PO.263

Cross comparison of aeroelastic state-of-the-art Tools on a 10MW scale wind turbine

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Aims and Content

In development of innovative wind turbines as part of the Innwind.EU project, the present work aimed at identifying possible shortcomings in aeroelastic modeling of Large Wind Turbines with respect to:

1. Structural modeling of complex designs (geometrical nonlinearities / coupled modes)
2. The increased excitation due to the lowering of the rotor frequencies towards the more energetic part of the wind spectrum.
3. The increased azimuthal variation of the wind inflow excitation and the related dynamic inflow modeling

Simulations within the INNWIND.EU project from 4 aeroelastic tools and their variants for the 10MW Reference Wind Turbine designed by DTU are compared. In order to address one by one the different aspects of modeling the following step were taken:

1. For the structural part, modal analysis and static loading cases; comparison with 3D FEM
2. For the assessment of the dynamic inflow, Stiff rotor operation in turbulent wind
3. For the full aeroelastic case: Normal operation in open and closed loop conditions

The tools

Code name	Institute	Structural modeling	Aerodynamics
Cp-Lambda	PoliMi	FEM Geometrically Exact FNL / Multi Body	BEM
HAWC2	DTU	FEM Timoshenko / Multi Body	BEM, Near Wake
hGAST	NTUA	FEM Timoshenko / Multi Body	BEM, Free Wake
NEREA	GAMESA	FEM Generalized Timoshenko	BEM

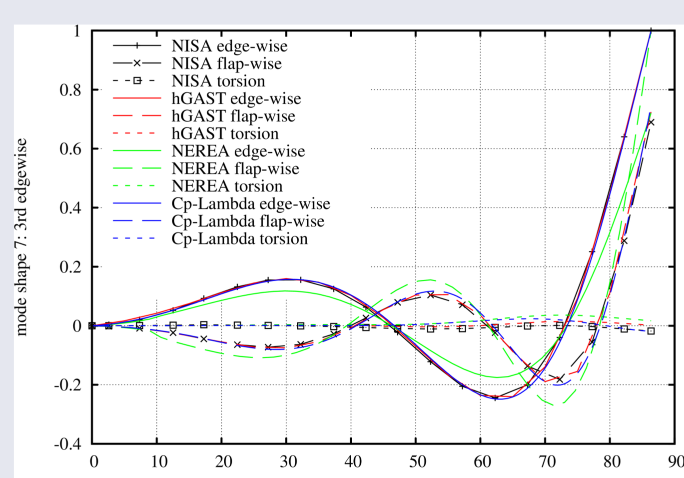
Structural Cross Comparison

Modal Analysis

Fair agreement with 3D FEM up to the 7th mode

(#)	mode	hGAST	NEREA	Cp-Lambda	HAWC2	NISA
1	1st flap	0.62	0.62	0.62	0.61	0.64
2	1st edge	0.94	0.94	0.94	0.93	0.96
3	2nd flap	1.76	1.74	1.76	1.74	1.85
4	2nd edge	2.80	2.79	2.80	2.77	2.86
5	3rd flap	3.59	3.52	3.60	3.57	3.76
6	1st torsion	5.40	5.36	-	6.60	6.01
7	3rd edge	5.73	5.61	5.74	5.70	5.82
8	4th flap	6.09	6.03	6.11	6.11	

