Tidal turbine rotor spacing influence on power performance: Simulating a scaled dual-rotor axial flow turbine

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Lake Superior – The Great Lakes of North America

Lake Superior

- One of North America's Great Lakes
- Largest freshwater lake in the world with $82{,}170\ km^2$
- Waves over $6.1\ m$ high

Research at U. of MN Duluth

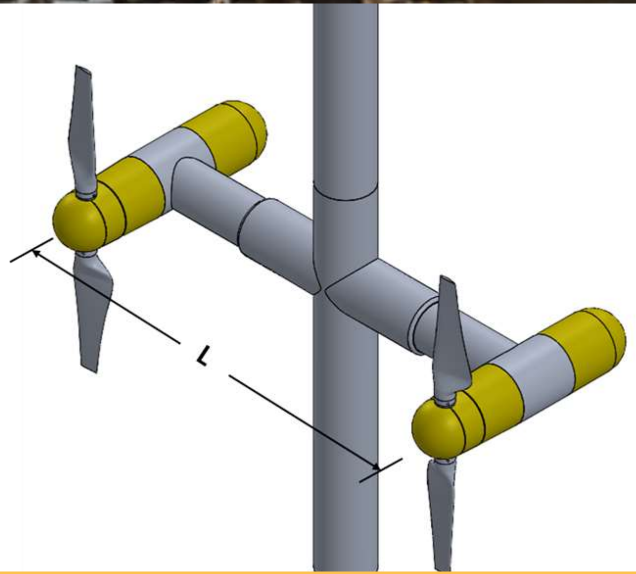
- Quantifying wave climate and wave energy resource across all five Great Lakes.
- Modeling wave energy converters in lower resource environments to explore Powering the Blue Economy integrations.
- Interactions between floating ice, waves, coastal structures, and MRE technologies.
- Low-cost observation systems for the marine environment.

