A free wake vortex lattice method combined with the Øye dynamic stall model for vertical axis wind turbines

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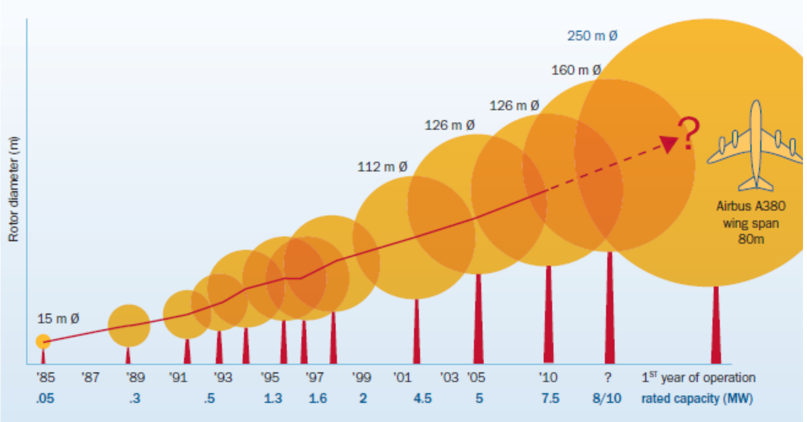
Contents

Introduction

➢ Up-scaling HAWTs



➢ Go for Vertical Axis Wind Turbines?

More research efforts:

- aerodynamic
- structure dynamic
- Control
- …

Research problems

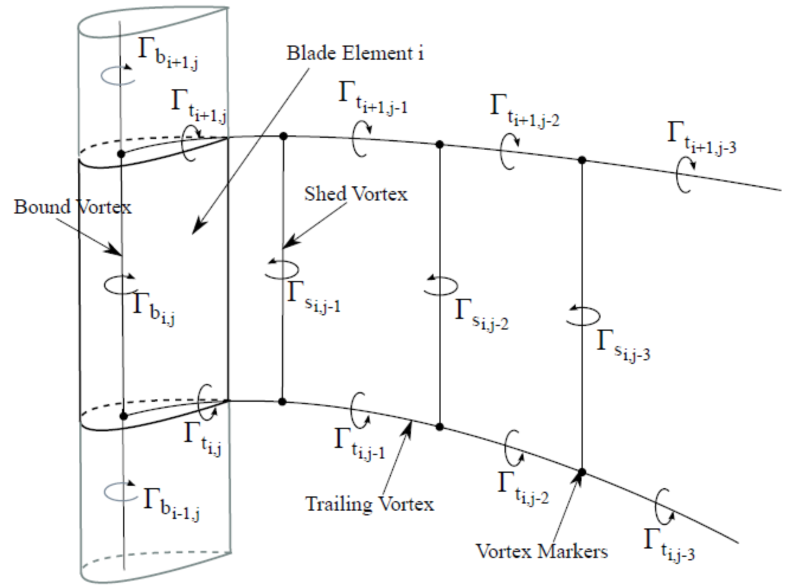
- Periodic blade loading over the rotation with dynamic stall
- Blade-wake interactions
- BEM validity for VAWT's is unsure
- Lack of fast and accurate aerodynamic codes for the flow field

Hence more complex but fast aerodynamic model are needed

3d free wake vortex lattice code - Theorems

A 3d vortex lattice code based on the following theorems:

