UNIVERSITY OF WISCONSIN-MADISON
DEPARTMENT OF ENGINEERING PHYSICS

Simulations of Dual Cross-Flow Turbines under High Confinement

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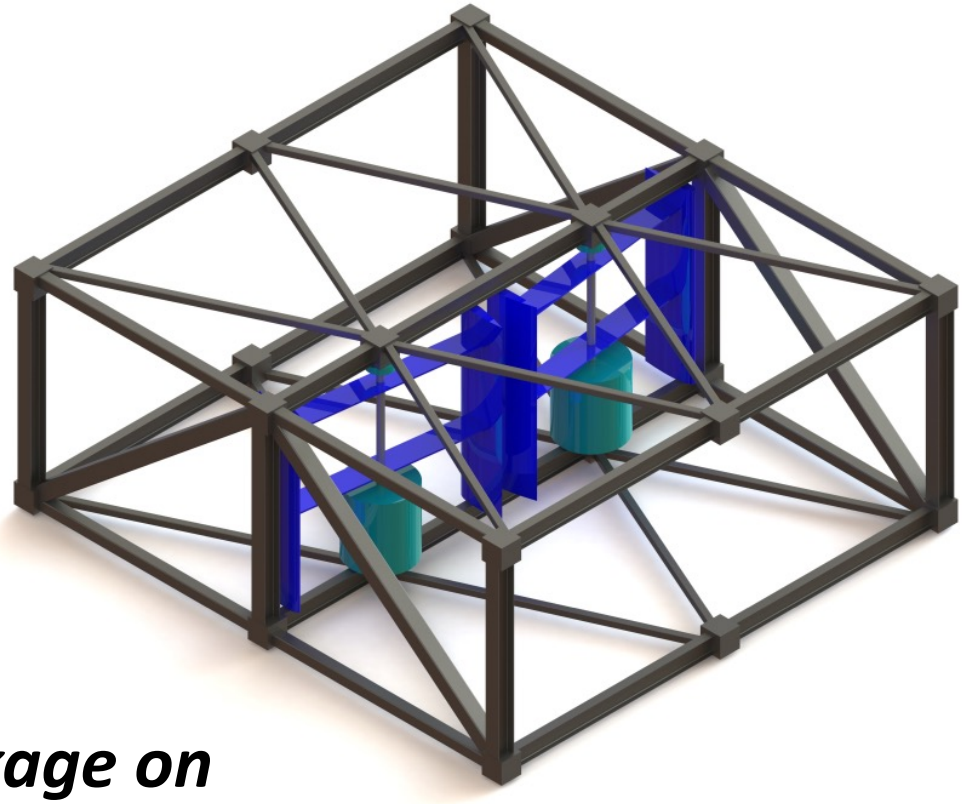
Jennifer Franck, Assist. Professor

Mukul Dave, PhD Student

Motivation

- ***ARPA-E SHARKS Project:*** use high confinement within cross-flow turbine arrays to lower LCOE

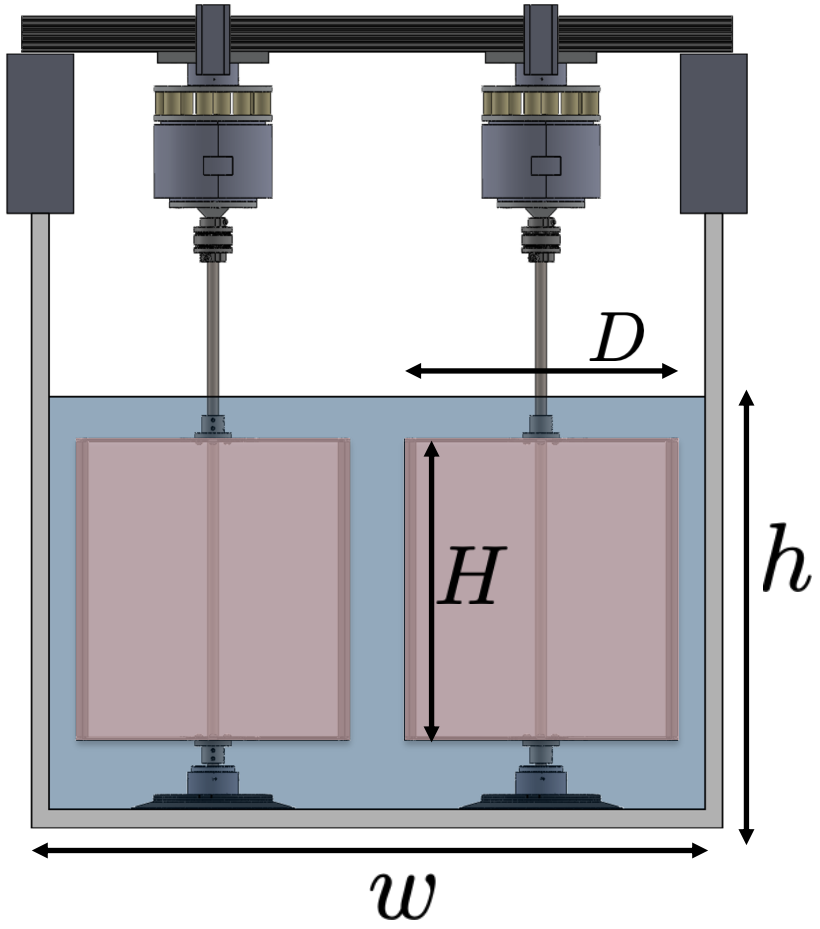
  (UW, UW-Madison, NREL, Oberon)
- Confined flow increases power, but also forces: competing factors in LCOE
- Model system: counter-rotating cross-flow turbine pair



Simulations of the turbine pair, effects of blockage on performance & hydrodynamics

Blockage model for 2D simulations

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



$$\beta_H = H/h = 72\%$$
$$\beta_W = 2D/W = 83\%$$
$$\beta = \beta_W \beta_H = 60\%$$

Blockage model for 2D simulations

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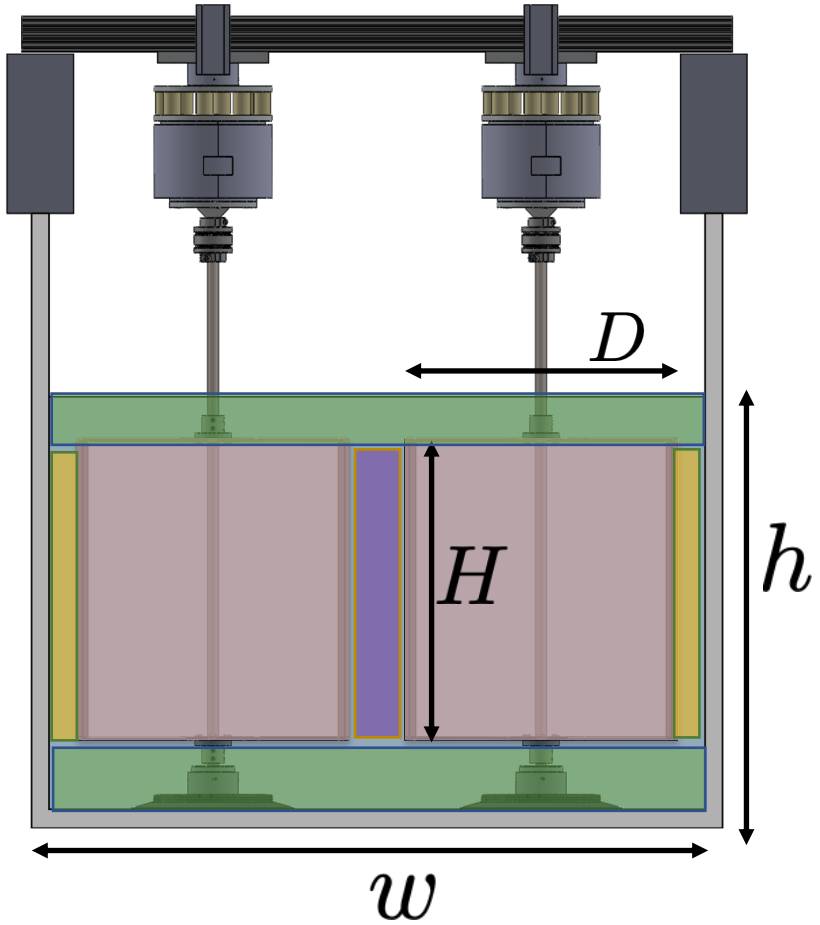

