HAW HAMBURG | CC4E

University of Strathclyde Glasgow

Literature review and preliminary actuator cylinder modelling of adjacent VAWTs

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Contents, or: VAWTs – why and how?

Different power gain mechanisms

Power gain illustration

The VAWT MRS

The Actuator Cylinder

Sharing my code ☺

Mechanisms of power gain in adjacent VAWTs

Wind Perpendicular to VAWT plane

Wind Oblique to VAWT plane

Source: Fluid dynamic mechanisms of enhanced power generation by closely spaced vertical axis wind turbines [1]

Mechanisms of power gain in adjacent VAWTs

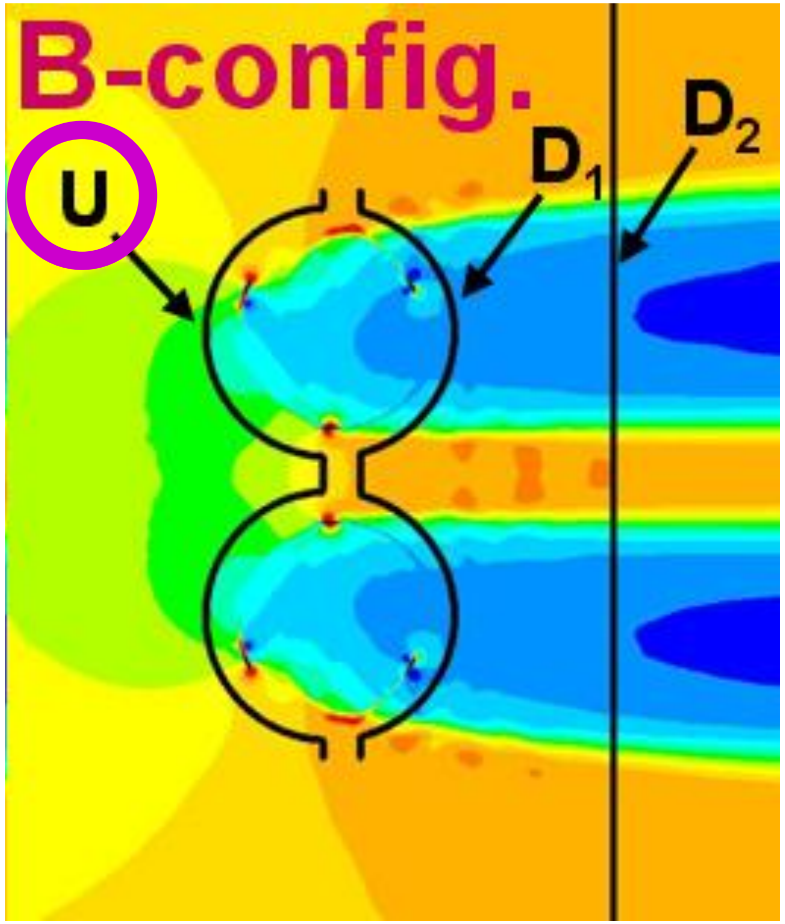
Wind Perpendicular to VAWT plane

On upwind half of blade revolution:

- Greater flow impedance
- ➢ flow rate decrease
- ➢ reduced power.

- Flow direction altered
- ➢ AoA more favourable for torque generation
- ➢ increased power.

- ➢ Net increase in power on upwind half.



Source: Fluid dynamic mechanisms of enhanced power generation by closely spaced vertical axis wind turbines

Mechanisms of power gain in adjacent VAWTs

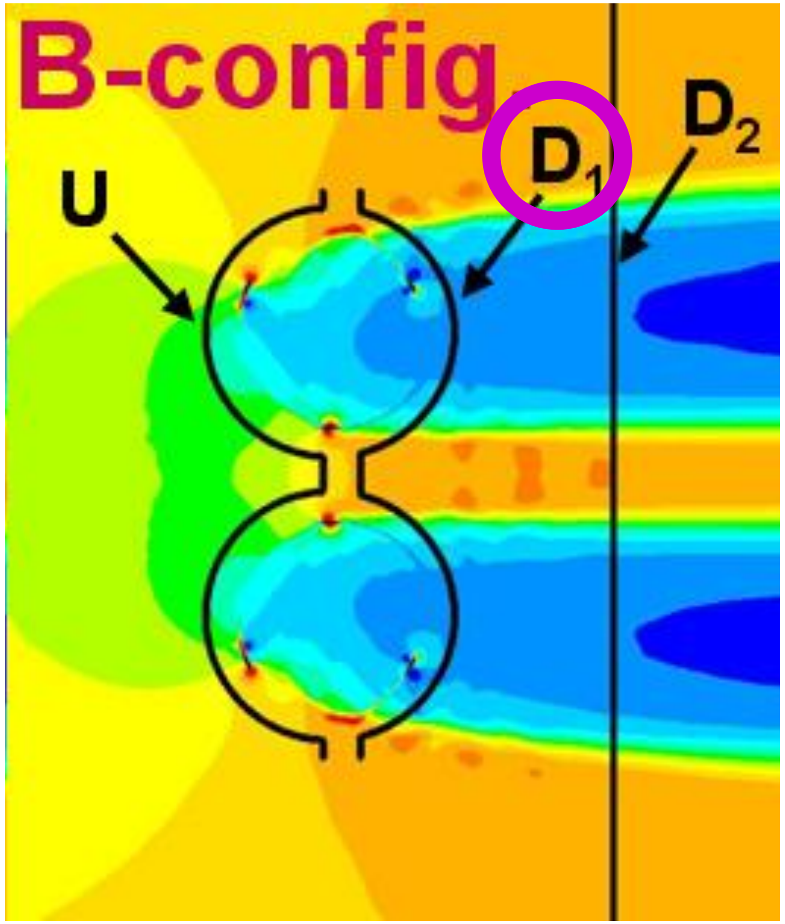
Wind Perpendicular to VAWT plane

On upwind half of blade revolution:

- flow impedance
- ➢ reduced power
- AoA better for torque generation
- ➢ increased power
- ➢ Net increase in power on upwind half.

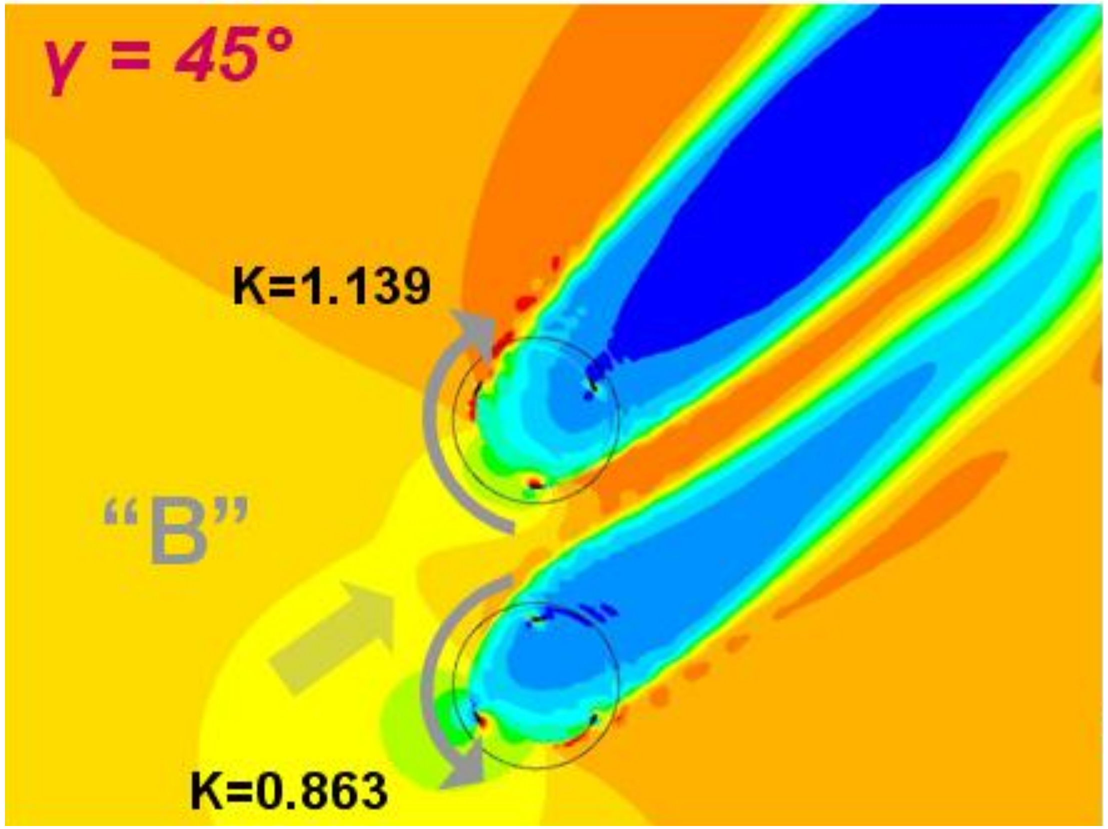
On downwind half of blade revolution:

- Flow can't 'escape' laterally
- ➢ greater flow rate through back
- ➢ more power.



