Study of Hydrokinetic Turbine Arrays with Large Eddy Simulation

"fastFlume" tutorial for SOWFA

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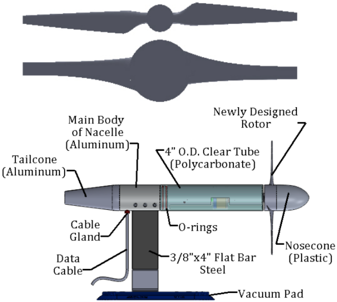
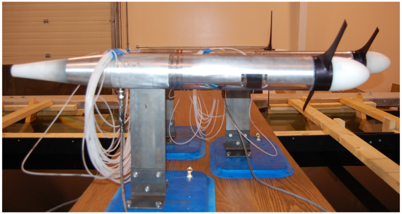
Focus

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

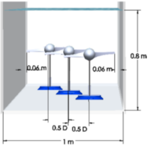
Tidal Turbine Reference Model 1

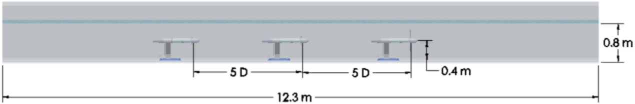


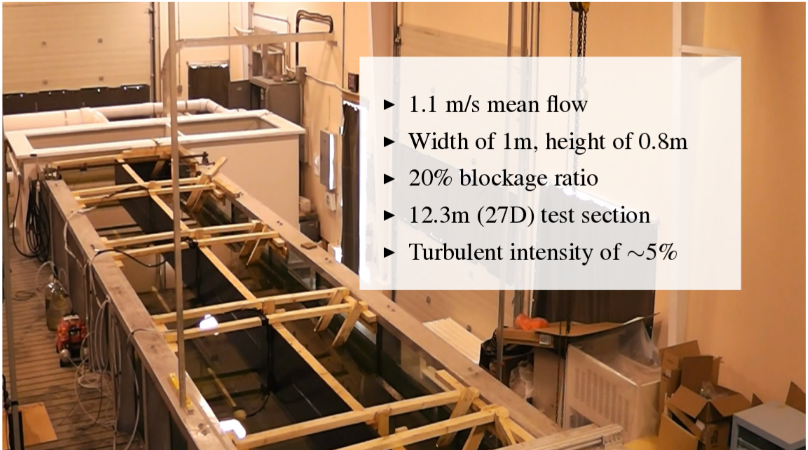


- horizontal-axis turbine, full-scale 550kW, diameter of 20-m
- created by US DOE to standardize experimental and numerical studies
- foils are NACA 4 and 6 series chosen for cavitation prevention and well known performance characteristics at low and high Reynolds
- laboratory turbine 45:1 scaling – 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



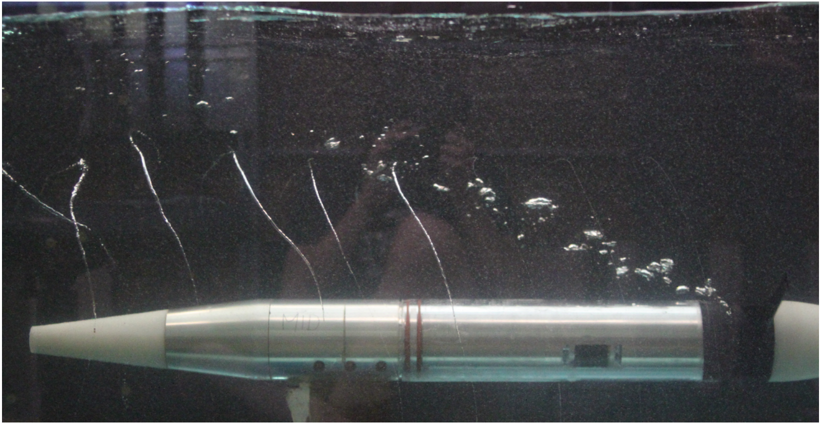




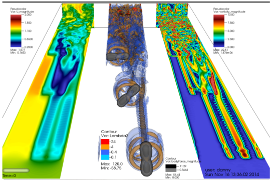
- 1.1 m/s mean flow
- Width of 1m, height of 0.8m
- 20% blockage ratio
- 12.3m (27D) test section
- Turbulent intensity of ~5%