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Flow is diverted through

a) top/bottom (green)

b) sides (yellow)

c) middle (purple)

Blockage model for 2D simulations

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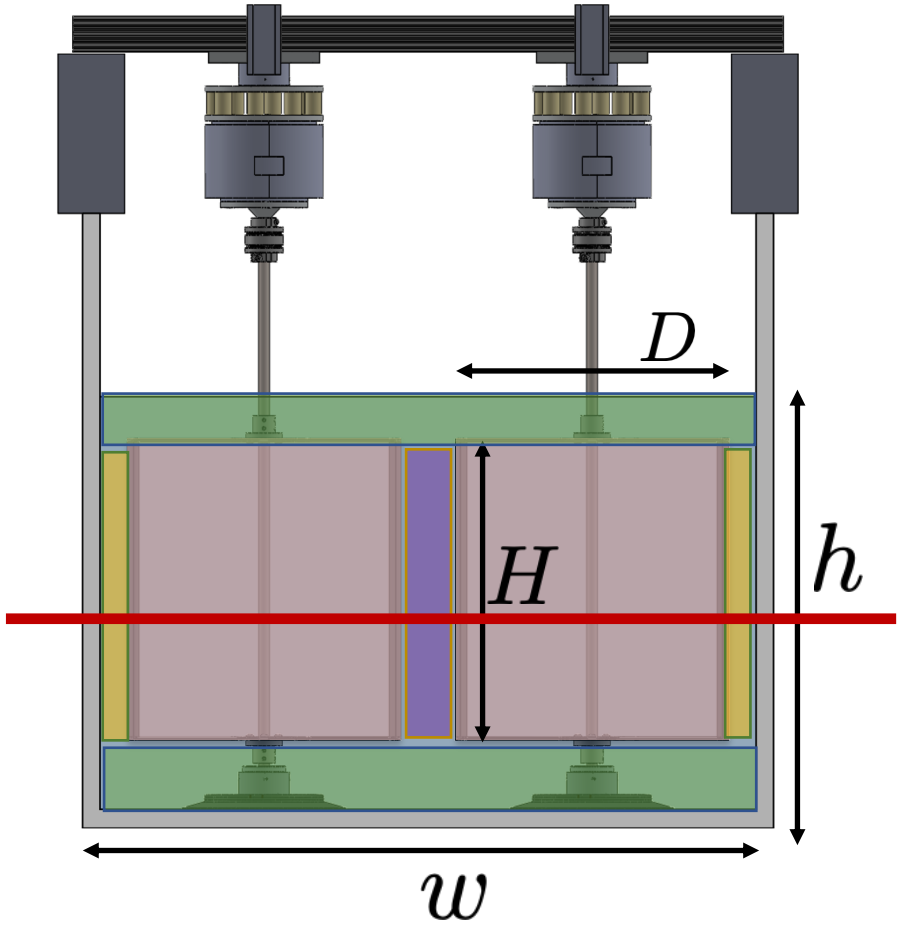


~~$\beta_H = H/h = 72\%$~~

$\beta_W = 2D/W = 83\%$

~~$\beta = \beta_W \beta_H = 60\%$~~

Flow is diverted through

~~*a) top/bottom (green)*~~

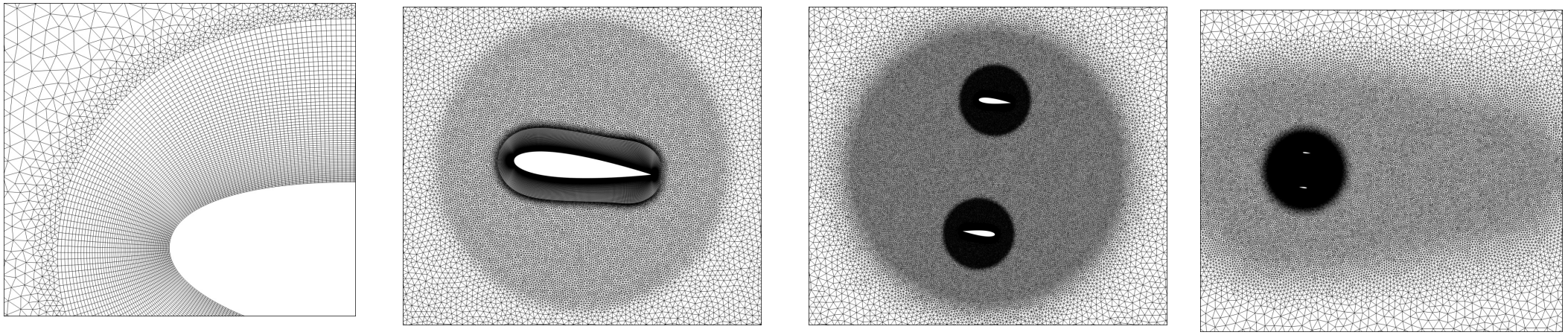
b) sides (yellow) ← modify wall-turbine gap to reduce wall by-pass velocity

c) middle (purple)

Computational method

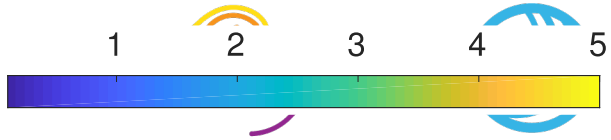
- 2D RANS with k-ω SST turbulence model
- NACA 0018 blade, 2-bladed turbine, Re=45,000
- Validated against experiments with single turbine, low blockage

