Objectives

Task 2: Wind Turbine Wakes and Clusters

Analyse and simulate turbulent wakes and turbine to turbine interaction subject to

- Wind shear
- Turbulent inflow
- Different wind directions
- Wind veer

Overall goals:

- Understanding of wake aerodynamics
- Development of turbulent wake model

Milestones Task 2

- **M7:** Parabolized stand-alone N-S park model. **Month 14.**
- **M8:** Validation of N-S model for wake behind a single wind turbine. **Month 24.**
- **M9**: Refined far wake model. **Month 24.**
- **M10**: Parametric study of wake interaction. **Month 36.**
- **M11:** Parametric study of wake stability. **Month 36.**
- **M12:** Refined Dynamic Wake model. **Month 48.**

Milestones Task 2

M7: Parabolized stand-alone N-S park model. **Month 14.**

Parabolised Navier-Stokes Solver (ParaSol)

- **Axial momentum equation**

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho ww)}{\partial z}=-\cancel{\frac{\partial p}{\partial z}}+\frac{\partial}{\partial x}\left[(\mu+\mu_t)\left(\frac{\partial w}{\partial x}+\cancel{\frac{\partial u}{\partial z}}\right)\right]$$

$$+\frac{\partial}{\partial y}\left[(\mu+\mu_t)\left(\frac{\partial w}{\partial y}+\cancel{\frac{\partial v}{\partial z}}\right)\right]+\cancel{\frac{\partial}{\partial z}\left[(\mu+\mu_t)2\frac{\partial w}{\partial z}\right]}$$

Parabolised Navier-Stokes Solver (ParaSol)

Basic Equations

- **Mass Conservation or Continuity Equation**

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

- **2D Momentum Equations in a plane orthogonal to the wind direction**

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho uu)}{\partial x}+\frac{\partial(\rho vu)}{\partial y}+\frac{\partial(\rho wu)}{\partial z}=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[(\mu+\mu_t)2\frac{\partial u}{\partial x}\right]$$

$$+\frac{\partial}{\partial y}\left[(\mu+\mu_t)\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\cancel{\frac{\partial}{\partial z}\left[(\mu+\mu_t)\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]}$$

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho vv)}{\partial y}+\frac{\partial(\rho wv)}{\partial z}=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left[(\mu+\mu_t)\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right]$$

$$+\frac{\partial}{\partial y}\left[(\mu+\mu_t)2\frac{\partial v}{\partial y}\right]+\cancel{\frac{\partial}{\partial z}\left[(\mu+\mu_t)\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]}$$

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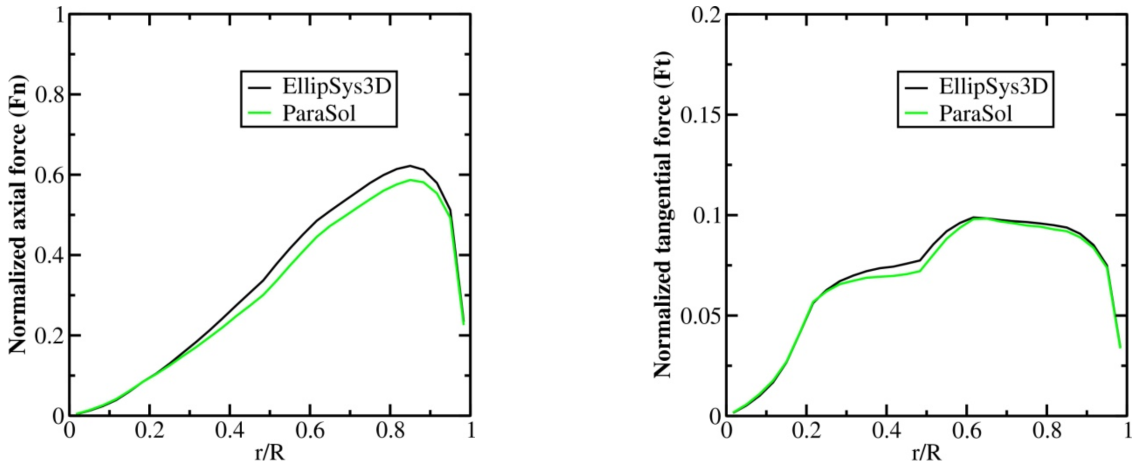
Parabolised Navier-Stokes Solver (ParaSol)



Figures: a) Normalized axial and tangential force coefficients and b) Iso vorticity for the flow past a NordTank 500 kW wind turbine at 10 m/s.

