Study of Hydrokinetic Turbine Arrays with Large Eddy Simulation

Danny Clay Sale
Nick Stelzenmuller
Teymour Javaherchi
Alberto Aliseda

University of Washington, Seattle, WA, USA
Dept. Mechanical Engineering
Northwest National Marine Renewable Energy Center

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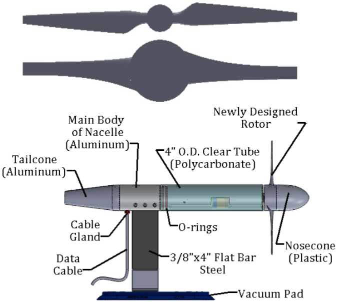
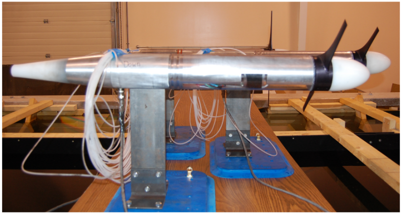
FOCUS

What is the potential power generation and environmental effects from marine hydro-kinetic (MHK) turbine farms?

- Areas to Investigate
  - fluctuations of power production and structural response due to turbulence
  - turbulence characteristics and wake evolution
  - near field pressure fluctuations in wake
- Comparison of Numerical Simulations and Experiment
  - physical testing of 3 turbines in water flume
  - large-eddy-simulation (LES) to replicate experiment

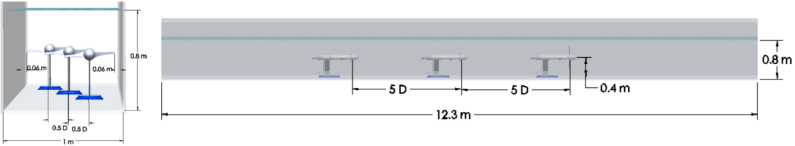
TIDAL TURBINE REFERENCE MODEL 1

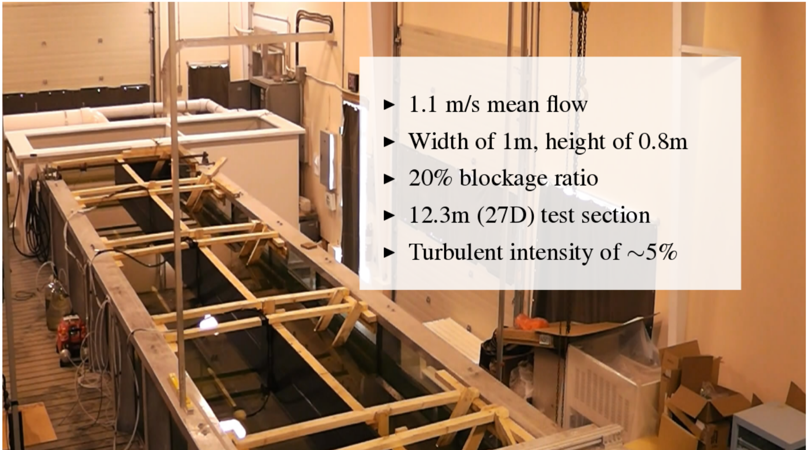




- horizontal-axis turbine, full-scale 550kW, diameter of 20-m
- created by US DOE to standardize experimental and numerical studies
- foils are NACA 4 and 6 series chosen for cavitation prevention and well known performance characteristics at low and high Reynolds
- laboratory turbine 45:1 scaling – diameter of 45-cm
- attempt to match power extraction and wake characteristics at lab-scale
- lab-scale rotor was re-designed to minimize Reynolds scaling effects

Flume Testing of 3 Turbines

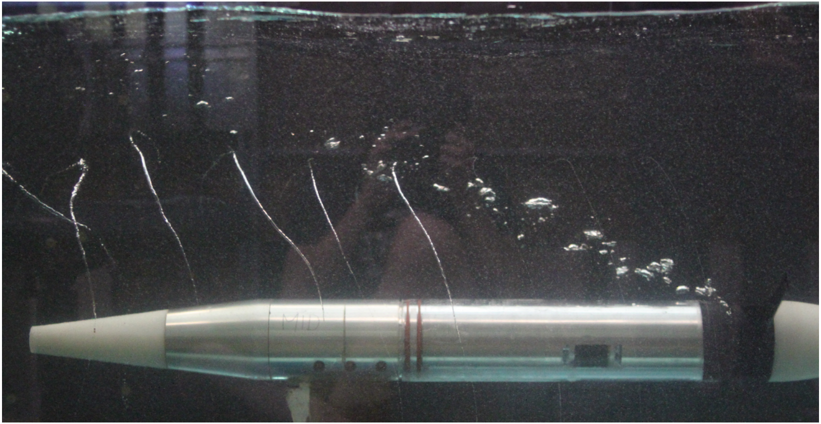




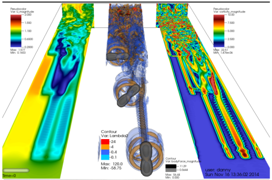
- 1.1 m/s mean flow
- Width of 1m, height of 0.8m
- 20% blockage ratio
- 12.3m (27D) test section
- Turbulent intensity of ∼5%

