

# Fiber Optic and System Characterization at Sandia National Laboratories

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



Sandia National Laboratories



## Outline

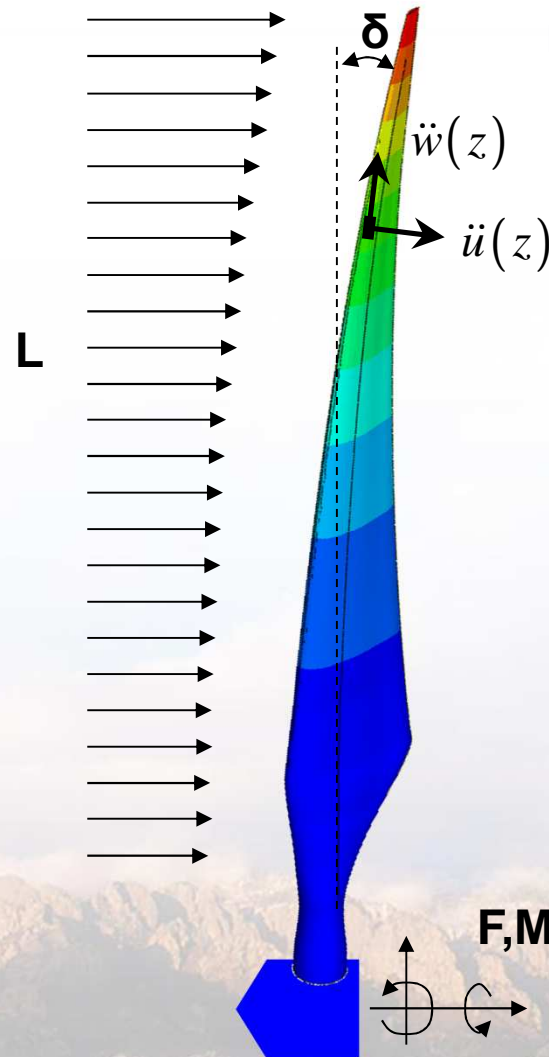
- You want what you can't measure
- What sensors are in the arsenal?
- What, where and how many?
- Quality and synchronization or bust
- Application examples



# *You want what you can't measure*

## ■ Desired:

- Deflection
- Bending moment
- Lift / drag
- Rotor imbalance
- Inflow front
- Impact detection



## ■ Measurable:

- Strain
- Acceleration\*
- Surface pressure\*
- Inflow velocity, direction and variation
- Etc.



# Monitoring over life-cycle

## 1 - Blade Fabrication (TPI Composites)



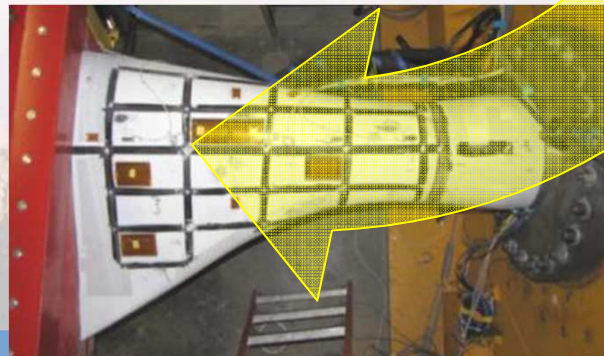
## 2 - Field Testing (USDA-ARS)



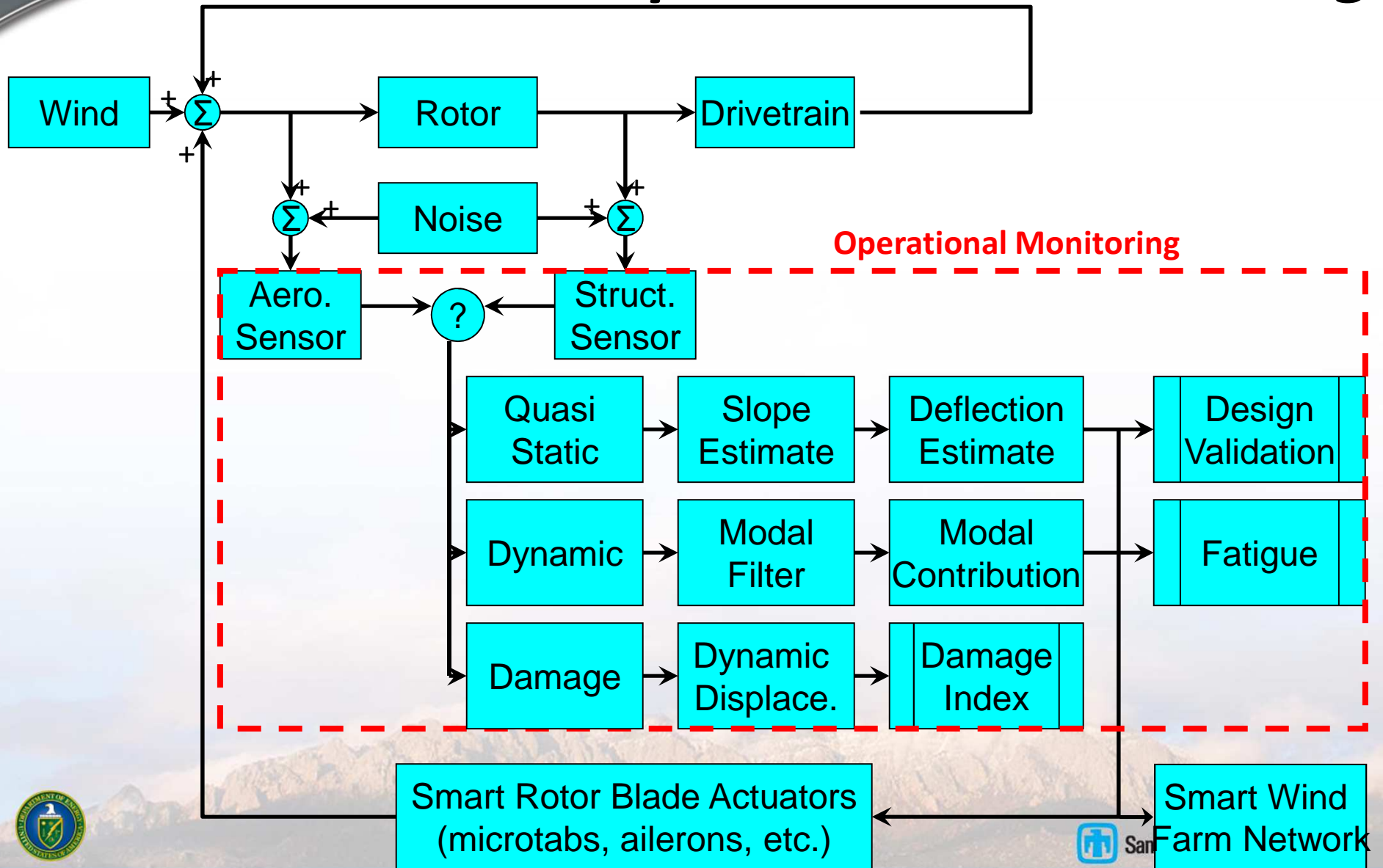
## 3 - Lab Testing (NREL - NWTC)



