Rotor Aerodynamics in Atmospheric Flows

DTU, LM, SIEMENS
presented by
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Background

Turbines are operating in the atmosphere:

- Realistic Reynolds numbers
- Turbulent inflow
- Vertical and horizontal shear
- Thermal stratification
- Misalignment between turbine and the flow (Yaw and Tilt)
- Time variation of the inflow
- Influences from the surroundings, the terrain, forest, turbine wakes
- Rain, ice, salt .....

Aerodynamics

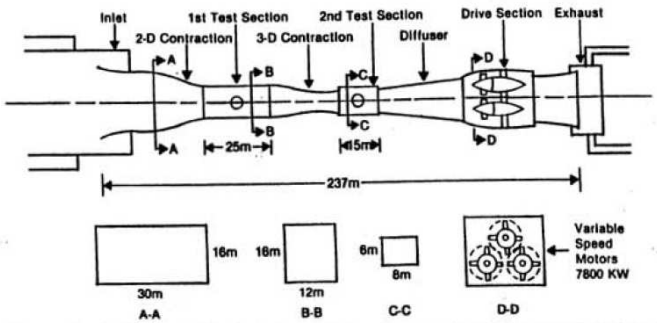
The aerodynamics can be split into different scales:

- The airfoil
  - Dynamic effects
  - Effects of inflow turbulence on the transition process
  - Effects of rain, ice, salt ...
- The rotor aerodynamics
  - Changes in the wind speed, (dynamic wake effects)
  - Yaw, tilt, shear
  - Effects from thermal stratification
  - Influences from the surroundings, the terrain, forest, turbine wakes

Rotor Aerodynamics in Wind Tunnels

Wind Tunnel Studies in the Past:

- FFA studied of STORK 5.0 WPX in the Chinese CARDC tunnel (1989 and 1992)
- NREL/NASA Ames 1999
- MEXICO, Model Rotor Experiments under Controlled Conditions (2001-2006)
- NREL has plans to enter the tunnel again in the near future !



Open-circuit low-speed wind tunnel (two test sections) at the Low-Speed Aerodynamic Research Institute near Mianyang

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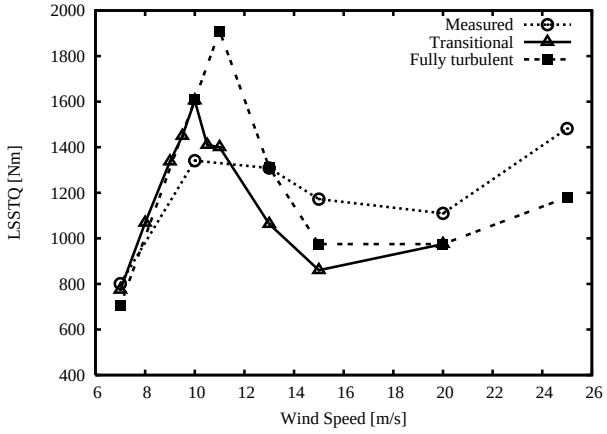

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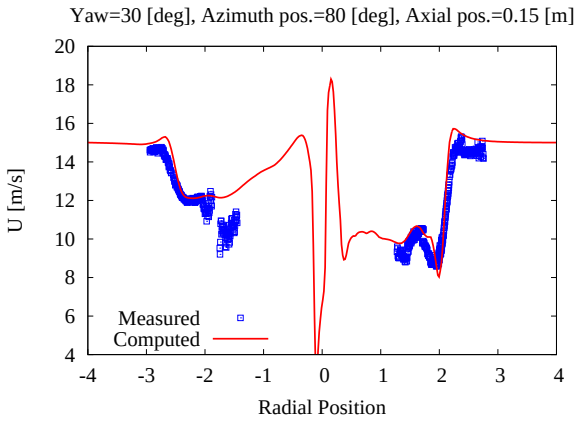
Figure 2.4: Model turbine on balance



Comparison with DAN Aero. Exp.
Test Cases

A series of cases have been selected
to investigate some of these problems:

- Non-sheared inflow.
- Sheared inflow.
- Yawed inflow. (combined with shear)

All cases with inflow from undisturbed direction and minimal wind turning.

