Analyzing Wind Turbine Controller Effects on Structure Stress

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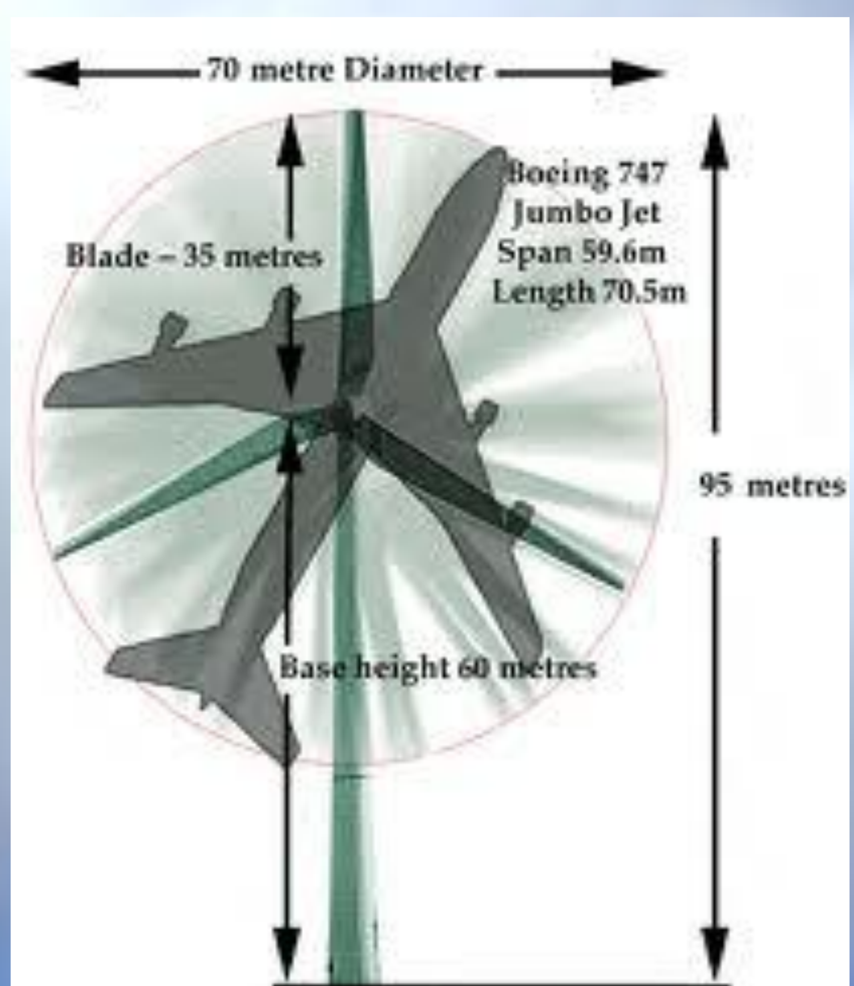
Abstract

Utility scale wind turbines are big, up to seven megawatts. (Note the person.)



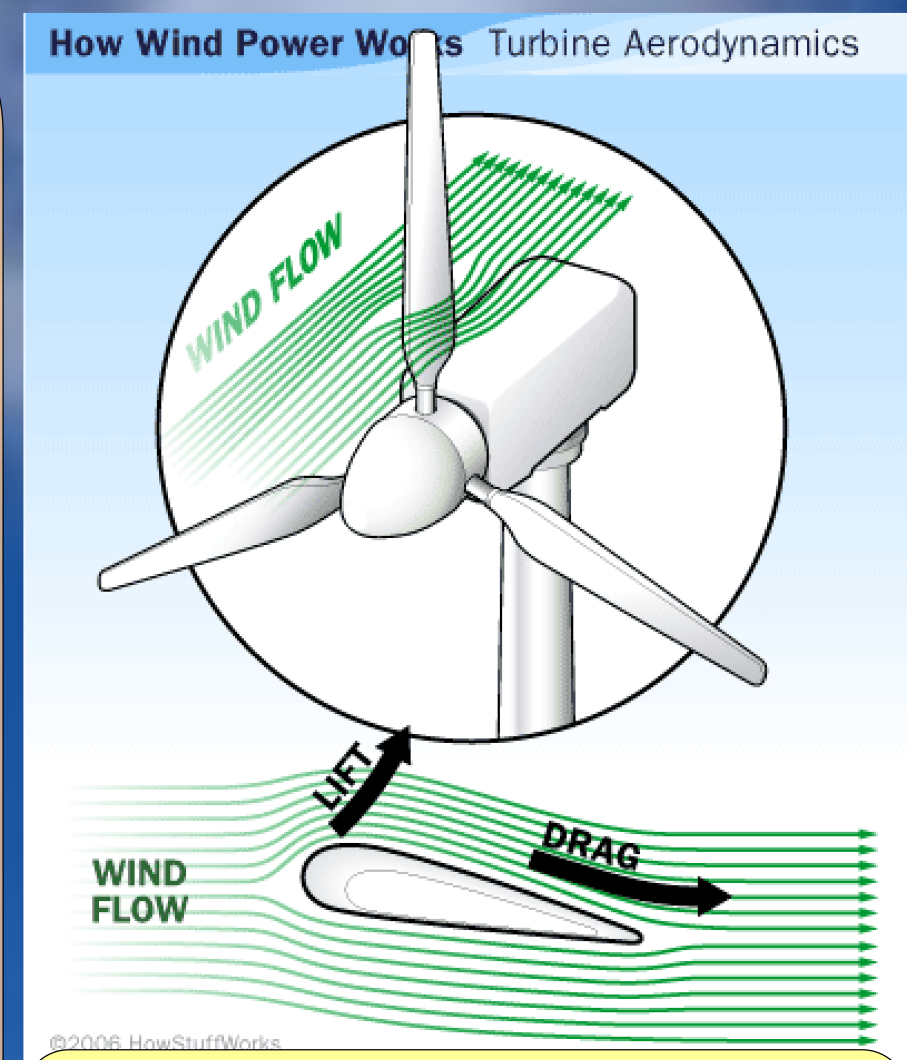
Some are bigger than a 747.