(*Dave et al., 2021)*



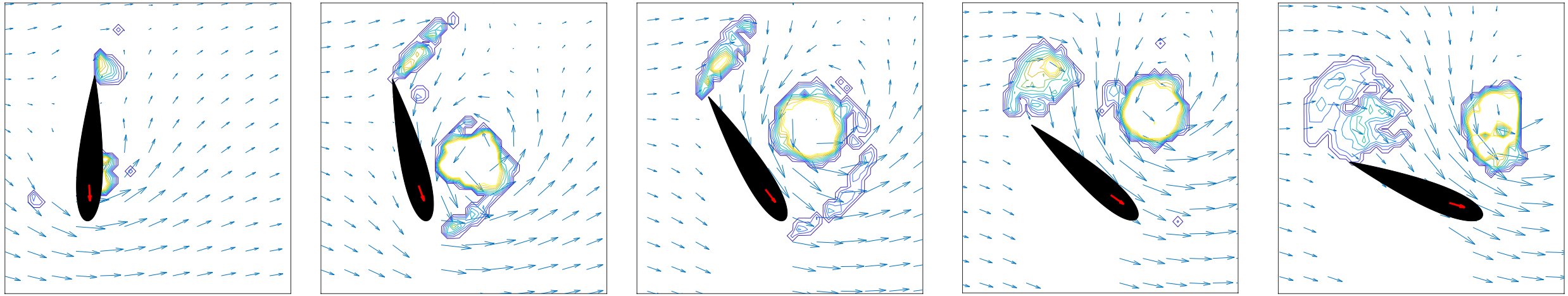
Validation: single turbine

swirl strength $\frac{Sc}{U_\infty}$

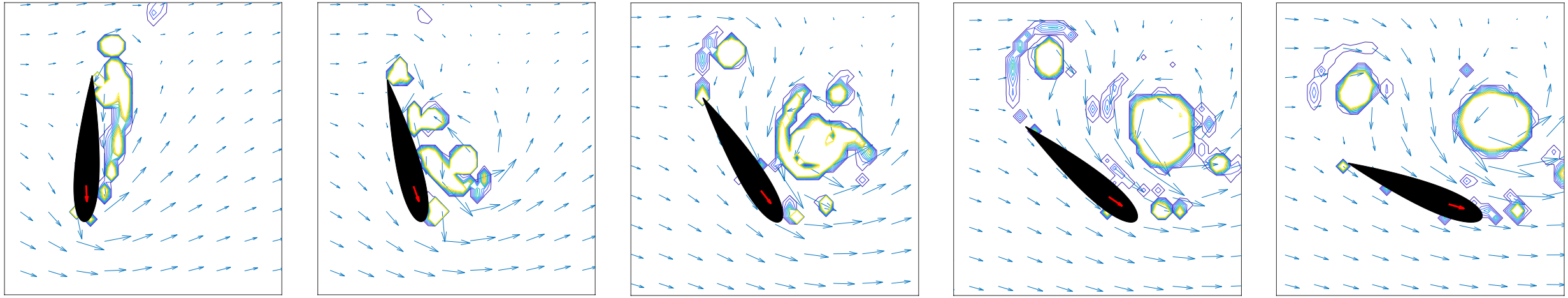


$\lambda = 1.1$

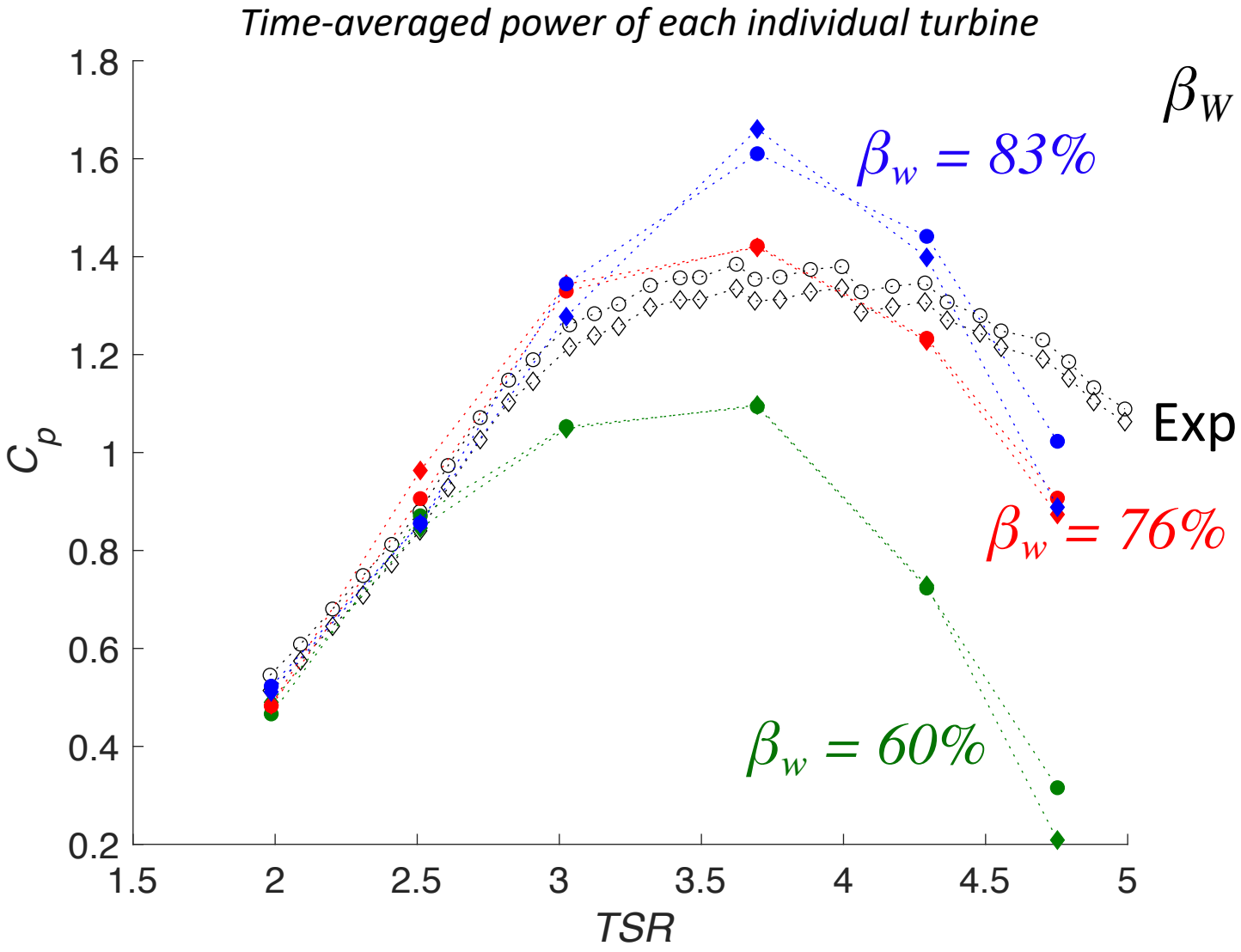
PIV

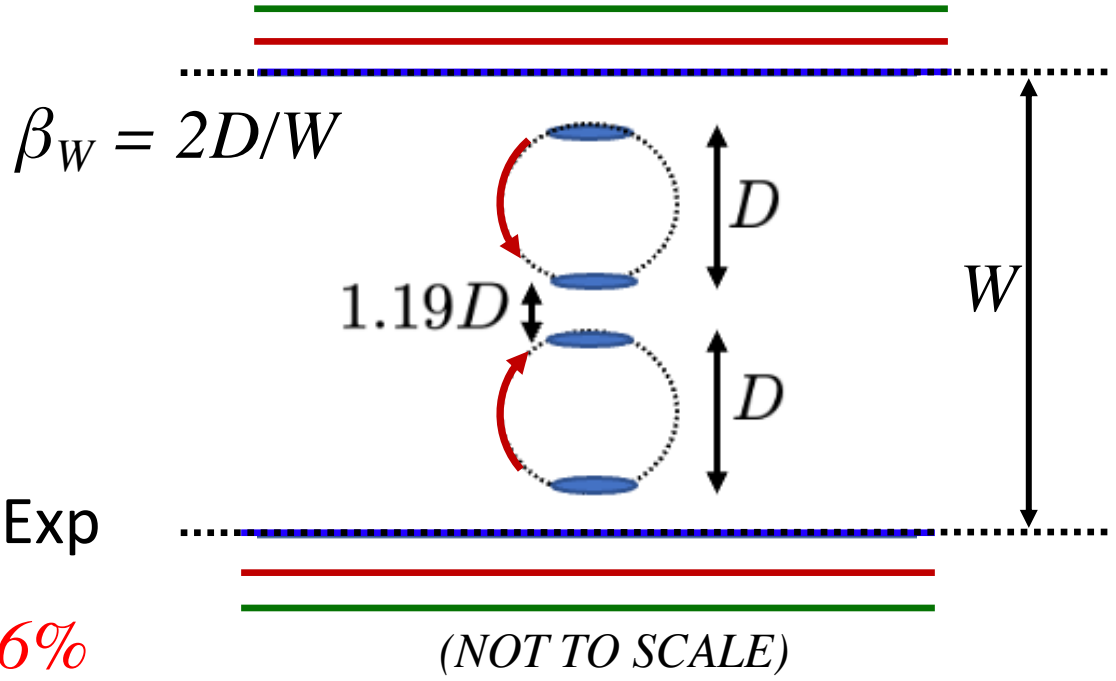


RANS