Current Case Study

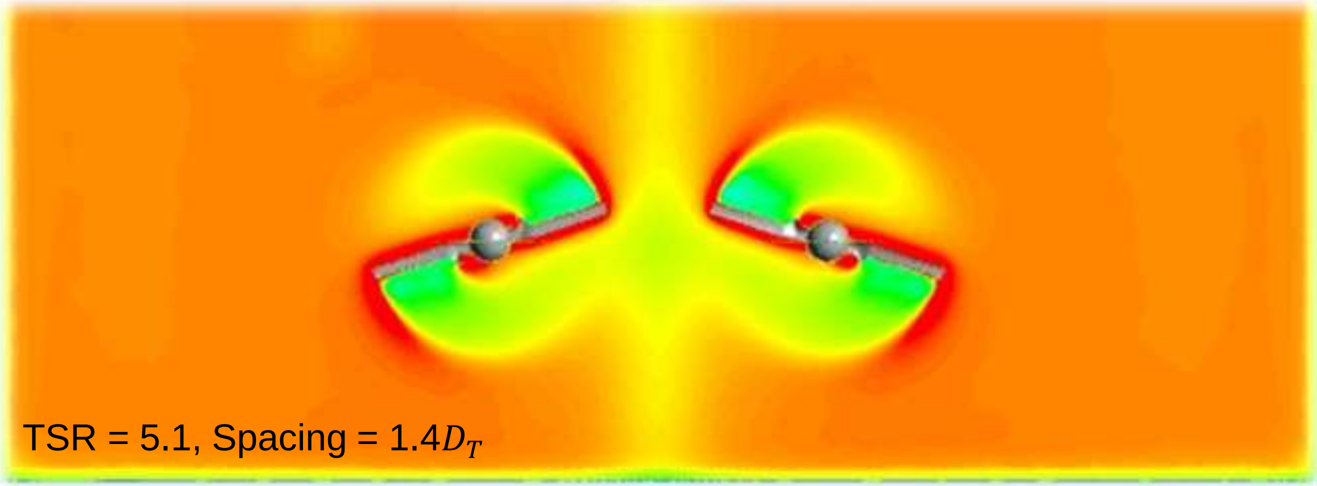
Field Scale Prototype

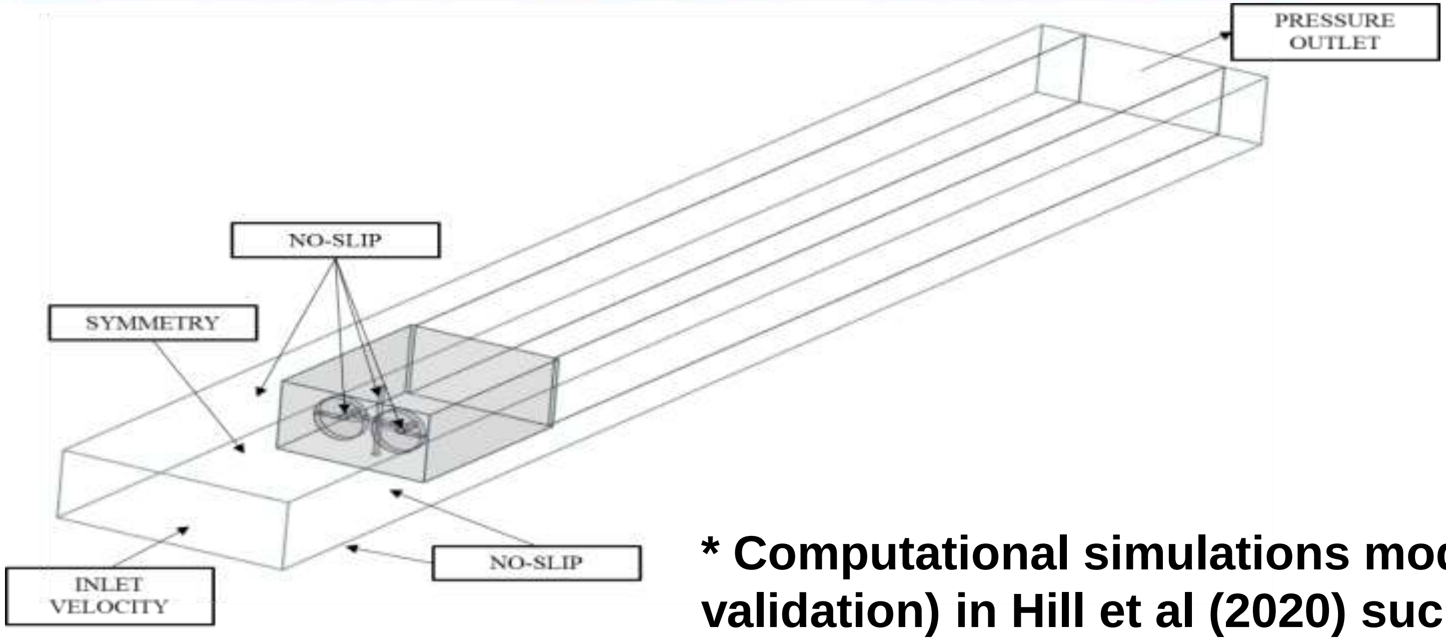
Axial Flow 1:40 Scaled Model

- Rotor diameter $= 0.5\ m$
- Rotor offset $= 1.4\ D_T$
- Height hub = 1 D_T
- NACA-4415 airfoils



