Wind turbine aerodynamics

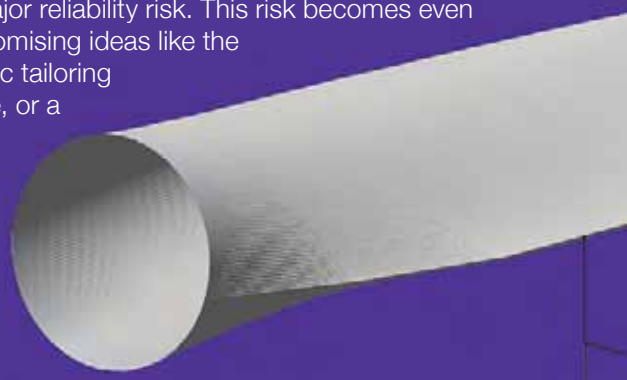
Virtual testing of realistic, full-scale conditions

Current wind turbine blade technology, based on composite laminates, is labor intensive and requires a highly qualified workforce, creating a critical bottleneck in terms of industrial workforce and infrastructure. This hampers a rapid expansion of wind energy in the US.

The monolithic conception of today's blades also poses huge challenges in terms of transport logistics and crane capacity. Blades operate under a complex combination of fluctuating loads. Huge size differences complicate the extrapolation of experimental data from the wind tunnel to the prototype scale. The complex interaction of physical processes that characterize the coupled aeroelastic problem still exceeds the capacities of existing commercial simulation codes.

Fernando Ponta has been awarded a 2010 Faculty Early Career Development Award from the National Science Foundation to help reduce the uncertainties related to wind turbine blade dynamics.

"There is a very understandable tendency of the industry to be cautious with the introduction of new concepts in blade design and construction—even though it could cut down weight and reduce the amount of qualified labor and the use of expensive materials," Ponta explains. "New blade design would be likely to introduce unpredictable changes in the aeroelastic response, and that would involve a major reliability risk. This risk becomes even greater when considering more innovative and promising ideas like the adaptive-blade concept, which involves aeroelastic tailoring of the flexo-torsional modes of the blade structure, or a segmented-blade concept that could be split into easy-to-handle, cheap-to-produce modules."



To help solve this dilemma, Ponta and his research team are creating a virtual test environment where the aeroelastic dynamics of innovative prototype blades and their associated control strategies can be tested at realistic, full-scale conditions.

Ponta has combined two advanced numerical models implemented in a parallel HPC supercomputer platform. The first is a model of the unsteady separated flow that simulates the complex dynamics of the vortex-shedding process and associated aerodynamic forces. The second is a model of the structural response of heterogeneous composite blades, which can reduce the geometrical complexity of the blade section and allow accurate modeling of the 3D blade structure as a 1D finite-element problem.

Both models are solved simultaneously in a common ODE framework, which allows for the simultaneous analysis of the aeroelastic problem together with any innovative control strategy, into a single computationally efficient self-adaptive algorithm.

Ponta and his research team have first been testing their own designs, from standard to increasingly innovative blades. "In terms of blade design, our ultimate objective is to create a reliable adaptive blade of segmented construction that can be mass produced at a fraction of the current cost," says Ponta. "In terms of dynamical modeling, the goal is to provide the industry with a tool that helps them to introduce new technological solutions to improve the economics of blade design, manufacturing and transport logistics, without compromising reliability."

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Pictured: Typical geometry of a classical blade, with detailed views of the finite-element meshes for the internal structure and the flow field around the airfoil sections.