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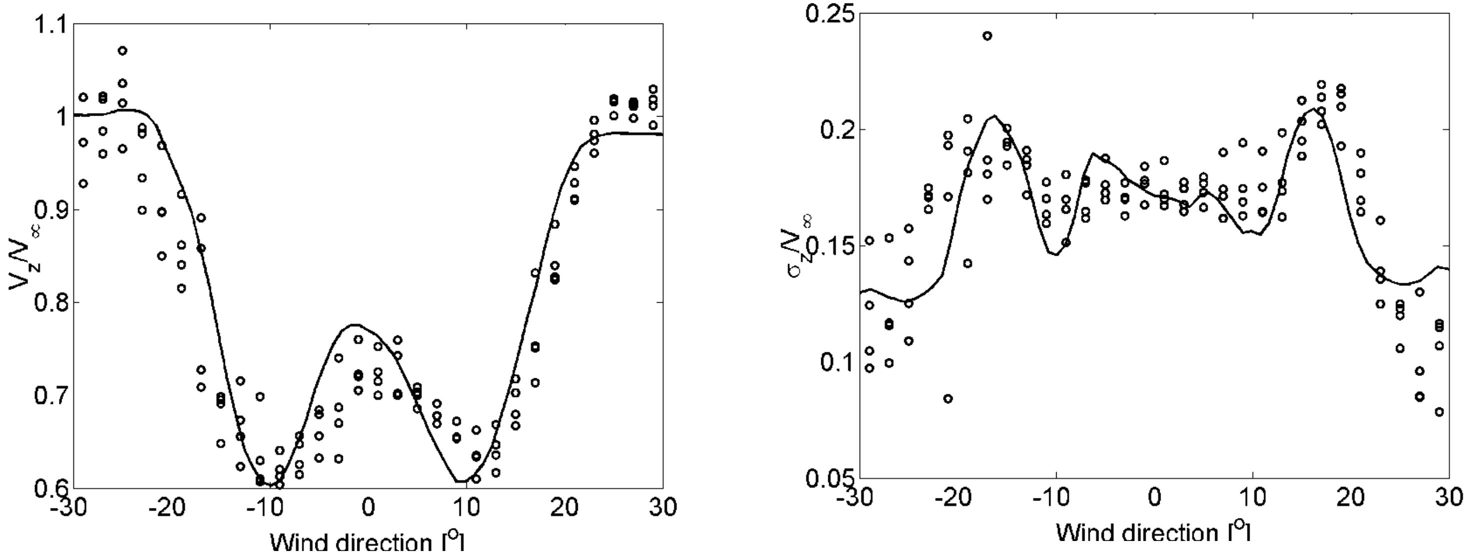
Conclusions on parabolized solver

- A parabolised Navier-Stokes code (ParaSol) has been developed.
- For each time step, the code is about 5 times faster than EllipSys3D with AL.
- No sub-iteration is needed
- The code needs only a few iterations to reach the correct loading and power before the wake is developed
- A numerical wake model based on the actuator line technique and body forces has been included
- The model enables to study single wake behaviour as well as the interaction of wakes from a multiplicity of wind turbines

Milestones Task 2

M8: Validation of N-S model for wake behind a single wind turbine. **Month 24.**

Comparison of velocity and turbulence intensity for 300 kW Combi wind turbine at Nørrekær Enge



