Experimental evaluation of advanced control strategies for high-blockage cross-flow turbine arrays

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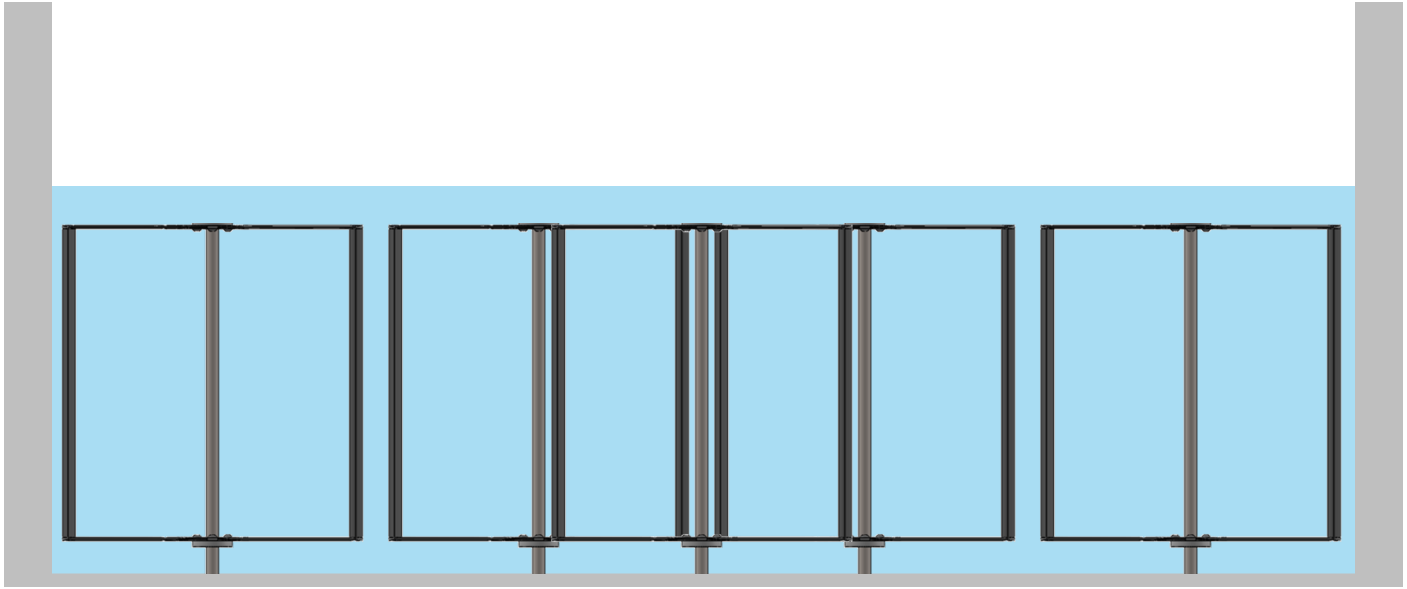
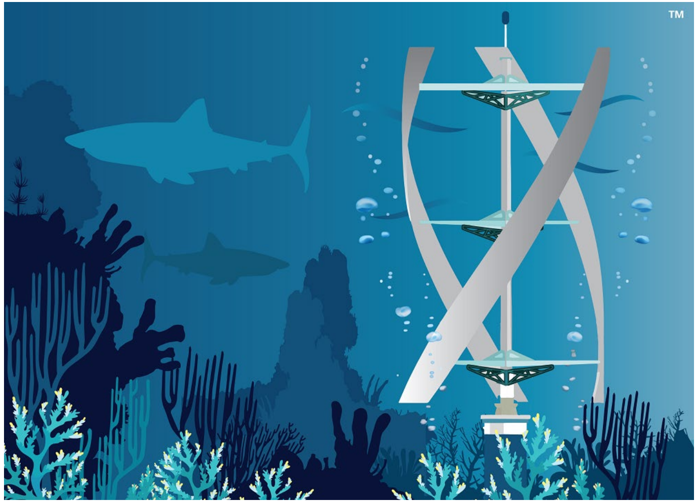
High -Blockage Arrays



- Blockage increases power and thrust
- Cross-flow turbines well suited to achieving high blockage
- Blockage in real channels can vary