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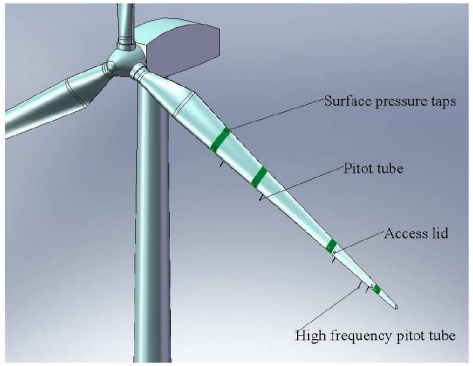


DAN Aero, Non-sheared axial case

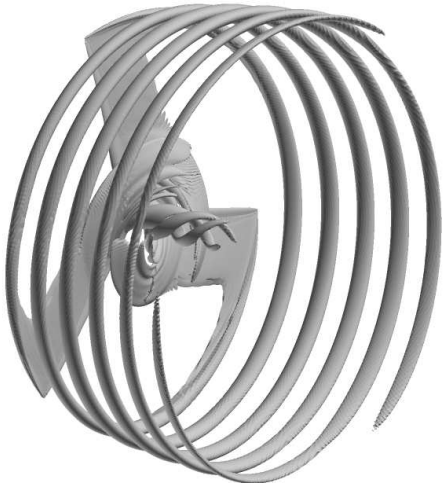
Using the most simple case available in atmospheric conditions, we can:

- Investigate a rotor at realistic Reynolds numbers.
- Investigate the necessity of including laminar/turbulent transition.
- Investigate the importance of inflow turbulence.

Using detailed load in the form of pressure and integrated spanwise force distributions.

DAN Aero, Non-sheared axial case
Grid dependency

Grid Level	Million Cells	LSSTQ [Nm]	Thrust [N]
S4	0.4	250.47×10^3	9.500×10^4
S3	3.6	247.38×10^3	9.344×10^4
S2	28	244.19×10^3	9.246×10^4
S1	226	244.14×10^3	9.186×10^4
C1	14	243.55×10^3	9.188×10^4



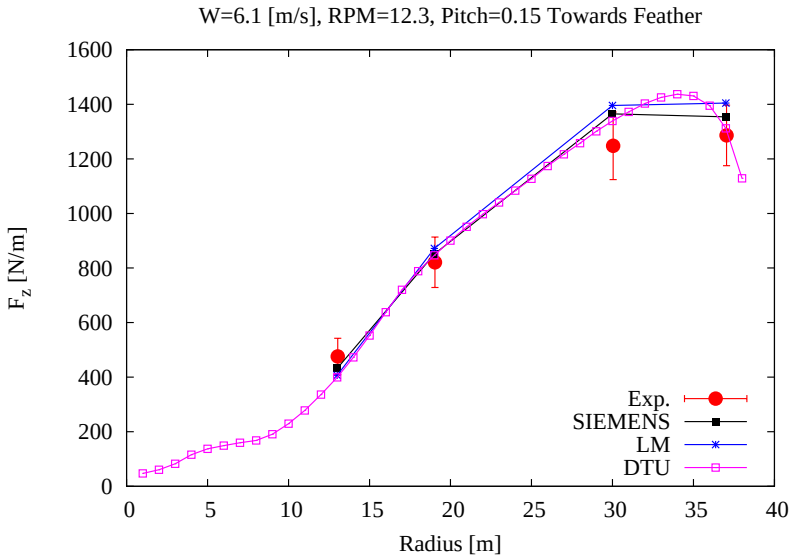
DAN Aero, Non-sheared axial case
Comparison between computations

