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Citation for the original published paper (version of record):
Broström, G., Bergqvist, B., Fredriksson, S. et al (2018)
LES and Actuator Line Method for Modeling the Tidal Power Plant Deep Green, Using OpenFOAM
Proceedings of the 13th OpenFOAM Workshop: 79-80

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LES AND ACTUATOR LINE METHOD FOR MODELING THE TIDAL POWER PLANT DEEP GREEN, USING OPENFOAM

SAM T. FREDRIKSSON[1], GÖRAN BROSTRÖM[2], BJÖRN BERGQVIST[3], JOHAN LENNBLAD[4], HÅKAN NILSSON[5]

[1]*Department of Marine Sciences, University of Gothenburg, Sweden, sam.fredriksson@gu.se*

[2]*Department of Marine Sciences, University of Gothenburg, Sweden, goran.brostrom@marine.gu.se*

[3]*Minesto AB Gothenburg, Sweden, bjorn.bergqvist@minesto.com*

[4]*Minesto AB Gothenburg, Sweden, johan.lennblad@minesto.com*

[5] *Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg, Sweden, hakan.nilsson@chalmers.se*

Keywords: *Tidal energy, Turbulence, LES, Actuator Line Model (ALM)*

Tidal energy has a great potential as a renewable electric energy source, following the sustainable development goals of the UN. Tidal energy can be harvested in different ways, of which one way is to directly extract the energy from the flowing water. The tidal stream is special in the sense that it is oscillating back and forth, with rather low velocities. The turbulence behaves differently in the accelerating and decelerating phases of the tidal cycle. Furthermore, the marine environment is particularly harsh for technical equipment, and tidal power plants must co-exist with other marine activities. A tidal energy plant must be able to handle such situations with a high efficiency, and with low environmental and social impacts. The tidal power plant Deep Green, developed by Minesto AB uses a novel technology with a 'flying' wing with an attached turbine that sweeps the tidal stream with a velocity several times faster than the mean flow, see Figure 1. The trajectory of the wing is controlled by an advanced control system and forms a sideways figure eight that is almost perpendicular to the tidal flow. The trajectory is fully submerged during operation, but the wing can reach the surface for maintenance. The wing is attached to the seabed by a tether, through which the electric power from the turbine is transmitted to a local distribution network that connects a number of Deep Green plants in a farm to the land-based electric grid. A farm of Deep Green power plants must be designed so that the individual power plants have a minimum negative impact on the other power plants in the farm. The distance must be large enough to avoid collision, both at full tidal stream and when the flow reverses. Most of the energy can be extracted during full tidal stream, and then it is important that the farm is designed to minimize any negative effects of the wakes on downstream power plants. The aim of the present work is to accurately model the influence of the Deep Green power plant on the turbulent tidal flow. The results can be used to increase the knowledge of the Deep Green wake, which in turn can be used to design optimized Deep Green farms. The results can also be used as input to models of the dynamics of the wings, to determine how the control systems should be designed to safely consider both the tidal turbulence and wakes from upstream wings.

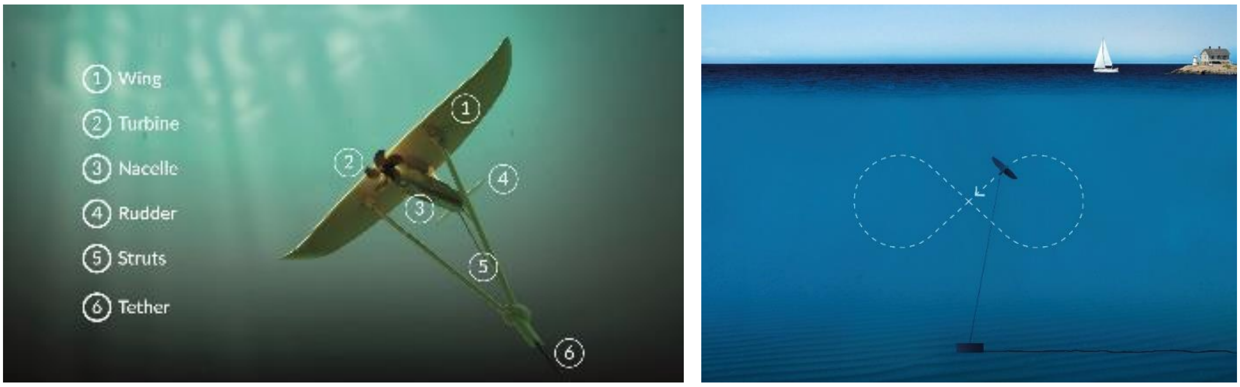

Figure 1: The tidal power plant Deep Green, with its components and operating procedure.

