Optimization of Intracycle Velocity Control for Cross Flow Turbines

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PMEC
Pacific Marine Energy Center

UAF UNIVERSITY OF ALASKA FAIRBANKS

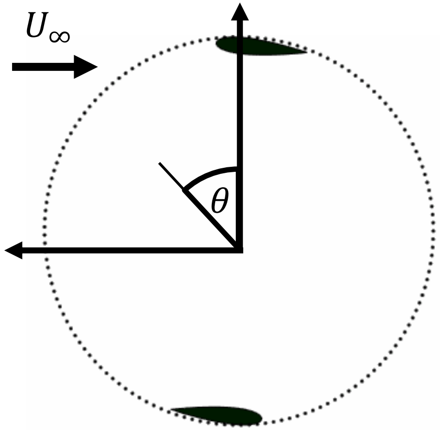
Oregon State University

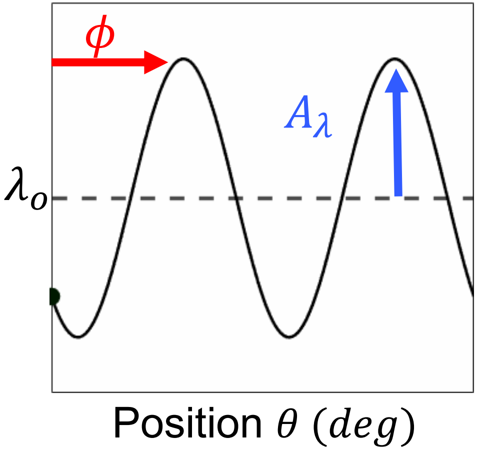
UNIVERSITY of WASHINGTON

Intracycle Velocity Control

$$\lambda_{control} = \lambda_o + A_\lambda \cos(n(\theta - \phi)), \quad \lambda_o = \frac{\omega_o D}{U_\infty}$$

- Strom et al., (2017) found 53% improvement in efficiency



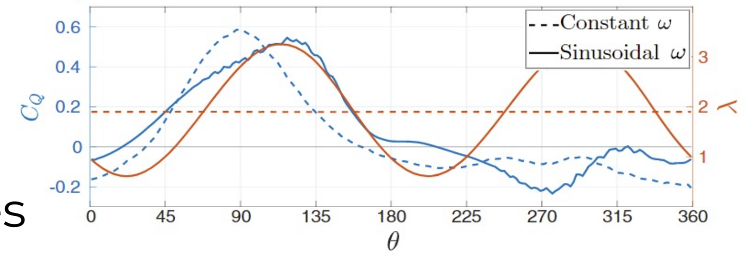


Strom, B., Brunton, S. L., & Polagye, B. (2017). *Nature Energy*.
Dave, M., Strom, B., Snortland, A., Williams, O., Polagye, B., & Franck, J. A. (2021). *AIAA Journal*.

Intracycle Velocity Control

$$\lambda_{control} = \lambda_o + A_\lambda\, cos(n(\,\theta - \phi))\,,\, \lambda_o = \frac{\omega_o\, D}{U_\infty}$$

- Strom et al., (2017) found 56% improvement in efficiency
- Max rotation rate aligned with fluid forces (Strom et al., 2017; Dave et al., 2021)



Adapted from Dave et al. (2021)

- Other combinations of A_λ & ϕ have not been explored

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Goals of this Project

- Lab-scale exploration of sensitivity of intracycle control performance space
- Explore loading and power tradeoffs of intracycle control
- Tie performance variation to hydrodynamic structures under off-nominal conditions