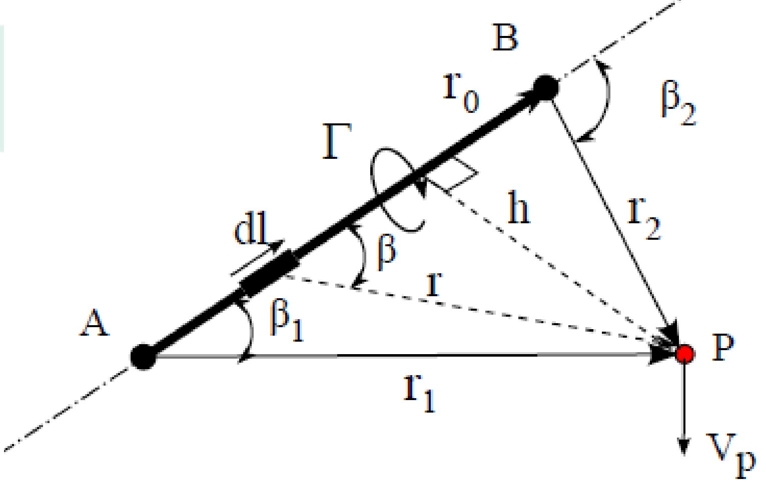
- Biot Savart → Induced velocity field
- Kelvin → Conservation of circulation
- Helmholtz → Closed and constant filament strength
- Kutta-Joukovski → Relation between lift and circulation



3d free wake vortex lattice code - Implementation

On top of that:

- **Regularized Biot-Savart kernel for the vortex line element**
- **Vortex viscous core spread model (Lamb-Oseen model)**
- **Second order time integration method (Adams-Bashforth)**



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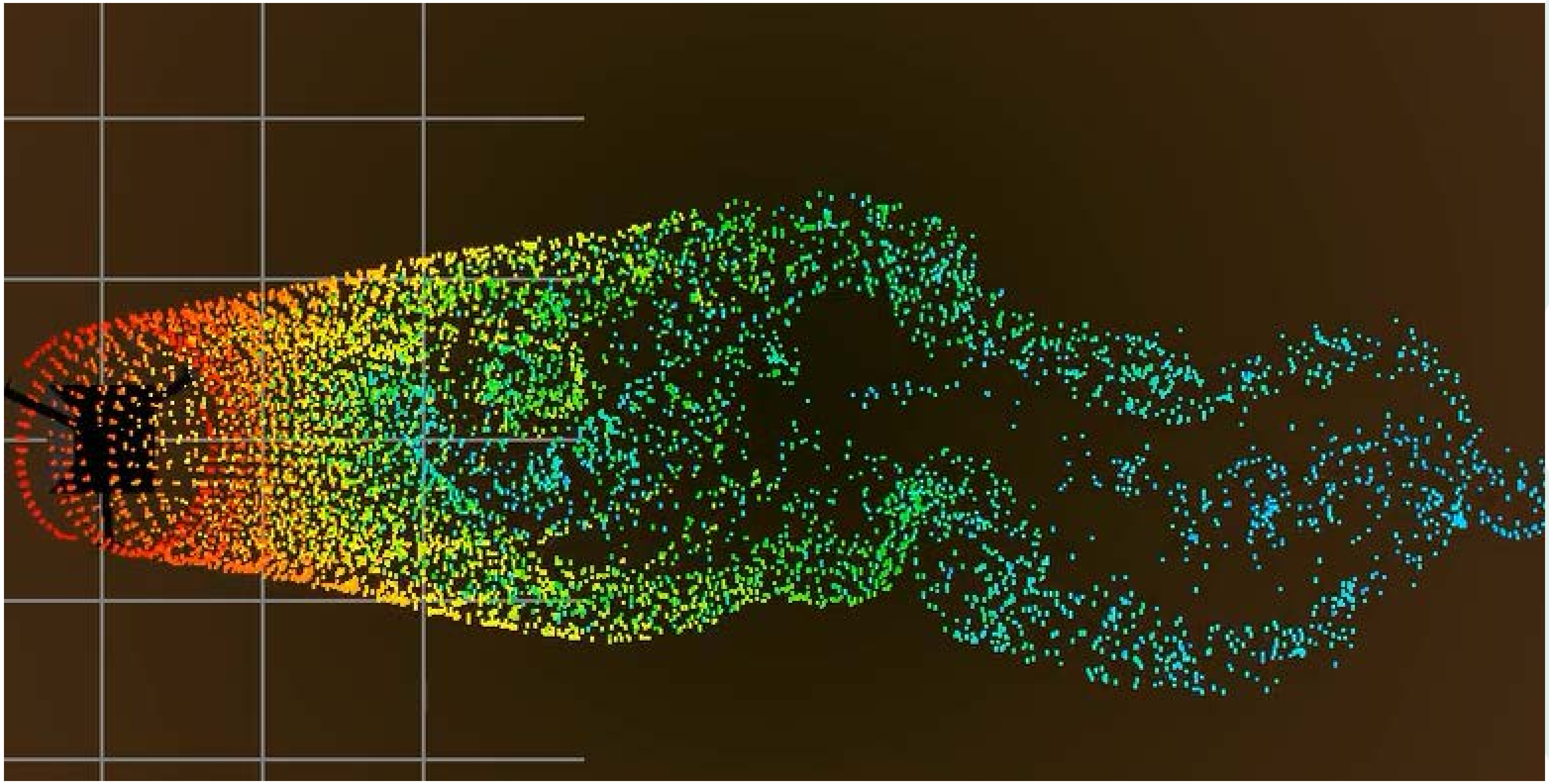
3d free wake vortex lattice code - Theorems



