Rotor/ABL Aerodynamics, TASK-1

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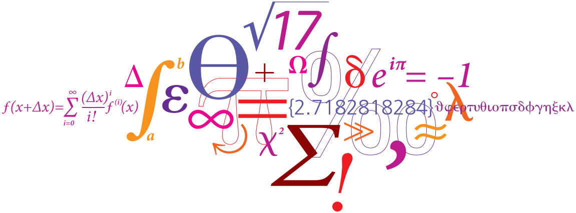
Department of Wind Energy · DTU

DTU Wind Energy, 14-11-2013



Outline

1. Project and Project Period
2. Tools
3. Results
   - MIRAS code validation, (Néstor R. García)
   - EllipSys2D, Development, (Dmitry K. Kolmogorov)
   - EllipSys3D, ABL Validation, (Niels N. S. et al)
4. Future Planning

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The ComWind Project

Original Project Period: 01-01-2010 to 31-12-2015, 6 years project.

Final date moved to 31-12-2016 (7 years project)

Original Partners: (DTU-MEK, DTU-RISOE, LM-Glasfiber, Siemens, Vestas, Vattenfall)

Present Partners: (DTU WIND, LM-Glasfiber, Siemens, Vestas, Vattenfall)

- Task-1: Rotor/ABL Aerodynamics
- Task-2: Wind Turbine Wakes and Clusters
- Task-3: Wind Farms
- Task-4: Siting in Forested and Complex Terrain
- Task-5: Atmospheric Boundary Layers

Project and Project Period

Task-1

Focus on CFD computations and advanced aerodynamic models using the resolved geometry of the rotor, with large scale effects in the form of turbulent inflow and yaw, and blade scale laminar/turbulent transition.

The original plan was to base the work on the DAN-AERO and Siemens Boulder exp.

Expected results:

Comparison of state of the art CFD/Aerodynamic models with multi-scale aerodynamic data. Development of phenomenological ’engineering’ models describing dynamic stall and yaw.

Partners (DTU-WIND, LM-Glasfiber, Siemens, Vestas)

Task-1, original planning

The following milestones were defined within the present package, or are related to the work

	Deliverable	Month
M1	Parametric study of two modern turbines in atmospheric shear	12
M2	Evaluation of the importance of cross flow instabilities for modern wind turbine rotors	24
M3	Parametric study of two modern turbines in yaw	24
M4	Development of refined ’engineering’ yaw model	36
M5	Evaluation of dynamic stall models and airfoil characteristics with respect to dynamic inflow and inflow turbulence	48
M6	Simulation of various unsteady inflow conditions for the NM80	36
M12	Parametric study of wake/wake interaction between two or more turbines	36

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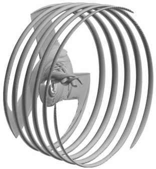
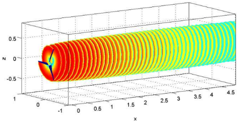
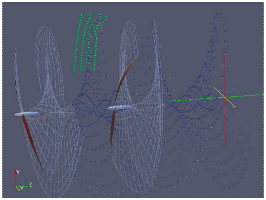
Codes used and developed in the project

Code Inventory:

- EllipSys2D/3D (Finite Volume CFD codes)
- MIRAS (3D rotor Free Wake, Viscous-inviscid based on Q3UIC)
- Vortex method coupled with HAWC2
- Q3UIC (Viscous-inviscid)







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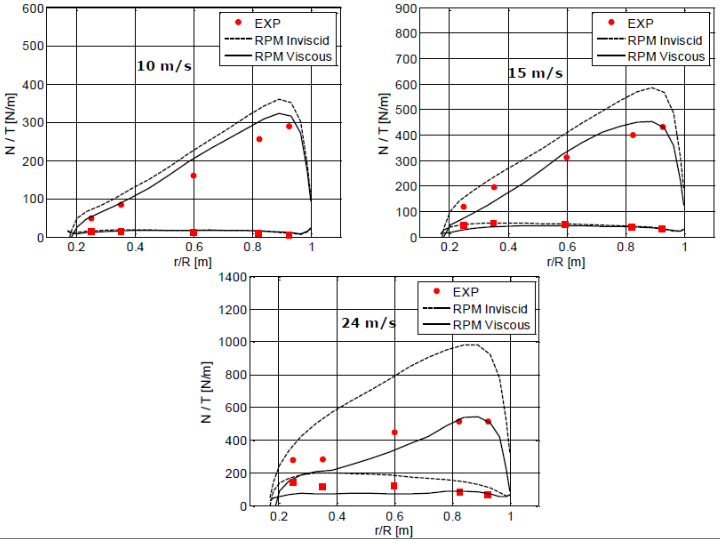
MEXICO Rotor



