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

Gerard Schepers
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 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/](http://www.claymath.org/millennium/)).
  - Simplified aerodynamic models are needed!
    - How should we simplify?
• 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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• 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

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

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)

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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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Because it is the **only** MONDIAL (Asia, Europe, American Continent) format for cooperation and exchange of information between wind turbine aerodynamicists
1. **Specific aerodynamic research projects**
   - 1997-2001: IEA Task 18 (Field Rotor Aerodynamics, enhanced, Operating Agent: ECN))
   - 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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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
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
PHATAS modified modelling (derived from analysis of measurements \textsuperscript{1})
Normal force: Agreement generally improved
Overprediction in tip forces reduced

\textsuperscript{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)
2001-2006

Measurements in German Dutch Wind tunnel, DNW

- North East Polder (Netherlands)
- Open test section: 9.5 x 9.5 m²
- 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 a function of radial position at 30 cm behind the rotor plane at $\phi_{\text{blade1}} = 0$ degrees and $\phi_{\text{blade1}} = 120$ 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