Similar mode shapes - Coupled modes

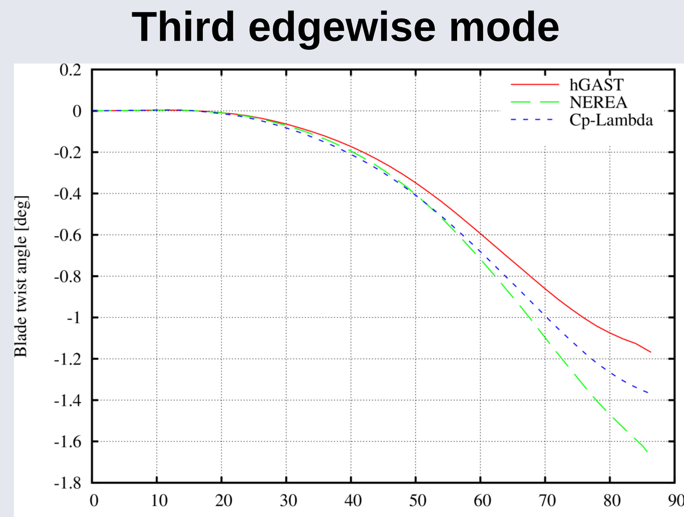


Third edgewise mode

Static flapwise Loading

Good agreement (max uncertainty in the torsion angle=0.4° at the tip)

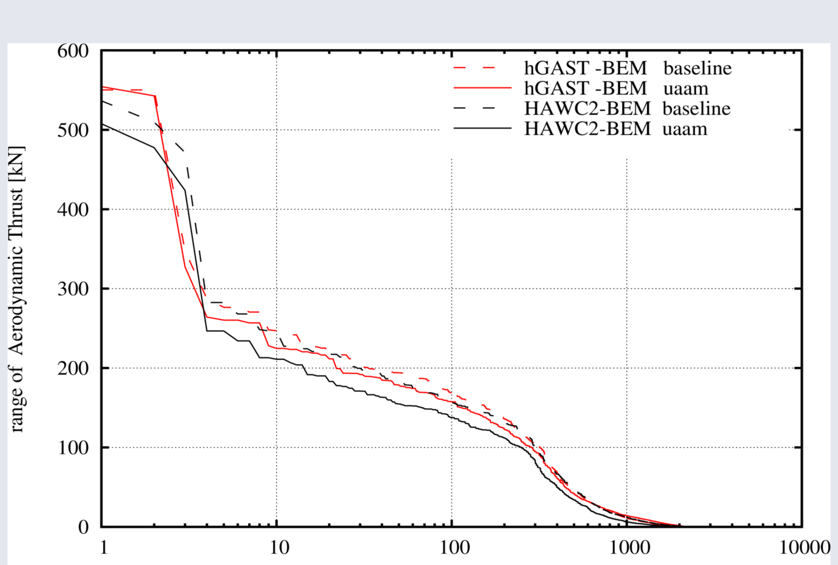
The bending-torsion geometric nonlinear effect is triggered due to the high flapwise deflections (about 10% of the blade length).



Twist angle

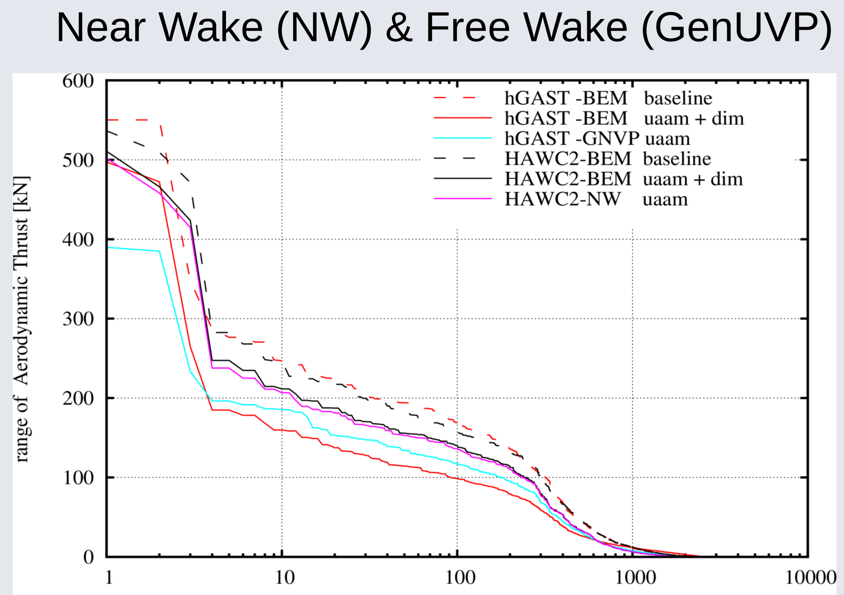
Aerodynamic simulations

Baseline BEM
vs
Unsteady airfoil aerodynamics (uaam)



