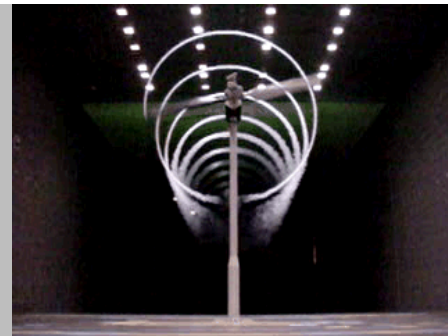


*Exceptional service in the national interest*



## Overview of Planned Wake Validation Experiments

David Maniaci

TEM#82 on Uncertainty Quantification of Wind Farm Flow Models

June 12, 2015

# What is a Validation Focused Program?

## Goal

- Formalized highly collaborative approach to planning and executing joint experimental/modeling programs for the purpose of characterizing model accuracy for an intended application

## Why?

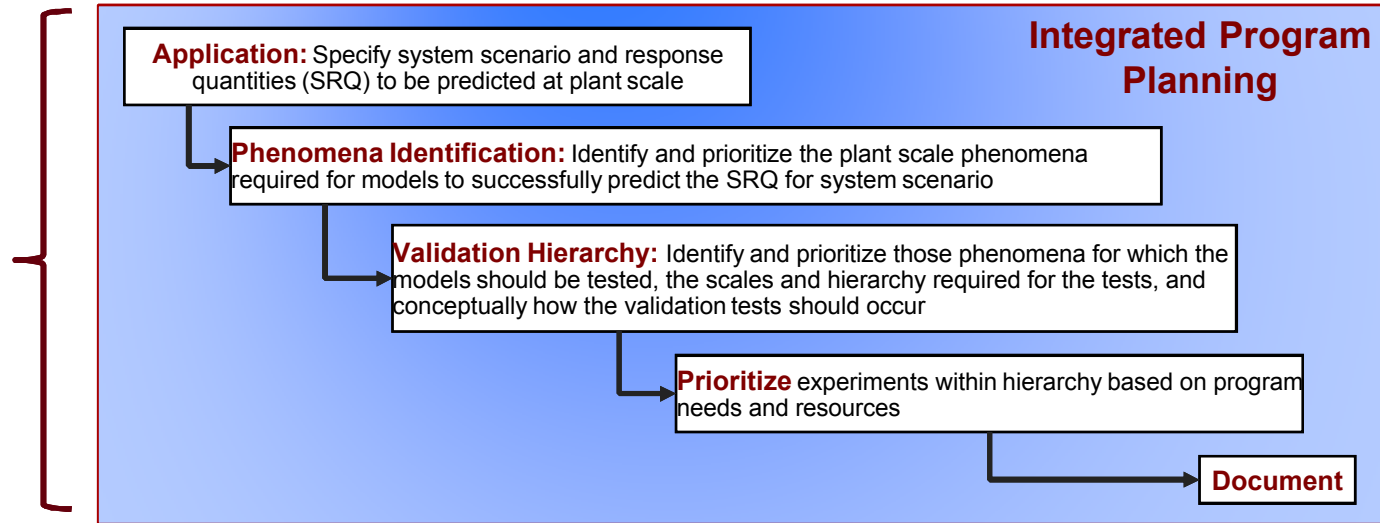
- Provides a transparent, structured, documented approach for integrate program planning across scales
- Applicable to models of all fidelity, including reduced order models
- High quality data sets well suited for collaborative model validation efforts
- Quantifies prediction uncertainty for use by designers

## Foundation of framework used

- Framework developed for nuclear energy, SNL NW, and other programs
- Framework consistent with various ASME and AIAA V&V Guides, Codes and Standards

