The Influence of Swell Waves on a Tidal Stream Turbine Wake

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Arrays, Wakes and Near-Field Effects

Objectives

To maximise energy extraction from tidal stream sites it is likely that tidal stream turbines will be installed in arrays with devices in close proximity. Most of the potential sites are at exposed locations where waves and current coexist, it is therefore important to understand the influence of waves on array performance. Experiments have been conducted to quantify the effect of waves on open channel turbulence characteristics and a single turbine wake.

Open Channel Turbulence Characteristics

Depth profiles of time varying velocities were recorded within an open channel flow with a depth averaged velocity, U_0=0.45m/s. Profiles were recorded using an ADV probe with a sampling frequency of 200Hz. Profiles were recorded for wave frequencies between 0.5Hz and 0.8Hz opposing the flow and compared to a depth profile of flow only. Waves were generated continuously during the recording of each depth profile and with measured significant wave heights (Hs) between 78.6mm to 113mm. The streamwise mean velocity profile was found to be represented by a 10^{th} power law. The addition of opposing waves caused little variation in mean velocity profiles. Turbulence intensity ($TI=U_{rms}/U_0$) was calculated with U_{rms} including both turbulent and wave induced oscillations. The 0.5 Hz and 0.6Hz waves lead to an increase in turbulence intensity throughout the water column, whilst the 0.7Hz and 0.8Hz waves increase intensity close to the free surface (Figure1).

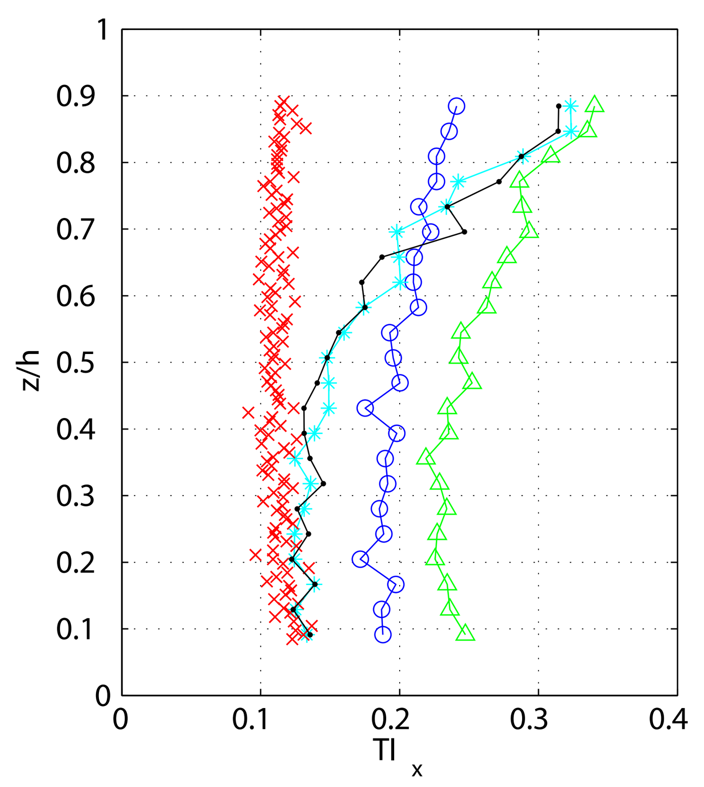

Figure 1: Turbulence Intensity. No waves (red), 0.5Hz (blue), 0.6Hz (green), 0.7Hz (cyan) and 0.8Hz (black) opposing waves.

A high pass filter of increasing filter frequency was applied to the time varying velocities before calculation of turbulent kinetic energy (TKE). Figure 2 shows that the addition of opposing waves causes an increased TKE for filter frequencies above the wave frequency. This indicates that the fluctuations are not the linear superposition of wave induced fluctuations on open channel turbulence and that interaction occurs.