RFC of Thrust– 8m/s

Baseline BEM
Vs
Unsteady airfoil aerodynamics (uaam)
+Dynamic Inflow modeling (dim)
Vs
Near Wake (NW) & Free Wake (GenUVP)

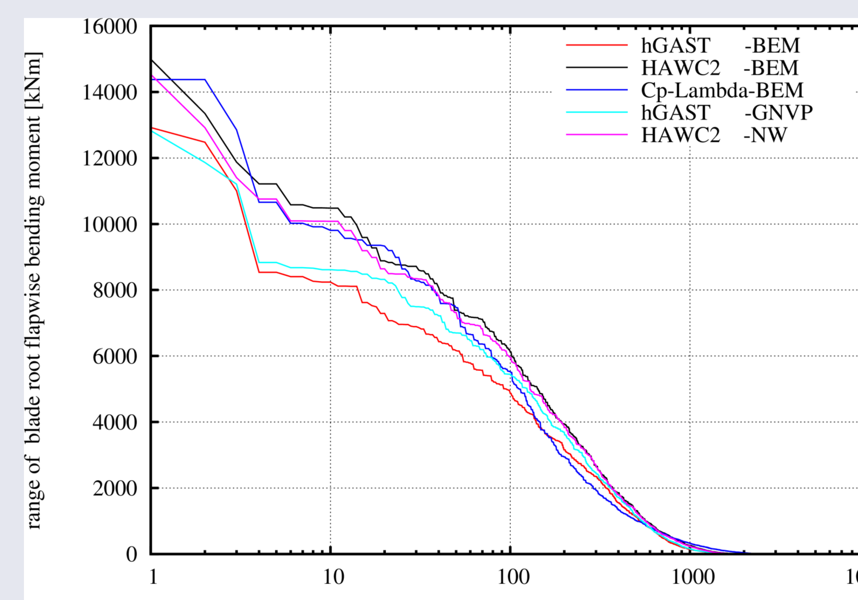


RFC of Thrust– 8m/s

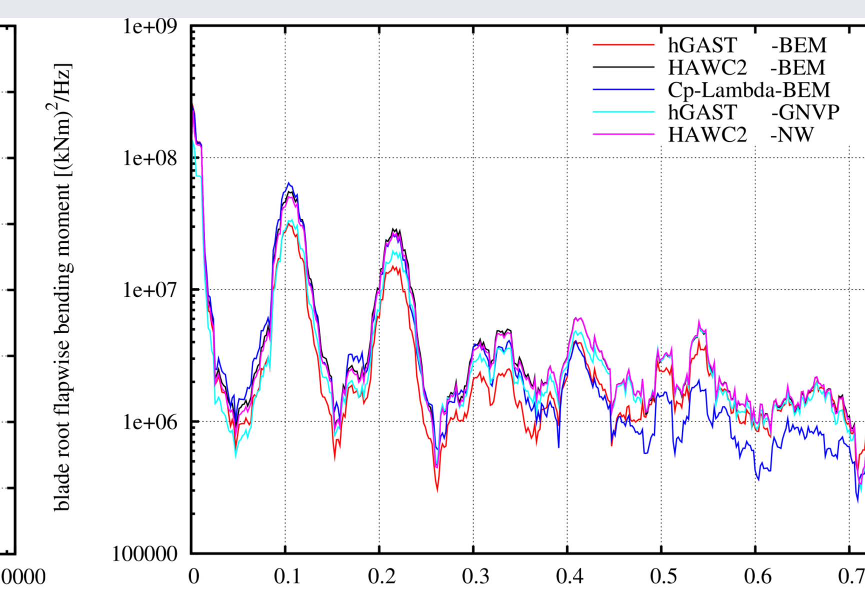
In these simulations the rotor is stiff while the inflow turbulent. When the dynamic inflow is switched off the ranges in the RFCs agree well. On the contrary when it is switched on the expected range decrease is not the same. The cylindrical model in hGAST-BEM over-filters the excitations compared to HAWC2 BEM while the near and the free wake models fall in between.