Source: Fluid dynamic mechanisms of enhanced power generation by closely spaced vertical axis wind turbines

Mechanisms of power gain in adjacent VAWTs



Wind Oblique to VAWT plane

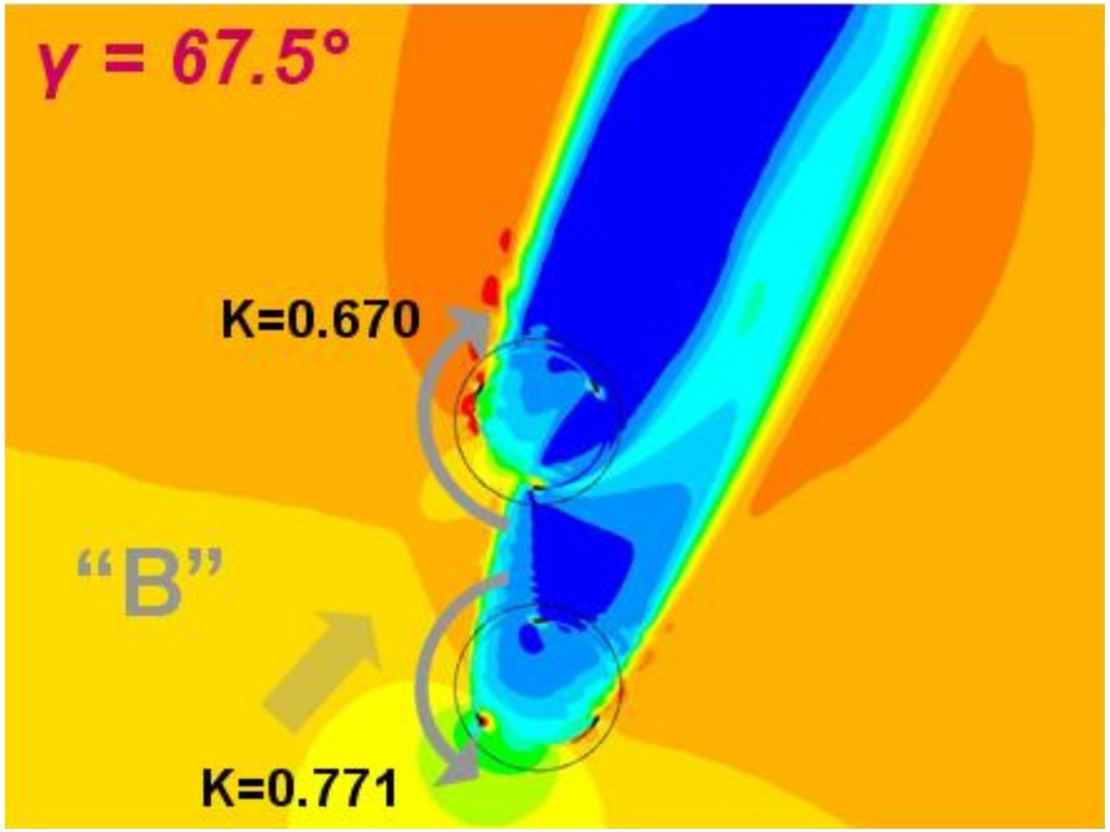
At small angles:

- Wake of front turbine cannot fully develop
  - ➢ sight decrease in power
- Back turbine is hit by accelerated flow from around front turbine
  - ➢ increase in power

➢ Net increase in power

Source: Fluid dynamic mechanisms of enhanced power generation by closely spaced vertical axis wind turbines

Mechanisms of power gain in adjacent VAWTs



Wind Oblique to VAWT plane

At small angles:

- Wake of front turbine cannot fully develop
  - ➢ sight decrease in power
- Back turbine is hit by accelerated flow from around front turbine
  - ➢ increase in power

➢ Net increase in power

At large angles:

- Front turbine wake further obstructed
  - ➢ even less power
- Back turbine shadowed by front turbine
  - ➢ now decreased in power

Source: Fluid dynamic mechanisms of enhanced power generation by closely spaced vertical axis wind turbines

Wind Perpendicular to

VAWTs – why and how?

Different power gain mechanisms

Power gain illustration

The VAWT MRS

The Actuator Cylinder

Sharing my code ☺

Power gain

Significantly more power in pairs

Good gains at multiple separation distances

Strong yaw insensitivity

Experimental Validation:

- IDW@1.3D: 13.1% gain
- IDW@1.2D: 13.6% gain
- IUW@1.3D: 15.9% gain

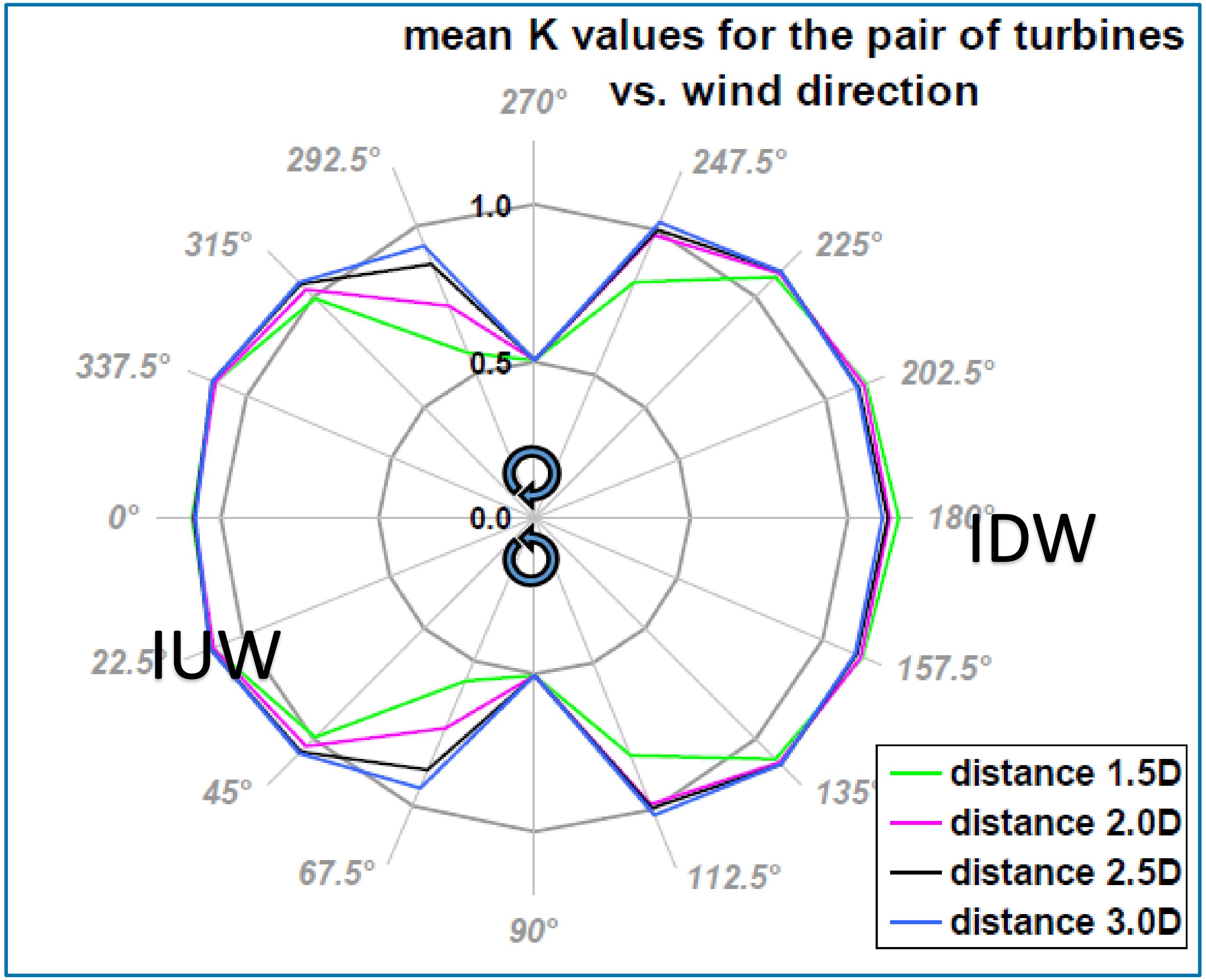


Image source: Fluid dynamic mechanisms of enhanced power generation by closely spaced vertical axis wind turbines
Validation source: Experimental validation of the power enhancement of a pair of vertical-axis wind turbines

VAWTs – why and how?

