Wind Turbine Engineering R&D

at Los Alamos National Laboratory

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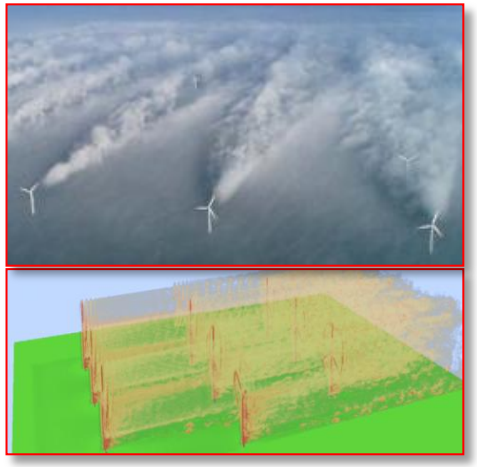
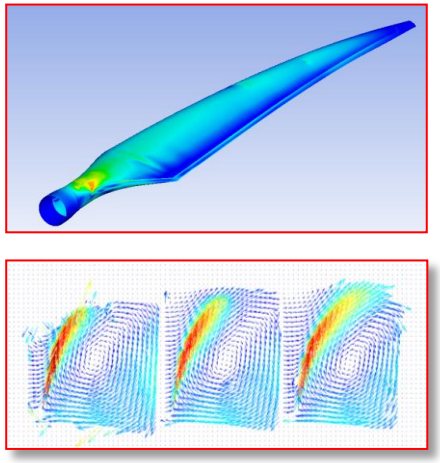
Applied Engineering & Technology Division

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

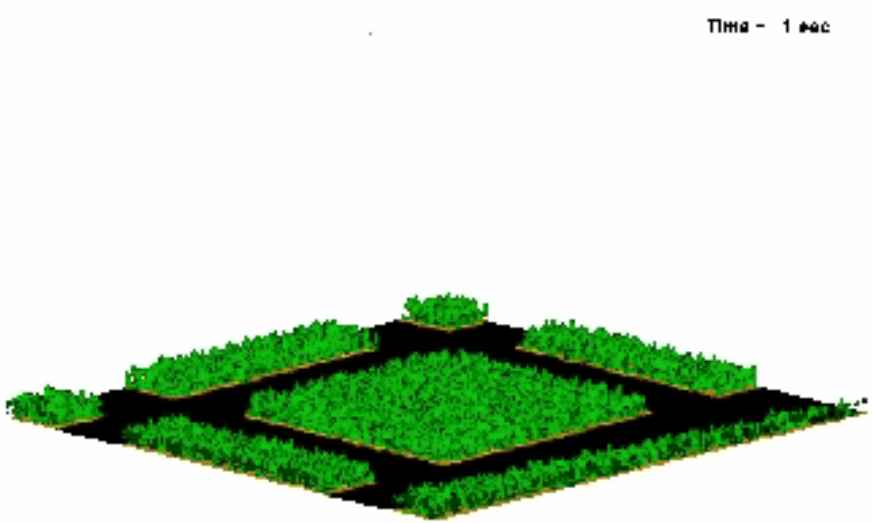
- **HPC wind turbine/plant simulation**
  - true wind loading with turbulence on multiple scales
  - damaged and undamaged aeroelastic rotors
- **Experimental wind turbine aerodynamics databases**
  - new diagnostic techniques focused on needs of large-scale wind turbines
  - high-quality experimental 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



