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A new, high fidelity offshore wind turbines aeroelasticity prediction method with significant CPU time reduction

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1. Abstracts

Industry standards for Offshore Wind Turbines (OWTs) aeroelastic simulations are based on the Blade Element Momentum Theory (BEM). BEM method offers a very good computational efficiency and an acceptable flow response, thanks to the introduction of additional sub-models. However, the accuracy of this approach is limited when dealing with OWT rotors, due to the existence of highly skewed flows, heavy detachments and important blade deflections. Hence, the use of more sophisticated Computational Fluid Dynamics (CFD) techniques is justified.

2. Objectives

This study reviews the potential of CFD-based tools in Offshore Wind Energy sector. Both computational and engineering times were significantly reduced thanks to the use of innovative numerical methods. The set-up of a high fidelity fluid model allowed us to identify the complex 3D mechanisms driving rotor aeroelasticity.

3. Methods

Numerical aeroelastic simulations were performed using the commercial CFD package FINE^{TM} /Turbo (see NUMECA International, 2013).

The level of complexity of the used technologies was increased together with the understanding of the physical processes involved.

Concerning flow modeling, two different approaches were followed:

- **Steady flow / Unsteady flow**

A structural model could be optionally added to our flow simulation, leading to two different configurations from this point of view:

- **Rigid structure / Flexible structure**

3.1 Steady flow model

A Reynolds Averaged Navier Stokes (RANS) approach was used in order to perform 3D steady simulations. Due to the interesting trade-off between accuracy and computational time of RANS methodology, it has become the industry standard for CFD analysis.

3.2 Unsteady flow model

Regarding unsteady flow simulations, industry has relied on a straightforward variant of RANS methodology, often referred as URANS.

However, the required computational time in order to perform an URANS simulation of a complex geometry is often impossible to fit in an industrial workflow.

The possibilities of the application of an alternative (and less costly) methodology were explored in this study. Indeed, the Non-linear Harmonic (NLH) approach presented by Vilmin et al. (2006), allows to drastically reduce the required computational time by assuming that the unsteady nature of the flow is periodic.

3.3 Flexible structure model

Blade structure is represented by its natural frequencies and mode shapes. These are determined outside the flow solver and prior to any CFD computation, either by computation with a Finite Element Method (FEM) structure solver or by experiments.

Using these structural properties, the elastic body deformation under the action of the fluid loads is computed by a linear structural solver integrated inside the flow solver (Debrabandere, 2014).

4. Results

To illustrate the performances of the developed methodology, DTU-10MW Reference Wind Turbine was studied (Bak et al., 2013). Two meshes of the assembly were automatically generated within a short time thanks to Autogrid5^{TM} (see Figure 1, where 1 out of 2 grid lines have been skipped for clarity purposes).

