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Differences in Modeling Blade- and Inflow-induced Rotor Aerodynamic non-Uniformities

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1 Background and methodology

Despite being researched in the wind energy community for several decades, the accuracy of rotor aerodynamic models used for wind turbine design remains an important topic. Higher fidelity Computational Fluid Dynamic (CFD) models have appeared but the necessity for short computational times still results in lower fidelity Blade Element Momentum (BEM) models being favored as the industry workhorse. Associated with these models are inherent shortcomings, due to the underlying assumptions on which they are built, which are subject to improvement using engineering extensions. Previous work within the framework of International Energy Agency (IEA) Wind Task 47 has revealed inherent shortcomings in case of non-uniform inflow conditions [1]. Differences in unsteady loads between CFD, Free vortex wake (FVW) and BEM codes were showcased, and based on momentum considerations several model improvements were proposed. The advent of larger rotors has made flow non-uniformities (e.g. shear, veer, turbulence) more important. At the same time, non-uniformity can also be induced by differences between the blade, for example by application of individual pitch control which has become more commonplace for modern wind turbines. Building on the previous work on this topic [1, 3], the current research will investigate to what extent blade induced non-uniformities require special attention as well.

To this means, three simulation rounds were executed with different fidelity models, featuring the well researched DanAero turbine, as summarized in Table 1. To create an analogy with the exponential shear inflow case (Case_shear), a harmonic pitch angle variation was designed as a function of blade azimuth angle, resulting in a similar load amplitude as for the sheared case. As such, the harmonic pitch variation was actuated at a decrease of 1.25 degree for the blade pointing up and an increase of 1.25 deg for the blade pointing down (Case_IPC), without having a vertical shear. For Case_IPC_shear, the inverse of the mentioned pitch angle variation was implemented together with the vertical wind shear, to observe whether the two effect can be cancelled out. Two CFD codes (DLR_Tau and DTU_EllipSys3D), a FVW code (TNOAero-AWSM) and five different BEM type codes were used.

Table 1: Summary of mean conditions and configurations investigated.

Case Name	Hub H. Wind Speed [m/s]	Shear Exp [-]	Rot. Speed [rpm]	Pitch [deg]	Ax. Ind. Factor† [-]	AOA† [deg]	Model Type
Case_shear	6.1	0.35	12.3	3.00	0.25	2	Rigid
Case_IPC	6.1	0.00	12.3	3.00 +/- 1.25	0.25	2	Rigid
Case_IPC_shear	6.1	0.35	12.3	3.00 -/+ 1.25	0.25	2	Rigid

† estimate at 80% span based on BEM simulations

2 Results and discussion

From a visual inspection of Figure 1, it can be observed that the normal force variation for the pitch case indeed is comparable to the sheared case. If we zoom in on the load amplitudes in Figure 2 (here r1 to