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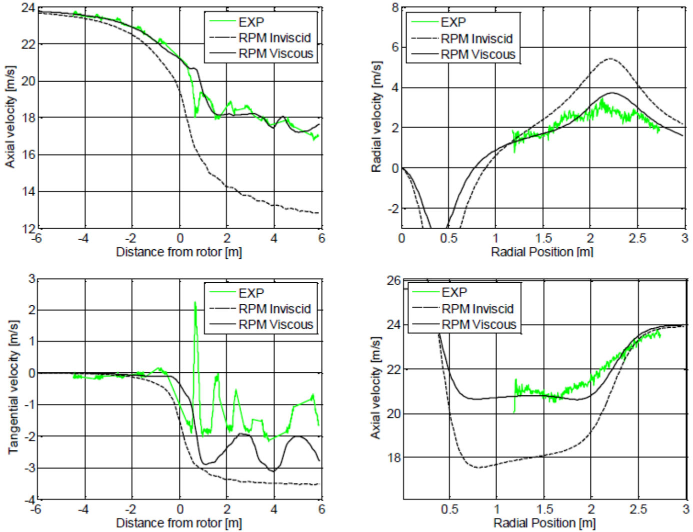
Results
MIRAS code validation, (Néstor R. García)

MEXICO Rotor



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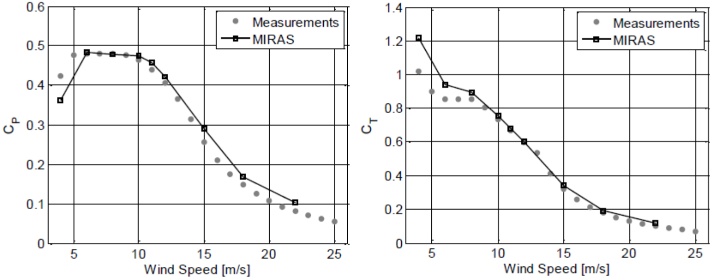
Results
MIRAS code validation, (Néstor R. García)

NM80 Rotor



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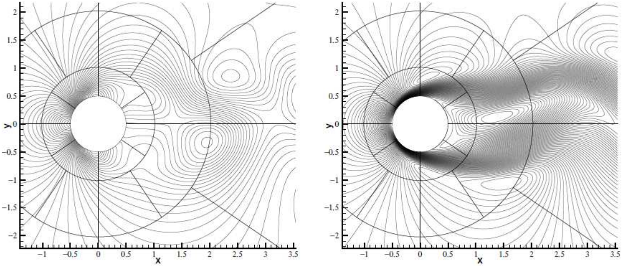
Results
EllipSys2D, Development, (Dmitry K. Kolmogorov)

Sliding Meshes

- Discontinuous grid interfaces
- Consistent momentum interpolation
- Multi-grid methods

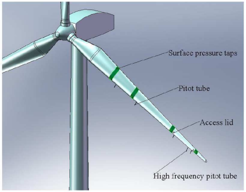


Results
EllipSys3D, ABL Validation, (Niels N. S. et al)

DanAero Setup

DanAero experimental setup:

- The DanAero experiment features a 3 blade modern wind turbine in the ABL
- Pressure measurements at four stations are available [13, 19, 30, 37]
- Pitot tubes, strain gauges, microphones, met mast inflow measurements, Lidar measurements