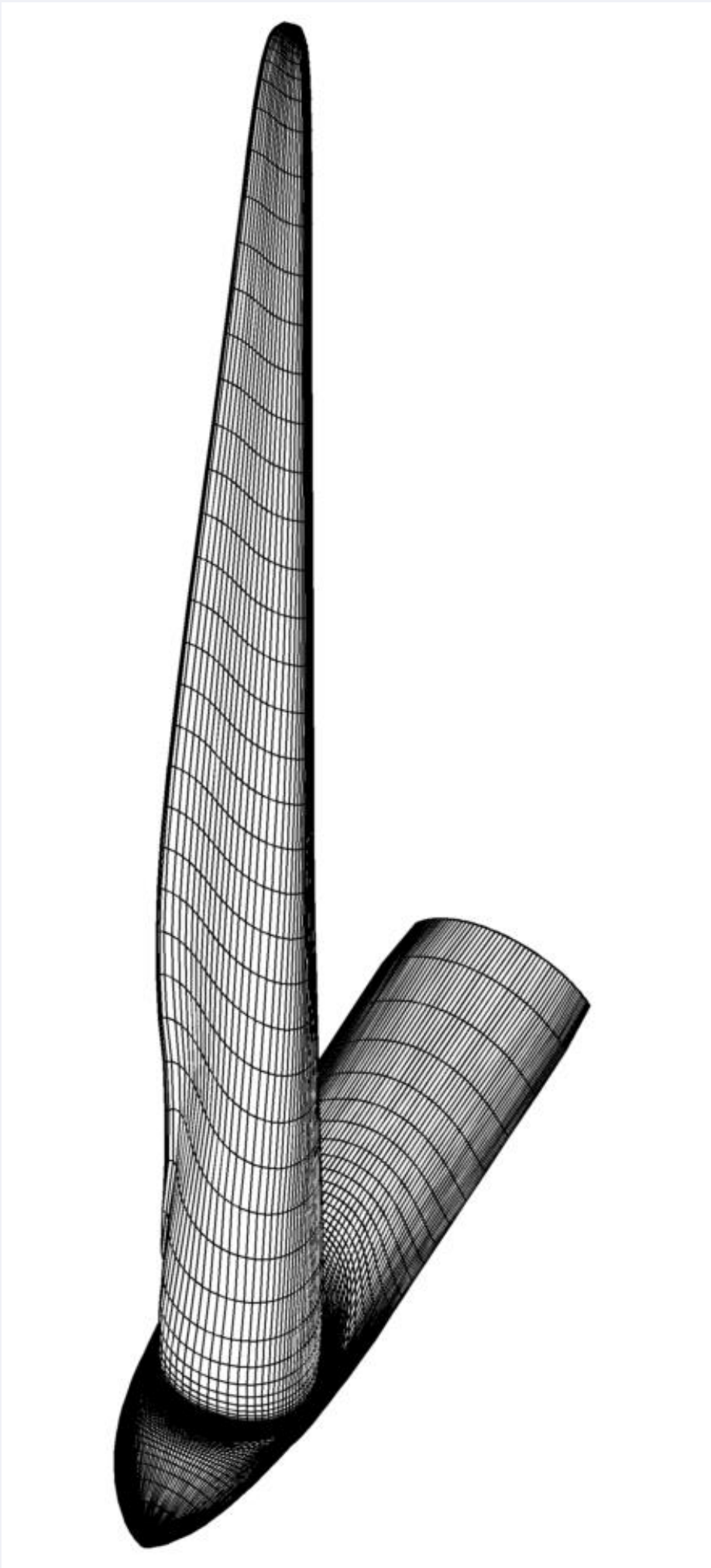

Figure 1.a: *Rotor Only* mesh (7.2 millions of nodes)

