# Actuator Disc Modeling of the MEXICO Rotor Experiment

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**Abstract.** A differential Actuator Disc (AD) based on 2D airfoils data has been prepared for the so called MEXICO rotor experiment. A commercial Navier-Stokes-Solver (FLUENT 5.7) without any turbulence modeling has been used. The geometrical model includes both the full DNW Large Low speed Facility (LLF) wind- tunnel geometry where the experiment was performed as well as a cylindrical domain used for the boundary-free case, to estimate the blockage effects of the wind tunnel. Results have been prepared for rotor performance, loads and velocity fields in the near-wake which were measured for the first time during the experiment and are also compared to an RANS model.

## 1 Introduction

Modeling Wind-Turbine Flow may be studied in levels of varying sophistication: The Blade Element-Momentum (BEM) theory has been used since almost hundred years now being replaced by CFD models of RANS kind, which are exposed to the usual difficulties concerning the turbulent and transitional part of the flow necessary to reproduce the high lift-to-drag ratios on the blade. As an intermediate step simplified Actuator Disc (AD), Actuator Line (AL) and Actuator Surface (AS) models are used instead. To mention only few of them who applied these methods to the MEXICO Experiment (described in [1]) and the IEAwind Mexnext Project: BEM model by [2], the RANS model by [3], the AL model by [4], the AS by [5].

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Unlike others [6] used loads from measurements to explain the so far un-explained differences in simulated flow field from the measured ones.

## 2 Methods

The actuator disc was meshed using ICEM CFD software using O-type topology. Only structured meshes were used. The number of cells at the disc was: 36 in radial, 72 in circumferential and finally 2 in axial direction (Fig.1a). A hybrid mesh has been used for meshing the wind tunnel (Fig.1b). A Quad-dominant mesh was used to prepare the surface grids and the Tetra-mixed method was used for the volume part of the geometry. The disc then was merged inside the wind tunnel mesh to prepare the model for full wind tunnel and results in 6.08 Mcells and 1. Mnode resp. For boundary-less flow, a cylindrical O-type (Fig.1c) was modeled. In the mesh had about by 1.04M cells and 1.06M nodes to resolve the walls of the wind tunnel as well as the on the wake behind the rotor. No mesh dependence study was performed.

The action of the rotor was modeled in the usual way by introducing body force-densities, see equations (1 - 3) along x, y and z directions respectively. These forces are regarded as to be originated from 2D airfoil data in combination with the BEM-technique. Velocities necessary for computing the total inflow velocity (eq. 4) are taken at each iteration loop. All can be done very easily using the UDF-interface provided by FLUENT.

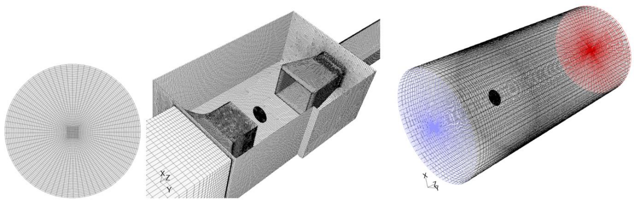
$$mom_x = \rho W^2 Bc(C_l.\sin\phi - C_d.\cos\phi)\sin\theta/(4\pi rt) \quad (1)$$

$$mom_y = \rho W^2 Bc(C_l.\sin\phi - C_d.\cos\phi)\cos\theta/(4\pi rt) \quad (2)$$

$$mom_z = \rho W^2 Bc(C_l.\sin\phi + C_d.\cos\phi)/(4\pi rt) \quad (3)$$

$$V_{rel} = \sqrt{(r.\omega + (v.cos\theta - w.sin\theta))^2 + u^2}, \phi = tan^{-1}(u/V_{rel}) \quad (4)$$