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VAWT MRS

48MW floating offshore MRS

- 4*24 500kW rotors
- 17.73m*88.65m rotor

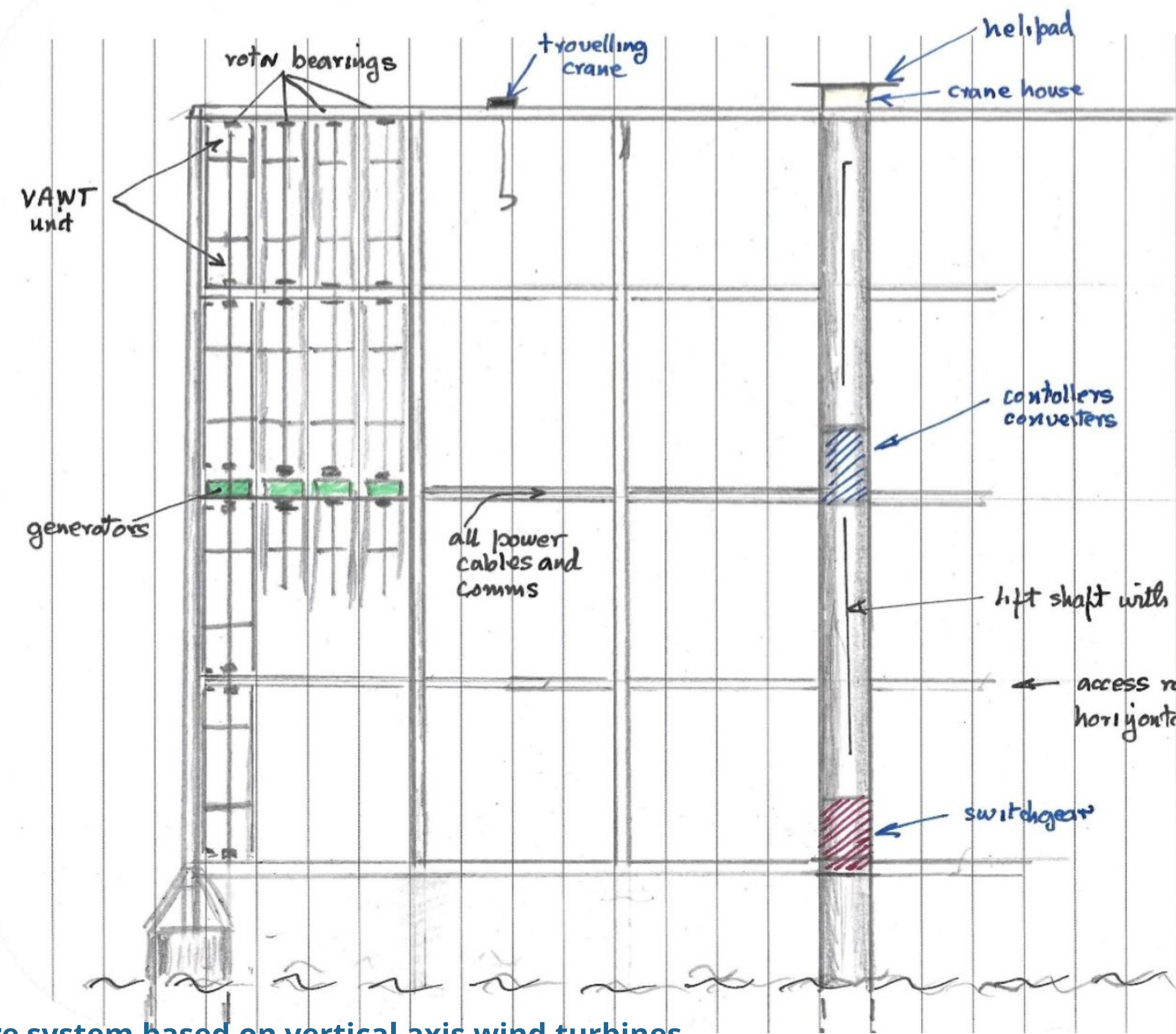
Typical MRS advantages

VAWT advantages:

- Connections at top/bottom of rotor (causing blockage instead of drag)
- 4x fewer generators

VAWT mitigations:

- high aspect ratio contained easier
- pseudo-helical torque input



Reference: Development of a multi rotor floating offshore system based on vertical axis wind turbines