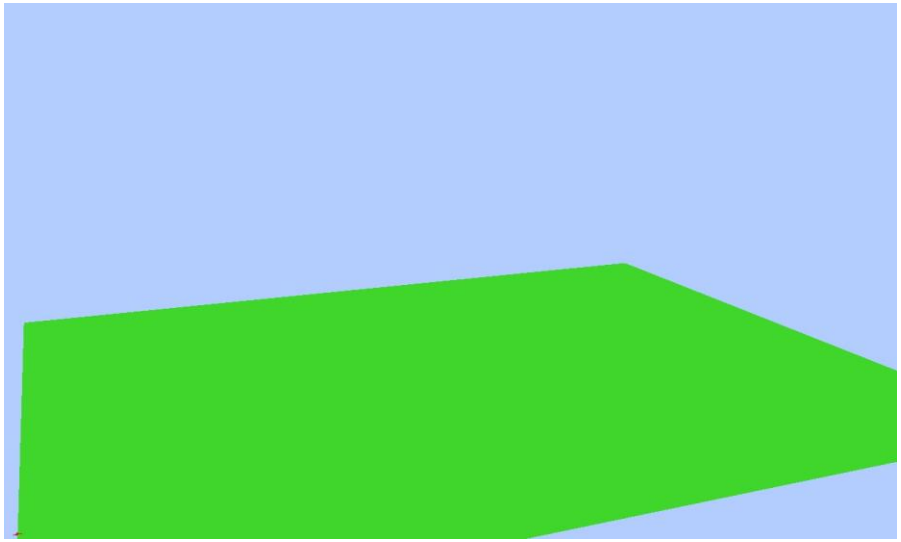


WindBlade: LANL's Turbine and Plant Simulation Code

- **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

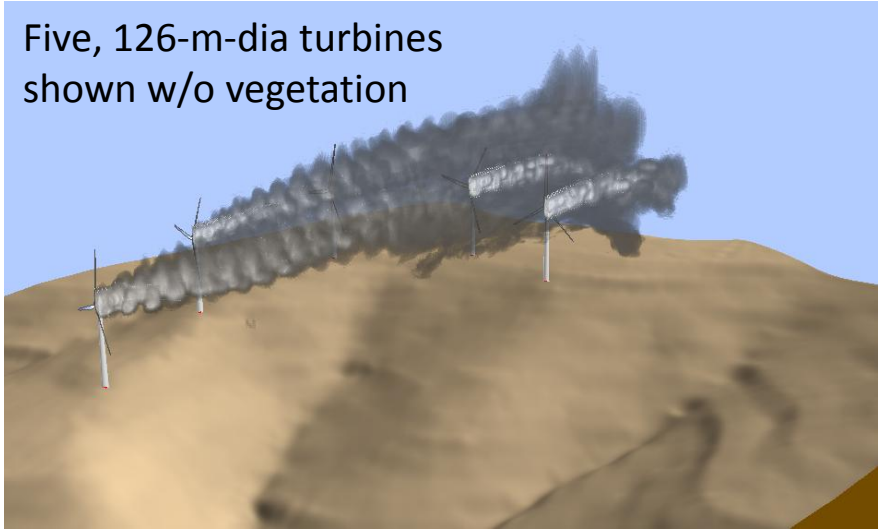


***HIGRAD/FIRETEC* Wildland Fire Simulation**

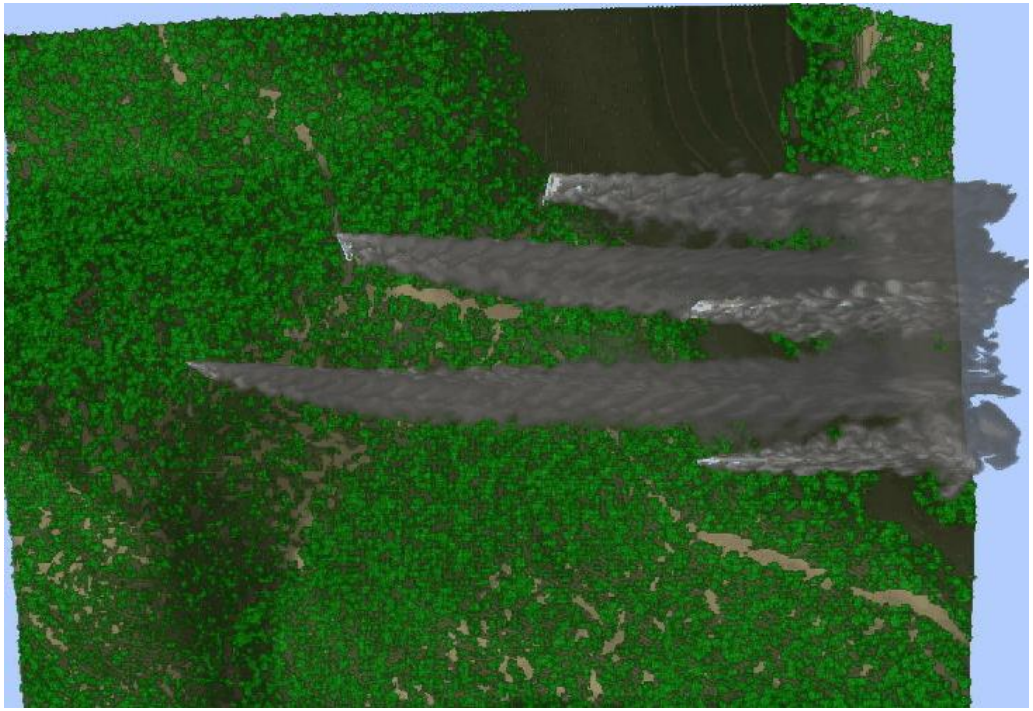


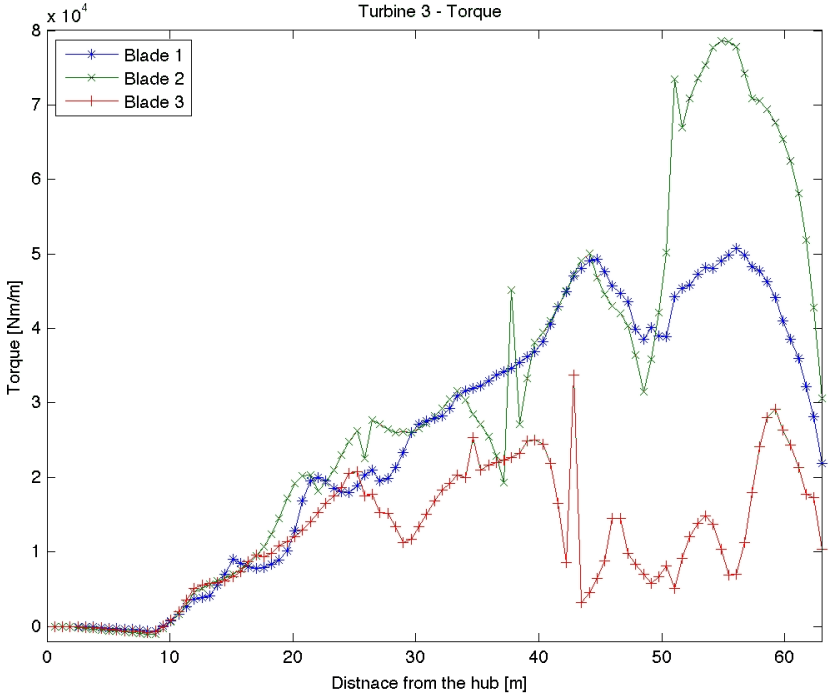
***WindBlade* 9-Turbine Simulation (100m Diameter) Showing Turbulence-Induced Vorticity**

