Evaluation of the RANS-BEM Method for Wakes and Loading of Arrays of Rotors

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Arrays, Wakes and Near-Field Effects

Effective array planning will require knowledge of turbine interaction and the loads on turbines within arrays. Several studies have considered the use of RANS-BEM methods to predict the flow-field downstream of single and multiple turbines (i.e [1] and [2]) however limited comparison has been made to experimental measurements of wake interaction for multiple devices. This study compares a steady-state RANS-BEM method to measurements of the downstream flow-field and loading on one and three row arrays of rotors [3].

Single Rotor

Experiments were conducted with 3-bladed rotors of diameter D = 0.27m in water depth d = 0.45m and with mean streamwise velocity U = 0.463 m/s [3]. The RANS-BEM method was implemented within the CFD code STARCCM+. Turbulence is represented using a k-ω model with inlet k and ω equivalent to TI=12% and L=d/2. The rotor C_P and C_T is shown in Figure 1.

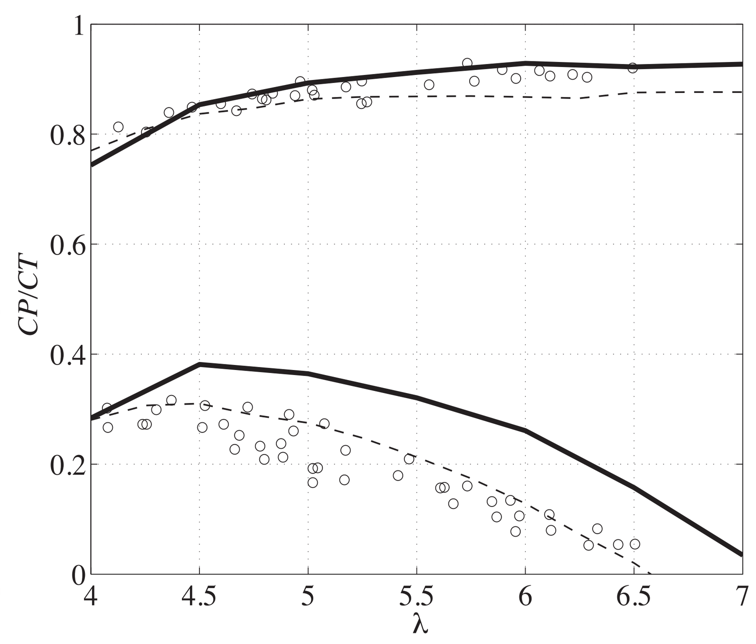

Figure 1 - C_P and C_T of BEM(- -) RANS-BEM (-) and experiments (o)