Current Case Study





Computational Fluid Dynamics

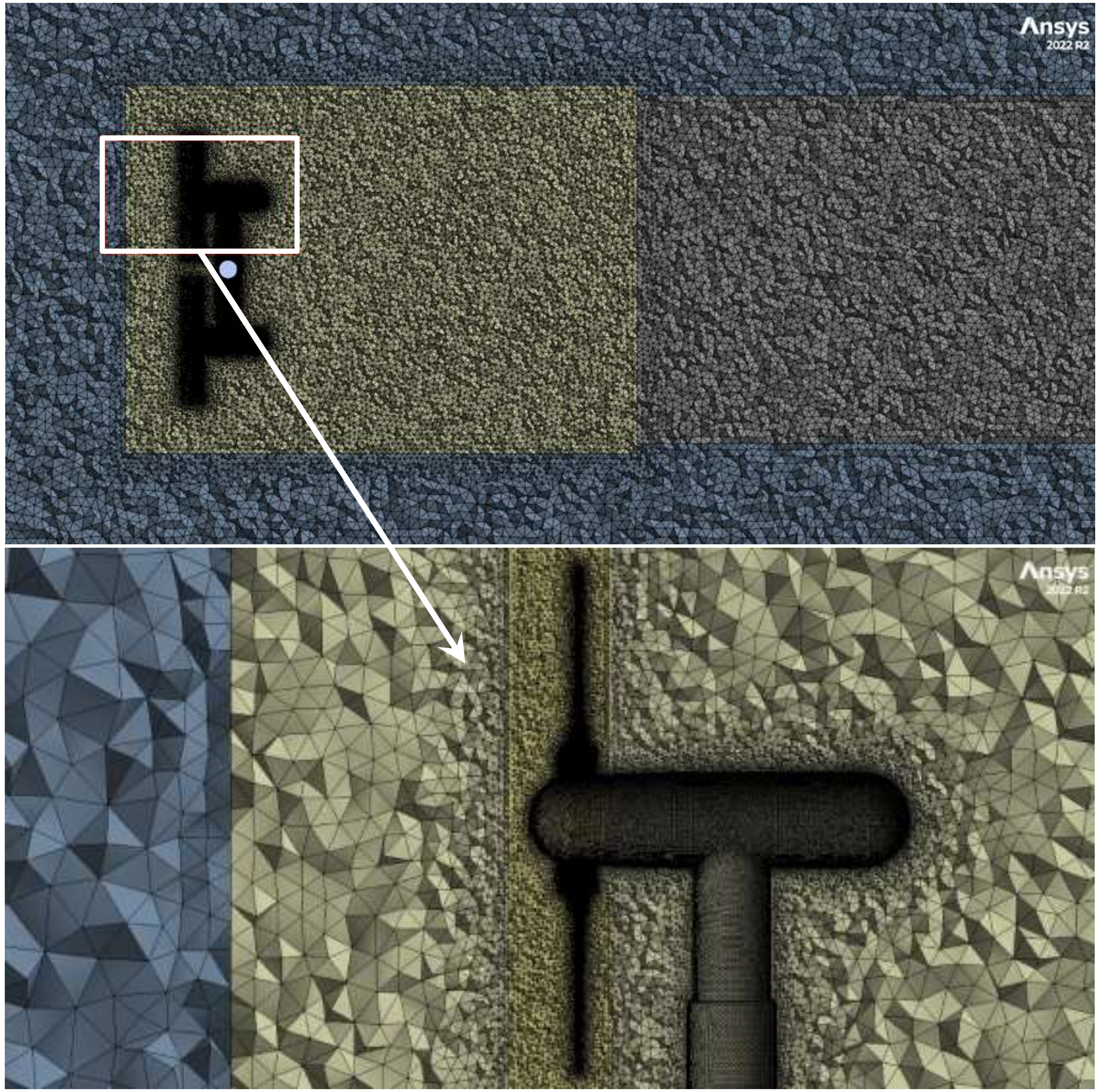
- ANSYS Fluent running on supercomputers at Minnesota Supercomputing Institute (MSI)
- Sliding Mesh (SM)
- $k - \omega \; SST$ Turbulence Model