WindBlade: Turbulence on Multiple Scales

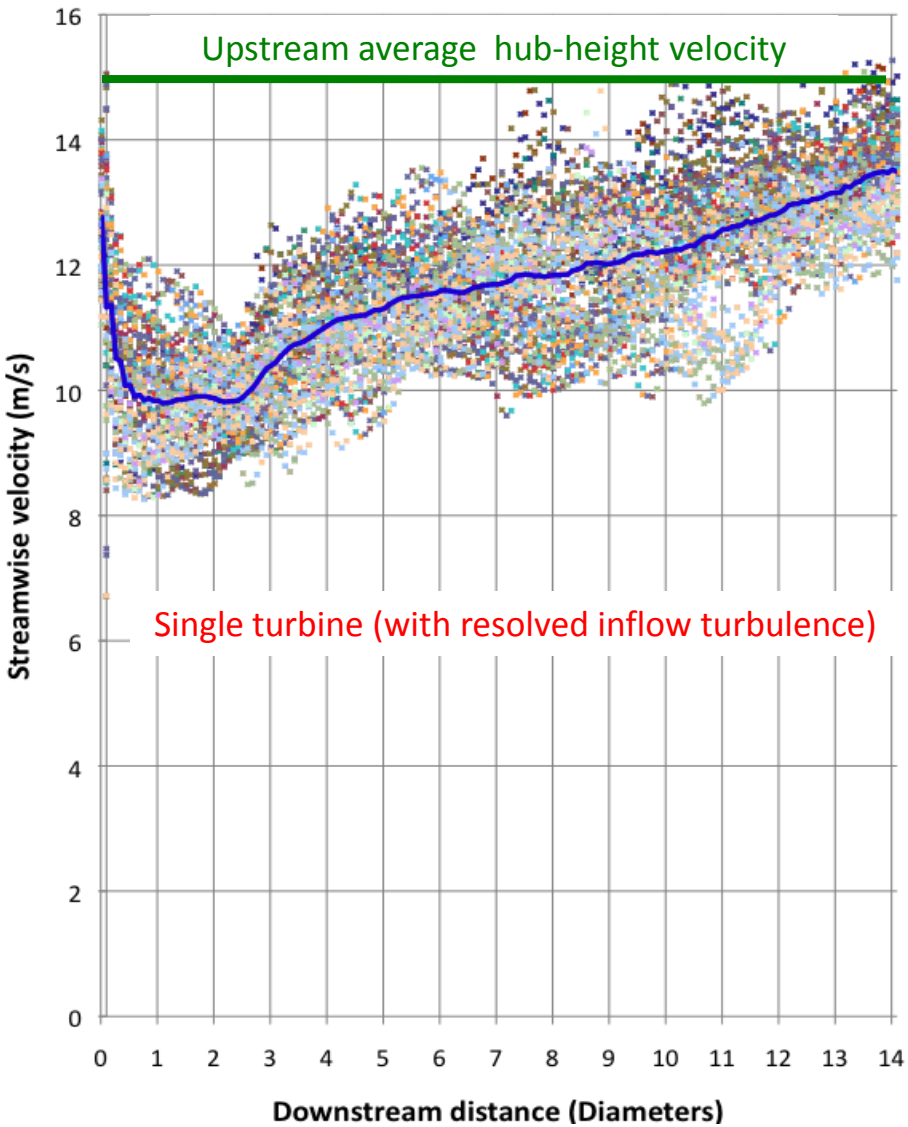


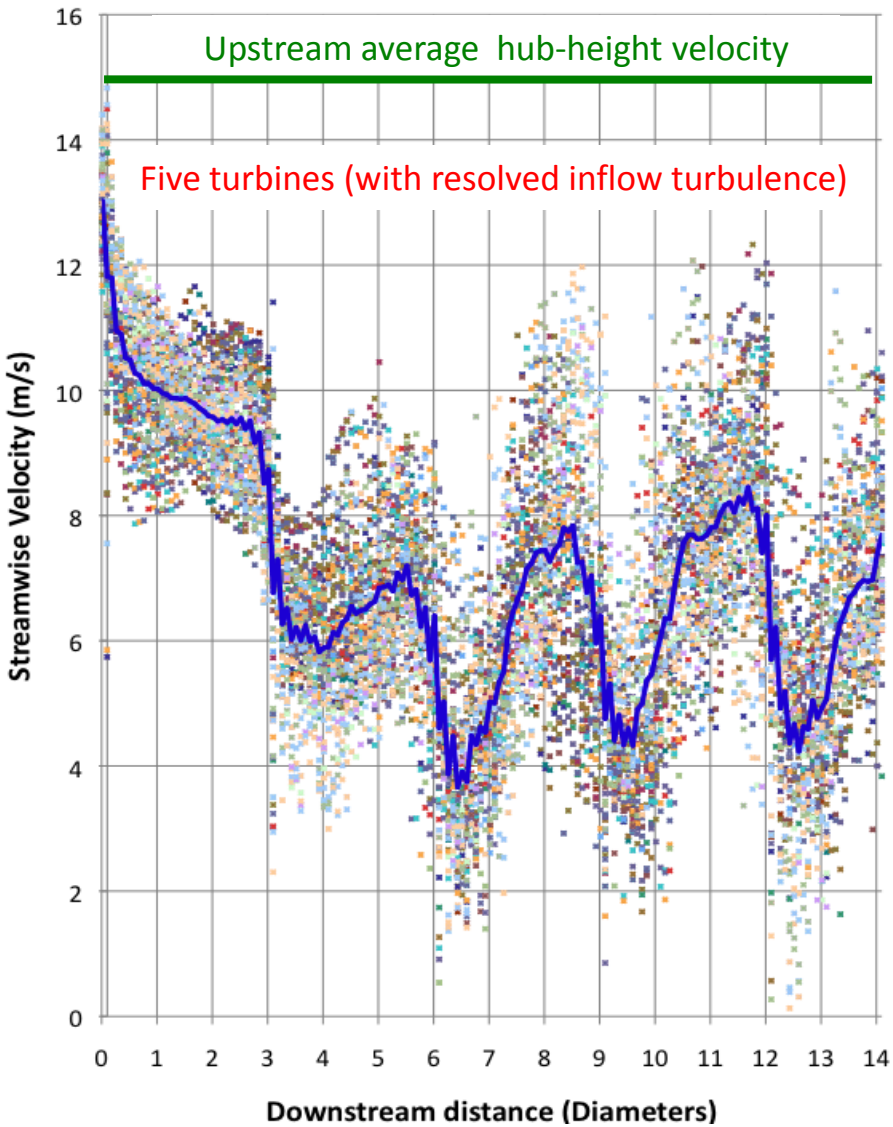
- Actual site near Las Vegas, NM
- Realistic heterogeneous vegetation and terrain contribute to turbulence
- Automatic yaw control adjusts for changing wind direction
- Instantaneous loads extraction