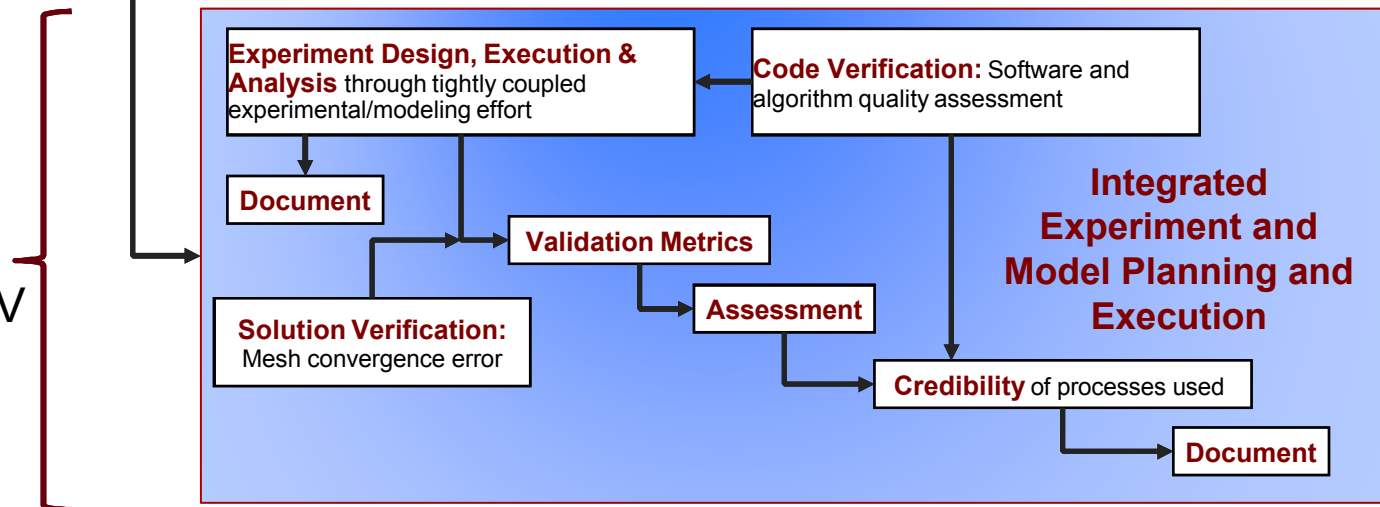
## Integrated Planning

- Program leaders, modelers, software developers, experimentalists, V&V specialists