Two-turbine: comparison to experimental data

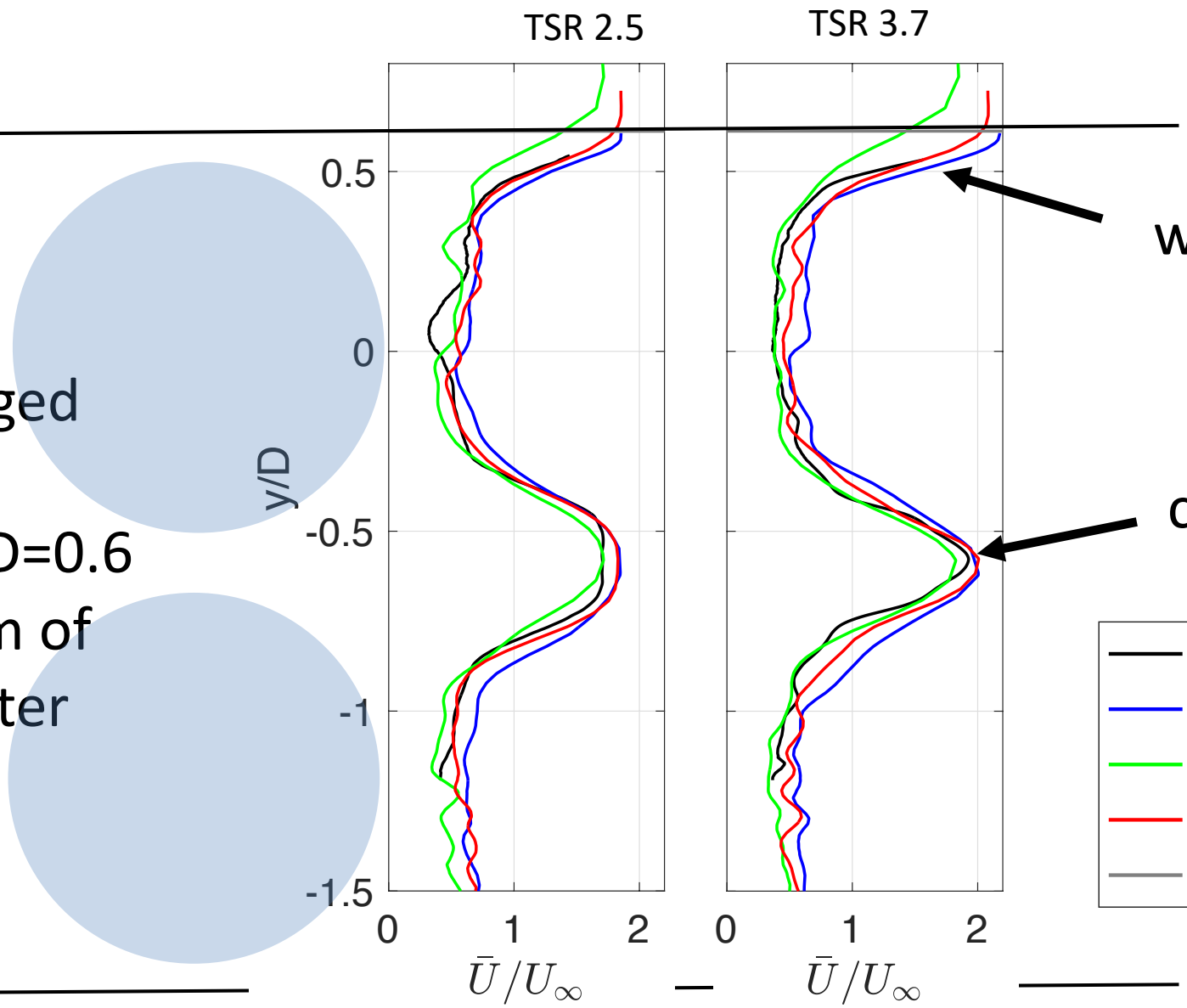




- Free surface deformation at high TSR modify experimental blockage

Comparison of mean velocity fields

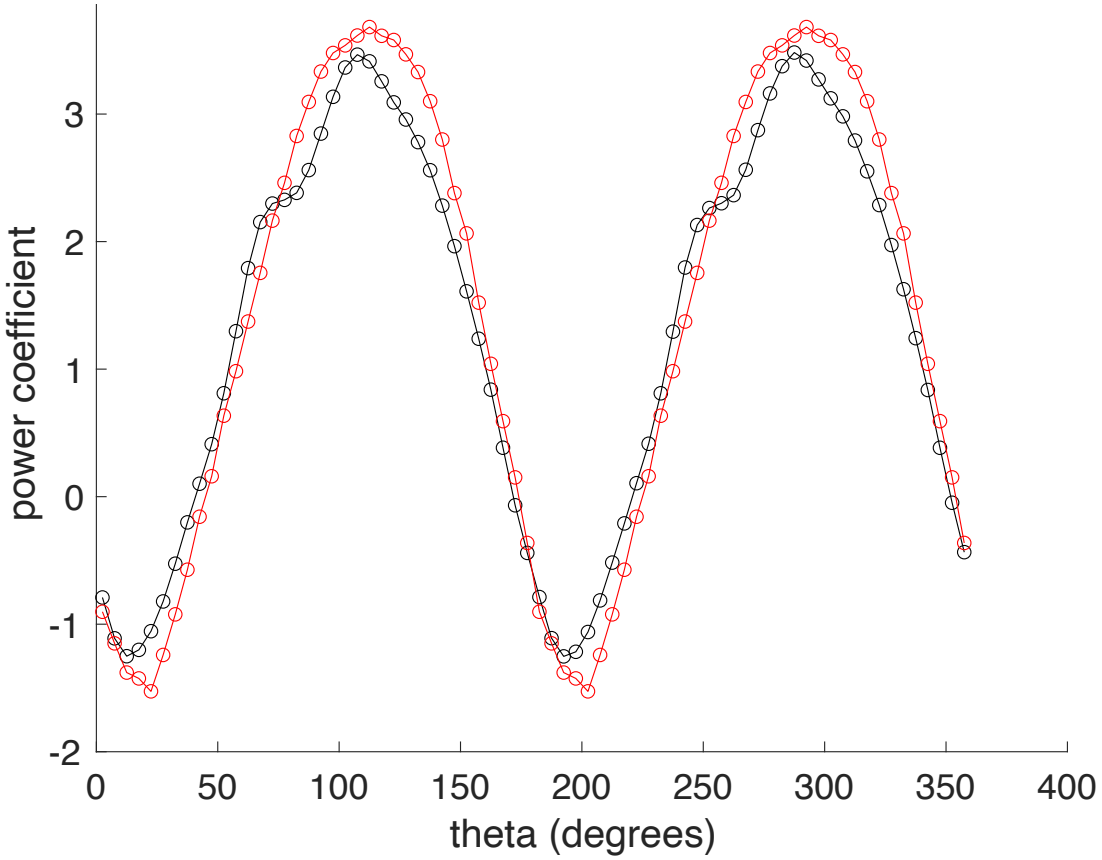
Time-averaged streamwise velocity; x/D=0.6 downstream of turbine center