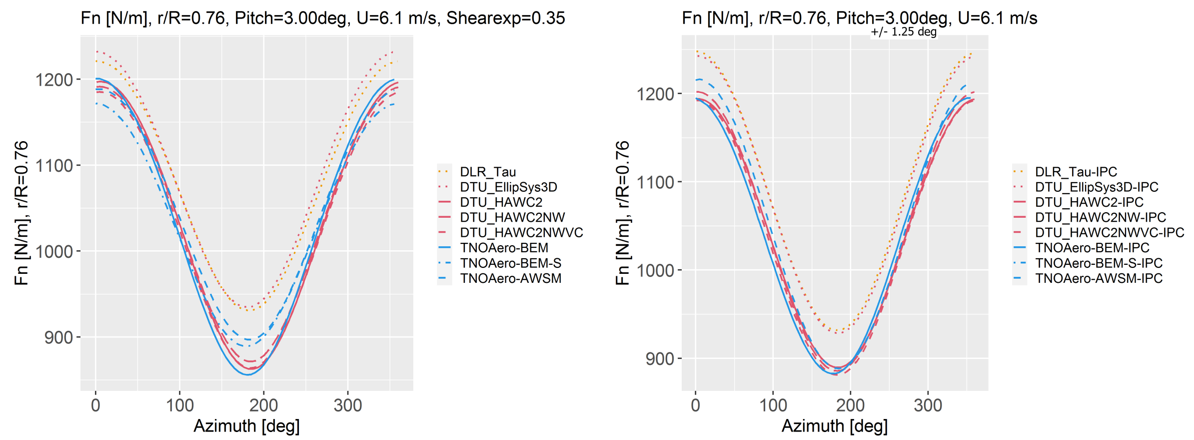

Figure 1: Comparison of chordnormal force variation with rotor azimuth angle at 30 m (76%R) from the rotor center for Case_shear (left) and Case_IPC (right).

r4 represent spanwise locations of 33, 48, 76 and 92 %R respectively), the difference between the various code types for the shear case is apparent, illustrating lower amplitudes for CFD and FVW simulations versus the BEM results. However, this image does not persist in the IPC case, where we can observe a good agreement between all codes. This also holds for the axial induced velocities. As a consequence, the momentum curves are in good agreement with local momentum theory in Figure 3. Hence it can be concluded that although non-uniformity in the inflow is problematic for most BEM type codes, this seems not the case for non-uniformity in terms of loads.

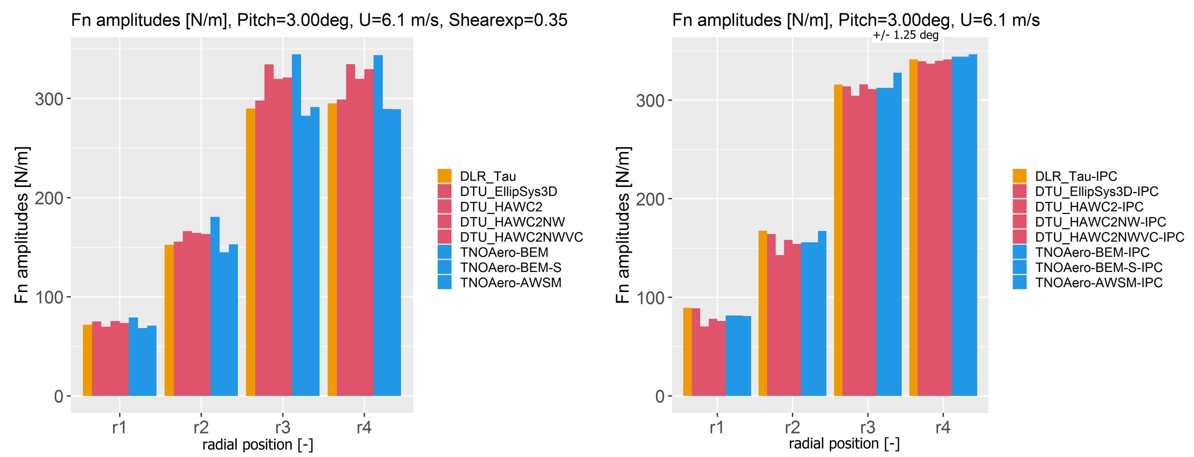

Figure 2: Comparison of chordnormal force amplitudes for Case_shear (left) and Case_IPC (right).

Shifting the attention to a mixture of both uniformities, the pitch variation in Case_IPC_shear was designed to cancel out the load variation due to shear. Figure 4 confirms the load variations to decrease, but they do not fully cancel out. The trend from the two CFD codes is distinctively different from the BEM type codes, featuring two similar peaks. Despite a level offset, the trend from the FVW code seems to agree with CFD. The axial induced velocity variation can be shown to feature a clear difference in amplitude again, dependent on code type and its implementation. The momentum curves in Figure 4 show a similar pattern compared to the conventional shear case, with the FVW loop inclined at a large angle compared to the theoretical and BEM curves.

