Using Smoothed Particle Hydrodynamics in the development of a novel vertical axis stream turbine design.

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ABSTRACT

The global demand for low carbon electricity requires a variety of energy generation approaches, the choice of which is dependent on multiple criteria. Tidal flows have long been identified as a reliable source of energy, with a high degree of predictability. To this end a novel turbine has been developed that could be well suited to energy generation in both tidal flows, or water courses. In this study a Smoothed Particle Hydrodynamics (SPH) model, namely DualSPHysics, is used to predict the behavior of this novel turbine design. Which will be used to guide the design process. The SPH method was chosen as the design of the turbine uses several connected parts, that requires free movement and interactions to properly represent the prototype and was found to be capable of expressing this behavior.

1. Introduction

There is an increasing demand for electricity globally while there is a pressure for that electricity to be produced using low emission methods. To this end, a vertical axis turbine, namely CarBine; has been developed at Cardiff University (Harries, 2014; Harries *et al.*, 2016) to be suitable for use in low-head flows, such as can be found in small rivers/streams that could provide energy to small isolated communities, and in tidal regions such as the Severn Estuary where the potential for tidal energy generation has long been identified (Sustainable Development Commission, 2007).

CarBine is composed of a number of flaps mounted around a central axle. Flaps are hinged at both ends to allow them to rotate freely. When in flow, the flaps stop against each other such that they generate increased drag in the direction of flow when closed, and minimal resistance when open parallel to the flow (Harries, 2014). The CarBine design concept can be seen in Fig. 1.

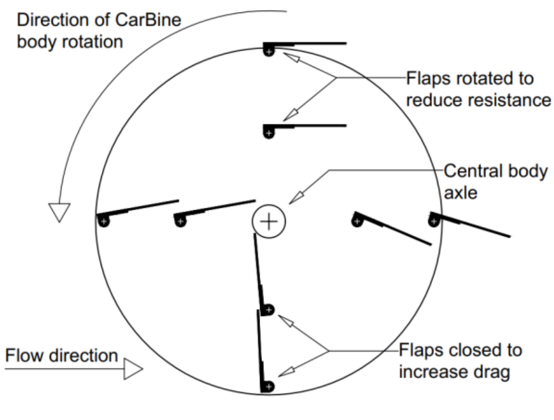

Fig. 1. Plan view section of CarBine.

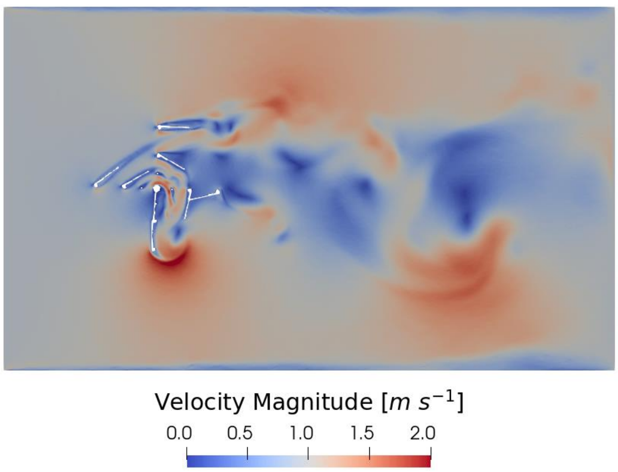

Fig. 2. CarBine model in two-dimensional representation, with velocity magnitude of fluid field during calibration testing.

2. Method

Computational modelling which allows changes to the design to be assessed at a reduced cost and faster timescale is one the key approaches used for further development and improving the performance of the turbine. Smoothed Particle Hydrodynamics (SPH) was identified as a technique for this modelling due to the ability to represent multi-body and fluid structure interactions with relative simplicity compared to finite element, finite volume or finite difference methods that would require dynamic meshing and complex solvers (Monaghan, 2005).

The model was built using the software DualSPHysics (Crespo *et al.*, 2015). DualSPHysics was chosen due to the open-source license, the high performance of simulation that can be achieved by performing operations on the graphical processing unit (GPU), and the inclusion of the rigid body solver Chrono (Mazhar *et al.*, 2013). CarBine was represented in the model using different components which were defined as appropriately linked solid bodies. The solid bodies being themselves composed of connected particles; to realistically describe the turbine behavior. Results from this model could then be compared to the flume experiments, and to other numerical models such as simulations being carried out using ANSYS CFX and pseudo-transient or dynamic meshing in order to evaluate accuracy and performance of the model.

DualSPHysics does not currently include capability to calculate turbine characteristics itself, but due to the nature of the particle method, turbine outputs can be calculated from first principles. By extracting the position and velocity of all the particles that form the turbine, the total momentum and angular inertia can be determined at every timestep. Since torque is the change in angular momentum over time this can then be calculated for the entire timeseries using a backward differencing scheme, and then the result scaled up to account for the change from two to three dimensions.

3. Results

The turbine has been represented in a two-dimensional (effectively depth averaged) model, shown in Fig 2, in order to reduce the computational cost. This greatly reduces the number of particles and therefore computational cost although it presents some challenges of its own. The process of calibrating the initial model to the results of a recent initial experimental study was carried out. This required an array of sensitivity tests to determine how best to define the geometry and physical characteristics of the CarBine in this approximate solution, as well as where and how to define the model boundaries and behaviour.

4. Conclusions

To improve the CarBine performance; with the calibrated model, a variety of design modifications are to be investigated. These will include, but not be limited to changes in flap configuration, and restraints. The performance changes shown in the model, will guide the development of the physical prototype, to best utilize laboratory time and resources.

Representing this complex turbine and the flows, both through and around it, have been achieved through the application of an innovative modelling approach. This has so far improved understanding of the flow states and performance indicators of the turbine in motion. The torque outputs however still require additional calibration and consideration.

Acknowledgements

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