In equations (1 - 4), $\rho$ is air density, $V_{rel}$ is relative velocity to the local airfoil, $B$ is blade number, $c$ is local chord, $C_l$ and $C_d$ are lift and drag coefficients of the airfoil, $\phi$ is flow angle, $\theta$ is azimuthal angle of the element in the disc plan, $r$ is the local radius of the element, $t$ is the rotor thickness, $\omega$ is angular velocity of the rotor



(a) (b) (c)

**Fig. 1** (a) Structured mesh for the actuator disc, (b) Hybrid mesh for the LLF wind tunnel and (c) structured mesh for the boundary-free model

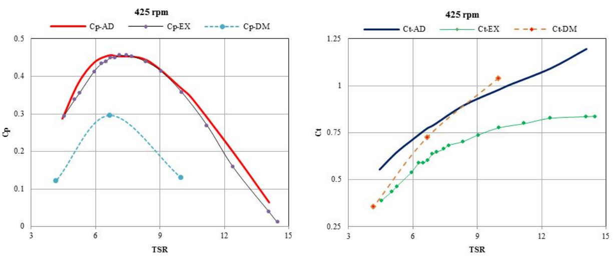
(44.45 $rads^{-1}$ ), $u$, $v$ and $w$ are axial ( z-direction), vertical ( x-direction) and horizontal ( y-direction) components of the flow velocity on the element, respectively, x and y are vertical and horizontal distance of the element to the rotor center. In these equations, lift and drag coefficients are called from a airfoil data base. Flow velocity components $(u, v, w)$ and the planar location components (x,y) of the element are measured from the Navier-Stocks domain in the iteration process. Equations (1 - 3) have been obtained from blade element analysis. Unknown variables in equation (1), (2) and (3) are calculated from equations (4) in the iteration process. Two different types of Subroutines were used within the UDF interface. The Source (body forces)-providing Subroutines and those for integrating thrust and power and their coefficients and averaged velocities in front of and behind the rotor. Both wind tunnel and boundary-free models were run under different inflow conditions.

## 3 Results and Discussion

The results of these runs are presented into four sections: Rotor Performance, blade loads, wake visualization and wake traverse lie-graphs.

### *3.1 Rotor Performance*

Both full wind tunnel and boundary-free models show almost the same values for power and thrust. Power coefficients (Fig.2a) derived from our AD model exhibit remarkable agreement with experimental measurement (EX) for the 425 rpm case. The Thrust coefficient (Fig.2b) is overestimated compared to the measurement with a constant value in the order of 0.1. Results from the RANS model of [3] *DM* are also included. Whereas DM underestimates power constantly our (AD) results for the AD-thrust fits reasonable to DM nut give much larger values than measured.




(a) (b)

**Fig. 2** Power (a) and thrust (b) coefficients from AD and RANS (DM) models compared to experimental data

### 3.2 Radial Resolved Force Data

Both wind tunnel and boundary-free simulations of AD model result in approximately the same values for axial and tangential forces for the 425 RPM case (see fig. 3). Both AD and DM exceed the experimental measured values, especially when r/R > 0.6. The difference between AD and DM-Model is more pronounced for the tangential forces.

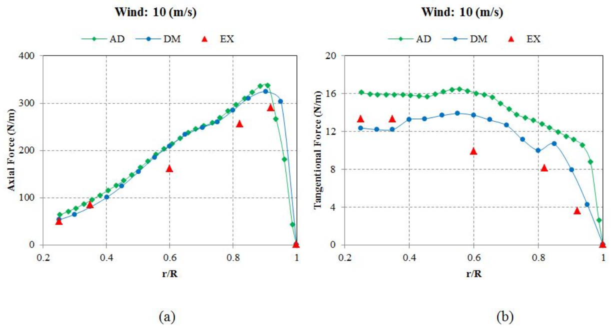



**Fig. 3** Radial (spanwise) distribution of normal (a) and tangential (b) forces on one Mexico rotor blade

### 3.3 Wake Visualization

Fig. 4 shows the most important outcome of our work: the visualization of the near wake behind the rotor. It is clearly seen that the nozzle of the wind-tunnel is far too close to the disk (fig. 4-top), thereby preventing development of the free wake (fig. 4-down). The color scales are in the same range (from -5.11 $m.s^{-1}$ to 21.3 $m.s^{-1}$).

