

A2e V&V

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Workshop on How High-Fidelity Modeling Can Connect to Improvement of Wind Industry Design Capability

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What is V&V?

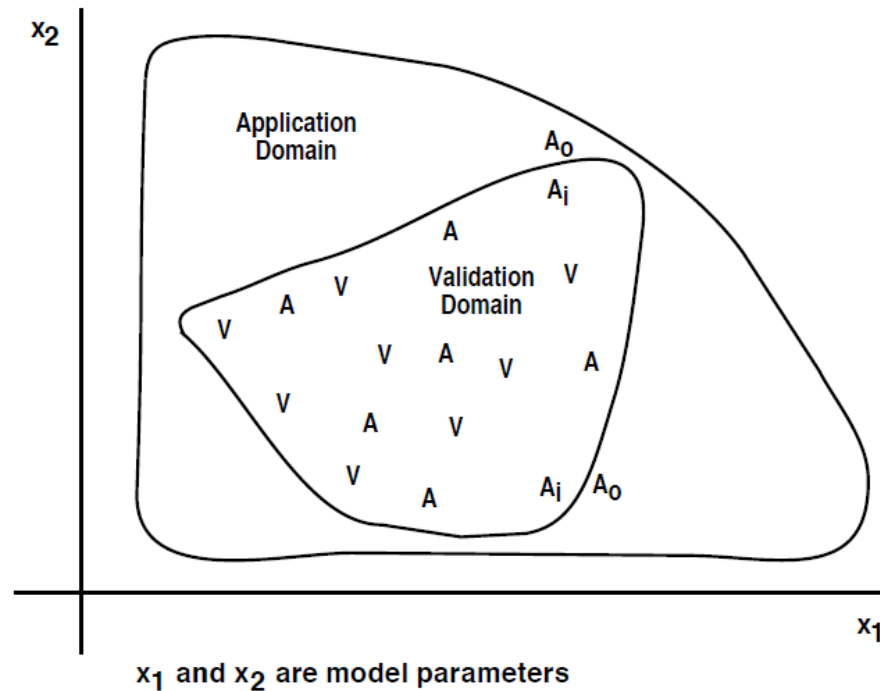
ASME definitions:

- Verification: The process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.
- Validation: The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.
 - “Validation tests against independent data that have not also been used for calibration are necessary in order to be able to document the predictive capability of a model.”
 - » Ref Gaard and Henriksen

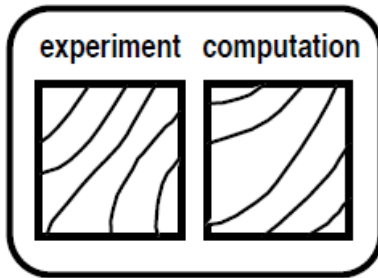
Why invest in V&V?

-> Increasing Role of Computational Modeling

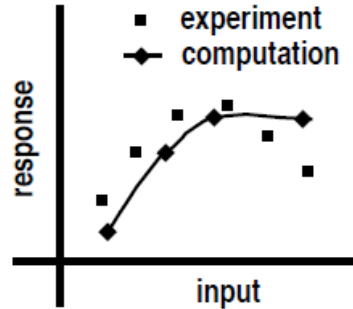
- Technology innovation demands higher fidelity models and increased validation precision as wind turbine technology matures
- Increasing system complexity, size, and cost combined with more rapid development cycles driving increased reliance on computational models



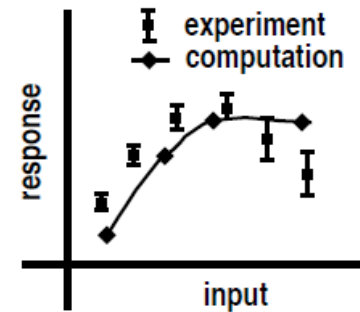
Levels of Precision in Comparing Simulations and Experiments