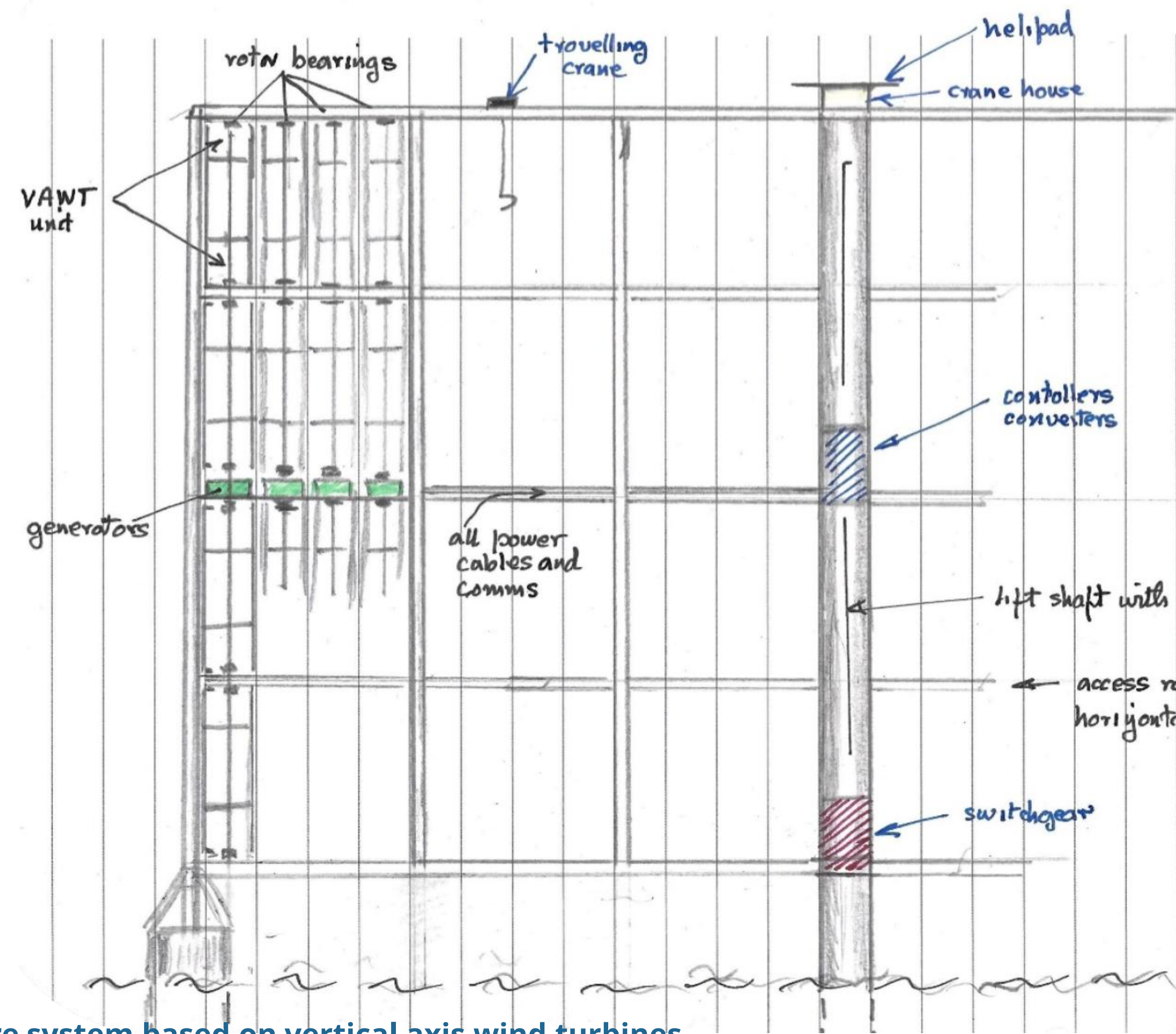
My Research: MRS

Very tight spacing planned

- Impact on power
- Impact on yaw sensitivity
- Impact on wakes

Rotation direction layout of a long row

Consider 3D effects



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The Actuator Cylinder

The Actuator Disk

Idealise rotor as flat disk

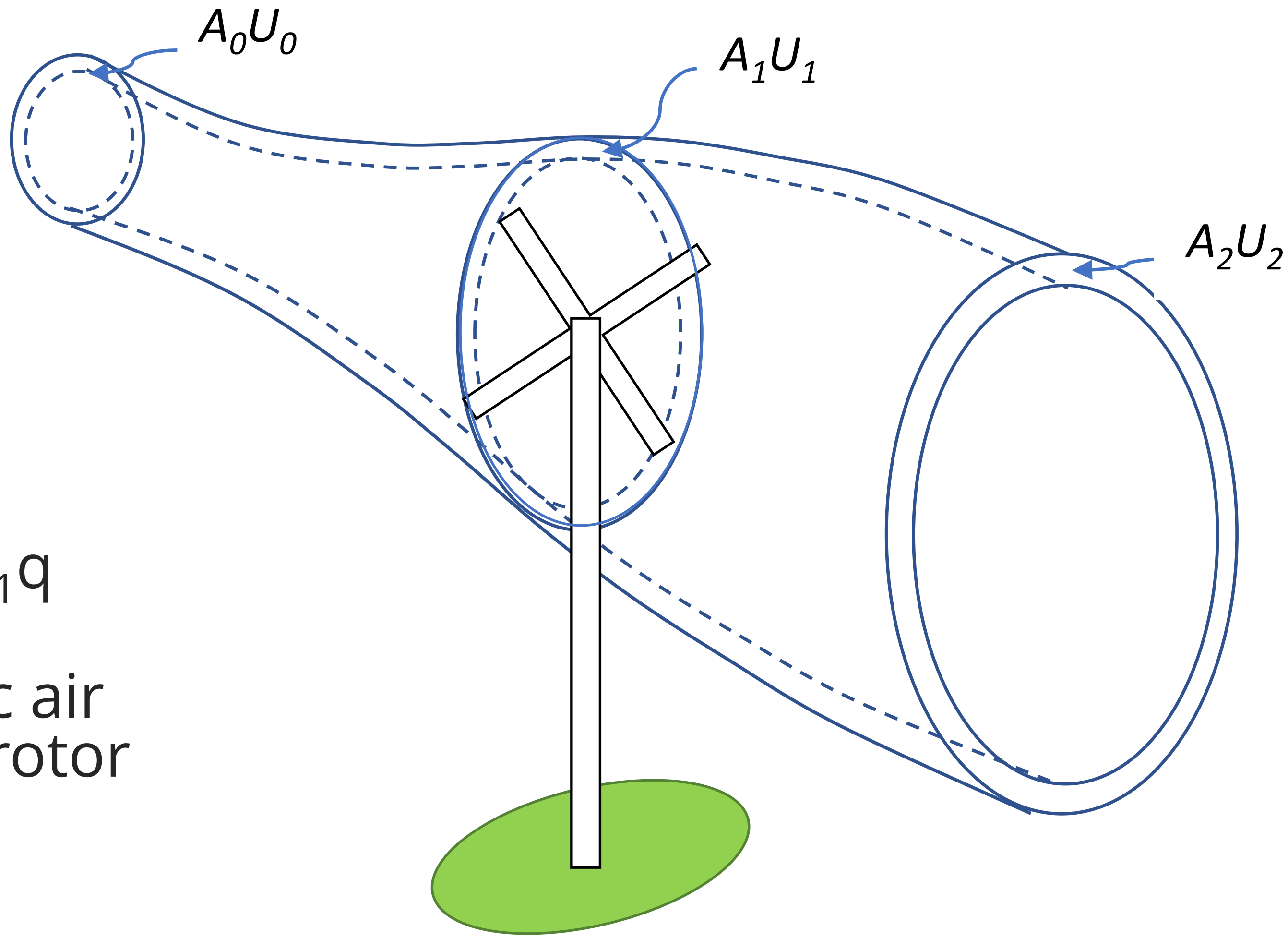
Consider flow from far upwind to far downwind

Mass flow conservation:
$A_0U_0 = A_1U_1 = A_2U_2$

Momentum conservation:
$(\rho U_0 - \rho U_2)AU$ = rotor force = A_1q

q is also the difference in static air pressure Δp either side of the rotor

Power extracted: $P = (A_1q)U_1$



The Actuator Cylinder

Instead of idealising rotors as disk…

…we idealise rotors as a cylinder…

…and approximate cylinder by a 2D slice

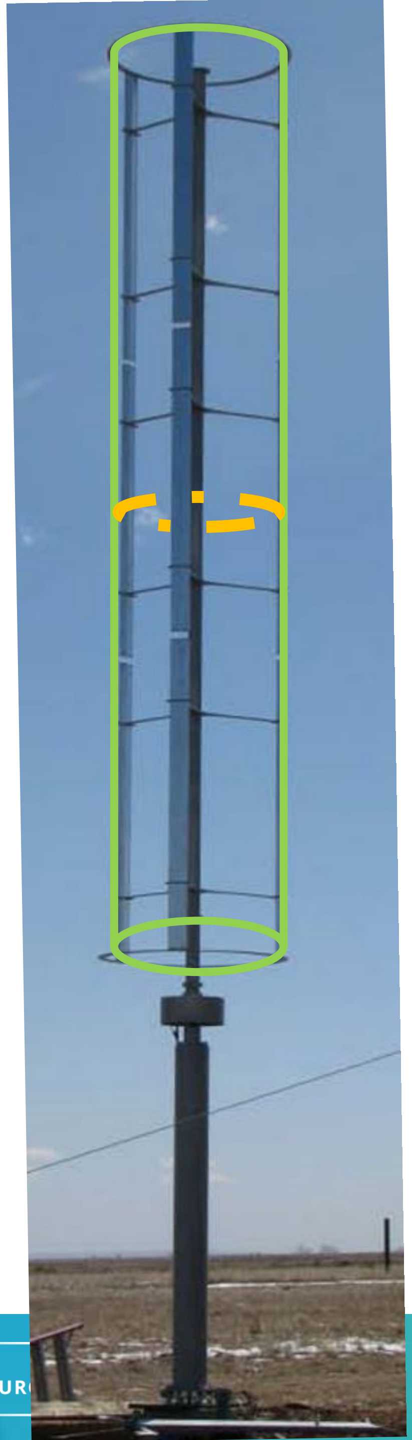


Image source: Wind Turbine Safety and Function Test Report for the Mariah Windspire Wind Turbine

The Actuator Cylinder

Instead of idealising rotors as disk…

…we idealise rotors as a cylinder…

…and approximate cylinder by a 2D slice

Instead of q constant, now have q(θ)

Power extracted = $\int_0^{2\pi} v_r(\theta)q(\theta)Rd\theta$ (per unit height)

Low complexity/computational time, medium fidelity!

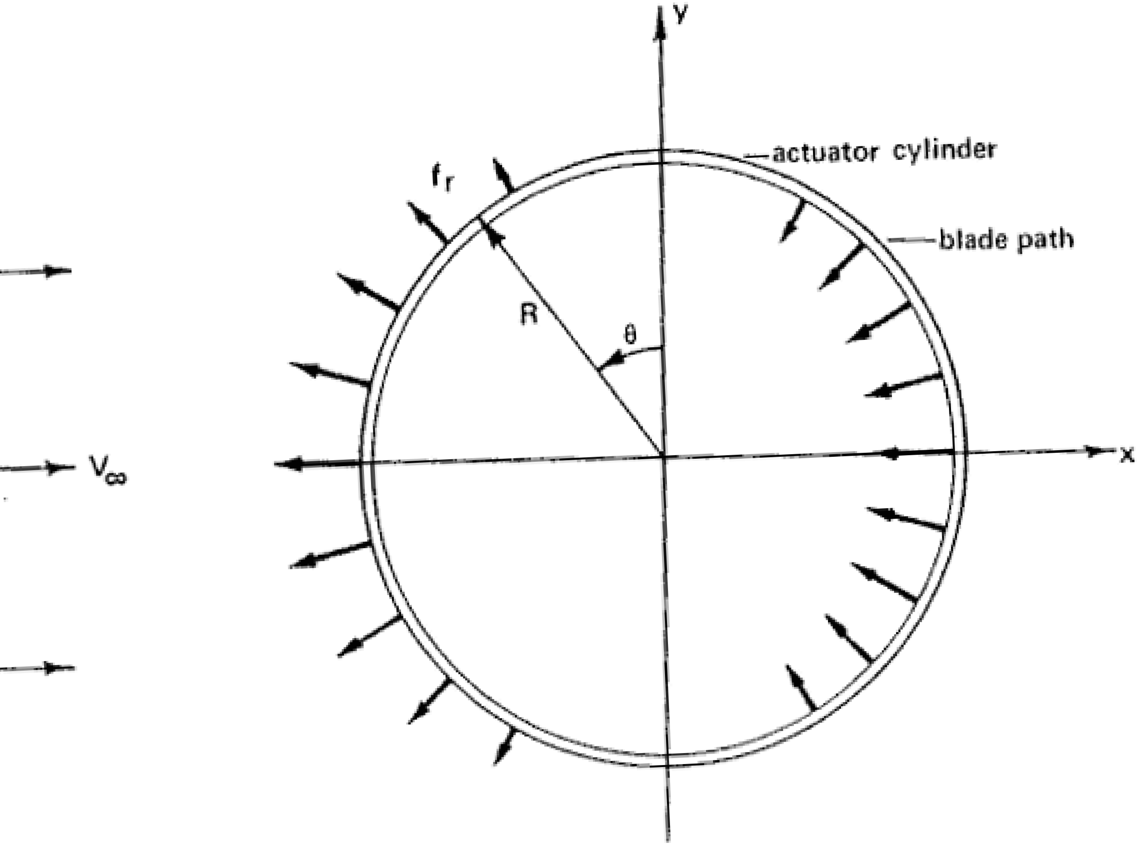


Fig. 2b. The representation of a vertical axis wind turbine by an actuator cylinder, plan view.