Fully coupled simulations in Turbulent inflow

Open loop operation



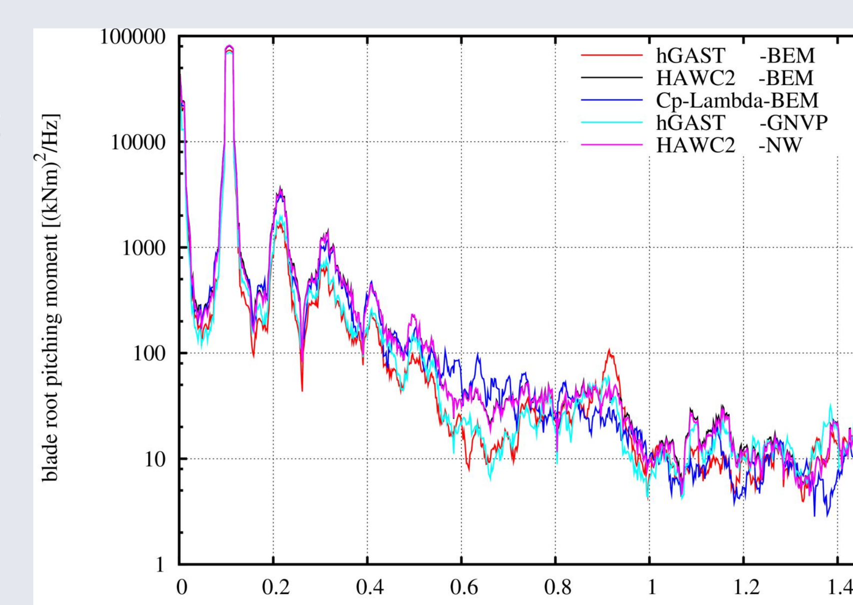
RFC of the flapwise moment – 8m/s



PSD of the flapwise moment – 8m/s

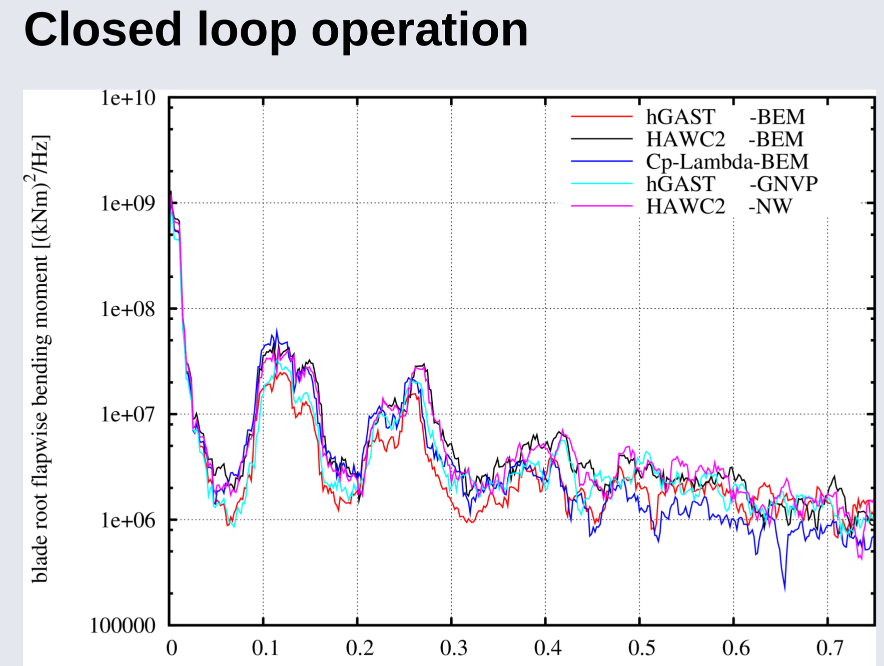
As in the stiff rotor case the cylindrical wake model under-predicts the ranges compared to the more elaborate models while the free-wake models fall in between. In the corresponding PSD the deviations are mainly concentrated on the 1P & 2P response which is also attributed to the differences in the modeling of the dynamic inflow.