DOE, National labs, Industry,  
Universities, and non-wind companies  
“win-win-win-win”



# Real-Time Operational Monitoring



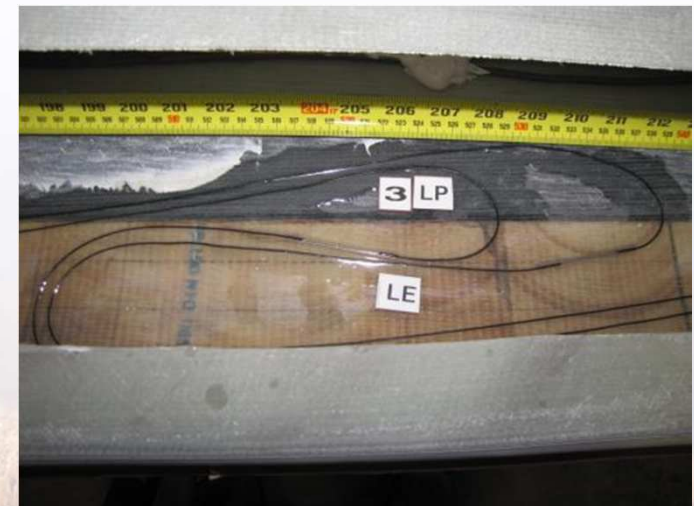


## ***What sensors are in the arsenal?***



# Structural Measurements

- Strain Gage
  - ◆ Uses: strain measurement, model validation, damage equivalent loading, modal analysis
  - ◆ Partners: Vishay
- Fiber Optic
  - Uses: strain measurement, model validation, damage equivalent loading, modal analysis
  - Partners: **Micron Optics**, Aither Engineering, Intelligent Fiber Optic, Luna Innovations
- Examples:



# Structural Measurements (cont.)

- Accelerometer

- Uses: acceleration measurement, modal analysis, CHM, SHM, prognostics
- Partners: PCB Piezotronics, Silicon Designs
- Examples:



- Acoustic Emission

- Uses: high-frequency vibration measurement, damage detection
- Partners: Physical Acoustics
- Examples:



- Active Piezoelectrics

- Uses: strain measurement and creation, damage detection, SHM, operational monitoring
- Partners: Los Alamos Labs, NASA-KSC
- Examples:



- Digital Image Correlation

- Uses: displacement and strain measurement, model validation, modal analysis
- Partners: SNL, Univ. Mass. – Lowell



# Aerodynamic Measurements

- Pitot Tube

- Uses: angle of attack measurement, controls, model validation
- Partners: Aeroprobe, PSI
- Examples:



- Pressure Sensor

- Uses: pressure measurement, CFD model validation
- Partners: Measurement Specialties
- Examples:



- Pressure Taps

- Uses: differential pressure measurement, CFD model validation
- Partners: Aeroprobe, PSI
- Examples:



- Stagnation Point

- Uses: angle of attack measurement, model validation
- Partners: SNL, Univ. Mass. – Lowell



# Aerodynamic Measurements (cont.)

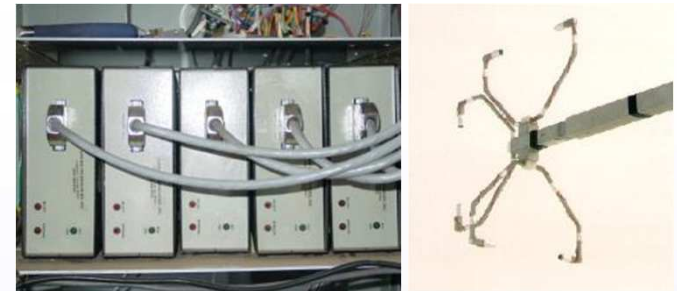
- Cup Anemometer

- Uses: wind speed, inflow estimation
- Partners: Teledyne, MetOne, NRG
- Examples:



- Sonic Anemometer

- Uses: 3D wind speed, wind vector
- Partners: Applied Technologies
- Examples:



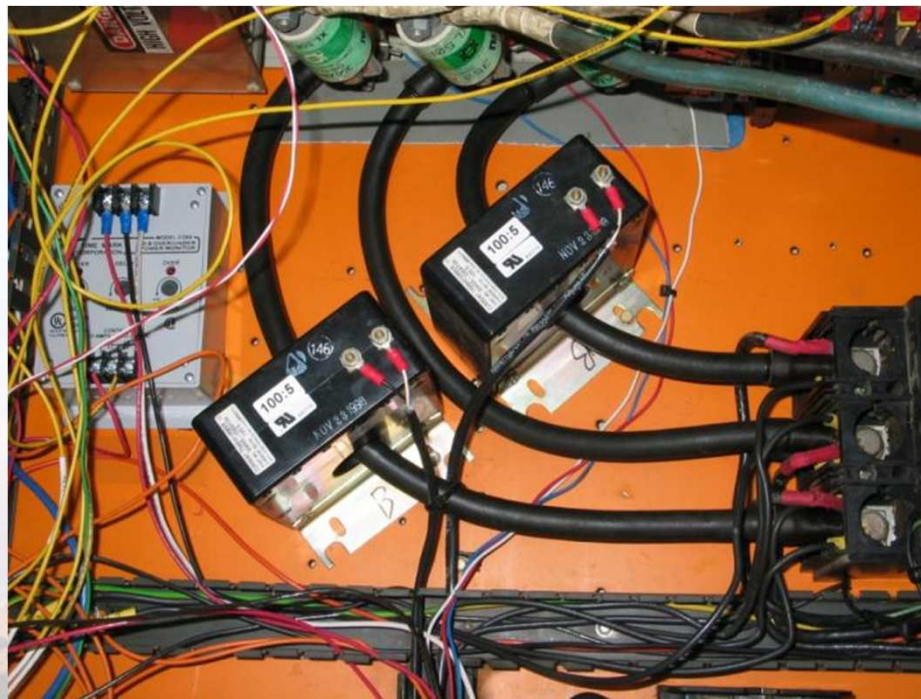
- Wind Vane

- Uses: wind direction
- Partners: MetOne, NRG
- Examples:



# Electrical Measurements

- Power
  - ◆ Uses: three-phase voltage, current, total power, VAR
  - ◆ Partners: Ohio Semitronics
  - ◆ Examples:



# SNL Sensor Blade 1 Project

LANL: SHM

NASA: SHM

Luna: continuous FBG

PAC: AE NDT

IFOS: DOE-SBIR

LTI: Shearography

UML: Digital Image Correlation (DIC)

# NDE/NDI/NDT and QA Tools

UML,TPI,SNL,NREL  
DOE ARRA

S. STARRETT CO. ATHOL, MASS. U.S.A.  
60 70 80 90 100

SNL: Computed Tomography

SNL: Phased Array UT

SNL: Ultrasonic NDT

SNL/NREL/PAC: Acoustic Emission NDT

Energy\*

<100

100-1000

>1000

TX-100

Spar Cap

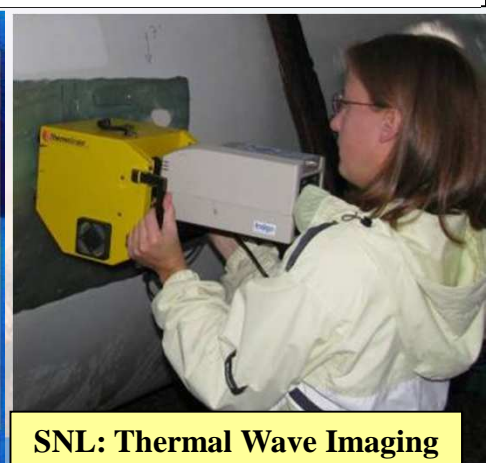
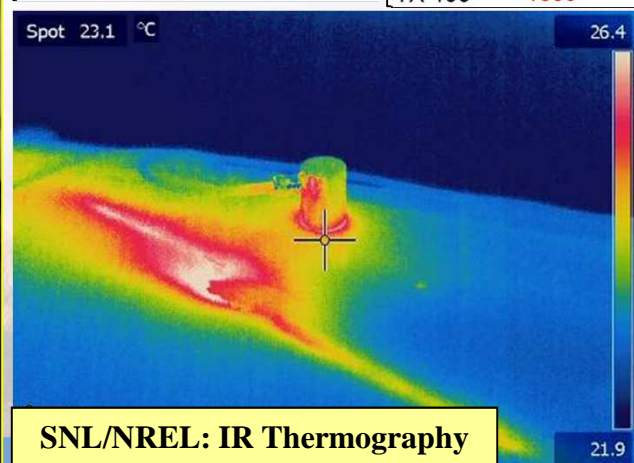
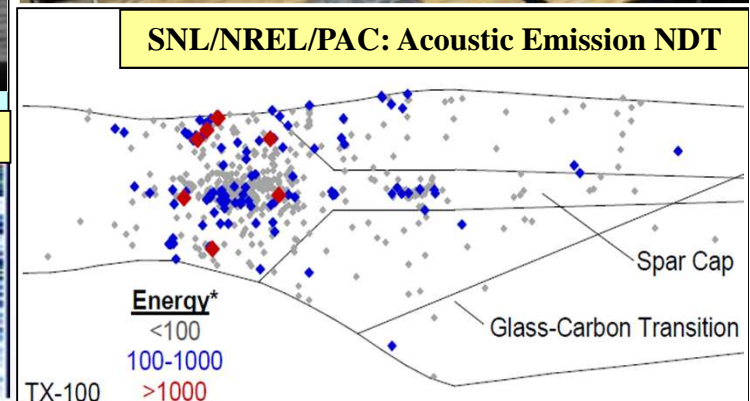
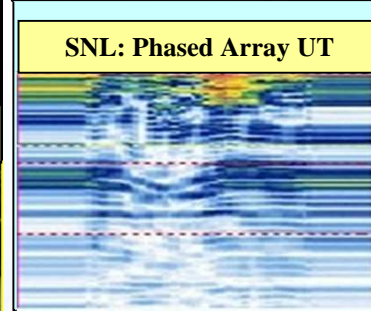
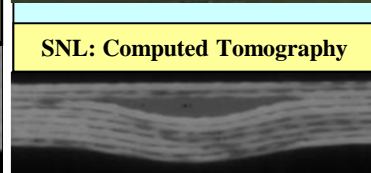
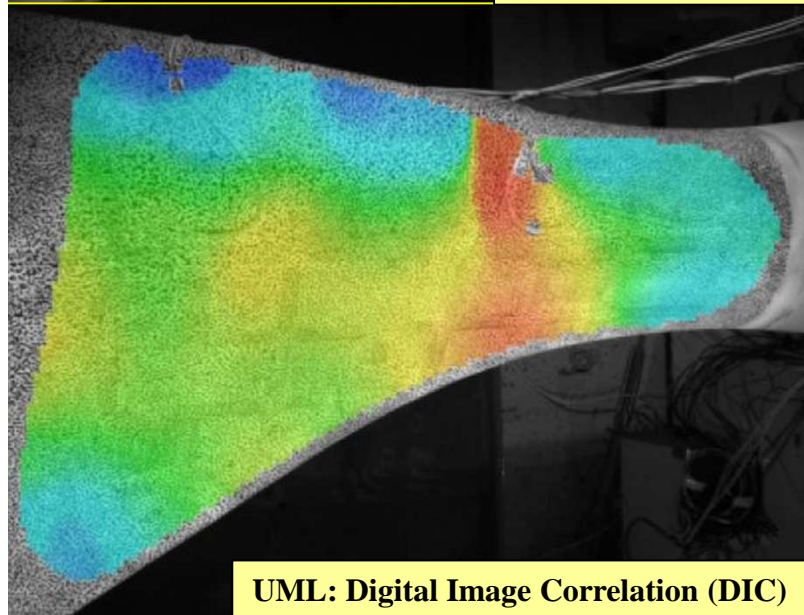
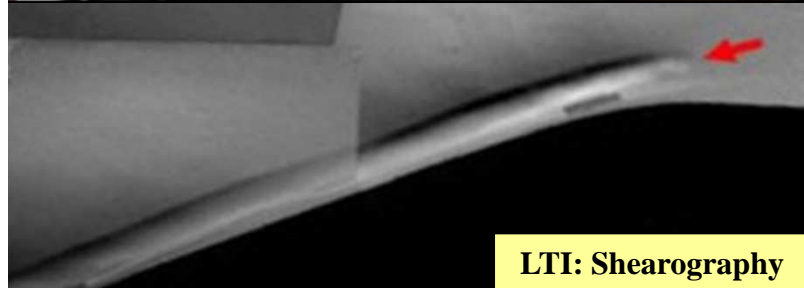
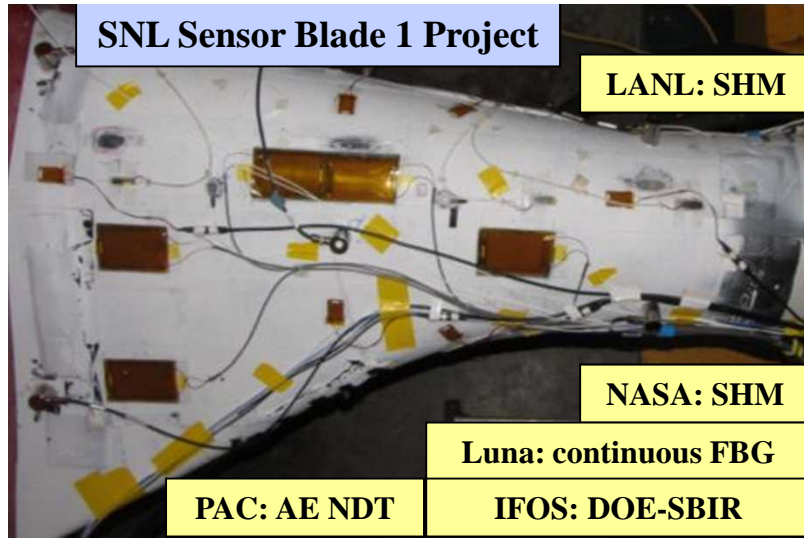
Glass-Carbon Transition