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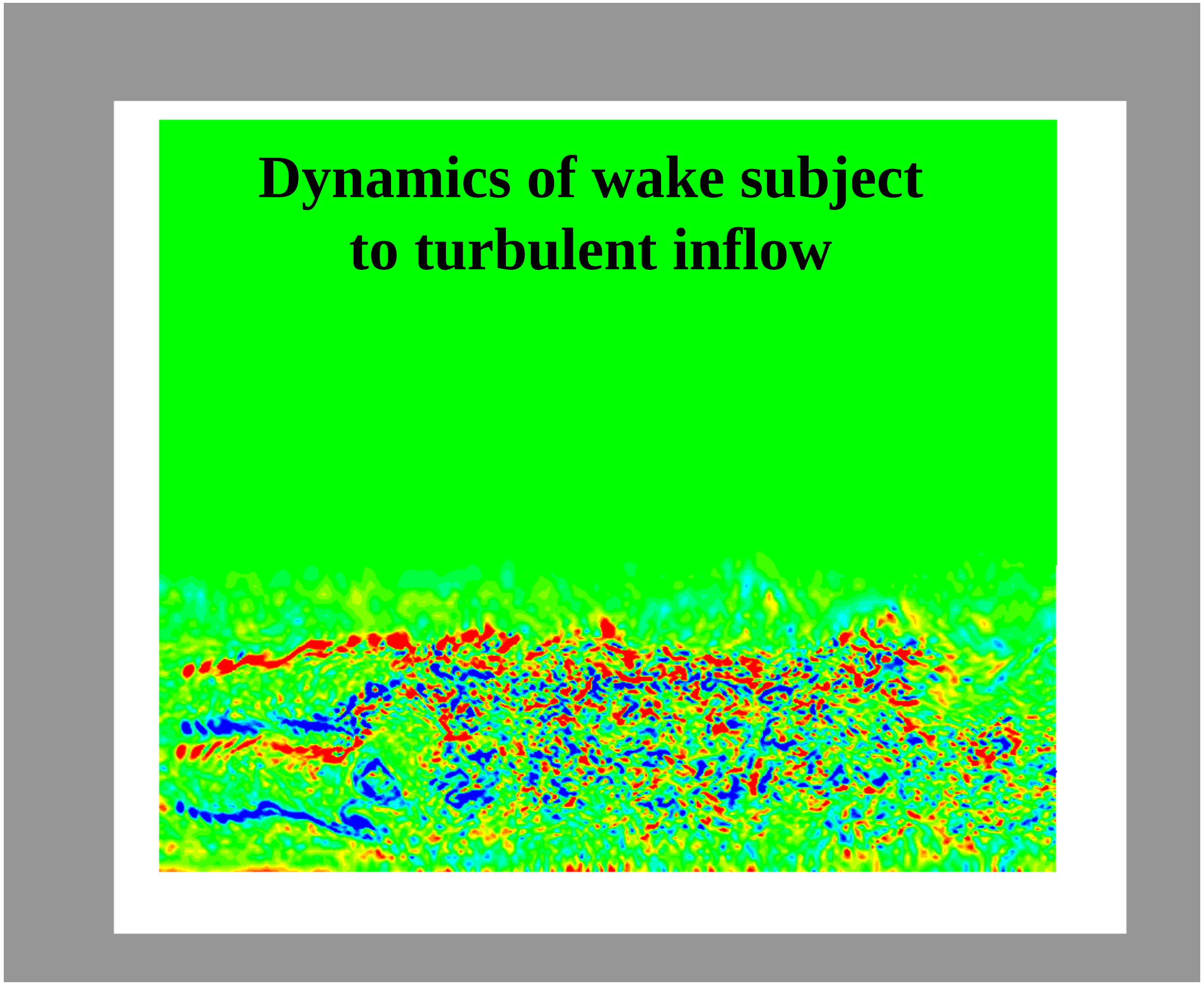
Milestones Task 2



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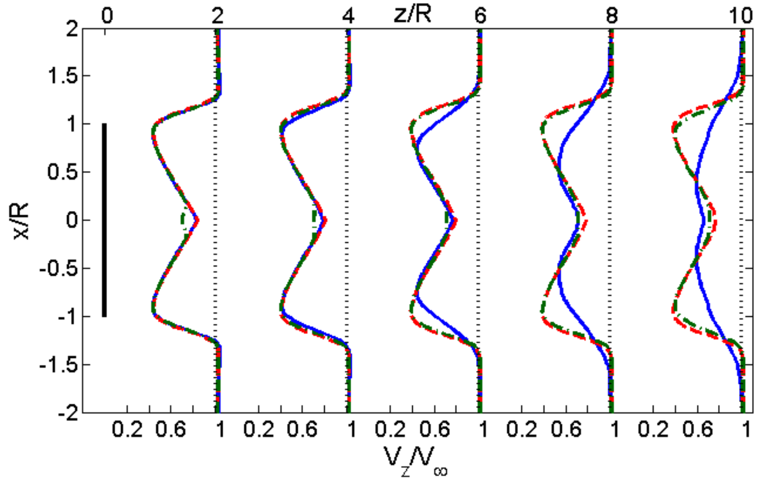
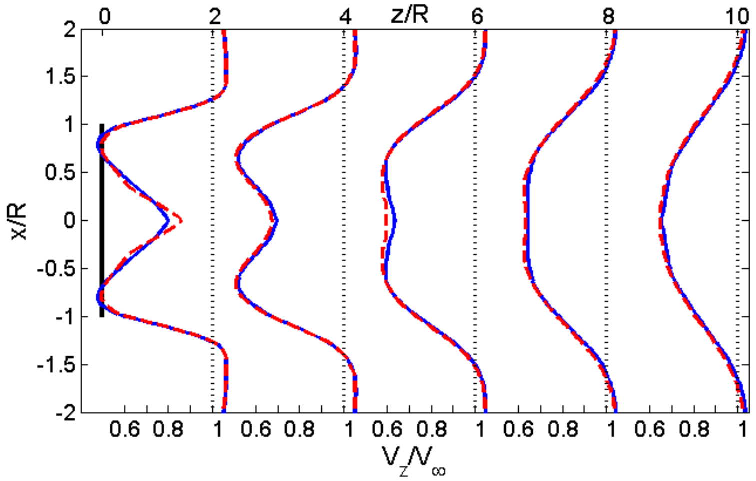
Milestones Task 2