The conditions of the tidal flow are in the present study resembling those at a test site west of Holy Island, along the west coast of Wales. The depth is 80m, with a rather smooth seabed with individual boulders of about 2x2x2m. A bottom roughness is introduced in the simulations to give mean velocity profiles in accordance with field measurements. The Coriolis force and any surface shear forces are neglected. A precursor cyclic one-equation eddy-viscosity LES simulation of two full tidal cycles is used to set initial conditions for the Deep Green simulation. An additional half tidal cycle proved that the oscillating flow is fully developed. The tidal flow of the precursor simulation is obtained by a sinusoidal varying body force, adjusted to fit the tidal peaks at the test site. The simulation with the Deep Green power plant is started at a condition with accelerating flow at approximately 1.6m/s, close to the tidal flow peak (at 2.0m/s). The initial condition is taken from the precursor simulation, and the inlet boundary condition that drives the flow in this simulation is mapped from the precursor simulation each time step. The Deep Green power plant is modelled using the Actuator Line Method (ALM) [1, 2] from the turbinesFoam [3] package, adapted to the particular trajectory of the Deep Green wing. The lift and drag along the wing profile for different angles of attack are taken from a separate RANS simulation of the Deep Green wing, using the k-ω turbulence model. A momentum sink is added to take the turbine into consideration [4].

Figure 2 shows the results of the Deep Green simulation. The wing is visualized by a green iso-surface of the force field from the ALM. Grey iso-surfaces of the Q-criterion is used to visualize the turbulent vortices at the seabed and the wing wake in the form of tip vortices. The domain boundaries and five cross-sections are coloured by the velocity magnitude. The cross-sections are located at the centre of the wing trajectory, and at 1-4 trajectory widths downstream the centre of the wing trajectory. A single wing is considered in the simulation, but since cyclic conditions are used at the sides of the domain the results resemble an infinite number of wings side-by-side. The plots show the time-averaged vertical and horizontal velocity profiles, going through the centre of the trajectory of the wing at the different downstream positions. It can be seen that the wake of the wing influences the flow throughout the computational domain. The wake is asymmetric in the vertical direction, due to the vertical shear in the main flow. The horizontal width of the wake and its number of peaks decrease with distance to the wing. The wake tends to stabilize its shape at about $3D_y$ downstream the wing.

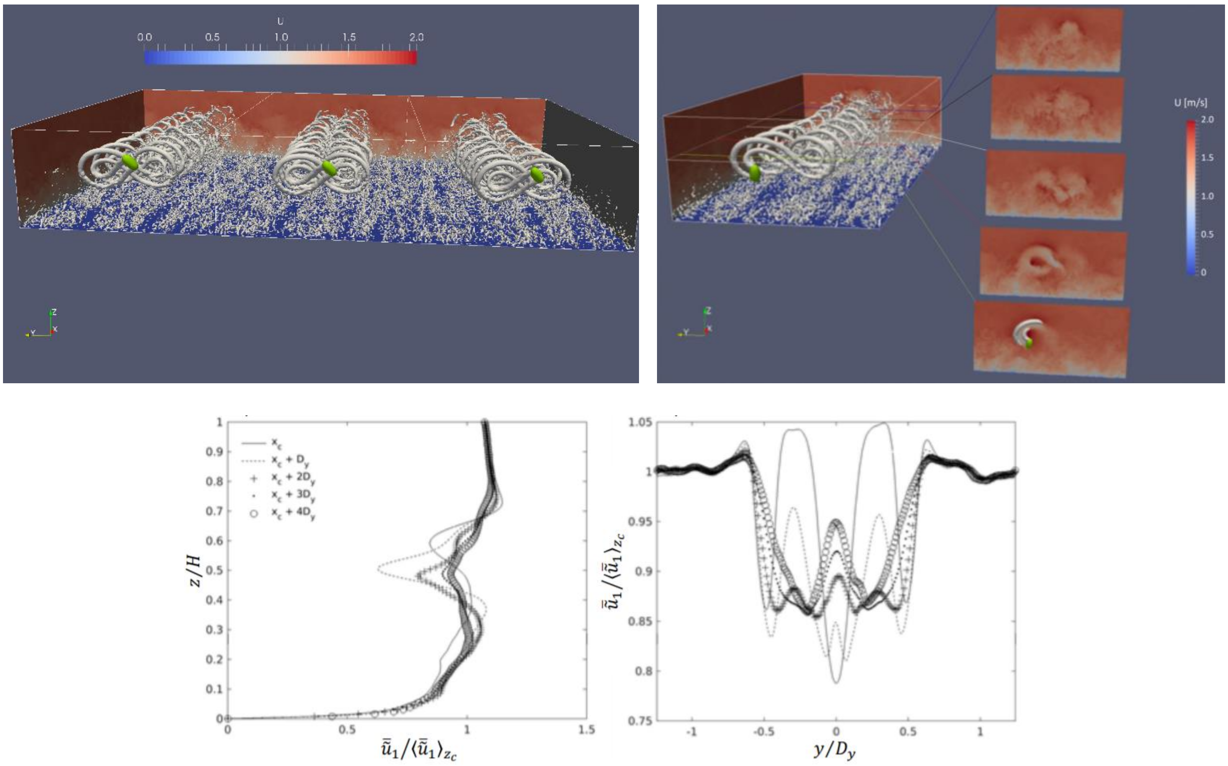

Figure 2: Wake of the Deep Green power plant, visualized by iso-surfaces of the Q-criterion and velocity plots.

Acknowledgements
The authors thank the Swedish Energy Agency for the project financing.

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