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Assessment of aero-elastic instabilities on partially assembled unattended WT rotors during installation or maintenance

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Abstract

Suppression of installation costs of onshore wind turbines contributes to the continuing battle for reducing the levelized cost of wind electricity (LCoE). Under moderate wind conditions, assembly of the full wind turbine system in one shot might not be always feasible, as wind speed often exceeds the safety limits. In this case, equipment and people remain idle on site, causing delays and consequently cost increase. A way to overcome the issue is to assemble the turbine in multiple phases, including a two-phase rotor installation. During the first phase, a single or two blades are mounted and left unattended for some period until the second -completion- phase initiates. Then, the question that rises is whether the unfinished turbine is safe against aeroelastic instabilities.

In this work we present the methodology and representative results from the aero-elastic analysis performed for single-bladed and two-bladed unattended configurations under moderate to high wind speeds (corresponding to unattended periods of less/equal and higher than one week) with the rotor in idling mode and the blades pitched to feather position. Both mechanisms that potentially trigger aeroelastic instabilities are examined; stall and vortex induced vibrations (SIV and VIV) on all relevant rotor and tower modes. The analysis is performed applying engineering tools that rely on tabulated airfoil data (i.e. polars).

Objectives

a. The investigation of the aeroelastic behavior in standstill/idling of incomplete rotor set-ups in terms of stability and loading
b. The build-up of a comprehensive framework for performing SIV and VIV analysis using airfoil polars-based engineering aeroelastic tools
c. The identification of critical design parameters affecting SIV and VIV loading

Method

The aero-elastic analysis is performed using the non-linear, multi-body aeroelastic tool iGAST [1].

SIV analysis relies on eigenvalue-based stability calculations, providing total modal damping values (structural plus aerodynamic), as well as on time domain simulations to estimate the relevant loads. ONERA, Beddoes-Leishman and steady stall models are employed, depending on the inflow yaw angle.

The VIV analysis extends EUROCODE "Approach 1" framework for steel structures [2] to wind turbine configurations including tower, nacelle and (incomplete) rotor arrangements. Both time-domain and modal analysis formulations are possible. In time-domain, iGAST applies the VIV load as dynamic external force, while modal analysis provides all additional information needed (i.e. modal shapes, frequencies, and total damping) to evaluate the semi-analytical expression of the displacement and load amplitudes.

Conclusions

An aero-elastic analysis procedure is presented that assesses possible SIV and VIV aero-elastic instabilities of (incomplete) rotor setups. The procedure employs engineering tools relying on airfoil polars.

The main conclusion of interest for the industry is that single- and two-bladed setups may be left unattended for a reasonable time (in the order of weeks) if properly designed and analyzed. This has the potential to reduce installation costs.

Even more important is the identification of specific design parameters such as the pitch locking position and the structural twist distribution that significantly affect the aero-elastic stability of the partially assembled rotors.

