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A Vortex-Lattice Method for the Prediction of Unsteady Performance of Marine Propellers and Current Turbines

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In this paper, the unsteady hydrodynamic analysis of marine propellers and horizontal-axis tidal current turbines is performed by using a vortex lattice method (VLM). A fully unsteady wake alignment algorithm is implemented into the VLM to satisfy the force-free condition on the propeller and turbine wake surfaces. It was found that the position of the trailing wake is very important in predicting the performance of propellers or turbines in steady or unsteady flow. The effects of a non-linear interaction between the inflow and the propeller/turbine blades have been taken into account by using a hybrid viscous/potential flow method, which couples the potential flow solver for the unsteady analysis of the propeller/turbine and a viscous flow solver for the prediction of the viscous flow field around them. The present method is then applied to predict unsteady hydrodynamic performance of a propeller and a horizontal-axis tidal current turbine. The predicted unsteady forces of a propeller subject to an inclined inflow are compared with those from experiments. The hydrodynamic performance of tidal turbine in yawed flow for various yaw angles is investigated. The numerical results are compared with existing experimental data.

INTRODUCTION

Tidal energy, like wind and solar energies, is distributed across large areas and regarded as a potential renewable energy for the near future.

The marine current turbines extract tidal energy from tidal flow by converting the sea water kinetic energy directly to mechanical power, hence avoiding the environmental impact caused by the conventional tidal power plant. Furthermore, the tidal turbines have become more and more economically competitive with conventional fossil fuels, due to the improvements of turbine technology. An experimental study on a 3-blade horizontal tidal turbine was performed in a cavitation tunnel and also in a towing tank (Bahaj et al., 2007a), and the corresponding power and thrust coefficients were presented for a range of tip speed ratios. The experimental data provide very useful information for the design of tidal turbines and for the validation of numerical models. Several numerical methods have been applied to analyze the performance of the same tidal turbine presented in Bahaj et al. (2007a), including a blade element method by Bahaj et al. (2007b); Batten et al. (2007, 2008), a boundary element method by Baltazar and de Campos (2008, 2009), Young et al. (2010), and Kinnas et al. (2011), which also considered the effects of 3-dimensional flow.

Marine propellers and tidal current turbines share many similarities in hydrodynamic characteristics but serve the opposite purposes: tidal turbines extract kinetic energy from the tidal flow and convert it into electricity, whereas propellers transmit engine power into propulsive power. The principles and methods that work for propellers can be applied to turbines without much modification. In this paper, the numerical models that were originally developed for cavitating marine propellers are extended to predict the unsteady hydrodynamic performance of a marine current turbine.

A marine propeller often operates in a non-axisymmetric flow field, which is generated by the viscous effect of ship hull and the unsteady motions of a ship. Similarly, a tidal current turbine is subject to various yawed inflows with a tidal current velocity profile. The development of a computational method that can accurately predict unsteady performance of propellers and turbines, for both wetted and cavitating flow, is essential in the design process. It is well known that the trailing wake sheet traveling downstream of a propeller blade experiences contraction and roll-up at the tip region. A similar phenomenon occurs for a marine current turbine. However, the trailing wake will experience expansion rather than contraction. The unsteady wake alignment developed by Lee (2002) and Lee and Kinnas (2005) can accurately predict the wake geometry by aligning the wake surface with the local velocities, i.e. by applying force free condition on the wake surface. This method is implemented in the vortex lattice method to compute the accurate wake geometry for both turbines and propellers. In the case of inflows with vorticity in them (which is often the case since the propulsor is working inside the boundary layer at the stern of the hull), the inflow to the propeller must be the *effective wake*, which takes into account the interaction of the vorticity in the inflow with the flow around the blade. The effective wake is defined as the difference between the resultant total flow and the propeller/turbine-induced flow. In order to evaluate the total flow we need to discretize the whole flow domain (as opposed to just the surfaces of the boundaries) and solve for the Reynolds-Averaged Navier-Stokes (RANS) equations in that domain. Since a full RANS computation for marine propeller increases the computational time substantially and requires complicated grid generation due to moving propeller blades, the coupling of potential method (applied on the blades) with a RANS solver (applied to

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