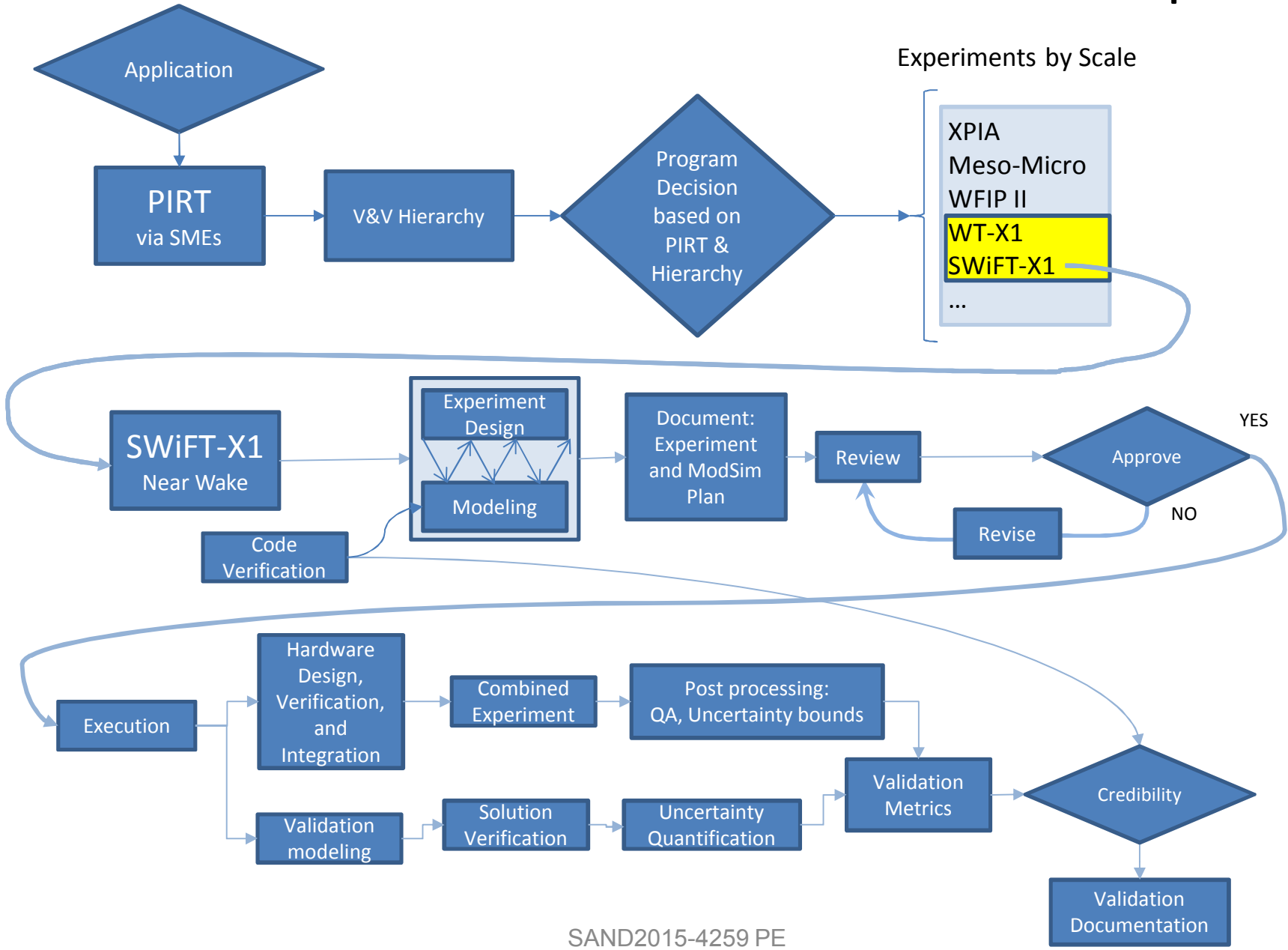


## Validation Planning

- Domain specific program leaders, modelers, experimentalists, V&V specialists, data acquisition specialists