Wake Velocities for Single vs. Multiple Turbines

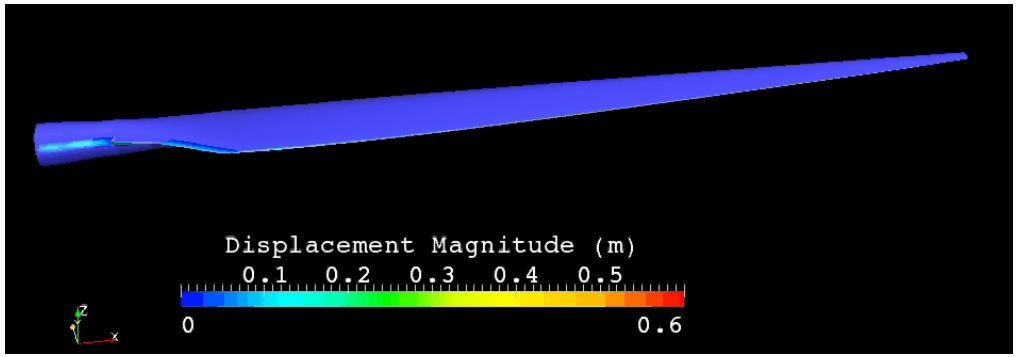




Aeroelastically Coupled Structural Blades

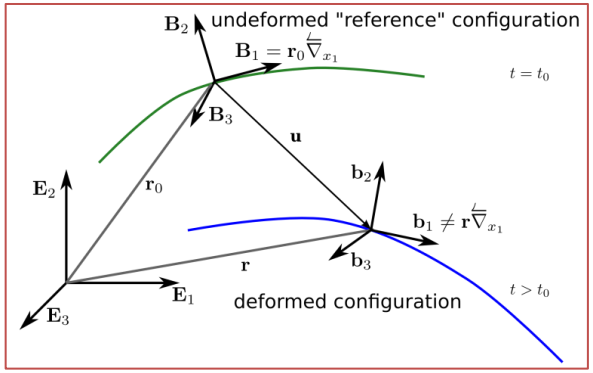
Adding Capability to WindBlade

- 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

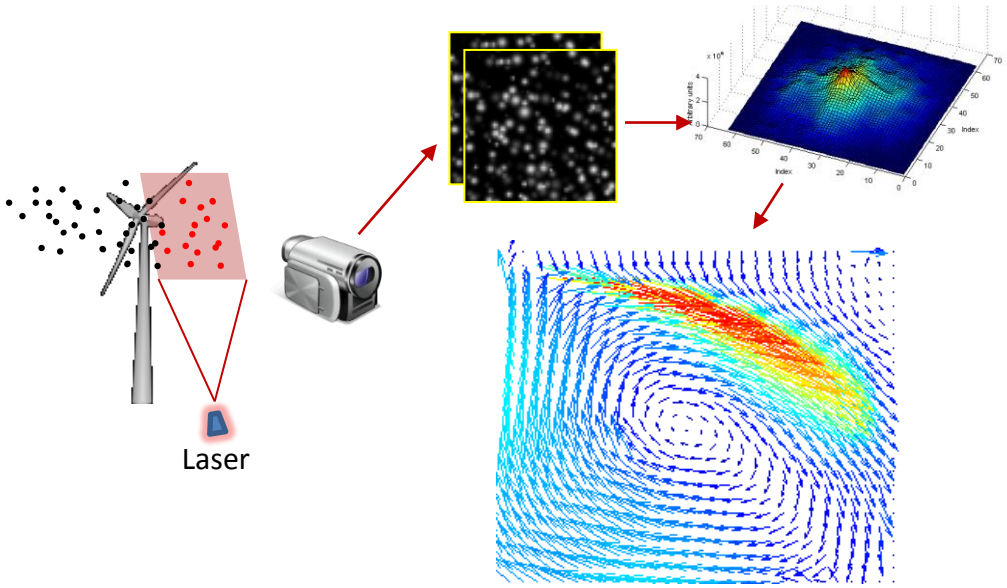
- 2011 LADSS project experiment
- Modeling of NREL CX100 fatigue test
- Verification test problems

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



<u>LF-PIV</u>: 300 Hz, 0.03m spatial resolution

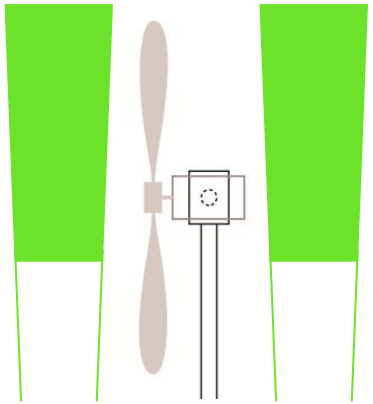