Wind turbines generate electric power from clean renewable sources. They must be robust and reliable. Utility-scale turbines are designed to produce power within a set of wind speed parameters. When winds change, wind turbine blade pitch is used to protect the turbine from over speed damage.

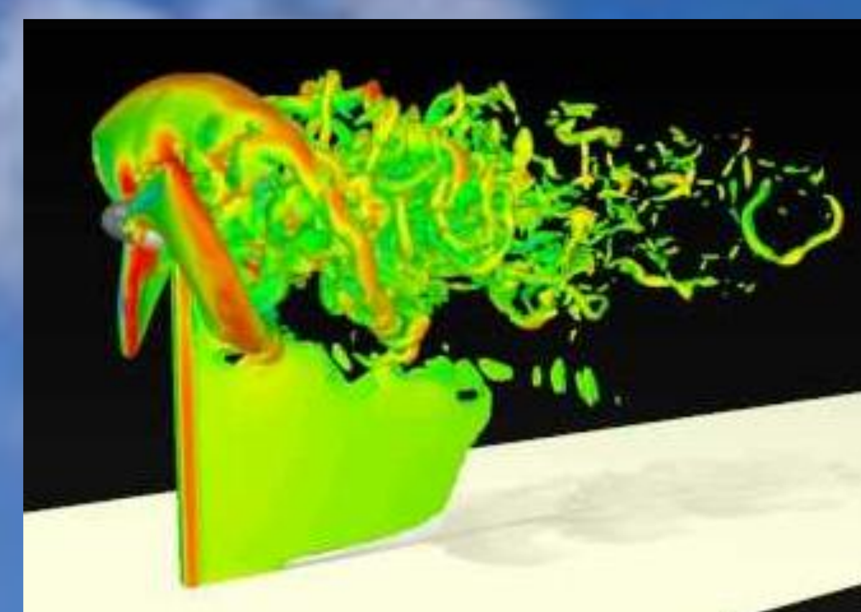
Advanced control algorithms can increase power by extending the performance envelope or they can extend lifetime by reducing stress. A FAST simulation written in MATLAB / Simulink is used to simulate the dynamics of the integrated aerodynamic, mechanical and control subsystems of the turbine. Resonance modes may lead to large amplitude displacements and damage. The goal of the control system is to limit these excursions.

We use simulation for parametric studies of the factors causing blade flex and, ultimately, degradation. Wind speed and its variation over time is one factor. We also study the effect of damage to a turbine blade by increasing the elasticity at a boundary between the modeled rigid segments of the blade structure. We compare a baseline controller with an adaptive controller. We also examine tradeoffs in control strategies that permit safe, but degraded, energy capture despite limited blade damage.

Wind turbines can be damaged by high winds.



Like a wing, a turbine blade is subject to lift and drag forces. These produce a torque.



Air flow around turbines becomes turbulent. These, in addition to flexibility of the blades and tower, can cause oscillations in the structures. These oscillations can degrade materials land lead to failure.

