The Influence of Waves on Tidal Stream Turbine Arrays

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Arrays, Wakes and Near-Field Effects

Background

An understanding of the flow-field downstream of a tidal turbine is likely to be critical for the accurate prediction of energy yield from turbine arrays. At many potential tidal stream sites both waves and current exist and so the influence of waves on wake recovery is an important consideration. An experimental approach is employed to quantify the influence of waves on an ambient turbulent flow and on turbine wakes. The suitability of computational methods for the modelling of such flows is also considered.

Experiment Measurements

Experiments were conducted in a wide flume with water depth d =0.45m with mean flow speed U_0 = 0.46 m/s. The flow is fully turbulent and represents a full-scale tidal stream at approximately 1/70th geometric scale. Wakes are generated using a small scale rotor [1] and using a porous disc each with diameter D = 0.67h and with equivalent thrust coefficient. Regular waves are generated that oppose the flow direction. Velocity measurements indicate an increase of flow kinetic energy (denoted FKE and due to both waves and turbulence) of the ambient flow over the water depth. The velocity deficit at mid-depth downstream of a single rotor reduces with wavenumber and the depth profile depends on non-dimensional wave number wavenumber (kd)[2].

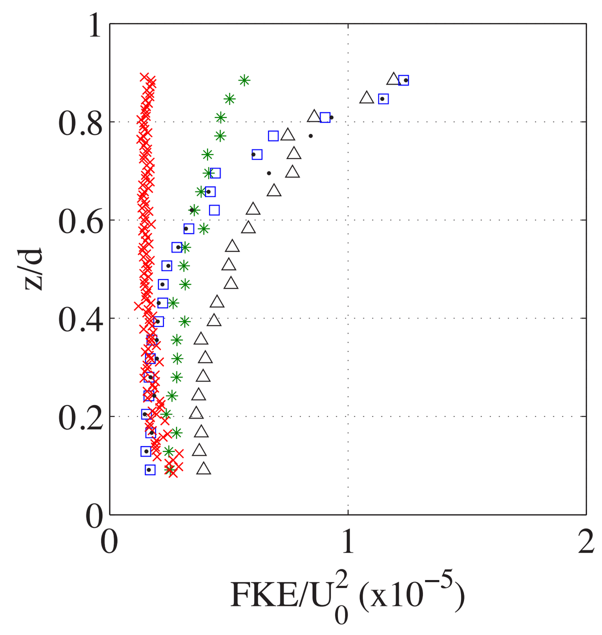

Figure1 - Kinetic energy of ambient flow due to waves and turbulence

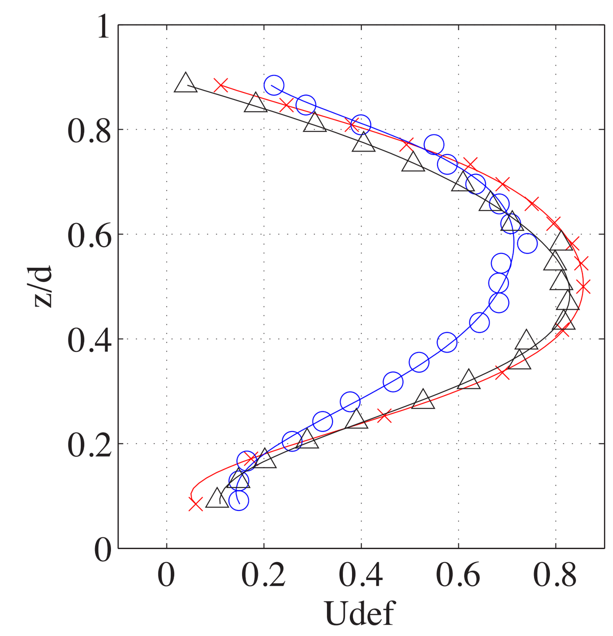

Figure 2 - Vertical profile through centreline of wake of rotor at 2 diameters downstream

The wake generated by a single row of five disks was similar both without and with waves. However, the wave energy density differs from the wake region to the bypass flow with up to 40% difference observed.