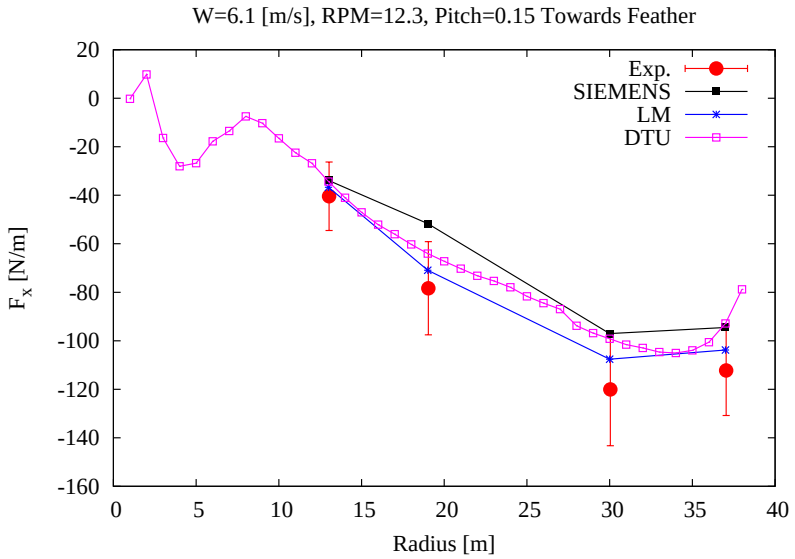
W [m/s]	LM_{ft}	LM_{tr}	$Siemens_{ft}$	$Siemens_{tr}$	DTU_{ft}	DTU_{tr}
6.1	3.07e5	3.25e5	3.13e5	3.45e5	3.12e5	3.39e5
8.0	-	-	6.71e5	7.41e5	6.86e5	-
12.0	-	-	1.61e6	1.88e6	1.66e6	-

Generally the differences between the computations are very small < 2 %

DAN Aero, Non-sheared axial case
Radial Blade Load Distributions

Turbulent computations at 6.1 [m/s]





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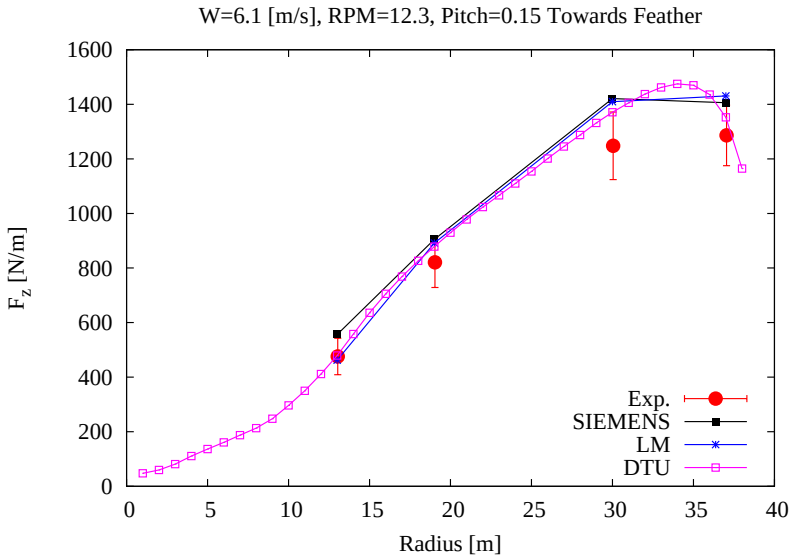
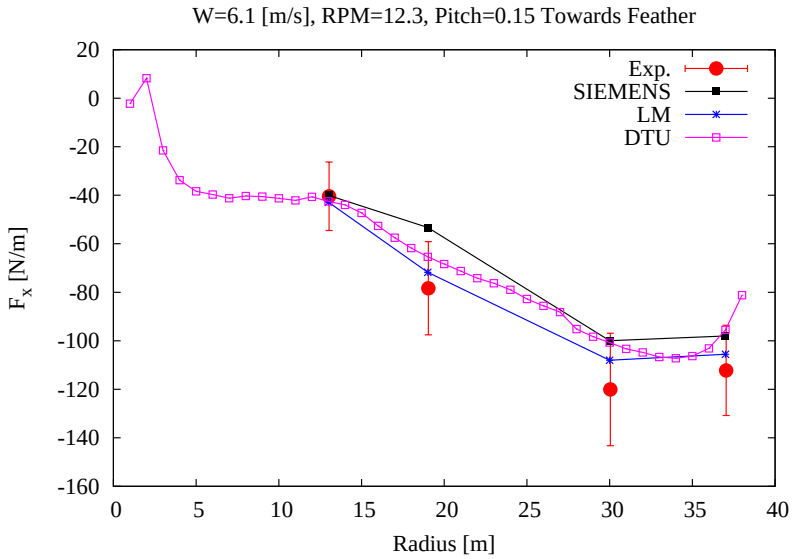
Radial Blade Load Distributions