Spot 23.1 °C

26.4

SNL/NREL: IR Thermography

SNL: Thermal Wave Imaging



# What, where and how many?

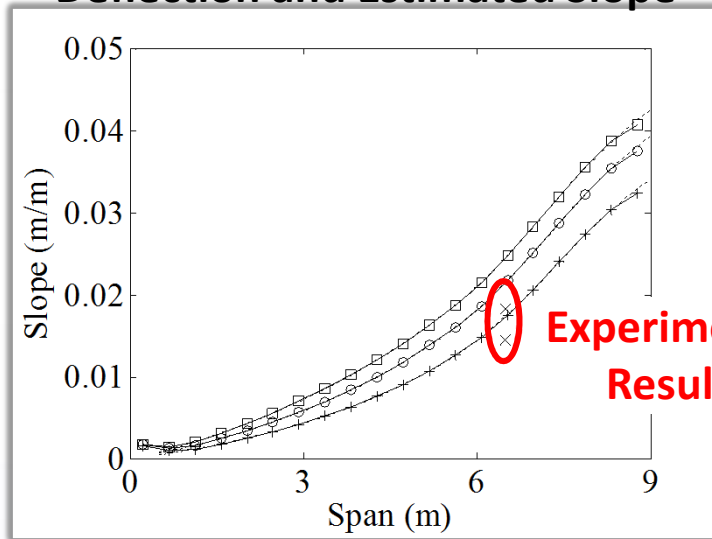
- Sensors and supporting infrastructure (data acquisition, cabling, etc.) are directly and indirectly costly.
- Must design sensor array, data acquisition to meet operational / development goals in advance of deployment.

Approach	Method	Optimization
Quasi-static Load and Response (<1P)	$\hat{u}_s \left( z, \frac{\partial u_s}{\partial z} \right) = \{ f(R, L, z) \}_{1 \times (n-3)} [ g(R, L, z_i) ]_{(n-3) \times m}^+ \left\{ \frac{\partial u_s}{\partial z} \right\}_{z_i} \}_{m \times 1}$	$E = \int_{z=0}^L [u(z) - \hat{u}(z)]_{1 \times z} \begin{bmatrix} w(z) & \dots & w(z) \end{bmatrix}_{z \times z} [u(z) - \hat{u}(z)]_{z \times 1}^T dz = E(U, z_1, z_2, \dots)$
Dynamic Load and Response ( $\geq 1P$ )	$\{ u_d(t) \}_{n \times 1} = [U]_{n \times r} \eta_r(t), \quad \text{with } / n \geq r$	$\mathcal{K}(U_{r \times n}) = \  \  U_{r \times n} \  \  \  U_{n \times r}^{-1} \  \ $
Damage Detection	$DI = \frac{\Delta k}{Mg} = \frac{W_{healthy} - W_{damage}}{W_{healthy} W_{damage}}$	

