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# Beam models for the analysis of curved, twisted and tapered wind turbine blades undergoing large displacements

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## Abstract

*The exploitation of renewable energy sources is becoming ever more important due to the growing rate of energy consumption, the concerns on environmental pollution and the reduction of fossil resources. Wind is one such renewable energy sources offering great opportunities, also because the extraction of energy from wind is now based on well-established technologies. The installations in this field has increased much during the last decade and the same is expected also for the years to come. Pursuing the logic of developing more efficient and cost effective horizontal axis wind turbines (HAWT), new methods are continually being sought to improve wind turbine performance in terms of energy capture, loads alleviation, structural efficiency and reliability. This goal can be achieved through the use of advanced materials, the optimization of the aerodynamic and structural behavior of the blades and by using suitable load control techniques. For example, one promising approach for load control is based on the bend-twist coupling (BTC) of the blades. This method offers the potential of shaping the power curve and reducing the fatigue damage of the wind turbines due to its effects on the aero-elastic behavior of the blades. This can be obtained in a geometric manner, by sweeping the shape of the blades, or using a material approach, by changing the orientation of the composite fibers of the blades, as demonstrated in several research programs. However, BTC and the continuous increase in the size and flexibility of modern blades make the interaction between aerodynamics, inertial loads and structural elasticity ever more important and the modeling of their aero-elastic behavior ever more challenging. For the structural part of this modeling, schematizing the blades as suitable beam-like elements currently provides the best compromise between computational efficiency and accuracy. In this regard, it is worth noting that modern blades are slender and flexible structures. They are likely to undergo large displacements, in- and out-of-plane cross-sectional warping, shear deformation, geometric couplings, as well as elastic couplings due to material properties. The development of suitable models, which are rigorous and application-oriented and account for those factors, is fundamental for the analysis and design of modern HAWT blades. The present work addresses the modeling of the mechanical behavior of such blades, considered as curved, twisted and tapered beam-like structures, which are likely to undergo large displacements, small strains, as well as in- and out-of-plane cross-sectional warping. After an introduction to modeling approaches for structures of this kind, a model suitable for the problem at hand is proposed. In particular, such a model is based on a geometrically exact approach. It provides*

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*a means to determine the strain and stress fields in the structure and can be used for the analyses of large deflections under prescribed loads, as well as for aero-elastic analyses when a suitable aerodynamic model is added.*

**Keywords:** rotor blades, beamlike structures, geometrically exact models.