The PSD plot of the pitching moment at blade root shows good agreement in the dominant 1P peak which dominates the response. There is an excitation at ~0.9 Hz that corresponds to the 1st edgewise mode. This cross talking is due to a bending-torsion coupling effect which gets more pronounced when high flapwise deflections appear.

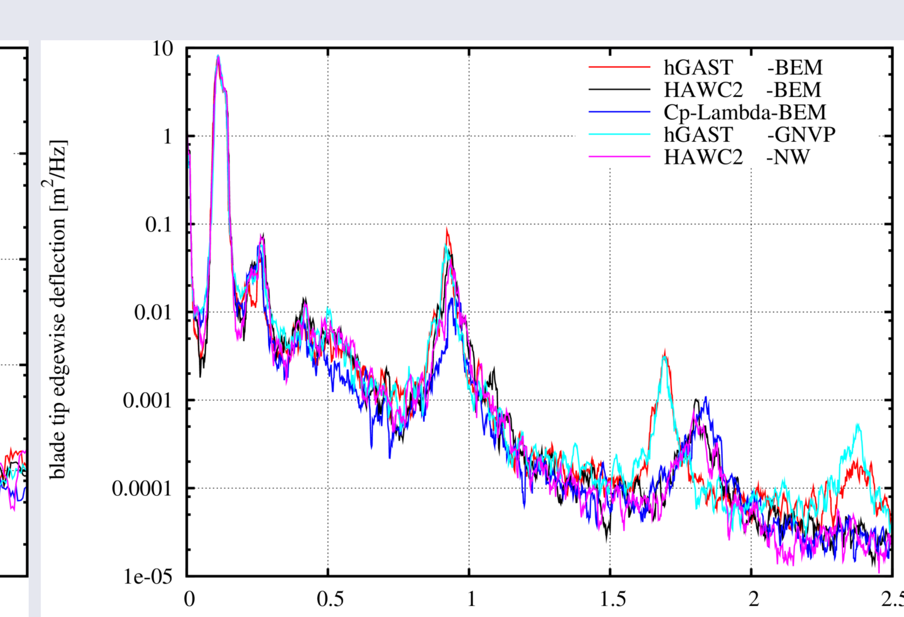


PSD of the pitching moment – 8m/s

Closed loop operation



PSD of the flapwise moment – 8m/s



PSD of the edgewise deflection – 8m/s

In closed loop operation the agreement in the flapwise bending PSD is slightly better. This is due to the variable speed operation. Then with respect to the edgewise direction, there is very good agreement in the corresponding PSD of the deflection at tip, at 1P (0.2Hz) and at the 1st edgewise mode (peak about 0.95Hz). At higher frequencies the response in the range 1.5-2Hz is predicted differently. In the results of both versions of hGAST the same frequency for the peak is predicted so it should be attributed to the different modeling of the nonlinear structural couplings.

Conclusions

- In purely structural terms the beam models was found to compare well to the 3D FEM data up to the 7th mode. 3D FEM predicted in general higher frequencies. Strong coupling effects are consistently predicted and a fair overall agreement is obtained in the shape of the modes. The beam models under predict the torsion angle and the coupled flapwise mode.
- In terms of unsteady airfoil dynamics, the existing models work similarly. In terms of dynamic wake modeling, the simple cylindrical model over-filters the response compared to more elaborate ones, while free wake results are in between. As a result in the fully coupled cases, in open loop operation deviations are seen in the 1P & 2P flapwise responses.
- In closed loop operation the agreement in the flapwise predictions slightly improves because of the controller, while different modeling of the bending torsion coupling leads to different response in the 2nd symmetric edgewise mode.

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