ECN

Energy research Centre of the Netherlands

The value of Aerodynamic Wind Energy Research and the role of IEA

Gerard Schepers

ECN

Content

- Why Aerodynamics
  - Inventory of aerodynamic research subjects
- Why IEA
- Results from IEA Aerodynamic projects
  - IEA tasks 14/18 (aerodynamic field measurements)
  - IEA Task 20 (Analysis of NREL's measurement in Nasa Ames tunnel
  - IEA Task 29 (Analysis of measurements from EU project 'Mexico')

Important for:

- Energy production
- Loads (strength, costs!)
- Stability (failure, damage)
- Control
  - Stall (!)
  - (Individual) pitch
  - Distributed control

And hence the overall success of a wind turbine design

AERODYNAMICS

- Aerodynamics is a difficult but important driver for a cost effective and safe wind turbine design
  - Basically aerodynamics means finding approximate solutions of the Navier Stokes flow equations
    - Proving the Navier Stokes existence and smoothness is one of the 7 Millennium Prize Problems (http://www.claymath.org/millennium/)
    - Simplified aerodynamic models are needed!
      - How should we simplify?

AERODYNAMICS

- Aerodynamics of wind turbines is even extremely difficult
  - Rotating
  - In lower part of atmosphere → extremely turbulent
  - Instationary
  - Stall(!)
  - Large variety in scales (Diameter can be twice span of Airbus A380!)
  - Constraints and interactions (eg costs, system dynamics, tip deflection)
  - Wind turbine aerodynamic calculations are extremely time consuming
    - Load calculations: Time domain, many long time series needed to get ‘statistics right’
    - (~10^6 nr of time steps)→ Calculational time of a design spectrum can easily be longer than lifetime of the wind turbine
    - Generally calculations are done with simplified **Blade Element Momentum (BEM)** Theory with engineering add-ons to cover instationary effects, stall, 3D effects, yaw etc.

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Inventory of Aerodynamic Research subjects

- Aerodynamic (Design) Modelling
- Aerodynamic Measurements
- Support design of new concepts, e.g. (thick) airfoils (with or without) boundary layer suction, distributed control devices (passive and active) etc

Research subjects (modelling)

- Validation projects generally show 10-20% accuracy of blade loads calculated with BEM for standard conditions, (excluding stall) see e.g. [1])
- Still large uncertainties (i.e. 50%) in off-design conditions [1])
- Research needed to improve the accuracy, among others by other types of modelling

[1]) Schepers, J.G.; Heijdra, J.J.; Thomsen, K.; Larsen, T.; Foussekis, D.; Rawlinson Smith, R.; Kraan, I.; Visser, B.; Øye, S.; Ganander, H.; Carlen, I.; Voutsinas, S.; Belessis, M.; Drost, L.
Verification of European wind turbine design codes
Presented at European Wind Energy Conference and Exhibition, Copenhagen, Denmark, 2-6 July, 2001.

Research subjects (modelling)

- Continuous improvement of engineering models added to BEM by more accurate tuning parameters for instationary and 3D effects (including yaw and stall). Additional problem: For very large turbines BEM does not model correctly:
  - Incoherent structures over the rotor
  - Extreme shear, low level jets, 3D shear effects (wind farms!)
- As an alternative much effort on (in-house and commercial) Computational Fluid Dynamics (CFD) codes and ‘intermediate’ models are developed (free vortex wake methods, Rotorflow).

Research subjects (measurements)

- **Measurements, measurements, measurements**!
- Detailed information of aerodynamic behaviour along rotor blades is very urgently needed in several conditions (yaw, instationary conditions, large shear, incoherent structures, tip effects etc)
- Boundary layer determines the wind turbine behaviour to a large extent but it has never been measured in real life
- Transition point on a blade has never been measured in public research on modern wind turbines [1])
- Detailed aerodynamic measurements under field conditions were carried out in the 90's (IEA tasks 14/18)
  - New initiatives on detailed aerodynamic field measurements (including transition) in Denmark, USA, EERA
- Wind tunnel measurements are valuable addition (IEA Tasks 20, 29)

[1]) Only: G. van Groenewoud and J. van Ingen *Investigation of the transition of the boundary layer on the rotorblades of the ECN HAT-25 turbine*, TUDelft Report LR-390, **May 1983 (!) (**In Dutch)

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WHY IEA?

