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AERO-SERVO-ELASTIC MULTIBODY MODELING OF WIND TURBINES

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INTEGRATED MULTI-DISCIPLINARY ANALYSIS

Structural elements assembled to describe arbitrary configurations

Comprehensive finite element based multibody model

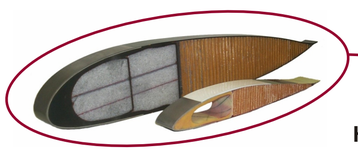
Aerodynamic models
- Lifting lines
- Inflow models
- Free-wake, CFD
- Interaction, wind models

Control modules
- Controllers
- Schedulers
- Sensors
- Actuators

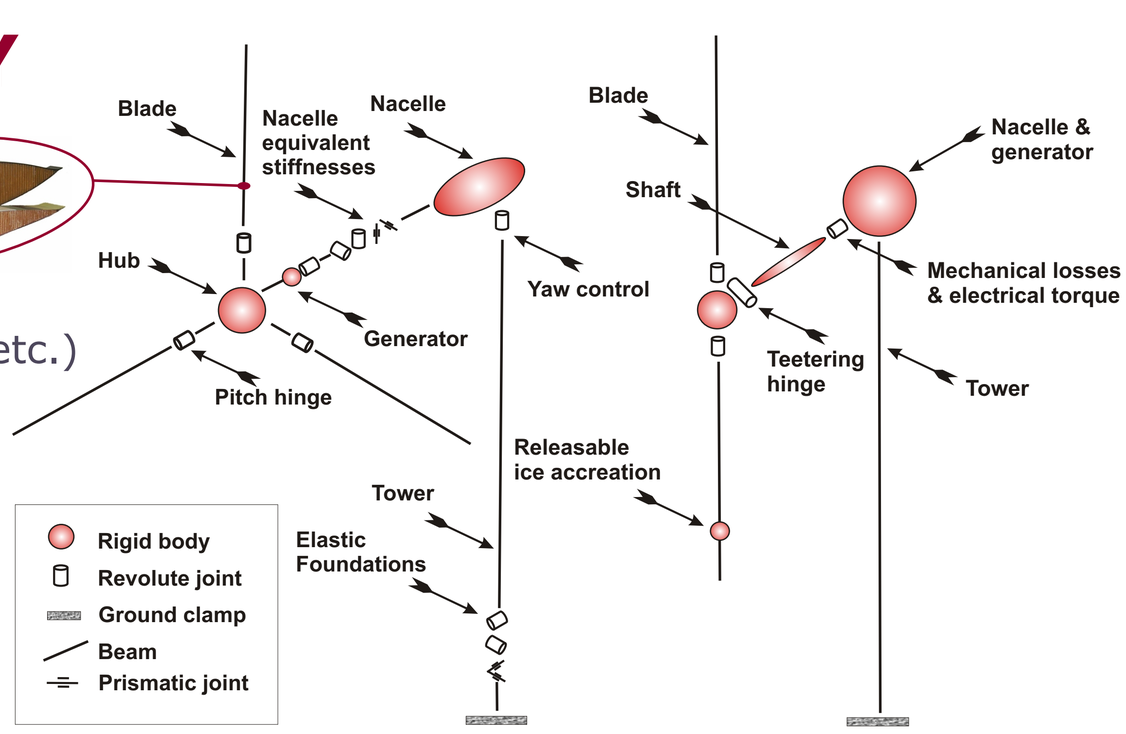
Analysis types:
- Static (deformed structural configuration under steady external, aerodynamic and inertial loads)
- Eigenanalysis about deformed equilibrium configuration
- Dynamic analysis (implicit time marching based on non-linearly stable energy preserving-decaying schemes, automatic time step selection)
- Stability analysis (by implicit Floquet method, and by transient response)

STRUCTURAL ELEMENT LIBRARY

Beam elements: geometrically exact, composite-ready
- Curved and twisted NURBS-based reference lines
- Bending, torsion, shear and axial flexibility
- Fully populated 6x6 stiffness matrix can model all aeroelastic couplings due to the use of composite materials (e.g., flap-torsion etc.)
- Offset of center of mass and shear center from reference line
- Properties can be specified at any number of stations along span