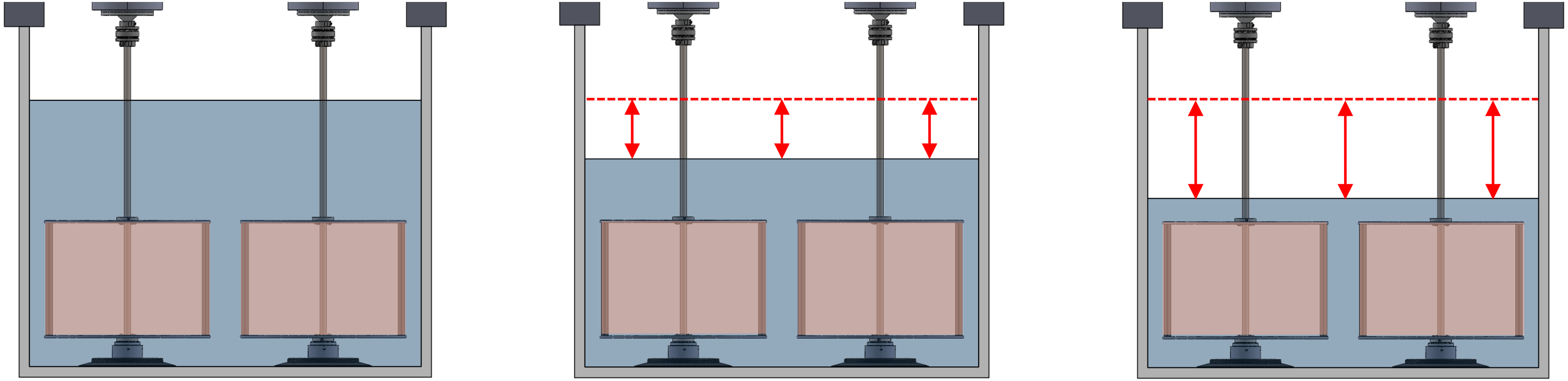
Confinement Exploiting Cross-Flow Turbine Arrays



Evaluation of Analytical Models: Hunt, Athair, Williams, Polagye, *Physical Review Fluids* (Forthcoming).
Geometry optimization: Hunt, Talpey, Calandra, Polagye, *Journal of Renewable and Sustainable Energy* (2025).

Varying the blockage

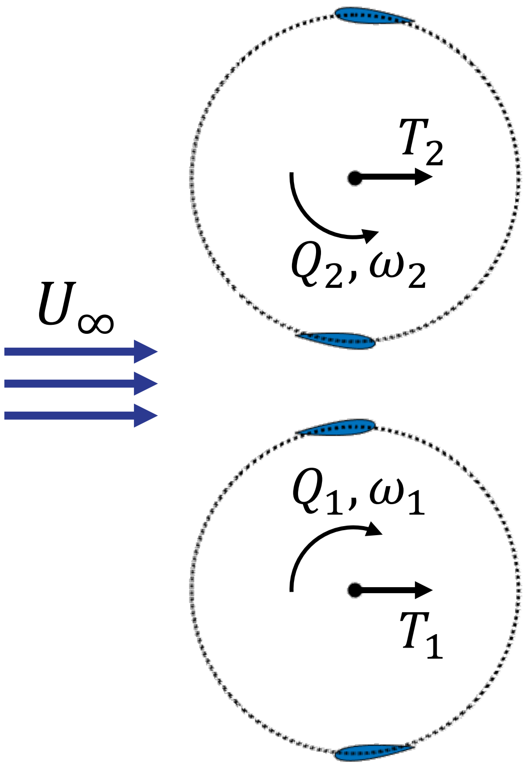
$$\beta = \frac{A_{turbines}}{A_{channel}}$$



$\beta = 35\%$ $\beta = 45\%$ $\beta = 55\%$

For all experiments: $Re_D = 1.7 \times 10^5, Fr_h = 0.219.$

Array Performance Metrics



Efficiency

$$C_{P,\text{array}} = \frac{Q_1\omega_1 + Q_2\omega_2}{\frac{1}{2}\rho U_\infty^3 A_{\text{turbines}}}$$

Kinetic energy only

Forcing

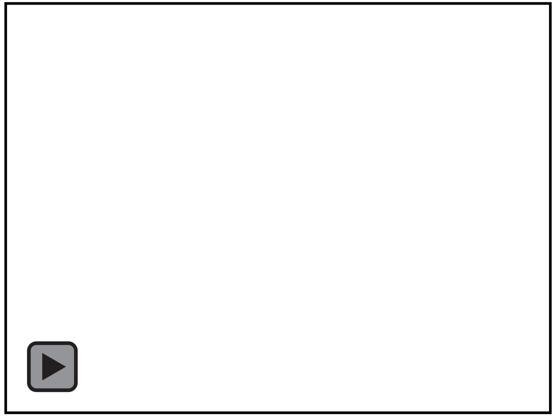
$$C_{T,\text{array}} = \frac{T_1 + T_2}{\frac{1}{2}\rho U_\infty^2 A_{\text{turbines}}}$$

