Modelling and validation of wind turbine aerodynamics/aeroelastics

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The problem-1

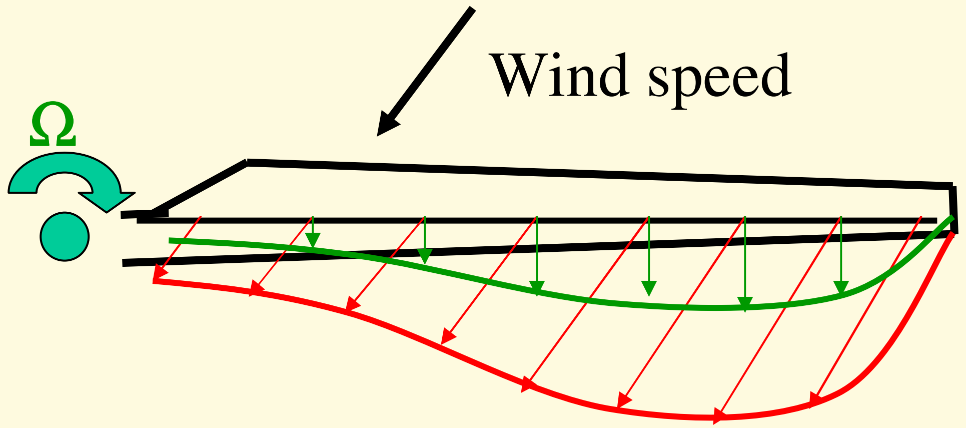
- Aerodynamics is basic to **power conversion** (main shaft torque), and to the all of the **loads** on the turbine
- Forces ⇨ bending moments/torque ⇨ loads and performance

$$M_{out-of-plane} = \int_0^R f_{oop} r dr$$

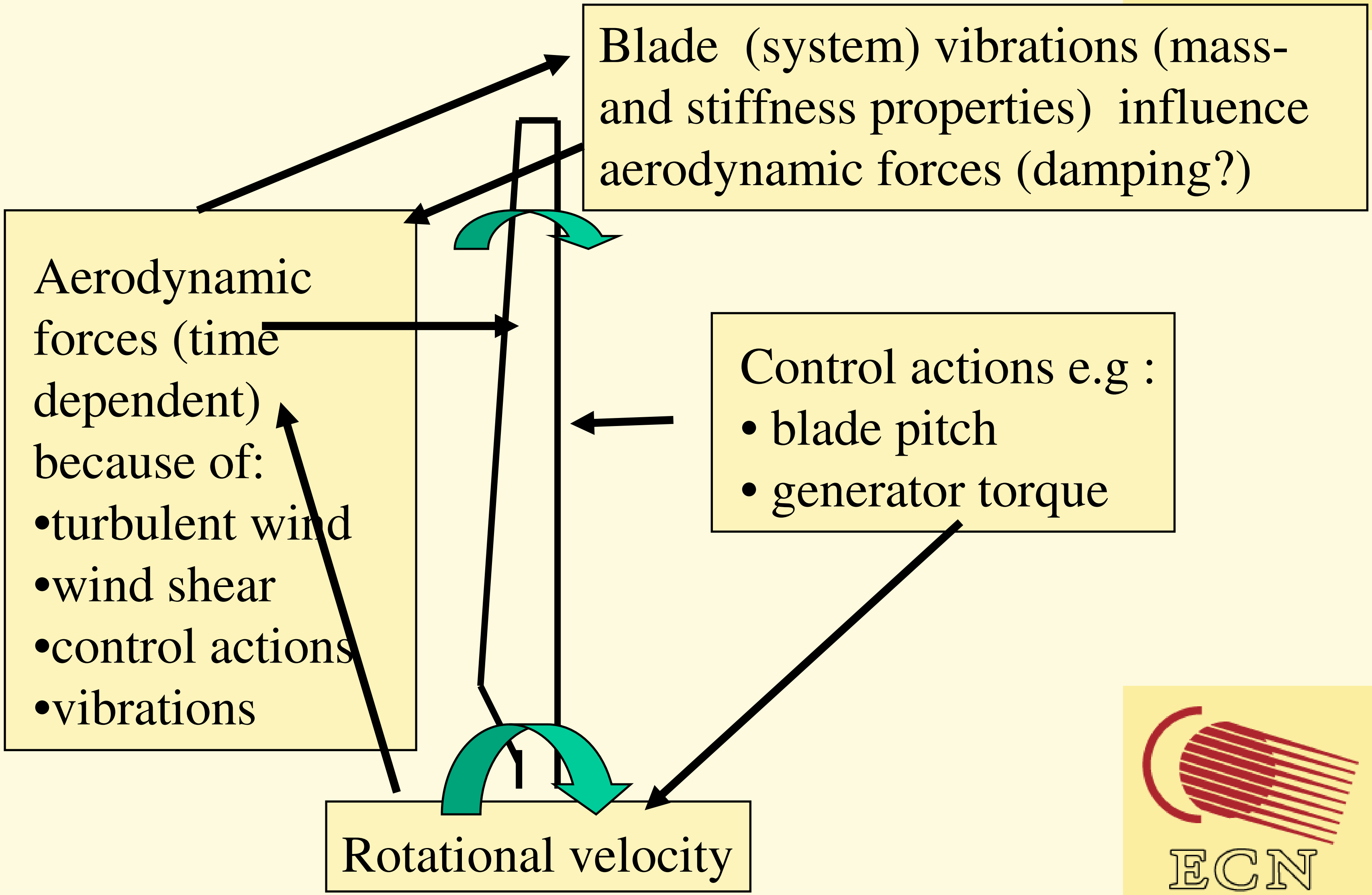
$$Torque = \sum_{3bladen} \int_0^R f_{ip} r dr$$