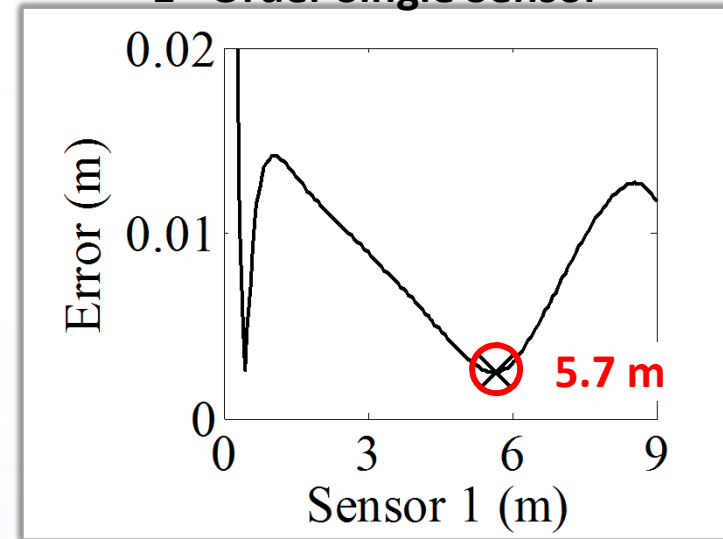


# Where?

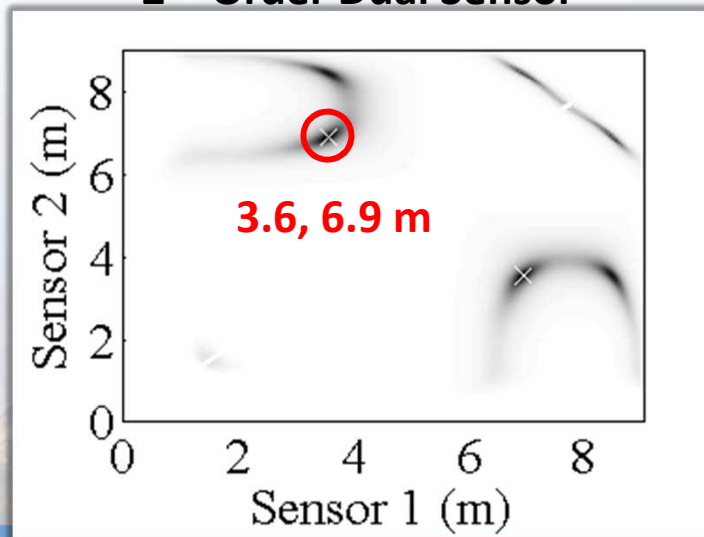
## Deflection and Estimated Slope



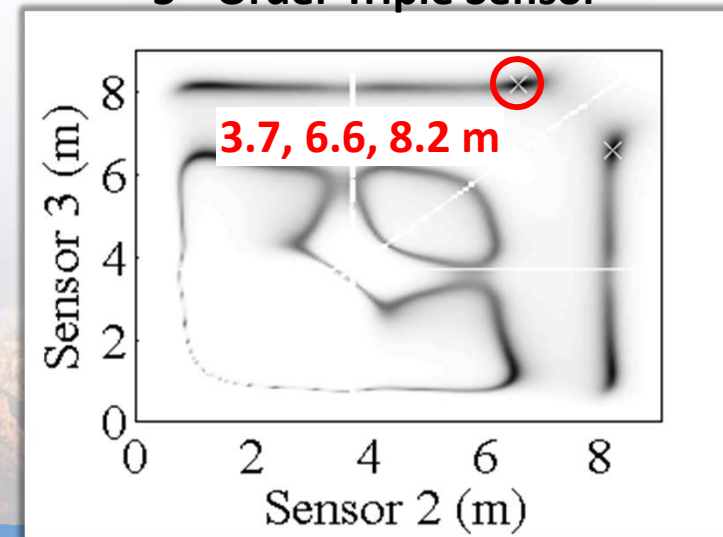
## 1<sup>st</sup> Order Single Sensor



## 2<sup>nd</sup> Order Dual Sensor

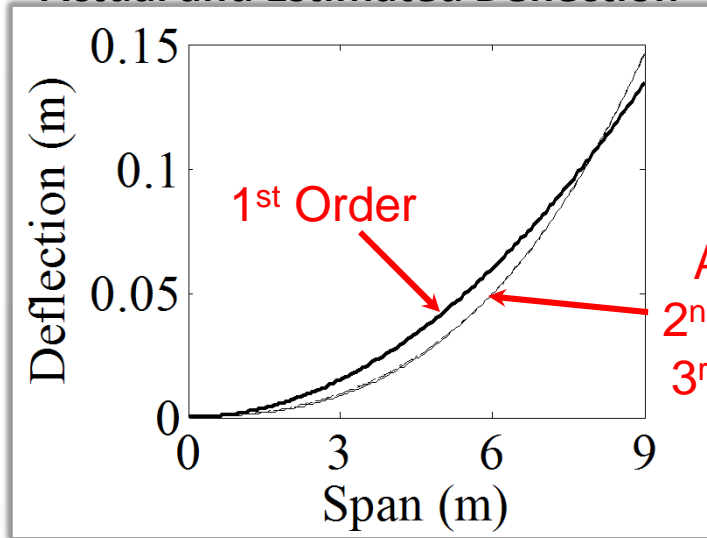


## 3<sup>rd</sup> Order Triple Sensor

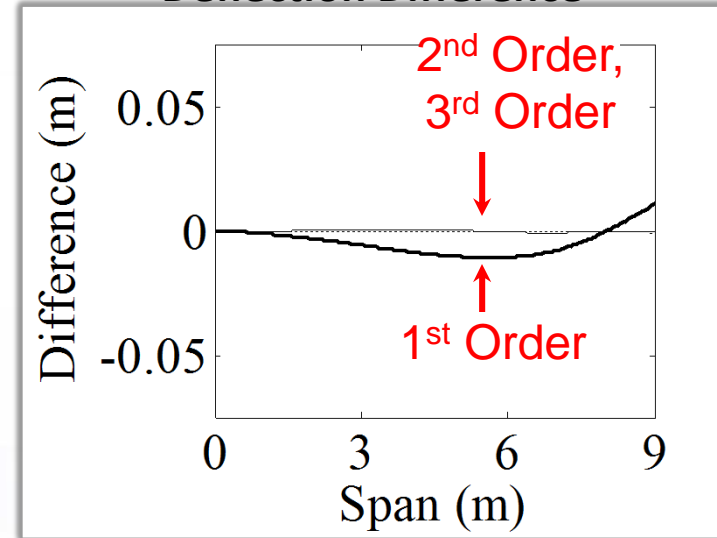