References

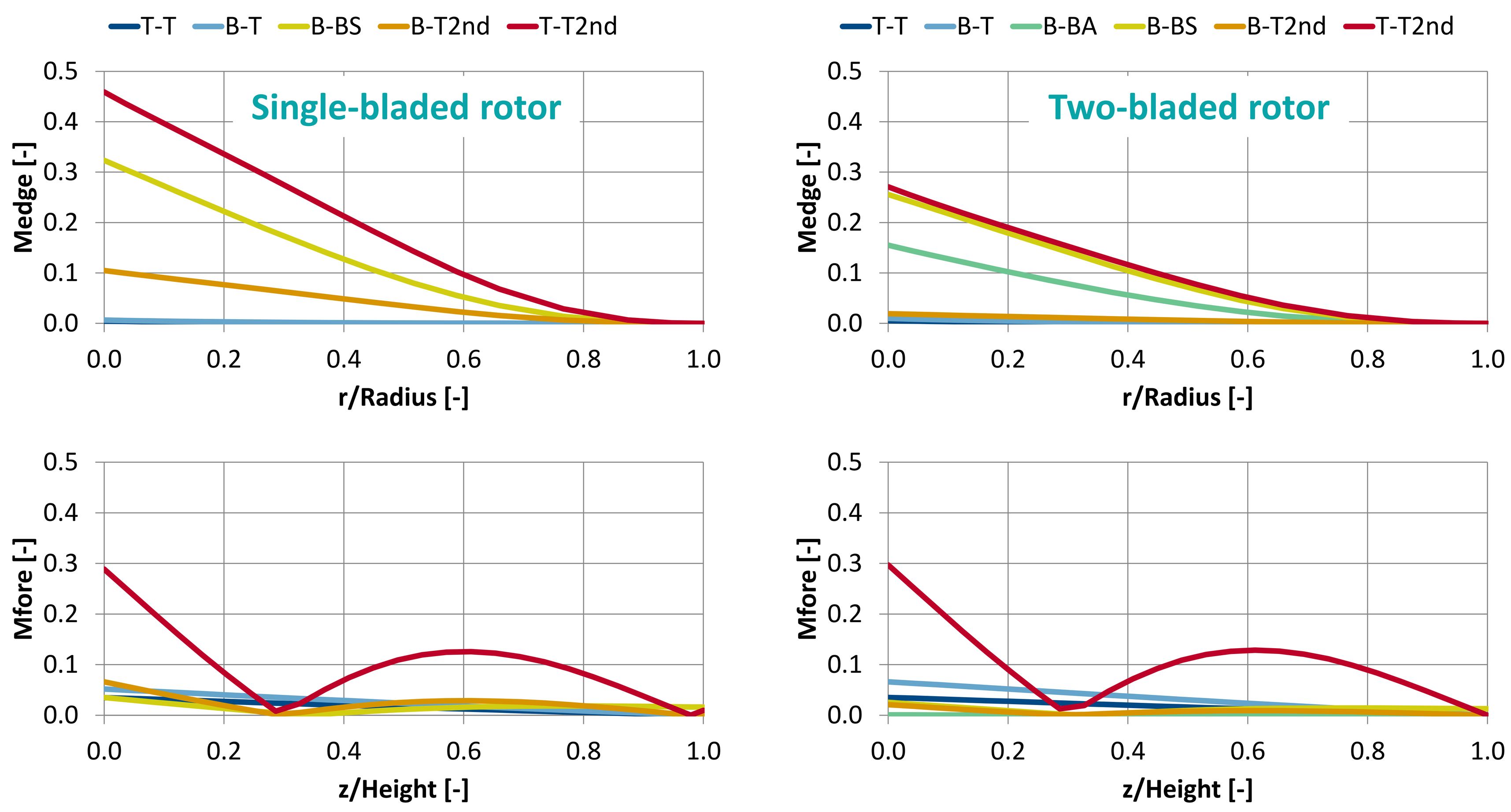
1. D. I. Manolas, V. A. Riziotis, and S. G. Voutsinas, Assessing the importance of geometric non-linear effects in the prediction of wind turbine blade loads, *Computational and Nonlinear Dynamics*, 2015, 10, 041008, https://doi.org/10.1115/1.4027684.
2. EUROCODE 1: Actions on structures - Part 1-4: General actions - Wind actions, EN 1991-1-4:2005: E.

Results

EUROCODE-based VIV analysis

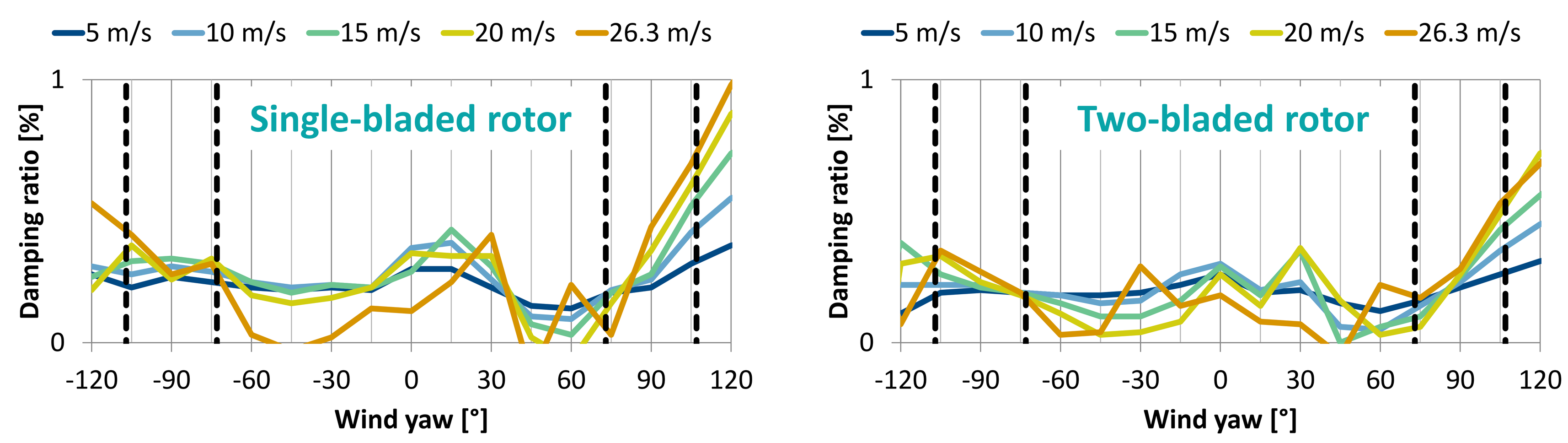
Cases considered in VIV analysis

#	Case	Excited mode	Shedding	St
1	T-T	1st tower fore-aft	Tower top	0.18
2	B-T	1st tower fore-aft	Blade root	0.15
3	B-BA	1st rotor edge asymmetric	Blade tip	0.12
4	B-BS	1st rotor edge symmetric	Blade tip	0.12
5	B-T2nd	2nd tower fore-aft	Blade tip	0.12
6	T-T2nd	2nd tower fore-aft	Tower mid	0.18