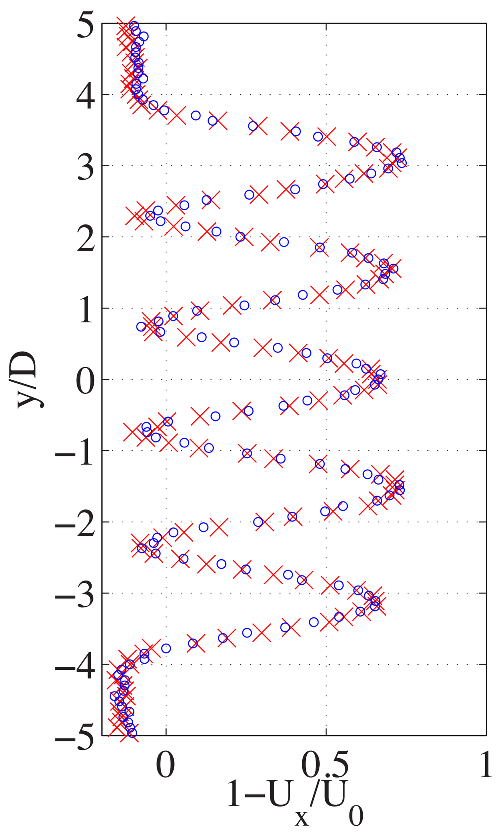

Figure 3 - Transverse profile of velocity at mid-depth 2 diameters downstream of a row of 5 porous discs with (x) and without (x) opposing waves

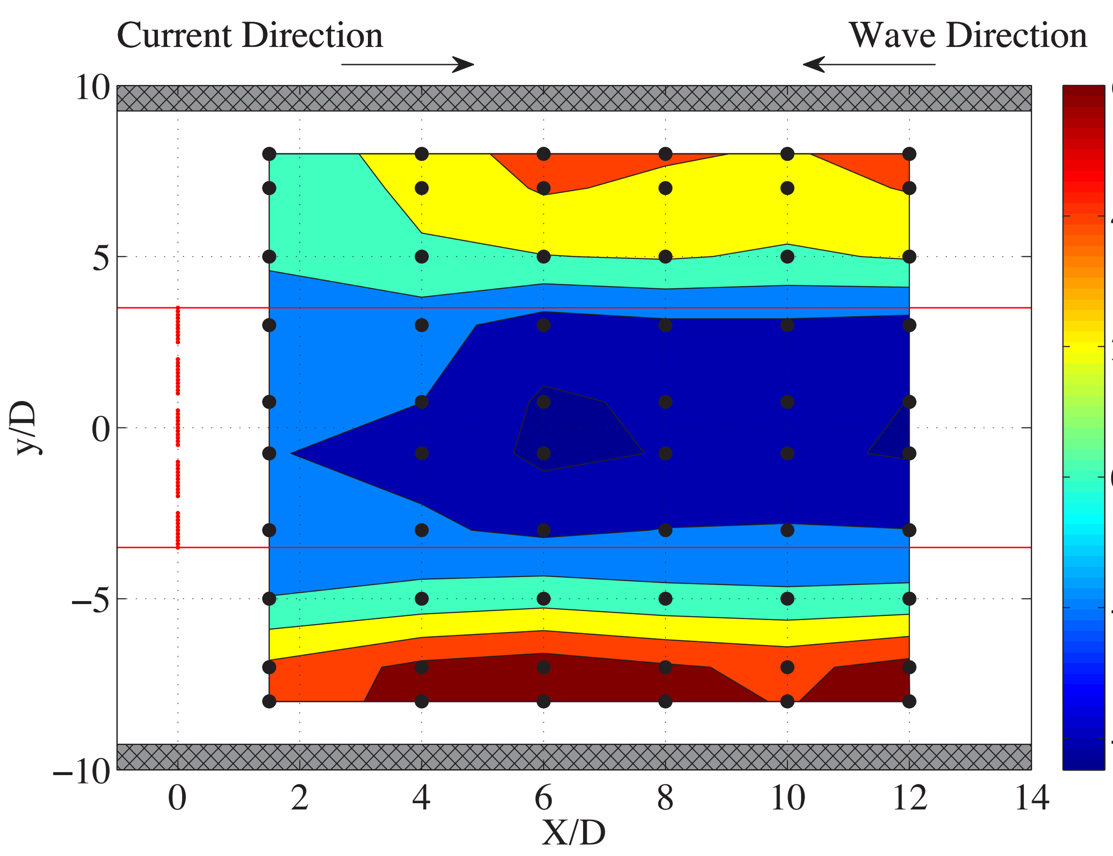

Figure 4 - Percentage change of wave energy density over the wake and bypass flow regions downstream of a row of 5 porous discs relative to waves propagating over turbulent flow only. Wave probe location (●)

CFD Evaluation

Reynolds averaged Navier-Stokes (RANS) models are widely used for the simulation of tidal turbine wakes [3][4]. To-date most studies have primarily considered current only flows. Ongoing work is evaluating the capability of a Volume of Fluid RANS model to reproduce the depth profile of mean velocity and turbulence characteristics measured at laboratory scale data.