# How many?

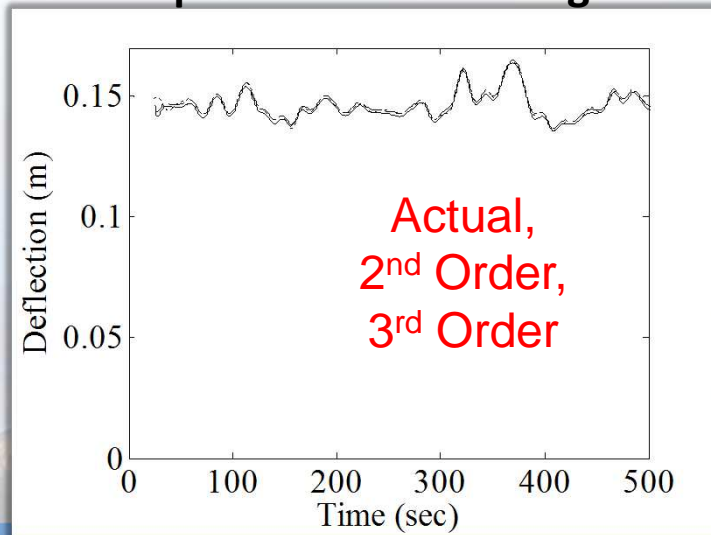
### Actual and Estimated Deflection



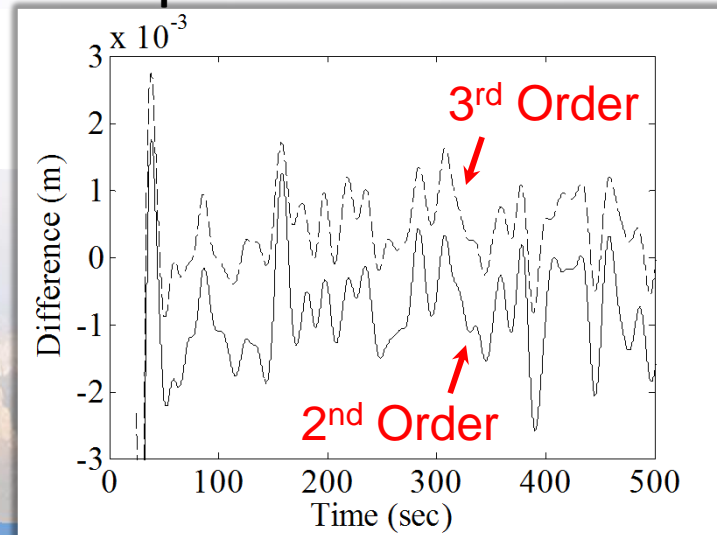
### Deflection Difference



### Tip Deflection Tracking



### Tip Deflection Difference





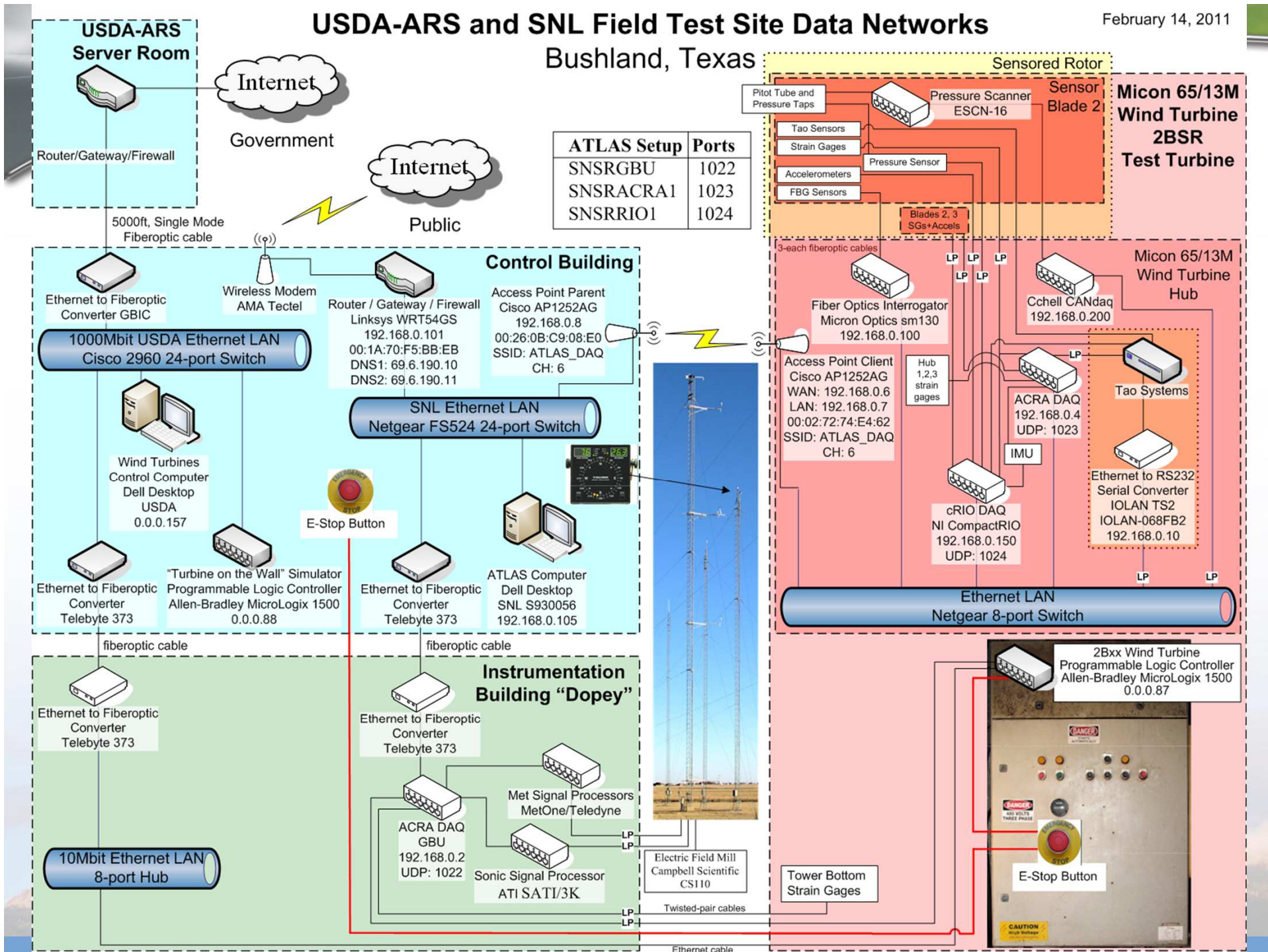
# ***Quality and synchronization or bust***



