Three dimensional flow in the root area of a wind turbine predicted by high fidelity CFD simulations

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The Main Question

What are the effects of rotor rotation on three dimensional charactristics of the load and wake responses in the root area of an isolated wind turbine?

Introduction

The flow situation in the root area of a wind turbine blade is very complex as it involves massively separated flow field at high angles of attack and under the influence of rotor rotation. This causes the augmentation of the sectional lift coefficient, and consequently the resulting blade loads, compared to the two dimensional (2D) conditions [1-3] hindering the use of simplified 2D approaches to predict the performance of the turbine. In order to assess these phenomena, high fidellity Computational Fluid Dynamics (CFD) simulations using the FLOWer code from the German Aerospace Center (DLR) were carried out. The computations were conducted based on a fully meshed MEXICO turbine.

Numerical Methods

Delayed-Detached Eddy Simulation (DDES) approach [4]

- RANS-mode near the wall using the SST model
- LES-mode outside of the boundary layer

Grid Generation

- 120° simulation model assuming periodicity
- Block-structured, moving component meshes with resolved boundary layer ($y^+ < 1$)
- Automated blade meshing script, using Gridgen software from Pointwise
- Overset grid interpolation [5]
- Wake vortex refinement

—> Overall: 37.5 Mio. Cells

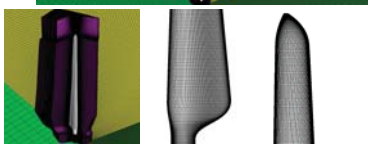

Fig. 1. Computational mesh [1].

Computational Parameters

Parameter	Magnitude
Inflow velocity	24 m/s
Revolution per minute	424 rpm
Pitch angle	-2.3°
Blade radius	2.25 m
Physical time-step	1° blade azimuth

Computational Results

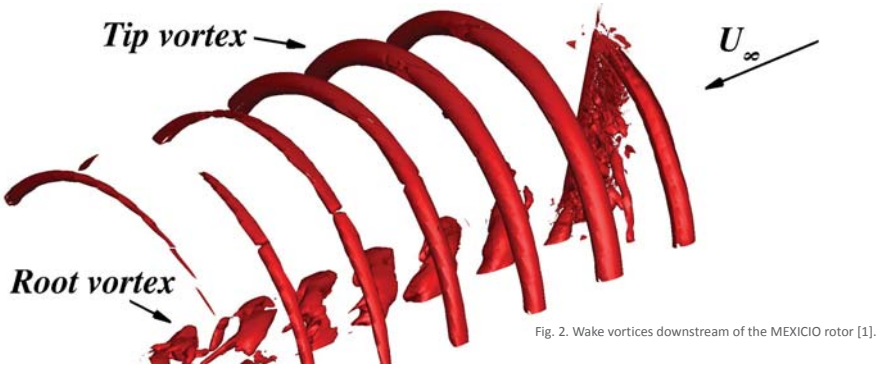

Fig. 2. Wake vortices downstream of the MEXICIO rotor [1].

Wake and Root Flow Characteristics

- Tip and root vortices travel downstream in hellical manner
- Axial flow accelerates near the hub ($U/U_\infty > 1$)
- The presence of root vortices are observed from the change of sign of the circumferential (V_θ) and radial velocity components (V_r).

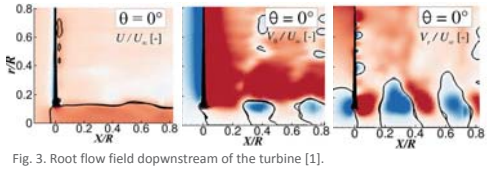

Fig. 3. Root flow field dopwnstream of the turbine [1].

Sectional Loads and Pressure Coefficient

- Good agreement compared with experimental data [5]
- The deviation between CFD and experiment at 0.35R occurs because the hub was not modeled
- The suction peak of Cp is accurately captured

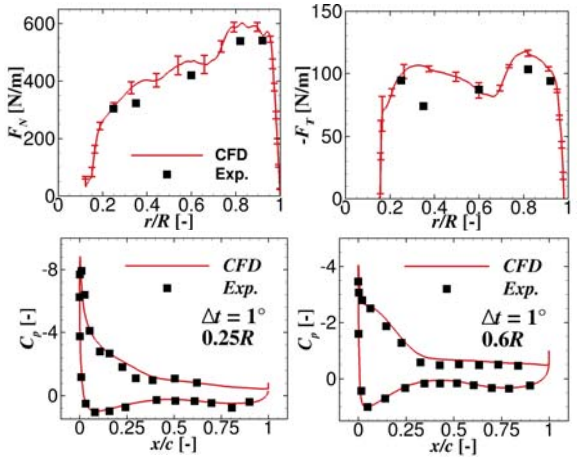

Fig. 6. Sectional loads and pressure coefficient distributions [1].

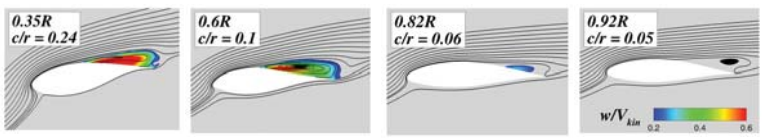

Fig. 4. Time-averaged wall bounded radial flow in rotating frame of reference [1].

3D Effects and Wall Bounded Radial Flow

- Rotational augmentation occurs in the inboard area characterized by lift increase compared to 2D conditions
- Drag reduces compared to 2D results due to separation delay
- The strong 3D effects are observed only when the relative radial velocity is strong and the chord-to-radius (c/r) ratio is greater than 0.1. In this case, it occurs within $r/R < 0.6$.

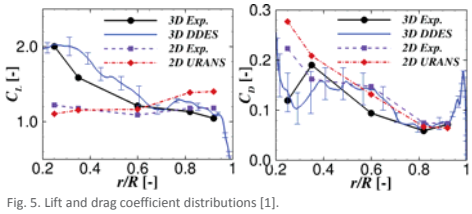

Fig. 5. Lift and drag coefficient distributions [1].

Conclusions

Three dimensional simulations using DDES for the MEXICO rotor have been carried out. The studies reveal the importance of root vortices on load and wake characteristics of the turbine. The 3D effects are strongly influenced by the wall bounded flow, causing lift augmentation and drag reduction. The current simulations agree well with the measurement data though some discrepancies are observed as no hub was modeled in the simulations.

References

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