# Verification and Validation Process Example



# Backbone of Prioritization Process: PIRT

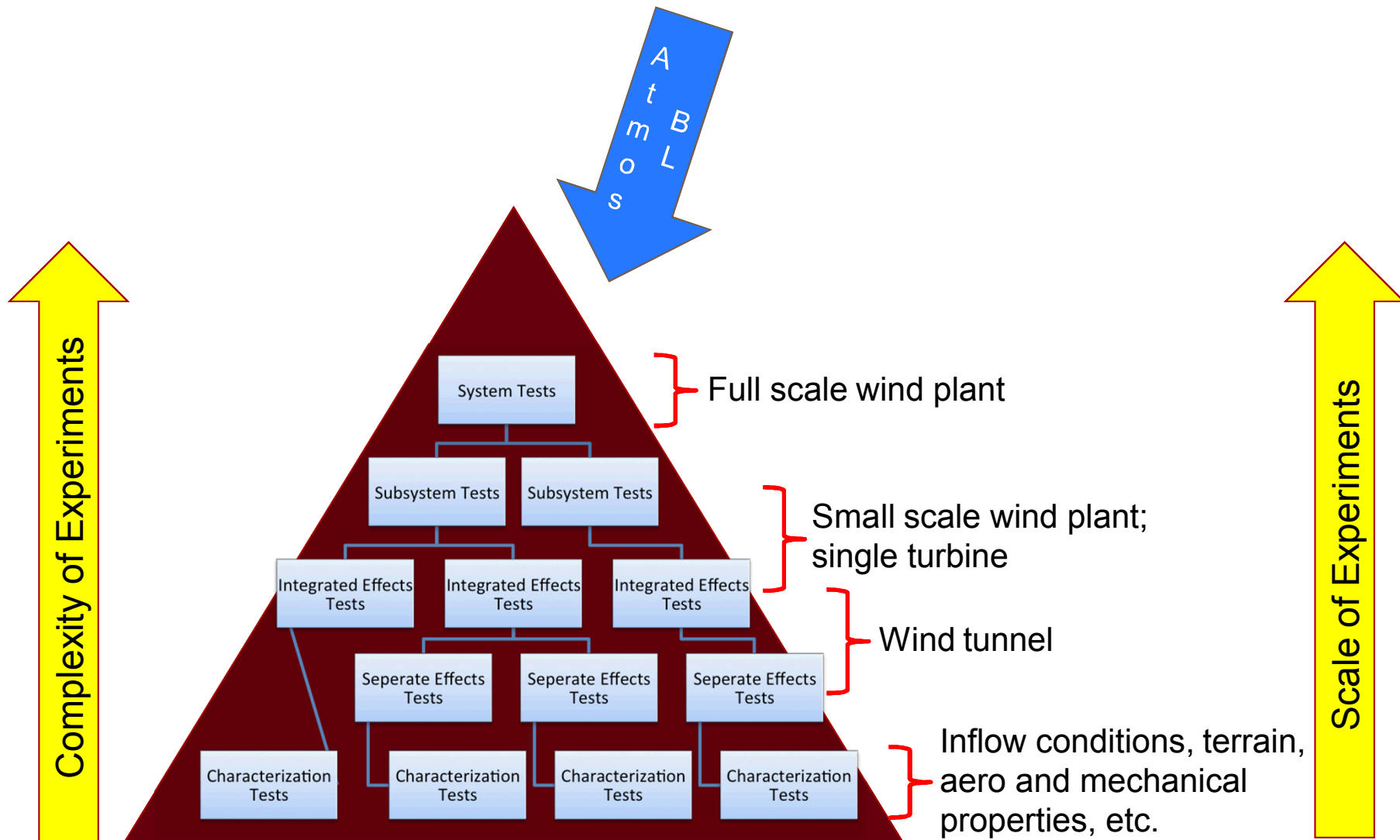
## PIRT: Phenomenon

### Importance Ranking Table

- Consensus based
- Provides gap analysis of ability to model phenomena
  - Physics gaps
  - Numerical gaps
  - Data gaps
  - Validation gaps
- Gap analysis used to prioritize planning, including experimental planning

Phenomenon	Importance at Application Level	Model Adequacy		
		Physics	Code	Val
<b>Turbine scale flow phenomena</b>				
Blade Aero / Wake Generation				
Blade load distribution effects and rotor thrust	H	M	L	L
Tip and root vortex development, and evolution and merging	H	M	L	L
Vortex sheet and rollup (in addition to tip/root vortex)	M	M	M	L
Blade generated turbulence characteristics (energetic scales)	H	L	L	L
Root flow acceleration effect ('hub jet')	Unknown	M	L	L
Boundary layer state on turbine performance (roughness, soiling, bugs, erosion)	H	L	L	L
Boundary layer state (Re)	L	M	L	L
BL details near TE and LE	H	M	L	L
Rotational augmentation	H	L	L	L
Dynamic stall	H	L	L	L
Unsteady inflow effect (turb. intensity, spectra, coherence; veer, shear)	H	L	L	L
Blade flow control	M	L	L	L
Tower/rotor/nacelle wake interactions	H	M	L	L
Icing	L	L	L	L

# PIRT Leads to the Validation Hierarchy



**Validation is a process of characterizing model error, not a binary statement of model validity**

## **Characteristics of a successful validation programs**

- Highly collaborative – team includes experimentalist, modelers, V&V specialist
- Models are used during the design phase to
  - Assure that the experiments are sensitivity to the phenomena of interest
  - Help optimize the experiments, i.e. define sensor location, density, sampling rates, ...
  - Assure that the experiments can be unambiguously modeled (failure to do this is the most common reason for the failure of a validation exercise)
- Estimates of data uncertainty and model prediction uncertainty play a key role model validation process
- Model credibility is established by following a formal verification and validation process

## Definition of a Modeling Campaign:

- 1.) What is to be predicted?
- 2.) Under what scenario?
- 3.) Impact of the model results on final design decisions?

## Definition of an Experimental Campaign:

- 1.) **Objective:** What will be validated and what are the test conditions?
- 2.) **Method:** How will this data be gathered? What is the setup and instrumentation?
- 3.) **Environment/Requirements:** What are the requirements and constraints on the test campaigns? What is the required resolution/accuracy/time-scale?
- 4.) **Desired Outcome:** What will success mean? How will it be quantified? How will this increase credibility at full scale?

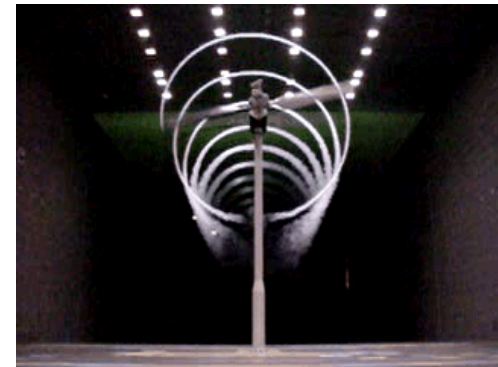
# Validation data request

- An example Validation Data requirement:
  - Objective: quantify distribution of blade spanwise load
  - Method: surface pressure measurements and/or spanwise strain measurements
  - Environment: clean uniform inflow, turbulent inflow with quantified turbulence character and shear character
  - Success criteria: measurement data available with quantified inflow including uncertainty bounds.

