How can we Improve Underwater Turbines with Hydrodynamic-Exploiting Control?

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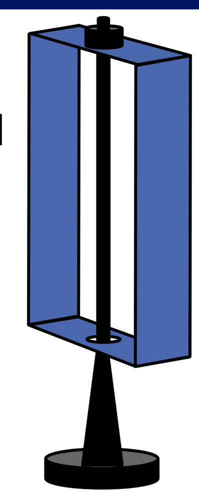
Introduction

Cross-Flow vs Axial-Flow Turbines

- Lower individual efficiency, higher per unit area[1]
- Constructive interference
- Insensitive to flow direction
- Lower optimal rotation rate



Why Variable Speed Control?

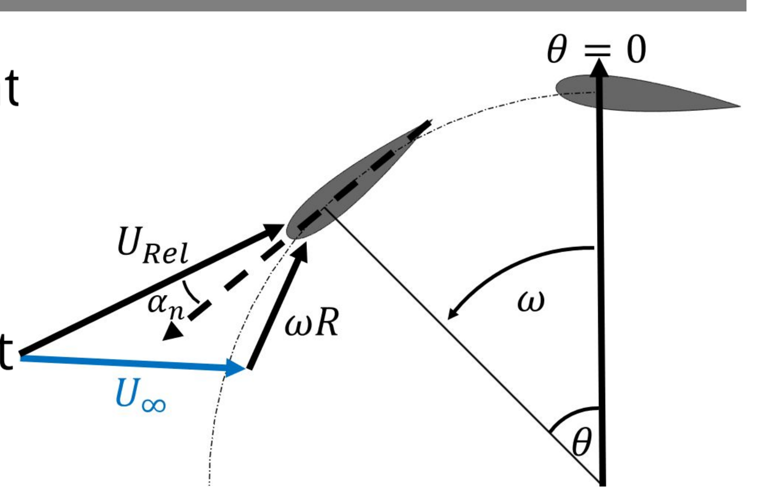
- Controlling angle of attack and hydrodynamics with fixed geometry[2,3]
- Improves understanding of beneficial flow phenomenon
- Simple control scheme

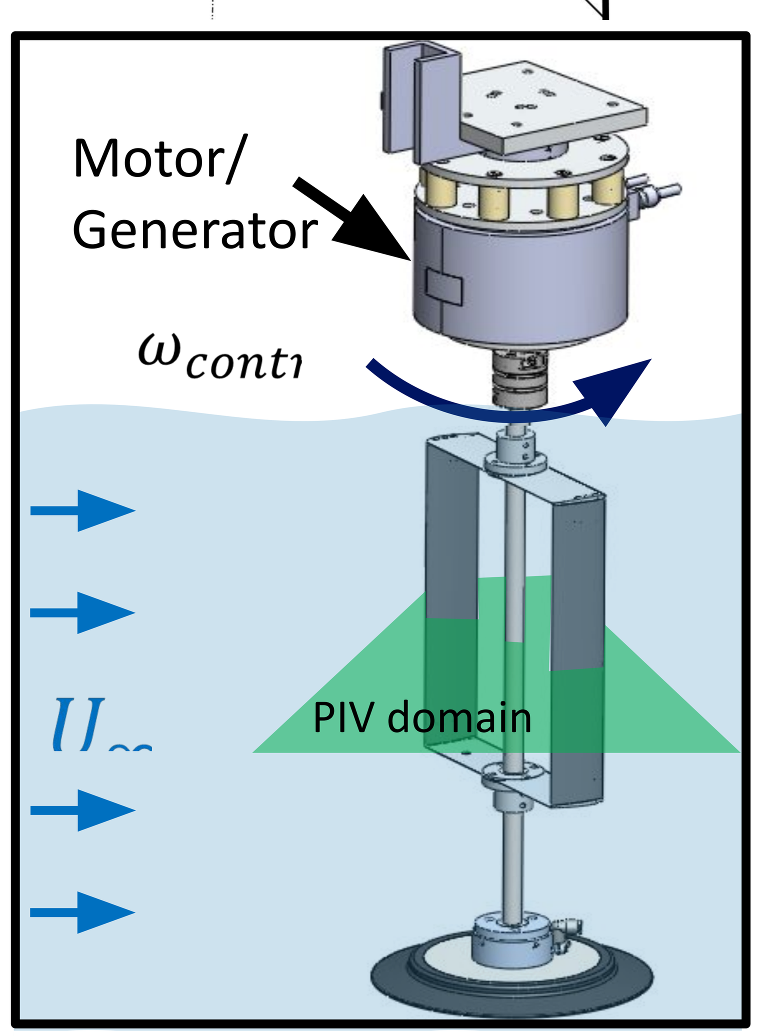
$$\omega_{control} = \omega_0 + A_{\omega} Cos(2(\theta - \phi))$$