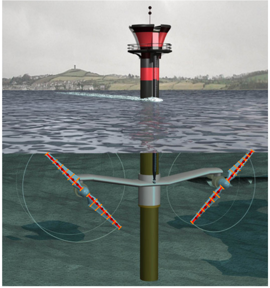
Visualization of Tip Vortex

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)

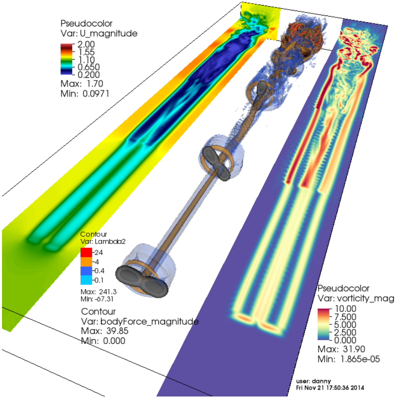


Figure : coarse mesh 465x50x40, dx = 0.020 m

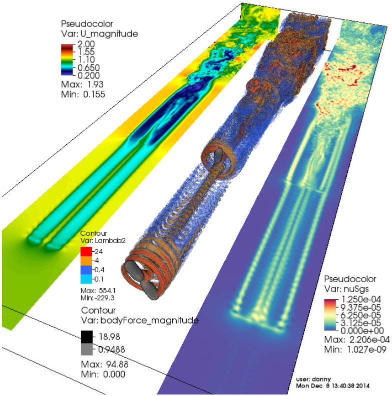
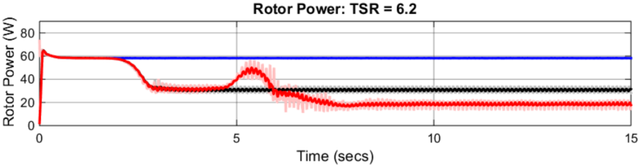
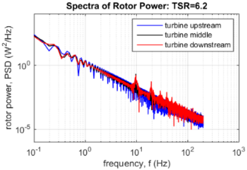
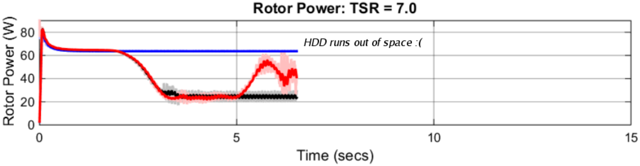
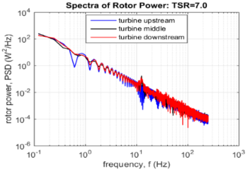


Figure : medium mesh 698x75x60, dx = 0.013 m

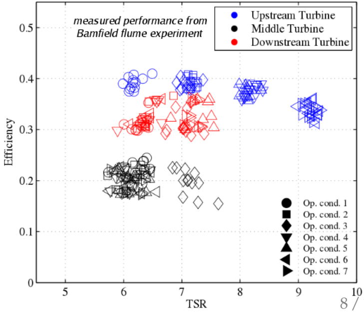








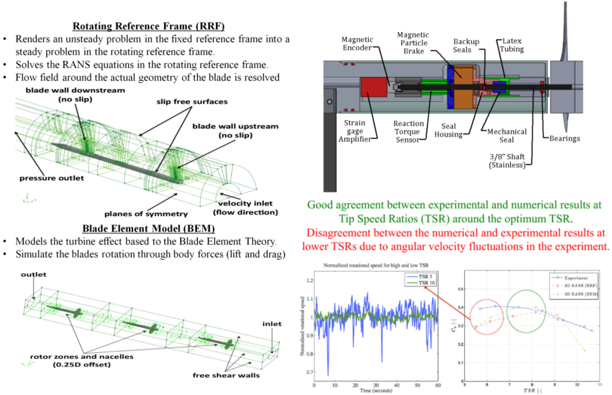
- can observe moments when wakes impact rotors
- passage of rotor blades apparent in FFT, higher freqs. due to turbulence
- LES still too coarse for quantitative comparison yet
- care is needed to compute efficiency of individual turbines in farms