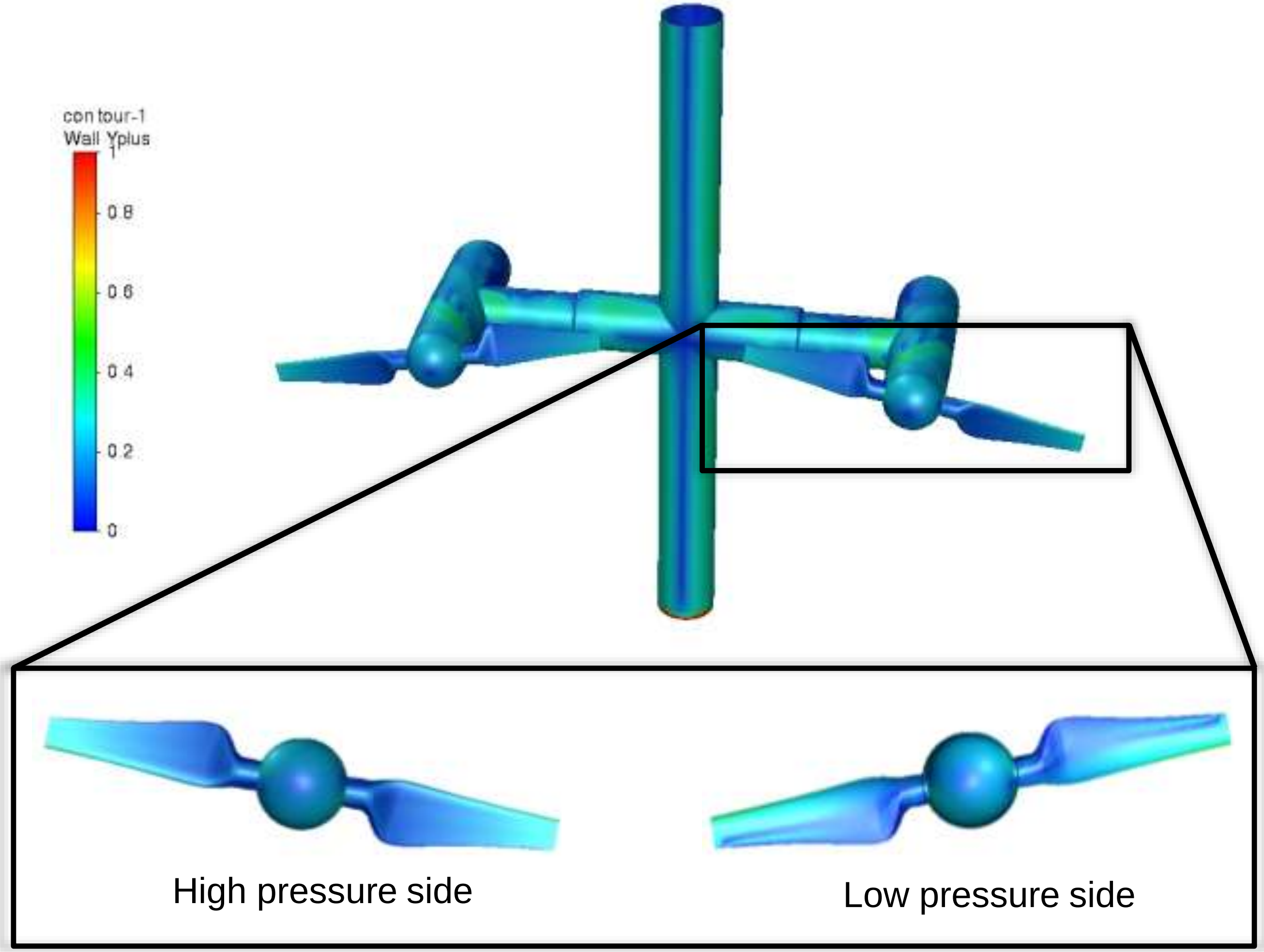
Boundary Condition

- Inlet velocity $= 1.04 \; m/s$
- Inlet TI $= 5\%$
- Outlet pressure $= 0 \; Pa$ (gage)
- Outlet TI $= 5\%$
- Top face $=$ symmetry
- Walls $=$ no-slip

*** Computational simulations model the exact experimental conditions (used for validation) in Hill et al (2020) such as channel geometry and flow conditions.**