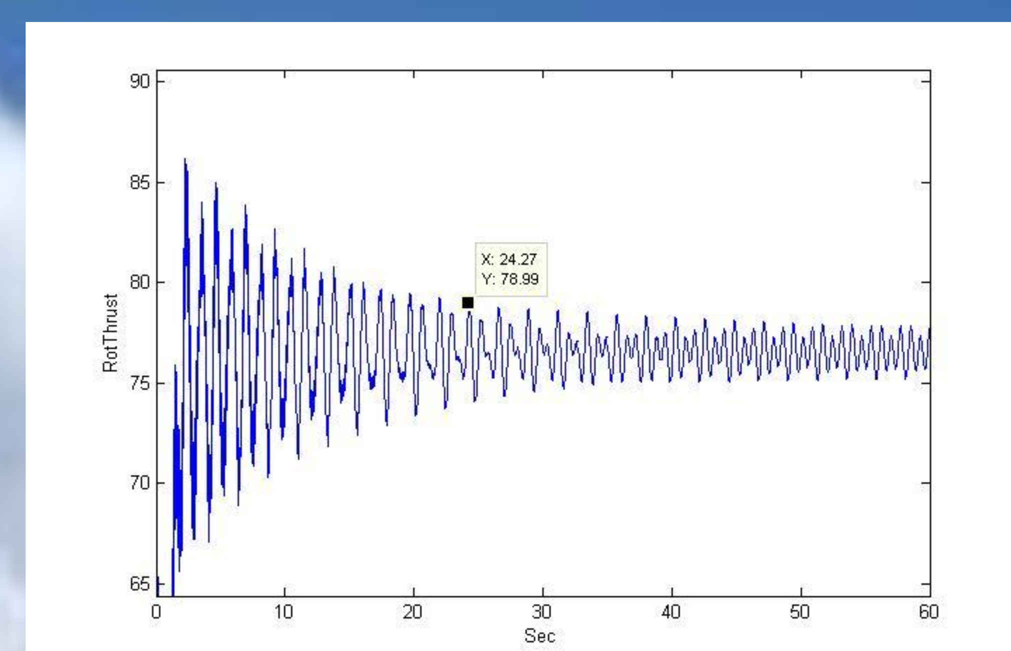
Methods

The FAST code models the wind turbine as a combination of rigid and flexible bodies. For example, two-bladed, teetering-hub turbines are modeled as four rigid bodies and four flexible ones. The rigid bodies are the earth, nacelle, hub, and optional tip brakes (point masses). The flexible bodies include blades, tower, and drive shaft. The model connects these bodies with several degrees of freedom [DOF]. These include tower bending, blade bending, nacelle yaw, rotor teeter, rotor speed, and drive shaft torsional flexibility. The flexible tower has two vibration modes each in the fore-aft and side-to-side directions. The flexible blades have two flap-wise modes and one edgewise mode per blade. These DOFs can be enabled by setting switches in an input file.

Wind power (P) captured by the rotor is proportional to:

- Cube of wind speed (V^3)
- Rotor swept area (A)
- Air density (ρ)
- Turbine specific power coefficient (C_p)