Comparative study between fully resolved rotor and AL. Laminar inflow.



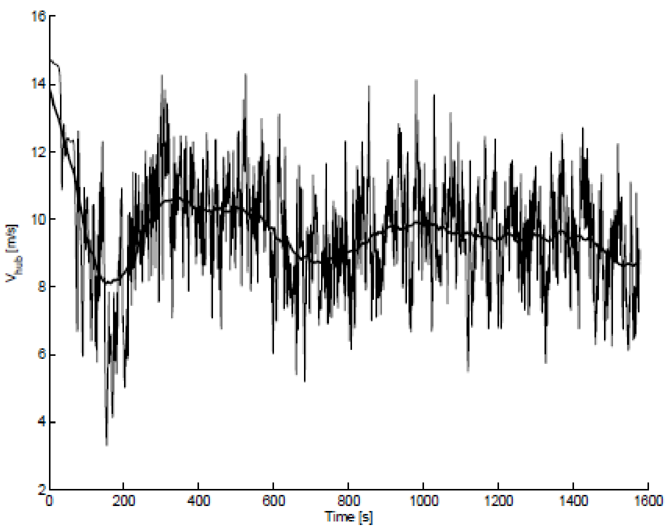
Comparative study between fully resolved rotor and AL. Turbulent inflow.



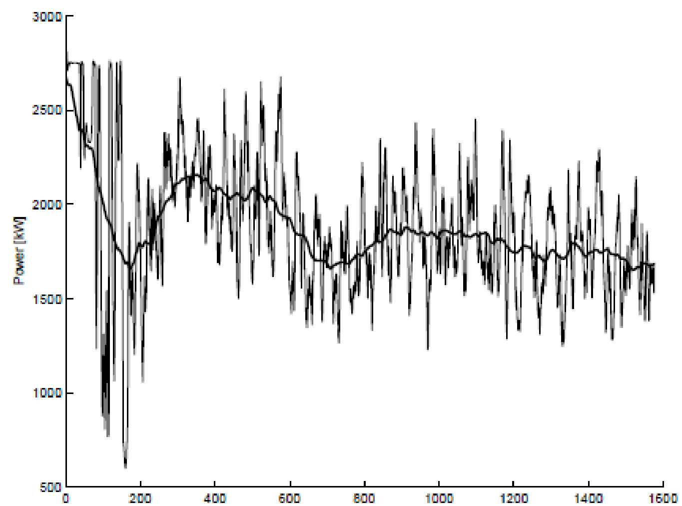
Milestones Task 2

M9: Refined far wake model. **Month 24.**

Computations carried out for NM80 rotor subject to periodic boundary conditions; Corresponding to wind turbine ine the middle of a wind farm