Spatial Discretization





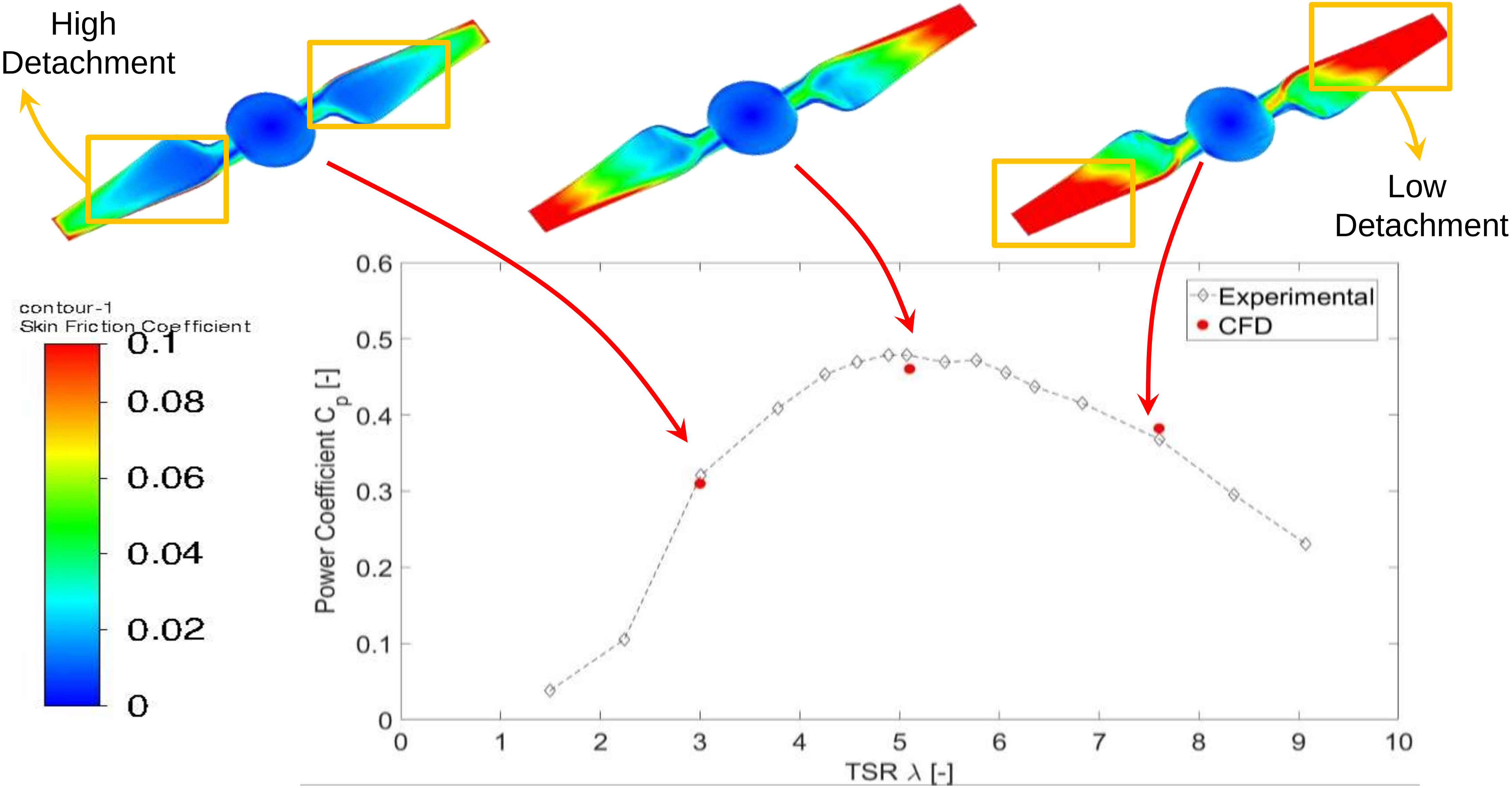
Temporal And Spatial Discretization

	Cells (Millions)	Averaged C_P (-)	Difference (%)
Coarse	19.89	0.43	9.634
Medium	**21.93**	**0.461**	**3.058**
Fine	48.01	0.468	1.615
Experimental	**--**	**0.476**	**--**

Time Step (s)	Averaged C_P (-)	Difference (%)
0.00001	0.463	2.73
0.001	0.463	2.73
0.003	**0.461**	**3.15**

Less than 5% difference to experimental data using 'Medium' mesh and time step of $3\ ms$