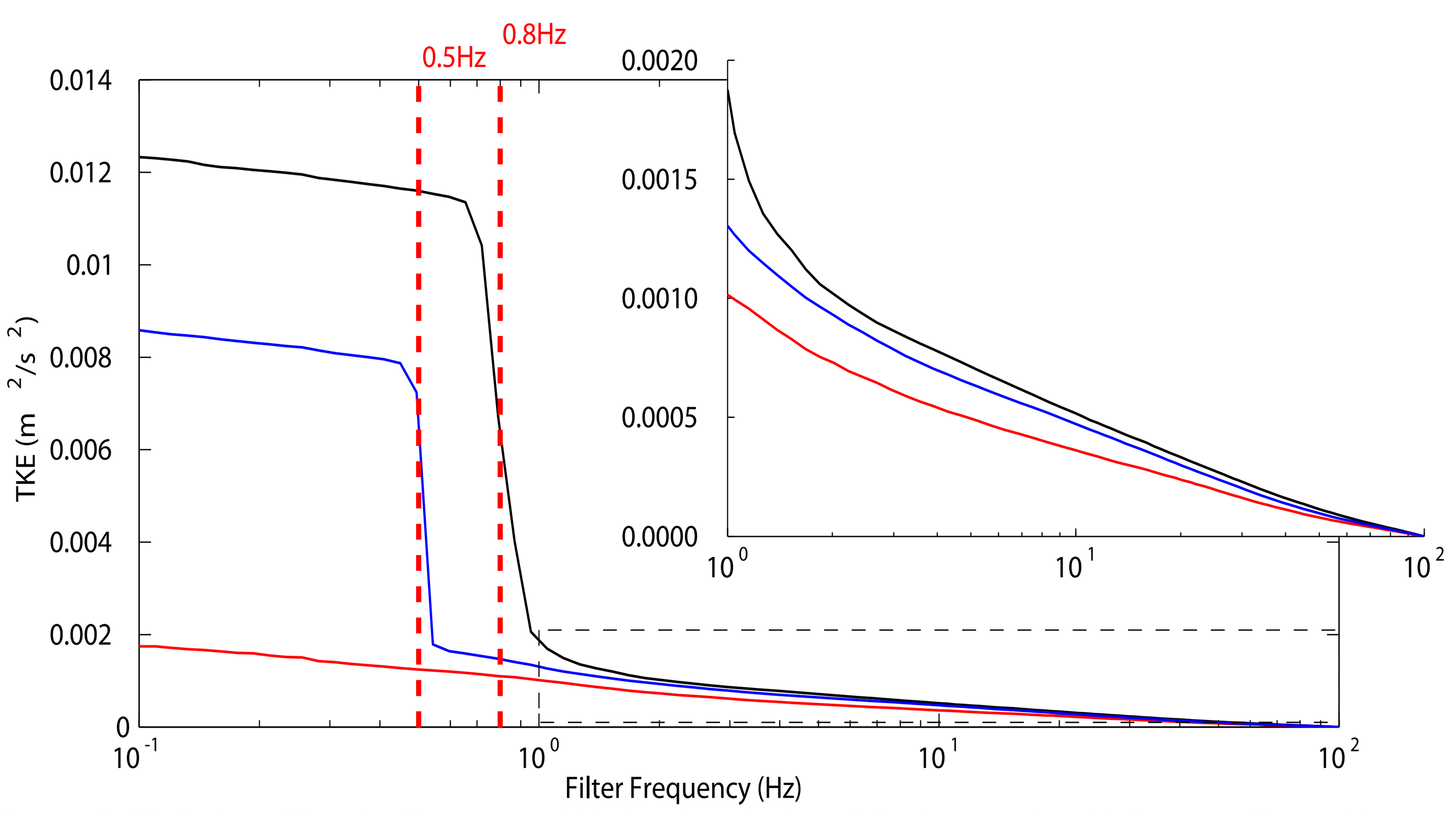

Figure 2: Turbulent Kinetic Energy at 1/4 depth calculated for increasing high pass filters. No wave (red) , 0.5Hz wave (blue) and 0.8Hz wave (black)

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Effect of Opposing Waves on Single Turbine Wake

The mean and turbulent flow characteristics of the velocity field downstream of a single tidal stream turbine were examined by experiments at approximately 1:70th scale. The wake was generated using a 3-bladed rotor with a diameter (D) of 270mm developed as part of the ETI commissioned PerAWaT project [1]. During experiments constant torque is applied to develop a mean Tip Speed Ratio (TSR) of 5.5+/-5%. This corresponds to thrust coefficient (Ct) and power coefficient (Cp) of 0.79-0.83 and 0.25-0.3 respectively. Depth profiles of time varying velocity were recorded across the wake centreline for opposing waves between 0.5Hz and 0.8Hz at 2D and 4D downstream.

