Near Wake Simulation of Mexico rotor in Axial and Yawed Flow Conditions with Lifting Line Free Wake Code

F. Grasso

A. van Garrel

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NEAR WAKE SIMULATION OF MEXICO ROTOR IN AXIAL AND YAWED FLOW CONDITIONS WITH LIFTING LINE FREE WAKE CODE

F. Grasso[1], A. van Garrel[2]

[1]**Energy research Centre of the Netherlands (ECN), Rotor and Wind Farm Aerodynamics,**
Westerduinweg 3, 1755LE Petten, the Netherlands,
e-mail: grasso@ecn.nl

[2] **Energy research Centre of the Netherlands (ECN), Rotor and Wind Farm Aerodynamics,**
Westerduinweg 3, 1755LE Petten, the Netherlands,
e-mail: vangarrel@ecn.nl

ABSTRACT

The scope of the present work is to have a better understanding of the accuracy in numerical simulations of the wake generated by wind turbine rotors. Due to the extensive measurements performed in near wake, MEXICO project has been used as reference for this investigation. A code based on lifting line theory and coupled with a free wake method has been used during the analyses and the results have been compared to the experimental data.

NUMERICAL MODEL

A code, named AWSM, based on generalized lifting line theory in combination with a free vortex wake method has been developed at ECN by van Garrel [1]. Validation tests can be found in [2].

The main assumption in the lifting line theory is that the extension of the geometry in span-wise direction is predominant compared to the ones in chord and thickness direction; because of this, the real geometry is represented by a line passing through the quarter chord point of each cross section and all the flow field in chord-wise direction is concentrated in that point.

In the AWSM flow model, the vorticity is shed from the trailing edge of the surface and convected downstream as time advances. The blade geometry consists of one or more strips that carry a vortex ring whose bound vortices are located at the quarter chord position and at the trailing edge. The vortex strengths Γ of these vortex rings are to be determined. Each timestep Δt, new vortex rings with these strengths are shed from the trailing edge (TE) and joined with the older vortex rings. These vortex rings together will form a vortex lattice. The position of the first shed free spanwise vortex behind the TE lies at some fraction between the current TE position and the wind-convected TE position from the previous timestep. In accordance with vortex-lattice practice this fraction is chosen to be 25 percent of the chord. Upstream of this position, the vortex rings have a strength equal to the corresponding vortex ring at the configuration. The position of the downstream part of the wake is determined each timestep by convection of the wake vortex-lattice nodes. This convection is applied in two separate steps; convection by the onset wind velocity and convection by the "induced velocity" of all bound and trailing. The wake shed vortices are formed by the adjoining sides of two vortex rings from successive timesteps. This means that they cancel each other in case the vortex ring strengths are identical. For steady flows therefore only the trailing vortices are active.

MEXICO PROJECT

Within the framework of the EU FP5 project MEXICO [3], a sophisticated aerodynamic experiment was designed, and executed in the Large Scale Low Speed Facility (LLF) of the German Dutch Wind tunnel Organization (DNW). The principal objective of this project was to significantly reduce these uncertainties by providing an experimental database, measured in a large wind tunnel under controlled and hence known conditions and by using the increased physical insight resulting from the experiments in engineering design methods.

Part of the MEXICO measurements was dedicated to determine the three-dimensional flow field around the wind turbine in detailed quantitative way. To do this, PIV technique was used and both the upstream and downstream regions of the turbine were explored.

NEAR WAKE SIMULATIONS

The induced velocity in points of the external domain can be calculated in AWSM [4], so comparisons with experimental data coming from PIV measurements have been performed. Both, axial and yawed conditions have been considered. The calculation were performed considering 13 rotations (in order to have steady flow conditions [5]) and the wake partially free to rollup.

For axial condition, three values of wind speed have been used and all three components of velocity computed for axial traverse and radial traverse measurements (Figure. 1-Figure. 4).