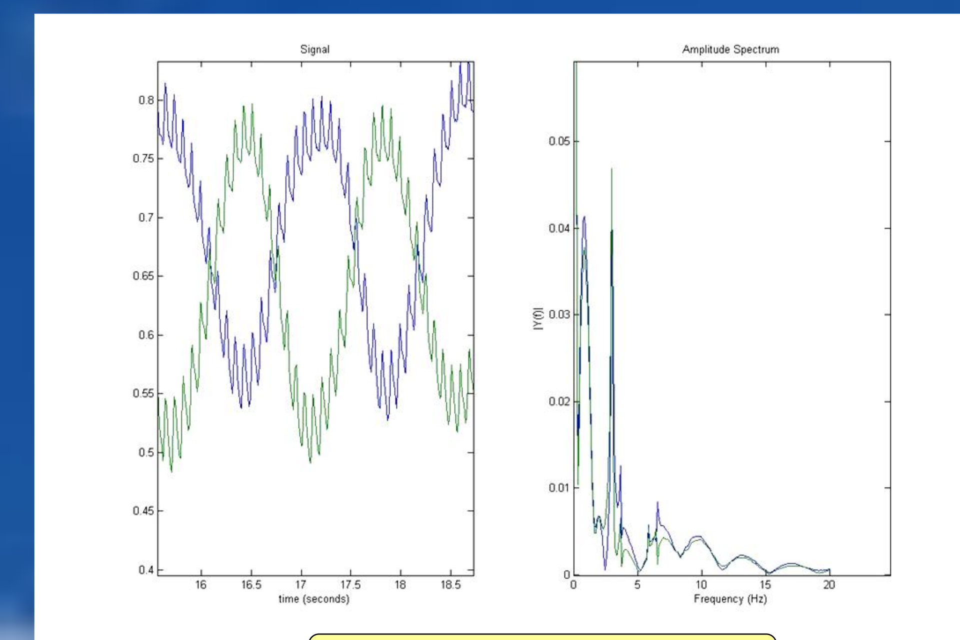
$$P = C_p \rho A V^3$$



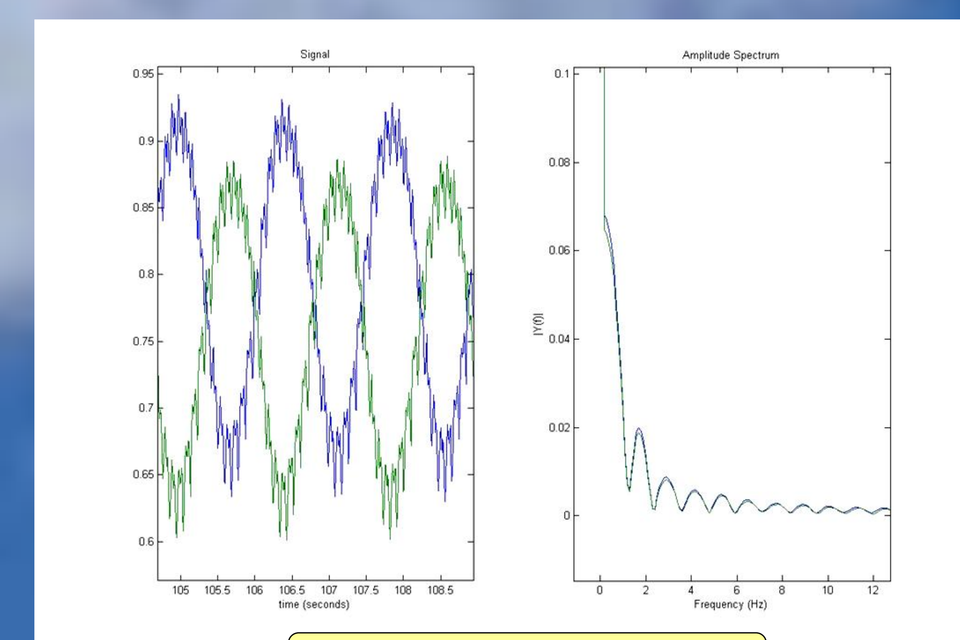
Rotor thrust oscillations.

Results

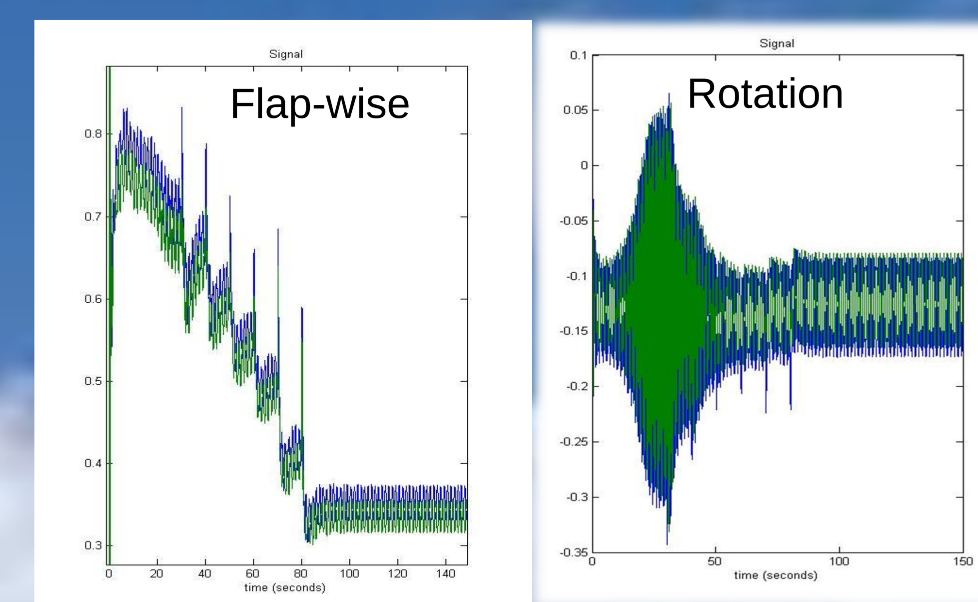
We wrote and modified MATLAB code manipulating environmental and damage parameters. The adaptive controller reduces blade flap. Below are model run results. Blue is 50% damaged blade, green is undamaged. Left is blade flap. Right is power spectrum.



Adaptive controller



Baseline controller



Higher winds and pitch modification change the amplitude of oscillation modes.

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