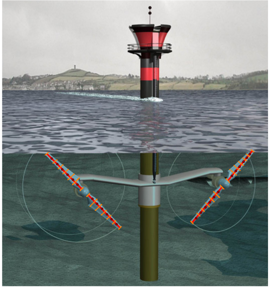
VISUALIZATION OF TIP VORTEX

bubbles are released from the nacelle to visualize tip vortex (movie)



The turbine model uses the velocity field from the LES to compute the hydrodynamic forces imparted on the turbine blades, and then body forces are projected back onto flow field. [1]





- Large-Eddy-Simulation (LES)
  - code: OpenFOAM (Field Operation and Manipulation)
  - second-order accurate finite-volume (FV) formulation
  - filter is implicitly defined by the mesh and FV discretization
  - subgrid-stress (SGS) model is constant coefficient Smagorinsky
- Actuator-Line-Method (ALM)
  - code: FAST (Fatigue Aerodynamics Structures Turbulence)
  - creates turbulent wake and captures blade tip and root vortices
  - similar to blade element method discretize blades into spanwise sections
  - depends on airfoil lookup tables for lift, drag, moment, min. pressure coefficients
  - normalized forces projected onto flow field with equal and opposite direction

[1] NWTC Information Portal (SOWFA). https://nwtc.nrel.gov/SOWFA

TURBINES=3 TSR=6.2 MESH=(COARSE, MEDIUM)

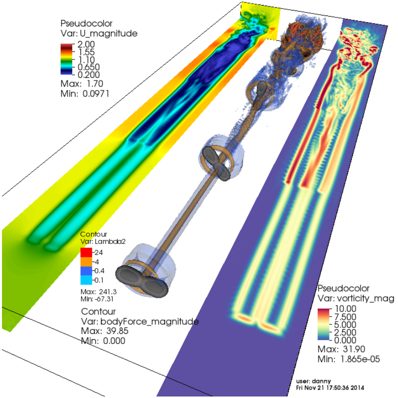


Figure : coarse mesh 465x50x40, dx = 0.020 m

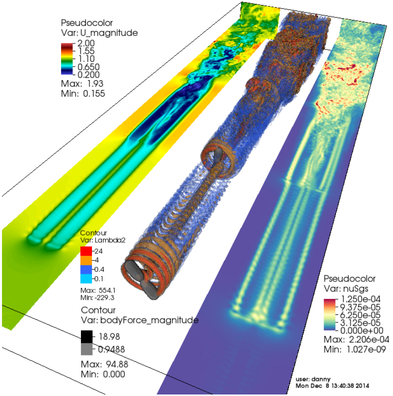
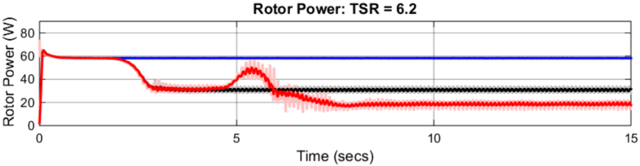
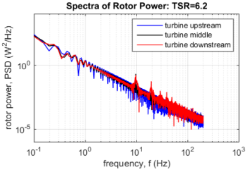
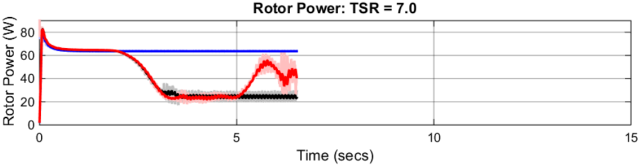
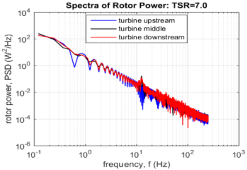


Figure : medium mesh 698x75x60, dx = 0.013 m

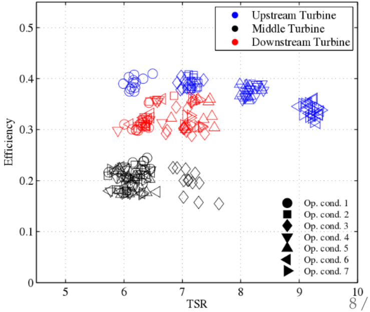








- can observe moments when wakes impact rotors
- passage of rotor blades apparent in FFT, higher freqs. due to turbulence
- LES still too coarse for quantitative comparison yet
- care is needed to compute efficiency of individual turbines in farms



FUTURE WORK

- Code and Computers
  - prototype simulations for running on more powerful hardware
  - shared memory, distributed memory, co-processors
  - want to understand resolution required to resolve wakes and turbine performance accurately
  - based upon free and opensource software, available on GitHub (dcsale/SOWFA)
- Ambient Turbulence
  - turbulent structures within ambient flow can cause loading events with significance comparable to when turbines operate in upstream wakes
- Control Strategies
  - dynamical model of rotor to allow variable TSR as response to fluctuations in rotor torque

Thank you!!! Questions, Suggestions ???