- Downside: models predict higher loads associated with improved performance

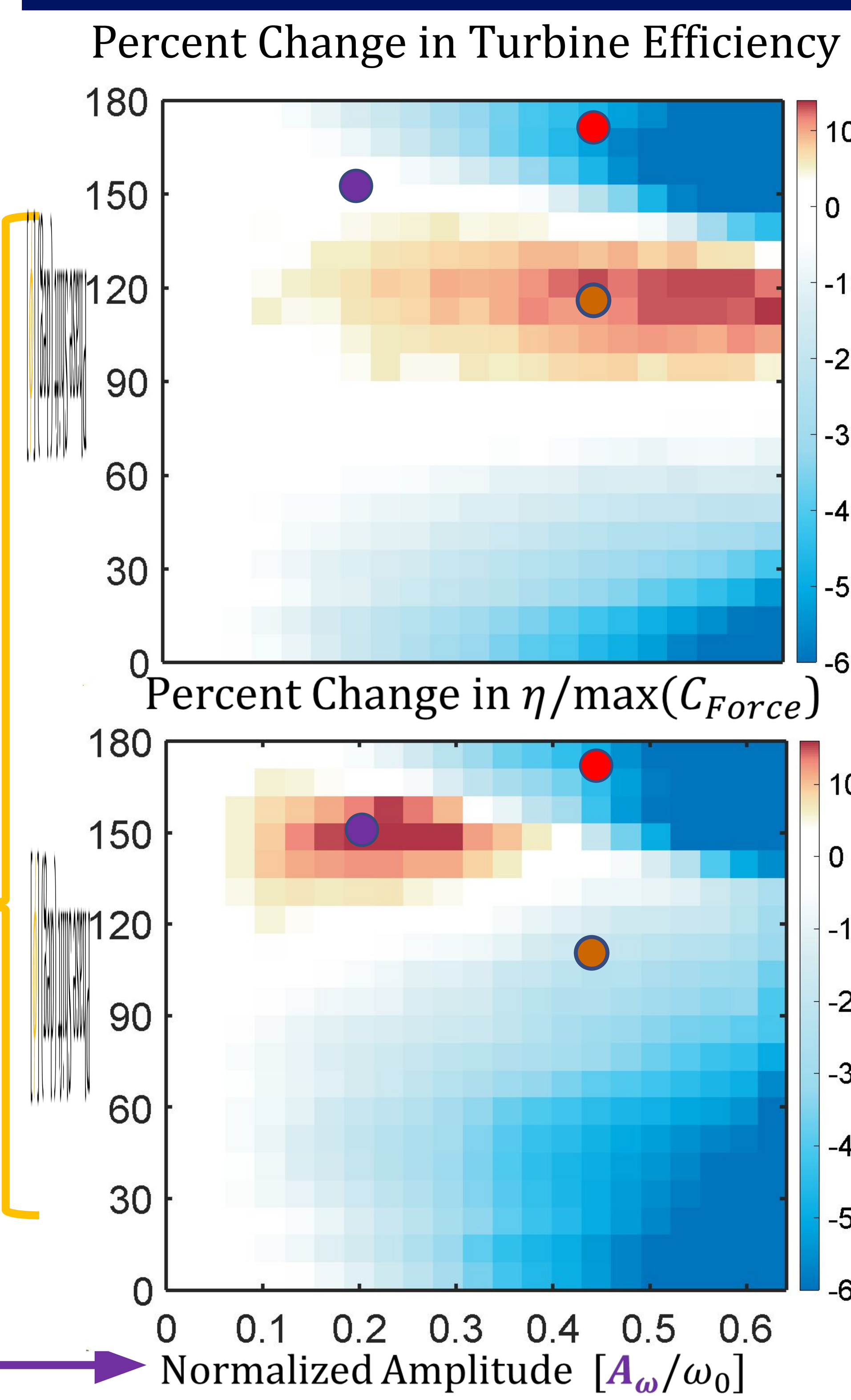
Methods

- Alice C. Tyler Flume test facility at Harris Hydraulics Lab
- Forces and moments measured with 6-axis load cells mounted at top and bottom of turbine
- Sweep of control parameters fixing $\omega_0 = 21 \frac{\text{rad}}{\text{s}}$ the optimal value for our turbine
- Particle Image Velocimetry (PIV) for key cases to explore near blade hydrodynamics
- Metrics of Interest:
  - Power producing efficiency, η
  - Ratio of average η to max in plane force, C_{Force}





Control Parameter Sweep



- Max efficiency improvement 15%
- Low sensitivity to changes in A_ω
- Higher sensitivity to changes in ϕ
- Narrow region of beneficial kinematics, more combinations produce poor performance
- It is possible to decrease loading while still improving performance!

