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Simplified Aerodynamic Models with Limited Rotor Data for the Design of Floating Offshore Wind Turbine Support Structures

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Abstract

The industry recently gains momentum in the design of floating offshore wind turbines. An industrial design cycle including all manufacturers is still missing. A coupled analysis for the design of the floating foundation taking also the aerodynamic loads into account is necessary. Detailed **information on the aerodynamic properties of the rotor blades and the wind turbine controller is necessary for coupled simulations** using standard approaches like BEM. However, the required input data is often confidential. **Simplified models for the estimation of aerodynamic loads help to close the gap between turbine manufacturer and floater designer when confidentiality is important.**

Objectives

- Development of **simplified engineering-level model** for the computation of **aerodynamic loads** without the need of confidential data,
- **Calibration** of non-dimensional coefficients compared to full model simulation,
- Simulation of **design load cases (DLC) for power production and storm** using simplified model, analysis of statistics and comparison to full model.

Thus, the floater designer is enabled to **perform a coupled analysis to a certain level of detail and to estimate tower base loads** which are important for the design of the substructure.

Methodology

The simplified model is named Actuator Point (ACP) model. **Aerodynamic forces** F_{xyz} and **moments** M_{xyz} are applied by an **actuator** that is located at the **hub centre** (see Fig. 1). F_{xyz} and M_{xyz} have wind speed depended and constant components. **Non-dimensional coefficients** c_{xyz} and $c_{m,xyz}$ are determined during **calibration**. F_{xyz} represents a drag force on a quadratic plane (see grey square in Fig. 1). The turbulent wind disturbance is measured at the hub centre and effects of **relative velocity** due to floater motion and wind turbine **yaw** are included. However, Non-uniform wind distribution across the rotor disk is not considered.

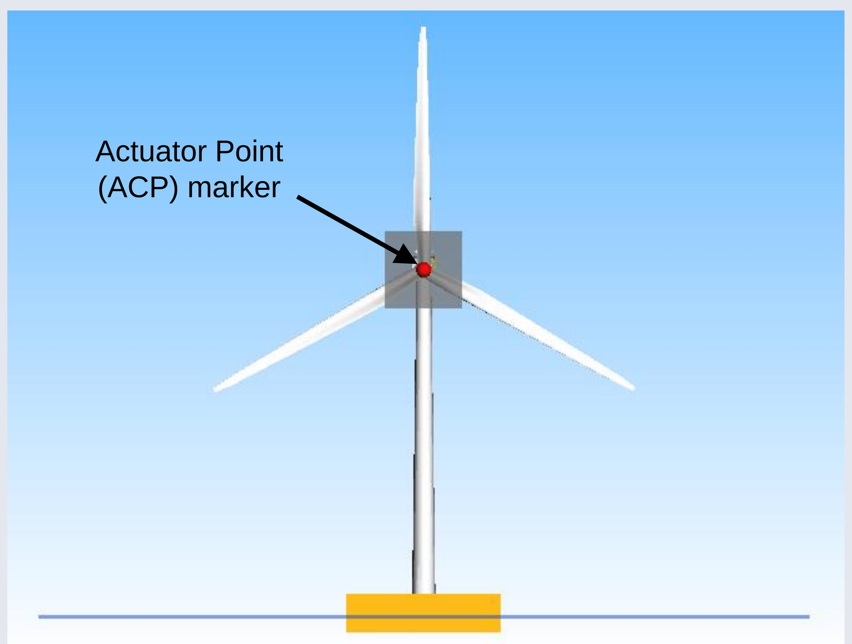

Fig. 1: Aerodynamic forces and moments are applied at the actuator (red) located at the hub centre

$$F_{xyz} = c_{xyz} \cdot \frac{\rho}{2} \cdot |u_{xyz}| \cdot u_{xyz} \cdot A + F_{xyz,const}$$

$$M_{xyz} = c_{m,xyz} \cdot \frac{\rho}{2} \cdot |u_x| \cdot u_x \cdot A \cdot l + M_{xyz,const}$$

For consideration of **winds loads on the tower at extreme wind conditions**, e.g. DLC 6.1, the tower is divided into n equidistant sections and the drag **forces** $F_{xy,wind}$ are applied (see Fig. 2) on the cylindrical structure. The drag coefficient c_d is determined according to the Reynolds number.