### 3.4 Near and Far Wake Traverse

Fig. 5 gives a more quantitative comparison of the development of the wake. Fig. (5a) shows axial-velocity in wind-direction whereas Fig. (5b) gives the same velocity in a rotor-plane about 1.4 rotor-diameters downstream. It can be seen that the differences between the tunnel-model and boundary-free model are smaller as compared to the measurements.

From Fig. (5a), is can be seen that wind tunnel model seems to have lower inlet velocity when compared to the boundary-free model.

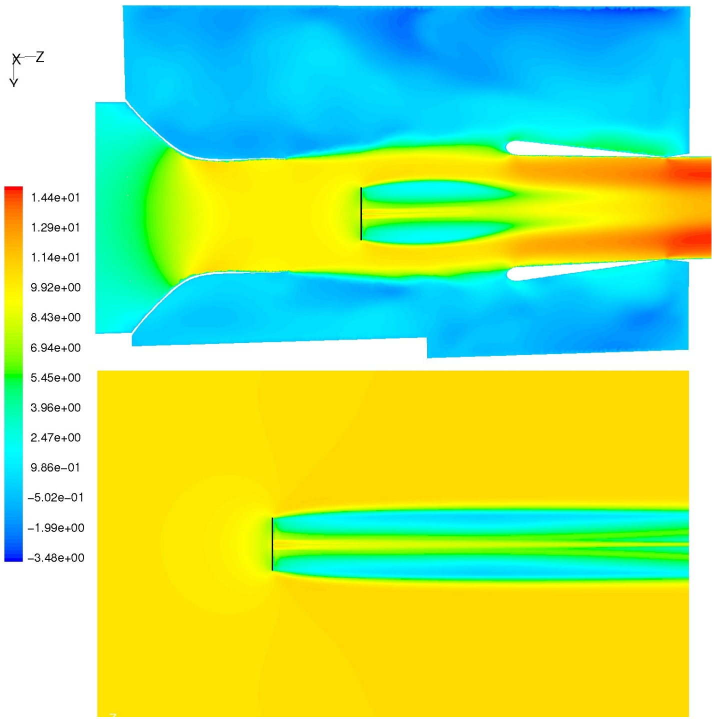
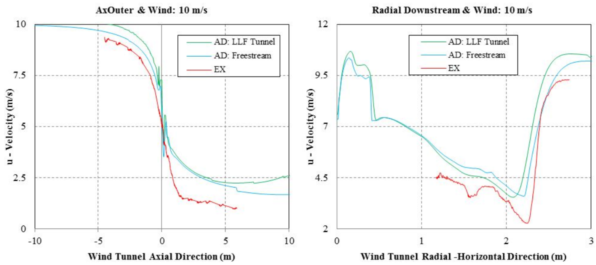



**Fig. 4** Variation of axial velocity for the full wind tunnel model (top contour) and the boundary-free case (down contour) both in a range of -5.11 $m.s^{-1}$ to 21.3 $m.s^{-1}$




(a) (b)

**Fig. 5** Axial velocity component along axial (a) and radial directions (b)

## 4 Summary and Conclusions

A differential Actuator Disk (AD) model was prepared using the commercial CFD-RANS code FLUENT 5.7 for the MEXICO rotor. The results were compared with a RANS model of Jeromin and Schaffarczyk and measurements. Our main conclusions are as follow:

- Power correlation for actuator disc exhibited good agreement with measurement.
- Blade loads study showed that AD and DM models behave the same for predicting much more axial forces than measured.
- Collector nozzle and breathing slots show strong influence to the wake development.
- Wake length decreased due to collusion the wind by the compressor nozzle and crossing from breathing slot zone of LLF wind tunnel.
- AD gives slightly more precise agreement than DM for the near wake modeling.

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