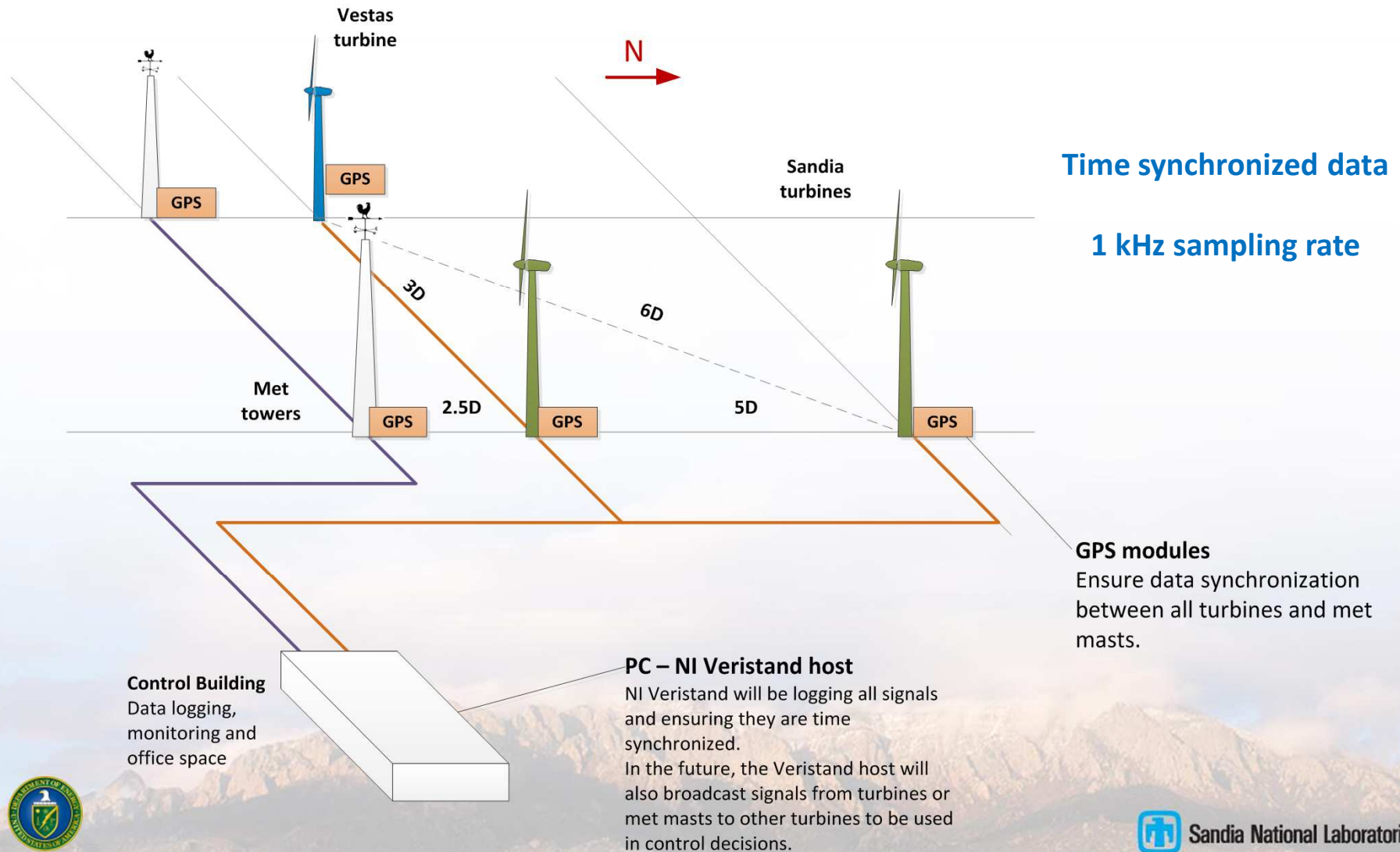
# USDA-ARS and SNL Field Test Site Data Networks

February 14, 2011

Bushland, Texas



# Scaled Wind Farm Technology Facility DAQ and Control Network





# *Application examples*





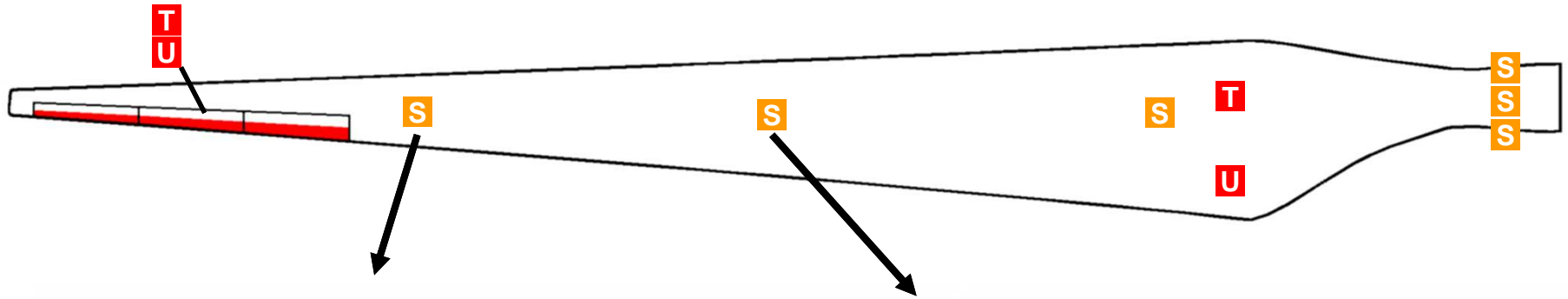
# SNL Data Acquisition

- Wireless Connectivity
- Micron Optics Fiber Interrogator
- GPS Time Synchronization
- Backup Power
- Ethernet Lightning Protection
- Pitot Tube Heater
- Power Conditioning

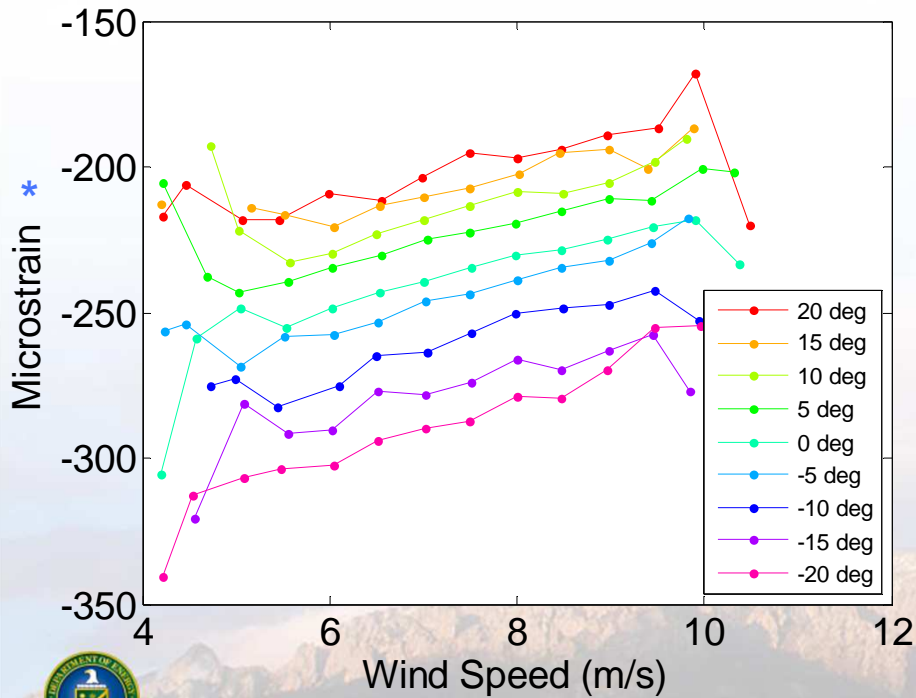
- NI cRIO Data Acquisition
- S.E.A. GPS Time Synchronization
- Lightning Protection
- Hub IMU
- Intranet Network
- Acra Data Acquisition
- Lightning Protection