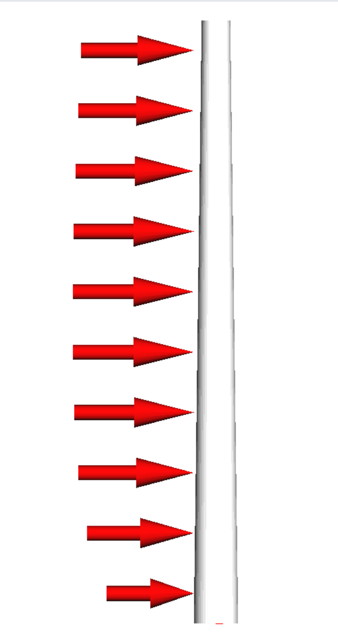

Fig. 2: Illustration of wind loads on tower

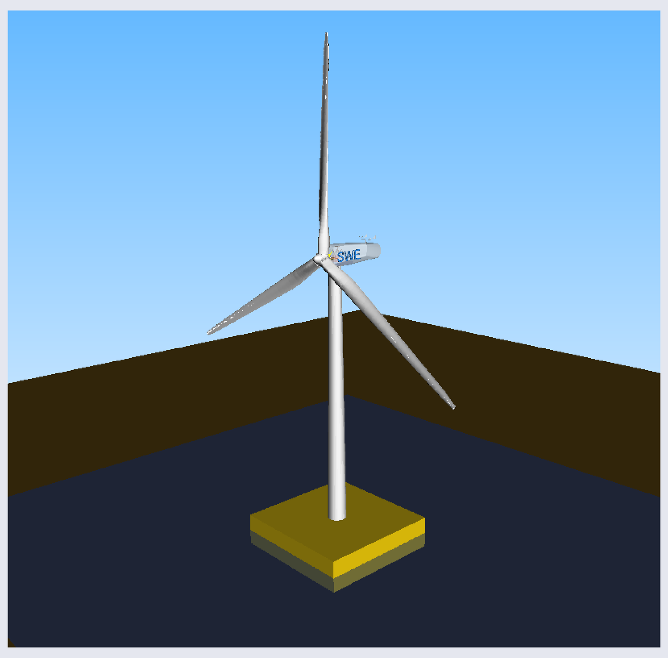

Fig. 3: Illustration of the floating offshore wind turbine model

Numerical simulations of the standardized **NREL offshore 5-MW** baseline wind turbine mounted to the conceptual floating foundation ITI Energy **Barge** are conducted by means of the **Multibody System** (MBS) software SIMPACK. Hydrodynamic forces are calculated via a coupling to NREL's software package HydroDyn. A **quasi-static mooring line model** is used to apply restoring forces. The tower properties and floater damping characteristics of the baseline model are modified to represent a more realistic design.

Results

A **procedure for calibration** of non-dimensional (c_{xyz}, $c_{m,xyz}$) and constant ($F_{xyz,const}$, $M_{xyz,const}$) coefficients is developed. **Reference results** are based on the **full model** (aerodynamics: BEM) at onshore conditions. For **each wind speed and design situation**:

1. Full model: Perform DLC simulations and evaluate statistics of tower base loads
2. Simplified model: Perform DLC simulations **iteratively**, evaluate **statistics of tower base loads** and **compare to full model**
   a. Tune c_{xyz} and $c_{m,xyz}$ with respect to **standard deviation**
   b. Tune $F_{xyz,const}$ and $M_{xyz,const}$ with respect to **mean**
   c. Tune c_{xyz} and $c_{m,xyz}$ with respect to **minimum** and **maximum**

After calibration **numerical simulations of design situations** derived from IEC 61400-3 [1] are conducted and results are compared between full and simplified model.

Power production: DLC 1.2
v_{hub} = 6 m/s, H_s = 1 m, T_p = 8 s

Parked (idling, storm): DLC 6.1a
v_{hub} = 47.5 m/s, H_s = 9.3 m, T_p = 15 s, zero heading