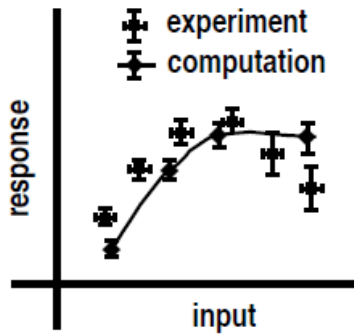
(a) Viewgraph Norm



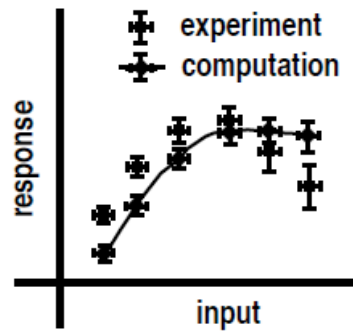
(b) Deterministic



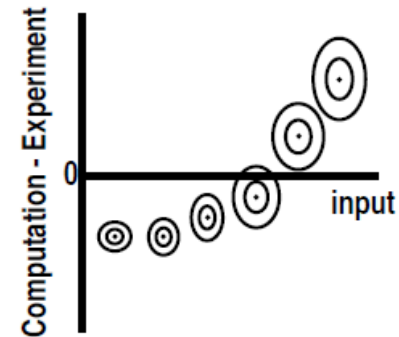
(c) Experimental Uncertainty



(d) Numerical Error



(e) Nondeterministic Computation



(f) Quantitative Comparison

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

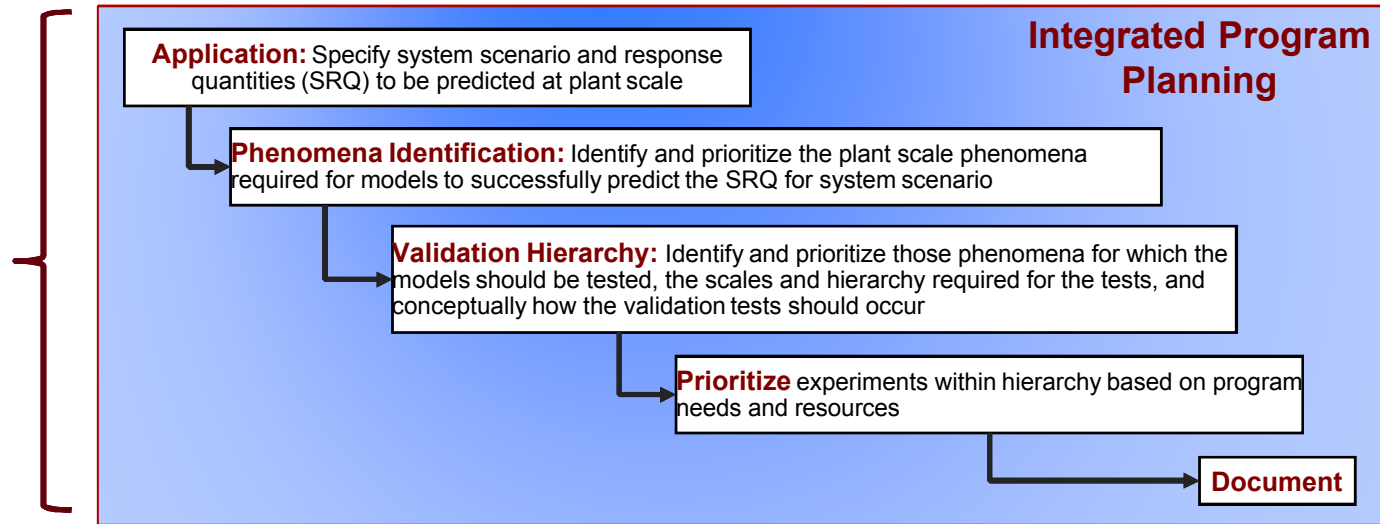
- Framework developed for nuclear energy, SNL NW, and other programs
- Framework consistent with various ASME and AIAA V&V Guides, Codes and Standards

V&V Framework

(2015 Hills, Maniaci, Naughton)