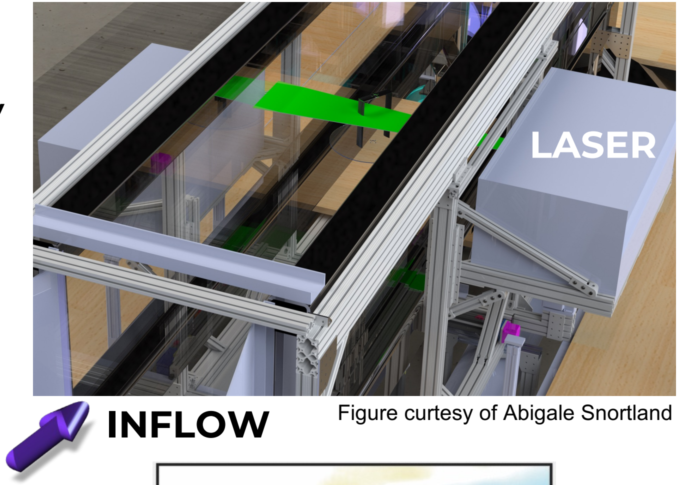
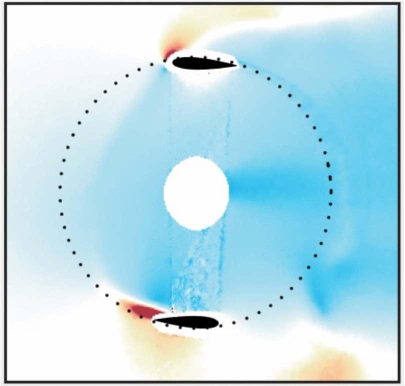
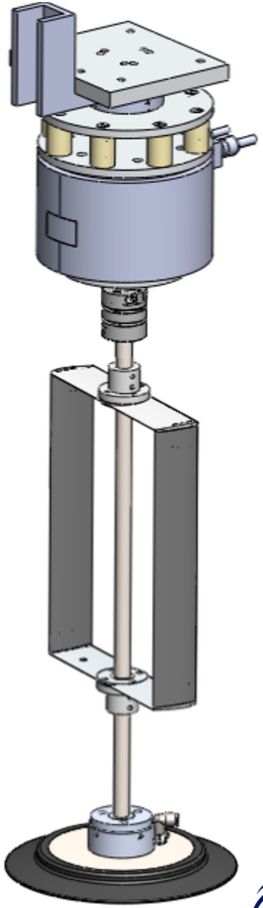


Figure curtesy of Abigale Snortland



Test Facility and Turbines

- University of Washington Alice C. Tyler Flume
- Temperature, depth and inflow velocity can be controlled
- 2-Bladed Turbine operating at a preset pitch angle of 6 deg with a NACA 0018 airfoils



Parameter Sweep

- Parameters
  - $\lambda_0 = 2$
  - ϕ(deg)= $[0 \;\; 180]$
  - A_λ(TSR)= $[0 \;\; 0.64\lambda_0]$
- Performance metrics of interest
  - Turbine efficiency
  - Average power to peak force ratio

Metrics:

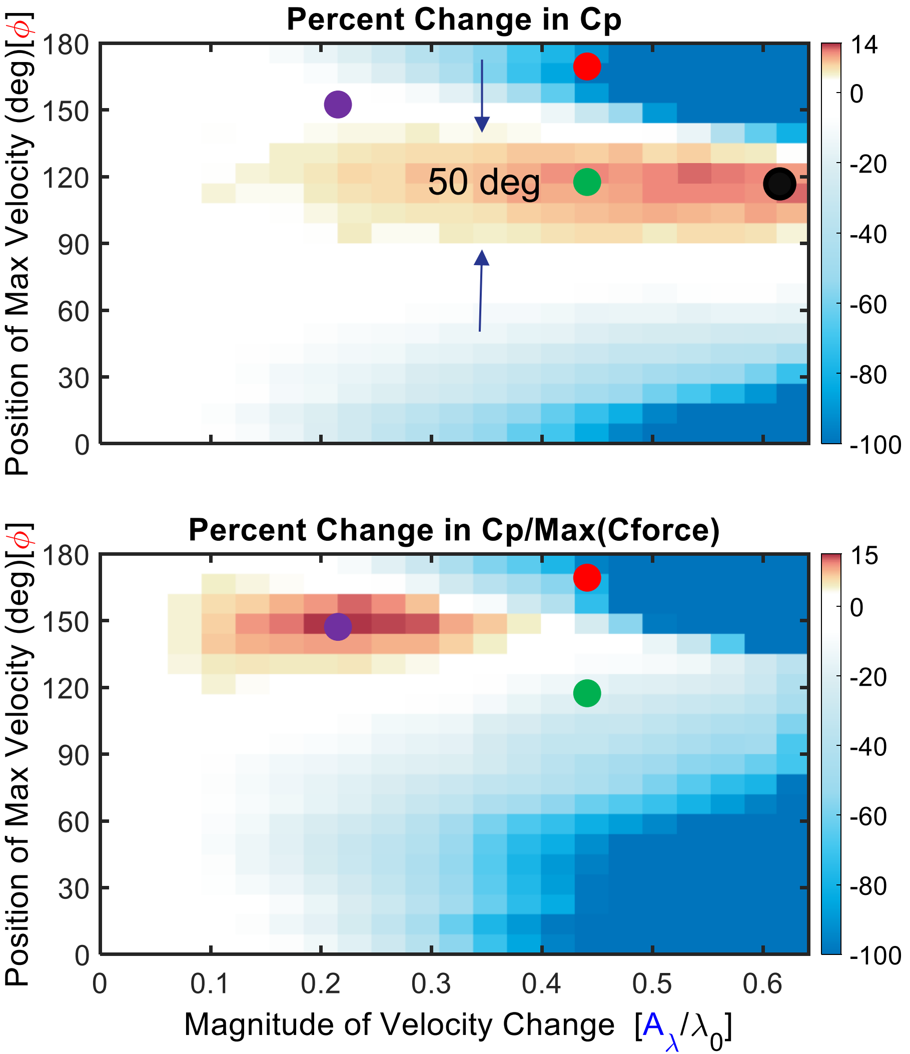
$$C_p = \frac{\tau\,\omega}{\frac{1}{2}\rho\, A\, U^3}$$

