Computational Modeling of Tethered Underwater Kites for Power Generation

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Abstract:

Ocean currents and tidal energy are significant renewable energy resources, and new concepts to extract this untapped energy have been studied in the last decades. Tethered undersea kite (TUSK) systems are an emerging technology which can extract ocean current energy. TUSK systems consist of a rigid-winged kite, or glider, moving in an ocean current. One proposed concept uses an extendable tether between the kite and a generator spool on a fixed or floating platform. As the kite moves across the current at high speeds, hydrodynamic forces on the kite tension the tether which extends to turn the generator spool. In effect, the TUSK system is a current speed enhancement device with enhanced power output compared to a fixed marine turbine.

Since the TUSK system is a new technology, the process of bringing a TUSK design to commercial deployment is long and costly, and requires understanding of the underlying flow physics. The use of computational simulation, has proven to be successful in reducing development costs for other technologies. Currently, almost all computational tools for analysis of TUSK systems are based on linearized hydrodynamic equations in place of the full Navier-Stokes equations. In this talk the development of one of the first dedicated computational tools for simulation of TUSK systems is described. The numerical tool models the flow field in a moving three-dimensional domain near the rigid undersea kite wing. A two-step projection method along with Open Multi-Processing (OpenMP) on a regular structured grid is employed to solve the flow equations. In order to track the rigid kite, which is a rectangular planform wing with a NACA-0021 airfoil, an immersed boundary method is used. A PID control method is also used to adjust the kite pitch, roll and yaw angles during power (tether reel-out) and retraction (reel-in) phases to obtain desired kite trajectories.

A baseline simulation study of a full-scale TUSK system in conducted. The simulation captures the expected cross-current, figure-8 motions during a kite reel-out phase where the tether length increases and power is generated. During the following reel-in phase the kite motion is along the tether, and kite hydrodynamic forces are reduced so that net positive power is produced. Kite trajectories, hydrodynamic forces, vorticity contours near the kite, kite tether tension and output power are determined and analyzed. The performance and accuracy of the simulations are assessed through comparison to theoretical estimations for kite power systems. This talk also highlights the effects of different key design parameters in TUSK systems, including tether drag and tether retraction velocity. Future work which could further enhance the simulations will also be discussed.