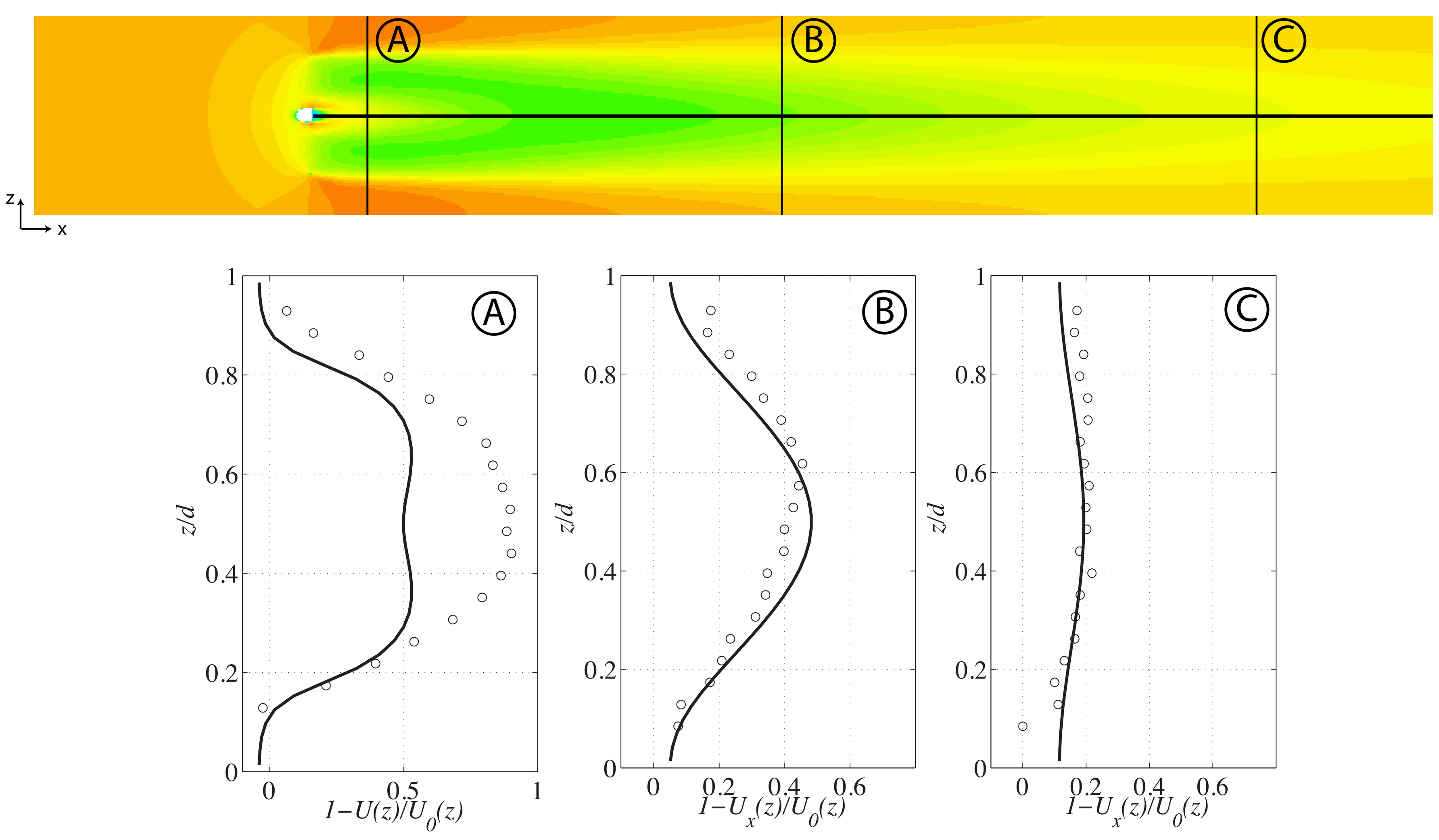

Figure 2 - Vertical Profiles of Velocity 1.5D, 4D and 8D downstream of a single isolated rotor. RANS-BEM (-) and experiments (o)

Close to the rotor (X<4D) the RANS-BEM method under-predicts the maximum velocity deficit. This is thought to be caused by the method not fully capturing the blade scale turbulence. A good agreement of the downstream flow-field was found at distances of greater than 4 diameters.(Figure 2 and Figure 3)