Transitional computations at 6.1 [m/s]





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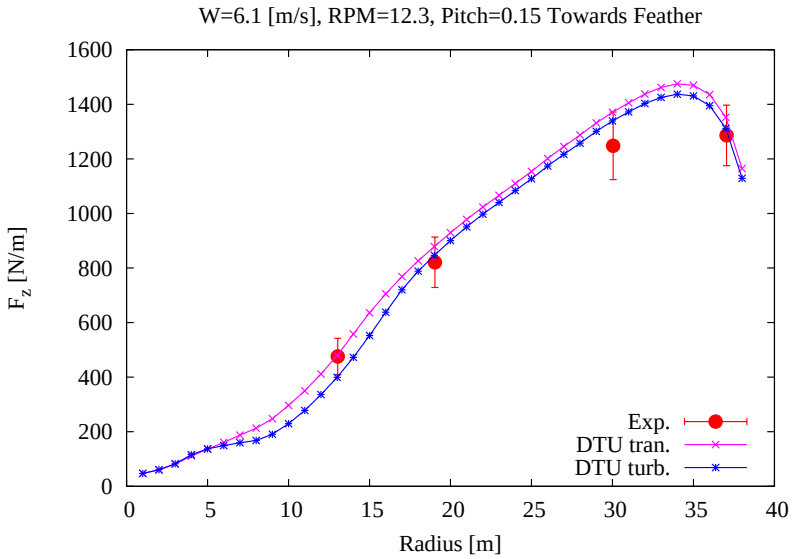
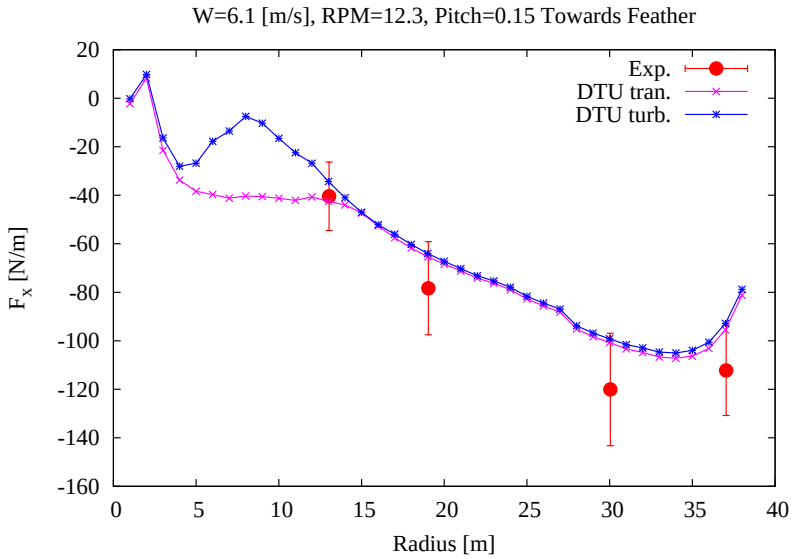
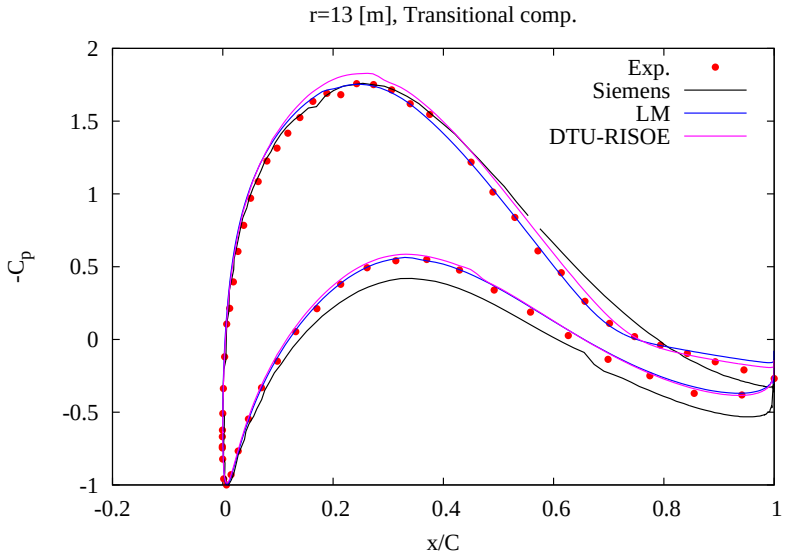
Radial Blade Load Distributions