Because it is the **only** MONDIAL (Asia, Europe, American Continent) format for cooperation and exchange of information between wind turbine aerodynamicists

IEA INVOLVEMENT ON AERODYNAMICS

1. **Specific aerodynamic research projects**
   - 1991-1997: IEA Task 14 (Field Rotor Aerodynamics, Operating Agent: ECN)
   - 1997-2001: IEA Task 18 (Field Rotor Aerodynamics, enhanced, Operating Agent: ECN))
   - 2001-2007: IEA Task 20: Analysis of NREL's Phase VI experiment (NASA-Ames, Operating Agent: NREL)
   - 2008-2011: IEA Task 29: Mexnext (Mexico, Operating Agent: ECN)
2. **198x-2005: IEA expert meetings on aerodynamics**
   - Annual meetings
   - Often attended by > 20 aerodynamicists all over the world
   - Informal meeting, Aerodynamic 'free wheeling' and brainstorming
   - Very effective way of exchanging information
   - Restart needed

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IEA Task 14/18

- In the 90’s many institutes instrumented ‘full scale’ turbines with pressure scanners, at test fields under atmospheric conditions
- These programs were coordinated within IEA Task XIV (1991-1997) and IEA Task XVIII (1997-2001)

Aerodynamic measurements

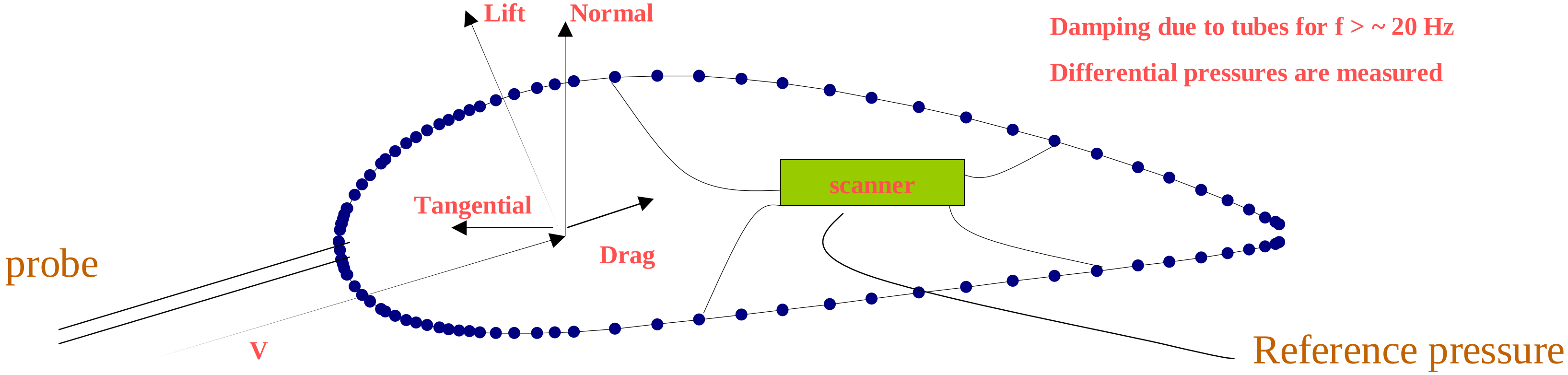
- To develop and validate aerodynamic models
- Conventional measurement programs: Only indirect, global aerodynamic information
- Desired: Direct local aerodynamic properties (I.e. pressure distributions, inflow angles, inflow velocities)

