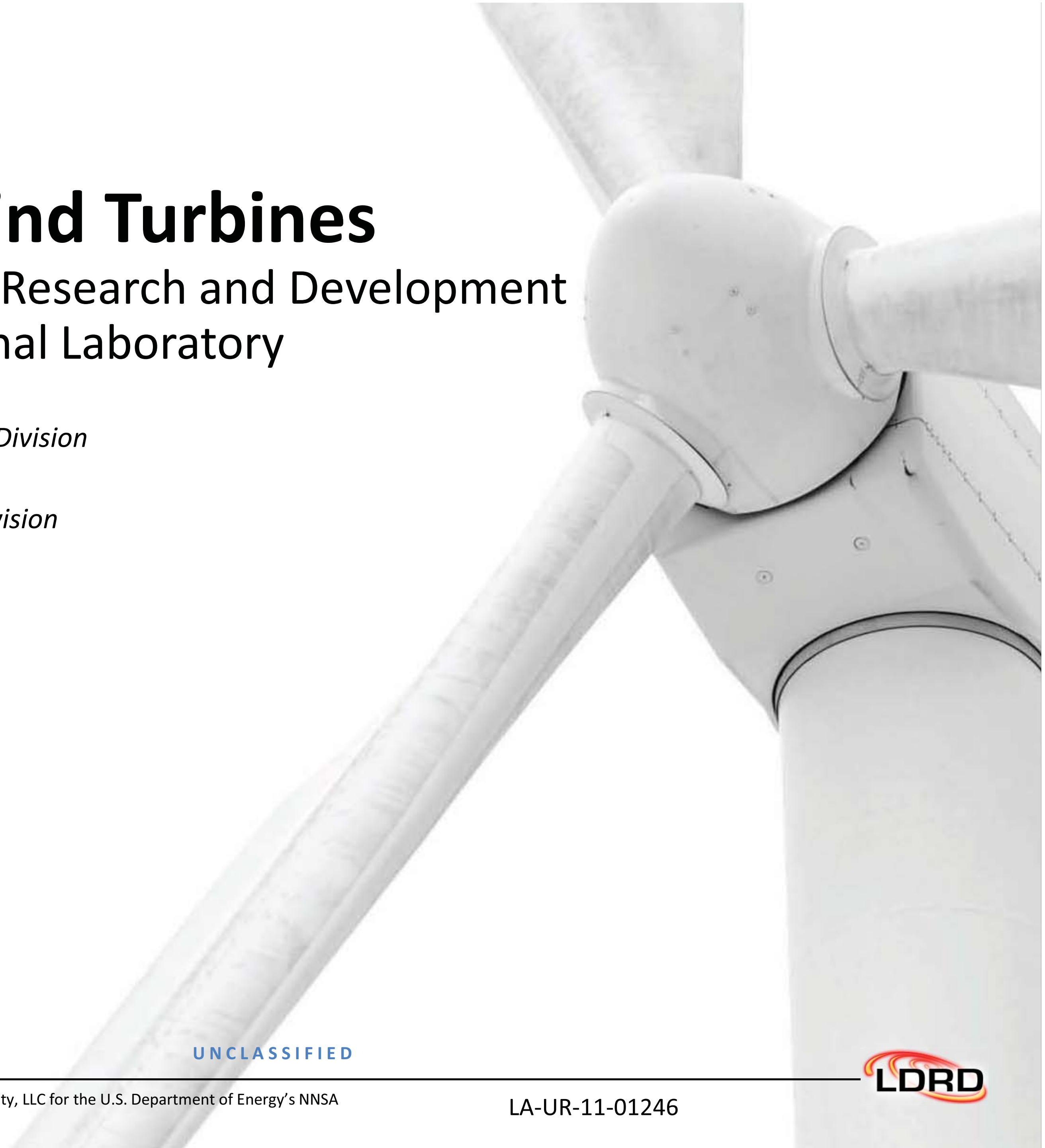
Intelligent Wind Turbines

Laboratory Directed Research and Development at Los Alamos National Laboratory

Curtt Ammerman (PI)
Applied Engineering & Technology Division

Rod Linn (Co-PI)
Earth & Environmental Sciences Division

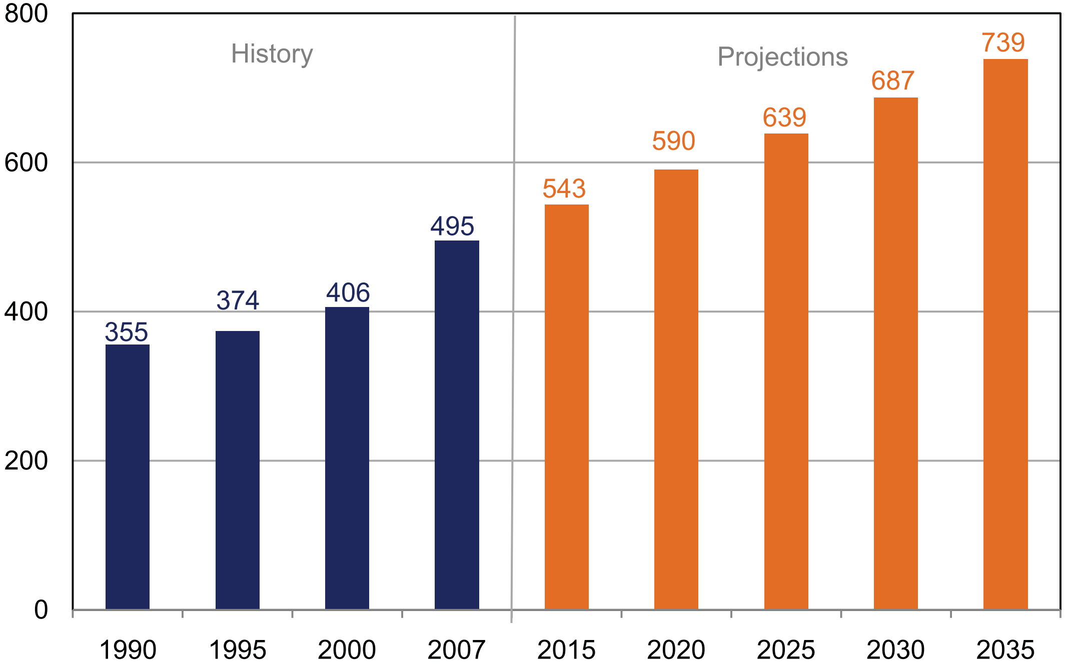
Gyuhae Park (Co-PI)
Engineering Institute



3-Year Project Funding Profile

FY10:	$1.81M
FY11:	$1.78M
FY12:	$1.65M
	$5.24M

Why is Wind Energy Important for the US?