It is hypothesized however, that if the pitch actuation as function of blade azimuth would be different between the blades, a dynamic wake effect will make its entry, as the wake velocities will change in time for each rotor-azimuthal sector. As a consequence, the resulting combination of non-uniform and dynamic

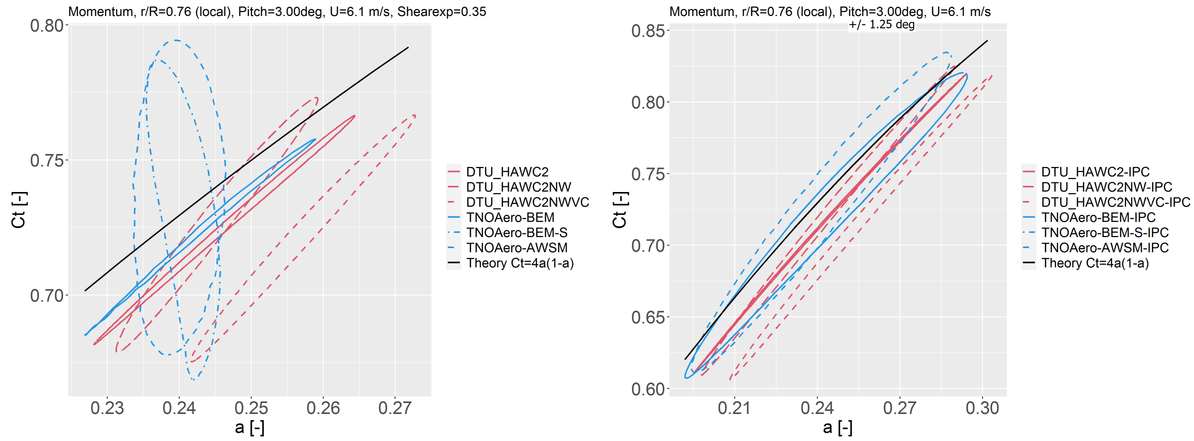

Figure 3: Comparison of agreement with the theoretical momentum curve at 30 m (76%R) from the rotor center using the local approach for Case_shear (left) and Case_IPC (right).

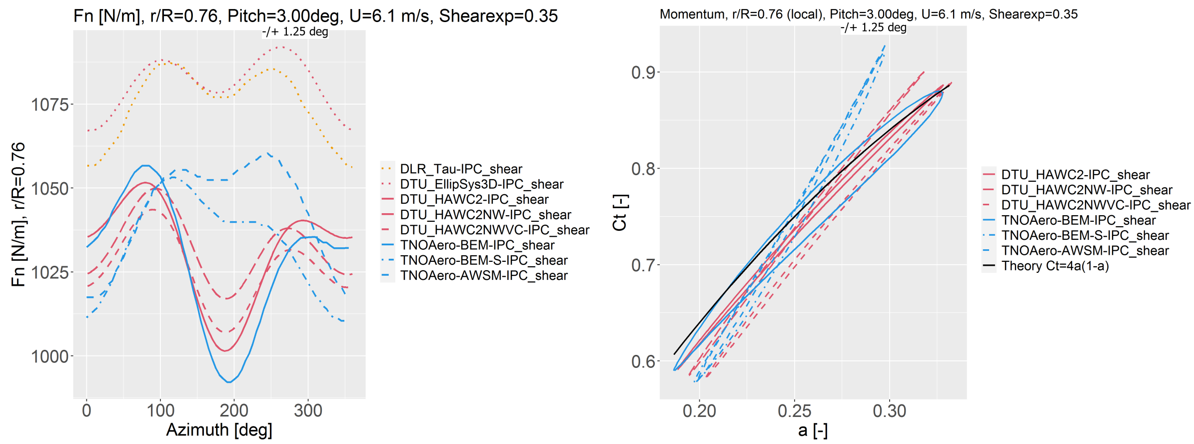

Figure 4: Comparison of chordnormal force variation (left) and agreement with the theoretical momentum curve for the local approach (right) for Case_IPC_shear at 76%R.

wake effects is expected to pose a challenge for BEM type codes. This has previously been demonstrated by wind tunnel tests [2], where pitching steps were executed for one out of three blades only, showcasing a good agreement with measurements for a FVW simulation but poor for the BEM type simulation. The observations and improvements are subject to further investigation and part of the ongoing efforts within IEA Wind Task 47.

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