- can measure flows not measured by LIDAR or sonic anemometers with high spatial and temporal resolution, ability to measure blade and near turbine flows

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)

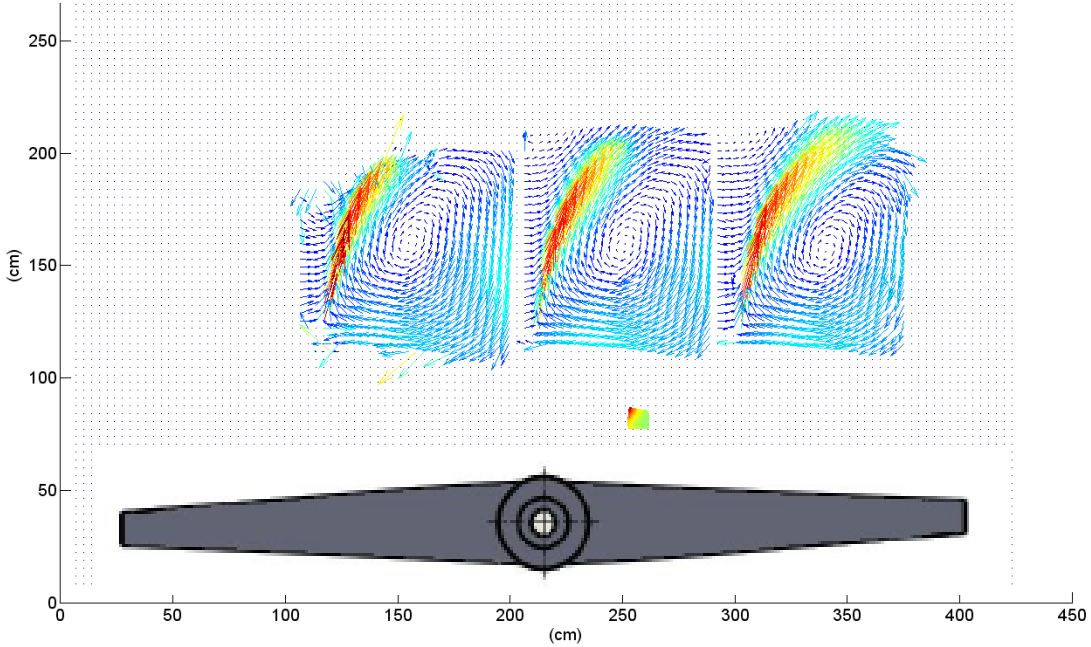
Non-intrusive inflow and wake using LF-PIV

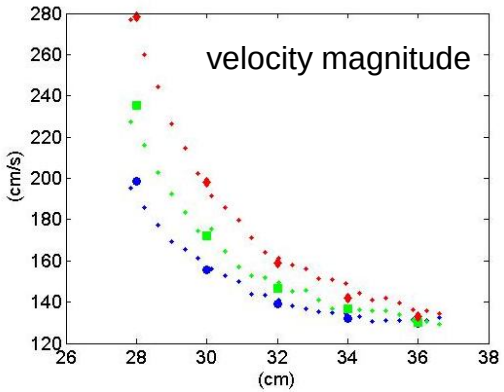


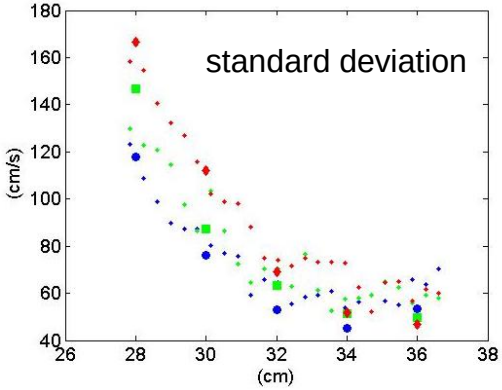
Large Format PIV: Multi-point, precise velocity measurement, measurement of time-series wake profiles, two-point spatial and temporal correlation contours in the wake - Scalable to 20m x 2m.