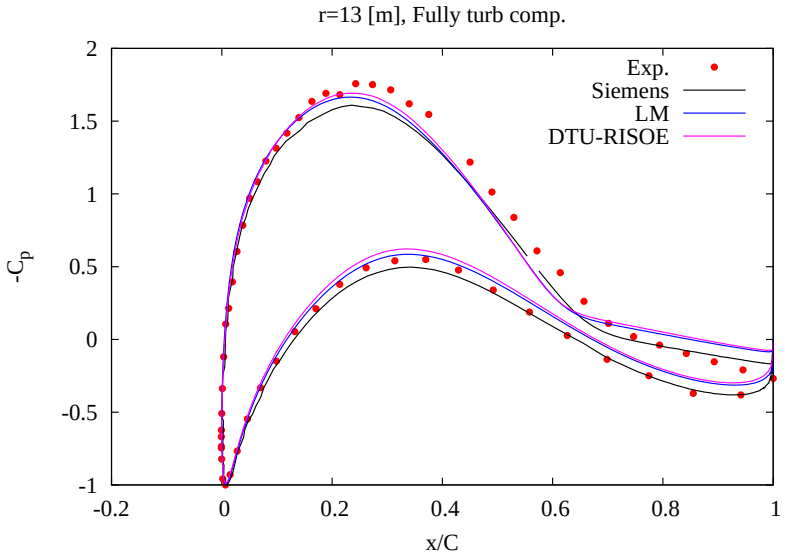
Comparison of turbulent and transitional computations at 6.1 [m/s]





DAN Aero, Non-sheared axial case
Pressure Distributions





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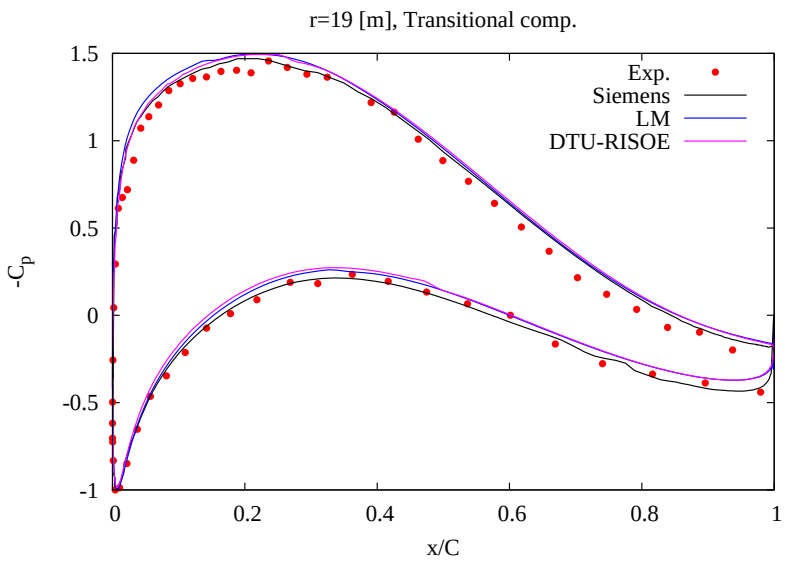