# Wake Generation, Propagation, Dispersion

## PIRT Issues related to **wake propagation, dispersion:**

- Skew and meander of aggregate wake, wake vorticity diffusion, dissipation,
  - All heavily influenced by ABL
- Best tested in ABL wind tunnel for which BL inflow state (including turbulence) is well characterized and controlled with sufficient instrumentation resolution in the wake region using a smaller rotor ( $D \sim 1$  m)



# Wake Generation, Propagation, Dispersion

## Scale up to natural ABL at Reynolds number closer to utility scale

- ABL wind tunnel does not include the large scale unsteady inflow effects observed in nature – SWiFT does

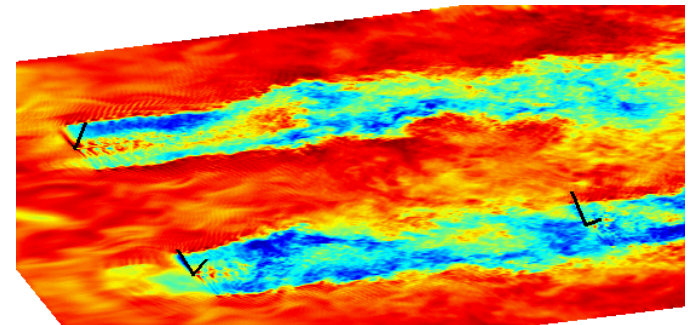


## Why SWiFT?

- Provide ABL that includes the unsteady effects at more relevant scales and larger Reynold's numbers
- Provides a test bed to develop/test field instrumentation at a scale that will be used for eventual tests at full sized facilities

## Future Steps: Turbine-turbine interaction:

- Near future SWiFT testing
- Possible Milan wind tunnel tests
- Follow-on testing in operating wind plant

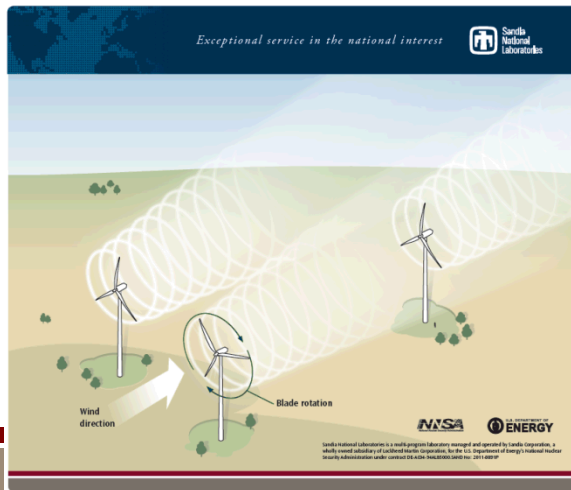


# SWiFT site layout and capabilities

DOE/SNL Scaled Wind Farm Technology (SWiFT) facility  
hosted by Texas Tech University (TTU)

SWiFT exists to:

- Reduce turbine-turbine interaction and wind plant underperformance
- Public, open-source validation data
- Advance wind turbine technology



Facilities:

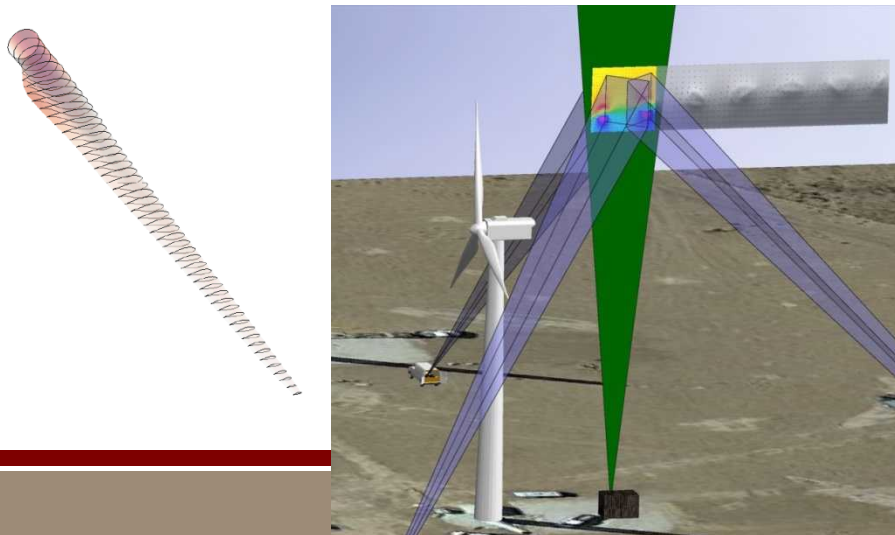
- Three variable-speed variable-pitch modified wind turbines with full power conversion and extensive sensor suite
- Two heavily instrumented inflow anemometer towers
- Site-wide time-synchronized data collection