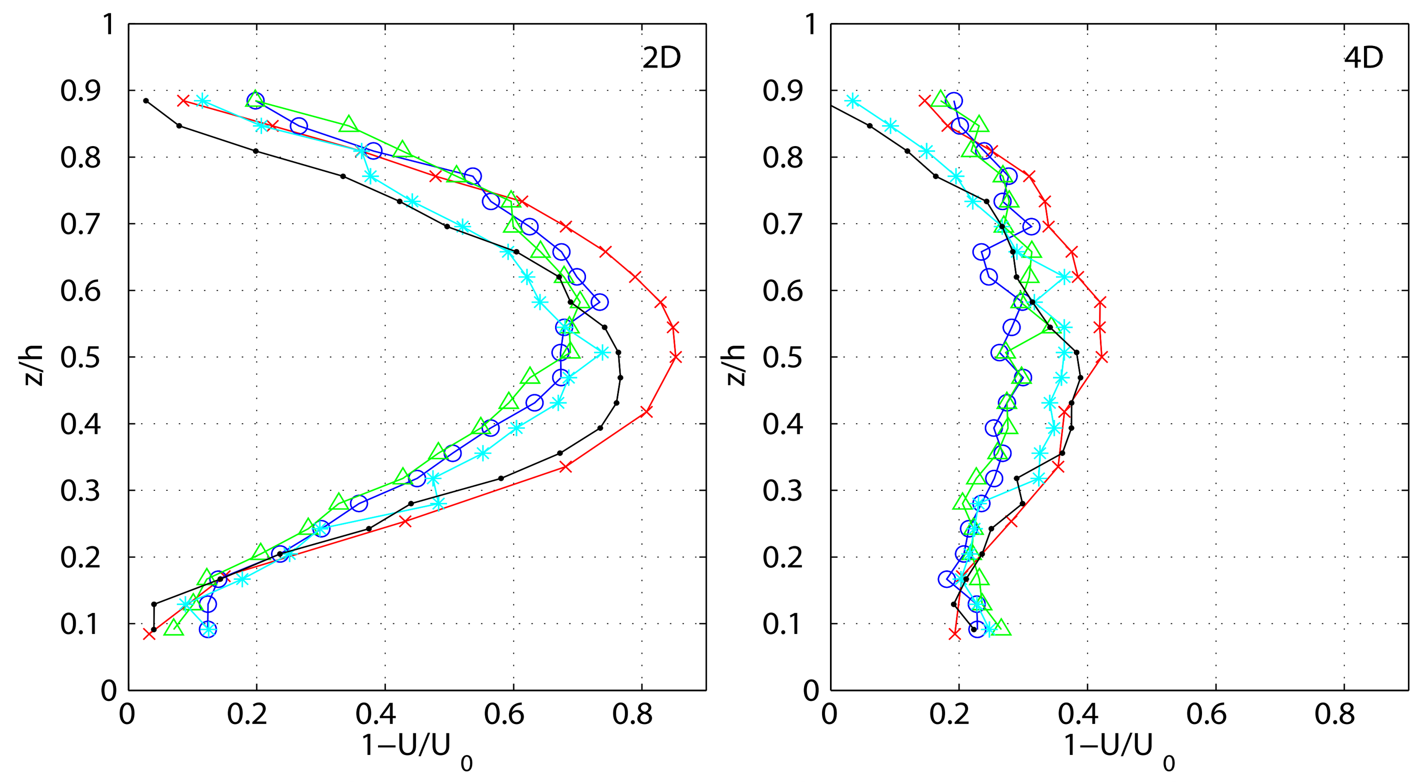

Figure 2: Velocity Deficit across wake centreline of single turbine at 2D (left) and 4D (right) downstream. No waves (red), 0.5Hz (blue), 0.6Hz (green), 0.7Hz (cyan) and 0.8Hz (black) opposing waves.