Daily Price of Oil, Previous 12 Months

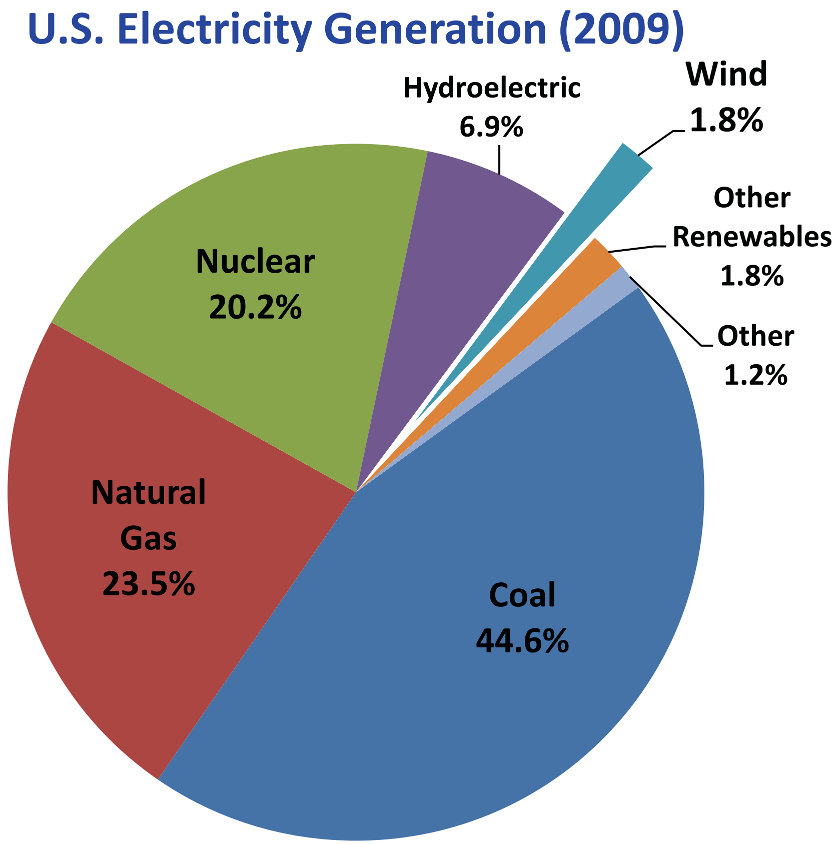
Administration Goals
- Reduce carbon emission 50% by 2030, 80% by 2050
- Reduce oil consumption 50% by 2030, 80% by 2050
- Stimulate jobs and economic recovery through renewable energy development

DOE Wind Program Goals
- Grow wind power deployment to meet future energy demand
- Lower Wind COE through innovation and reliability improvements

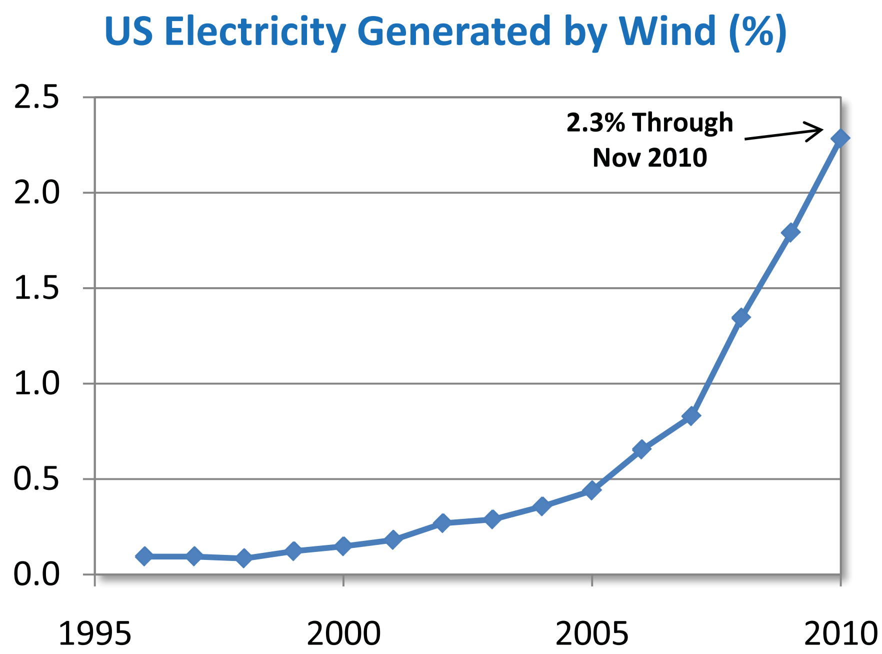
Los Alamos NATIONAL LABORATORY EST.1943

IWT LDRD DR

DOE's Goal is to Increase Wind Power to 20% by 2030



Source: US Energy Information Administration



Los Alamos NATIONAL LABORATORY EST. 1943

IWT LDRD DR

Cost of Energy is Major Barrier to Wind Deployment

Challenges to Overcome in Wind Energy

- Increasing blade cost & weight
- Blade failures & reliability concerns
- Drivetrain/gearbox failures
- Need for efficiency improvements
- Wind project underperformance
- Reliability and maintenance

Desired Benefits from Targeted R&D

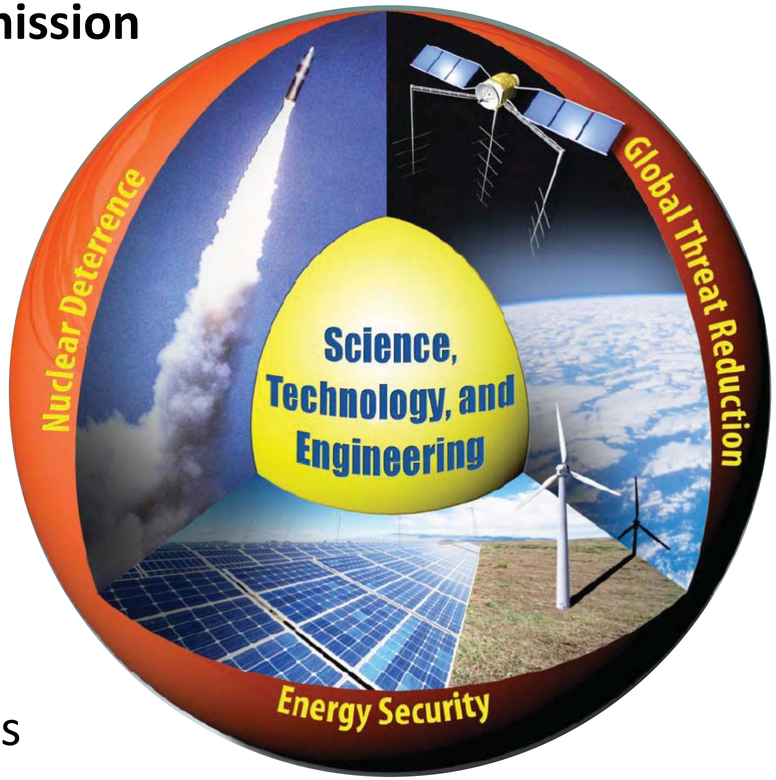
- Increased turbine performance
- Increased plant performance
- Increased turbine reliability
- Decreased turbine costs
- Innovative products

DOE's Goal is to Reduce Cost of Energy 20% by 2020

Why Study Wind Turbines at Los Alamos?