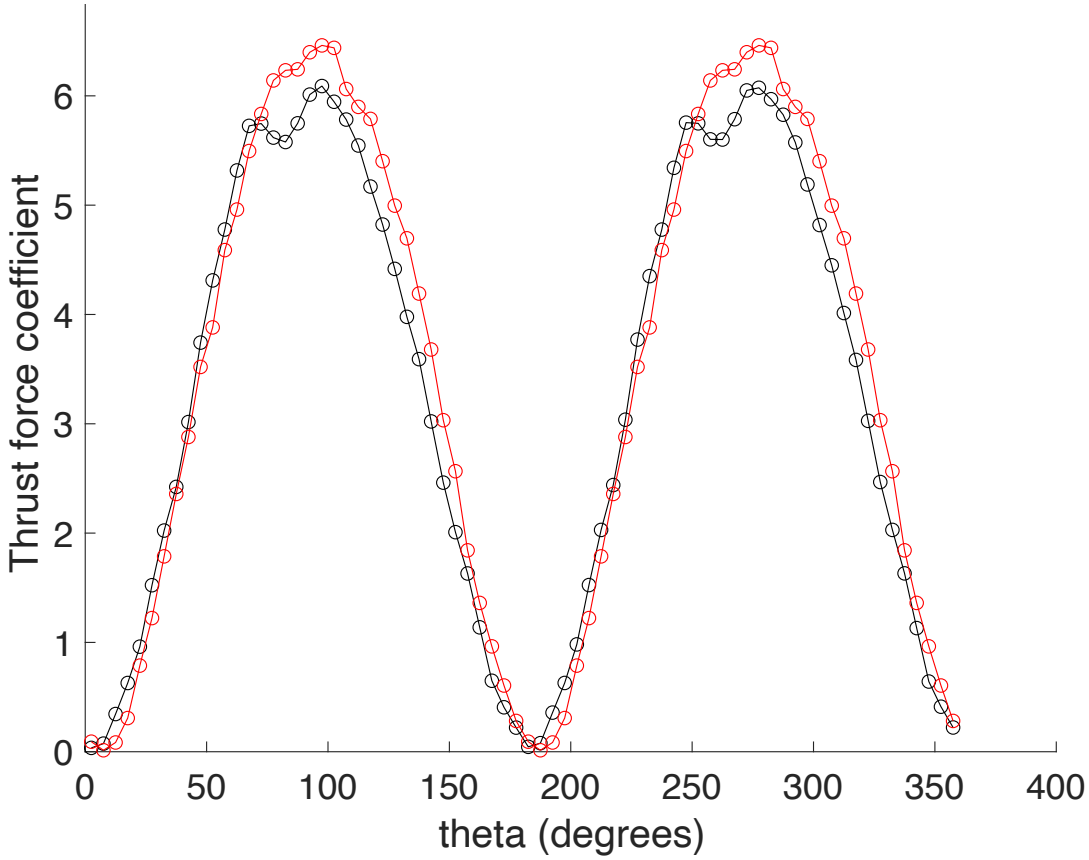


Comparison with experiments at peak TSR=3.7

Experiments at β = 60%

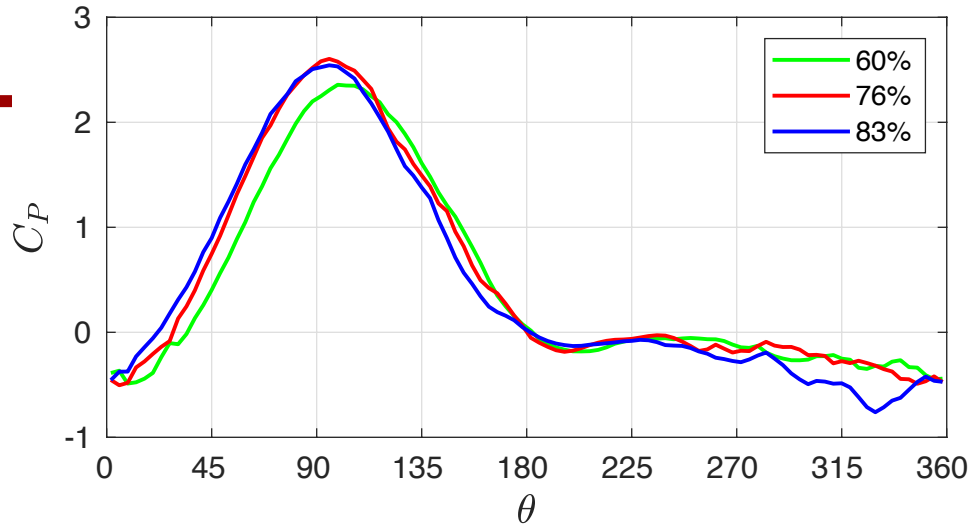
2D Simulations at β_w = 76%

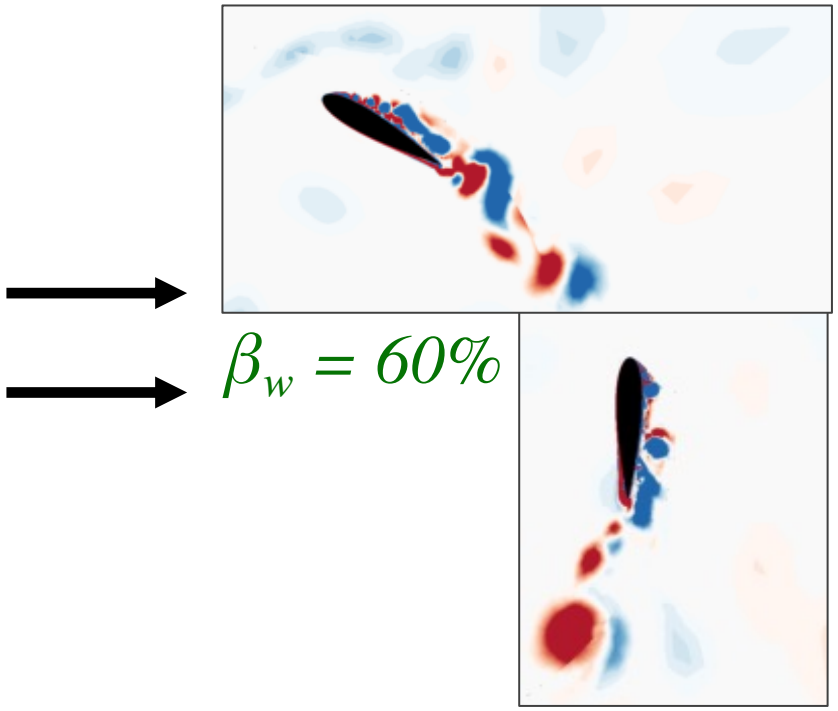




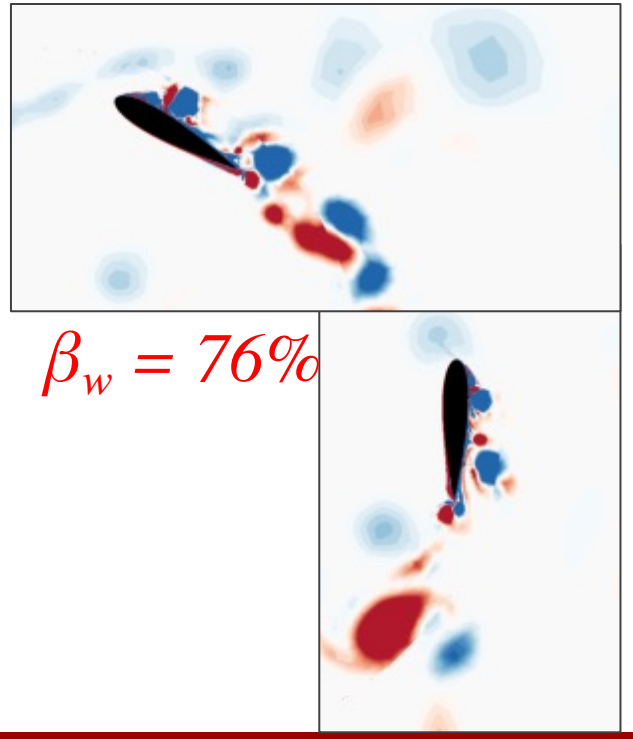
Trends in flow field

TSR=2.5
(sub-optimal)