Power Curve Characteristics



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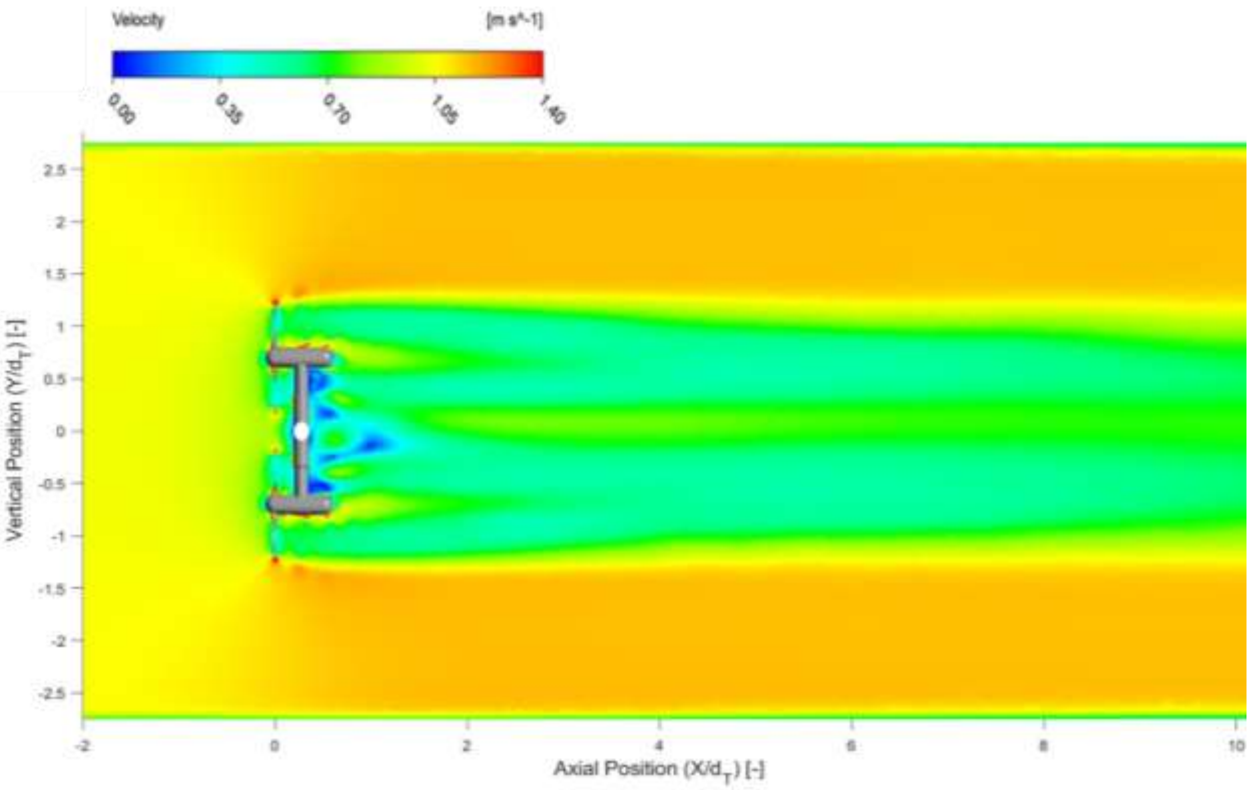