Typical scan rate: 15 kHz port to port

~500 Hz for complete scan

Damping due to tubes for f > ~ 20 Hz

Differential pressures are measured



IEA Annex XIV/XVIII: Participants

- Netherlands Energy Research Foundation, ECN (NL; Operating Agent)
- Delft University of Technology, DUT (NL)
- Imperial College/Rutherford Appleton Laboratory, IC/RAL (UK, Only Annex XIV)
- National Renewable Energy Laboratory, NREL (USA)
- RISØ, The Test Station for Wind Turbines (DK)
- Mie University (JP, Only Annex XVIII)
- Centre for Renewable Energy Sources, CRES (Gr, Only Annex XVIII)

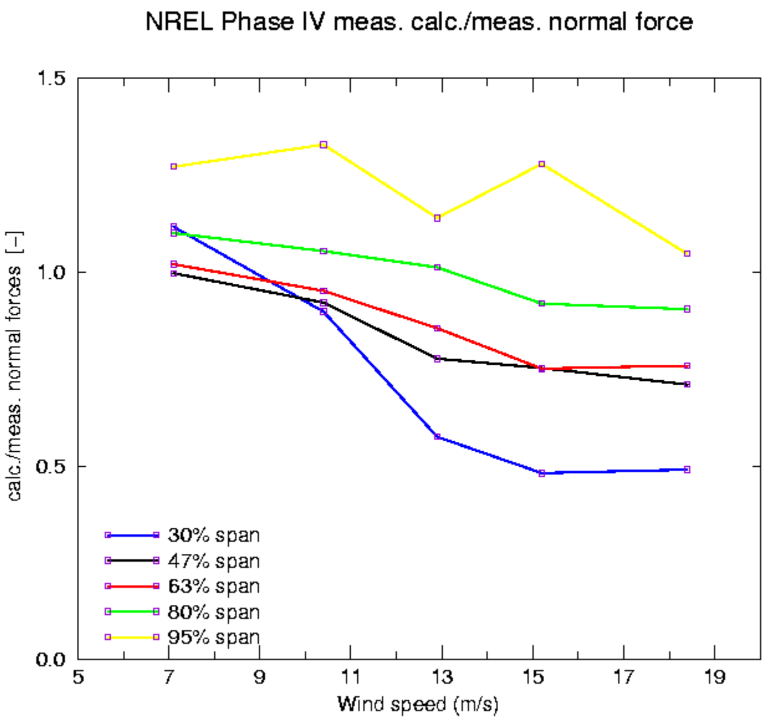
IEA Annex XIV/XVIII: Facilities, Ctd

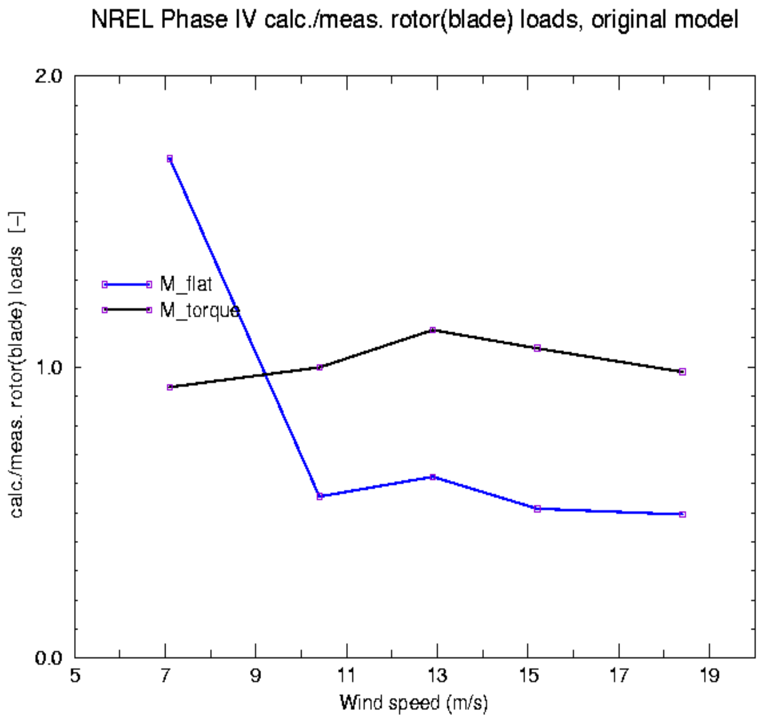
- NREL
  - Rotor: 10 m diameter,
    - untwisted untapered blades;
    - twisted untapered blades
  - Pressure tap stations:
    - 30%, 47%, 62%, 80%, (95%)
    - simultaneous;
  - five hole probe and/or wind vanes
    - 34%, 51%, 67%, 84%, 91%