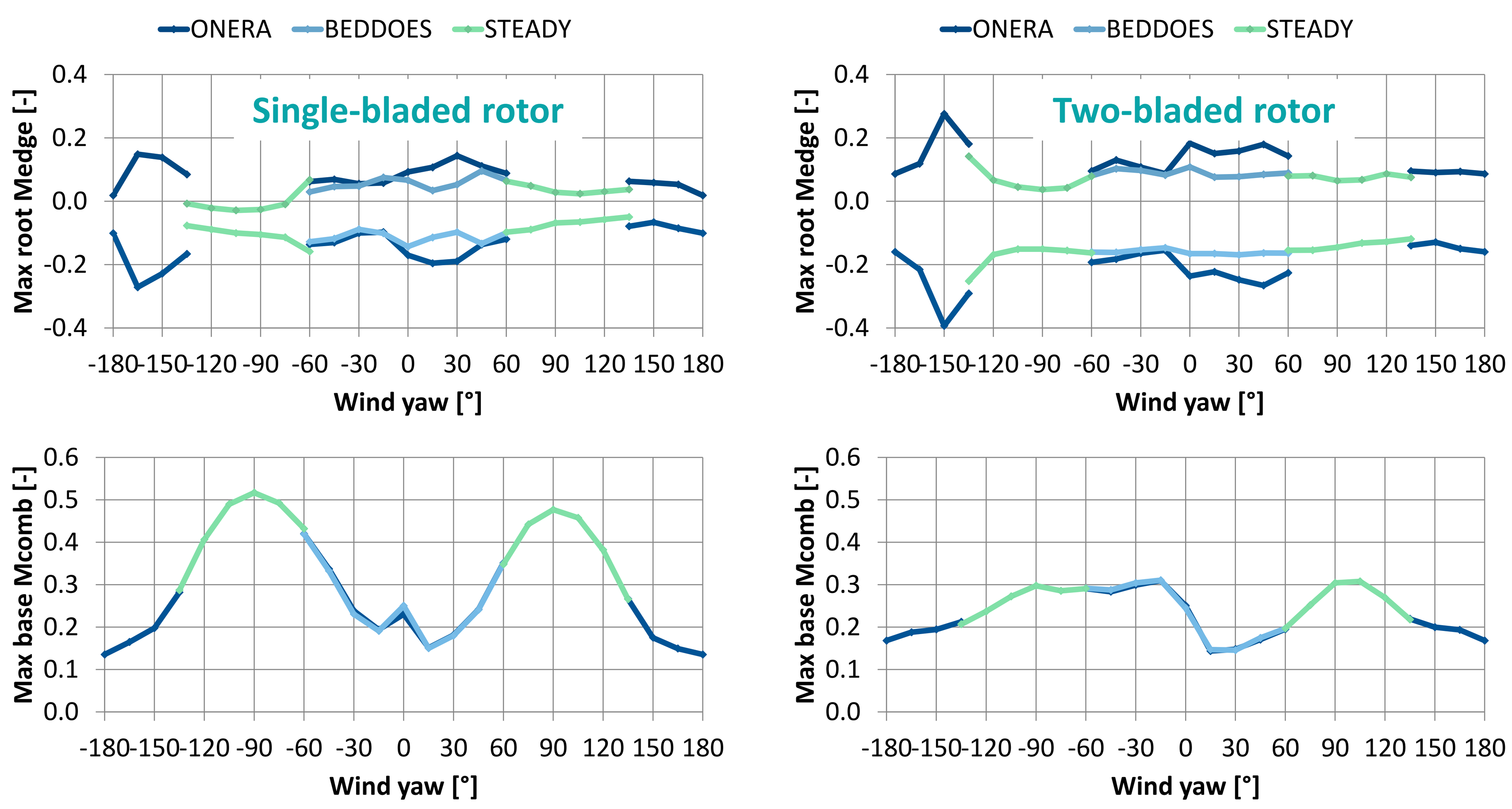
Spanwise distribution of the non-dimensional VIV oscillation amplitude of the **blade edgewise moment** (top) and the **tower fore-aft moment** (bottom).

Eigenvalue-based stability SIV analysis



Total (structural and aerodynamic) damping ratio of the 1st rotor symmetric edgewise mode at various wind speeds with steady-state aerodynamics.

Time domain non-linear SIV analysis



Non-dimensional ultimate blade **root edgewise moment** (top) and tower **base combined moment** (bottom). Idling rotor, blades pitched to feather, V(7-days) wind speed.

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