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3d free wake vortex lattice code - Implementation

Øye dynamic stall model

Obtain static separation from static lift coefficient:

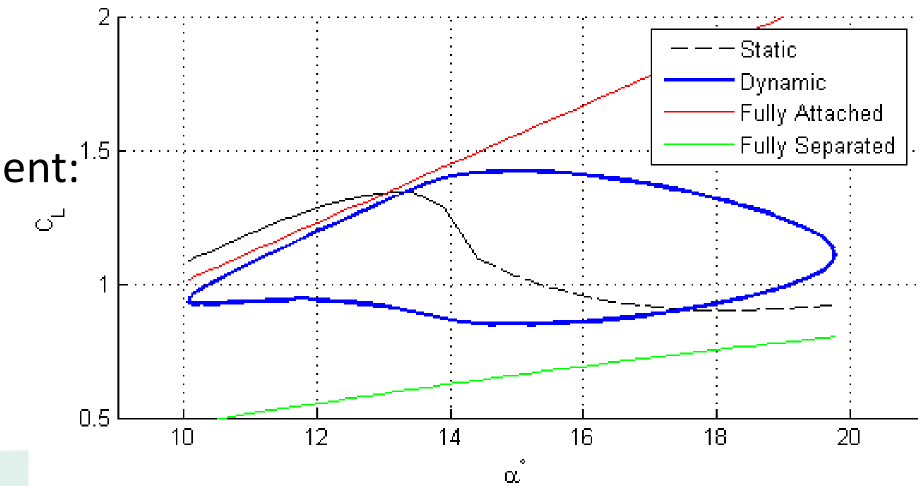
$$C_{Ls}(\alpha) = f_s(\alpha) \cdot C_{Latt}(\alpha) + (1 - f_s(\alpha)) \cdot C_{Lsep}(\alpha)$$

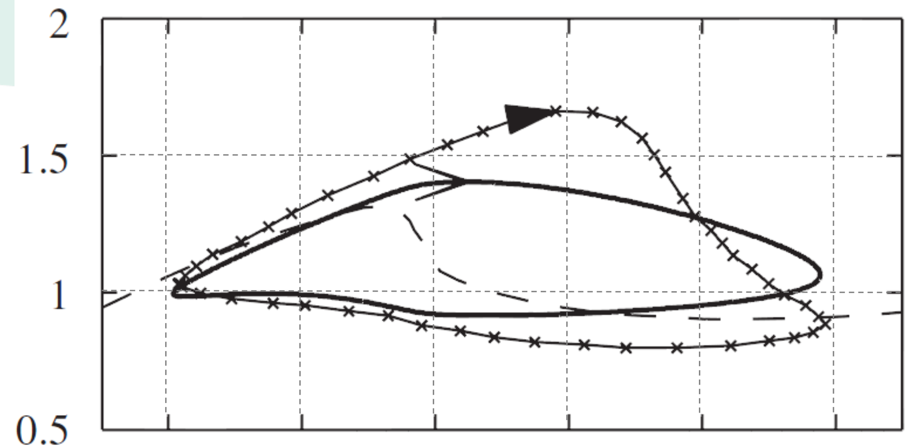
From static to dynamic separation point:

$$f_{d,i}(t) = f_{d,i-1}(t) + (f_s(\alpha) - f_{d,i-1}(t)) \cdot \Delta t / \tau$$

Obtain dynamic lift coefficient from dynamic separation:

$$C_{Ld}(t) = f_d(t) \cdot 2\pi(\alpha - \alpha_0) + (1 - f_d(t)) \cdot C_{Lsep}(\alpha)$$



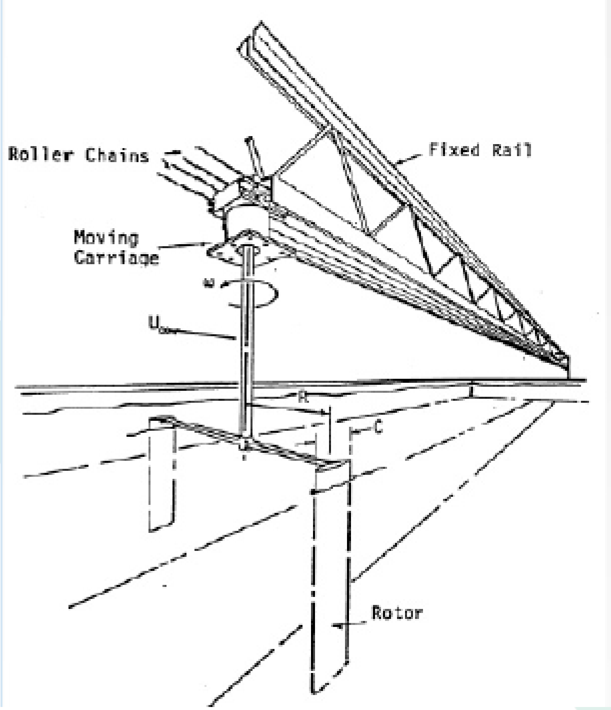


Øye's results and experiment results

Verification and validation – experiment setup

Strickland's water tank experiment setup

Number of blades	1,2,3 [-]
Rotor diameter	1.22 [m]
Blade height	0.91 [m]
Blade Chord	0.0914 [m]
Airfoil	NACA0012
Reynolds number	4.0e+04 [-]
Kinematic viscosity	1.044e-06 [m^2/s]
Tip speed ratio	5 [-]