IEA Task XIV/XVIII some results

- Database on http://www.ecn.nl/nl/units/wind/projecten/field-rotor-aerodynamics-database/
- ‘Discovery’ of
  - Stall delay
  - Overprediction of tip loads when using 2D airfoil coefficients
  - ‘Compensating’ errors when using global measurements

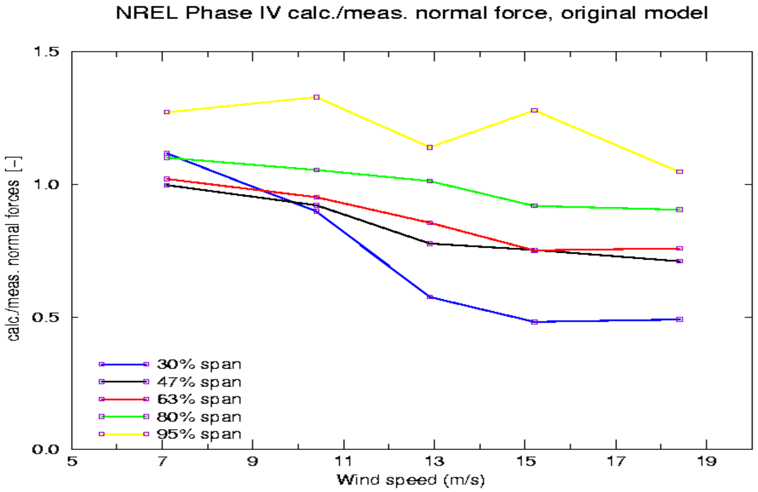
NREL, Phase IV (D=10m) Comparison between measurements and (ECN) calculations

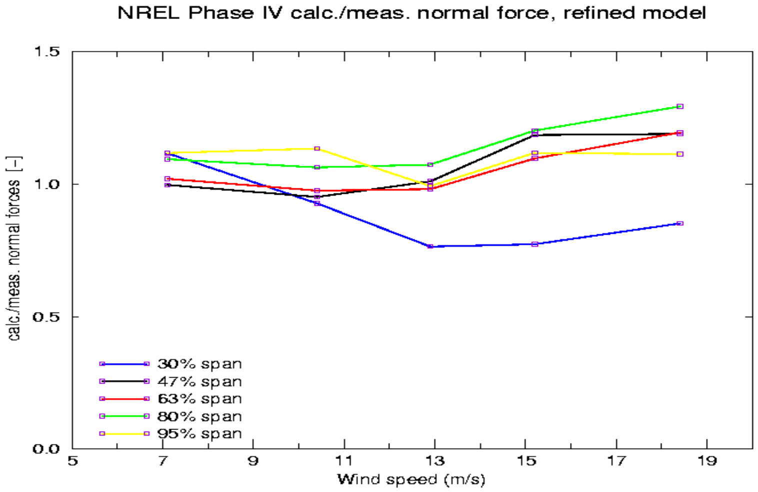




- Normal forces predicted well at low wind speeds but underpredicted at high wind speeds(a.o.a's) at inner part (stall delay underpredicted!) --->
  - Flatwise moments underpredicted
  - Good agreement in torque is a result of compensating errors: Underprediction in normal force is compensated by overprediction in tangential force
- Overprediction at tip (95% span) due to use of 2D airfoil coefficients at the tip