$$Power = Torque \times \Omega$$

$$Axial\ force: \sum_{3bladen} \int_0^R f_{oop} dr$$



The problem-2



The problem-3

- The aerodynamic interaction between wake and rotor is much more complicated than for fixed wind aerodynamics
- Both structural dynamics (large deflections) and aerodynamics (incursions into stall) are non-linear
- Fatigue due to load fluctuations must be analysed. Up to 10^9 fluctuations in the life time of 20 - 25 years!
- Unsteady time scales are relatively small, combined with high Reynolds number (10^8 - 10^9) for large turbines, hence high temporal and spatial resolution needed. Low Mach numbers

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Design and certification requirements

- For certification, approximately 100*10 minutes real time load and response calculations are required, for offshore possibly more and/or longer. These are done with aero-elastic codes(such as ECN Phatas code), with turbulent wind input
- **Navier Stokes for aerodynamics in this type of calculations in not a good idea if time to market is important.**
- Hence sacrifice completeness of calculations and cover by safety coefficients
- Anyway, Navier Stokes results must be validated : transition, turbulence (atmospheric and in boundary layer, bypass effects, rough surface effects, etc)

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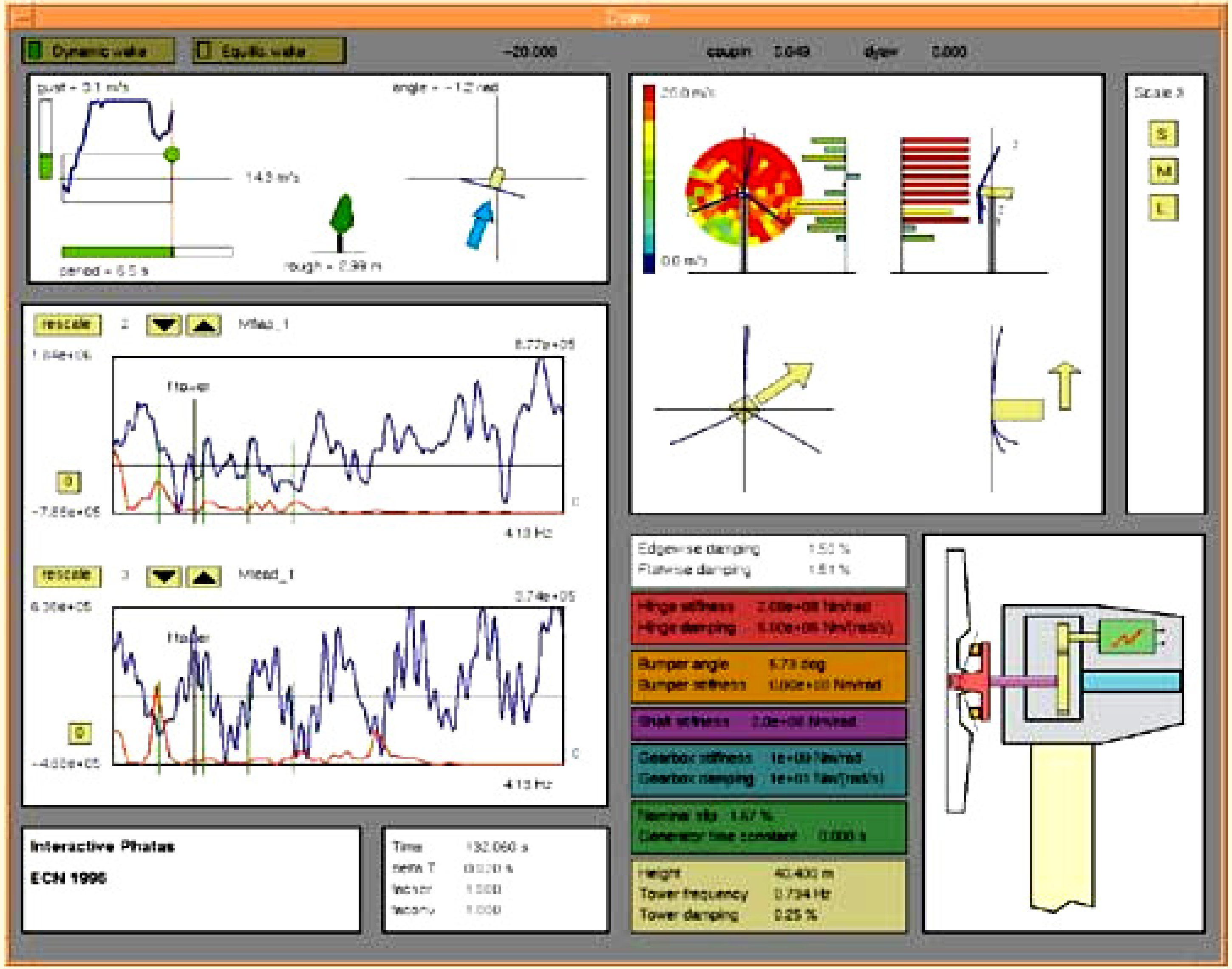
PHATAS visualisation



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Current practice

- Aerodynamics through Blade Element Momentum Method using 2D profile data, improved through 3D rotating effects and airfoil unsteadiness (so called ‘Engineering Methods’)
- Further improvements through better wake-rotor flow interactions (Euler codes, free vortex wake codes)
- Navier Stokes studies for flow about blades, RANS, LES, DES, to be used for further development but also to increase physical understanding and fine tune Engineering Methods
- Verification!!

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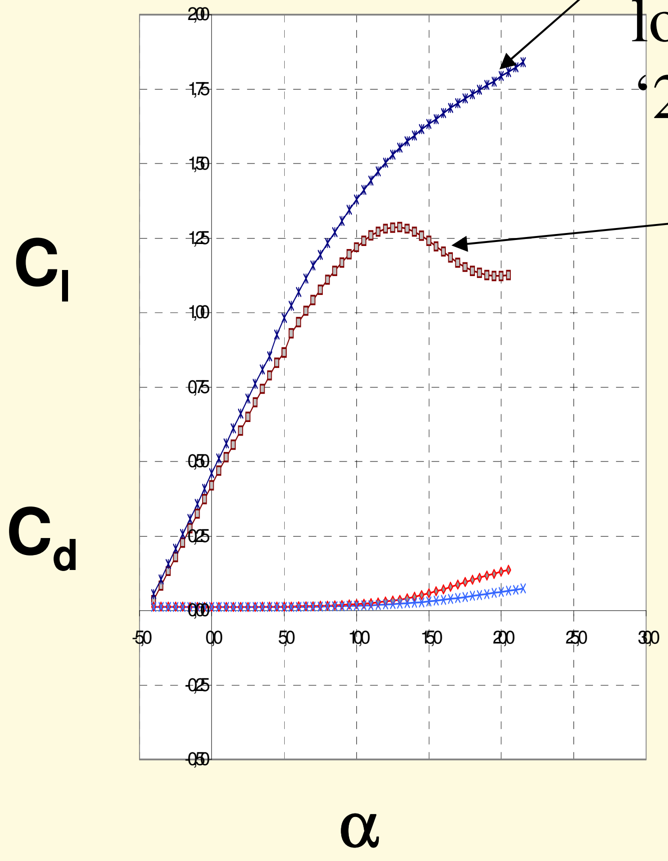
Example of improvements



