Integrated aero-structural optimization of wind turbines

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Abstract

The present work describes new methods for the integrated aero-structural optimization of rotors. This is part of an ongoing research effort on the development of holistic methods for wind turbine design [1, 2, 3, 4]. Goal of the algorithms is to identify the structural and aerodynamic rotor design characteristics that achieve the minimum cost of energy for a given wind turbine configuration. Given the strong couplings that exist between aerodynamic and structural design choices, the methods are formulated so as to address both problems simultaneously in an integrated manner, resulting in tools that may help avoid suboptimal solutions or lengthy design loops.

All methods considered here make use of high fidelity simulation models [5], that include a 2D cross sectional analysis model, a multibody aeroservoelastic model, and detailed 3D FEM models. The design is based on current industrial standard procedures. All desired features of the solution are enforced by means of appropriate constraints appended to the optimization problem. Aerodynamic constraints include maximum blade tip speed, on account of noise or compressibility, maximum chord for transportability, in addition to a variety of geometric constraints to ensure smoothness or specific requirements on the blade shape, as for example conditions on spanwise tapering or solidity. Structural constraints include stress, strain and fatigue allowables, but also the placement of blade natural frequencies to avoid resonant conditions, tower clearance to avoid blade strikes, as well as a variety of geometric constraints to enforce manufacturing, technological and other conditions.

Within this simulation-based constrained optimization environment, in this work three different aero-structural approaches are considered, realizing three different compromises on computational efficiency, generality, level of automation and robustness [4]. The algorithms operate at multiple levels. A "coarse" aeroservoelastic level is based on quasi-3D models of the entire machine, comprising of a flexible beam multibody model supplemented with 2D sectional models. The load analysis is performed at this level, yielding both fatigue and ultimate loads at all points of interest on the structure. 3D finite element models are then used to refine the coarse solution. The overall organization of the algorithm is reported in Fig. 1. The three aero-structural design methods were applied to the DTU 10 MW RWT, which was chosen as a significant test case representing the next generation very large HAWTs [6].

All three methods converged to essentially the same solution, demonstrating that all are capable of solving the multidisciplinary optimization problem. The new improved design is characterized by a 12% increase in solidity. This allows for a more efficient structure, resulting in a 10% decrease in blade mass compared to the baseline, with a practically unchanged annual energy production of the machine.

Efforts are underway to improve the cost models, which play a crucial role here since they essentially drive the definition of the tradeoffs among the various disciplines and the many different requirements. The method of Ref. [7] is currently being implemented together with other detailed engineering estimates, with the goal of replacing as much as possible statistical extrapolations of costs based on historical data in favor of the detailed physical models that are used by the proposed design procedures. In fact, although cruder and hence faster wind turbine rotor design methods can be formulated, the level of detail implied by our methods allows for a more exact assessment of the various contributing factors to cost.

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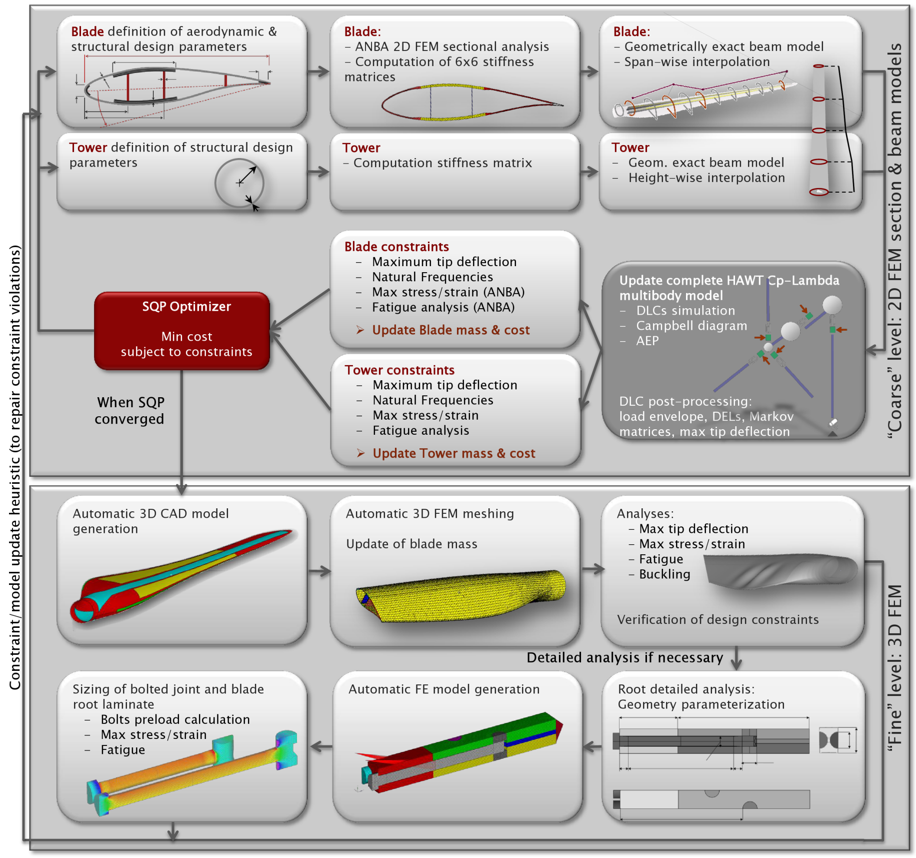

Figure 1: Multi-level rotor design optimization

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