Image source: The Actuator Cylinder: A Flow Model for Vertical Axis Wind Turbines

The Actuator Cylinder

Solve mass + momentum equations as before

Obtain nonlinear Poisson equation for wind pressure p

Deduce equations for wind velocity perturbations w_x, w_y

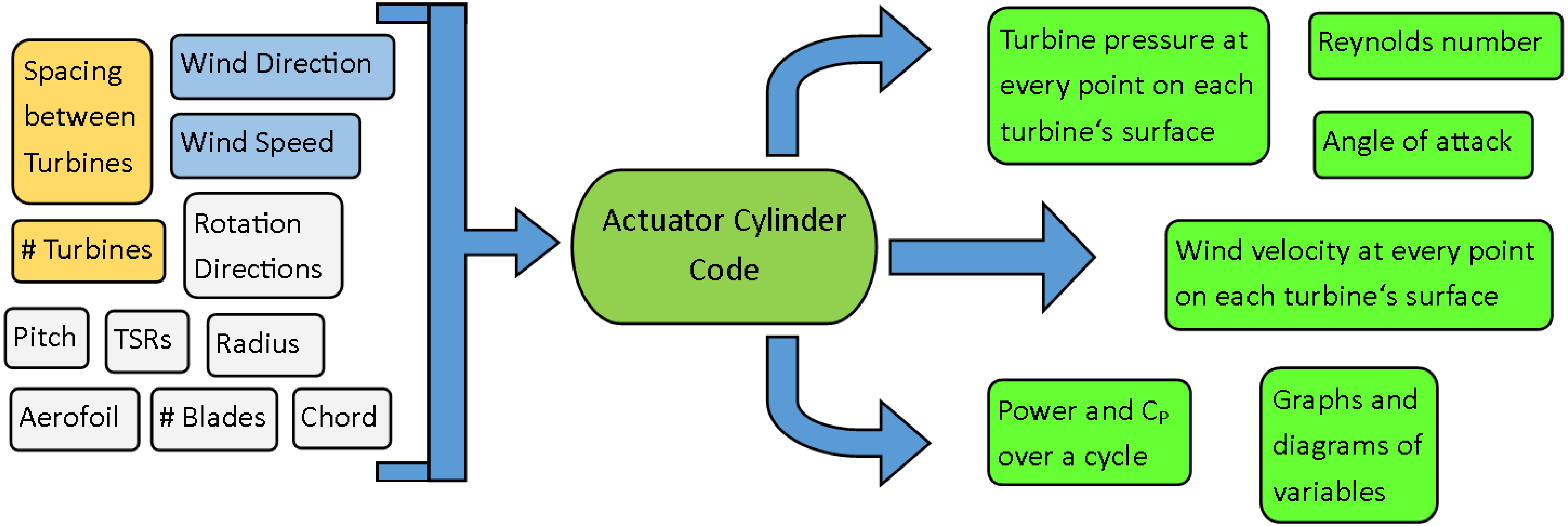
functions of q(θ)

Solution has linear and nonlinear parts

Linear solutions, prescribed q:	computational calculation
Nonlinear approximation:	…with correction term
Nonlinear solution:	…with iterative loop
Calculate q from w_x,w_y & aerofoil data:	…with (another) iterative loop

Source: Actuator Cylinder Theory for Multiple Vertical Axis Turbines
Source: The Actuator Cylinder – A Flow Model for Vertical Axis Wind Turbines

My Research: Code!



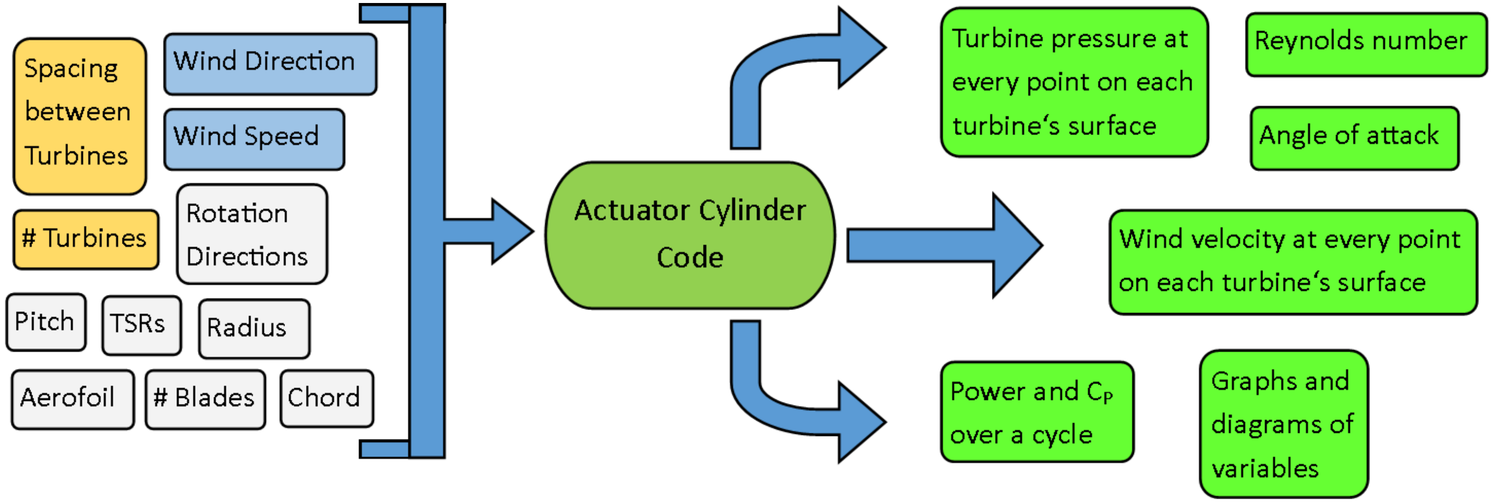
My Code

Based on Andrew Ning's work

Written in Matlab

Can batch-run + compare different setups

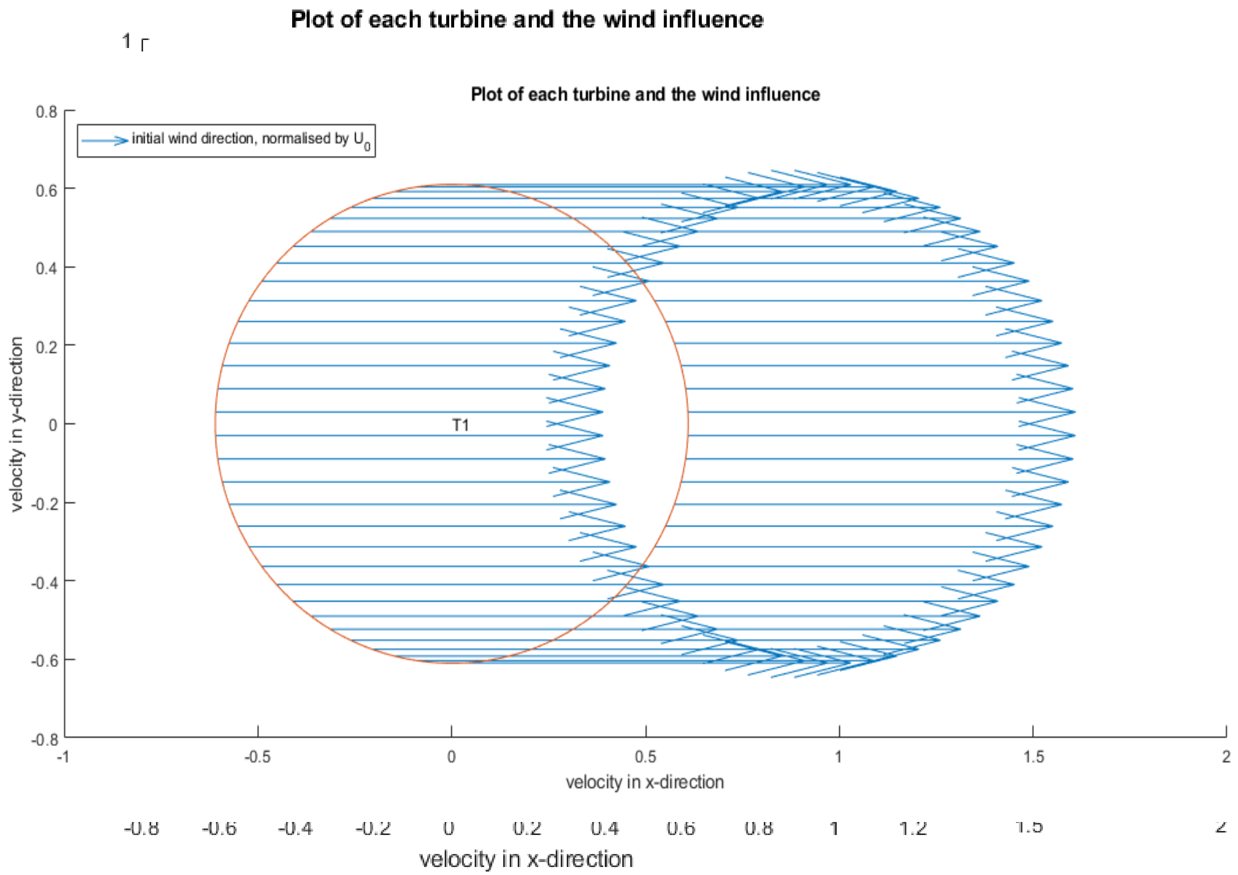
Current version: linear, q from aerofoil data