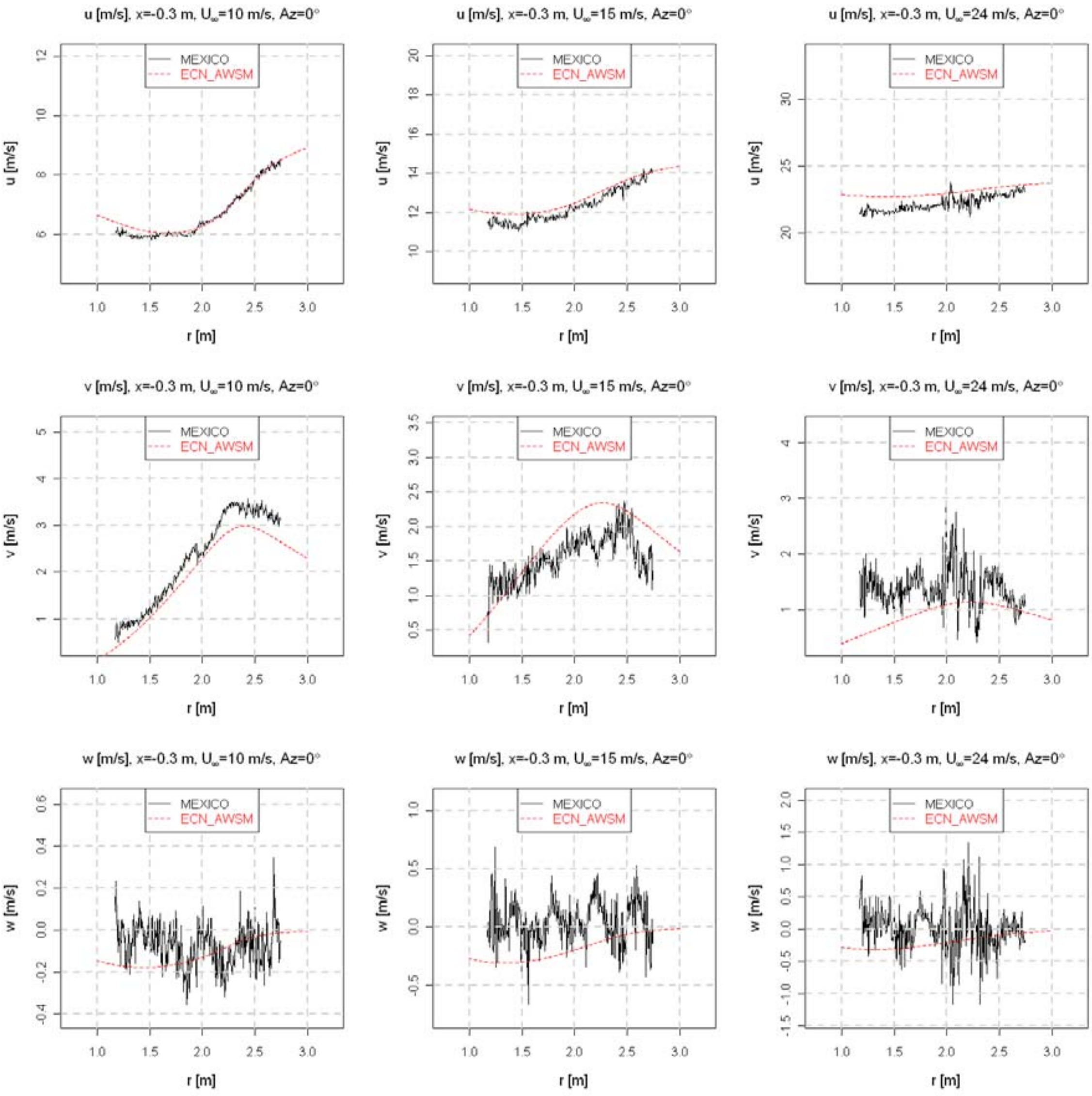

Figure. 1 Numerical-experimental comparison; upstream radial traverse, u, v and w components (axial, in-plane horizontal and vertical components) at 10, 15 and 24 m/s wind speed.

