Wind Turbine Engineering R&D
at Los Alamos National Laboratory

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LANL’s Internally Funded, 3-year Wind Energy Research Project

• **HPC wind turbine/plant simulation**
  – true wind loading with turbulence on multiple scales
  – damaged and undamaged aeroelastic rotors

• **Experimental wind turbine aerodynamics databases**
  – new diagnostic techniques focused on needs of large-scale wind turbines
  – high-quality experimental datasets for code validation

• **Advanced multi-scale sensing**
  – active and passive sensing suite for damage detection, state awareness, and operational diagnostics
  – energy harvesting techniques for wireless SHM nodes
WindBlade: LANL’s Turbine and Plant Simulation Code

• Based on R&D 100-winning HIGRAD/FIRETEC fire simulation code
• Provides capability to study realistic wind interactions with multiple rotating turbines
  – fully compressible atmospheric hydrodynamics code
  – Lagrangian tracking scheme that accounts for 2-way feedback between winds and moving solid objects
  – resolves complex environments: topography, unsteady winds, severe weather, solar heating/unstable mixing
  – aeroelastic, fluid-structure interaction (FSI) capability will be able to extract dynamic loads on blades and towers
WindBlade: Turbulence on Multiple Scales

- Actual site near Las Vegas, NM
- Realistic heterogeneous vegetation and terrain contribute to turbulence
- Automatic yaw control adjusts for changing wind direction
- Instantaneous loads extraction

Five, 126-m-dia turbines shown w/o vegetation
Wake Velocities for Single vs. Multiple Turbines

- Upstream average hub-height velocity
- Single turbine (with resolved inflow turbulence)
- Five turbines (with resolved inflow turbulence)
Aeroelastically Coupled Structural Blades

Adding Capability to WindBlade

- Model the geometrically nonlinear structural dynamic response of wind turbine blades
- Aeroelastically coupled within WindBlade

Current Code Development

- Scripted prototype Python code was migrated to a Fortran solver engine
- Solver engine wrapped by Python for standalone structural dynamic modeling and validation
- Python user-interface code developed

Verification and Validation

- 2011 LADSS project experiment
- Modeling of NREL CX100 fatigue test
- Verification test problems

Visualization

- Developed interface/translator to visualize results in Paraview
- Enables visualization of blade structural response consistent with WindBlade visualization tools
Large-Format PIV (LF-PIV) Diagnostic Development
High-resolution inflow turbulence, wake velocity structure

**LF-PIV:** 300 Hz, 0.03m spatial resolution
- can measure flows not measured by LIDAR or sonic anemometers with high spatial and temporal resolution, ability to measure blade and near turbine flows

VS

LIDAR: O(1m) spatial resolution (cannot measure flows very close to turbines, blade flows or very near wake regions)

Sonic Anemometer: 20Hz (intrusive, single point, slow)

- Scalable to 20m x 2m.
LF-PIV Ready for Large-Scale Field Experiments
Overcoming deployment barriers for wind turbines

- LF-PIV Field of View of 3m x 1m demonstrated in the laboratory by moving the flow apparatus (scalable to 20m x 2m)
- Novel seeding apparatus (above) developed for dispersal of particles
- Accuracy is good for capturing turbulence statistics and wake vortex signatures
Rotating PIV Diagnostic Development (R-PIV)
Measure flow around blades: separation, flaps, micro-tabs...

LANL’s In-blade rotating PIV system: Measure blade boundary layer at all phases of blade revolution. Time series of dynamic stall, micro tab performance, separation, and 3D effects.

[1] LANL-SNL Supported by DoE-EERE, In-blade PIV Diagnostic Development
Wind Turbine Field Experiment Campaign

Turbine-turbine interaction experiments

10x CSAT3 anemometers monitor inflow and wake; 2D RM Young; with LF-PIV/R-PIV

Aerodynamic, structural and power data:
Highly detailed integrated experimental datasets for CFD

Tilt-down sensor and turbine towers
LANL Wind Turbine Field Station
Multi-Scale Sensing at LANL

• Provide experimental data to
  – Validate physics-based numerical models
  – Estimate the current state of the structure, including detection of the onset and growth of damage
  – Predict future load characteristics (prognostics)

• Required to be
  – Low cost, low power, wireless desirable
  – Operate in relatively harsh environments
  – Optimally configured with minimal sensors when installed
LANL’s Structural Sensing System

• Multi-scale sensing for SHM and prognostic assessment
  – Local active sensing
  – Global passive sensing

• Piezoelectric transducers used as sensors and actuators
  – Dual use reduces the total amount of installed hardware

• Develop an integrated hardware / software solution designed specifically for wind turbine applications

Piezoelectrics can serve as both sensors and actuators
Hardware has evolved from previous experience in civil applications
Current prototype of the multi-scale sensing platform
Active Sensing SHM Techniques

- Lamb wave propagations
- High-frequency response functions
- Time series predictive models
  - CX-100 turbine blade 1-m section
  - Introduced simulated damage
Ongoing Fatigue Test at NREL

- Fatigue test conducted at NREL’s NWTC
- Excitation provided by the Universal Resonant EXcitation (UREX) system
- Multiple participants have instrumentation
  - SNL
  - Micron Optics
  - U. Mass Lowell
- Multiple sensing and diagnostic systems
  - Accelerometers
  - Fiberoptics
  - Piezoelectrics
    - Mid to High Frequency (1-50kHz)
    - Lamb wave (50-275kHz)
Sensing Project Culminates with Full-Scale Flight Test

- Full range of instrumentation on three, 9-m blades
  - **SHM Rotor Blade**: High-frequency SHM techniques to monitor blade transition region
  - **Blades 1-3**: Low-frequency sensing in partnership with SNL (e.g. strain, acceleration)
- **Tower-mounted sensors** to monitor upstream and downstream flow conditions
- Results fed into prognostic analyses and visualization algorithms to validate WindBlade and FE codes
- **Proof of concept** for validating embedded sensing
Conclusion: *We are Developing Wind Energy Solutions at LANL*

- We have unique expertise, facilities, resources, and ideas
- We complement the work of other labs, academia, and industry
- We are laying the foundation for a future wind program at Los Alamos