- Directly supports LANL's **energy security mission**
  - promotes clean energy concepts
  - mitigates impact of global energy demand

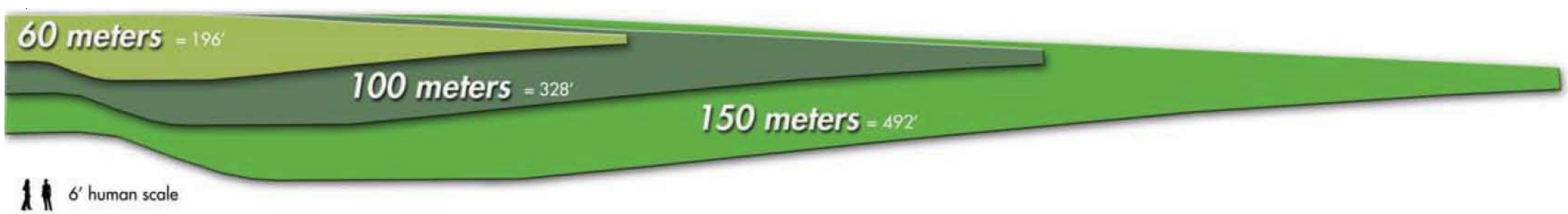
- We are uniquely positioned to contribute
  - **HPC wind turbine and plant simulation**
  - **structural health monitoring**
  - **model validation and verification**
  - **large-scale technology integration**



- Complements DOE's wind energy strengths
  - LANL is working collaboratively with other National labs, industry, and academia

Our Research Is Centered On Turbine Blades

- **Why start with the turbine blades?**
  - blades failure rates are relatively high
  - blades continue to grow in size, thus encounter more severe dynamic loading
  - true wind loads on blades are not accounted for in design process
  - blades are the origin for loads on the hub, gearbox, and generator
- **We have a comprehensive engineering R&D program focused on wind turbines that is delivering**
  - turbine/plant simulation with realistic wind loading
  - multi-scale sensing for damage detection and shape reconstruction
  - structural health monitoring (SHM) with damage prognosis
  - model validation and uncertainty quantification
  - enabling research to explore advanced control concepts
  - large-scale technology integration
  - wind collaborations with industry, National labs, universities



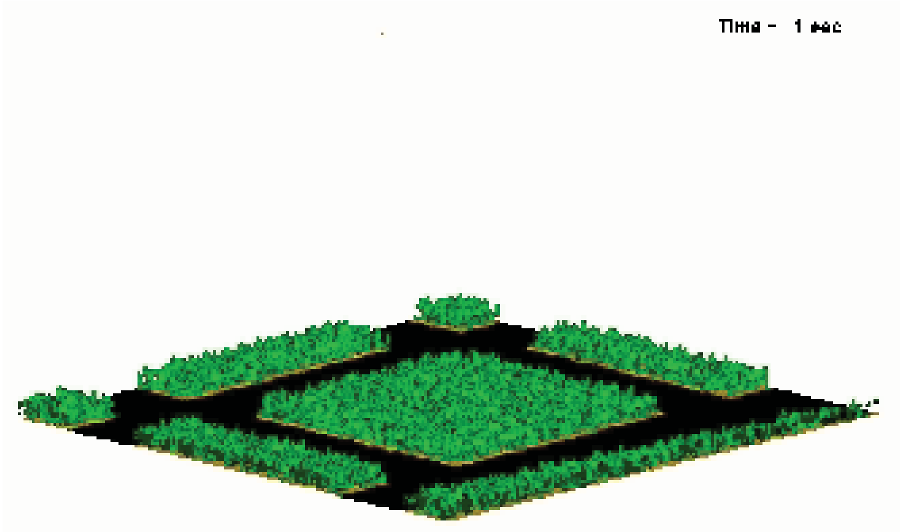
The Project is Focused on 3 Major Deliverables

- **Validated WindBlade turbine and plant simulation tool** capable of modeling
  - true wind loading with turbulence on multiple scales (e.g. atmospheric, terrain, vegetation, upstream turbines)
  - blade and hub loading
  - damaged and undamaged aeroelastic rotors
  - control schemes
  - rotor power output
- **Experimental wind turbine aerodynamics databases**
  - new experimental techniques focused on needs of large-scale wind turbines
  - high-quality experimental datasets for code validation
- **Prototype SHM hardware and software ready for tech transfer**
  - active and passive sensing suite for damage detection, state awareness, and operational diagnostics
  - damage prognosis
  - energy harvesting techniques for wireless SHM nodes

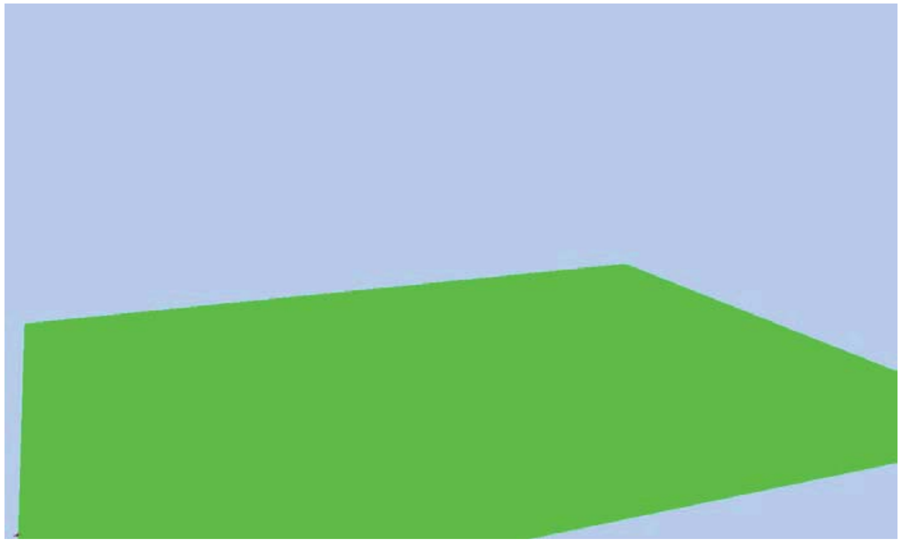

Modeling Tools for Wind Turbine Design
Designed for this...
...but experience this.