github.com/AngusBuck/Multiple-Actuator-Cylinder

Reference: Actuator Cylinder Theory for Multiple Vertical Axis Turbines

My code: qualitatively good



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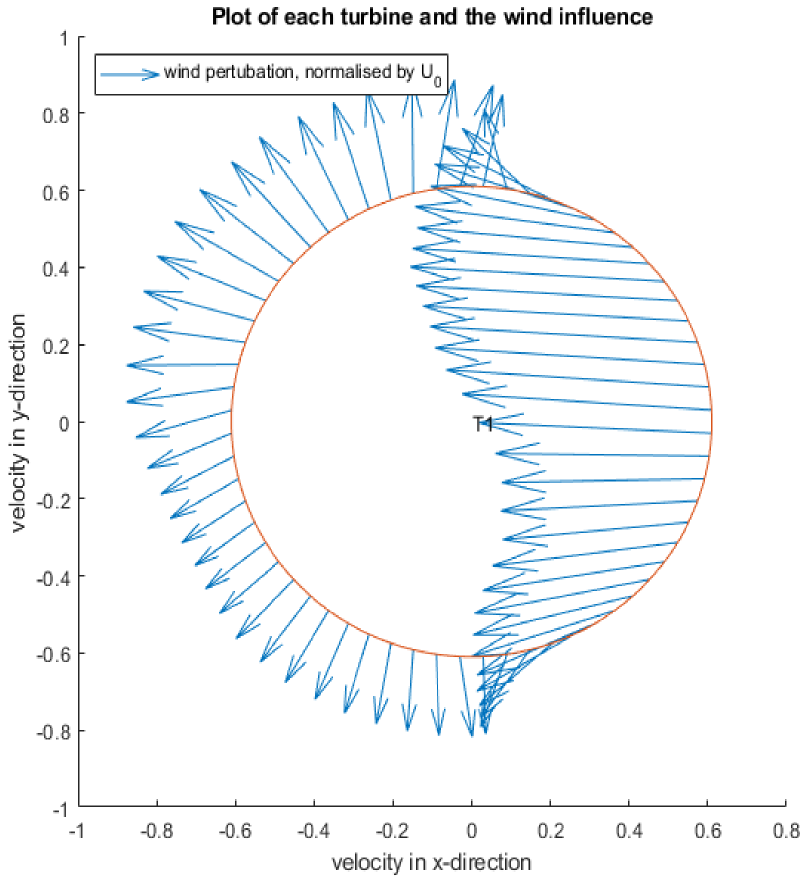

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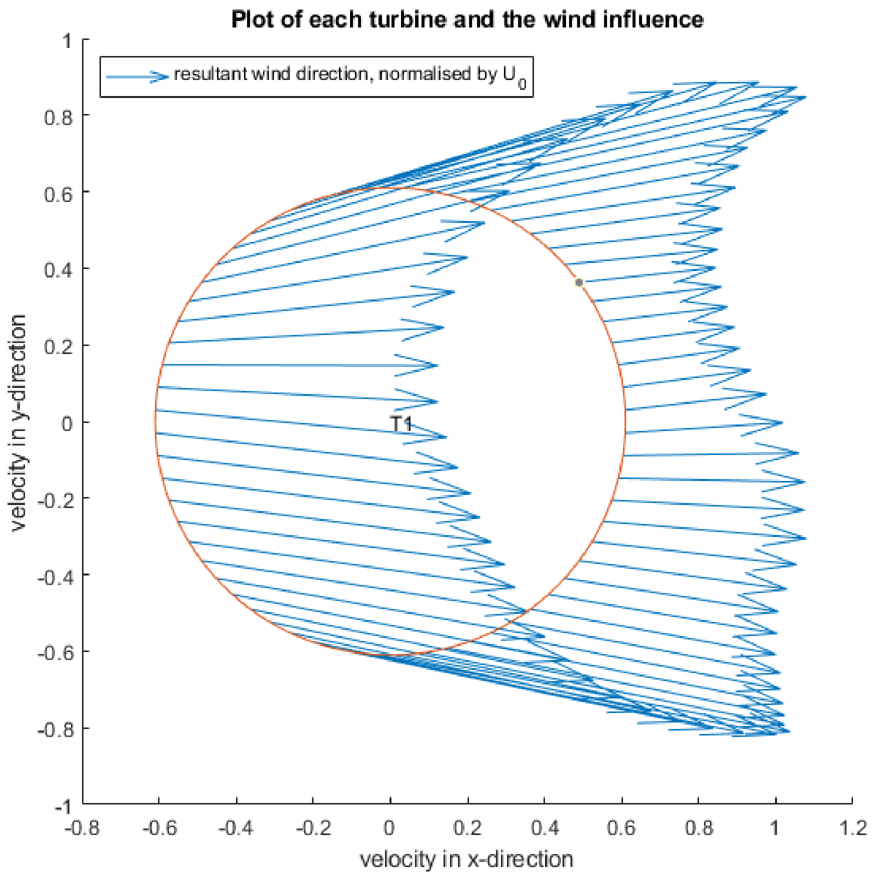

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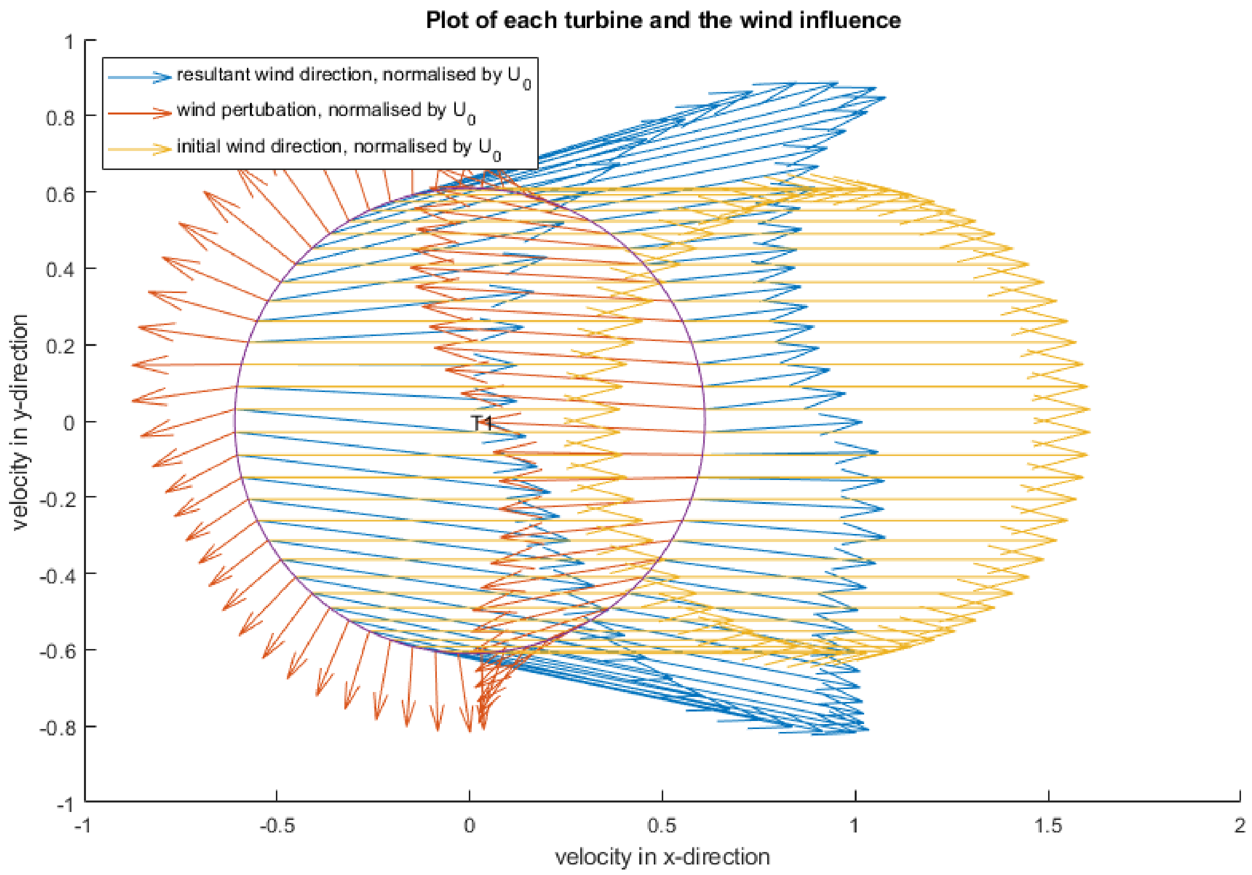