NREL, Phase IV (D=10m)
Comparison between measurements and (ECN) calculations





PHATAS modified modelling (derived from analysis of measurements [1])

Normal force: Agreement generally improved

Overprediction in tip forces reduced

[1]) J.G. Schepers, L. Feigl, R. van Rooij, A. Bruining "Analysis of detailed aerodynamic field measurements, using results from an aero-elastic code", Journal of Wind Energy 7, 7:357-371, August 2004

Validation measurements, status at end of 90's

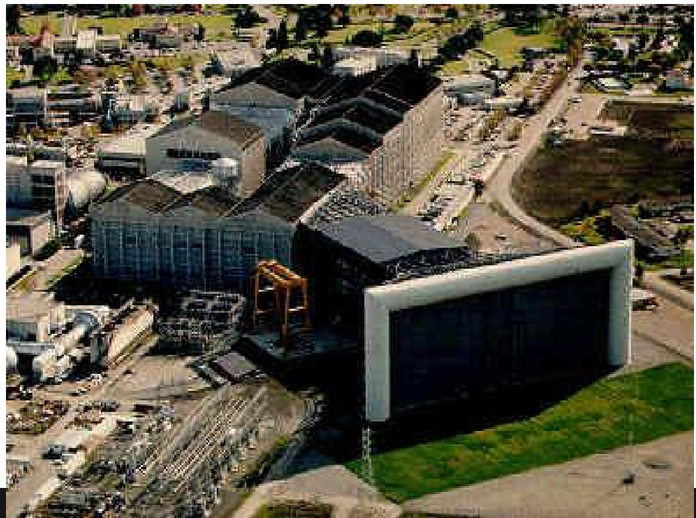
Validation measurements of power and loads showed differences but they were too global to form a basis for improvement of aerodynamic models

- Loads are integrated over blade
- Structural dynamics

Desired:

- Local aerodynamic loads (pressure distribution) (IEA Tasks XIV/XVIII)
- Constant, controlled conditions (→Windtunnel)

Measurements in NASA-Ames wind tunnel



Carried out by NREL (National Renewable Energy Laboratory), USA

Spring 2000

24m x 36m NASA-Ames wind tunnel.

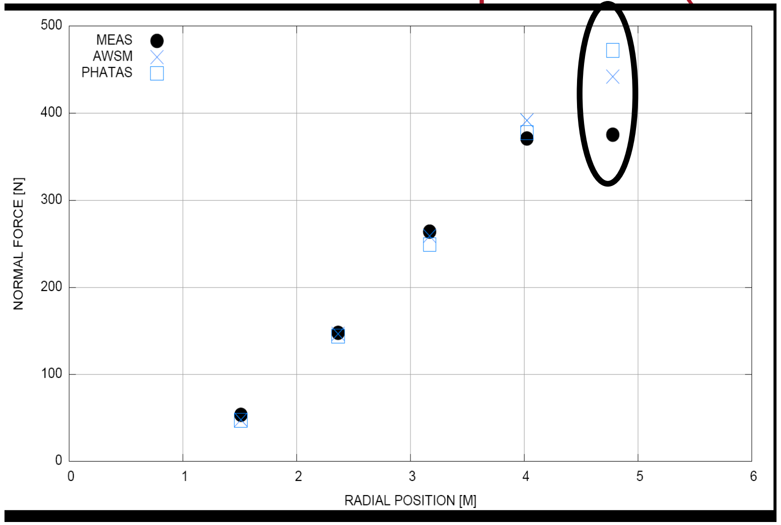
10 m rotor

Measurement of pressure distributions at 5 locations along rotor blade

Analysed in IEA Task XX (Scott Schreck)