WindBlade: LANL’s Turbine and Plant Simulation Code

- Couples R&D 100-winning HIGRAD/FIRETEC with LANL’s new turbine/wind interaction modeling technique, **WindBlade** (*patent pending*)
- 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**

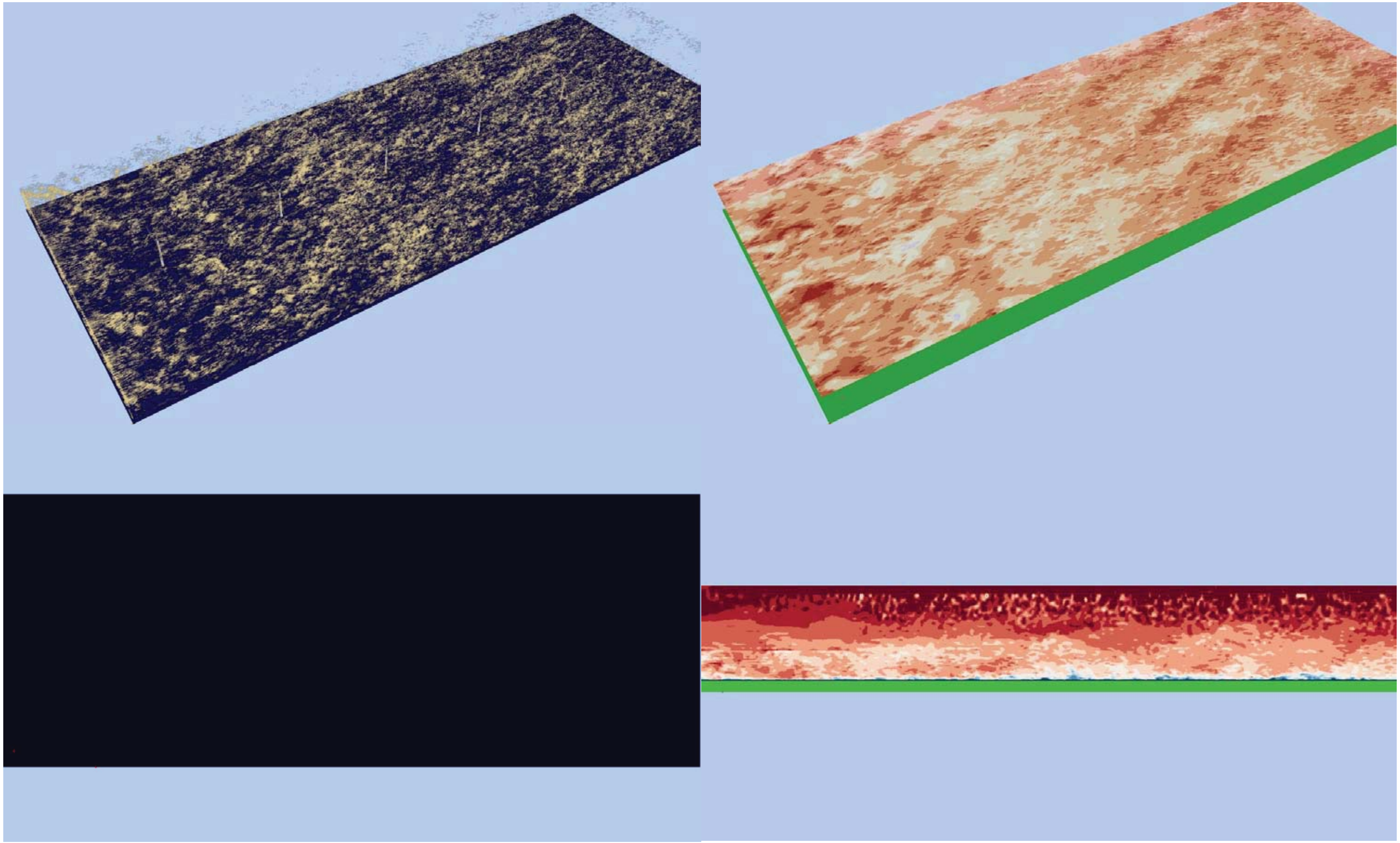


***WindBlade* 9-Turbine Simulation (100m Diameter) Showing Turbulence-Induced Vorticity**

Los Alamos NATIONAL LABORATORY EST. 1943

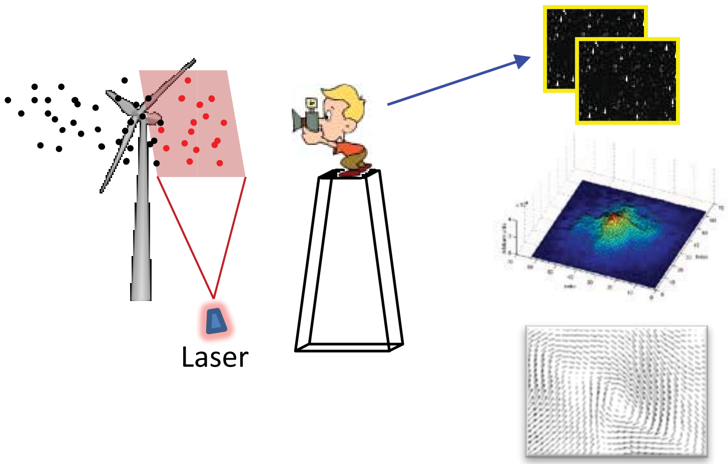
IWT LDRD DR

Five, 126m-Diameter Turbines w/ 3D Spacing



We are Developing New Diagnostic Techniques to Measure Detailed Flows Around Wind Turbines

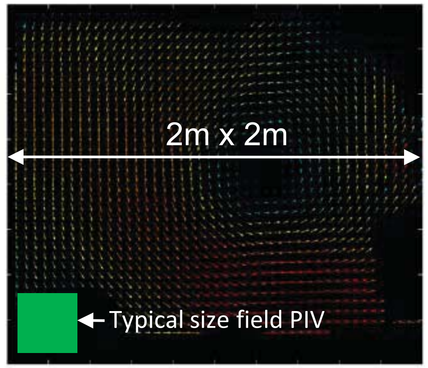
Large-Format Particle Image Velocimetry (LF-PIV)



2 images separated by microseconds (dt)

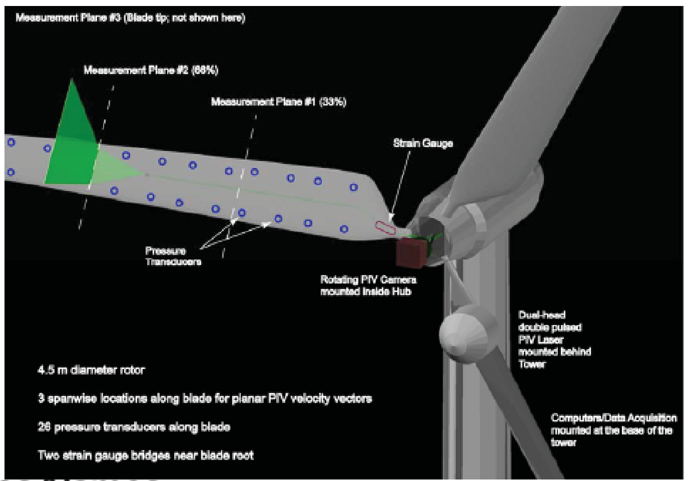
Cross-correlation to obtain displacement (dx)

2D velocity field with high spatial, temporal resolution



Scalable to 2m x 20m!