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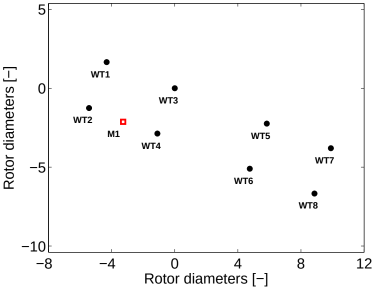
DanAero

Location and park configuration:

- The experimental turbine (WT3) is part of a small park
- The park is close by the cost



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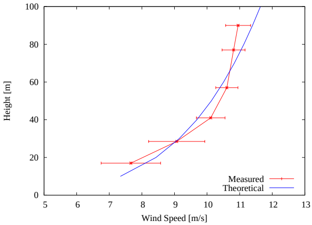
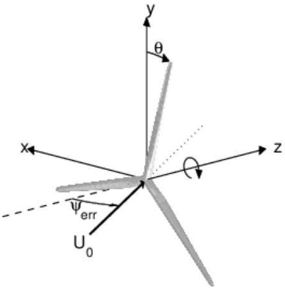
Selected yaw case

- Wind from South South-East ($\sim 155^\circ$)
- Weak shear $\sim U_\infty \left(\frac{z}{H}\right)^{0.2}$, with $U\infty = 10.3[\mathrm{m/s}]$ and $H = 57[\mathrm{m}]$
- Negative yaw error of 17.1 degrees defined according to the drawing below
- The RPM is 16.2





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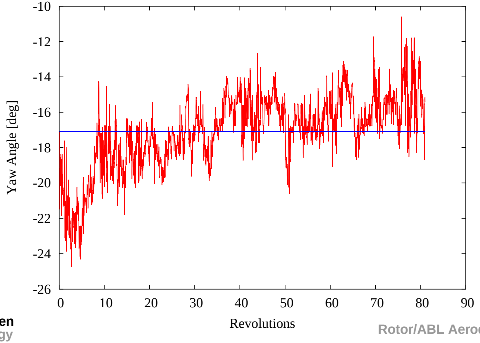
DanAero

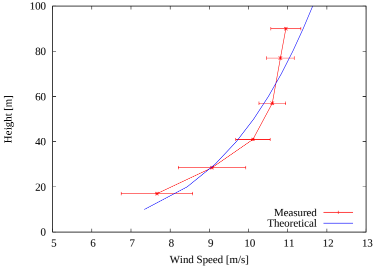
Some of the issues of ABL experiments

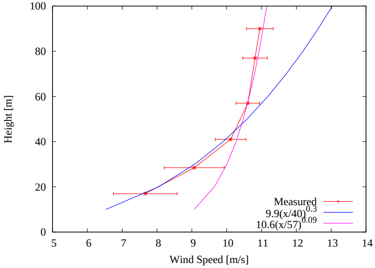
- The theoretical velocity profile do not fit the measured profile well at all heights
- We suspect that the actual profile has an growing internal boundary layer due to the close-by shore
- Due to the unsteady nature of the ABL, the yaw error is not constant.



DanAero

Better approximation of the vertical shear:





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In-house flow solver, EllipSys3D.

- Incompressible Navier-Stokes equations
- Rotation enforced through a moving grid option
- Turbulence is modelled by $k - \omega$ SST model
- Fully turbulent simulations
- Second order accurate in times
- Convective terms is modelled by QUICK
- Time-step 1600 per revolution, with 4 sub-iterations
- The computations are accelerated by using a three level grid sequence [1, 4, 8 $\sim$ 10] revolutions

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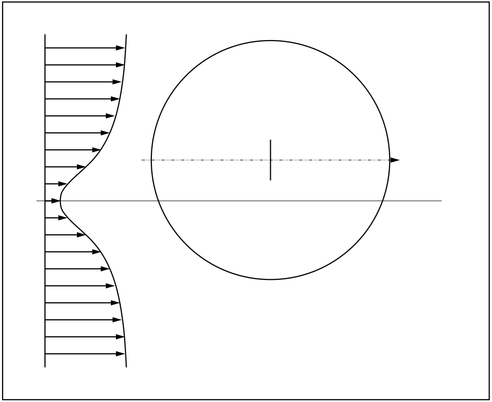
Problem Setup

$$U(z) = U_\infty \left(\frac{|x+57|\tanh((\frac{x+57}{10})^4) + 4(1-\tanh((\frac{x+57}{10})^4))}{57} \right)^{0.2}$$