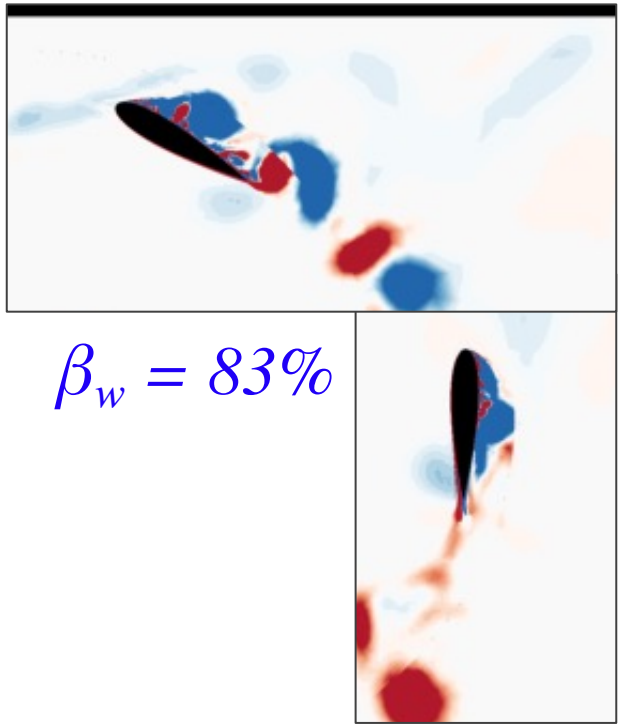




$\beta_w = 60\%$



$\beta_w = 76\%$



$\beta_w = 83\%$

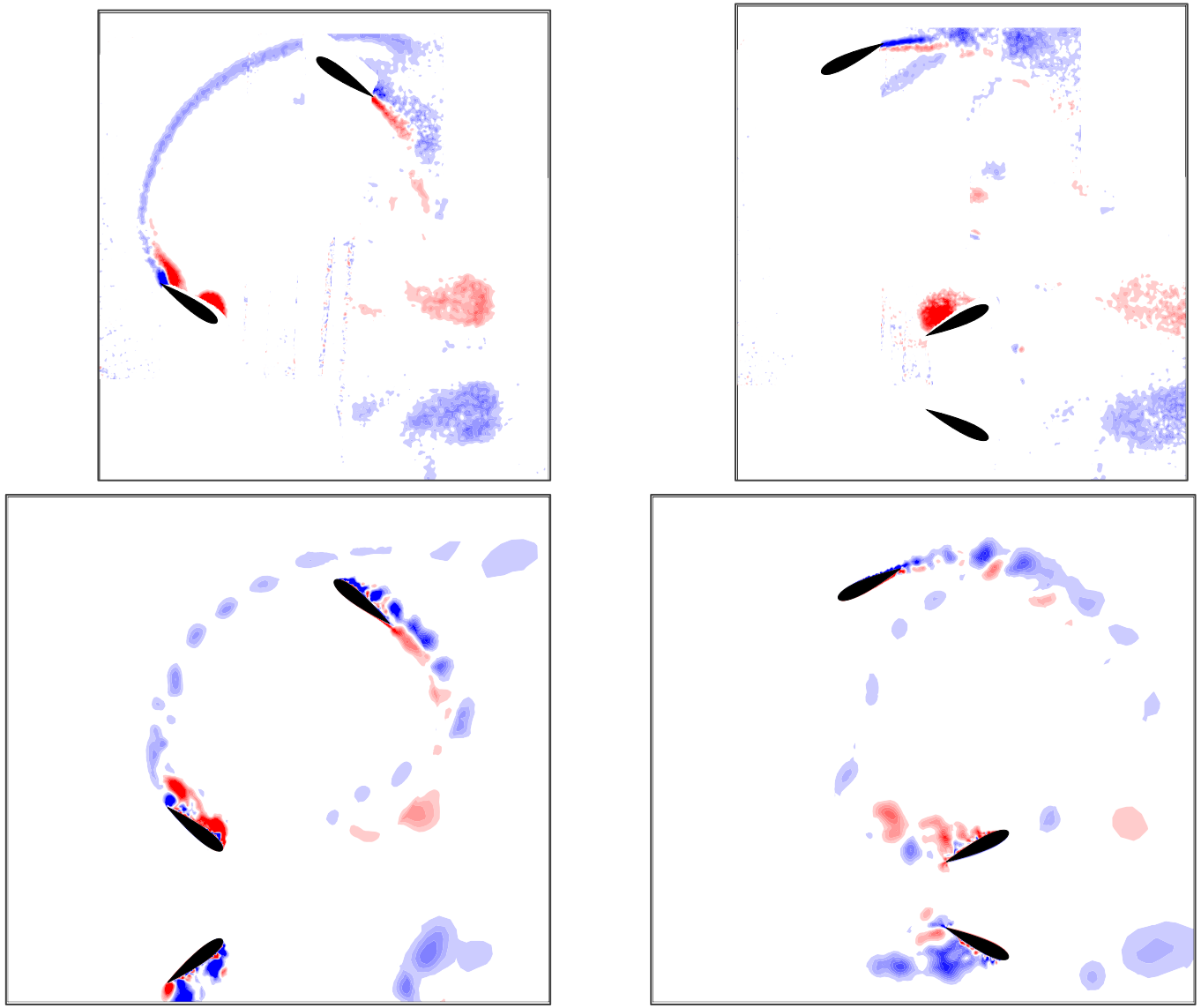
TSR=2.5 comparison with *PIV*

PIV

$\beta = 60\%$

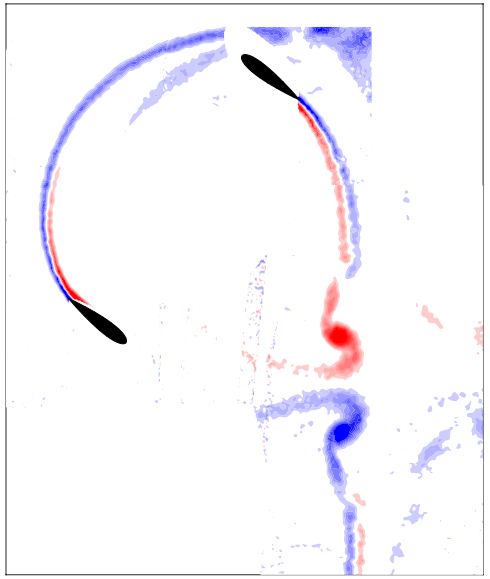
RANS

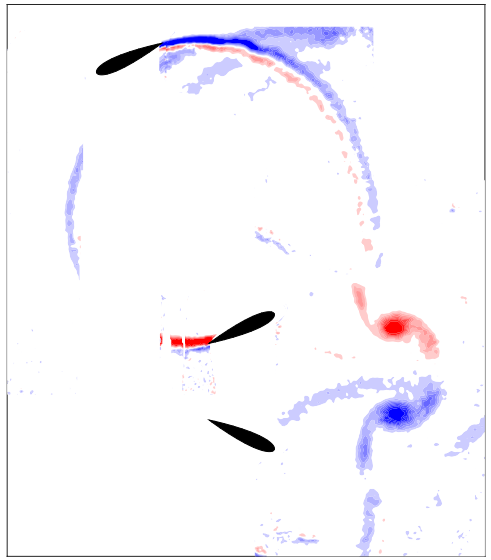
$\beta_w = 76\%$



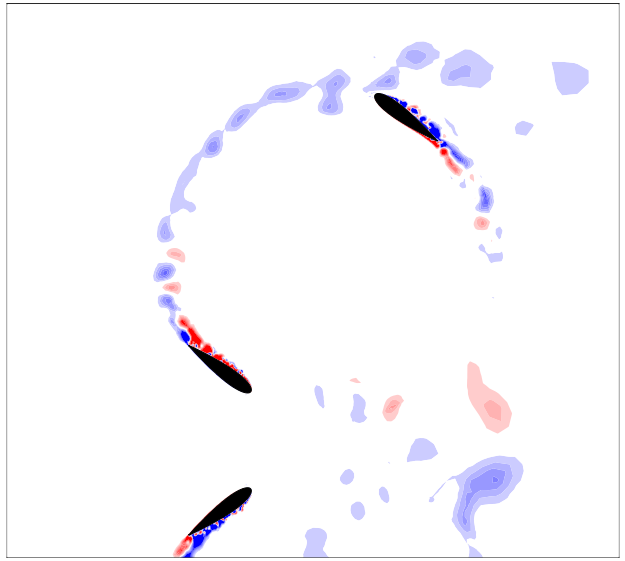
TSR=3.7 comparison with *PIV*

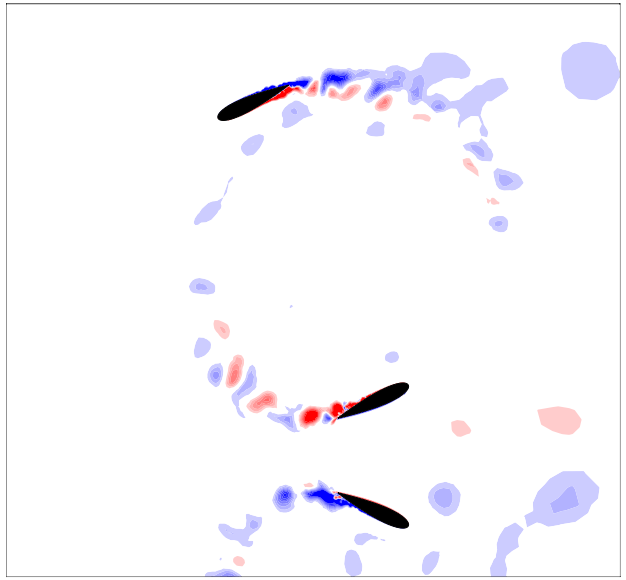
PIV
$\beta = 60\%$