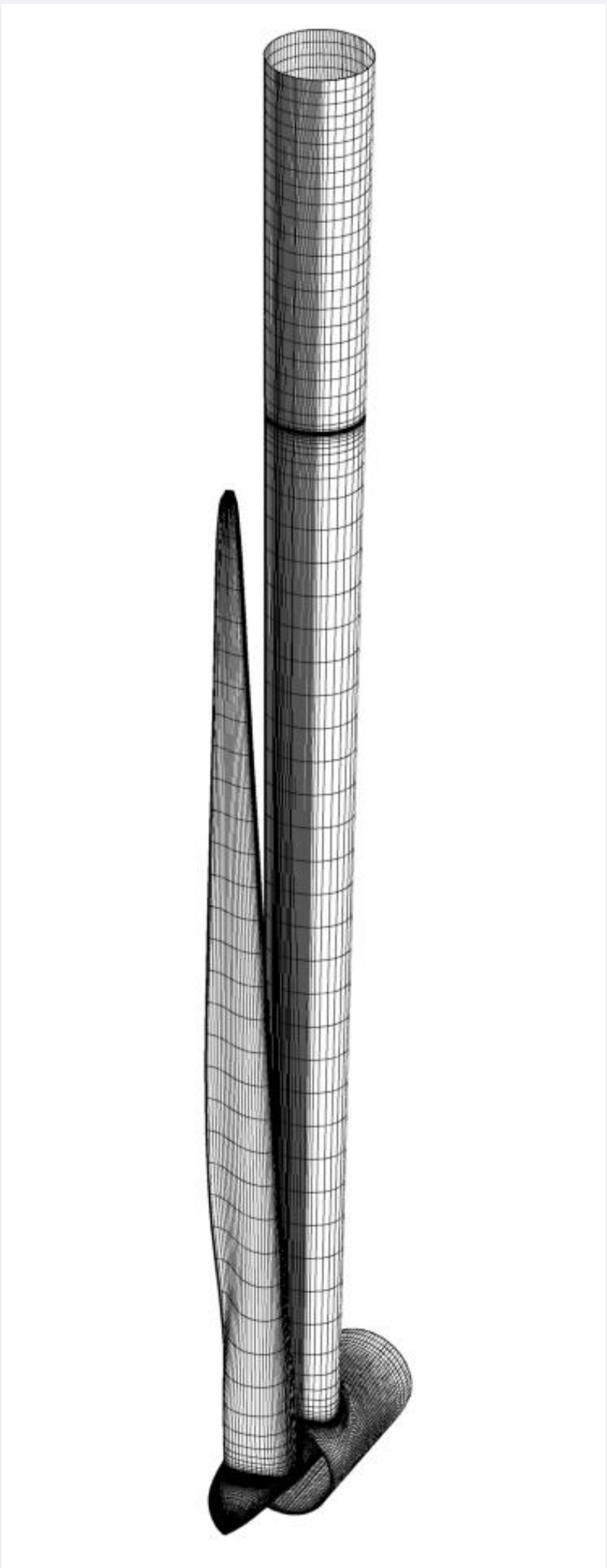

Figure 1.b: *Rotor+Tower* mesh (13.7 millions of nodes)

4.1 Rotor Only simulations

Steady flow simulations were performed, assuming a rigid structure in a first approach. RANS technique allowed not only to compute the global performance parameters of the rotor in a very short time (16 hours on 8 processors), but also to analyze detailed flow aspects. As an example, the effect of the installation of *Gurney flaps* on flow streamlines at rated speed operating point is illustrated in Figure 2.