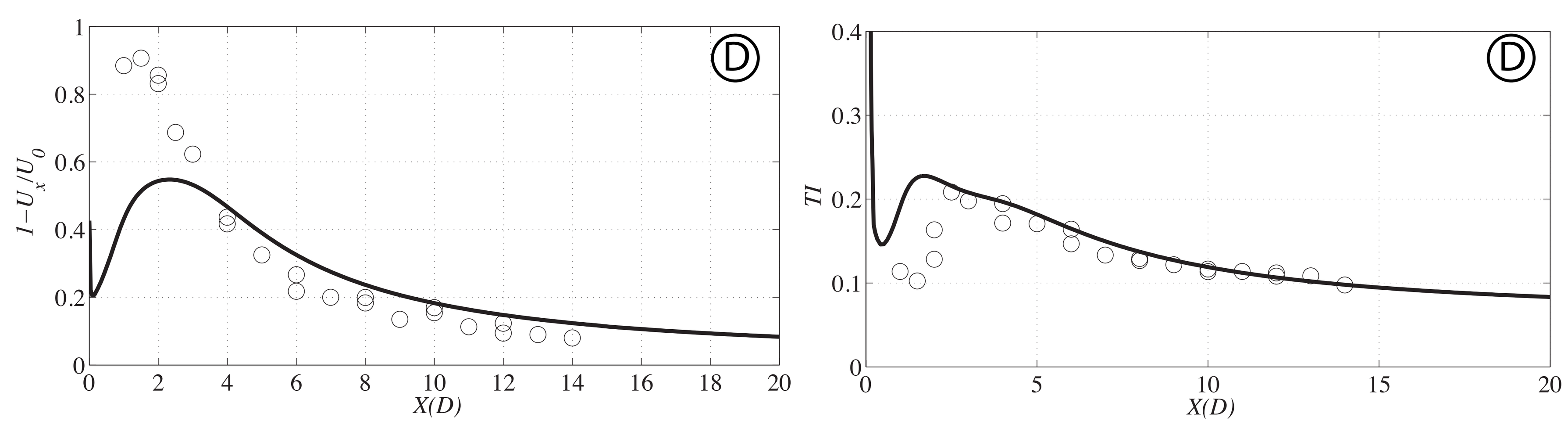

Figure 3 - Longitudinal profiles of U_x and TI. RANS-BEM (-) and experiments (o)

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Arrays

Predicted wakes and rotor loads were compared to experimental measurements from arrays of one and three rows of rotors (e.g. Figure 4 and Figure 5). The tip-speed ratio of each turbine is imposed to be equal to that measured experimentally.