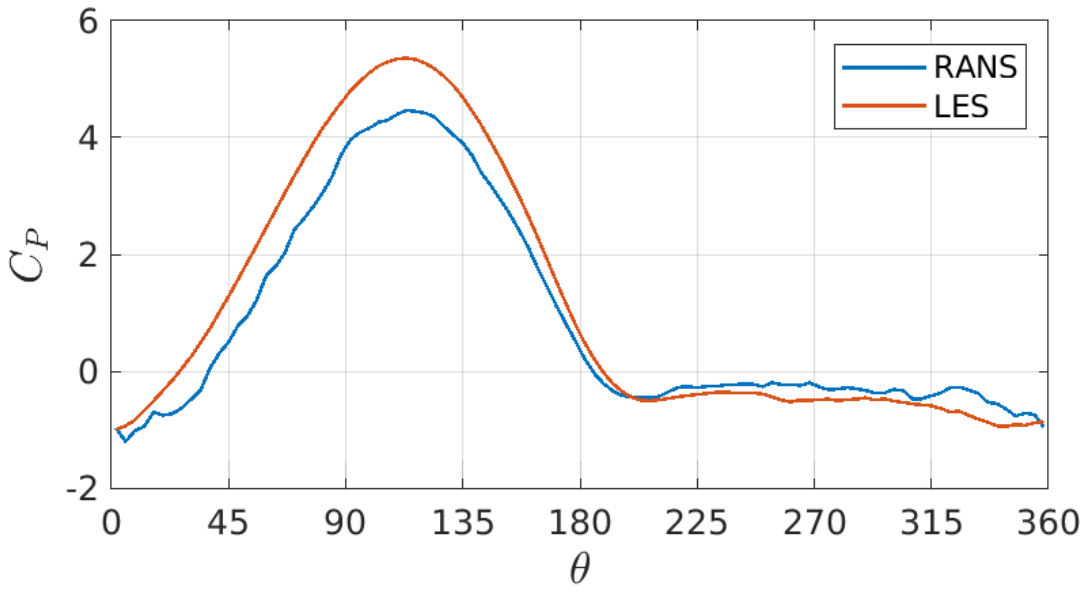
RANS
$\beta_w = 76\%$

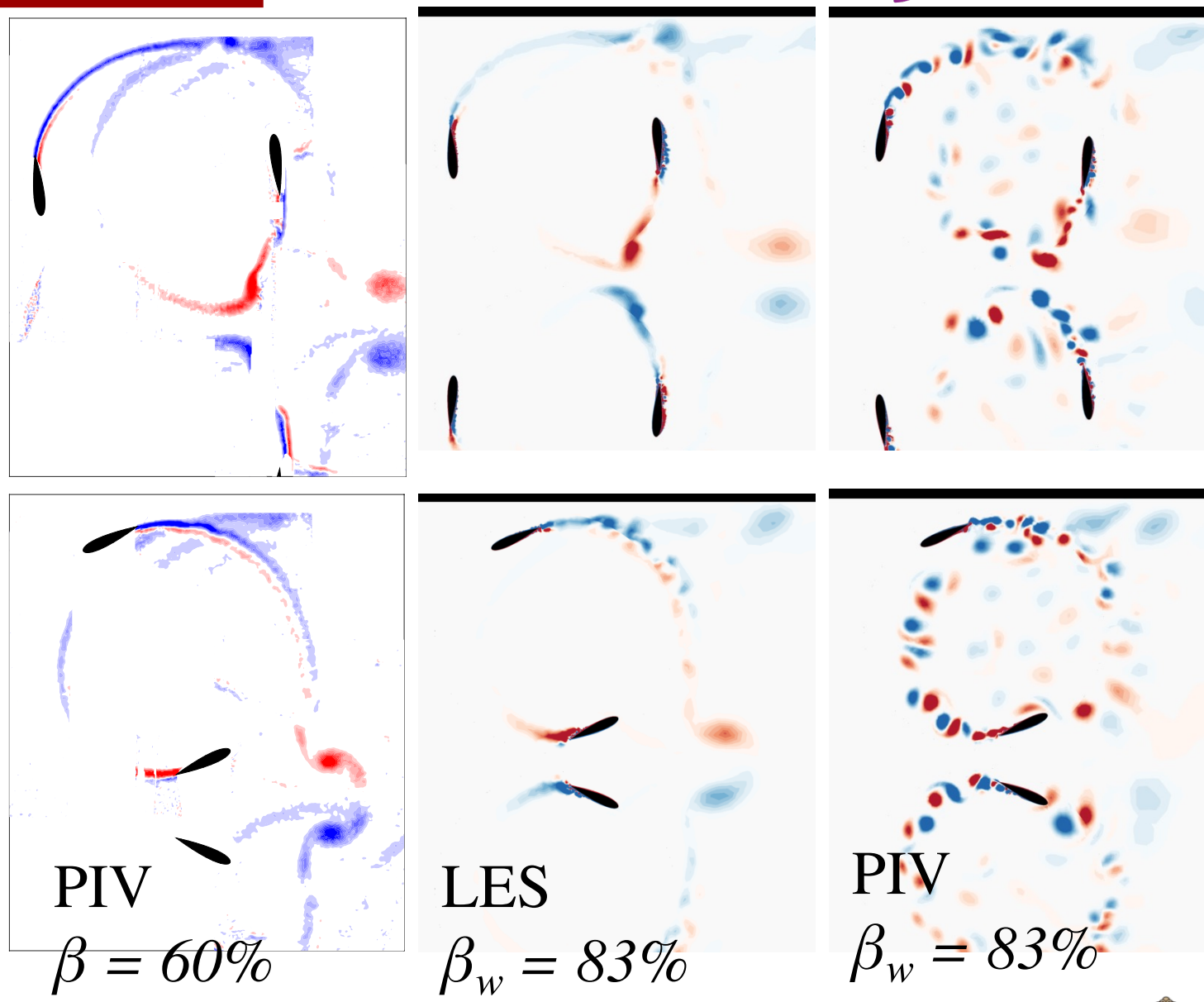




Preliminary large-eddy simulations

- 2.5D LES : methodology single turbine, *Dave et al. 2021, JRSE*
- $\beta_w = 83\%$; TSR=3.7





Summary & next steps

- Accounting for additional blockage, the 2D RANS model captures forces, performance and qualitative flow of confined 2-turbine system
- Lower TSR (sub-optimal) are influenced by vortex dynamics