The simulations were performed at 0.3m upstream and downstream for radial traverse, and at 1.38m and 1.8m radius for axial traverse. The u component denotes the axial component, v and w components denote the in-plan horizontal and vertical components.

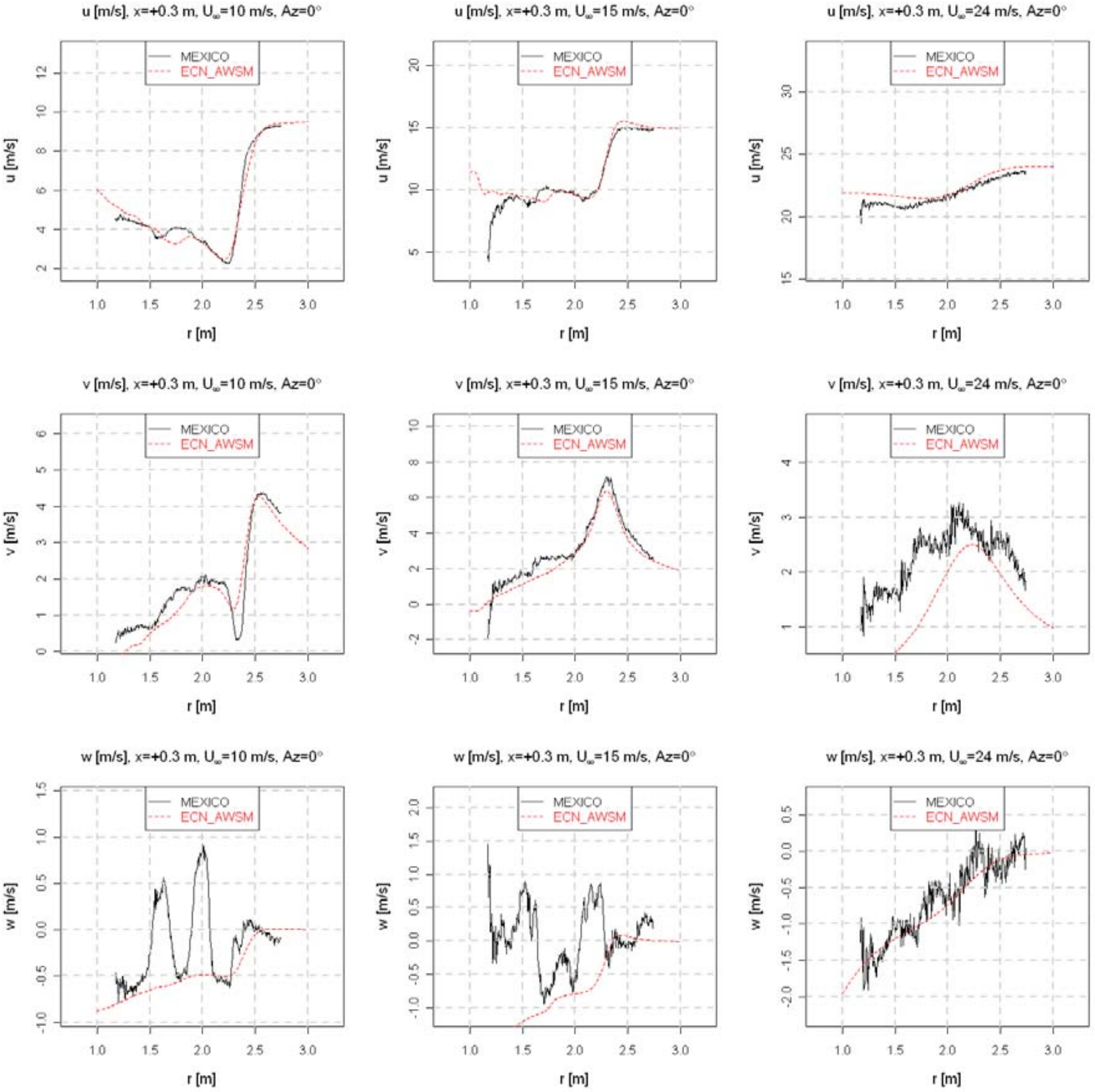

Figure. 2 Numerical-experimental comparison; downstream radial traverse, u, v and w components (axial, in-plan horizontal and vertical components) at 10, 15 and 24 m/s wind speed.

