Making Waves With CFD

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Work Stream 1: Numerical and Physical Convergence

Introduction

This poster describes a methodology for creating a surface wave boundary condition. The primary modelled wave is taken from work carried out in the experimental flume at Liverpool University [1]. This preliminary work has shown that a linear wave model is suitable for generation of small amplitude waves in a computational fluid dynamics program provided that a stretching mechanism is employed to account for the assumption of infinitely small wave heights in Airy wave theory, and that the velocity potential is specified through the water column. Waves can be generated with a current by altering the surface height at the inlet.

Surface Wave Theory

Linear Airy wave theory gives the elevation of the fluid height as a sinusoidal function of time t and distance x:

$$\eta = a\sin(\omega t - kx)$$

and for a finite water depth d, the horizontal and vertical particle velocities u and w are:

$$u = \frac{\partial\phi}{\partial x} = \omega h \frac{\cosh\{k(z+d)\}}{\sinh\{kd\}}\sin(\omega t - kx) \qquad w = \frac{\partial\phi}{\partial z} = \omega h \frac{\sinh\{k(z+d)\}}{\sinh\{kd\}}\cos(\omega t - kx)$$

Airy theory assumes infinitesimally small perturbations, so Wheeler stretching applies the kinematics at the mean water height to the actual water height, and throughout the fluid to the bottom by substituting the vertical coordinate z with a stretched version:

$$z' = (z - \eta)\frac{d}{d+\eta}$$

Modelling was carried out in Ansys CFX by importing a CFX Command Language (CCL) file and creating an inlet boundary condition based on the theory. A free surface was created by specifying a water volume fraction of 1 below and 0 above the fluid level:

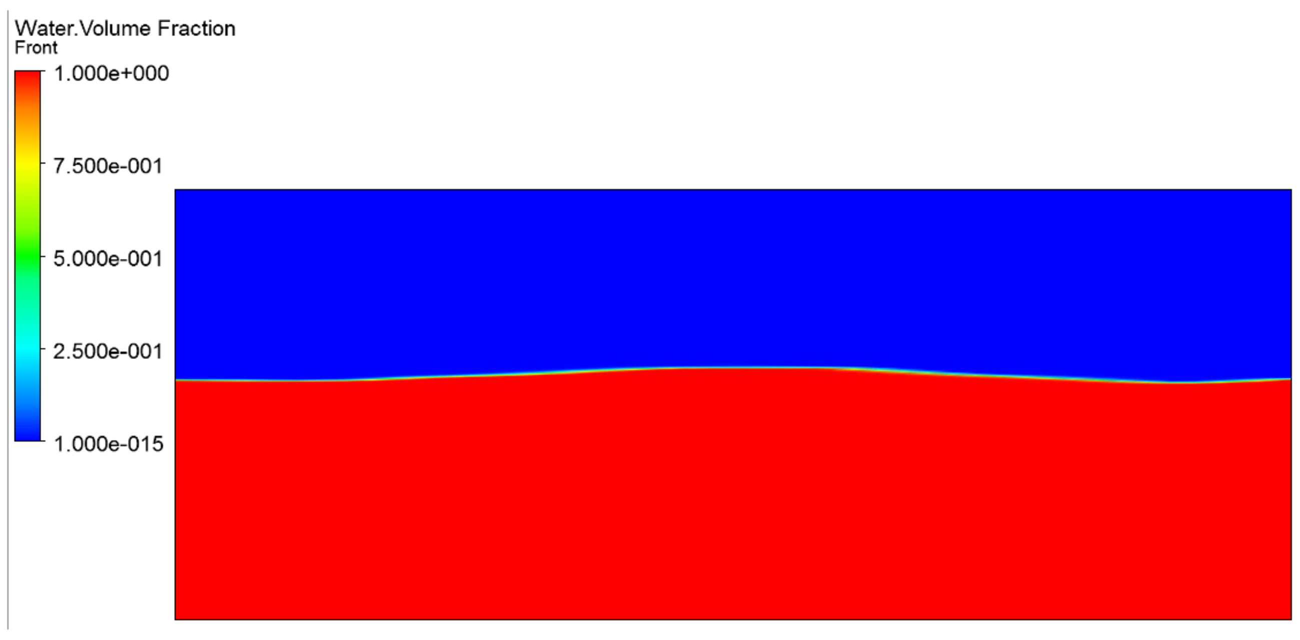
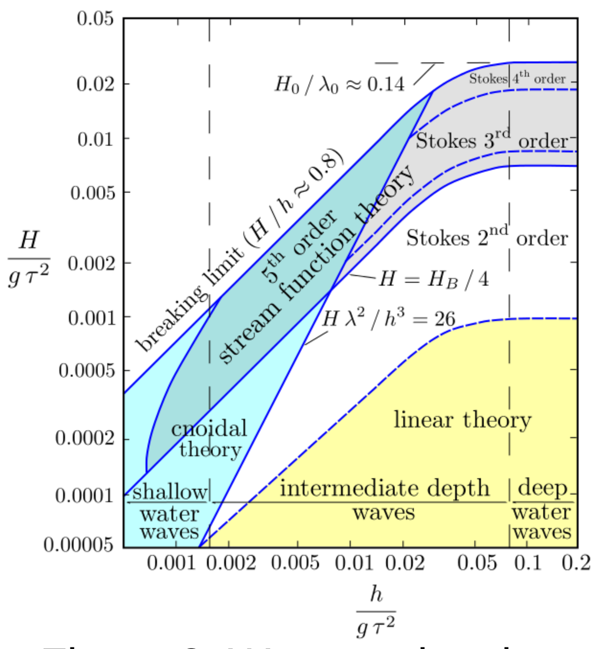