- Higher TSR (perhaps) impacted by surface deflection, altering blockage

Future steps:

- Effects of surface deflection
- Scale up to higher Reynolds numbers with RANS model
- Continue to explore LES as computational time allows

Acknowledgements

Thank you to experimental team at UW:

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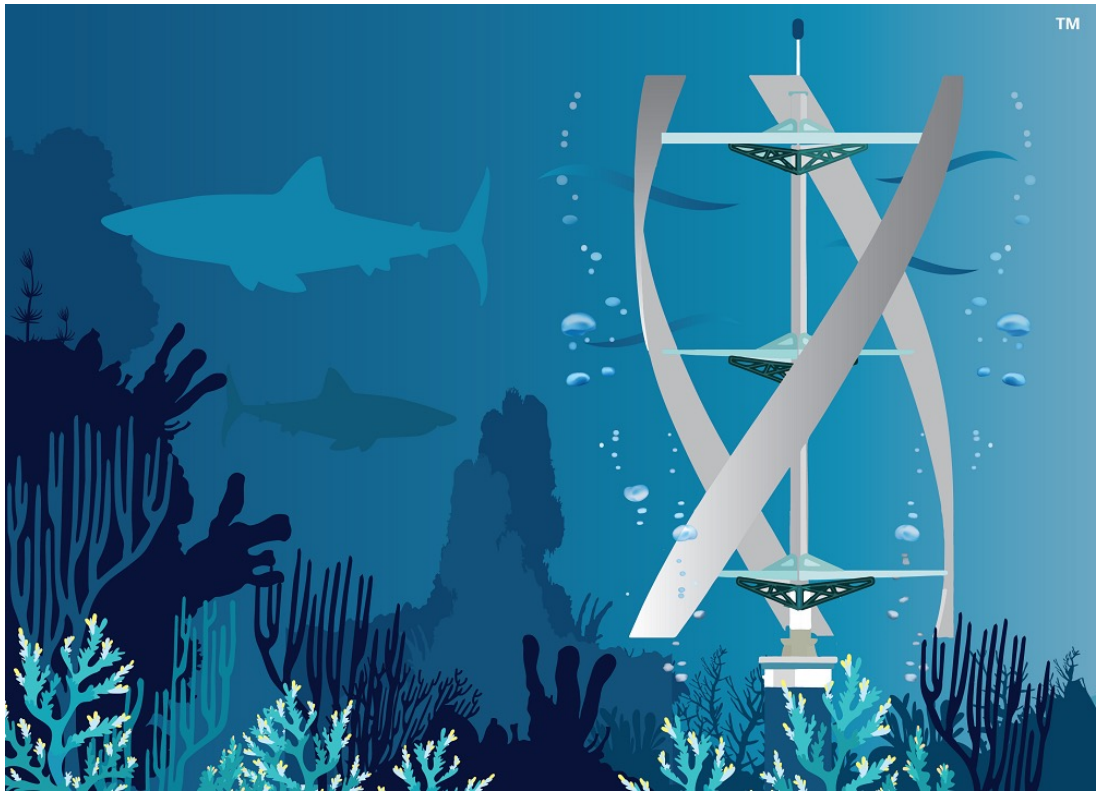
Owen Williams, Brian Polagye

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