The DANAERO MW experiments

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Overview

- **The DAN-AERO MW project carried out over a three years period from 2007-2010** (Risø DTU, LM, Vestas, Siemens, DONG Energy)
  - main objective to carry out the experiments but not to analyze the data

- **The DAN-AERO MW II project, 2010-2013** (Risø DTU, LM, Vestas, Siemens)
  - main objectives to set up a data base, analyze the data and use it to validate models and finally look at the impact on future blade and airfoil designs and testing
Background (2007)
Background

- Field rotor experiments in the period from 1987-1993 -- IEA Annexes XIV and XVIII
  - NREL (US), Risoe (DK), ECN (NL), DELFT (NL), MIE Univ. (Japan), Imperial College (UK)

- NREL Unsteady Aerodynamics Experiment (UAE) on a 10 m diameter rotor in the NASA Ames 80 foot by 120 foot in year 2000 -- IEA Annex XX

- MEXICO experiment in 2006 in DNW 9.5 m x 9.5 m wind tunnel on a 4.5 m diameter rotor – IEA Annex 29
Risoe experiment 1987-1993

19 m diameter rotor

aerodynamic forces measured on three blade segments and inflow measured with a 5 hole pitot tube
Risoe experiment 1987-1993

2D and 3D airfoil characteristics

Details of stalling characteristics

COMPARISON OF 2D AND 3D AIRFOIL CHARACTERISTICS

ATTACK (DEG.)

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Shortcomings of old data sets

- Blade and rotor designs not representative for modern MW rotors
- No influence of shear and atmospheric turbulence in the inflow to the rotor not present in the wind tunnel experiments
- No operation in wakes
- Low Reynolds number
- No influence of control actions, e.g. variable speed and blade pitch
Objectives of project
Objectives of the project

The overall objective of the project has been to provide data that can improve our knowledge of some fundamental aerodynamic and aeroelastic issues and in general improve the design basis for MW rotors. Specifically the experiments were designed to provide new insight into:

- correlation between 2D and 3D airfoil characteristics
- boundary layer transition characteristics in 2D wind tunnel flow environment compared with full scale 3D rotor flow transition characteristics
- inflow characteristics (shear and turbulence) on MW rotors with particular focus on the high frequency content
- dynamic induction characteristics
- wake flow characteristics
- pressure fluctuations in the boundary layer influencing turbulent inflow noise and trailing edge noise
experimental approach
Experimental approach

The DAN-AERO MW experiments
carried out in collaboration between Risoe DTU and theindustrial partners Vestas, Siemens, LM and DONG Energyfrom 2007-2010 comprise:

1. Wind tunnel tests of airfoils in three different wind
tunnels -- LM, Velux and Delft

2. Measurement of inflow characteristics on a MW wind
turbine at the Hoevsoere test site – the Siemens 3.6 MW
turbine

3. Measurement of blade surface pressure and inflow on a
MW turbine in the small Tjaereborg wind farm in Jutland
– NM80 2MW turbine
1) Wind tunnel experiments

The specific objectives with the wind tunnel experiments have been the following:

1. Verify and investigate the difference in 2D airfoil characteristics measured in three different wind tunnels, which in the past have been used for testing airfoils for wind turbines

2. Investigate the turbulence characteristics in the wind tunnels and investigate the correlation with boundary layer transition and surface pressure spectra

3. Measure the 2D airfoil characteristics on the four specific sections of the LM 38.8 m blade for comparison with 3D airfoil characteristics on the NM80 rotor.
Wind tunnel experiments

The LM wind tunnel
- closed test section and Reynolds no. up to 6-8 mill.

The Velux wind tunnel
- open test section and Reynolds no. up to 1.6 mill.
2) Inflow measurements

Objective

- characterize shear and turbulence of the inflow to a MW rotor during different atmospheric conditions and during operation in wakes from upstream turbines
Inflow measurements

The Siemens 3.6 MW turbine - a five hole pitot tube mounted on one of the blades in March 2007

The five hole pitot tube mounted at radius 36 m in a distance of about 0.80 m in front of the leading edge of the blade. Rotor diameter is 107 m.
3) Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

- surface pressure and inflow measured at 4 radial stations
- the outboard station also instrumented with around 60 microphones for high frequency surface pressure measurements
- high frequency measurements of the inflow
- measurements from June to September 2009
Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

Test blade installed on the turbine in May 2009
Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

Pressure and microphone holes

All pressure and microphone holes were covered with tape every evening to protect against rain and moisture.
Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

- high frequency inflow sensors
- five hole pitot tubes
Results
Results from tests in the different wind tunnels
Comparison of measurements from different wind tunnels

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Comparison of measurements from different wind tunnels

NACA 63418 clean, Re=3mio

Delft
LM
Stuttgart
NACA

AOA
Results from the inflow measurements on the 3.6 MW Siemens turbine in Høvsøre
Results – pitot tube inflow measurements

night

![Graph showing wind conditions at night](image)

Day

![Graph showing wind conditions during the day](image)

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Results – pitot tube inflow measurements

night

![Graph showing inflow measurements for night]

day

![Graph showing inflow measurements for day]
Data from the meteorology mast for the same day
Results from pressure and inflow measurements on the NM80 turbine at the Tjæreborg wind farm
DANAERO MW: Final Report

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DTU Vindenergi
Institut for Vindenergi
From final report:

Figure 9.4. Comparison of measured and computed $C_p$ distributions on the NM80 turbine operating at $V_\infty = 6.1 \text{ms}^{-1}$ at a rotational speed of 12.1 RPM and a pitch angle of 0.15°. a) r/R=0.325; b) r/R=0.475; c) r/R=0.750; d) r/R=0.925.
Results from the microphone measurements for transition location
Transition: yawed operation at 60deg
14:40, 19/8, 2009

A.228 cRIO_20090819_144710.tim

Figure 228. cRIO_20090819_144710.tim
Transition: normal operation, July 16th, 2009

More laminar boundary layer at the beginning of measurement period

C.25  cRIO_20090716_101410.tim

Figure 217. cRIO_20090716_101410.tim

C.26  cRIO_20090716_101510.tim

Figure 218. cRIO_20090716_101510.tim

Later
The DANAERO MW Experiments - What next?
A rotating test rig

Test rig based on a 100 kW turbine
- rotation of a 10m long flexible arm with an airfoil section of about 2x1m

Pressure measurements

Pitch actuator
The rotating test rig

- A facility for **testing new blade technology** such as **flaps** and **inflow sensors** under realistic conditions (atmospheric inflow, elastic suspension, realistic pitch control, rotating environment, Reynolds number close to full scale)

- Intended to **close the gap** between **wind tunnel testing** and **full scale testing**

- Detailed experiments with surface microphones to study **transisiton** and **aeroacoustic sources**

- A blade section (about 2m spanwise length and 1m chord) is rotated by a 10m boom mounted on the shaft of the Tellus 100kW turbine (standard rotor taken down)

- Detailed measurements of the aerodynamic loading on the blade section, inflow and structural response
Rotating test rig

Planned operational October-November 2013