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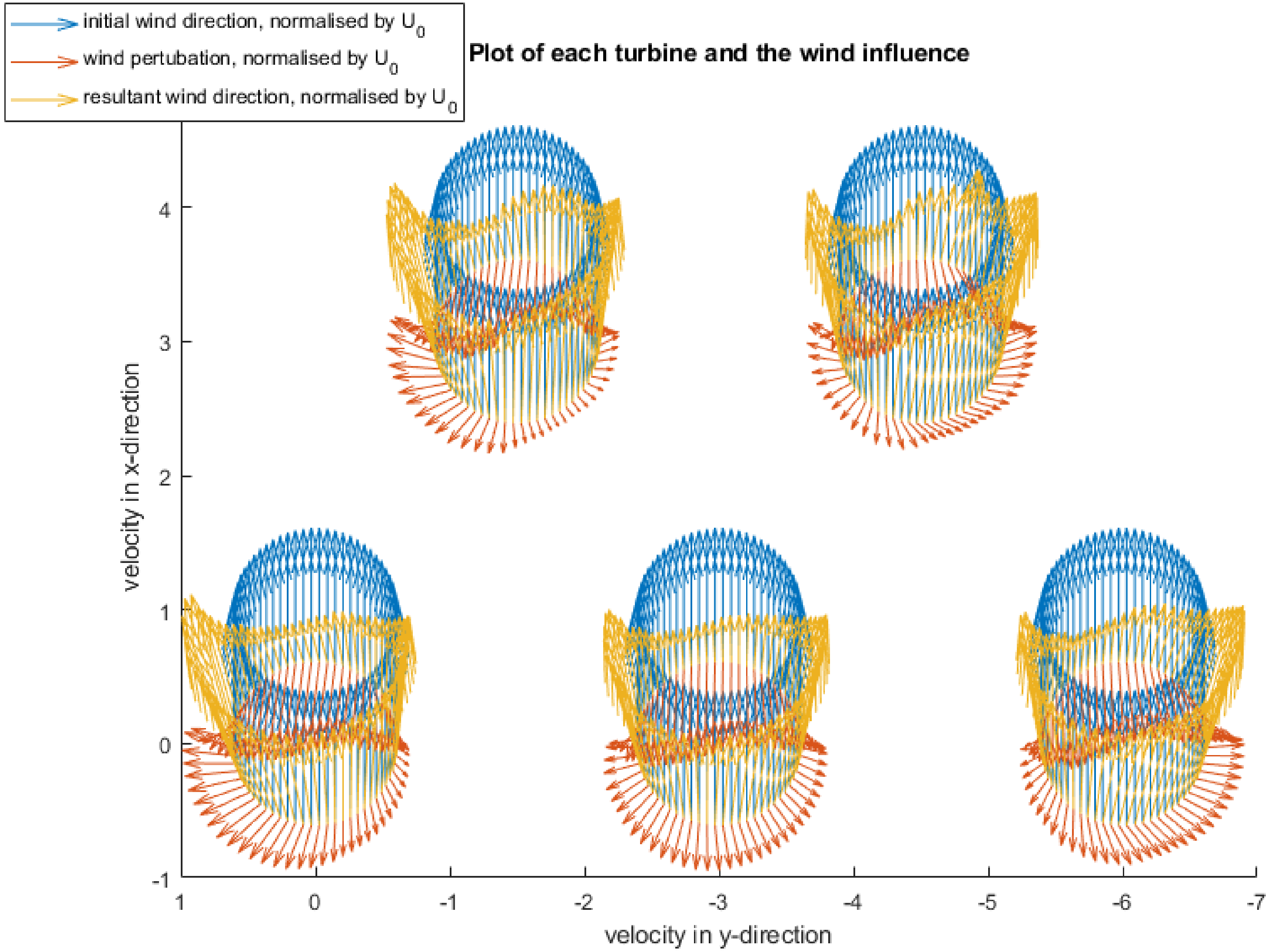
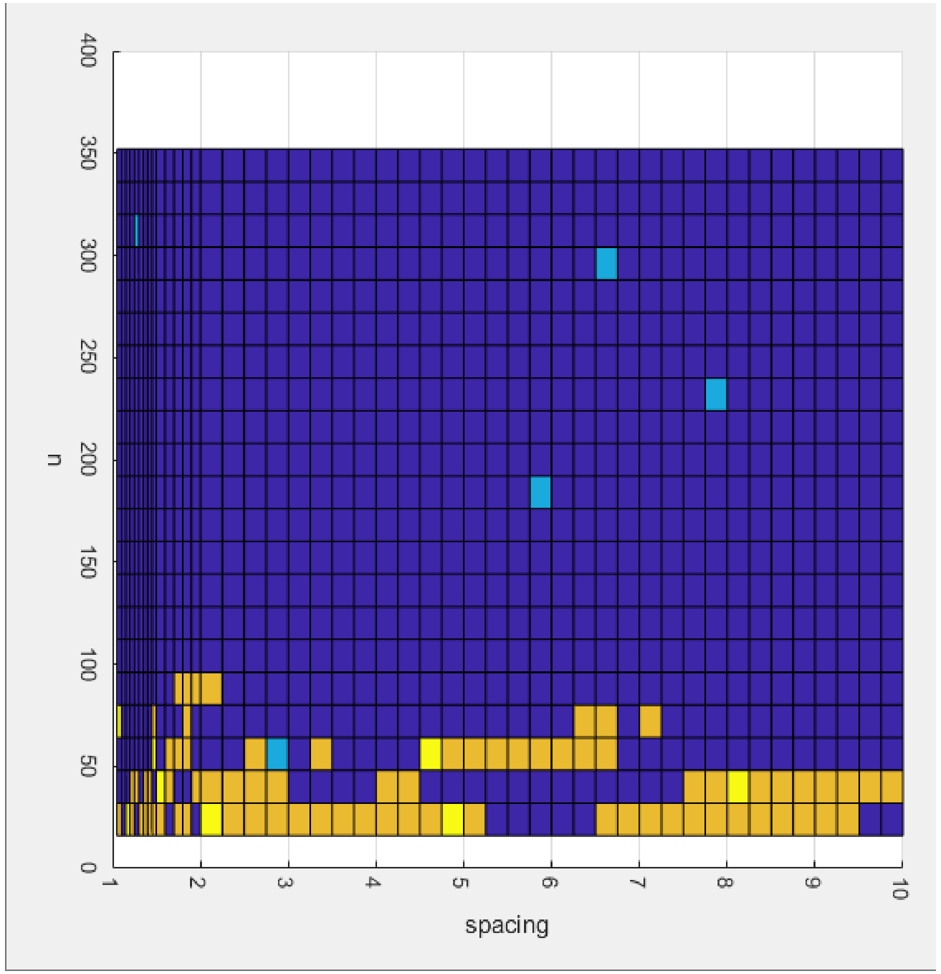
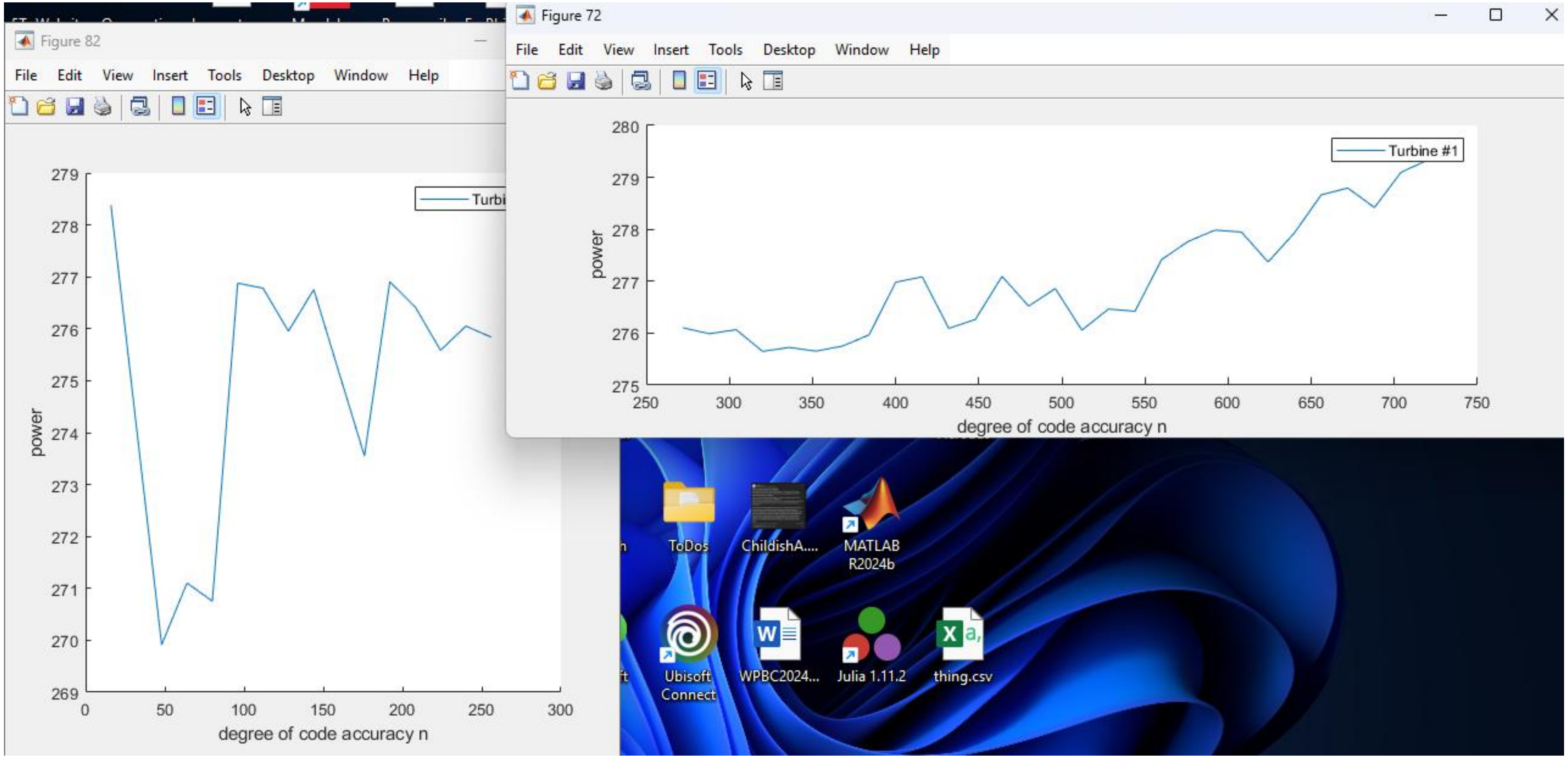