# SWiFT-X1: Near Wake Validation

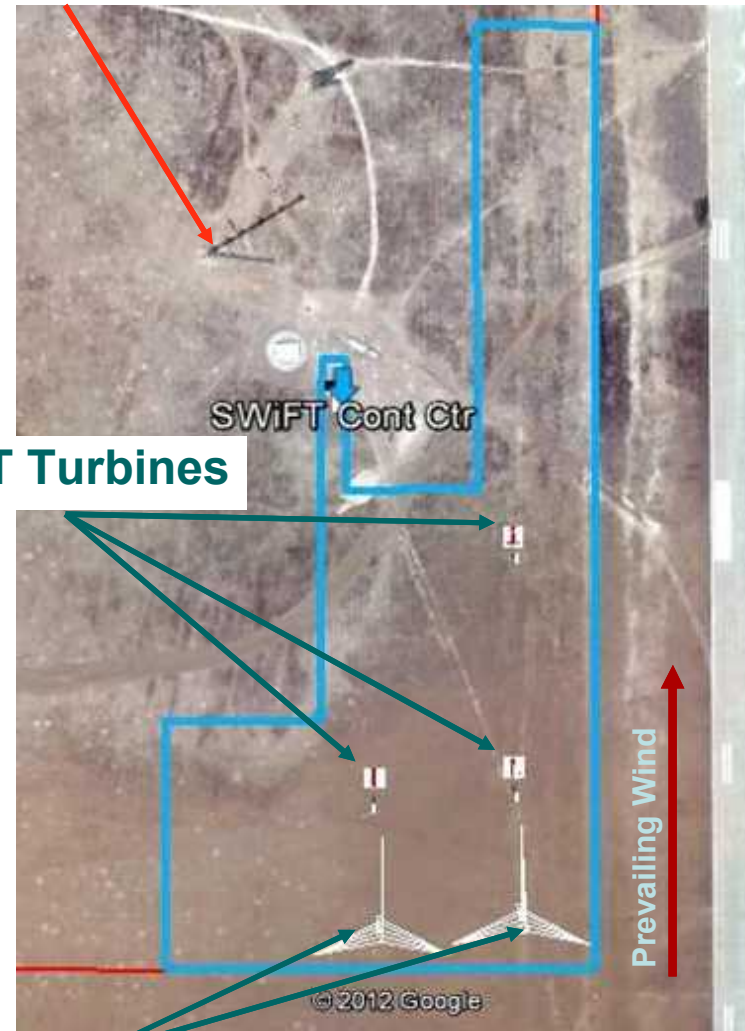
Goal: Validate HFM ability to predict blade loading and near wake structure given MET tower inflow measurements.

Measurements:

- ABL Conditions:
  - 200m MET, Sodar, and Radar Profiler
- Inflow: Dual 58.5m MET towers
- Rotor and Tower Strains and Accels.
- Rotor spanwise loading: Pressure taps and/or distributed strain measurements
- New rotors functionally scaled from utility turbine
- Near Wake Flow Diagnostic: SWIS



200m  
MET Tower



SWiFT Turbines

58.5m MET Towers

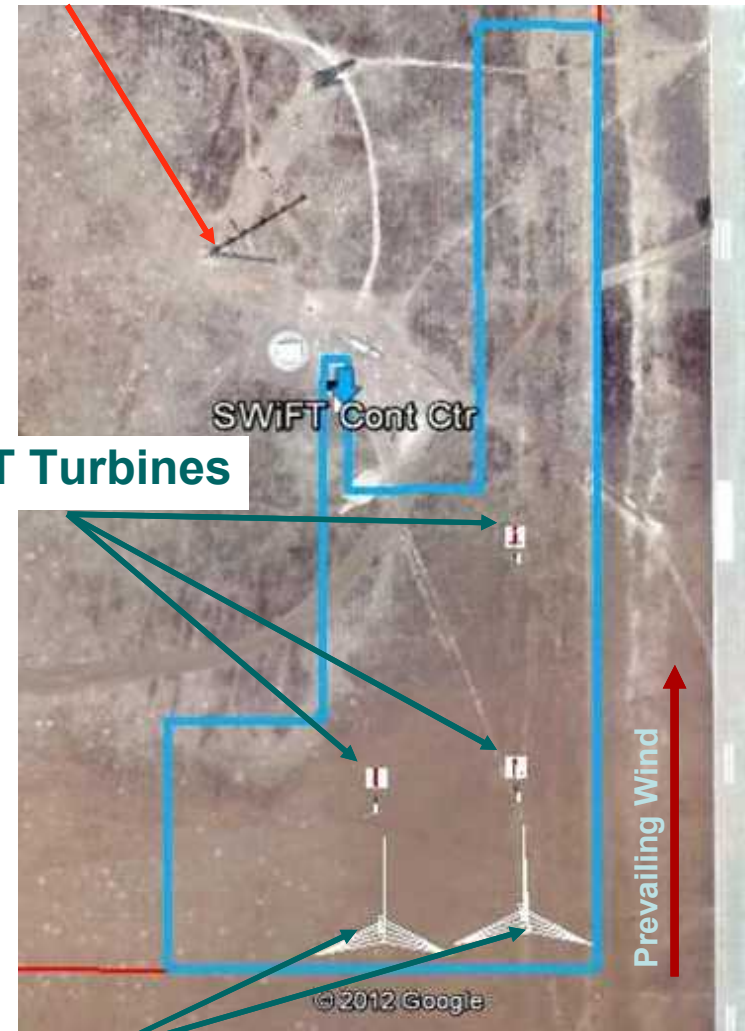
# SWiFT-X2+: Wake Meandering and Turbine-Turbine Interaction