3D rotating effects, depend on radial location on blade. Approached with a ‘2.5D’ version of XFOIL

2D

Need for Navier Stokes checks and for experimental validation

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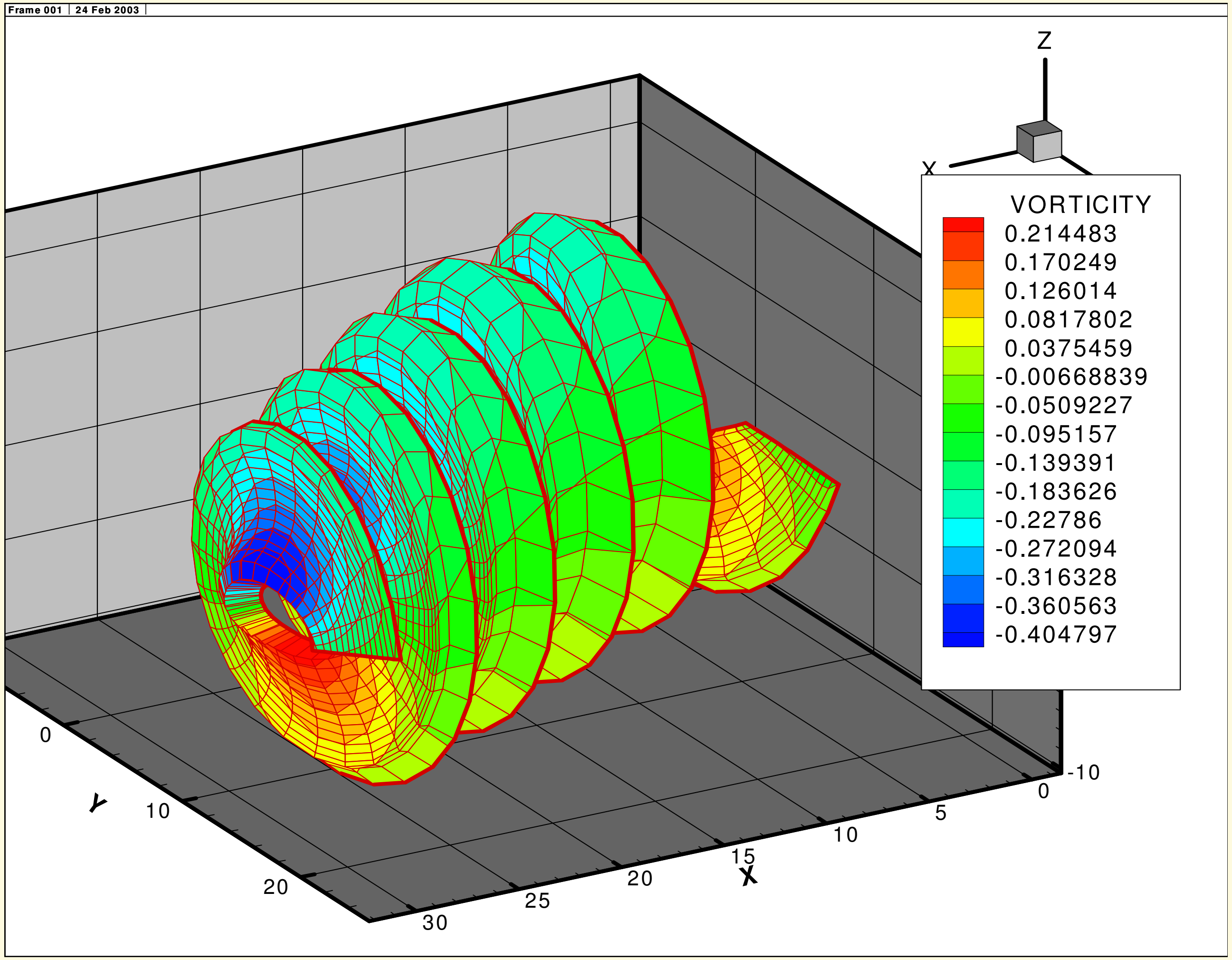
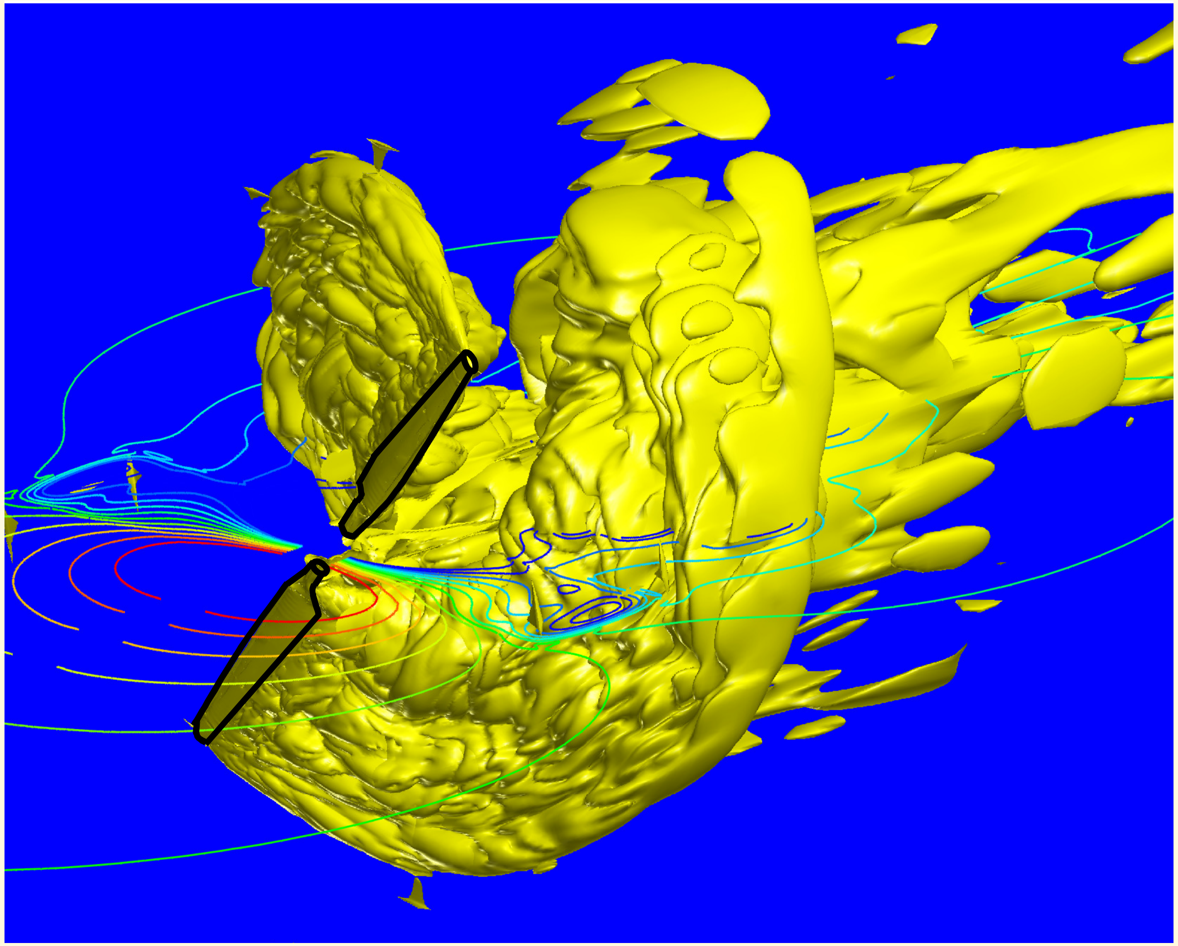
Example of free vortex wake calculations