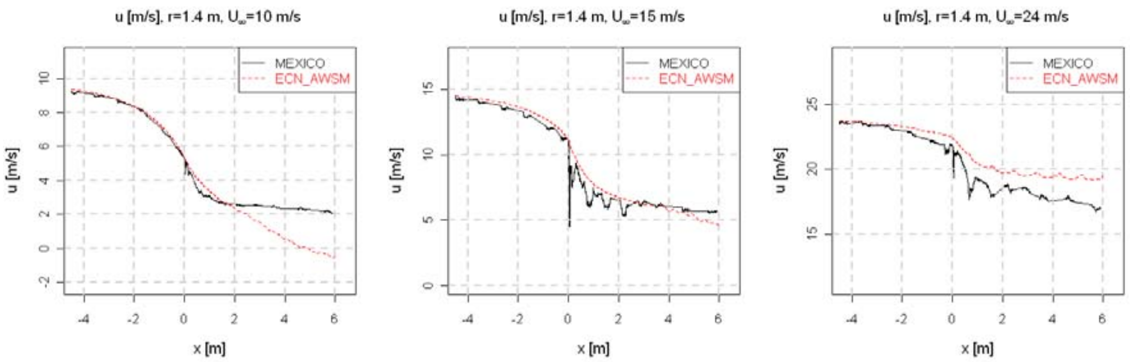

Figure. 3 Numerical-experimental comparison; axial traverse at 1.4m radial position, u (axial) component at 10, 15 and 24 m/s wind speed.

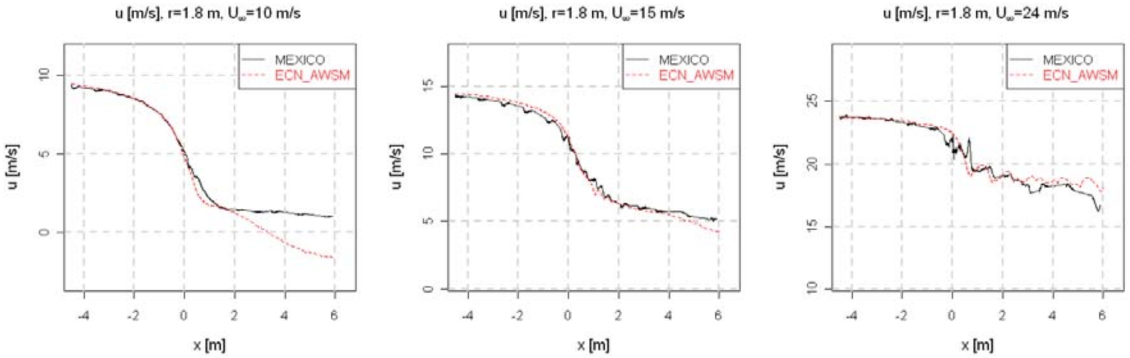

Figure. 4 Numerical-experimental comparison; axial traverse at 1.8m radial position, u (axial) component at 10, 15 and 24 m/s wind speed.

Following the test case definitions in MEXNEXT [6] project, four axial traverse stations (at 1.38m and 1.8m radius both sides of the rotor centre) have been take into account for the yawed condition (30degrees). The value of 15m/s for the wind speed is considered.