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

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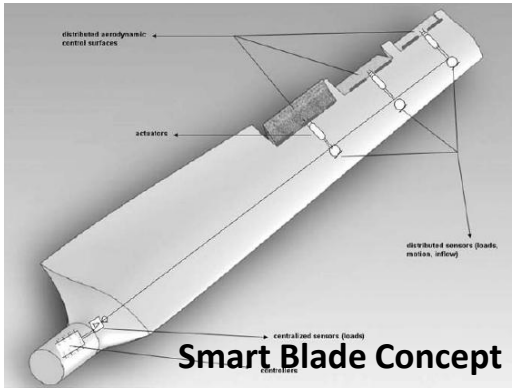
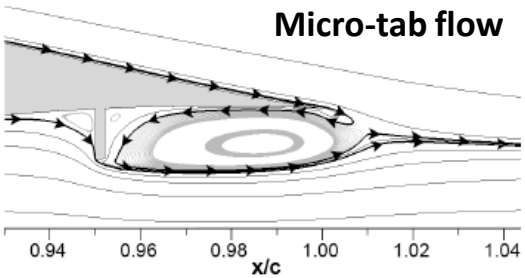
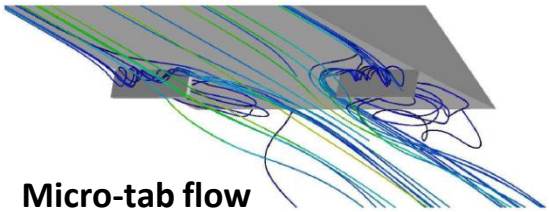
Rotating PIV Diagnostic Development (R-PIV)

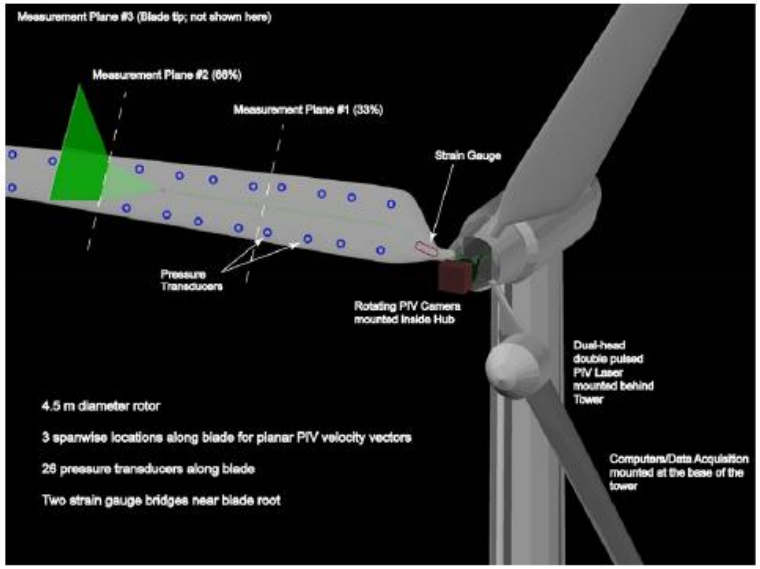
Measure flow around blades: separation, flaps, micro-tabs…

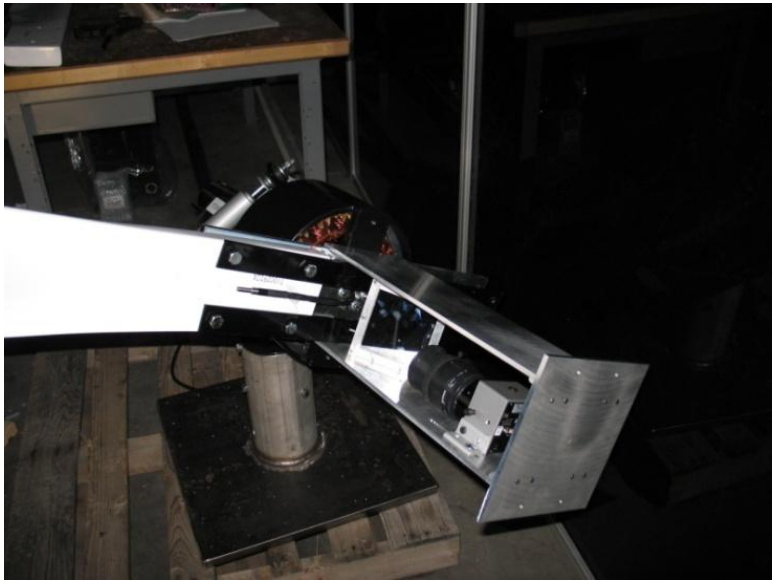






[1] Barlas & van Kuik, Progress in Aerospace Sciences (2010), [2] van Dam et al, Journal of Physics (2007), [3] Mayda et al, AIAA paper 2005-1185