- ETS (Canada)
- RISO/DTU (Denmark)
- CRES/NTUA (Greece)
- ECN/TUDelft (The Netherlands)
- IFE (Norway)
- CENER (Spain)
- HGO: (Sweden)
- NREL: (United States)

NASA-Ames experiment Normal forces at 5 radial positions (R= 5m)



- Comparison with results from AWSM (lifting line free vortex wake model) and PHATAS (BEM with Prandtl tip correction)
- Significant overprediction in normal forces at tip but overprediction in AWSM result is less.
- The better AWSM prediction may be explained by the Prandtl tip loss factor in BEM which is based on a simplified vortex wake method where AWSM is based on a more physical vortex wake model
- The 'remaining' overprediction may be explained by the use of 2D airfoil data at the tip (in both PHATAS and AWSM)

Validation measurements, status at ~ 2005

- Validation measurements of power and loads do show differences but they are too global to form a basis for improvement of aerodynamic models
  - Loads are integrated over blade
  - Structural dynamics

- Desired:
  - Local aerodynamic loads (pressure distribution) (IEA Annex XIV/XVIII)
  - Constant, controlled conditions (→NASA-Ames)
  - Induced velocities and wake velocities (→ Detailed flow field measurements)

EU project Mexico
Model rotor EXperiments In COntrolled conditions [1])

2001-2006

Measurements in German Dutch Wind tunnel, DNW

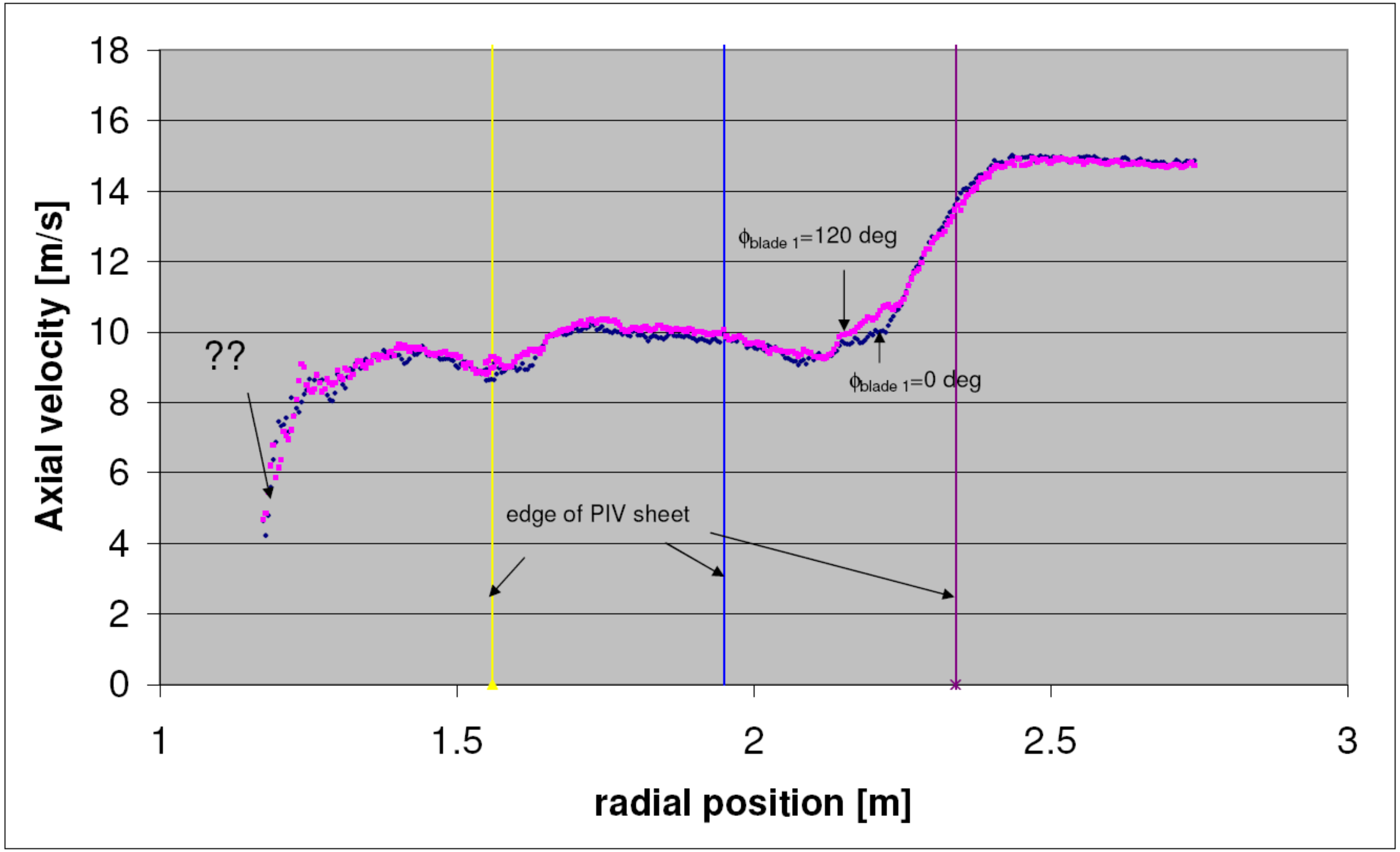
- North East Polder (Netherlands)
- Open test section: 9.5 x 9.5 m^2
- Diameter of rotor:4.5 m
  - Fast pressure measurements at 5 positions (25%, 35%, 60%, 82% and 92% span) along the blade and blade root bending moment measurements
  - Tower bottom load measurements
  - Particle Image Velocimetry (PIV): Quantitative flow visualisation