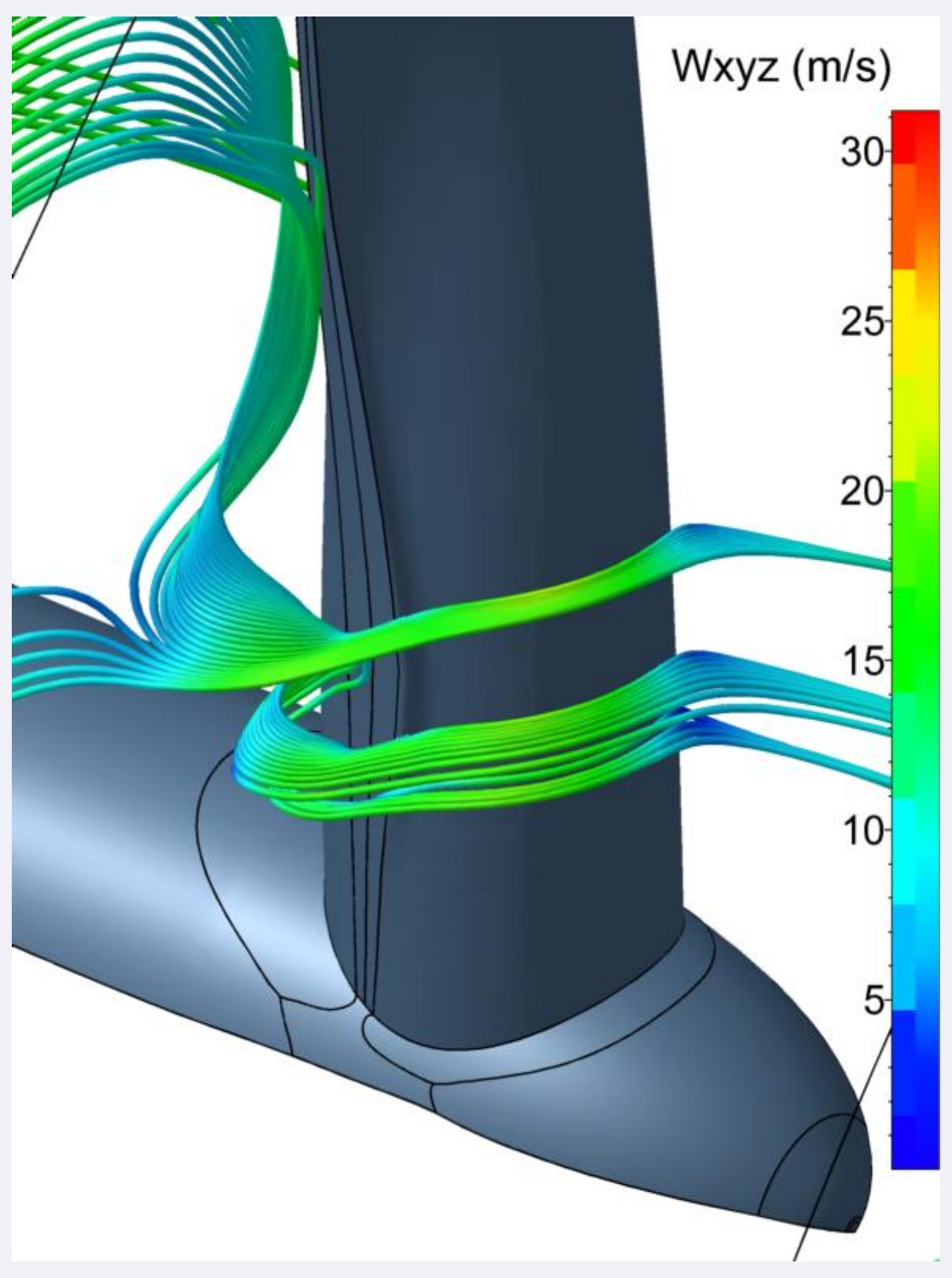

Figure 2.a: Original blade geometry (OR configuration)