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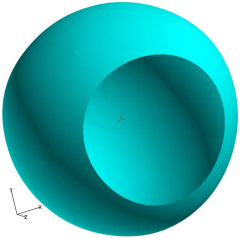
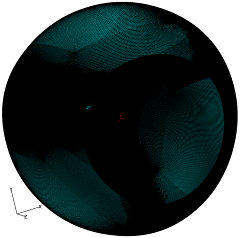
Computational Grid

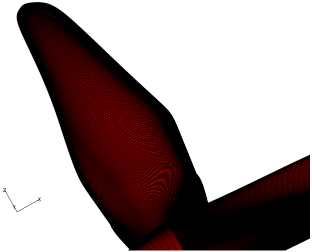
- The domain is $\sim$ 20 rotor diameters in diameter
- O-O-Topology of 432 blocks of 64^3 $\sim$ 113 Million points

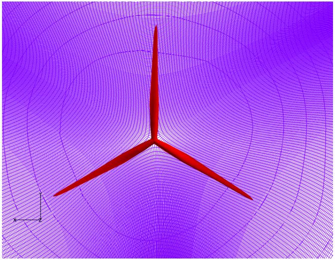




Computational Grid

- Chord-wise 512, Span-wise 256, Normal 256
- The wall normal y^+ is less than two on the blade surface





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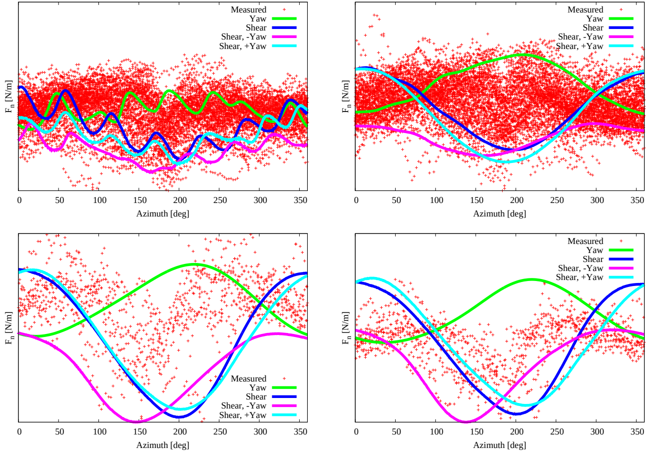
Normal Forces

The Azimuth variation of the normal forces

r=13 [m]

r=19 [m]



r=30 [m]

r=37 [m]

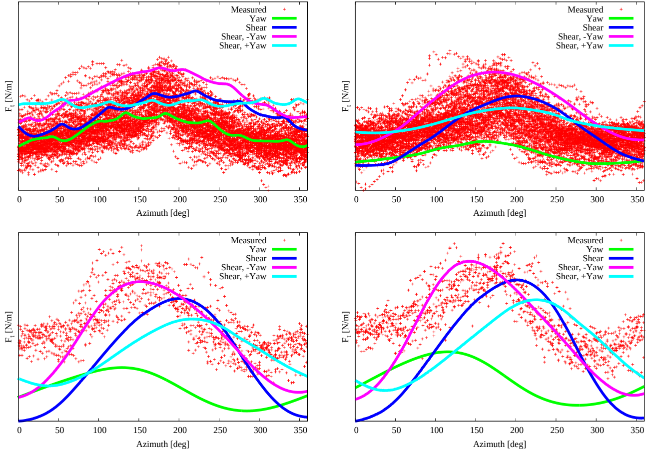
Results
EllipSys3D, ABL Validation, (Niels N. S. et al)

Tangential Forces

The Azimuth variation of the Tangential forces

r=13 [m]

r=19 [m]



r=30 [m]

r=37 [m]