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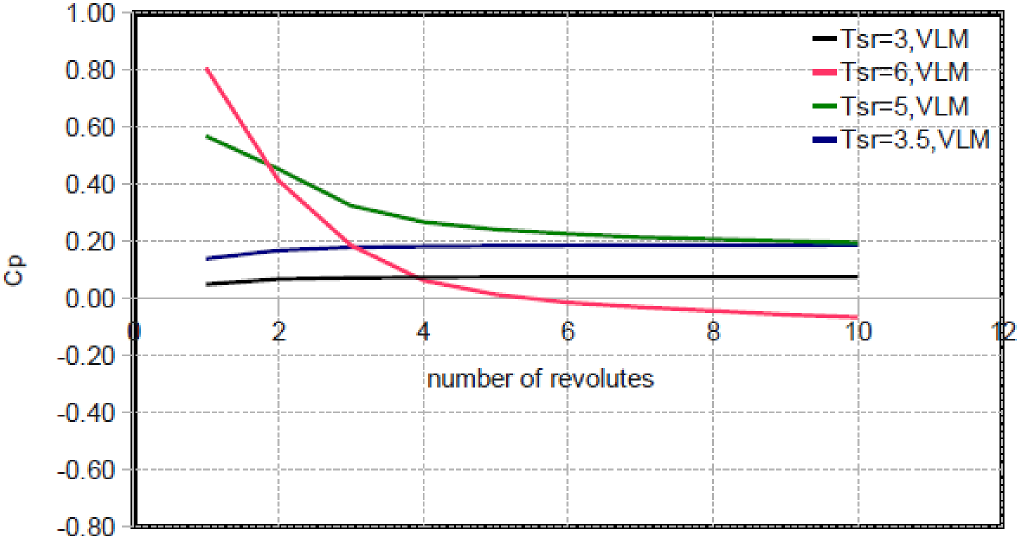
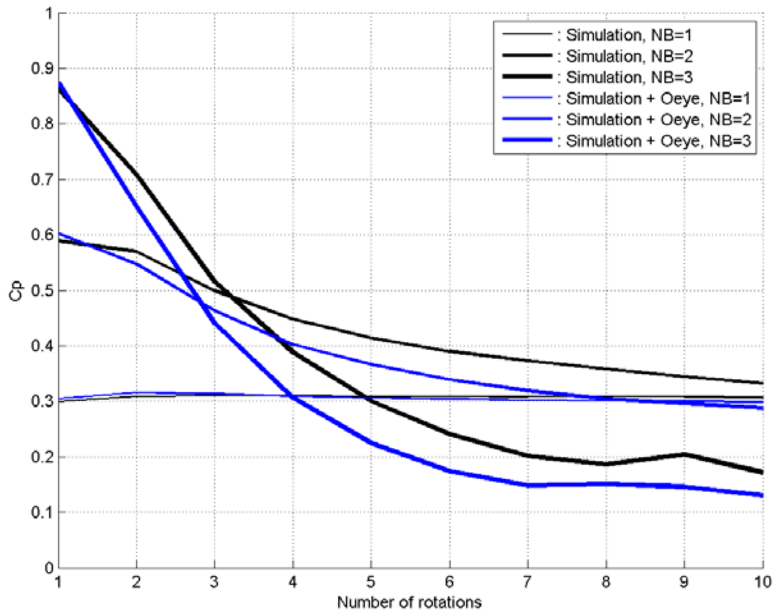
Verification – convergence study and Cp



Convergence check: Cp for a 2-bladed turbine



Convergence check: Cp for 1,2, 3-bladed turbine at TSR = 5

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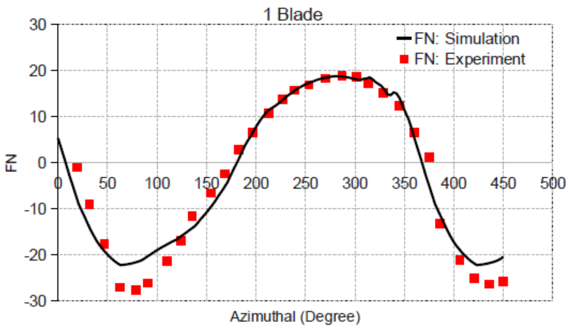
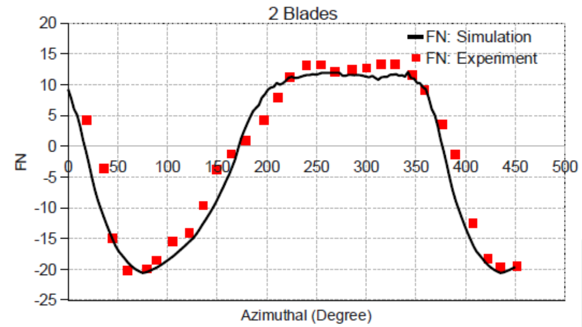
Validation – the baseline code