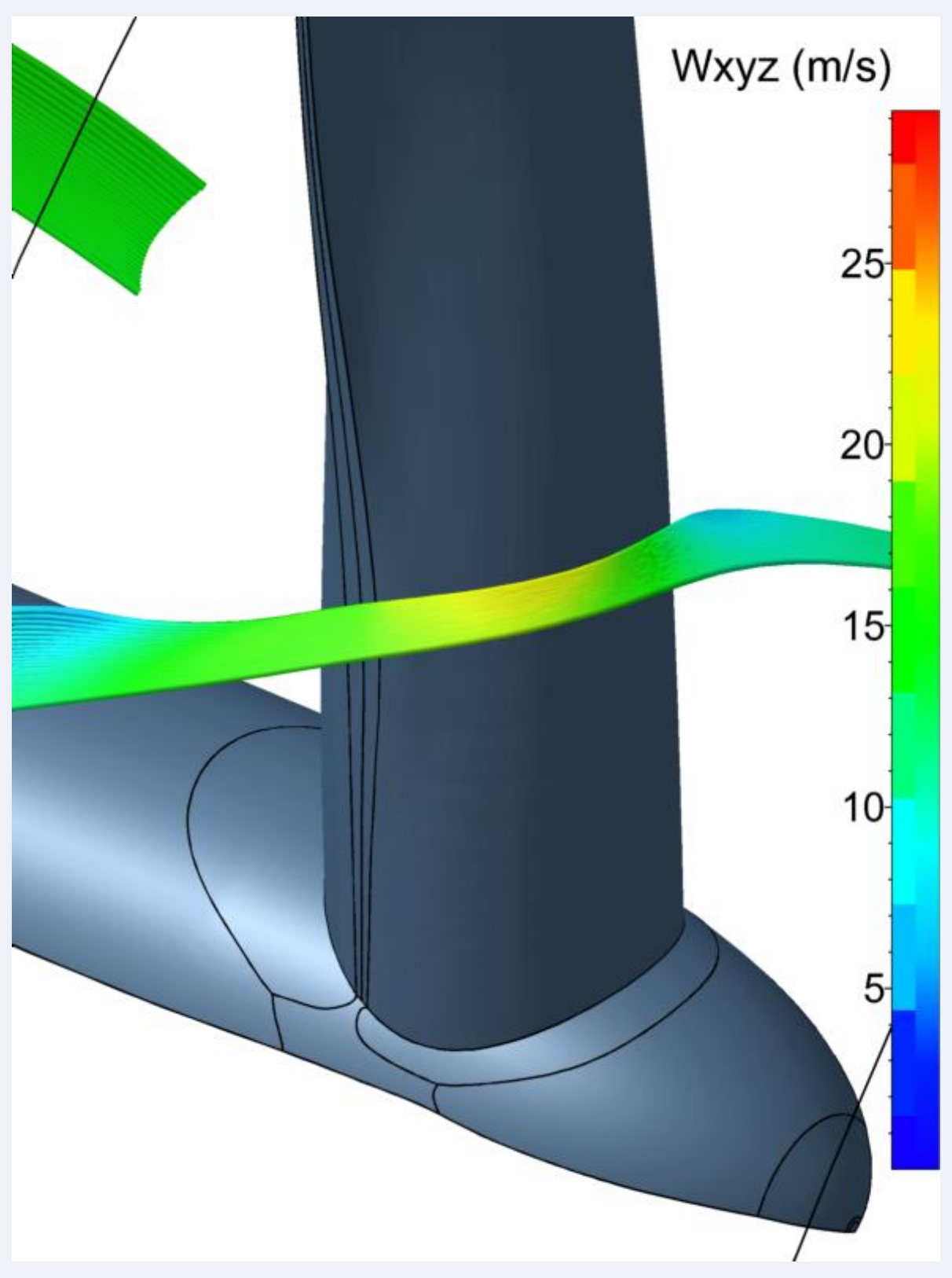

Figure 2.b: Geometry without *Gurney flaps* (NG configuration)

After including DTU-10MW blade structural model in our CFD set-up, two-way coupling simulations have been performed (see Horcas et al., 2014). Only 8 hours of computational time on 8 processors were needed. Important deflections have been observed along the blade, mainly dominated by bending mode (see Figure 3).

The whole DTU-10MW 0 deg pitch operating range has been studied in this research. Figure 4 shows that both the installation of *Gurney flaps* and the deflection of the blade do have an impact on the overall performances of the wind turbine (due to the new considered aerodynamic scenario).

