installed. It can be seen that the cases with high intensity (cases 2 &3), I~10%, result in much higher thrust coefficients than the low turbulence case. The highest thrust coefficient is recorded for a ℓ_x/D ratio of 0.2 and a lower thrust for ℓ_x/D =0.6, as found in [6].

Table 1. Thrust coefficients with different turbulence characteristics.

case	*I* (%)	ℓ_x/D	C_T
1	4.5	2	0.73
2	10	0.2	0.97
3	10	0.6	0.90

One implication of this finding is the increase in thrust coefficient of over 20% in a high turbulence case when compared to the low turbulence case. If the design and performance predictions of turbine rotors are performed in low turbulence conditions then the forces may be severely underestimated. This highlights the need to fully consider the site specific turbulence characteristics for accurate predictions to be made. Further work is required to accurately represent site specific turbulence characteristics in laboratory experiments.

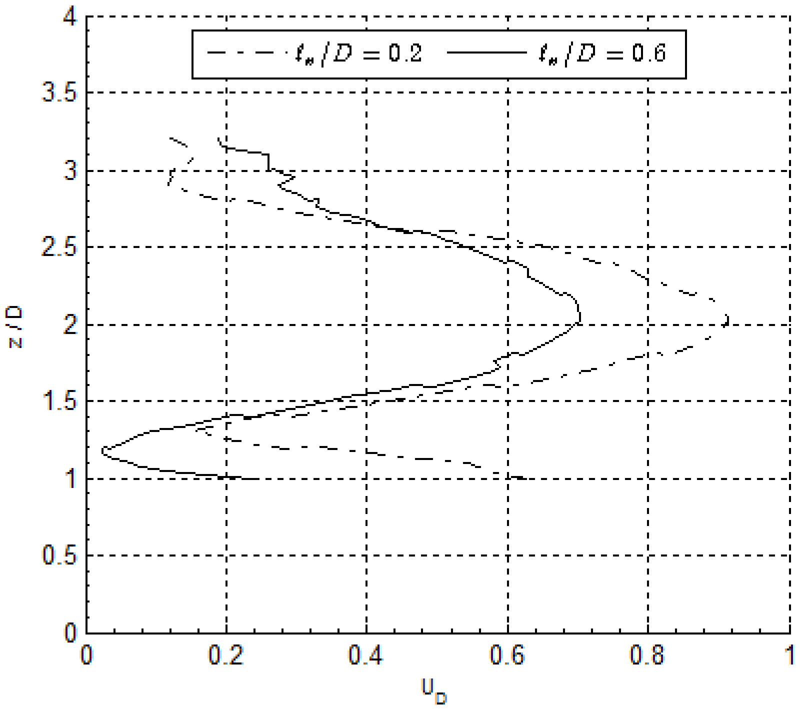


Figure 3. Velocity deficit at 3 diameters downstream with different integral length scales.

Velocity profiles at 3D downstream

Figure 3 shows the velocity profiles 3D downstream of the porous disc for cases 2 and 3 with ℓ_x/D of 0.2 and 0.6 respectively. It can be seen that the velocity deficit is lower for case 3 with $\ell_x/D = 0.6$. This is consistent with the thrust measurements with the thrust coefficient being lower for case 3 than case 2. This is to be expected as for case 2 with a higher thrust coefficient, a greater pressure difference is required and hence a greater drop in velocity across the porous disc.

Figure 4 shows the turbulent fluctuations in the axial (Figure 3(a)) and transverse (Figure 3(b)) directions. Note, these are akin to the Reynolds stress components and therefore a measure on the turbulent mixing in the wake. It can be seen that the case 3 with larger length scales of $\ell_x/D = 0.6$ has larger turbulent fluctuations, about double that of case 2 with $\ell_x/D = 0.2$. Due to this increased turbulent mixing with larger length scales high momentum fluid from the bypass flow can be mixed with the low momentum wake more rapidly, resulting in a lower velocity deficit. This explains the trends seen with velocity profiles and thrust coefficients, and further highlights the sensitivity on the specific turbulence conditions of a site, or experiment.

Due to time constraints detailed wake mapping was not possible. Further work is required to consider a wider range of turbulence length scales and to capture the wake profile downstream of the disc. However, these initial results do show the significance of turbulence on the near wake of a porous disc rotor simulator.

The implication of these results is for array special design and optimization. Due to the variations in wake profile with different turbulence characteristics, turbines may not be optimally placed if the site specific characteristics are not considered.

CONCLUSIONS

Flows with different turbulence characteristics were generated using grids installed in the flume, as commonly used in wind tunnels. It was shown how significant variations in thrust and wake profile behind a porous disc rotor simulator were observed with different turbulent inflows.

Variations in thrust coefficient in excess of 20% were measured which demonstrates the requirement to consider the site specific turbulence characteristics when designing the turbine. If turbulence is not considered, then the forces will be severely underestimated and the design could suffer from reliability issues.

Consistent with the thrust measurements, variations in the wake profile were also observed. The implication of this is for the design of multiple turbine arrays. If the

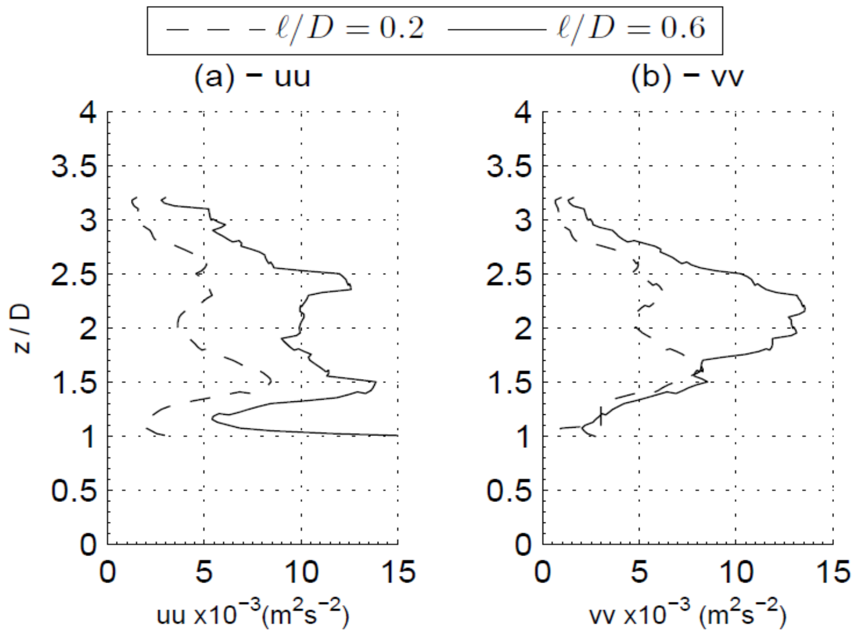


Figure 4, Turbulent velocity fluctuations in the axial (a) and transverse (b) directions 3 diameters downstream of the disc. Note, these are akin to the Reynolds stresses for an incompressible fluid.

turbulence is not considered the turbine locations in the array will be sub-optimal as wake recovery rates vary significantly with different turbulent inflows.

Further work is required to consider a broader range of turbulence inflows and capture a detailed wake map behind the disc. This would allow the mechanism, through which turbulence so greatly affects the thrust and wake, to be investigated. Further work is ongoing to reproduce turbulent flows that are representative of tidal energy sites to allow array optimization to be undertaken.

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