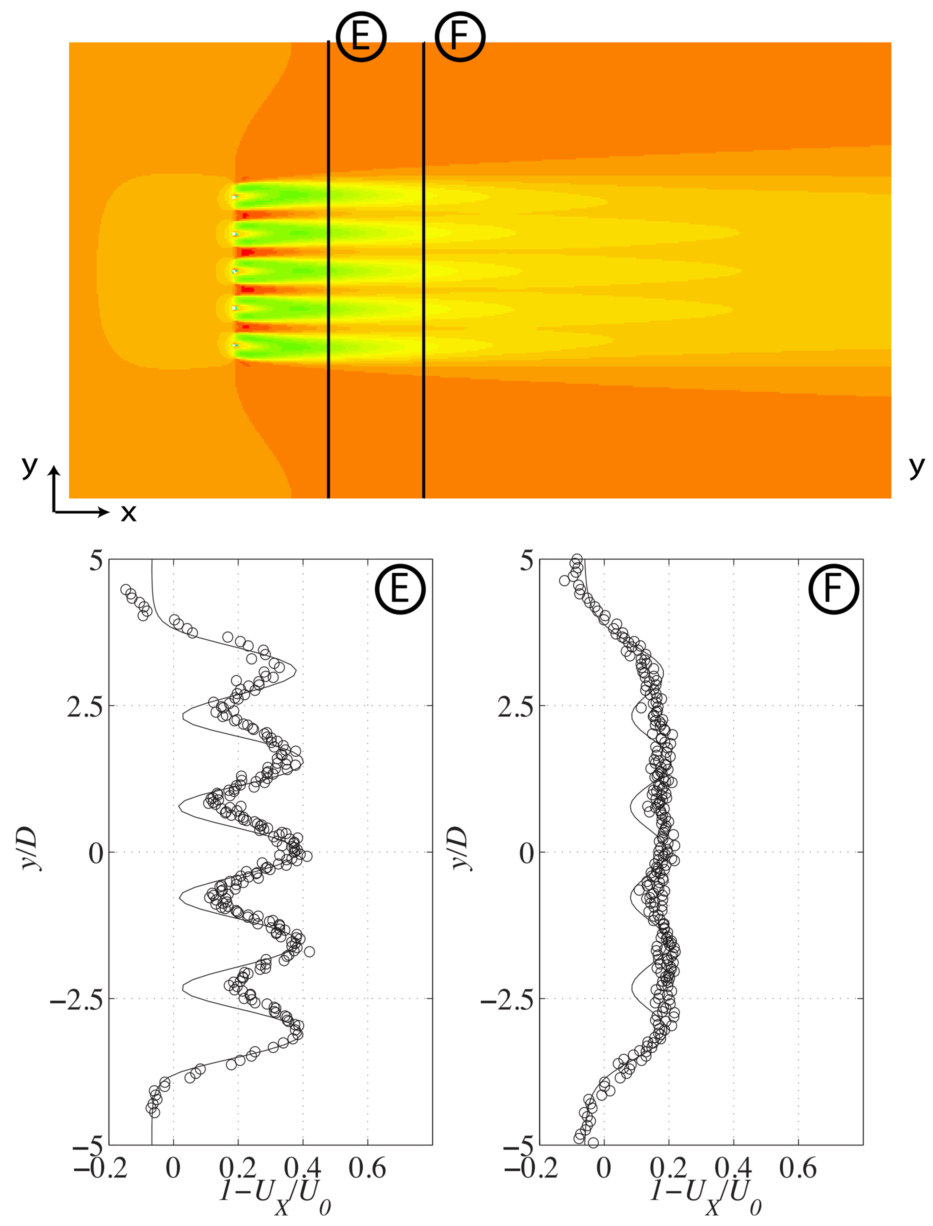

Figure 4 - Vertical Profiles of Velocity 4D and 8D downstream of a 5 turbine array. RANS-BEM (-) and experiments (o)