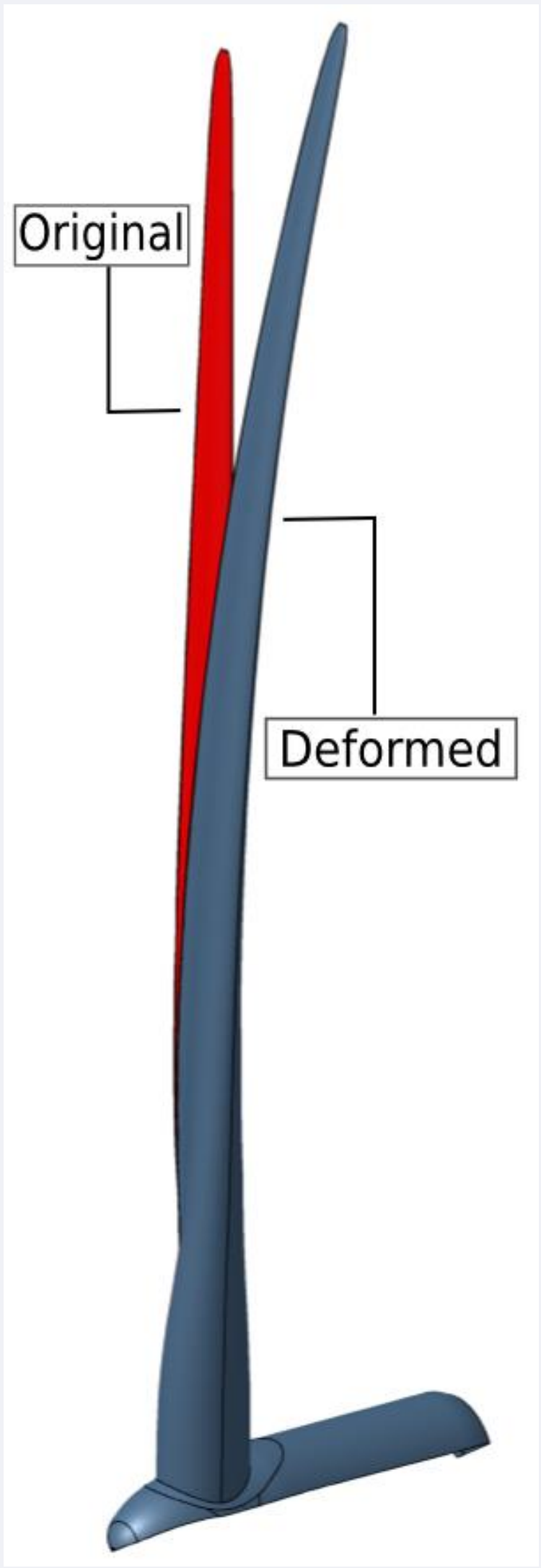

Figure 3: Deformed blade, rated speed

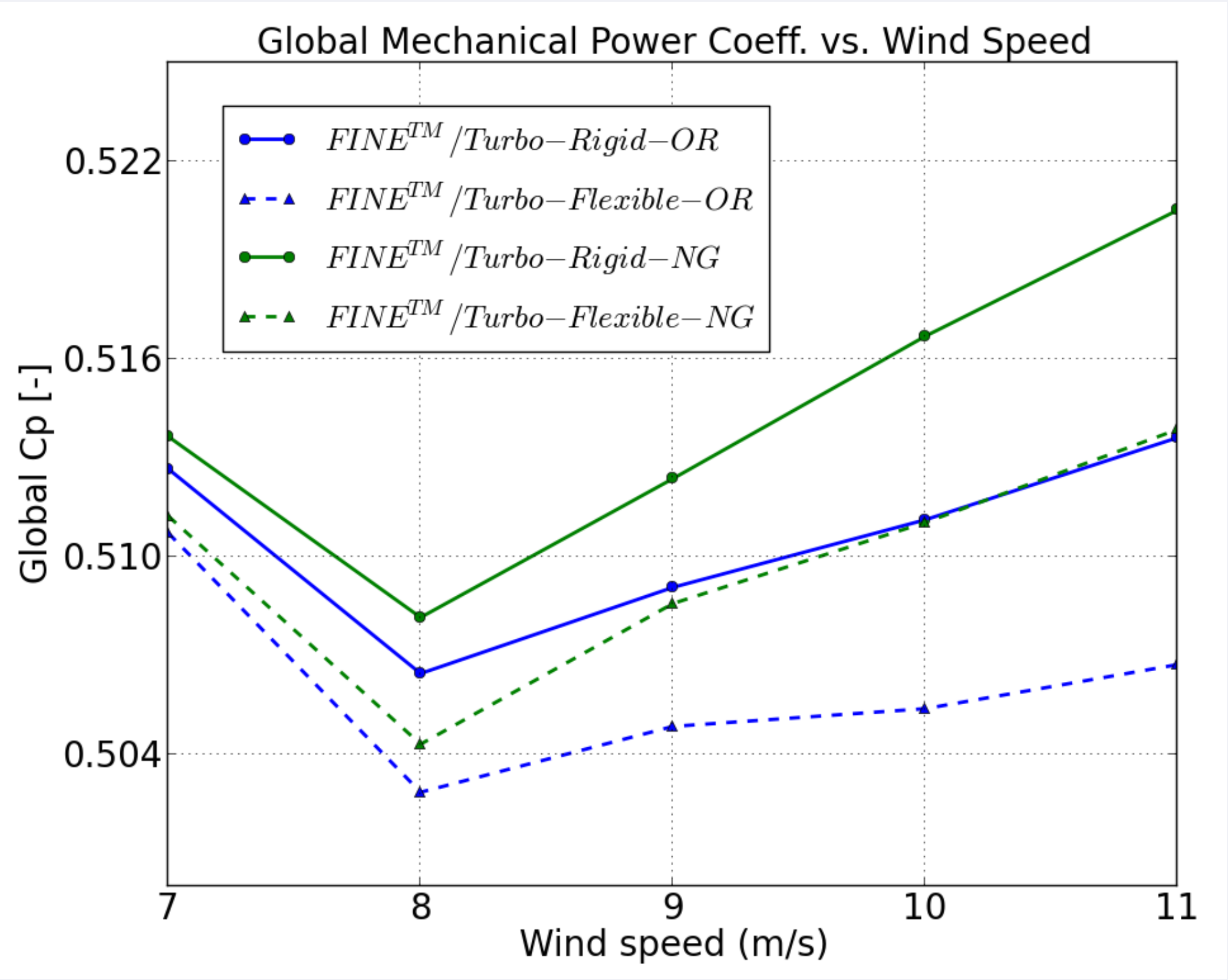

Figure 4: Impact of *Gurney flaps* and flexibility on global mechanical power coefficient. OR: Original geometry, NG: Non-Gurney geometry (see Figure 2)

4.2 Rotor+Tower simulations

An unsteady flow simulation at rated speed operating point was performed for the whole wind turbine assembly. A rigid structure was assumed in a first approach.

A 1-harmonic per row simulation has been launched. Only 8 processors were used for this computation, requiring a total time of 4 days to completely converge. Figure 5 shows the amplitude of pressure fluctuation harmonic. We can observe that both tower and rotor components are concerned by the unsteady effects related to blade passage.