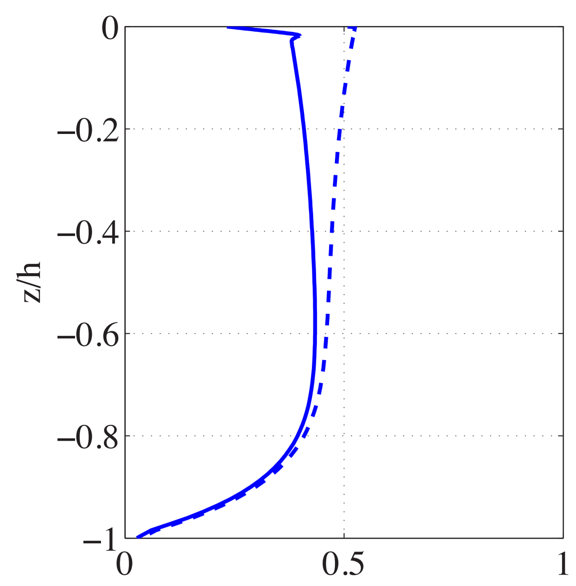

Figure 5 - Vertical profile of velocity under wave trough and crest

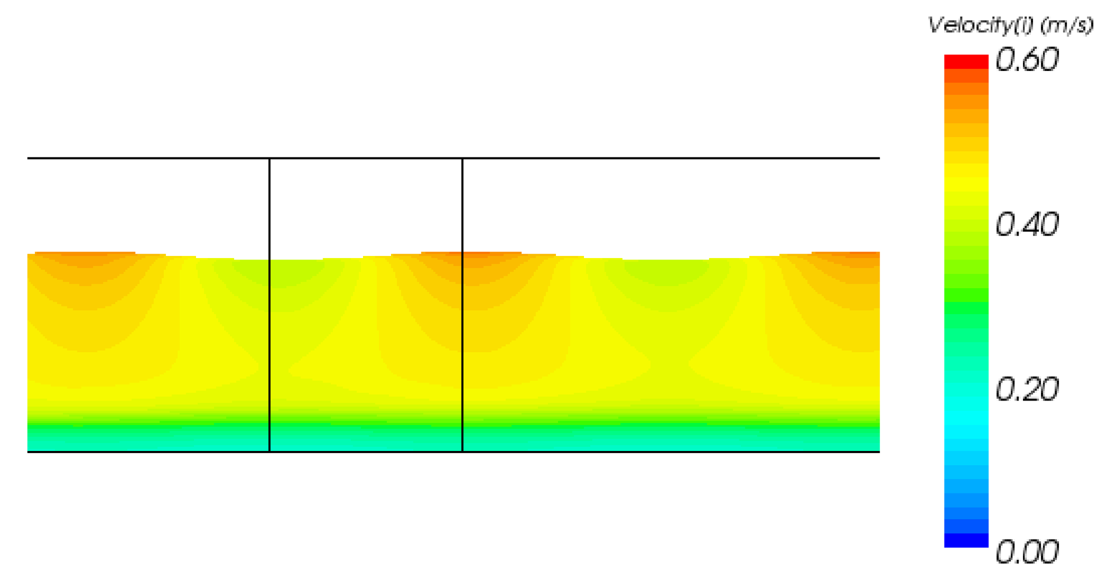

Figure 6 - Contours of horizontal velocity due to wave following sheared current

Actuator and blade element momentum thoery (BEMT) disk methods have been implemented for wake generation. Ongoing work is considering the suitability of such methods for simulating far-wake recovery due to combined turbulent flow and waves by comparison to laboratory experiments. For turbulent flow good agreement is found between the predicted and measured velocity deficit and recovery rate along the wake centreline over the range 6 - 20 diameters downstream.