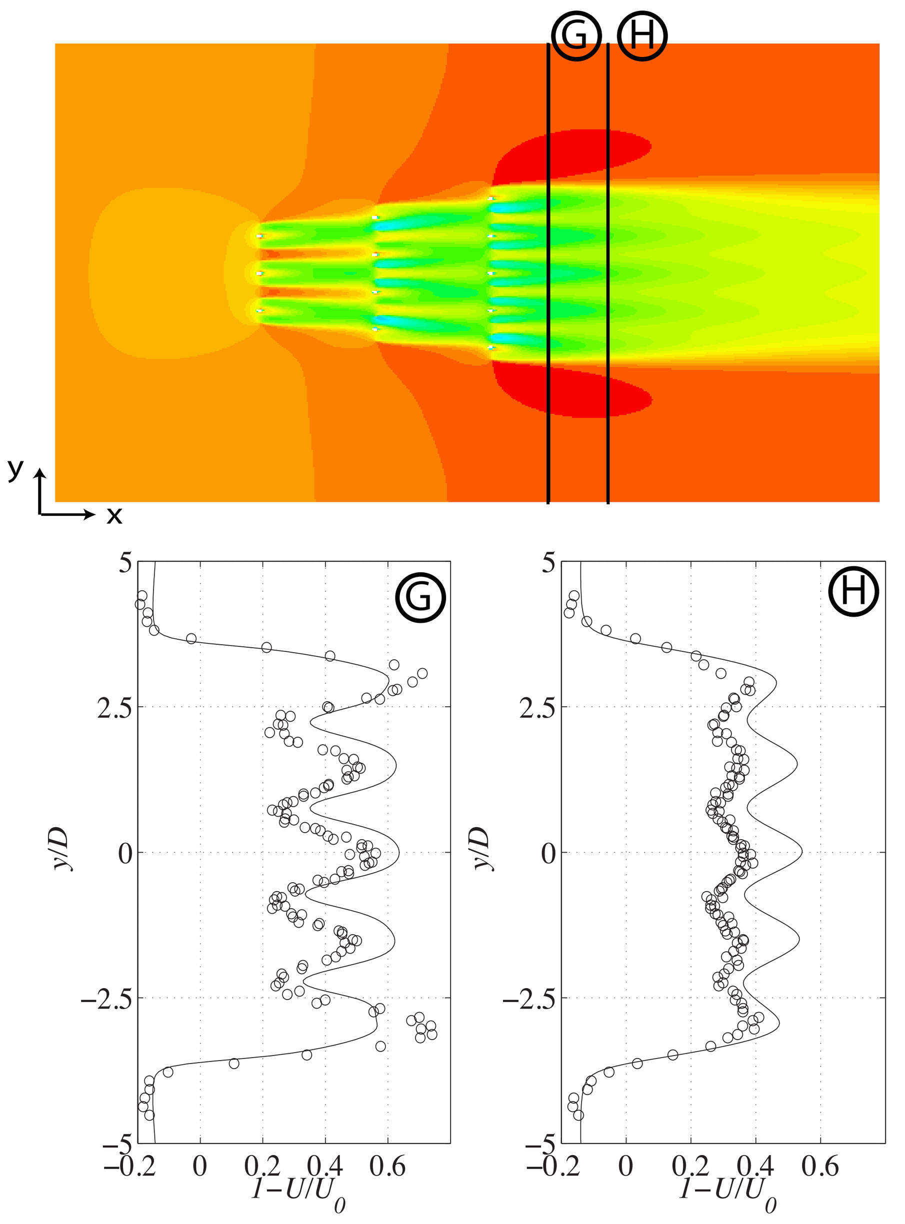

Figure 5 - Vertical Profiles of Velocity 2D and 4D downstream of final row of a three row array. RANS-BEM (-) and experiments (o)

For a single row array the RANS-BEM method over-predicts the magnitude of the inter-rotor by-pass, however in general, agrement is good. For a three row staggered array the velocity deficit over the central constrained wake is greater than that measured experimentally, however the peak deficit of the outer wake is lower. The array by-pass agrees well with that measured. The model gives a reasonable prediction of C_T except for the central turbines on the second row (Figure 6).

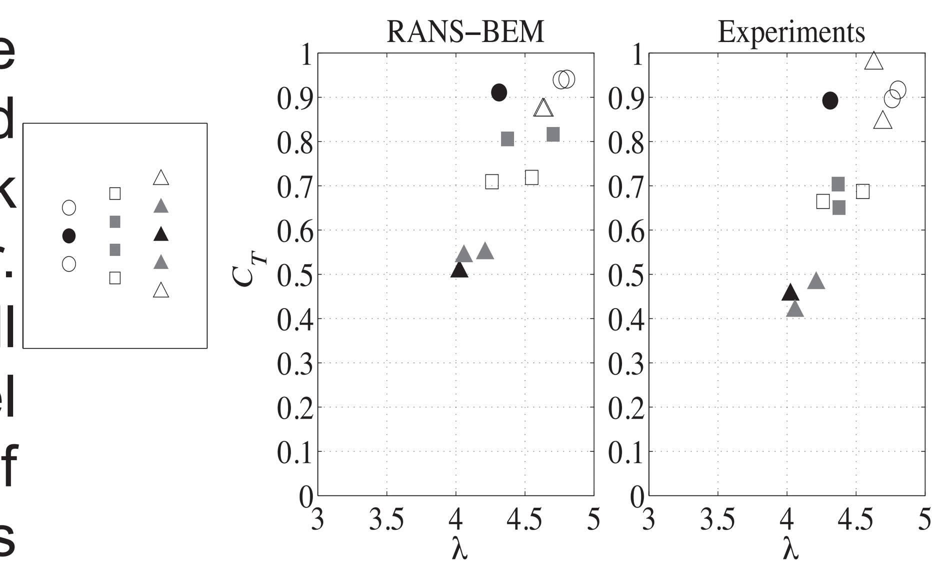

Figure 6 - Turbine load (C_T) on turbines within the array

References

[1] M. Harrison, "The Accuracy of the Actuator Disk-RANS Approach for Modelling Performance and Wake Characteristics of a Horizontal Axis Tidal Stream Turbine," PhD Thesis, 2011.

[2] R. Malki et al "Planning Tidal Stream Turbine Array Layouts using a Coupled Blade Element Momentum - Computational Fluid Dynamics Model," Renewable Energy vol. 63, no. c, pp. 46–54, Mar. 2014.

[3] T. Stallard et al "Interactions between tidal turbine wakes: experimental study of a group of three-bladed rotors," Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 371, no. 1985, pp. 20120159–20120159, Jan. 2013.