Relative Speed

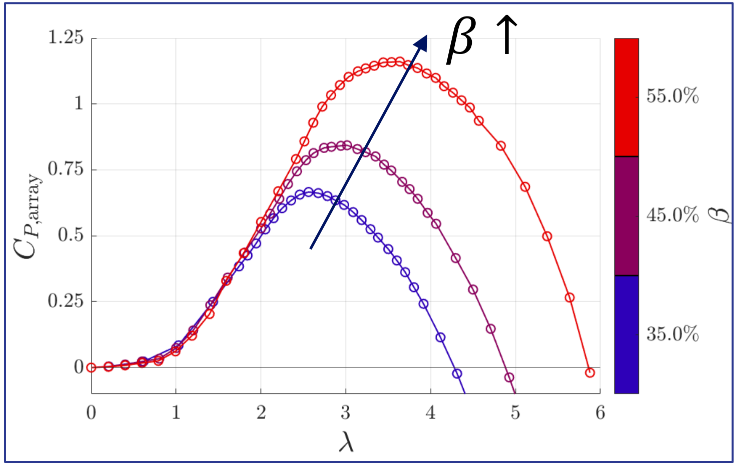
$$\lambda = \frac{\omega R}{U_\infty}$$

ω: Angular velocity
Q: Torque
T: Thrust force
ρ: Density
R: Turbine radius

Advanced Control Strategies



Array efficiency increases significantly with blockage



Can we further enhance array performance via different control strategies?

Constant speed control with different phase offsets

Benefits to arrays observed at lower blockage:

Scherl et al., *JRSE* (2020)
Scherl at al., Under Review at *Flow*

Intracycle speed control with fixed phase offset

Benefits to single turbines observed at lower blockage:

Strom *et al., Nature Energy* (2016)
Athair et al., *EWTEC Proceedings* (2023)

Constant Speed Control with Different $\Delta\theta$

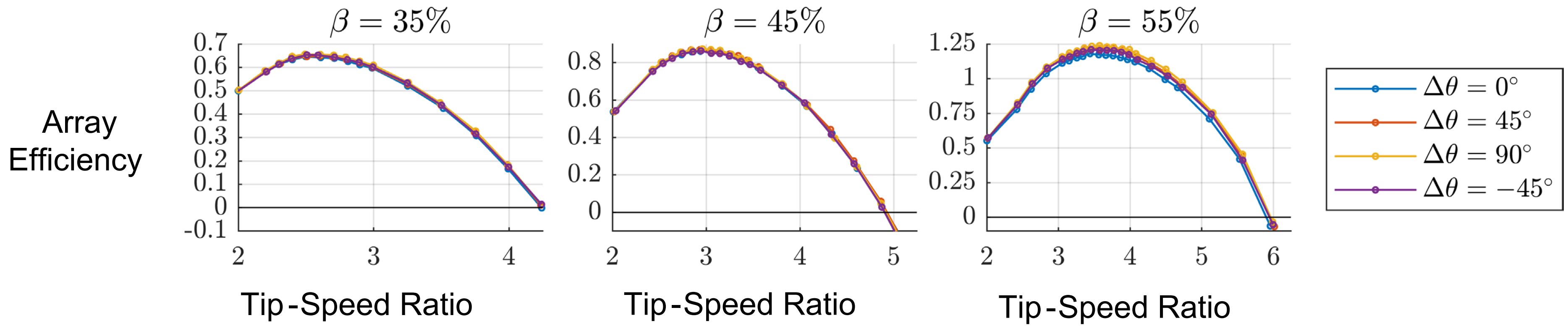
- Turbines rotate at same, constant speed
- Constant phase offset ($\Delta\theta$) between rotational cycles