Goal: Validate HFM ability to predict blade loading and near wake structure given MET tower inflow measurements.

Measurements:

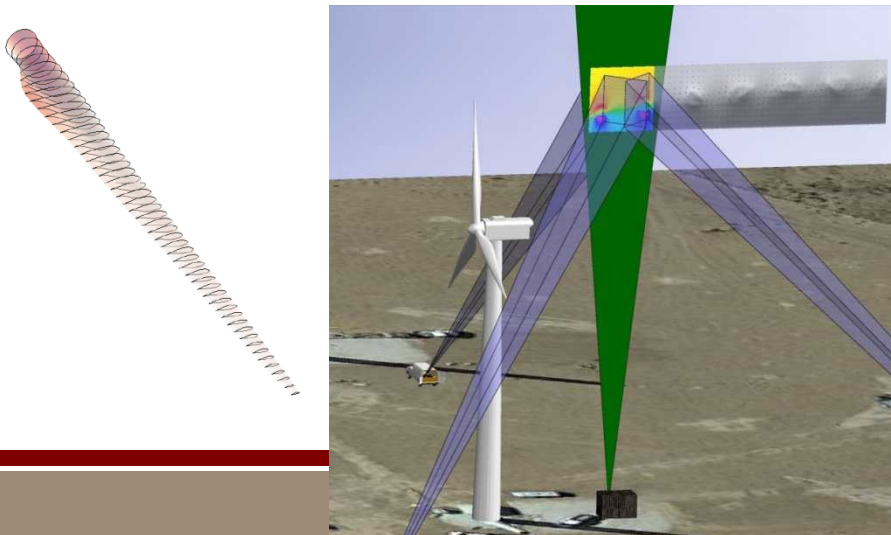
- Far Wake:
  - Re-deployable MET tower
  - Scanning Lidar
  - TTU Ka-band mobile Doppler radars
  - Flow-angle sensors on downstream turbine
- Downstream turbine loads
- Correlation with ABL observations