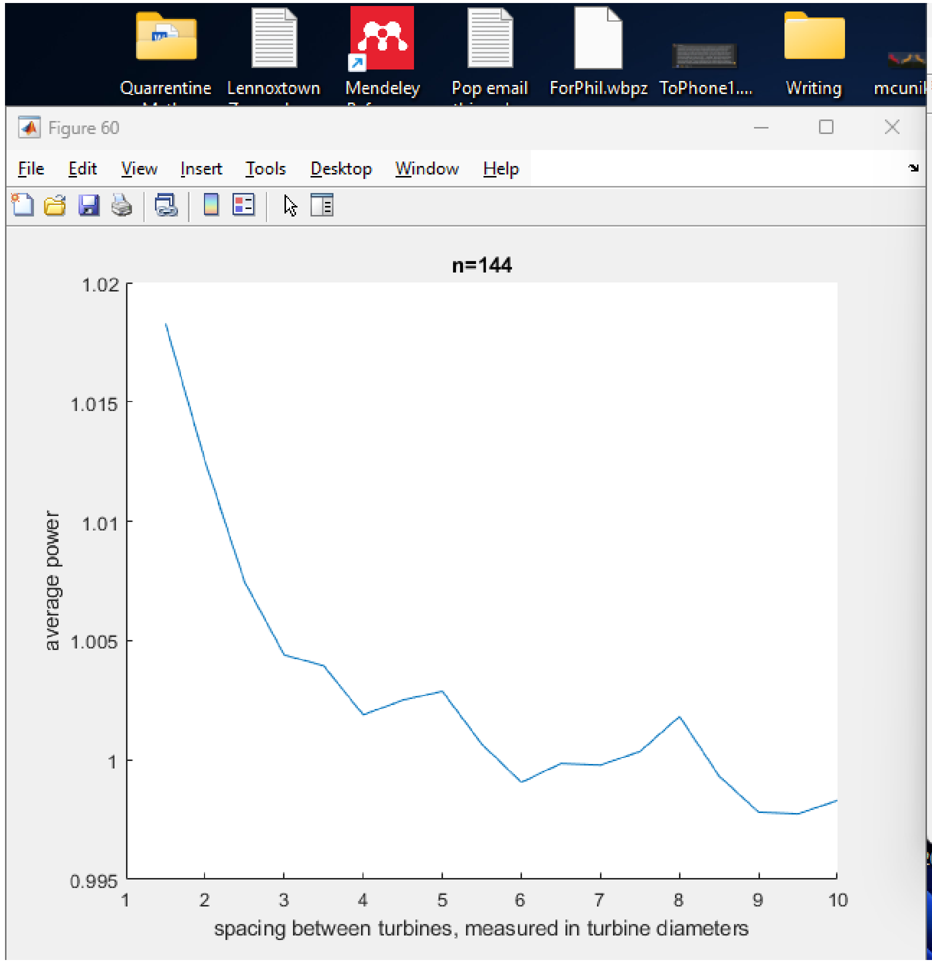
My code: quantitative issues

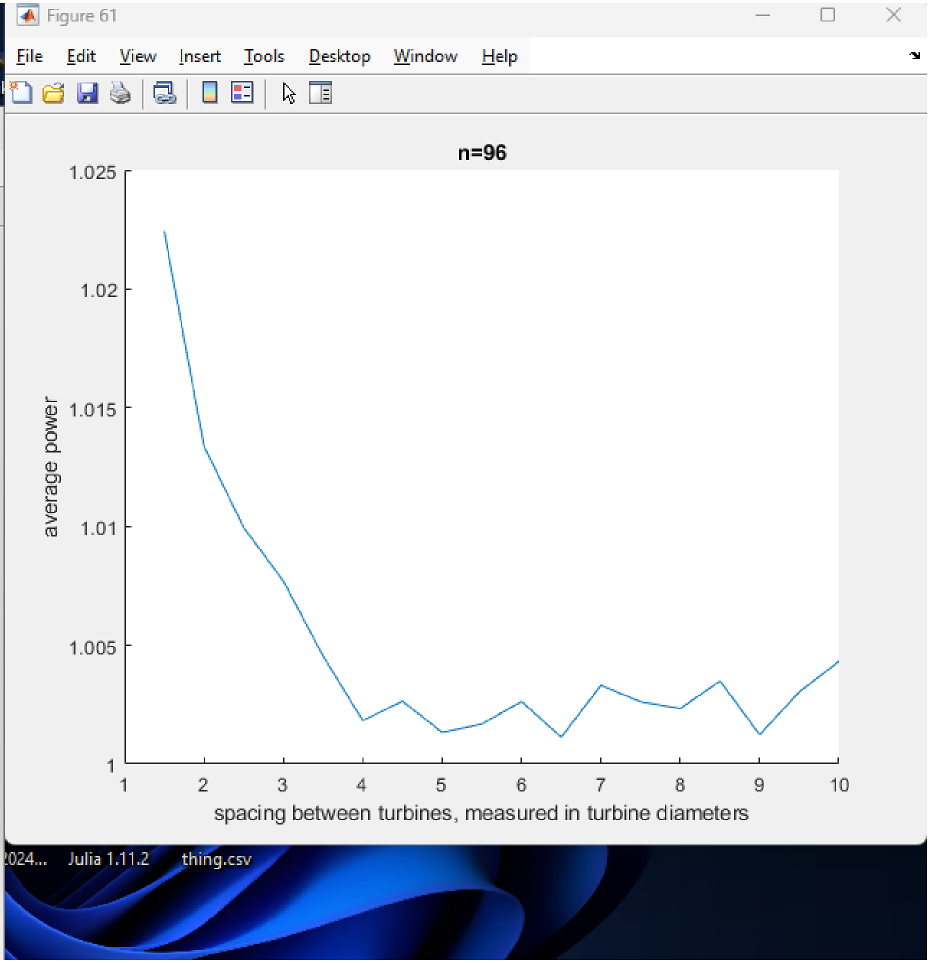


My code: quantitative issues



My code: quantitative issues





My code: next steps

Computational: make *fsolve* converge

Mathematical: nonlinearities

- correction term?
- full nonlinear?

Physical:

- virtual camber
- better wake model
- 3D adaptation

Things I didn't have time for

Other Interesting Physics

Rotation direction combos

Wake con/divergence

Tip-speed ratios

Other Investigation Topics

Does oblique wind increase power?

How close is "paired"/"isolated"?

How long a row before properties stop changing?

Connect to LCoE model

General guidelines/principles for VAWT pairs/rows

Summary

VAWT pair power increases from AoA gains + blockage gains

VAWT MRS takes strengths of VAWTs and mitigates their weaknesses

An actuator cylinder models VAWTs with low complexity and medium accuracy

My own code…

- is qualitatively correct
- will soon be brought up to standard
- will be improved to well model the MRS
- is available ☺

Thank you for listening!

github.com/AngusBuck/Multiple-Actuator-Cylinder

Please come ask me Qs/share thoughts at my poster or the dinner this evening! ☺

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