In-Blade Rotating PIV (*DOE Contract: LANL/SNL*)



- Camera mounted on hub

- Laser sheet projected perpendicular from blade

Provides:

- Details of blade boundary layer at all phases of blade revolution

- Time series of dynamic stall, separation, micro-tab performance, and 3D effects

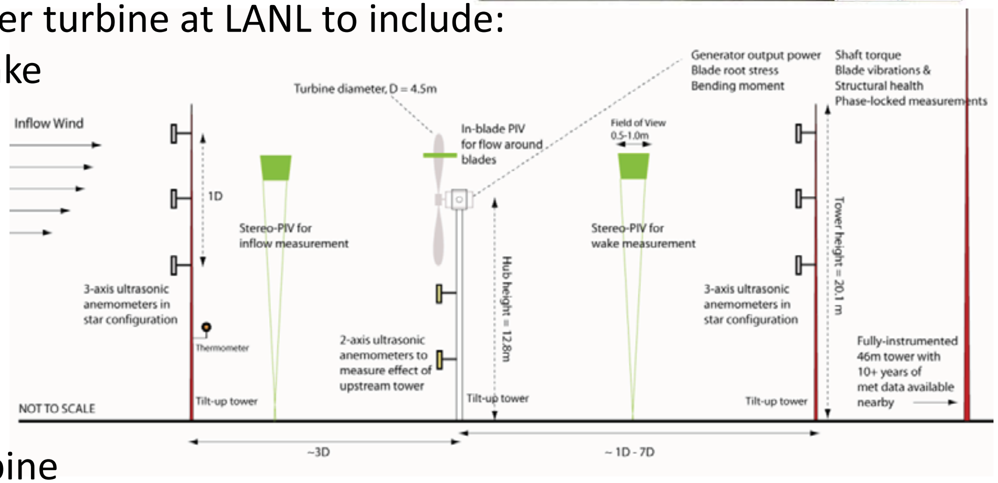
Advantages of these Techniques

- Excellent spatial resolution
- Velocities in a plane instead of at a point
- Non-intrusive technique
- Measure flow near and around blades without interference
- Robust to weather conditions

We are Characterizing Turbine Inflow, Near-Blade Flows, and Wake Regions with PIV

- Wind tunnel experiments using scaled turbines up to 0.2m diameter
  - PIV, hot wire, LDV → inflow, wake profiles, power output, RPM
  - Laminar and turbulent inflow under yaw

- Fully instrumented field test of 4.5m-diameter turbine at LANL to include:
  - LF-PIV measurements of inflow and wake
  - In-blade rotating PIV measurements of flow around blades



- LF-PIV measurements on 20m-diameter turbine in field with LANL 9m blades

Los Alamos NATIONAL LABORATORY EST. 1943

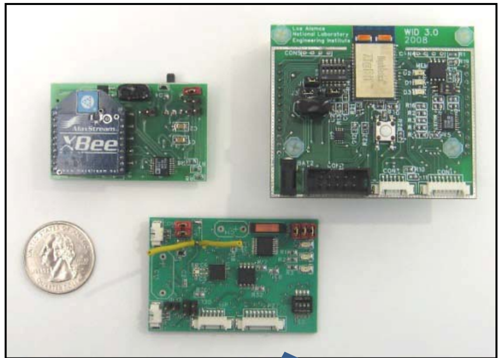
IWT LDRD DR

Turbine Blade Inspection

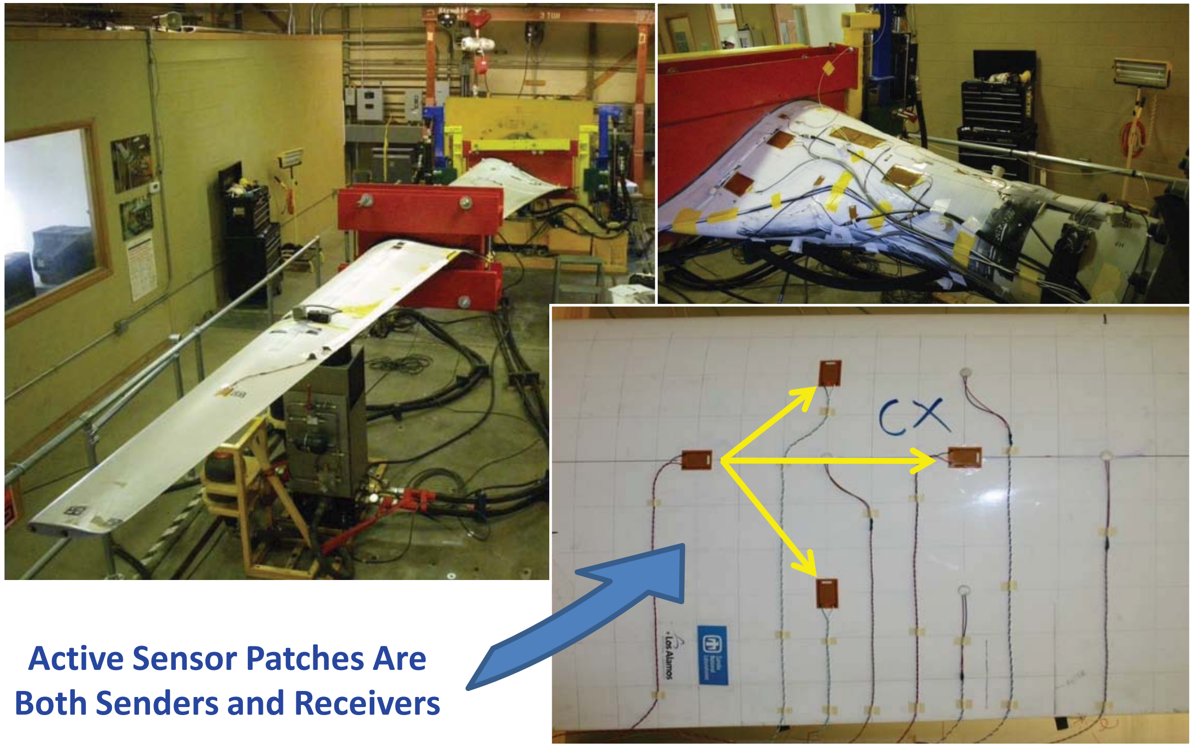
The Future of Damage Detection:
Real-Time Structural Health Monitoring (SHM)

- We are developing low-cost sensing systems to monitor blade health
- Embedded in each blade, this system will
  - Identify structural damage and monitor its progression
  - Predict remaining useful blade life (damage prognosis)