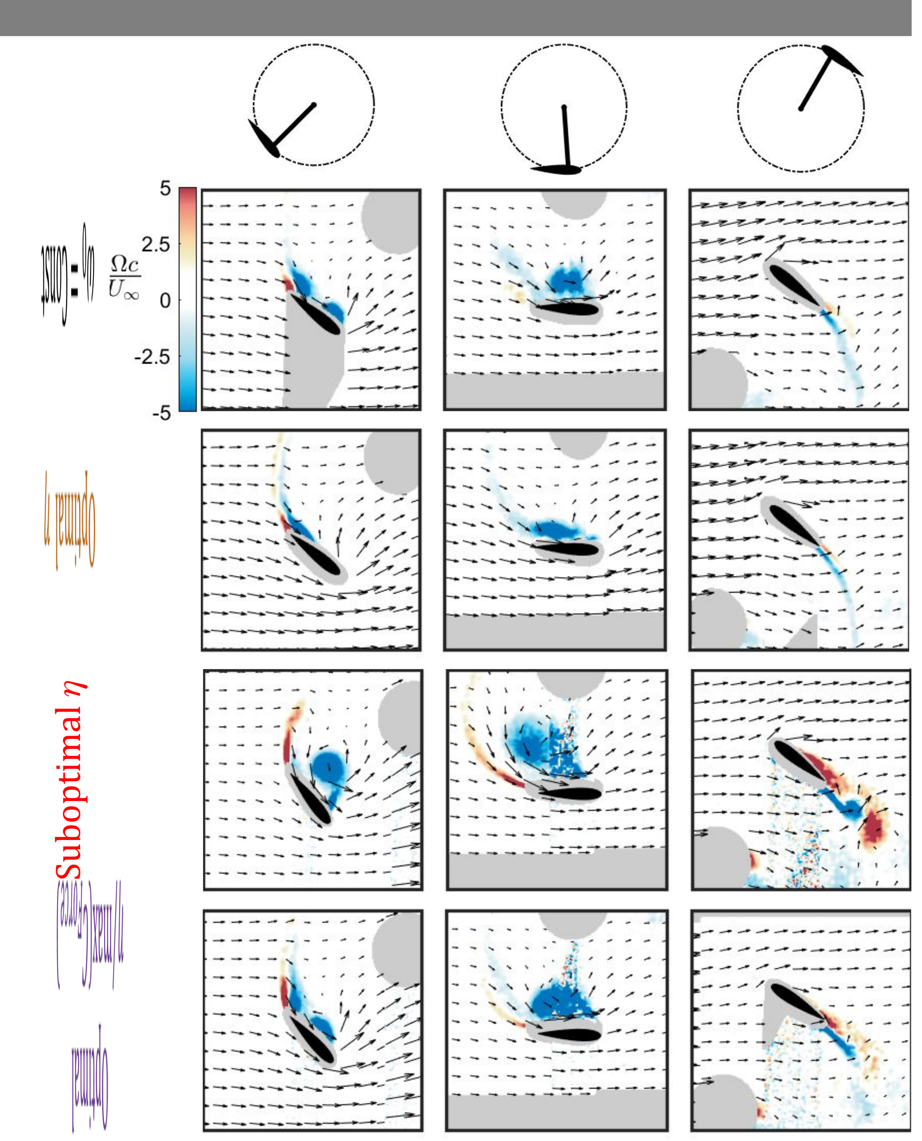
Optimal η

Suboptimal η

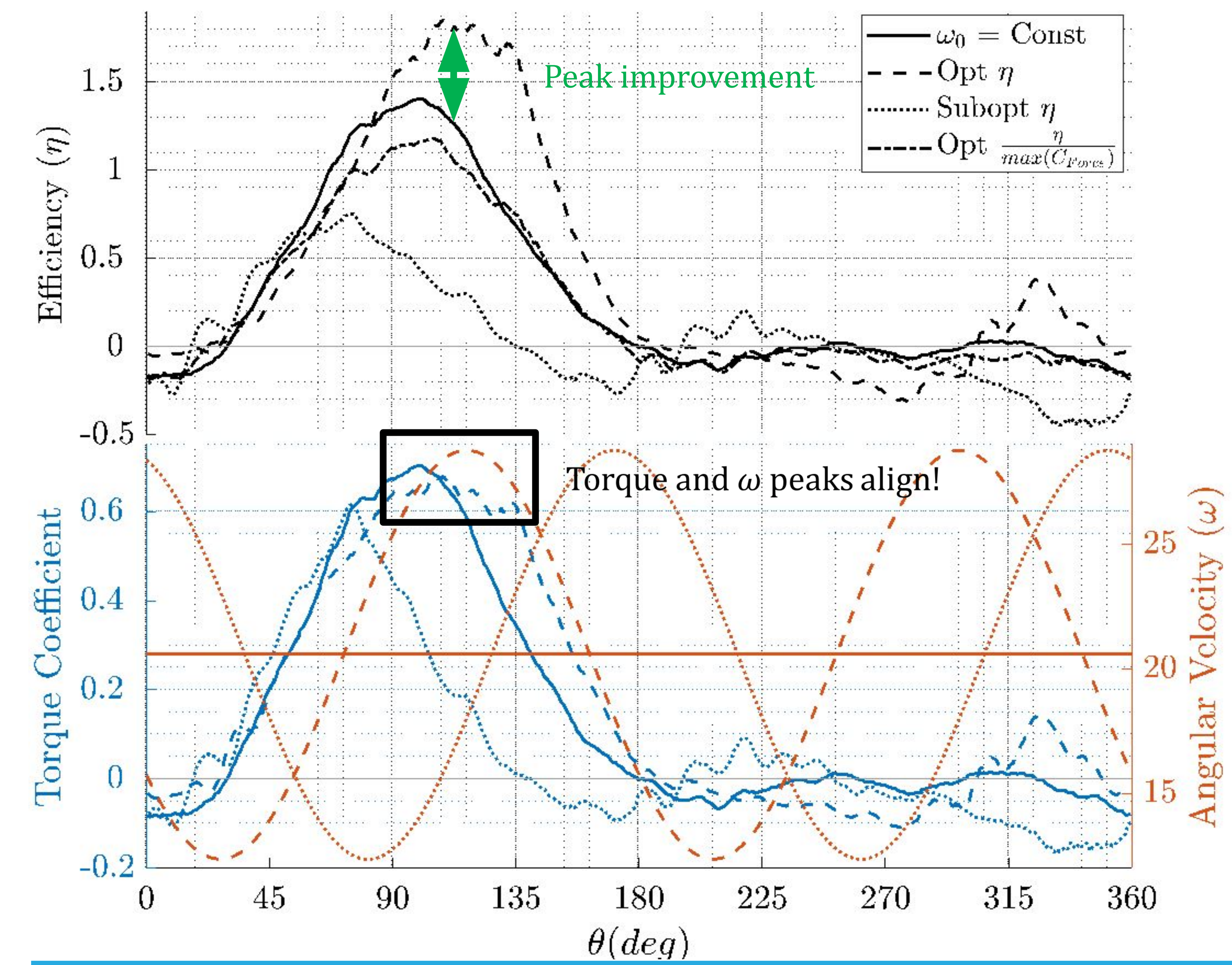
Optimal $\frac{\eta}{\max(C_{Force})}$

Near Blade Flow Fields

- Vortex suppression in optimal η case and improved reattachment
- Poor performing case shows stronger dynamic stall vortex and slower flow reattachment at the end of the cycle
- Optimal $\eta/\text{Max}(C_{F,xy})$ shows slightly worse shedding than constant case



Phase Averaged Analysis



Key Take Aways

- Variable velocity control can improve power generation by 15% through peak torque and angular velocity alignment
- **Structural costs can be decreased through a 16% reduction in $\eta/\max(C_{Force})$**
- Performance can be directly tied to flow field features deepening our understanding of beneficial flow phenomena

Future Work and Acknowledgments

- Data being used for CFD validation by collaborators at the University of Wisconsin
- Analysis of work repeated with the addition a cambered profile blades to assess impacts on hydrodynamics and performance
- Interpretation of results through the lens of Coriolis effects and virtual forces present in a rotational frame

Faculty: Dr. Owen Williams (AA) and Dr. Brian Palogye (ME)

References:

[1] J. O. Dabiri, (2011). “Potential order-of-magnitude enhancement of wind farm power density via counter-rotating vertical-axis wind tur-bine arrays,” JRSE.

[2] B. Strom, S. L. Brunton, and B. Polagye, (2017). “Intracycle angular velocity control of cross-flow turbines,” Nat. Energy.

[3] M. Dave, B. Strom, A. Snortland, O. Williams, B. Polagye, and J. A. Franck, (2021) “Simulations of intracycle angular velocity control for a crossflow turbine,” AIAA Journal.

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