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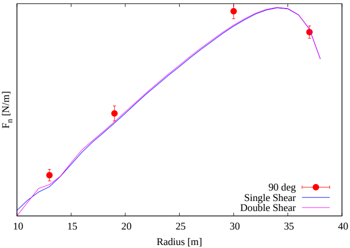
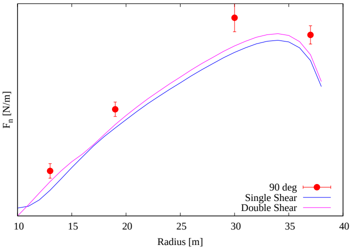
Effect of internal BL

The Azimuth variation of the normal forces

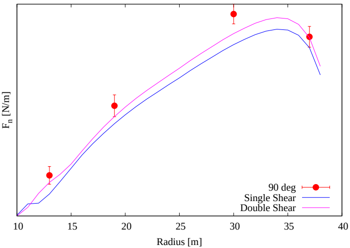
0 deg



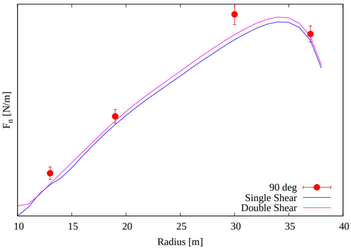
90 deg



180 deg



270 deg



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Effect of internal BL

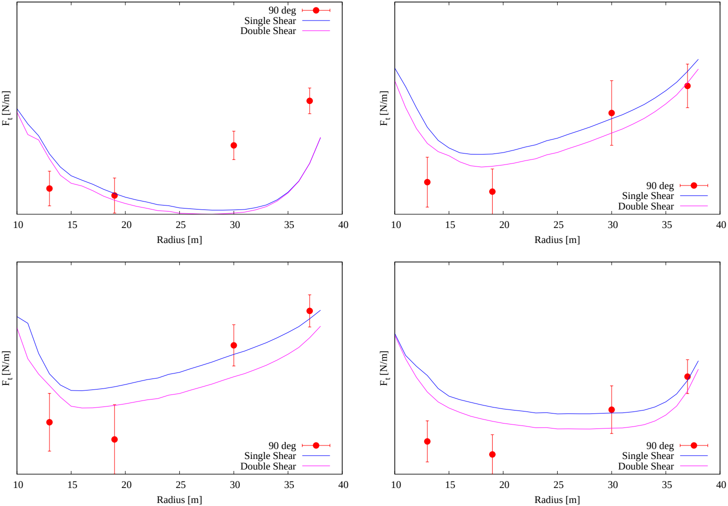
The Azimuth variation of the tangential forces

0 deg

90 deg

180 deg

270 deg



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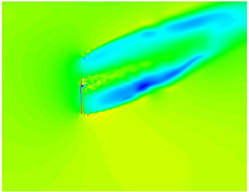
Conclusion and outlook

- Generally the azimuthal variation in the measurements are captured
- For the low yaw angle in the present case, shear is the dominant effect
- The improvement by including the internal boundary layer is minor
- The effect of the neglected tilt angle needs to be evaluated
- In the future we plan to look at higher yaw angles



Task-1, present planning

The following milestones were defined within the present package, or are related to the work

	Deliverable	Month
M1	Parametric study of two modern turbines in atmospheric shear	52
M2	Evaluation of the importance of cross flow instabilities for modern wind turbine rotors	60
M3	Parametric study of two modern turbines in yaw	60
M4	Development of refined ’engineering’ yaw model	50
M5	Evaluation of dynamic stall models and airfoil characteristics with respect to dynamic inflow and inflow turbulence	62
M6	Simulation of various unsteady inflow conditions for the NM80	60
M12	Parametric study of wake/wake interaction between two or more turbines	72

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Plans for the Coming Year

- Yaw and Shear Simulations (M3)
  - Continue with NM80 Cases
  - Mexico and NREL Phase-VI rotors
- Unsteady Inflow (M6)
  - NM80 in turbulent inflow
  - Pitch steps
  - Gust type simulations
- Transition (M2)
  - Transition studies on the NM80
  - Mexico rotor

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Plans for the Final Years

- Turbine in wake operation
  - Select a NM80 case
  - Nordtank/Tellus
  - 10 MW turbine
- Finalizing all project activities

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Task-1

Questions, Comments