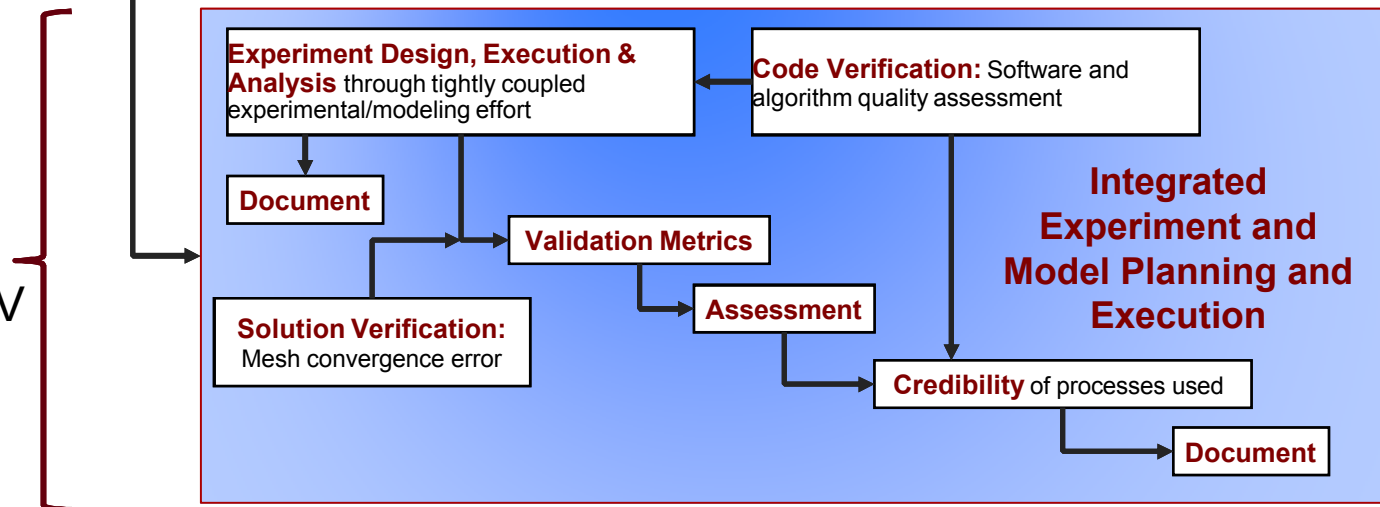
Integrated Planning

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



Validation Planning

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



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
Turbine scale flow phenomena				
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