200m  
MET Tower



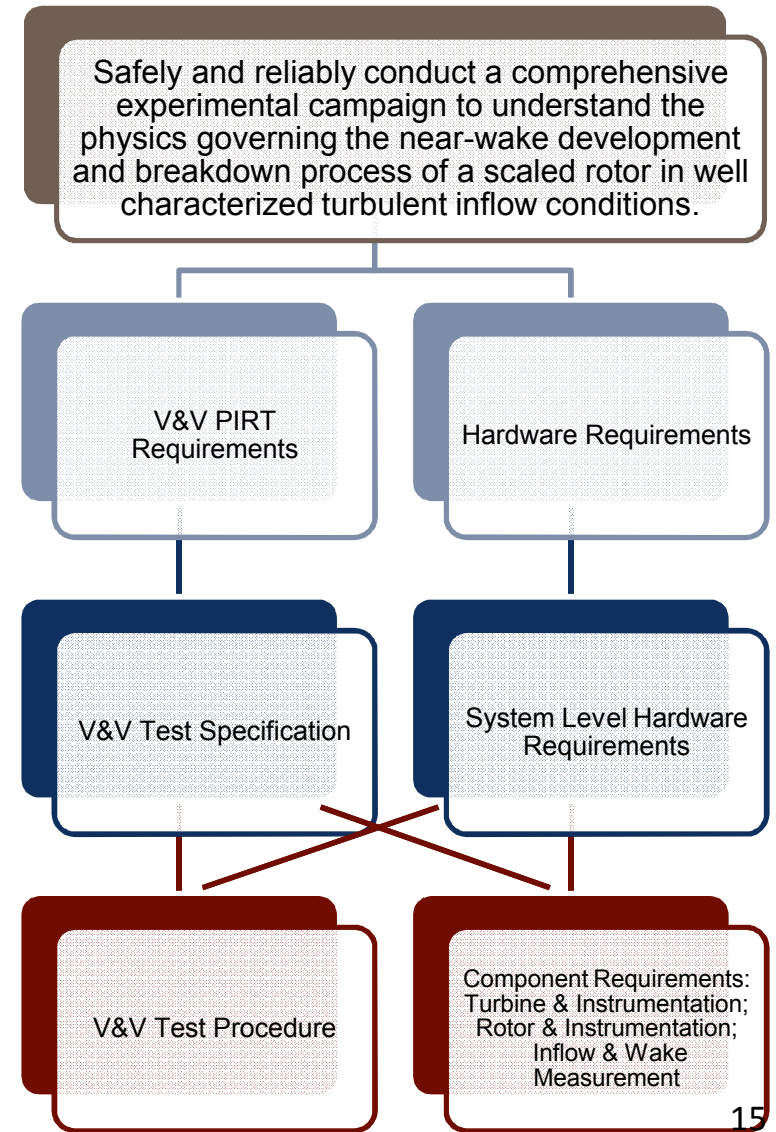
SWiFT Turbines

58.5m MET Towers



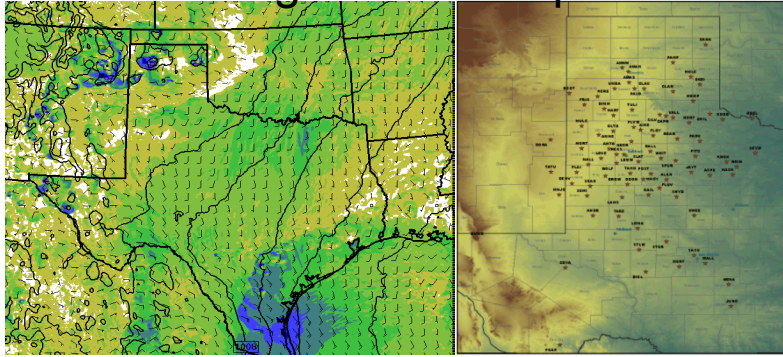
# SWiFT test requirements schema

- Design of new test hardware for SWiFT could be done based on known operational envelopes and using standard rotor design practices and standard farm flow measurements.
- At the same time, design of a V&V test campaign begins with the PIRT process, which determines a test campaign specification, which leads to a test procedure.
- Interdependency 1: The test campaign specification drives aspects of test hardware and test instrumentation.
- Interdependency 2: The hardware operational requirements drives aspects of the V&V test procedure.



# SWiFT Integrated Experiment Planning

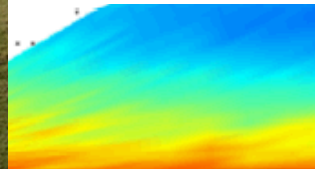
## Regional Atmosphere



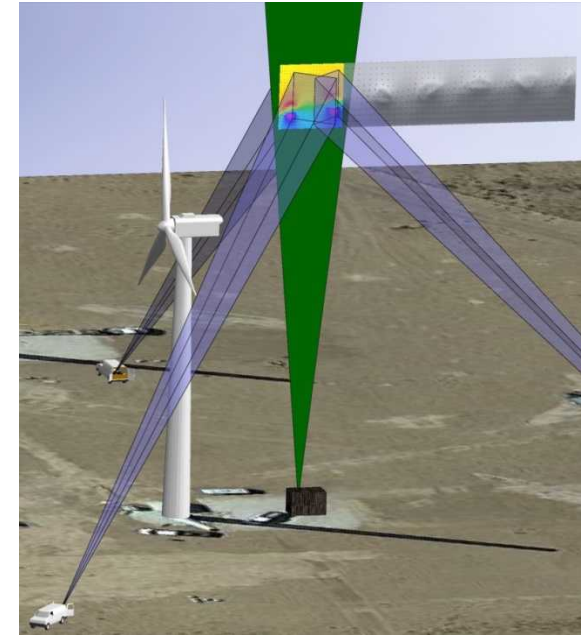
## Atmospheric Boundary Layer



## Wind Farm Flow



## Array Flow



## Wake Flow Structures

# Thank you!