Vortiticity distribution in wake (load history!) related to ‘induction’ (velocity reduction) in rotor plane

Detached Eddy Simulation (TUDk en RISO)



Why is further improvement needed?

Choices for design of very large wind turbines (largest existing is Repower 5 MW, 126 m rotor diameter):

- Conservatism of today: very high cost (cube square law)
- Reduced conservatism for lower weight and cost: very high risk with today's design methods
- **More reliable design methods, including more physics, for cutting edge design**

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Validation Efforts - 1

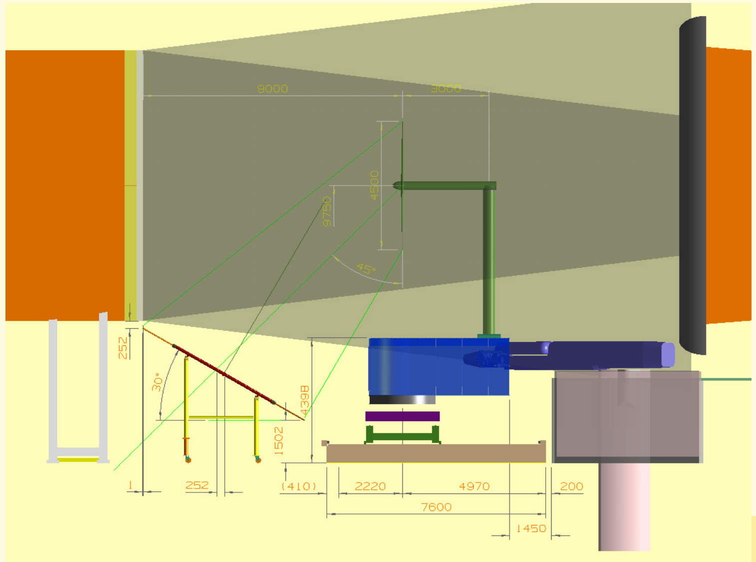
Two big projects:

- **NREL NASA Ames** measurements of 10 m diameter rotor in 90 ∗ 120 ft wind tunnel. Blade surface pressure measurements and total loads. **Presently 'data-mining' activity in IEA Annex XX**

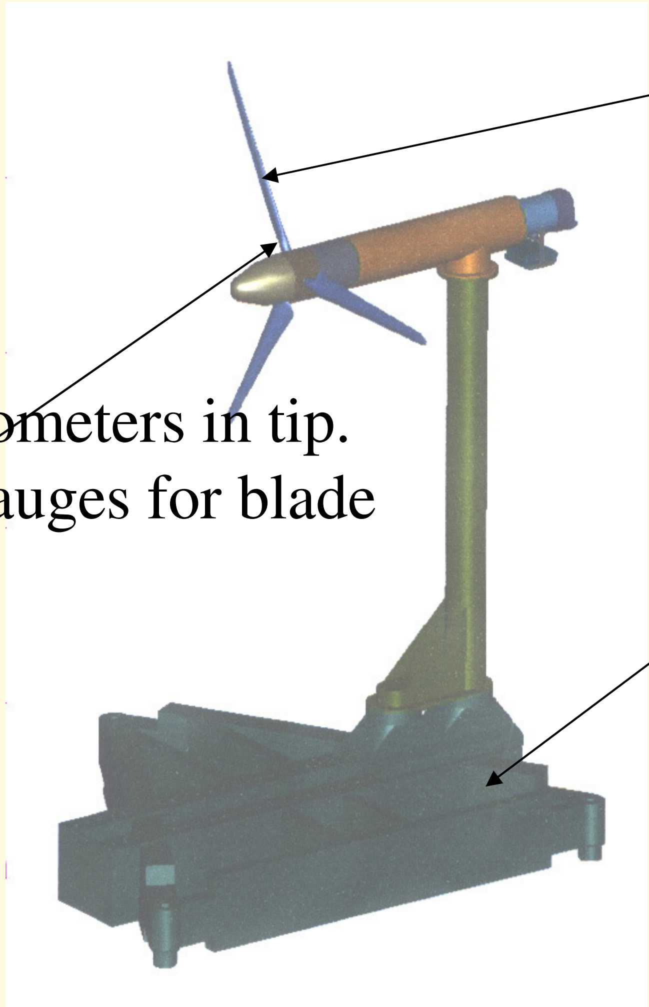
Validation Efforts - 2

- Model Experiments in Controlled Conditions, in DNW Large Scale Low Speed Facility:

  EU project **MEXICO**, 11 participants coordination ECN, 2001-2005.



MEXICO model rotor



Model rotor D=4.5 m, 148 electronic pressure sensors divided over 5 sections in three blades (1500 Hz).

Flow field measurement with PIV; in $9.5*9.5\ m^2$ open test section

Accelerometers in tip. Strain gauges for blade loads

Tunnel balance,

6 components of total loads

Model under construction, tunnel entry beginning next year

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Conclusions

- Exciting, complicated mixture of aero and structural dynamics
- Improvements necessary for next generation (10MW?) wind turbines for off-shore wind electricity centrals
- Areas:
  - Unsteady Aerodynamics on rotating blades, including massively separated flows
  - relation between wake and rotor-inflow
  - yawed flow
  - etc