Wind Turbine PIRT

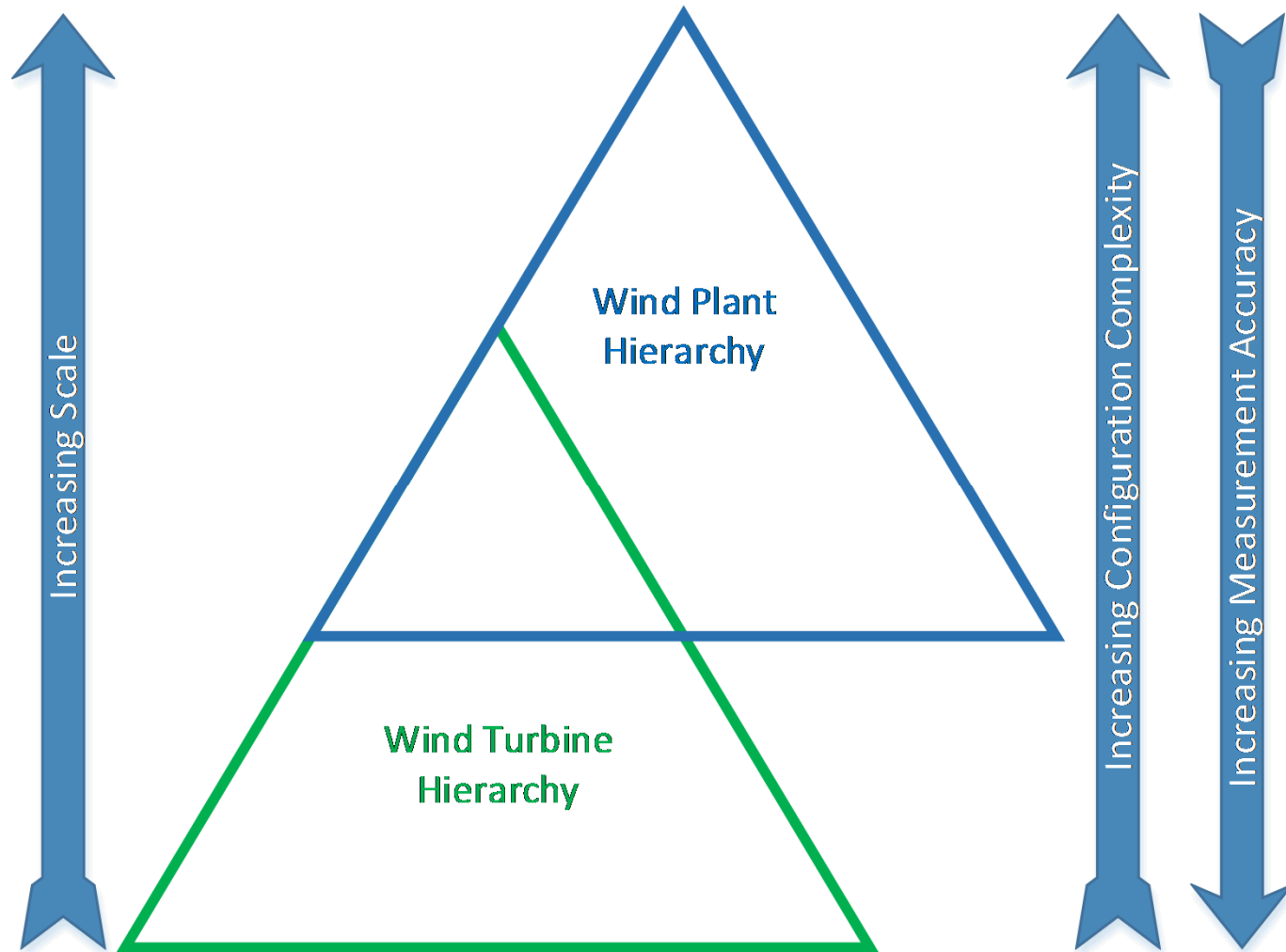
Phenomenon	Importance at Application Level	Model Adequacy		
		Physics	Code	Val
Blade Aero / Wake Generation				
Blade load distribution effects and rotor thrust	H	M	L	L
Tip and root vortex development, evolution and merging	H	M	L	L
Vortex sheet and rollup (In addition to tip/root vortex)	M	M	M	L
Blade generated turbulence characteristics (energetic scales at trailing edge)	H	L	L	L
Root flow acceleration effect ("hub jet")	Unknown	M	L	L
Boundary layer development (transition, separation)	H	M	L	L
Surface roughness effects (roughness, soiling, bugs, erosion)	H	L	L	L
Boundary layer details near leading and trailing edge	H	M	L	L
Rotational augmentation	H	L	L	L
Dynamic stall	H	L	L	L
Unsteady inflow effect (veer, shear, yaw, gusts, atmospheric stability, turbulence intensity, spectra, coherence)	H	L	L	L
Blade flow control	M	L	L	L
Icing	H	L	L	L
Wake Development (growth/recovery)				
Skew and meander of aggregate wake	H	L	L	L
Swirl instability	L	L	L	L
Vortex merging	L	L	L	L
Wake vorticity diffusion and dissipation	H	L	L	L
Asymmetry effects (ground plane, yaw, tilt, cone-angle)	M	M	L	L
Inflow effect (shear, veer, yaw, turb. intensity, turb. spectrum, coherence, gusts, atmos. stab.)	H	L	L	L