LANL Wireless Sensor Nodes

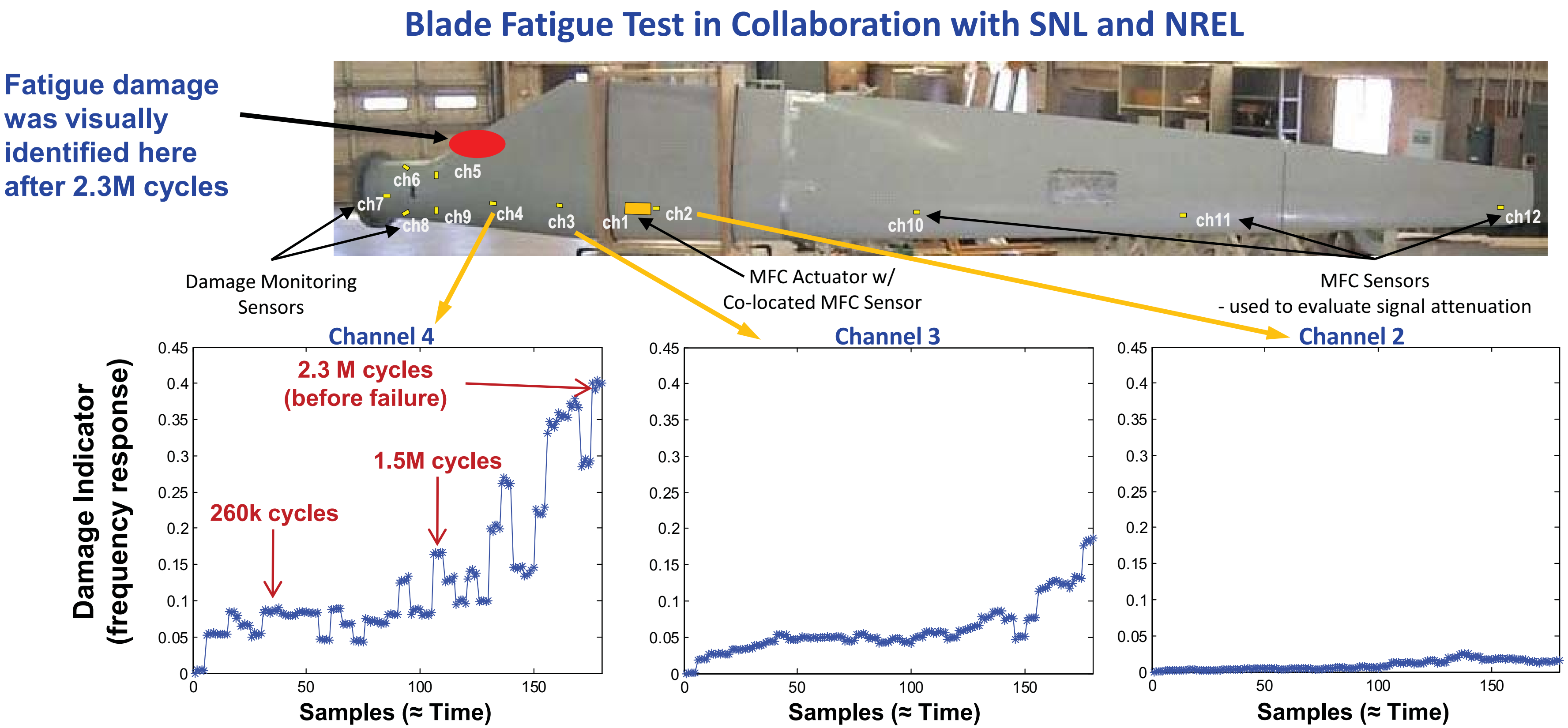


Energy Harvesting (No Power Links, No Batteries)



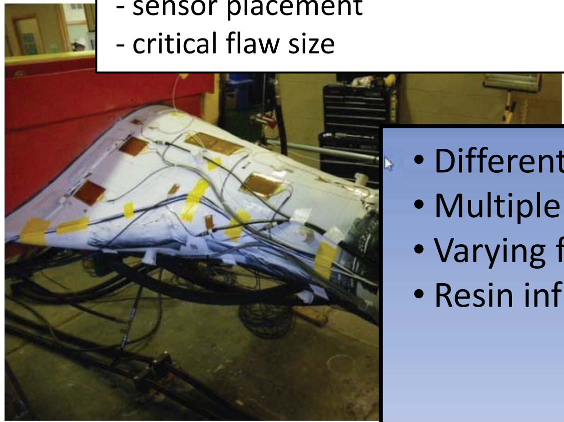
Active Sensor Patches Are Both Senders and Receivers

Active Sensing Detects Growing Crack In Blade

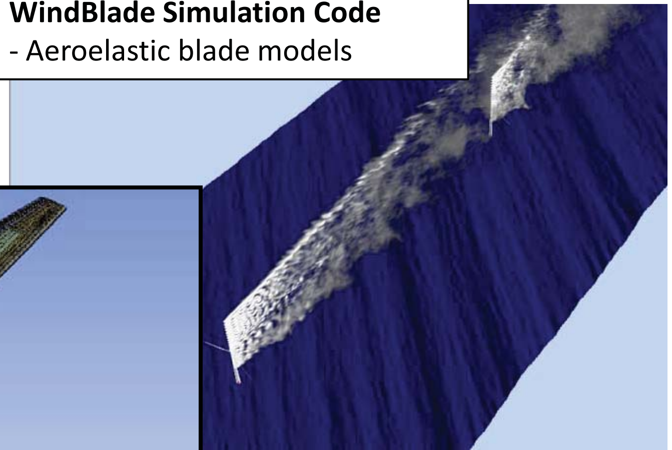


- We proved damage and damage progression are detectable with our techniques
- We characterized transmission loss in composite blade as a function of frequency (100Hz - 30kHz)
- In LANL fatigue test in May, we will focus on identifying **location** and **severity** of damage

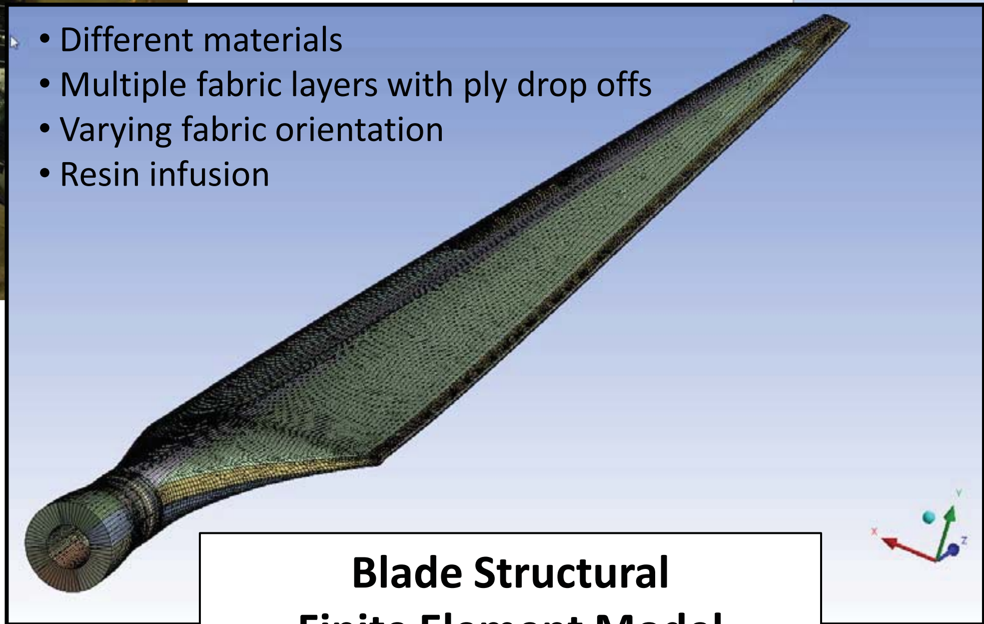
Blade Structural Model Vital to Many Aspects of Project