[1]) Participants: see http://www.ecn.nl/nl/units/wind/rd-programma/aerodynamica/projects/mexico/

MexNext: Participants

- Participation from the following research institutes from 11 different countries:
  - Canada (École de technologie supérieur, Montreal (ETS), University of Victoria (UVic))
  - Denmark(DTU-RISO/DTU(Mek))
  - Germany(University of Stuttgart (IAG), University of Applied Sciences, Kiel, Forwind)
  - Israel (Israel Institute of Technology (Technion))
  - Japan (Mie University/National Institute of Advanced Industrial Science)
  - Korea((Korea Institute of Energy Research (Kier) and Korea Aerospace Research Institute (Kari))
  - Netherlands(Energy Research Center of the Netherlands (ECN), University of Delft (TUDelft), Technical University of Twente)
  - Norway (Institute for Energy Technology/Norwegian University of Science and Technology (IFE/NTNU))
  - Spain(Renewable Energy National Centre of Spain (CENER) and National Institute for Aerospace Technology, INTA)
  - Sweden(Royal Institute of Technology/University of Gotland (KTH/HGO))
  - USA (National Renewable Energy Laboratory (NREL))
- Industrial participation from Suzlon Blade Technology (NL office of Suzlon) and Wind Guard (Germany)

Similarity between PIV measured axial velocity as f(radial position) at 30 cm behind the rotor plane at ϕ_{blade1} = 0 degrees and ϕ_{blade1} = 120 degrees and connection between different PIV sheets



Conclusions

- Wind turbine aerodynamics:
  - Is important
  - Many things are understood
  - Many things are NOT understood
- IEA has helped making the non-understood topics → understood topics
- Suggestion for new task:
  - Combine the ‘characters’ of the IEA Tasks 14, 18,20 and 29 (focussed on modelling and analysis of aerodynamic measurements) with the character of the aerodynamic free wheeling/brainstorming meetings