$\Delta\theta = 0°$

$\Delta\theta = 90°$

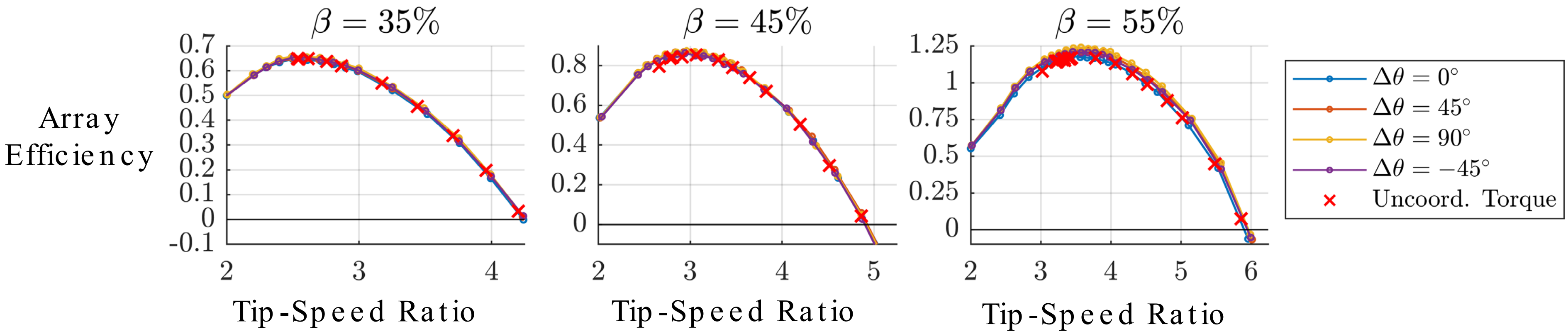
Scherl at al., Under Review at *Flow*

Coordinated Constant Speed Control



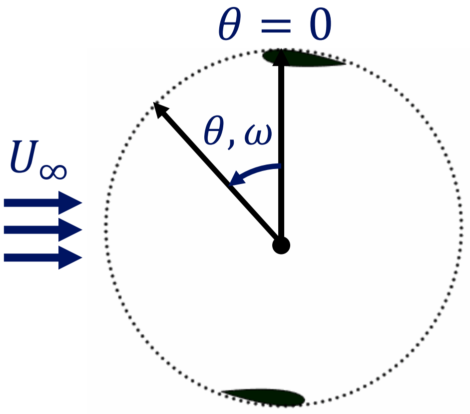
- Relative to effect of blockage, influence of $\Delta\theta$ is minor.
- Suggests limited benefit to coordination for this array.

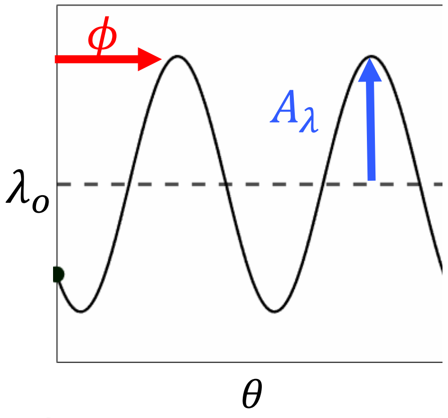
Comparison to Uncoordinated Torque Control



- Comparable performance obtained without coordination.
- Turbines self-synchronize around $\Delta\theta \approx 0°$

Coordinated Intracycle Velocity Control





Animation credit: Ari Athair

Rotation rate varies throughout cycle as a function of azimuthal position:

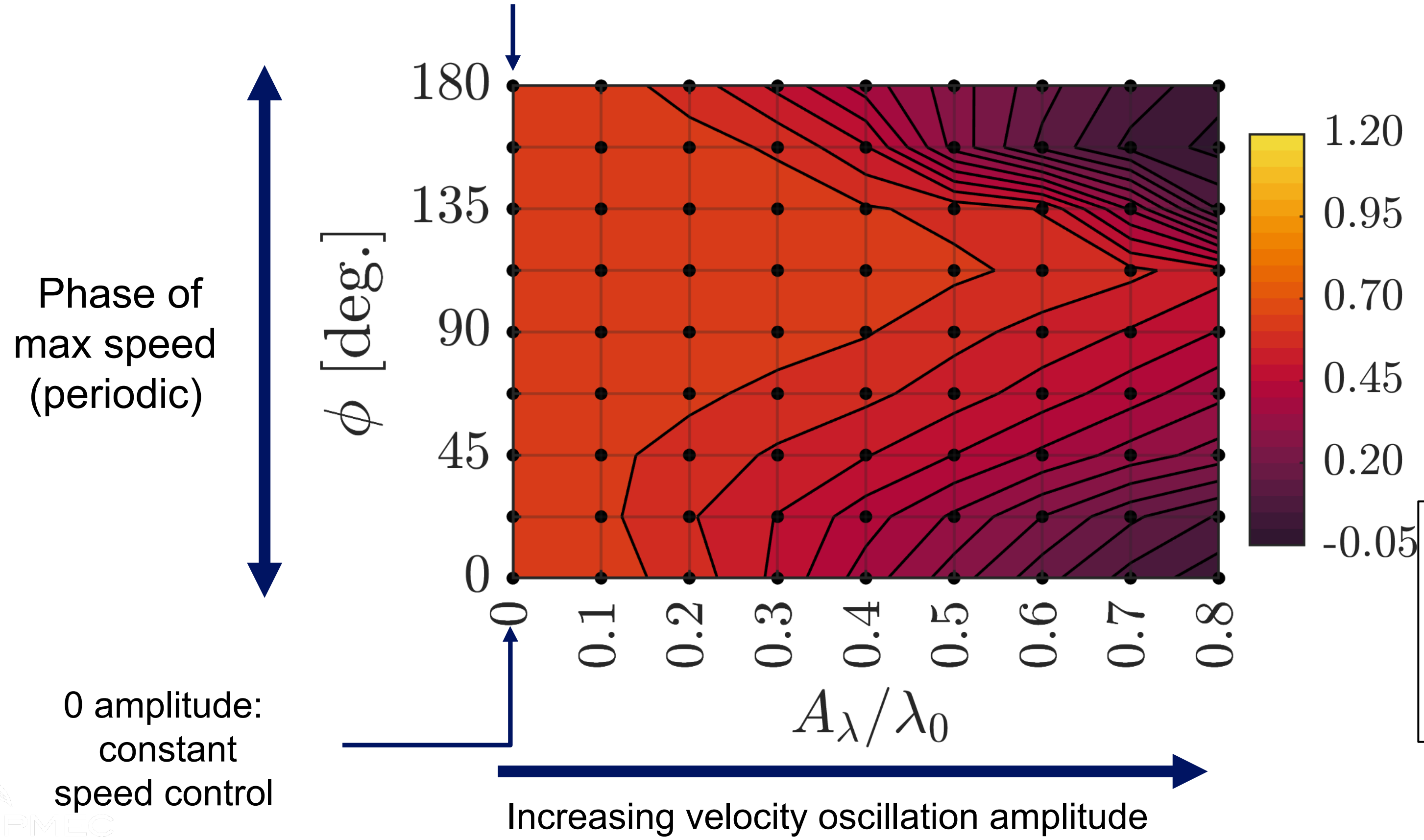
$$\lambda(\theta) = \lambda_o + A_\lambda \cos(N(\theta - \phi))$$

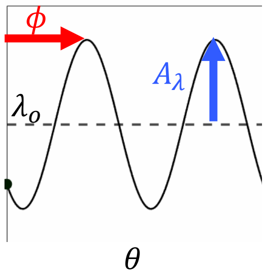
Where:
λ_o: Phase-average tip-speed ratio
A_λ: Tip-speed ratio amplitude
ϕ: Phase of maximum speed
N: Number of blades

For these experiments:

- $\Delta\theta = 0°$
- Both turbines follow the same waveform

Visualizing intracycle waveforms at a given β and λ_0



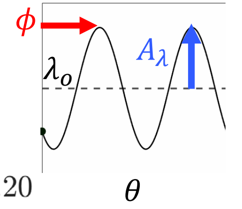


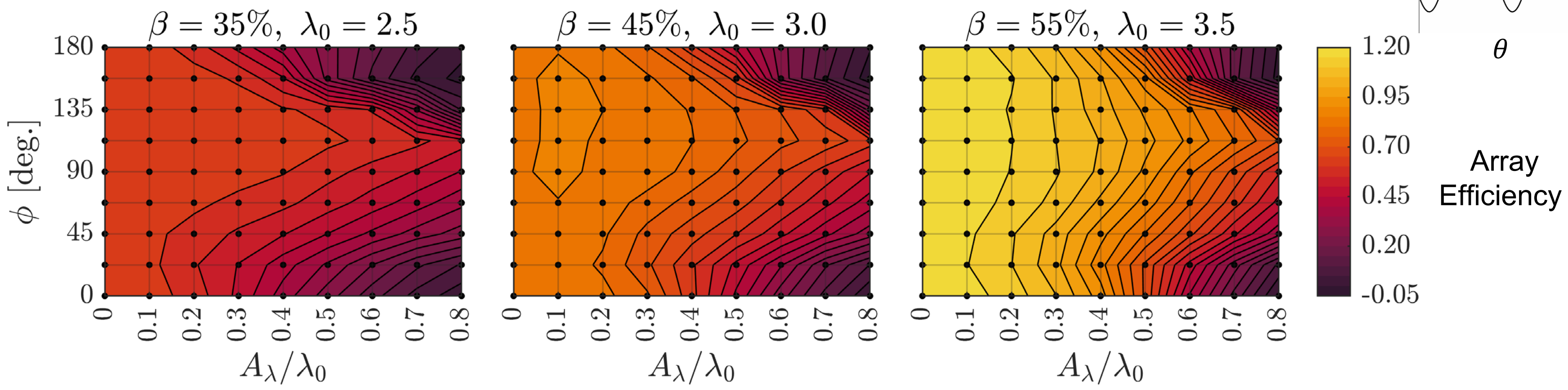
Animation credit: Ari Athair

Dots indicate tested waveforms

Contours indicate array performance

Intracycle Control Results

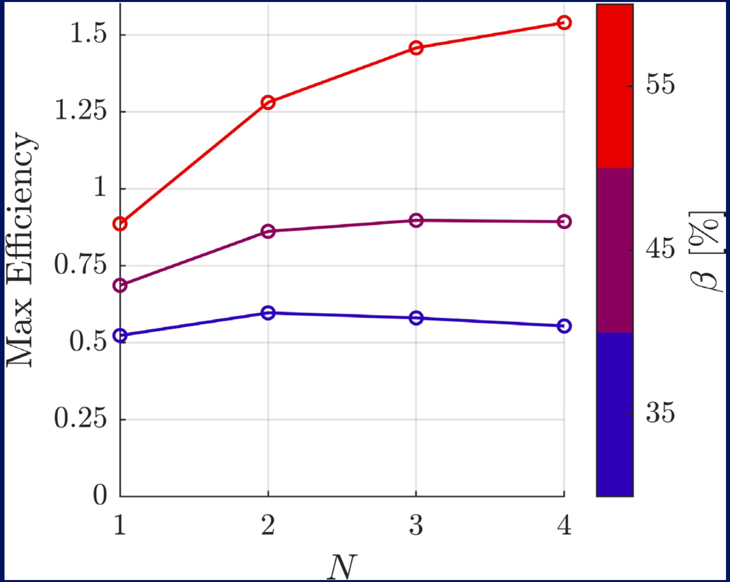




- Little -to -no efficiency benefit from intracycle control
- Intracycle control reduces array interaction with channel.

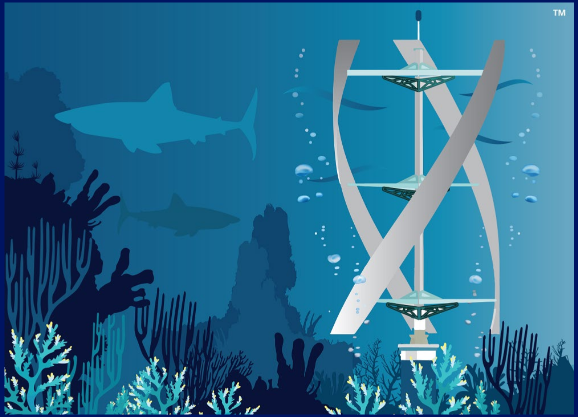
Conclusions

- For this array, limited benefit to advanced control strategies
  - Turbine-channel interactions are strongest influence on high-blockage arrays
  - Changing phase offset between turbines has little effect on these dynamics
  - Intracycle control can undermine these dynamics
- Conversely, optimizing performance via rotor geometry is simpler and more effective



Hunt *et al.* "Performance characteristics and bluff-body modelling of high-blockage cross-flow turbine arrays with varying rotor geometry", *JRSE* (2025)

Acknowledgments



Gregory Talpey

Dr. Brian Polagye

What to see more? Open access on arXiv:

Control: Hunt *et al.*, "Experimental evaluation of advanced control strategies for high-blockage cross-flow turbine arrays", *UMERC+OREC* (2025)

Geometry: Hunt *et al.* "Performance characteristics and bluff-body modelling of high-blockage cross-flow turbine arrays with varying rotor geometry", *Journal of Renewable and Sustainable Energy* (2025)

Analytical Models: Hunt *et al.* "Experimental validation of a linear momentum and bluff body model for high-blockage cross-flow turbine arrays", *Physical Review Fluids* (Forthcoming)