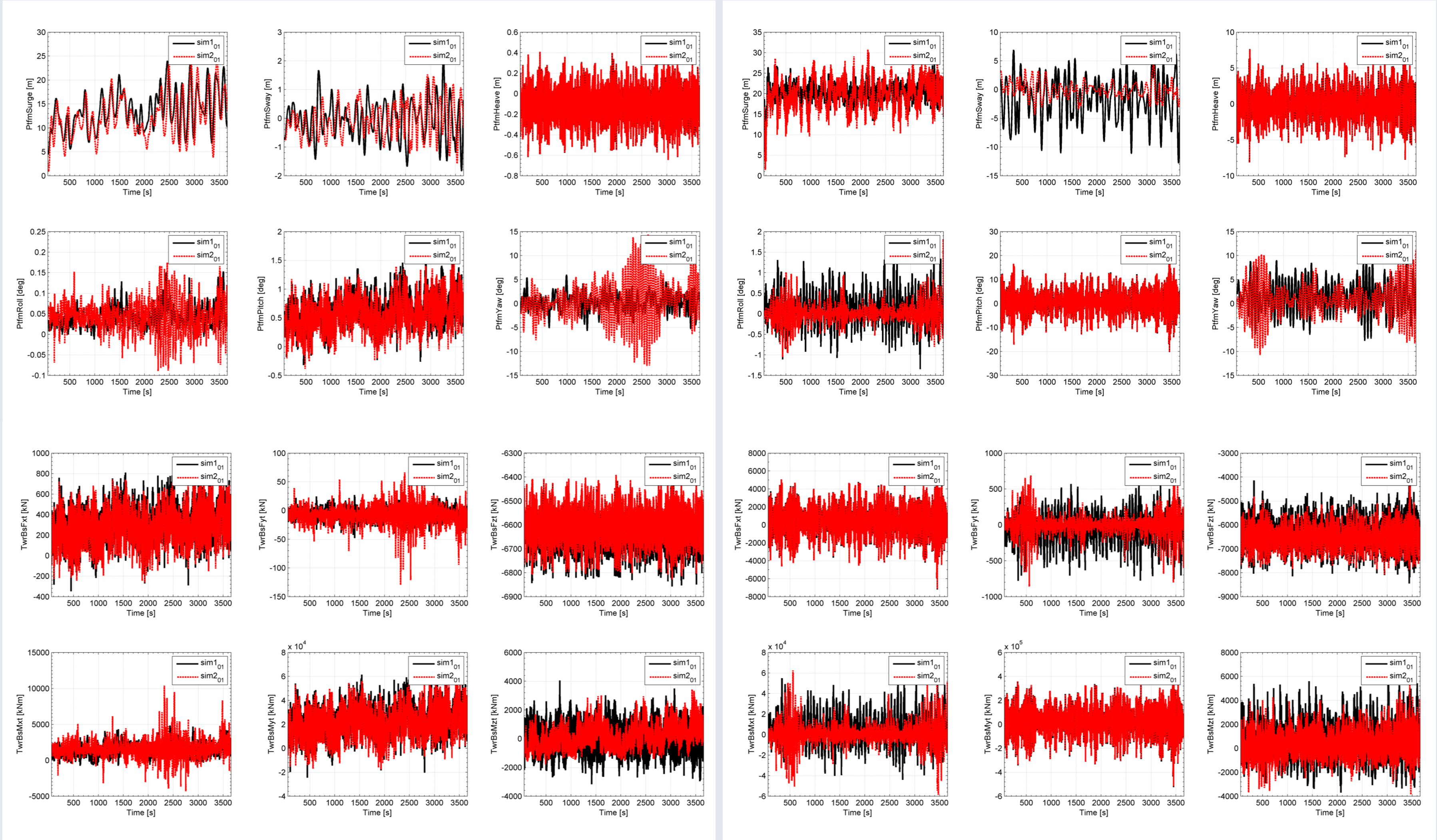

Fig. 4: Results of **floater motion** (top) and **tower base loads** (bottom) using **full (black)** and **simplified (red)** model

Conclusions

Results using the simplified model show that **extreme amplitudes of the floater motion and tower base loads are captured well** with respect to the full model, especially for above rated conditions. The most important condition for a simplified approach, to be **conservative**, is met.

The simplified aerodynamic model will be improved based on [2] by:

- Incorporation of a rotor effective wind speed to consider non-uniform wind,
- Inclusion of thrust and power curves to account for controller effects.

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References

[1] IEC 61400-3, International Standard, Edition 1.0, Geneva, Switzerland, 2009.
[2] Schlipf D., Schlipf D. J., Kühn M., "*Nonlinear Model Predictive Control of Wind Turbines Using LIDAR*", Wind Energy, vol. 16, no. 7, pp. 1107–1129, 2013.
[3] FLOATGEN (2014). "Kick-off meeting for the renewed FLOATGEN project, leading the way in European deep offshore wind energy with the first floating wind turbine demo in France," Press Release, Nantes, France, June 24th 2014.

SEVENTH FRAMEWORK PROGRAMME
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