NEAR-WAKE KINEMATICS FOR FLOW AROUND A SURFACE PIERCING CYLINDER AT SUPERCRITICAL REYNOLDS NUMBERS AND LOW KEULEGAN-CARPENTER NUMBERS

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The global necessity to increase reliance on renewable energies to combat rising atmospheric CO_2 has led to an intensified re-examination of a fundamental hydrodynamical problem: water flow around a circular cylinder. Applications include offshore renewable energy technologies such as monopile wind turbines, which are of significant importance in Northern Europe and where offshore wind is set to produce 40 GW of power by 2020 [1]. Operation and maintenance of the offshore turbines is complicated in comparison to onshore wind turbines and of an economically greater cost due to wind farms' distance from the shore. Maintenance of offshore wind turbines requires repair workers to mount the turbine from a *Crew Transfer Vessel* (CTV) that is abutted against the turbine with a constant thrust from the motor. The repair workers must rely on the vessel to remain stable for the duration of transfer to and from the turbine in order to provide a safe passing. However, the CTV can experience unwanted movement, creating a potentially unsafe environment for the workers. In order to address this issue, the aim of this project is to predict the motion of the CTV while under operating conditions. An assumption is made that the CTV lies entirely within the near wake of an offshore wind turbine, which is simplified here as a surface piercing smooth cylinder in a regular small-amplitude wave field. In this paper, a numerical solution using *OpenFOAM* [2] is sought for the kinematics within the very near wake of a circular surface-piercing cylinder in an oscillating linear wave field. A number of wave fields are considered, in which the wave height and the wave period are varied to enable an examination of the wake characteristics with the changing parameters [3].

The flow characteristics for the given location of the offshore wind turbines are characterised by three non-dimensionalised parameters: the Reynolds number *Re*, the Keulegan-Carpenter number KC and the ratio β of the two, i.e.

$$Re = \frac{UD}{\nu}\ , \quad KC = \frac{UT}{D}\ , \quad \beta = \frac{Re}{KC}\ . \tag{1}$$

In this representation U is the acharacteristic flow velocity, D is the monopile diameter, ν is the kinematic viscosity of the fluid (approximately $1e^6$ for water), and T is the wave period. For the current problem, the values of D = 6 m, T = 8 sec and h = 25 m were specified initially; the characteristic velocity U is based upon the wave field to give $U = akg/\omega$, where a is the wave amplitude $(= H/2)$, g is acceleration due to gravity, $\omega = 2\pi/T$ and the wave number $k = 2\pi/\lambda$ for wavelength λ is determined from the linear dispersion relation $\omega^2 = gk\,tanh(kh)$. An important physical parameter is the wave height, as existing models suggest that standard CTVs are only capable of safe transfer in wave heights $H_s < 1.5m$, depending on the vessel used [4]. Based on the small amplitude restriction on the vessels, it is appropriate to assume regular waves for this initial simulation. For incompressible time-dependent flow, the governing equations of the flow to be solved are the Navier-Stokes equations governing conservation of momentum and continuity, which are given as

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho((\mathbf{u}.\bigtriangledown)\mathbf{u}) = -\bigtriangledown p + \mu \bigtriangledown^2 \mathbf{u} \tag{2}$$

$$\bigtriangledown.\mathbf{u} = 0 \tag{3}$$

Despite the importance of this problem, very little information is available regarding the near-wake in a supercritical flow at very low Keulegan-Carpenter numbers. The scenario of interest for the given values of period, diameter, water depth and viscosity above gives $Re = 3.7875e^6$ and $KC = 0.8417$, which implies a fully turbulent supercritical regime in which vortices are formed at the cylinder but do not separate [3]; this suggests minimal wake effects but potentially high vorticity directly on the turbine. *OpenFOAM* is used to solve the incompressible Navier-Stokes equations numerically for the specified flow regime, with the computational domain chosen to be $L_x = 60 * D$, $L_y = 40 * D$, in terms of the cylinder diameter D and $-10 < z < 8$, where z refers to the depth, h, and is positive above the free surface. The vertical computational domain was reduced from h = 25 m to minimise computational costs and a slip condition is used on the bottom and sides of the computational domain; the slip condition can be considered valid for the bottom because boundary layer dissipation is negligible for this problem [5].

Both a non-slip condition and a slip condition on the cylinder were tested; the slip condition on the cylinder was considered as well because the flow is mainly inertia dominated and viscous effects can be neglected [6, 7] for these cases. By considering both a non-slip and slip conditions on the cylinder, comparisons can be made between inclusion and exclusion of the viscous boundary layer. The additional advantage of ignoring viscosity is the necessity for grid refinement in the boundary layer around the cylinder is significantly reduced, thereby decreasing overall grid size and computational cost.

The user-defined solver for free surface wave generation *waveFoam*, which is part of the *waves2Foam* package [8], was used for all cases. This application is an update of the multiphase solver *interFoam*, included with *OpenFOAM*, together with the inclusion of a relaxation zone technique to absorb outgoing waves and reflections off the cylinder; the length of the two relaxation zones were both set at approximately $1 * \lambda$. *WaveFoam* utilises the volume of fluid method to calculate the percentage α of each cell that is filled with fluid and the value of each field of interest is calculated based on the α value. The $k - \omega$ SST turbulence model was employed on the cylinder in the non-slip case.

Simulations were run for varied grid sizes and refinement levels. Surface elevation was measured using wave gauges included in the constant directory and the different parameters of the flow (pressure, velocity, vorticity) were measured using probes. Of interest was the effect that the inclusion of the viscous boundary layer had on the vorticity on or very near the cylinder in comparison to the slip condition. Additional relevant information was the general flow field in the near-wake and the effect of the turbine on the incident flow field. Further work will involve simulations for various wave heights, period, cylinder diameters, non-linear waves and irregular waves in the effort to approximate the flow field at the location of the turbine more accurately.

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