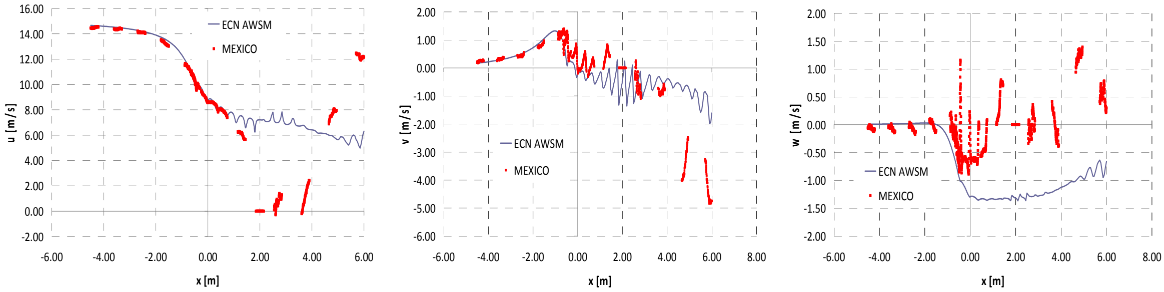

Figure. 5 Numerical-experimental comparison 30 degrees yaw; axial traverse at 1.37 m radial position, u, v and w components at 15 m/s wind speed.

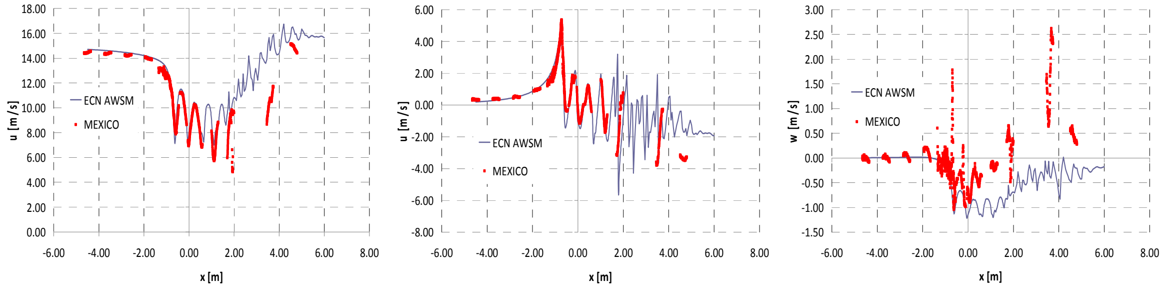

Figure. 6 Numerical-experimental comparison 30 degrees yaw; axial traverse at 1.8 m radial position, u, v and w components at 15 m/s wind speed

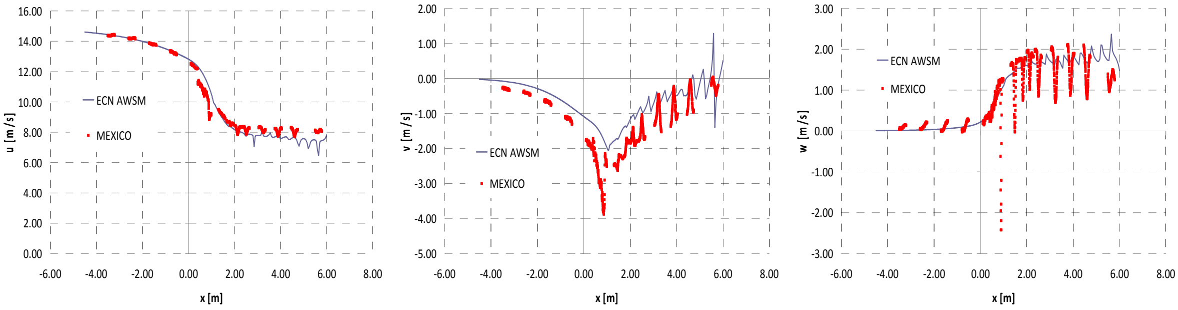

Figure. 7 Numerical-experimental comparison 30 degrees yaw; axial traverse at -1.37 m radial position, u, v and w components at 15 m/s wind speed

