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The Application of Smart Structures for Large Wind Turbine Rotor Blades

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NNSA National Nuclear Security Administration

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Objectives

- **Significantly reduce blade loads**
  - **vary with position on blade**
  - **vary with time scale of a few secondsIncrease energy capture**
- **Use local flow control**
- **Utilize distributed**
  - **sensors**
  - **intelligence**
  - **small, fast-acting control devices**
- **Modify local aerodynamics of the blade**
- **Maintain reliability**
- **Minimize additional cost**

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Local Load Control

- **Idea of distributed load control is not new**
- **Early work showed that controls could lower fatigue loads**

Why Revisit Local Load Control?

- **Size has increased**
- **Large size means loads vary quickly & dramatically along blade**
- **Active pitch control can only control "average" load on blade**
- **Passive load control cannot respond to local load variations**
- **Fatigue loads can drive the lifetime of all turbine components**

What Benefits do We Expect to Gain?

- Lower fatigue loads
- Increased energy capture
- Actively suppress vibration (certain modes)
- Control noise?
- To fully realize the potential benefits, may need to design a machine from scratch that integrates local flow control

Key Areas of Concern

- **Aerodynamics of airfoils with distributed control elements**
  - **Multiple devices available to adjust lift & drag**
  - **Need CFD(?) tools to determine device performance characteristics**
  - **Need aero/CFD(?) tools to determine control effects on entire system**
- **Actuators**
  - **Control device must be deployed, retracted, moved**
  - **Needs:**
    - low power
    - dependable
    - replaceable
    - cheap
    - immune to lightning
    - small?
  - **Bi-stable or multi-stable devices are interesting**

Key Areas of Concern

- **Sensors**
  - **Many types are available today**
  - **Needs**
    - cheap
    - reliable
    - accurate
    - durable (last 20 years)
    - replacable
  - **What do we need to measure?**
    - loads
    - state of flow
    - deflection
    - acceleration
    - ????

Key Areas of Concern

- **Controls**
  - **Major development required**
  - **Needs:**
    - fast
    - real-time load identification
    - fault tolerant
    - improved energy capture
    - site and condition adaptive (self learning)
    - failsafe
    - predictive?
    - multiple time scales, multiple impact levels

Key Areas of Concern

- **Communications and power supply**
  - **Not usually considered high tech problem**
  - **Needs:**
    - highly reliable
    - immune to lightning
    - avoid wires?
- **New blade materials and construction**
  - **Incorporate control devices/actuators/sensors**
  - **Preserve integrity of blade interior**
  - **Replaceable control elements**

Key Areas of Concern

- **Blade design and analysis tools**
  - **Increase capability**
  - **Accommodate**
    - innovative blade construction
    - new materials
    - distributed control

Development Process Stages

- **Research**
  - **analysis**
  - **laboratory testing**
- **Proof of Concept**
  - **small/medium scale prototype testing**
- **Commercial Viability**
  - **large scale prototype field testing**
- **Commercial application**