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Accurate and efficient wind blade modelling using non-linear, high-order beam elements

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Beam finite-element (FE) models have been instrumental in the predictive simulation of wind turbine blades. However, modern blades are challenging conventional design assumptions and analysis tools, due to large, non-linear deflections and the uptake of traditionally unexploited stiffness coupling coefficients. More specifically, optimised turbine designs are featuring blades with greater radii and increased compliance [1], thus deflections at ultimate loading are well within the non-linear elastic region and are incorrectly predicted by linear models [2]. In addition, such designs are exploring the benefits of aeroelastic tailoring either through geometric or material bend-twist coupling—hence accurate prediction of blade loads in response to small changes in the twist of aerofoil sections, and vice versa, is imperative.

In this work, high-order finite beam elements [3], in both a linear and co-rotational non-linear framework, are used to simulate the static test loading of an existing 7 MW wind turbine blade. The blade is an 83.5m swept blade [4], providing a good test case for predicting non-linear, coupled deflections. Additionally, a study into the convergence of high-order beam elements is presented to illustrate the benefits that they provide for modelling of modern blade structures.

This study highlights the necessity of non-linear beams in accurately predicting deflections of modern wind turbine blades, as a linear beam severely underpredicts deflections in an ultimate loading scenario (i.e. linear beam tip deflection 9% lower than non-linear for flapwise load case). Additional findings from the convergence study illustrate that high-order beam elements result in converged beam states (e.g. coupled beam deflections and modal frequencies) with far fewer nodes than conventional two-node elements. Given the large number of two-node elements required for convergence of this particular blade (Figure 1—121 nodes with 120 two-node elements vs 61 nodes with 30 three-node elements), it is clear that high-order beam elements can improve the computational efficiency of aero-elastic simulations. Furthermore, in an optimisation setting, the number of conventional two-node elements required for accurate structural modelling of large, tailored blades may even tend toward the impractical.

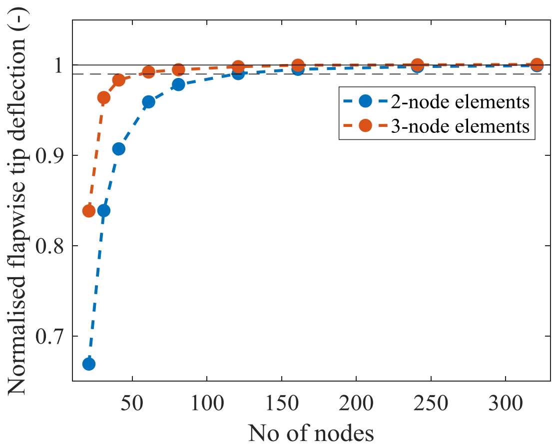

Figure 1 Convergence of flapwise tip deflection with number of two or three node beam elements. Lines indicating final/converged value (solid black) and 99% of final value (dashed black) are displayed.

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