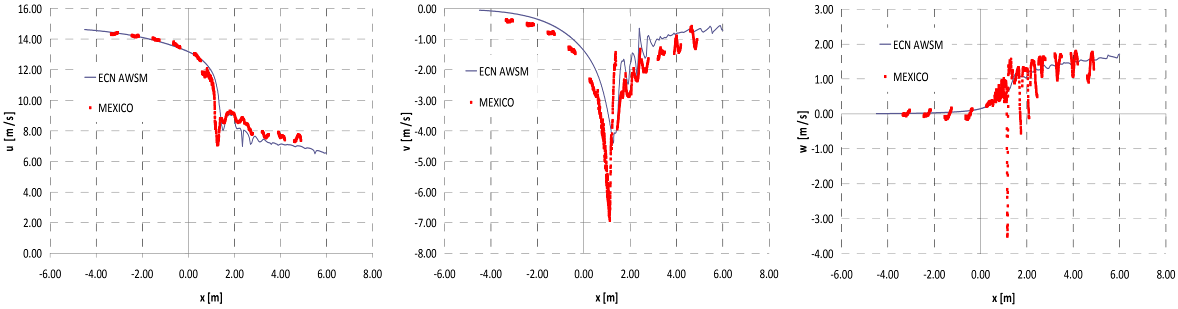

Figure. 8 Numerical-experimental comparison 30 degrees yaw; axial traverse at -1.8 m radial position, u, v and w components at 15 m/s wind speed

Looking at the comparisons, a general very good agreement is found both in axial and yawed conditions.

In axial condition, the most evident difference is in the axial component of the axial traverse for 10m/s wind speed, where numerical simulations predict a reverse speed area downstream the rotor plane. The reason of this difference with the experiments is still not clear and more on going investigations are focused on this aspect. However, it can be related also to the relative low wind speed.

For yawed condition, the differences are concentrated for one side of the axial traverse stations. Due to the yaw angle, the flow is catching the nacelle and the axial induced velocity goes to zero (fig. 5). In AWSM the nacelle is not modeled. Comparing the axial traverse stations, on one side, the axial induced velocity is increasing downstream the turbine, due to the wake that crosses the PIV measurement locations. This deviation is also well taken by AWSM (fig.6). It should be noticed also the good agreement for the other induced velocity components.

CONCLUSIONS

An extensive investigation has been performed on the near wake generated by a wind turbine. MEXICO rotor has been used as reference case. The very good agreement between experiments and numerical predictions, obtained by using a lifting line code coupled with free wake method, clearly show the level of accuracy that can be generally reached with this model and indicate that, at the least for near wake investigations, such tool can be suitable, also in yawed conditions.

REFERENCES

[1] Van Garrel, A., “Development of a Wind Turbine Aerodynamics Simulation Module”, ECN, ECN-C-03-079, Petten, the Netherlands, August 2003.

[2] Grasso, F., van Garrel, A., Schepers, G., “Development and Validation of Generalized Lifting Line Based Code for Wind Turbine Aerodynamics”, 49th AIAA Aerospace Sciences Meeting, Orlando, Fl, USA, 4-7 January 2011. AIAA 2011-146.

[3] Schepers, J.G., Snel, H., “Model Experiments in Controlled Conditions – Final Report”, ECN, ECN-E-07-042, Petten, the Netherlands, June 2007.

[4] Grasso, F., “AWSM External Field Calculations”, ECN, ECN-X-09-043, Petten, the Netherlands, April 2009.

[5] Maggio, T., Grasso, F., Coiro, D.P., “Numerical Study on Performance of Innovative Wind Turbine Blade for Loads Reduction”, EWEA, EWEC2011, Bruxelles, 14-17 March 2011.

[6] www.mexnext.org.

ECN
P.O. Box 1
NL 1755 ZG Petten
The Netherlands

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F. Grasso, A. van Garrel

Summary

The scope of this work is to have a better understanding about the accuracy in numerical simulations of the wake generated by wind turbines.

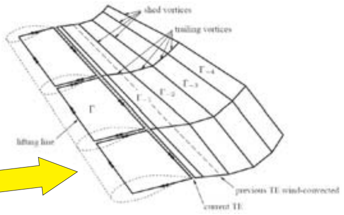
- Lifting line, free wake code used for numerical simulations.
- MEXICO data used as reference.