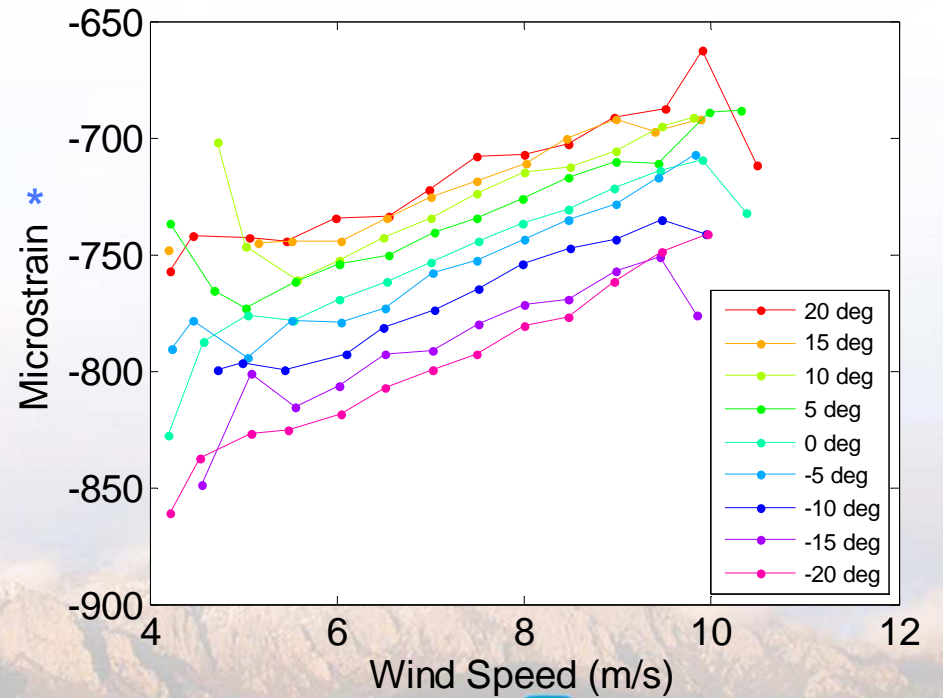
# Mean Strain Response vs Wind Speed



B2\_H2\_Strain\_6750\_Z\_HP



B2\_H2\_Strain\_4500\_Z\_HP



\* strain offset needs to be corrected

# University of Minnesota Clipper 2.5 MW Rotor DAQ

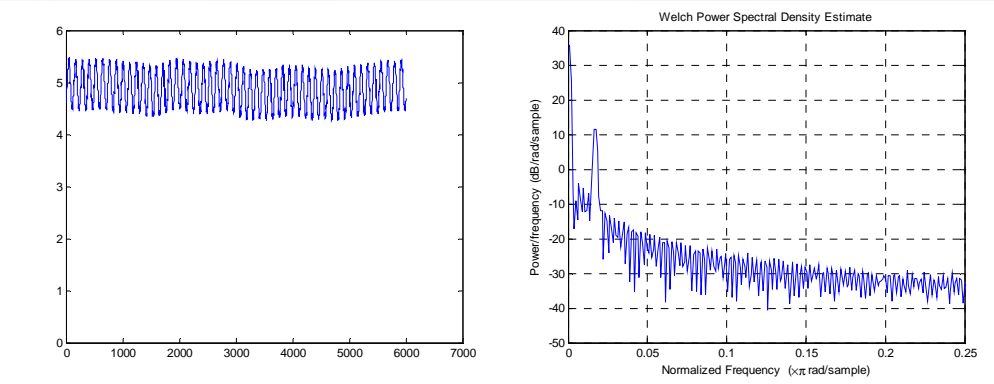
## Data Acquisition



## Instrumentation



## Preview Data



# ***Manufacturing, Packaging, Survivability***

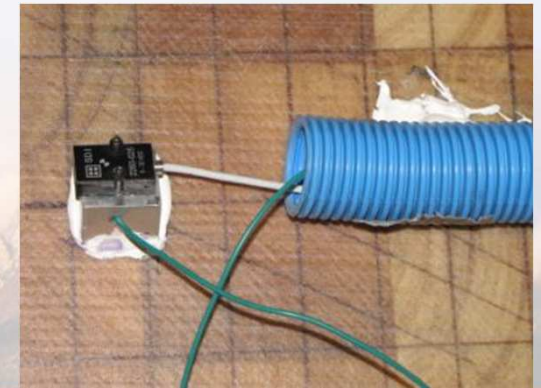
Unmanned Operation  
and Connectivity



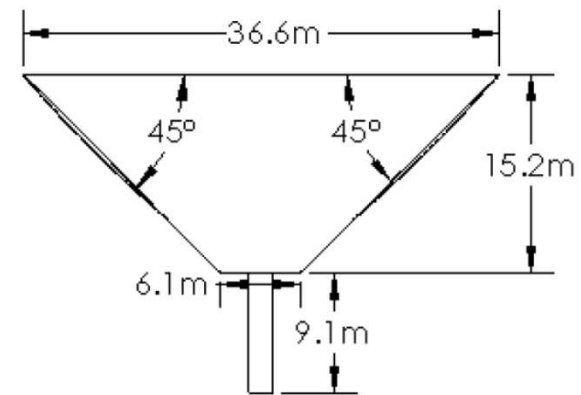
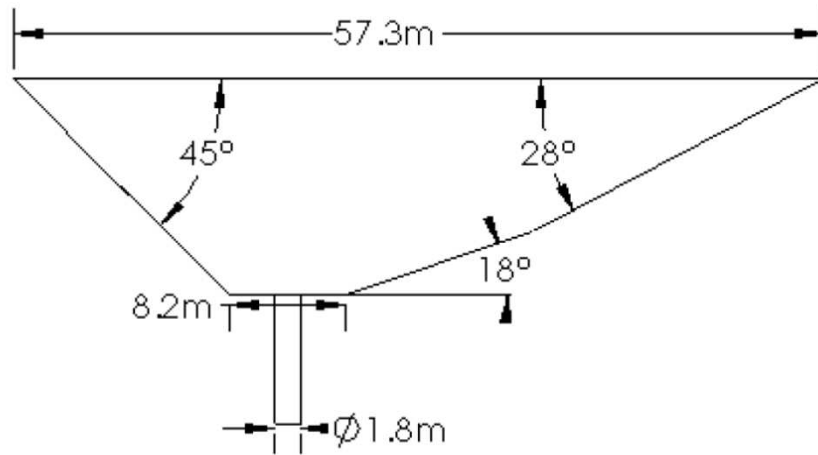
Reliable and Rugged Connectorizing



Rugged Sensors, Manufacturing, and Design



# SNL Testing Facility



# Thank You