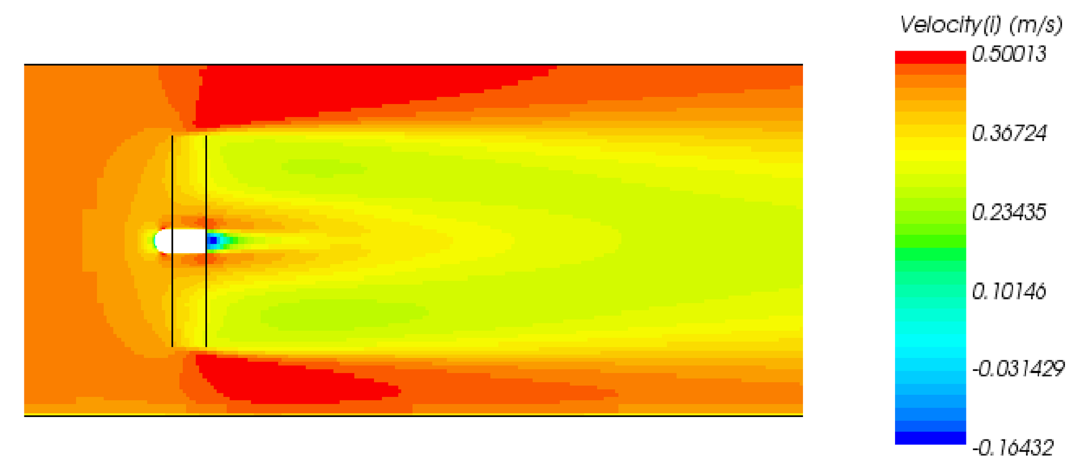

Figure 7 - Contours of streamwise wake velocity

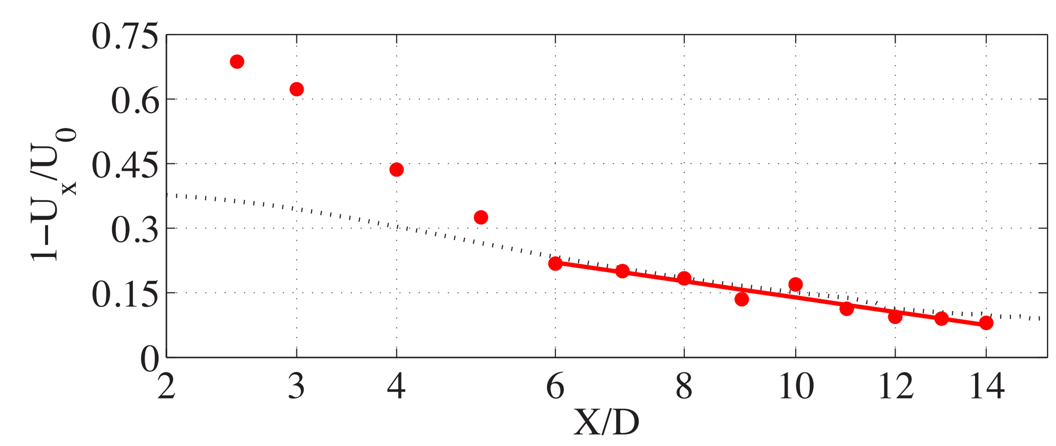

Figure 8 - Rate of wake recovery experiments (●). RANS BEM model (--). -1/2 Power Law decay (-)

References

1. Whelen, J., and Stallard, T (2011) Arguments for modifying the geometry of a scale model rotor. 9th European Wave and Tidal Energy Conference (EWTEC), Paper 50, Southampton
2. Olczak, A., Stallard, T. and Stanbsy, P. (2013) Influence of Waves on Tidal Stream Turbine Wakes,10th European Wave and Tidal Energy Conference (EWTEC), Aalborg
3. Harrison, M. Batten, W. and Bahaj, A. (2010). Comparison between CFD simulations and experiments for predicting the far wake of horizontal axis tidal turbines. IET Renewable Power Generation, 4(6), 613–613.
4. Gant, S and Stallard, T. (2008). Modelling a Tidal Turbine in Unsteady Flow. 18th International Offshore and Polar Engineering Conference (ISOPE), Vancouver, Canada. Paper 278, pp. 473–479.

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