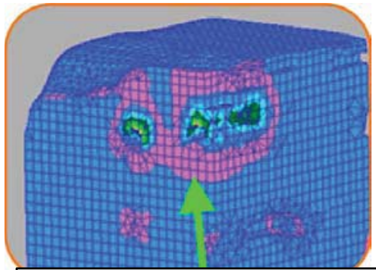
Structural Health Monitoring
- sensor placement
- critical flaw size



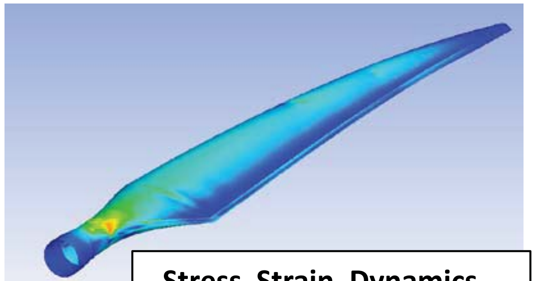
WindBlade Simulation Code
- Aeroelastic blade models



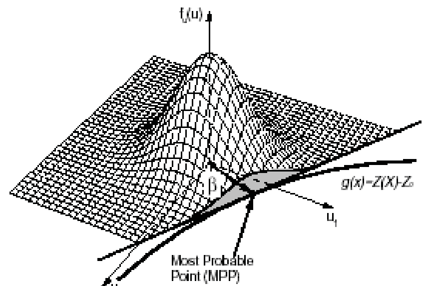
Blade Structural Finite Element Model



Lamina/Section (sub-blade) Models
-damaged models of blade sections



Stress, Strain, Dynamics…



Damage Prognosis

Los Alamos
NATIONAL LABORATORY
EST. 1943

IWT
LDRD DR

Our 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)
  - **Rotor Hub**: Hub mounted camera for PIV measurements of airflow over SHM rotor blade
- 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

Los Alamos NATIONAL LABORATORY EST.1943

IWT LDRD DR

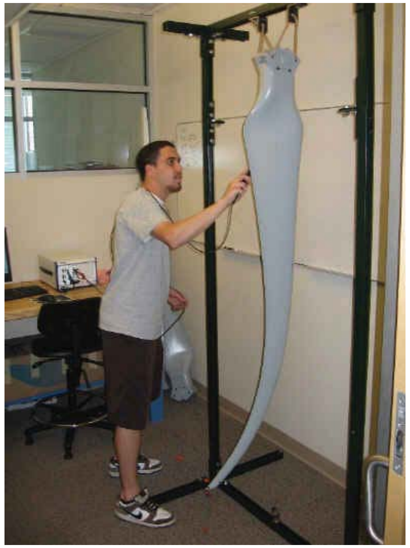
Major Accomplishments and Future Work

- **Wind Turbine and Wind Plant Modeling and Simulation**
  - Integrated NREL's TurbSim into WindBlade as front end BC and investigating impact on wake effects
  - Interfaced WindBlade with WRF model providing a path for validation with data from NWTC
  - Developed adjoint version of fluid-structure interaction (FSI) code to study advanced control concepts
  - Constructed FE model of 9m research blade and developed approach for incorporating into WindBlade
  - Incorporate coupled plant-scale aeroelastodynamic modeling within WindBlade
  - Perform WindBlade verification & validation studies
- **Experimental Wind Turbine Aerodynamics**
  - Using PIV/hot wire/LDV in wind tunnel to measure turbine wakes: laminar/turbulent inflow under yaw
  - Developed powerful new PIV techniques to measure turbine inflow, wake, and flow around blade
  - Generating valuable datasets for understanding of wake physics and validation of turbine design codes
    - making available to research community on new LANL website
  - Develop active grid for wind tunnel to enable systematic study of inflow shear and turbulence on wake
  - Perform first-ever field test with 4.5m turbine to generate unprecedented reference datasets
    - measurements include PIV, CSAT3, RM Youngs, power output, structural response
  - Apply LF-PIV to 20m turbine flight test in FY12 to provide first ever characterization of flowfields around large-scale, rotating turbine blade
- **Multiscale Sensing and Turbine Blade Structural Health Monitoring (SHM)**
  - Investigated different SHM diagnostic techniques that show promise for damage detection
  - Tested SHM hardware and software on full-scale fatigue test: detected damage and its progression
  - Developing low-cost, self-powered, wireless sensing node for blades: reducing weight, cost, power
  - Fatigue test LANL 9m blade at NREL this May: focus on identifying location and severity of damage
  - Custom fab 9m blades with built-in LANL sensors and fly operational prototype of SHM on 20m turbine

IWT Project Engineers Also Participate in Los Alamos Dynamics Summer School

- Proactive approach to training and recruitment of top students through an intense, 9-week summer school program
- Program goal: Get top engineering undergraduates enrolled in graduate school
  - Average GPA of these students: 3.8
  - Approx. 125/150 have gone on to grad school
  - 18 have completed their Ph.D.s
  - LANL has hired 14 Staff Members from this program
- Recent wind energy-related projects:
  - Structural Health Monitoring of a Floating Offshore Wind Turbine (2010)
  - Vibration Testing and Structural Damage Identification of Wind Turbine Blades (2010)
  - Structural Damage Identification in Wind Turbine Blades using Piezoelectric Active Sensing (2009)
  - Energy Harvesting to Power Sensing Hardware Onboard a Wind Turbine Blade (2009)
  - Real-Time Dynamic Measurements of a Wind Turbine Rotor Blade using Modal Filtering (2008)