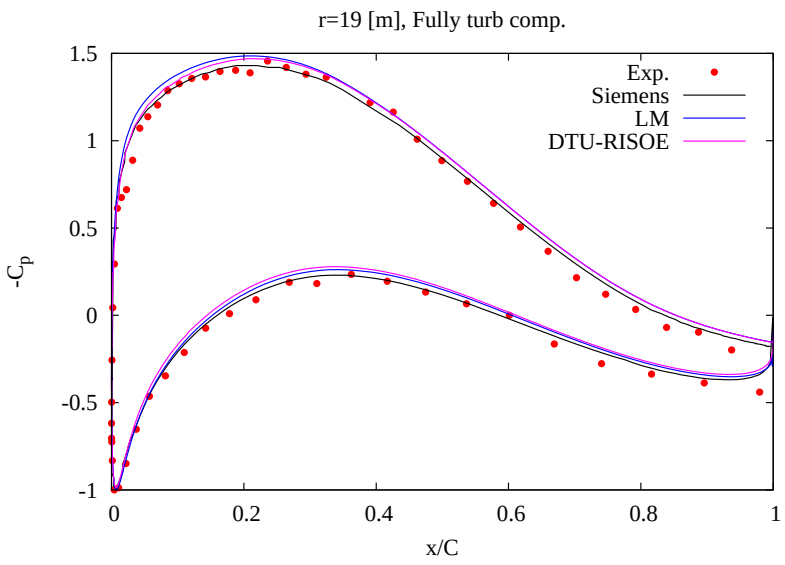

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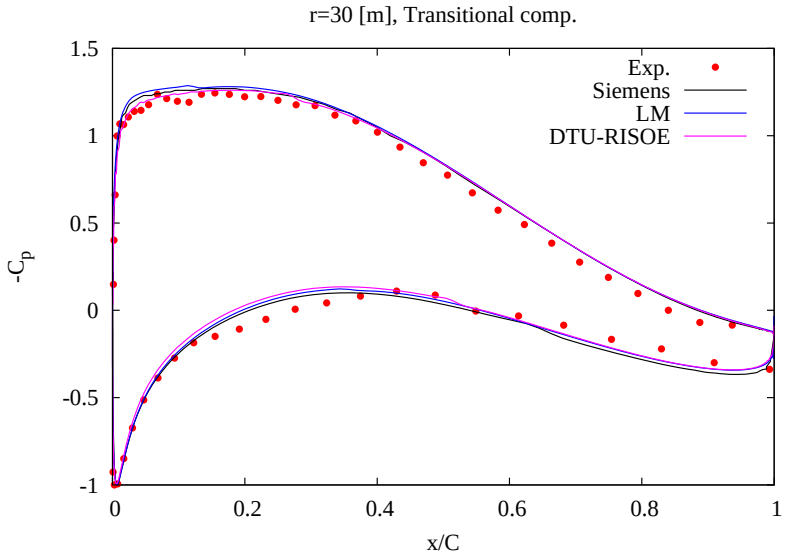