Figure 1: Wave successfully generated at 2m/s.

Wave Regimes

Wave parameters were non-dimensionalised to determine if a linear regime is appropriate.



The initial wave modelled from [1] falls outside of the linear regime according to [2],

Figures 1 and 3 show that Wheeler stretching provides a suitable approximation.

Figure 2: Wave regime based on non-dimensionalised wave parameters [2]

Preliminary Results

Velocity components under the fluid surface confirm orbital motion of particles as expected:

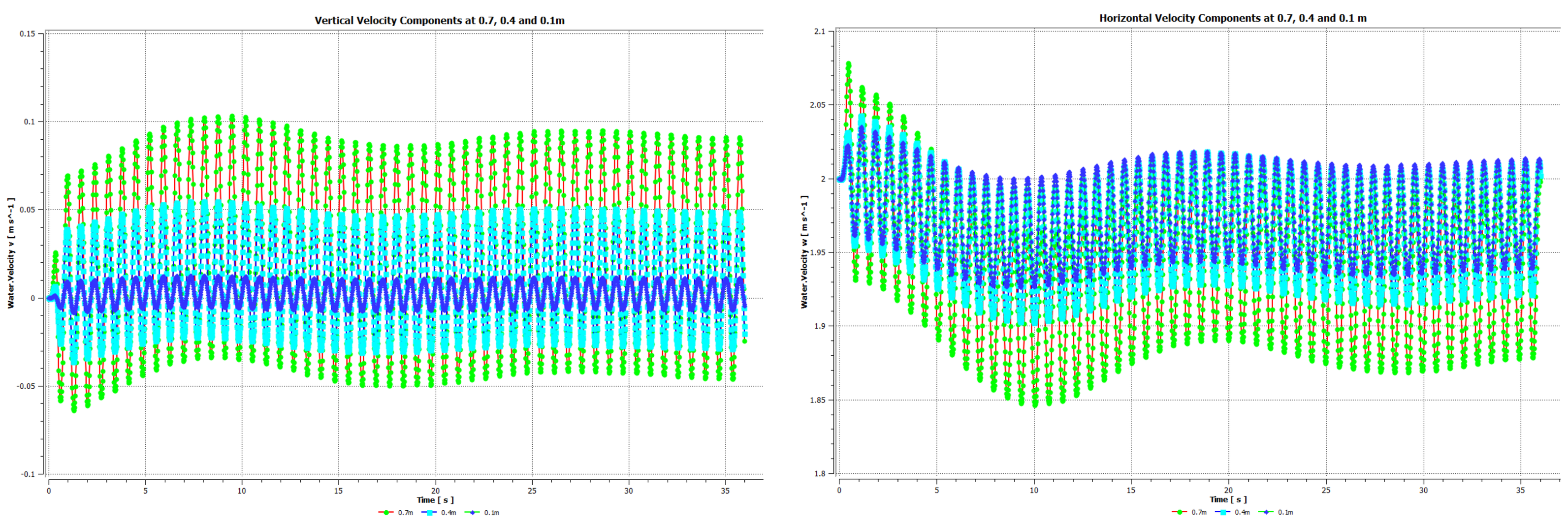


Figure 3: Sub-surface velocity components of fluid motion

Free Surface Turbine Modelling

Results will be validated against data from [1] and [3]