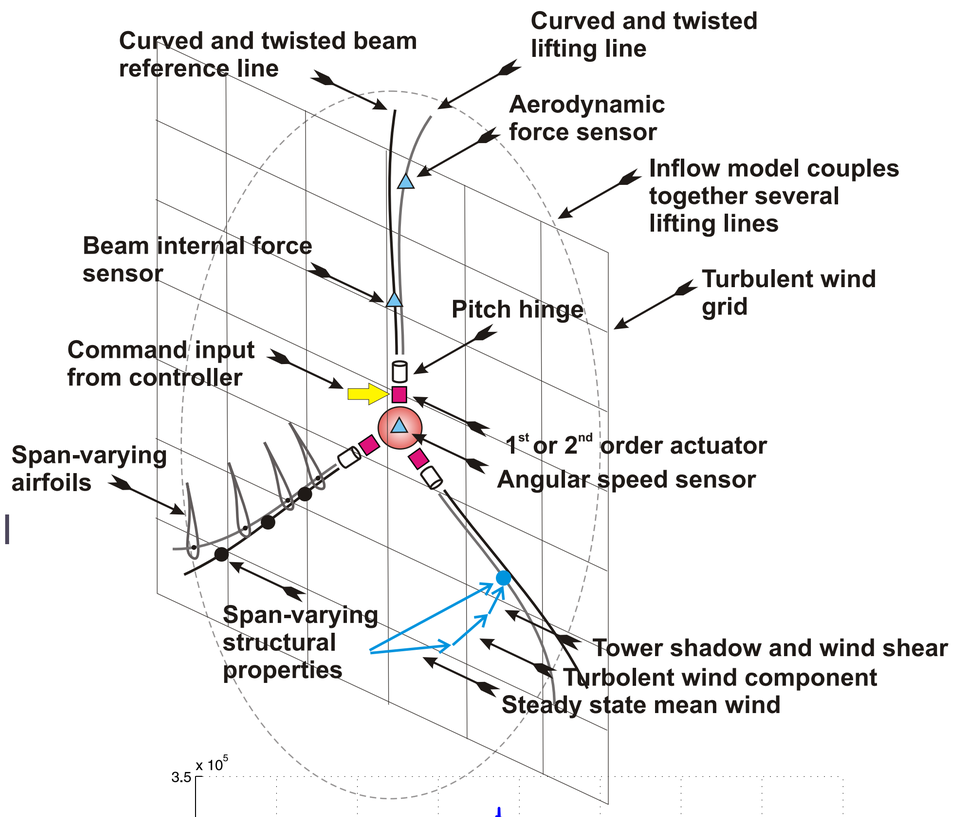
Joints:
- Augmented Lagrangian formulation
- All joints can be equipped with internal springs, dampers, backlash, and friction models
- Flexible joints: contact beam-cylindrical, prismatic or screw joint
- Unilateral joints (contact-impact analysis)
- Actuators: first and second order linear and rotational models



Structural models of standard and teetering wind turbines

AERODYNAMIC ELEMENT LIBRARY

- Curved and twisted NURBS-based lifting lines
- Airfoil aerodynamic characteristics stored in table look-up form
- Tip losses, radial flow, unsteady correction, dynamic stall
- Inflow models: Dynamic Pitt-Peters and Peters-He
- Generic interface to external CFD or free wake codes
- Wind models (according to IEC 61400-1)
- Deterministic gusts (EOG1, ECG)
- 3D stochastic turbolent wind (von Karman and Kaimal models)
- Wind shear: exponential and logarithmic models
- Tower shadow: potential flow model for a conical tower, downwind empirical Powles model, or an interpolation of the two

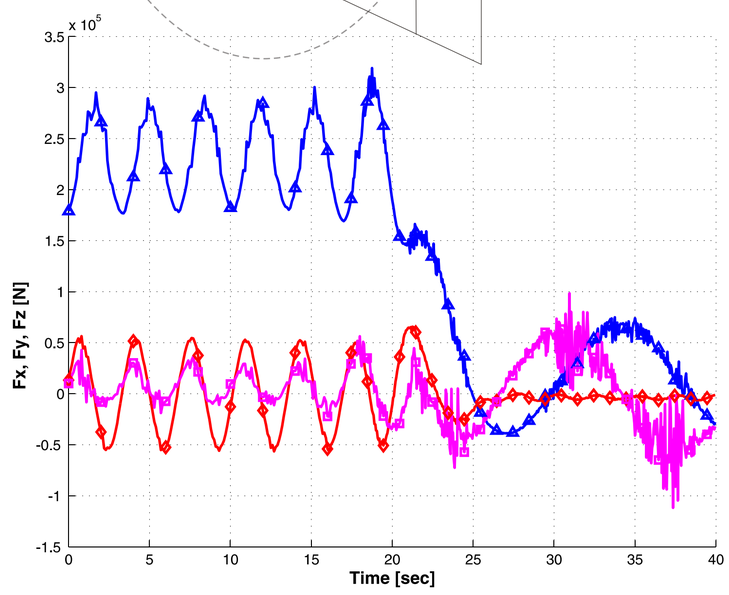


APPLICATION EXAMPLE

Emergency shut-down: EOG1 with simultaneous grid loss

Detailed multibody model includes flexible blades and tower, flexible tower foundations, hub, drive shaft, flexible drive train accounting for mechanical losses on the shaft bearings, nacelle, generator, and pitch actuators.
Aerodynamics based on lifting lines with inflow element, turbulence and gust wind models.

Wind turbine multibody model, with visualization of aerodynamic loads on the blades



Local components of blade root reactions