$$\frac{\overline{C_p}}{Max\left(C_{force}\right)} = \frac{\overline{\tau\omega}}{Max(F_{xy}) * U}$$

Performance Results

- Optimal C_p
- Sub Optimal C_p
- Optimal $\frac{\overline{C_p}}{\max(C_f)}$

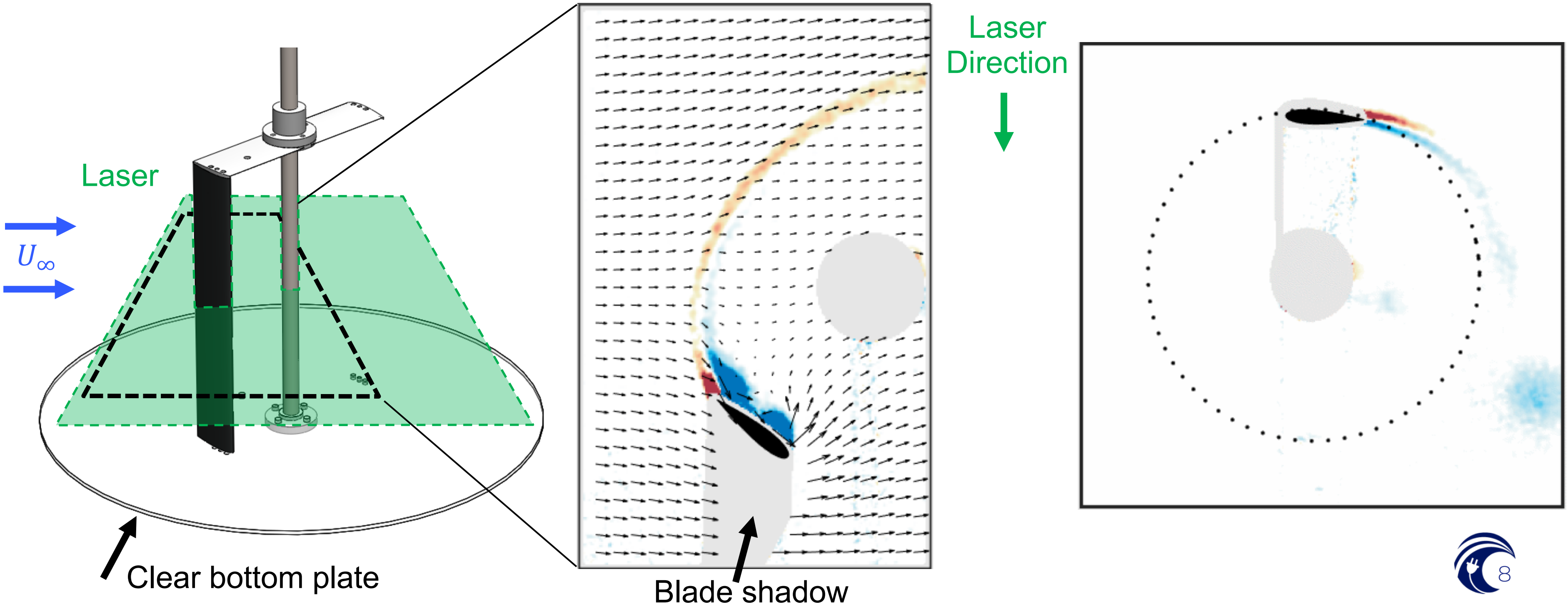
- Efficiency improved by 15%
- Optimal kinematics similar to Strom et al., (2017) and Dave et al., (2021)
- Maximum overturning loads can be reduced by 12% while still increasing performance by 3%



Hydrodynamic Mechanism of Improvement

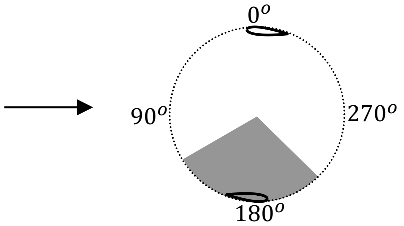
Particle Image Velocimetry (PIV)

