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Investigation of the effect of elastic blade deformations on the aerodynamic performance of large wind turbines by means of CFD

B. Stoevesandt, B. Dose, H. Rahimi, J. Peinke
Fraunhofer IWES, Oldenburg, Germany

Introduction

Due to the increasing rotor size and advanced light weight blade designs, significant blade deflections can be observed on a regular basis for modern wind turbine blades. However, especially for complex flow situations like yawed inflow, the role of blade deformations is still not completely understood. To shed more light into this open question, a fluid-structure coupled high-fidelity CFD framework is used to investigate the DTU 10 MW wind turbine rotor under yaw misalignment. The obtained findings are then compared to results computed by the BEM-based simulation tool FAST using common skewed wake correction models.

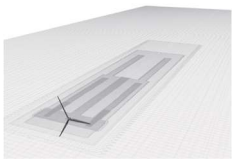
Investigated Cases

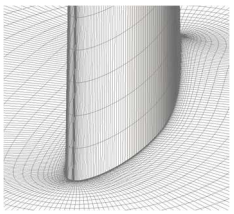
- The DTU 10 MW rotor [1] is simulated at rated conditions
- Three different yaw angles are investigated (15 deg, 30 deg and 45 deg)
- Two numerical approaches of different fidelity (CFD and BEM) used to investigate uncertainties in load calculations
- Uniform and laminar inflow considered
- Shaft tilt and gravity effects neglected
- Over 20 revolutions were computed for each approach and case

Numerical Methodology

Low fidelity - BEM with linear beam

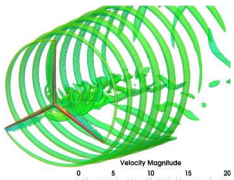
- NREL's FAST v8 [2] + AeroDyn v14 used in this work
- Employed skewed wake modelling approaches: Glauert (Pitt & Peters) & Generalized Dynamic Wake (GDW)
- Structural dynamics modelled by ElastoDyn (no torsion)

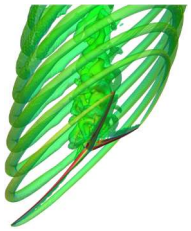




High fidelity - CFD with non-linear beam

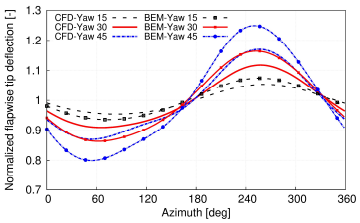
- Flow solver: Open source CFD toolbox OpenFOAM [3], turbulence modelling treated by URANS (SST), unstructured grid with 41 Million cells
- Structural solver: Inhouse structural solver BeamFOAM
- Based on geometrically exact beam theory [4]. Suitable for large deformations and rotations
- Inhouse partitioned FSI coupling approach utilizing parametric mesh deformation algorithm
- FSI coupling performed once per time step (Weak coupling)

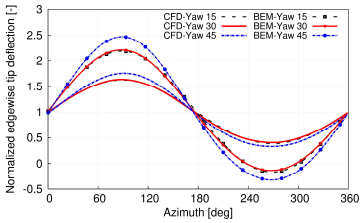




Results I: Structural Dynamics

- Normalization of all presented results based on mean values of each quantity averaged over one revolution
- Clear deviations observed for variations of structural tip deflections. BEM shows more pronounced variations than CFD





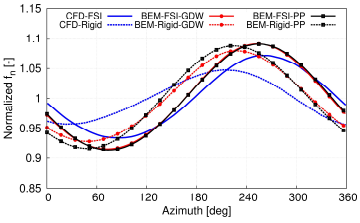
Results II: Aerodynamic Forces

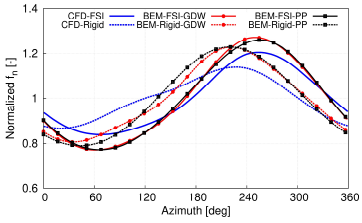
Yaw: 15 deg at 90% span

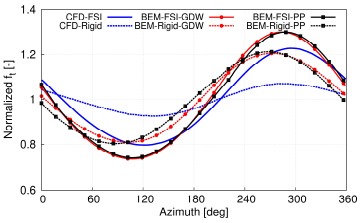
- Reasonable agreement for all approaches, more pronounced deviations for tangential forces
- Moderate effect of structural deformations (Up to 15% dev.)

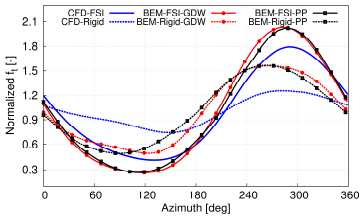
Yaw: 45 deg at 90% span

- Clear differences between numerical approaches, much stronger deviations for tangential forces
- Significant effect of structural deformations (Up to 50% dev.)









Conclusions

- DTU 10 MW rotor subjected to yawed inflow simulated by BEM and CFD-CSD for different inflow angles
- The results show: BEM overpredicts variations of both deformations and aerodynamic forces compared to CFD.
- Especially for large yaw angles, amplitude deviations up to 30% possible between BEM and CFD

References

[1] C. Bak et al.: "Description of the DTU 10 MW Reference Wind Turbine", Tech. Rep., DTU, 2013
[2] J. Jonkman, M. Buhl Jr.:"FAST user's guide", NREL, 2005
[3] OpenFOAM www.openfoam.org Version 4.1.0
[4] O. A. Bauchau: "Flexible Multibody Dynamics", Vol. 176, 2010