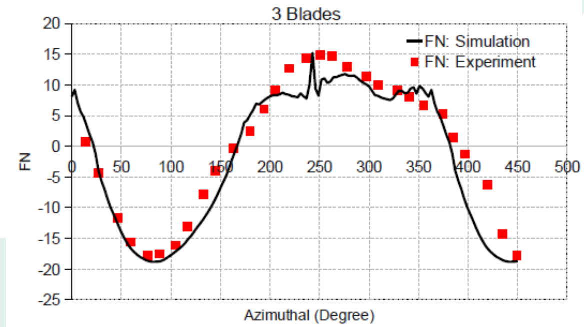
Red: experiment, Black: steady numerical

1B 2B 3B

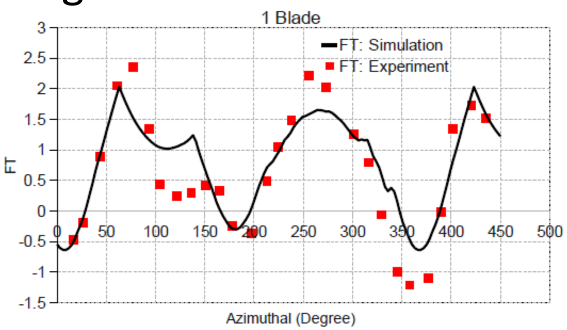
F_normal

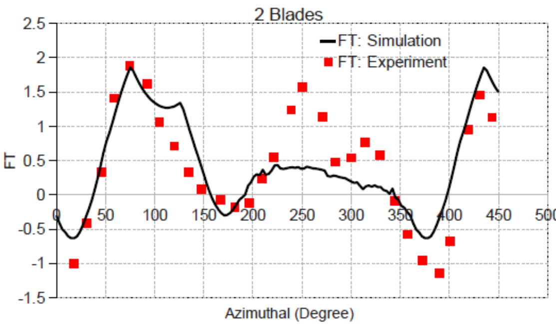


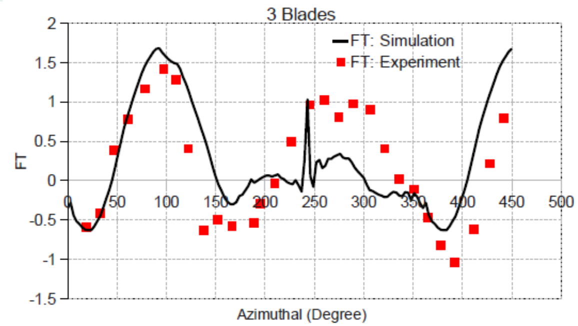