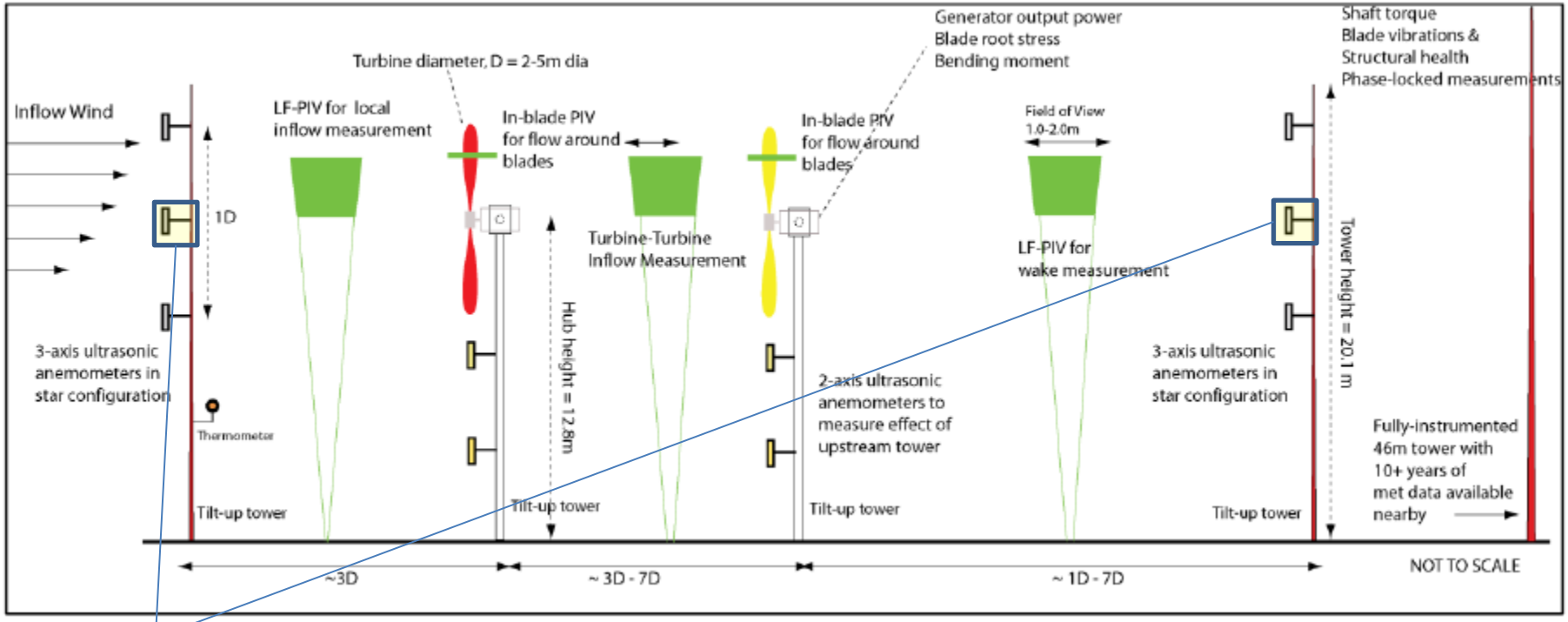


LANL's In-blade rotating PIV system: Measure blade boundary layer at all phases of blade revolution. Time series of dynamic stall, micro tab performance, separation, and 3D effects.

[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

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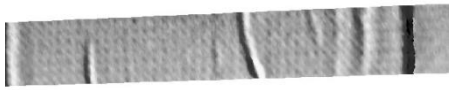
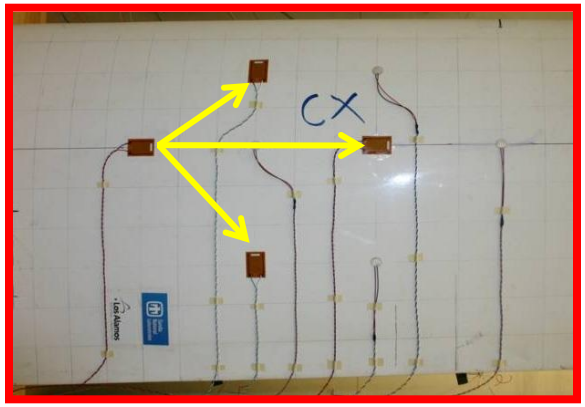
Multi-Scale Sensing at LANL