- Nonintrusive capture of in rotor hydrodynamics



Near Blade Hydrodynamics

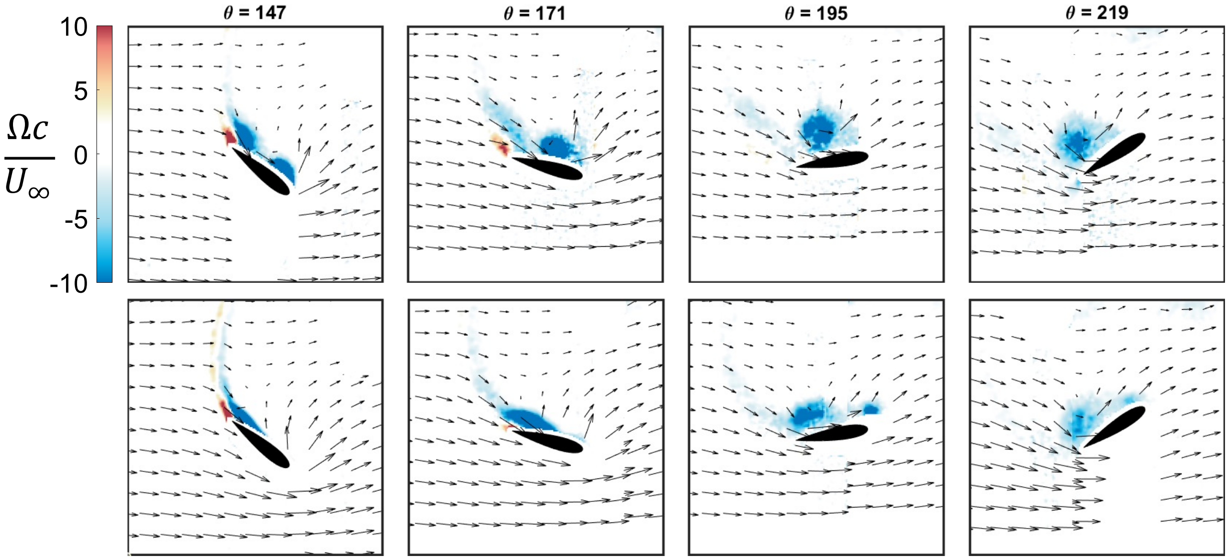
Single-bladed matching double-bladed kinematics



Constant speed

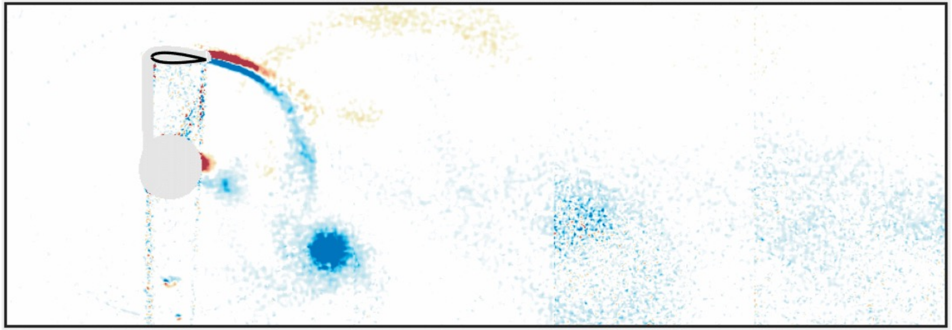
- Optimal Intracycle

- Sub-optimal Intracycle



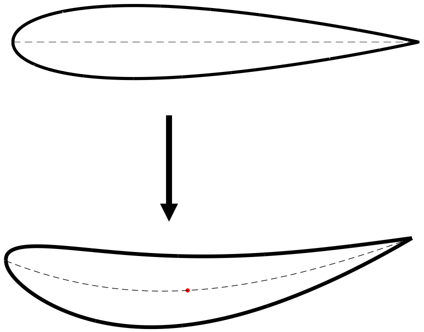
Conclusions

- Performance improved by 15% and improvement insensitive to local fluctuations in control
- Peak loading can be diminished by up to 12% with little to no loss of efficiency
- Delayed onset vortex formation and shedding is present in optimal performing control
- These datasets will be utilized by Jennifer Franck and her team at U. Wisconsin for validation of RANS simulations under varied kinematics



Future work

- Analyze more subtle hydrodynamics present in optimal Cp/max(Cf)
- Exploration of the influence of blade geometry (camber) on the generality of intracycle control benefits and sensitivities (TEAMER)
- Study utility of intracycle control to shed peak or average loading to reduce overturning probability (NAVFAC)



Questions?

2 Bladed Results