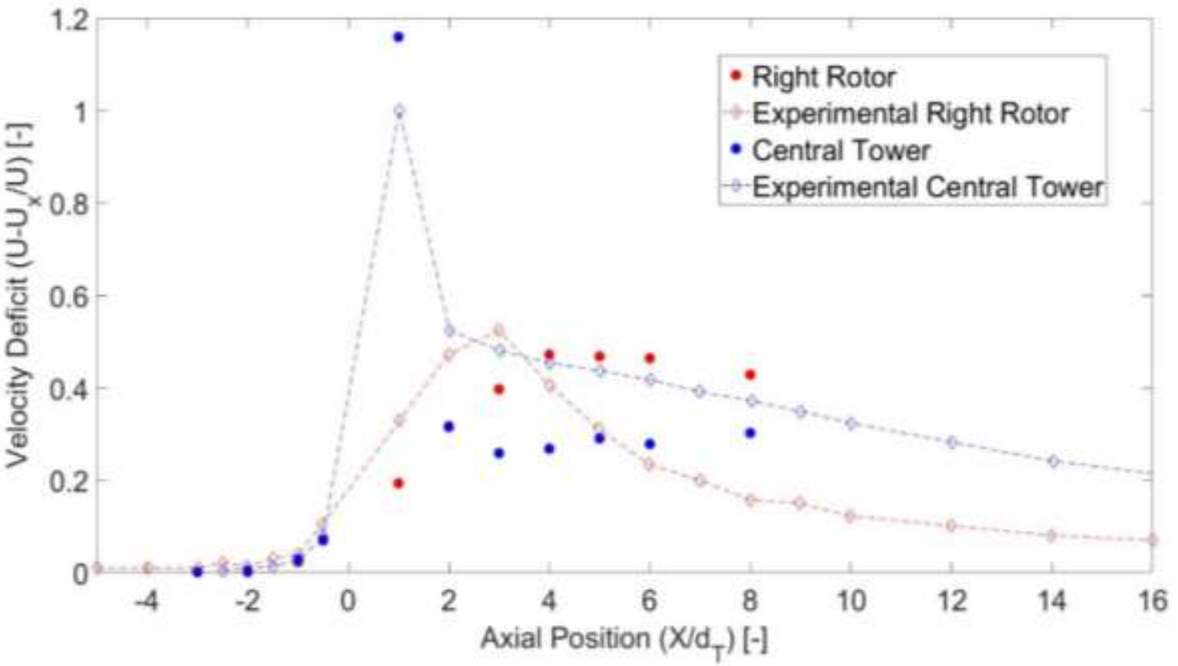
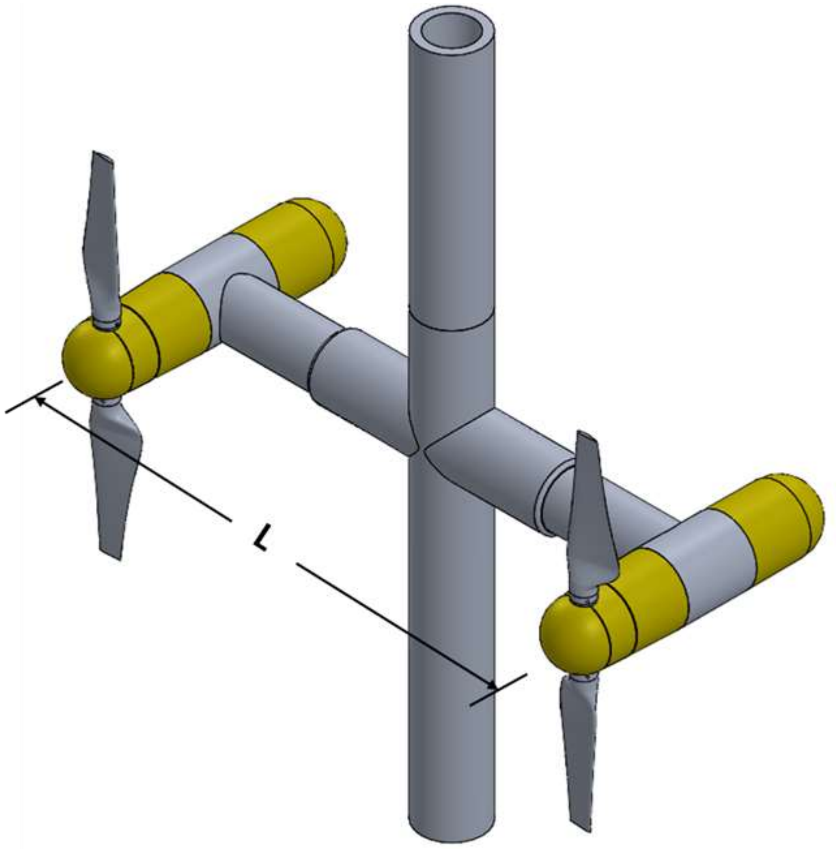
Inflow and Wake Characterization