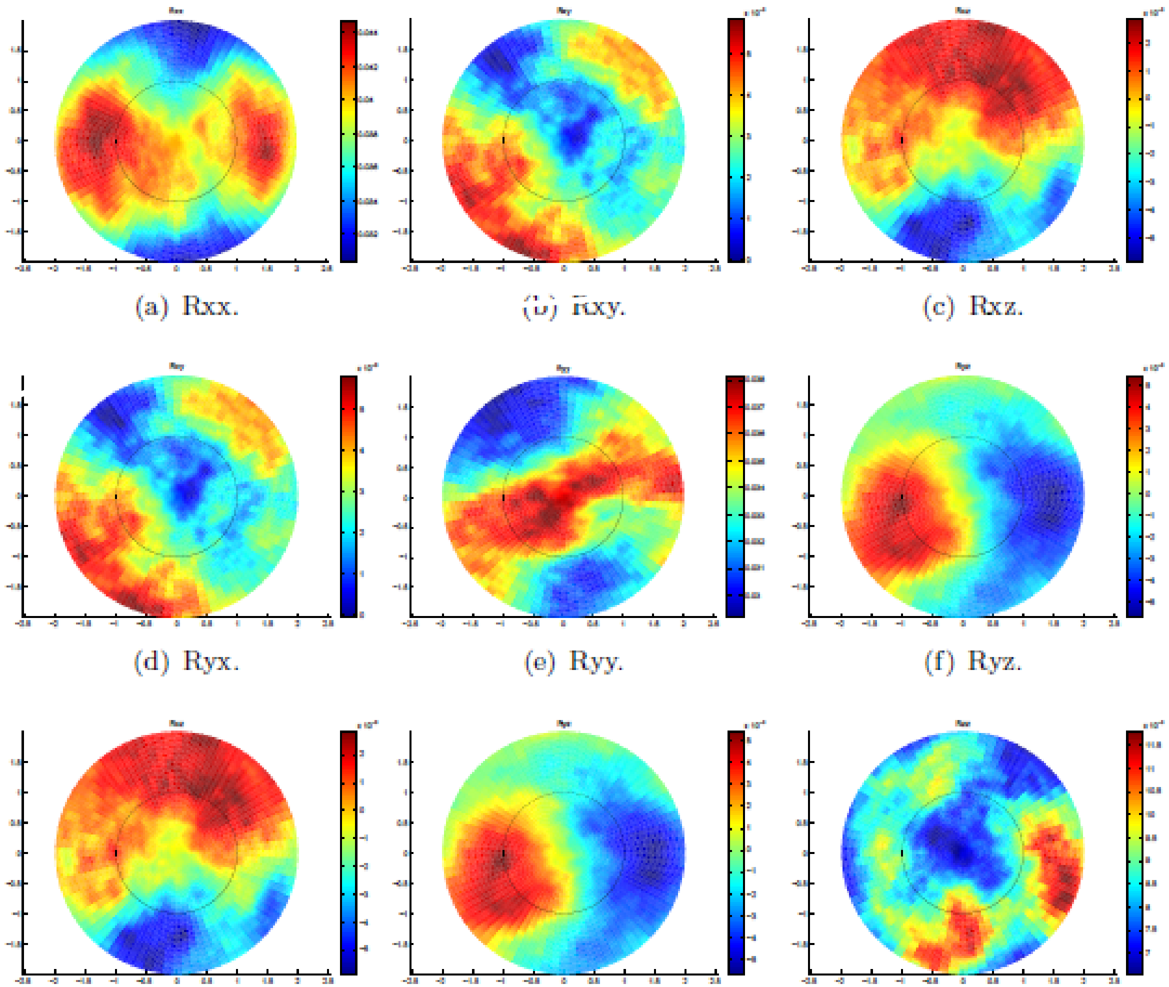


Computed wind speed at hub height



Computed power production

Milestones Task 2



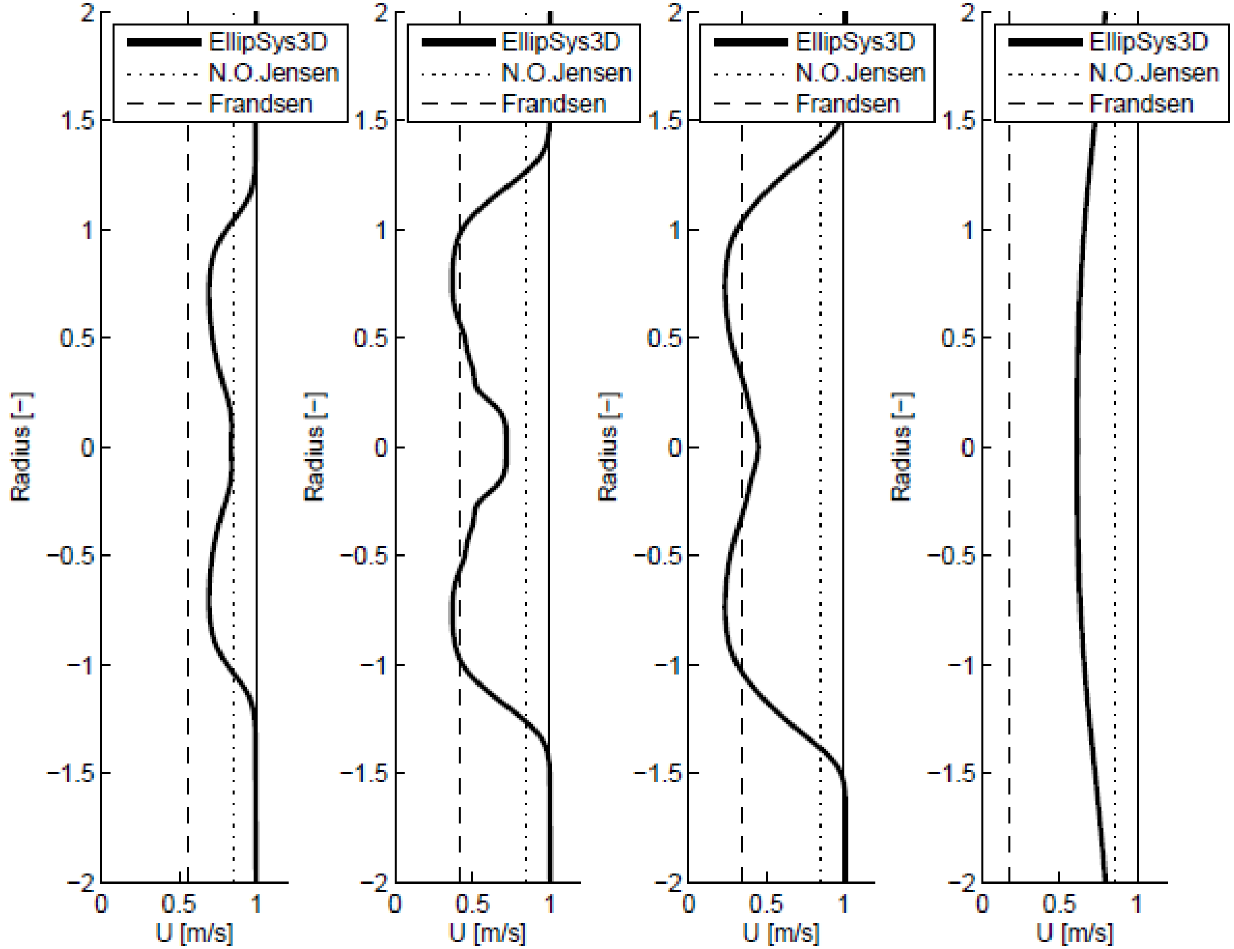
(a) Rxx. (b) Rxy. (c) Rxz.

(d) Ryx. (e) Ryy. (f) Ryz.

(g) Rxz. (h) Ryz. (i) Rzz.

Computed Reynolds stresses

Milestones Task 2

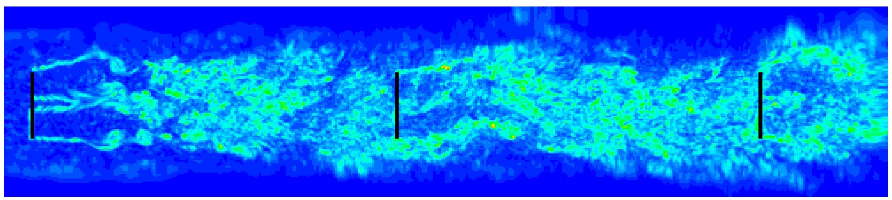


Velocity profiles behind 1, 2, 3 and 'infinitely' many turbines

Planes 2012: Task 2

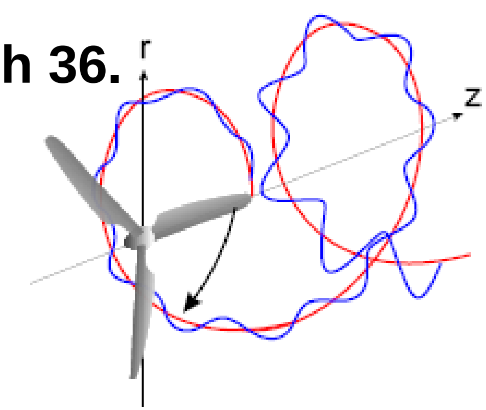
M10: Parametric study of wake interaction. **Month 36.**
Status:

- Initial computations carried out for turbines located along line



- Parametrical study will be undertaken

M11: Parametric study of wake stability. **Month 36.**
Status:



- Initial computations performed
- Parametrical study will be undertaken