F_tangential







TSR = 5.0 and Re = 40,000

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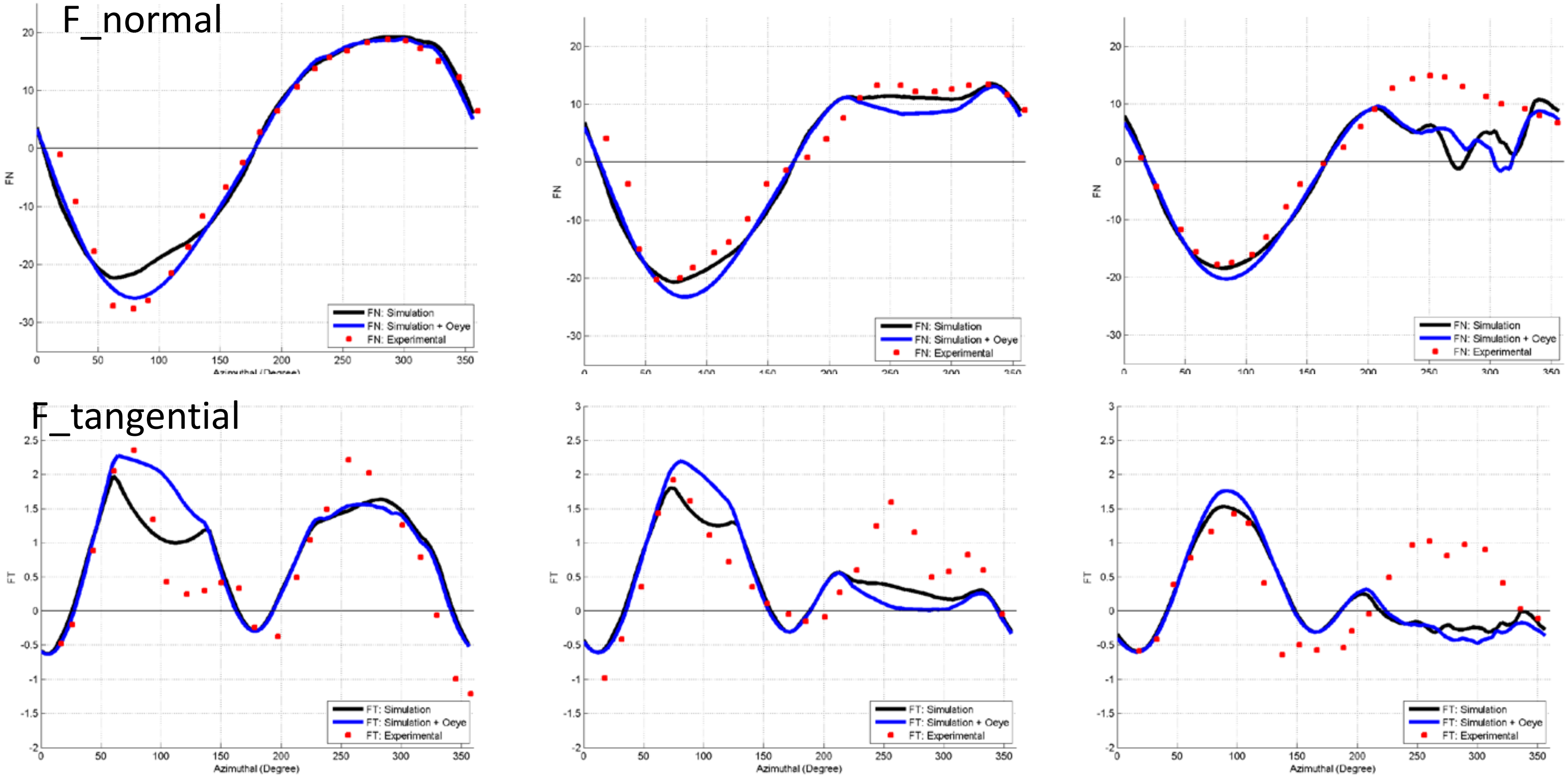
Validation – baseline vs dynamic stall version