Upstream region of the turbine, numerical results were in good concordance with experimental data as they differ by less than 5%. Appreciable difference at wake.

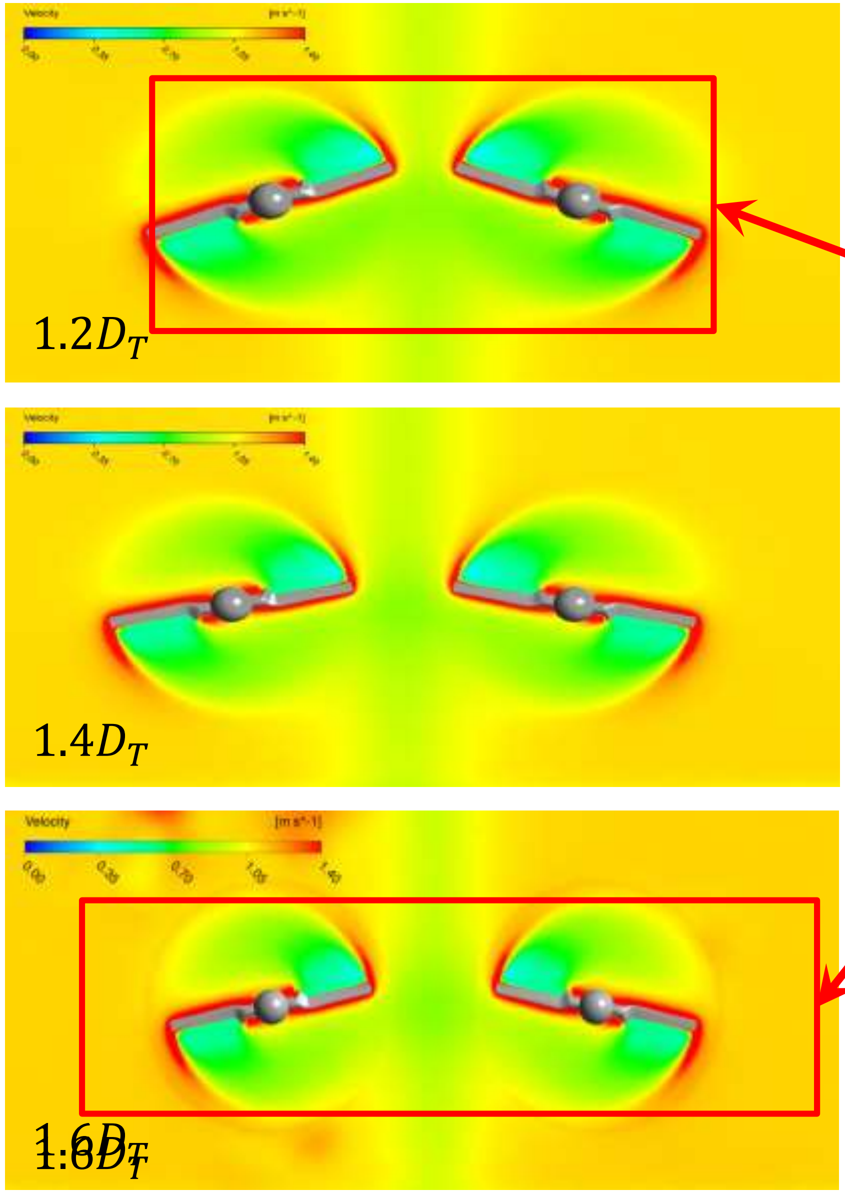
Rotor Spacing Influence



Lateral Axial Spacing L/D_T (-)	Averaged C_P (-)	Difference from 1.4 Case (%)
1.2	0.449	-2.6
1.4	0.461	0
1.6	**0.483**	**4.8**

4.8% increase in power production by spacing rotors 1.6 D_T apart

Velocity Contours At Rotor´s Plane



Choking effect constricts the velocity field passing between the two rotors, reducing its available kinetic energy, and therefore also reducing the energy extracted by the rotors.

Conclusions

Numerical simulations on a 1:40 RM1 scaled model using $k - \omega\ SST$ and sliding mesh technique were performed

- **Ability of k-ω SST to deal with low and high detached flows**
  - $TSR = 3, 5.1$ and 7.6
  - Numerical results with less than 5% difference to experimental data

- **Wake dynamics**
  - Good agreement for inflow conditions
  - Significant difference for Wake conditions
    - Isotropic turbulence by RANS models and lack of solving eddies

- **Power extraction versus rotor lateral spacing**
  - Three lateral spacing $= 1.2, 1.4$ and $1.6\ D_T$
  - Greater power extraction with higher lateral spacing
  - Higher power = higher torsional and bending moment on central tower
  - Economic study to determine if increase in C_P $=$ lower LCOE

Broader Implications for MRE Industry

Installation: Puget Sound, Washington

$1.4\ D_T = \$\ 809{,}000$ revenue *vs.* $1.6\ D_T = \$\ 841{,}000$ revenue

Gain $= \$\ \mathbf{42,000}$ (annually)

↓

Justifies increase in manufacturing costs?

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Future Work

- Support arm and central tower geometry and cross-section area
- Turbine's depth of installation
- Asynchronous rotor rotation
- Free surface simulation
- Higher Order Models (RSM, LES, DNS)
- Simulate additional Reference Models

THANK YOU!

QUESTIONS?

Lake Superior, Duluth, Minnesota, USA