- **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



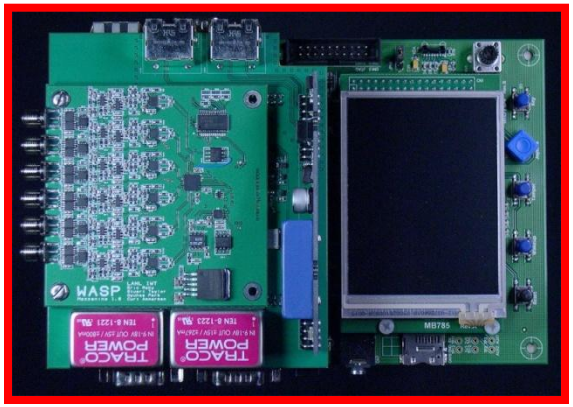
LANL's Structural Sensing System

- **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

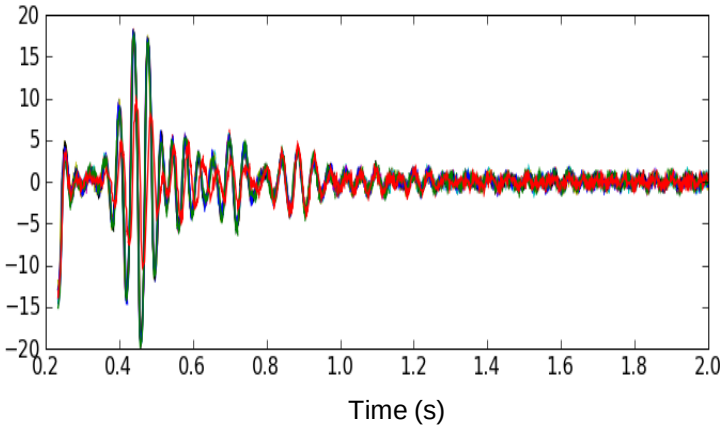
Hardware has evolved from previous experience in civil applications

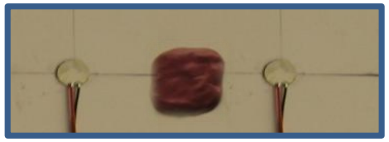


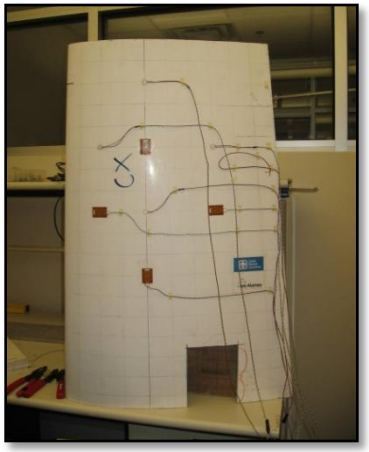
Current prototype of the multi-scale sensing platform

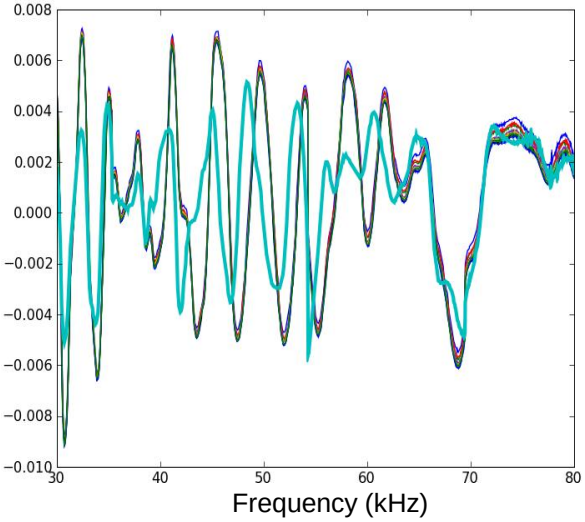
Active Sensing SHM Techniques

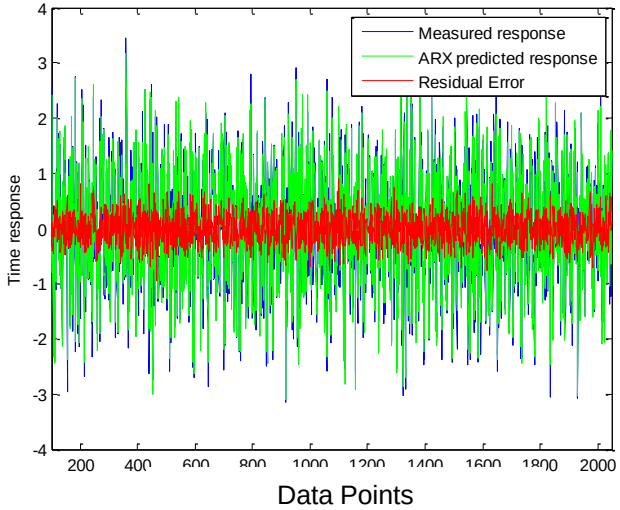
- **Lamb wave propagations**
- **High-frequency response functions**
- **Time series predictive models**
  - CX-100 turbine blade 1-m section
  - Introduced simulated damage





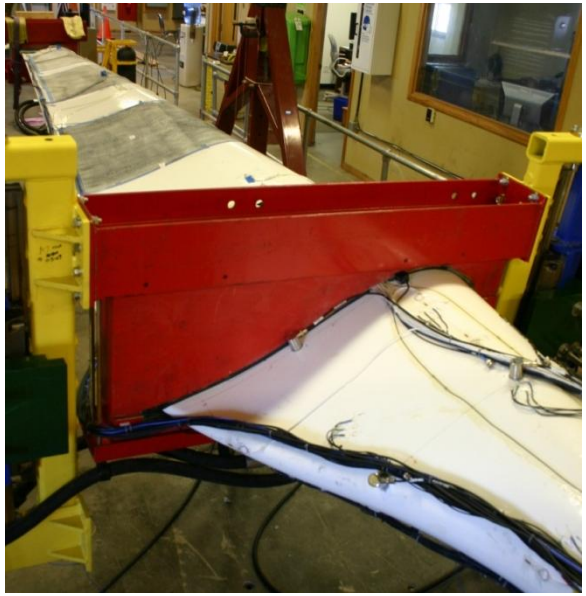






Ongoing Fatigue Test at NREL

- **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**