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
- Ambient Turbulence
  - turbulent structures within ambient flow can cause loading events with significance comparable to when turbines operate in upstream wakes
  - boundary data on inlet planes generated from either precursor LES or synthetic turbulence methods (e.g. pyTurbSim)
- Control Strategies
  - dynamical model of rotor drivertrain to allow variable TSR as response to fluctuations in rotor torque
  - rotor speed and pitch control for ”in-water” dynamometer testing

Simulations were performed with Reynolds Averaged Navier-Stokes (RANS) methods to resolve geometry of blades and nacelle. Turbine wakes measured using particle image velocimetry (PIV) and acoustic Doppler velocimetry (ADV), and efficiency derived from torque and rotational speed measurements. [2] [3] [4]

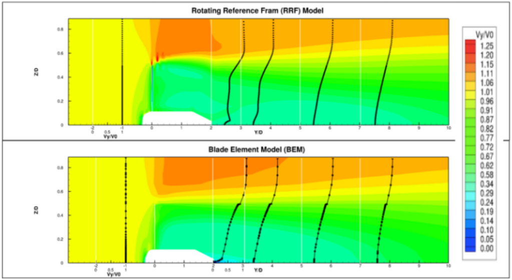


[2] T. Javaherchi, N. Stelzenmuller and A. Aliseda (2013) EXPERIMENTAL AND NUMERICAL ANALYSIS OF THE DOE REFERENCE MODEL 1 HORIZONTAL AXIS HYDROKINETIC TURBINE, GMREC, Washington D.C.

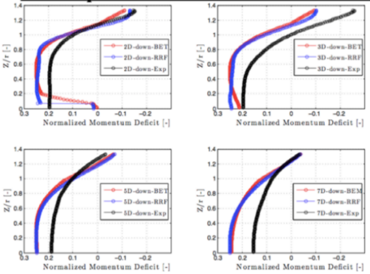
[3] T. Javaherchi (2014) Numerical investigation of Marine Hydrokinetic Turbines: methodology development for single turbine and small array simulation, and application to flume and full-scale reference models. PhD thesis, University of Washington

[4] N. Stelzenmuller (2013) Marine Hydrokinetic Turbine Array Performance and Wake Characteristics. MS thesis, University of Washington

Normalized velocity contours superimposed by velocity deficits



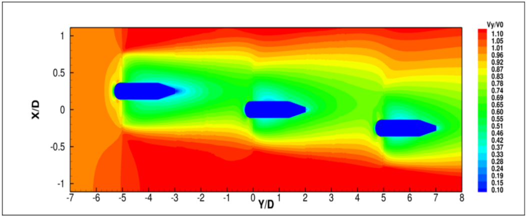
Comparison between the measured and predicted momentum deficit profiles at different stations downstream the turbine.



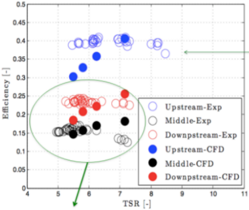
The RRF and BEM both predict slower wake recovery process in the turbulent wake due to:

1) Boundary conditions idealization.
2) Potential limitations of the closure model (SST k-w).

Normalized velocity contours by the velocity at the inlet

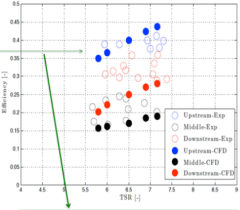


Performance curves of three coaxial turbines with 5D fixed spacing



Middle turbine enhances the turbulent mixing in the wake of the upstream turbine. This leads in to higher efficiency for the downstream turbine.

Performance curves of three offseted turbines with 5D fixed spacing



In the offset configuration the shear in the flow field and blockage effect increases the efficiency of each turbine in the array.

To-do: tabulate output from LES to compare with RANS and experiments.