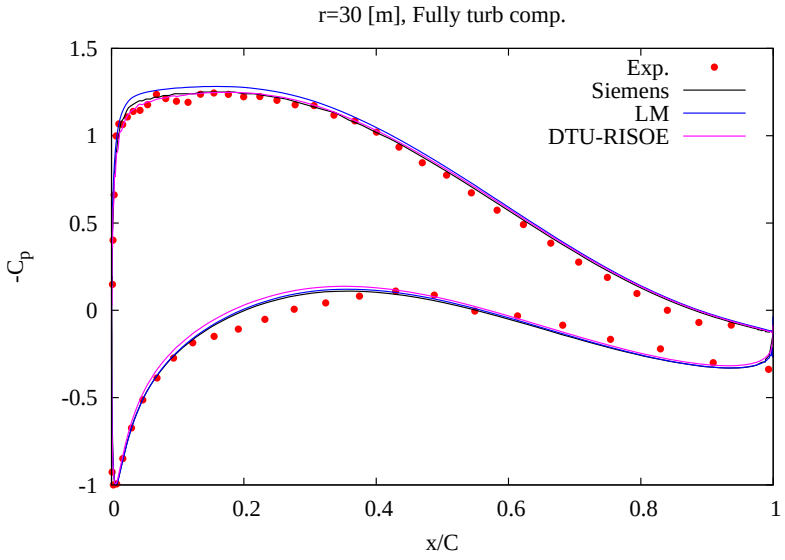

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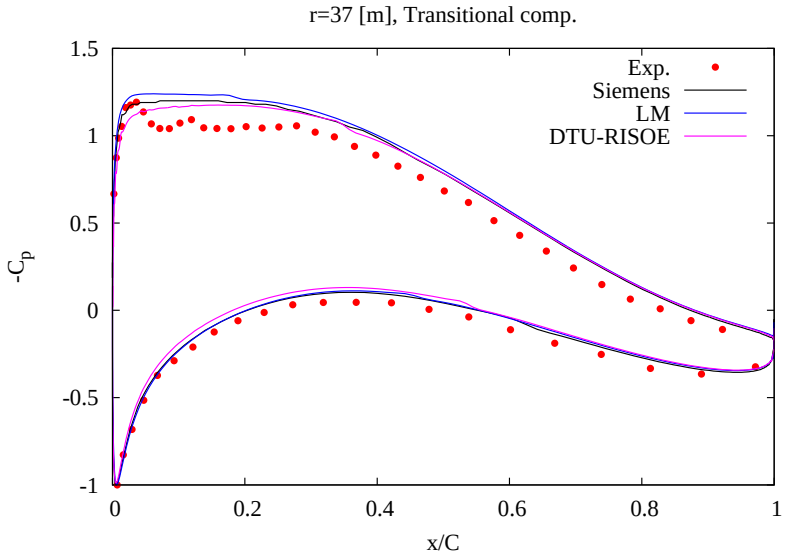

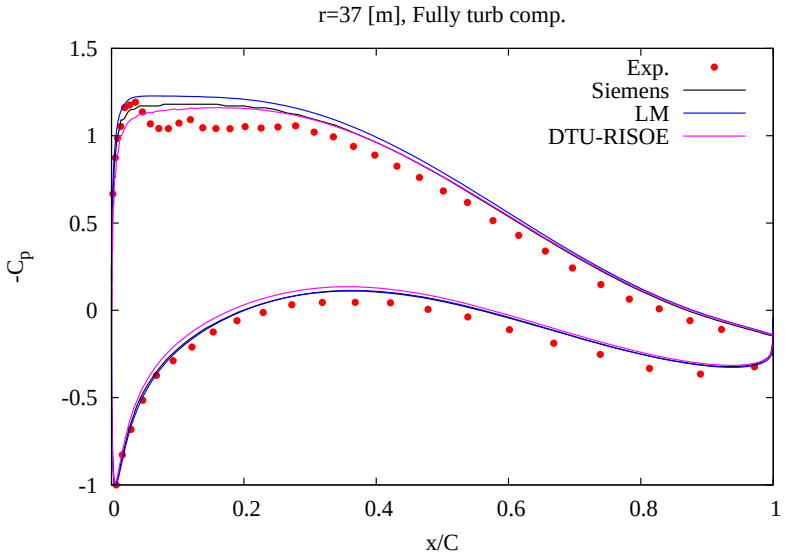

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DAN Aero, Non-sheared axial case
Pressure Distributions

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho\left(U_\infty^2 + (r\omega)^2\right)}$$

- The farfield pressure is not easy to estimate
- There is variability in the free stream velocity
- The RPM of the turbine will be varying

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Conclusions and Outlook

- The results show good agreement when considering the standard deviation of the measurements.
- With the spread in the present measurements it is hard to say whether laminar or turbulent computations produces the best results.
- It seems that most of the flow physics can be captured without considering the high inflow turbulence (6 percent).
- We will continue to look at the unsteady yaw and shear computations. So far the yaw computations has been studied without including the actual shear.

DAN Aero, Non-sheared axial case

Thanks for your attention
Questions please