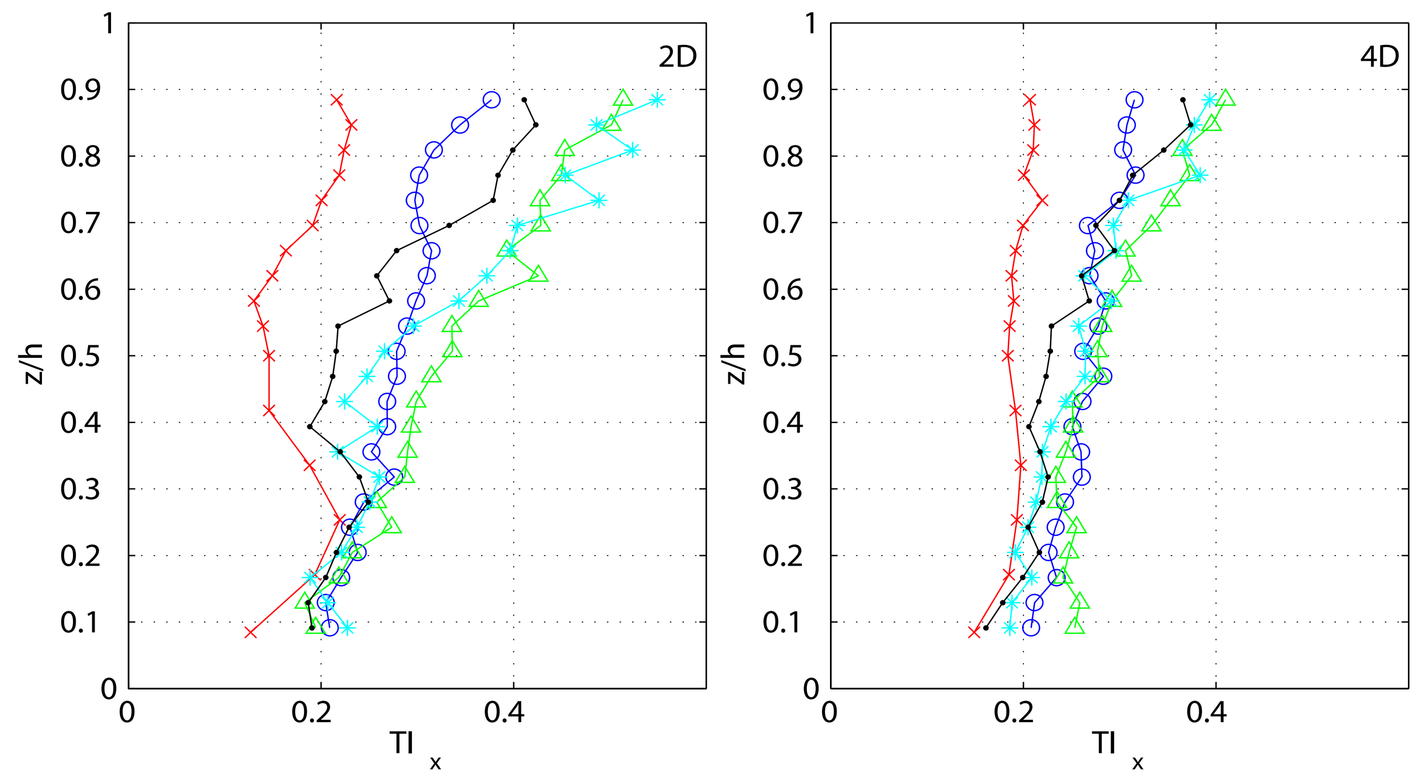

Figure 3: Turbulence Intensity across wake centreline of single turbine at 2D (left) and 4D(right) downstream. No waves (red), 0.5Hz (blue), 0.6Hz (green), 0.7Hz (cyan) and 0.8Hz (black) opposing waves.

Propagation of opposing waves over uniform flow reduces the centreline deficit for all wave frequencies considered. Vertical velocity deficit profiles differ considerably with wave frequency, waves of 0.5Hz and 0.6Hz reduced the velocity deficit in the lower half of the wake whilst 0.7Hz and 0.8Hz waves caused a reduced deficit in the upper half (Figure 2). For all wave frequencies an increased turbulence intensity occurred throughout the depth (Figure 3). In these experiments, the unsteady inflow causes a time-variation of rotor thrust and so wake generation differs from the steady flow case with the same mean thrust coefficient. Future experimental work aims to minimise this variation in thrust so that the effect of waves on wake recovery can be quantified.

References

1.Stallard et al (2012), Interactions Between Tidal Turbine Wakes: Experimental Study of a Group of 3-Bladed Rotors, Phil Trans Roy Soc Part A. (in press, accepted).