Numerical model

Numerical code, named AWSM, developed at ECN by van Garrel.

- Based on generalized lifting line theory.
- Coupled with free wake method.

- The blade geometry consists of strips that carry a vortex ring.
- Each timestep, new vortex rings are shed from the trailing edge and joined with the older vortex rings, in a vortex lattice.



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- www.mexnext.org.

MEXICO project

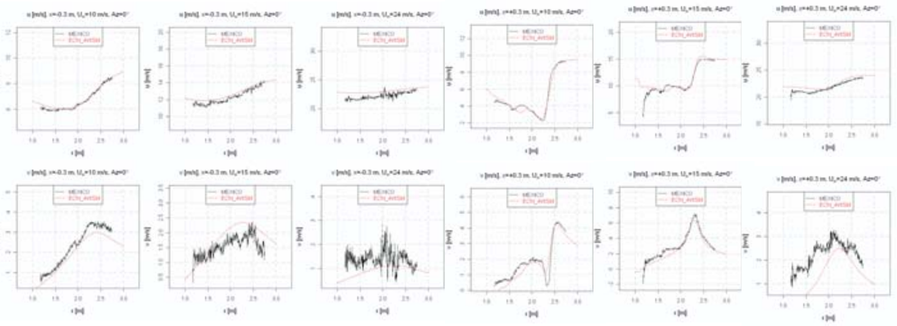
Project defined in EU Fp5, aimed to reduce the uncertainties in aerodynamics of wind turbines.

- Extensive wind tunnel tests performed at the Large scale Low speed Facility (LLF) of the German Dutch Windtunnel Organization (DNW).
- Part of the experiments dedicated to determine three-dimensional flow field around wind turbines. PIV technique used.

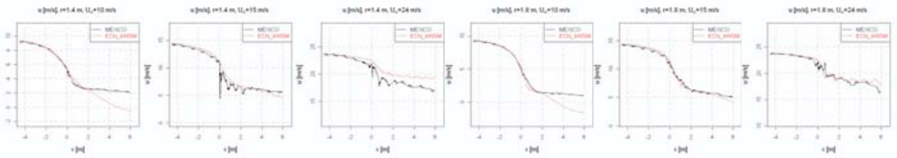
Results - axial condition

Upstream radial traverse

Downstream radial traverse

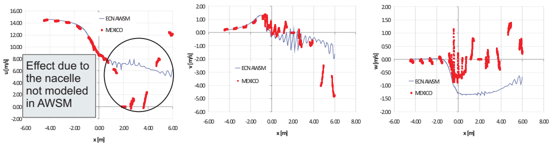


Axial traverse



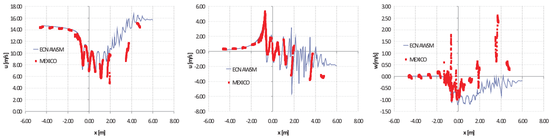
Results - 30deg yawed condition (15m/s)

Axial traverse r=1.4m

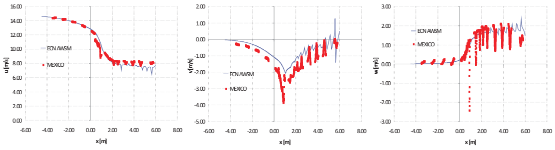


Effect due to the nacelle not modeled in AWSM

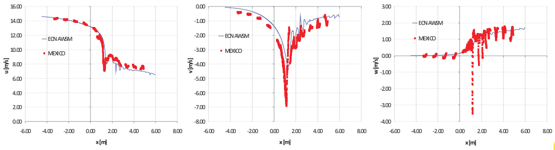
Axial traverse r=1.8m



Axial traverse r=-1.4m



Axial traverse r=-1.8m



Contact information

Francesco Grasso: grasso@ecn.nl, +31(0)224-564289

Arne van Garrel: vangarrel@ecn.nl, +31(0)224-564233

Energy research Centre of the Netherlands www.ecn.nl