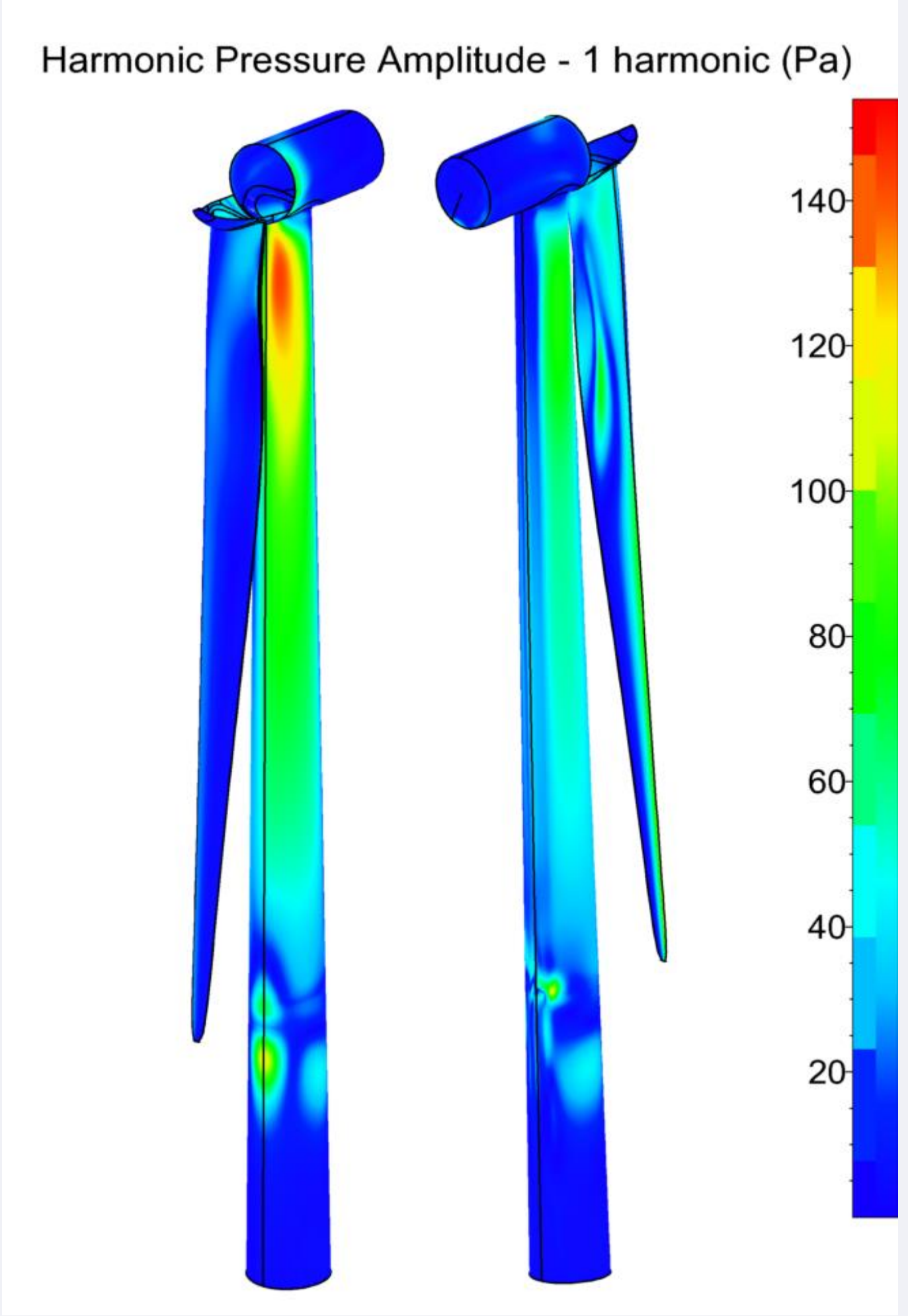

Figure 5: Amplitude of Pressure fluctuation harmonic (front and rear views)

5. Conclusions

This publication summarizes a CFD-based methodology for the analysis of aeroelastic effects in OWTs. Special attention has been put in the reduction of the required engineering and computational times. The NLH method has been applied in the context of OWTs for the first time, allowing us to model unsteady tower-rotor interactions at an affordable computational time. Future works will be devoted to extend the capabilities of NLH method in order to account for a structural model of the rotor (analogously to the introduced RANS approach).

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6. References

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