Red: experiment, Black: steady, Blue: unsteady

1B 2B 3B

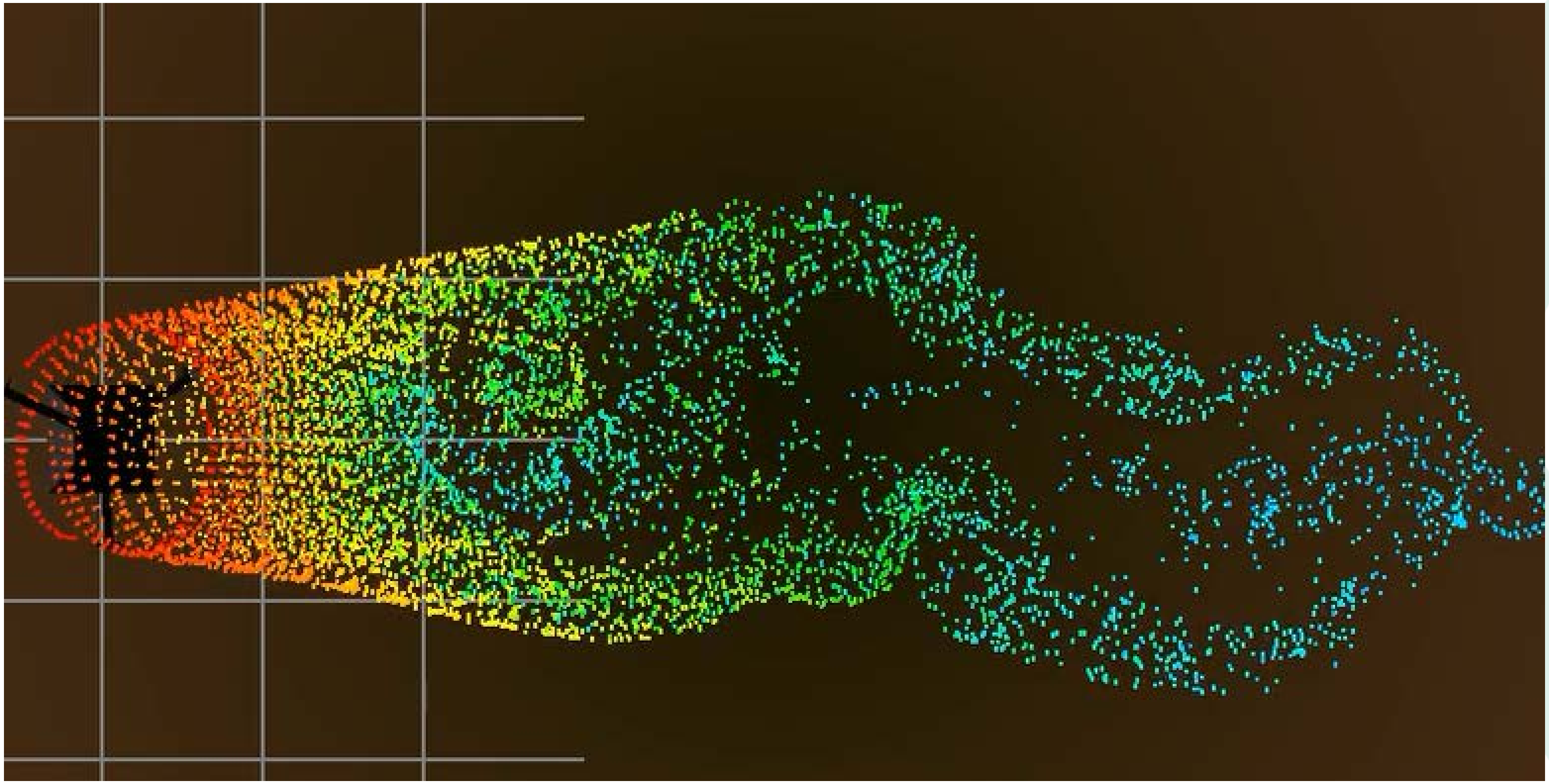


TSR = 5.0 and Re = 40,000

Conclusions

- The baseline vortex lattice code is capable of making an accurate prediction of the instantaneous aerodynamic forces on the blades with respect to the azimuthal position over the rotation.
- The effect of rotor solidity, a progressive retardation of the flow in the downstream region, is over predicted by the code.
- Øye's dynamic stall model results in a modelling improvement for the normal force for a 1-bladed rotor. This improvement vanishes for multiple blades, probably due to the predominant blade-wake, and wake-wake effects.

3d free wake vortex lattice code - Theorems



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Future works

- Modelling the blade-wake interaction for improving the computational accuracy in the downstream area.
- Development of a high performance free wake vortex **particle** code including more sophisticated viscous diffusion models, using fast algorithms and GPU parallel computational technique.
- Modelling the complete structure of the turbine for future aero-elastic simulation on VAWTs.

THANK YOU FOR YOUR ATTENTION

Any questions?

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