Wind Turbine Senior Design Project

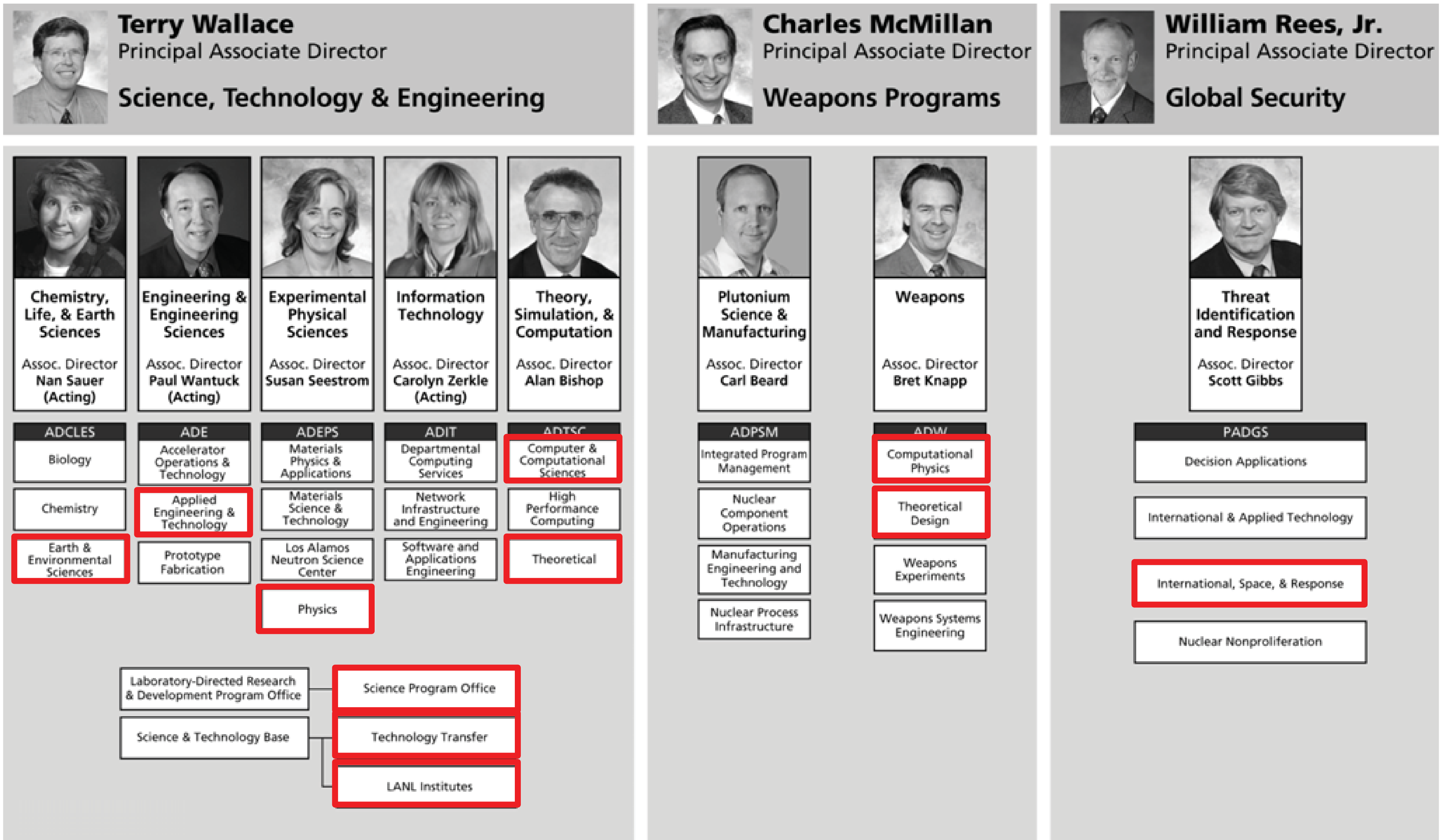
HARVEY MUDD COLLEGE

- Our IWT Project is sponsoring HMC Clinic project through a $45k subcontract
- Team consists of 4 seniors and 1 junior for two semesters (Fall'10 thru Spring'11)
- Project Title: **Wind Turbine Dynamic Modeling with Experimental Validation**
  - Purchase and erect 4.5m turbine and tilt-down tower
  - Generate finite element model of composite blades
  - Develop multibody dynamics model of wind turbine and tower
  - Instrument the turbine and tower and take experimental data
  - Compare wind turbine modeling results with experimental data

Los Alamos NATIONAL LABORATORY EST.1943

IWT LDRD DR

Our Team Cuts Across Entire Laboratory



Multi-Disciplinary Engineering Research Team

Modeling and Simulation

- C. Ammerman, *Mechanical & Thermal Engineering Group*
- G. Ellis, *Mechanical & Thermal Engineering Group*
- E. Koo, *Computational Earth Sciences Group*
- R. Linn, *Computational Earth Sciences Group*
- D. Luscher, *Fluid Dynamics and Solid Mechanics Group*

Sensing and Structural Health Monitoring

- T. Claytor, *Non-Destructive Testing & Evaluation Group*
- K. Farinholt, *Mechanical & Thermal Engineering Group*
- G. Park, *Engineering Institute*
- E. Raby, *Space Data Systems*
- S. Taylor, *Engineering Institute*

V&V/Prognosis/Data Management

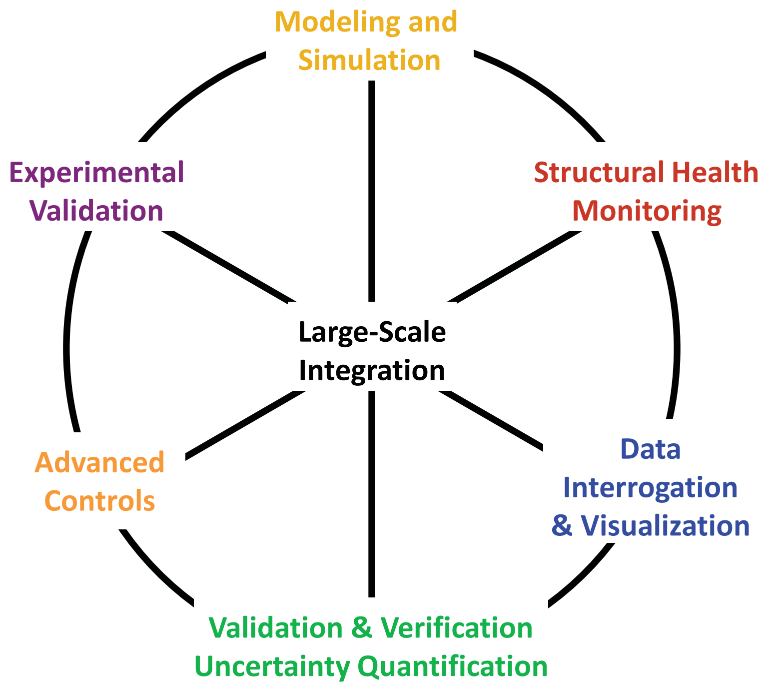
- J. Ahrens, *Applied Computer Science Group*
- F. Hemez, *Primary Physics Group*
- D. Hush, *Space and Remote Sensing Group*
- J. Patchett, *Applied Computer Science Group*
- J. Theiler, *Space and Remote Sensing Group*

Controls

- M. Bement, *Lagrangian Codes Group*

Experimental Validation

- B. Balakumar, *Neutron Science and Technology Group*
- S. Pol, *Neutron Science and Technology Group*



Program Development Mentor

- K. Ott, *Applied Energy Program Director*

Business Development-Tech Transfer Consultant

- M. Erickson, *Technology Transfer Division*

Remaining IWT Presentations

WindBlade: Coupled Turbine/Atmosphere Modeling
Rod Linn, Earth and Environmental Sciences Division, LANL

Blade FE and Coupled Plant Scale Aeroelastodynamic Modeling
Gretchen Ellis, Applied Engineering & Technology Division, LANL
DJ Luscher, Theoretical Division, LANL

Multiscale Sensing and Structural Health Monitoring
Kevin Farinholt, Applied Engineering & Technology Division, LANL

Experimental Wind Turbine Aerodynamics Research
BJ Balakumar, Physics Division, LANL

Modeling Development Activities
Curtt Ammerman, Applied Engineering & Technology Division, LANL