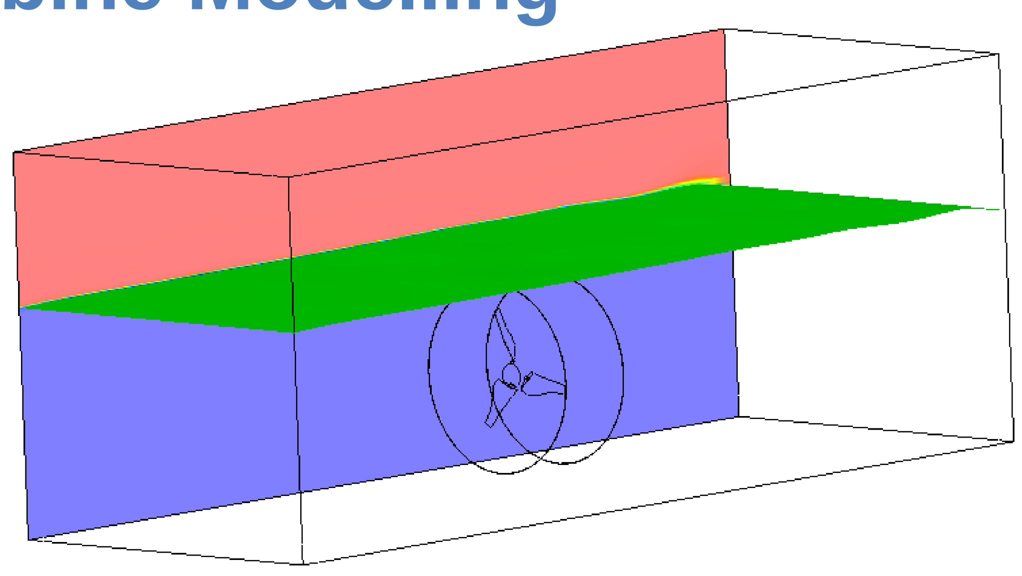


Figure 4: Turbine model with free surface

Next Steps

The waves fall outside of the linear regime when creating them with a mathematical model, so improved results will be obtained by repeating this work with a higher order wave model and more detailed boundary condition.

References

1.De Jesus Henriques, T. A., et al. (2013). The effects of wave-current interactions on the performance of a model horizontal axis tidal turbine. 10th European Wave and Tidal Energy Conference. Aalborg, Denmark.

2.Le Méhauté, B., 1976, An Introduction to Hydrodynamics and Water Waves, Springer-Verlag.

3.Mason-Jones, A., et al. (2012). "Non-dimensional scaling of tidal stream turbines." Energy 44(1): 820-829.