Wind Plant

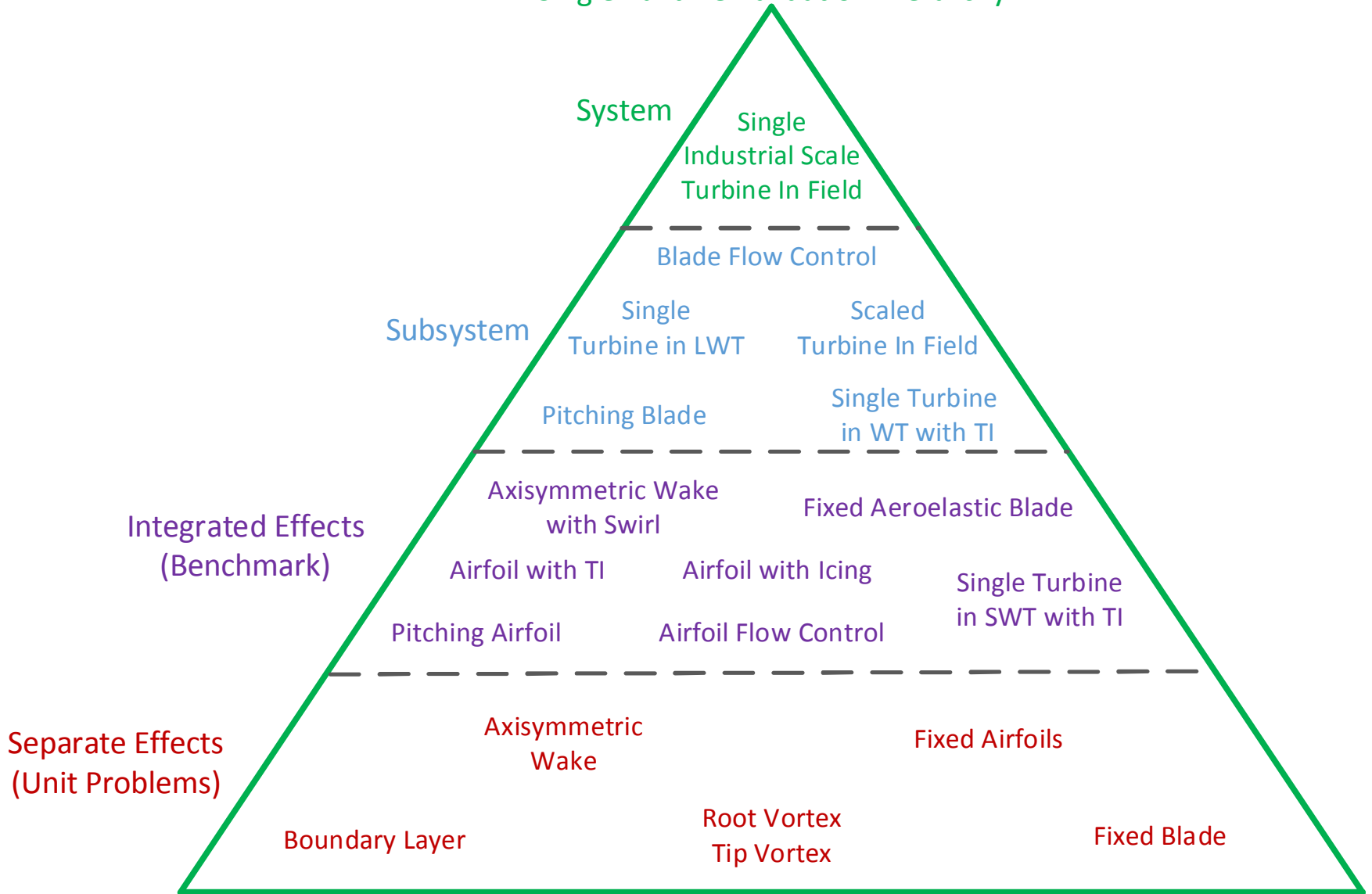
PIRT

Phenomenon	Importance at Application Level	Model Adequacy		
		Physics	Code	Val
Inflow Turbulence/Wake Interaction				
Wind direction (shear/asymmetry)	H	L	M	M
Turbulence characteristics (intensity, spectra, coherence, stability)	H	L	M	M
Coherent turbulence structure	H	L	M	L
Surface conditions (roughness, canopy, waves, surface heat flux, topography)	H	L	M	M
Momentum transport (horizontal and vertical fluxes)	H	L	L	L
Multi-Turbine Wake Effects				
Wake interaction, merging, meander	H	L	L	L
Plant flow control for optimum performance	H	M	M	L
Wake steering (yaw & tilt effects)	H	L	L	L
Wake dissipation	H	L	L	L
Wake impingement (full, half, etc.)	H	L	L	L
Deep array effects (change in turbulence, etc.)	H	L	L	L
Other Effects				
Wind plant blockage effects and plant wake	M	M	M	L
Acoustic Propagation	H	L	L	L

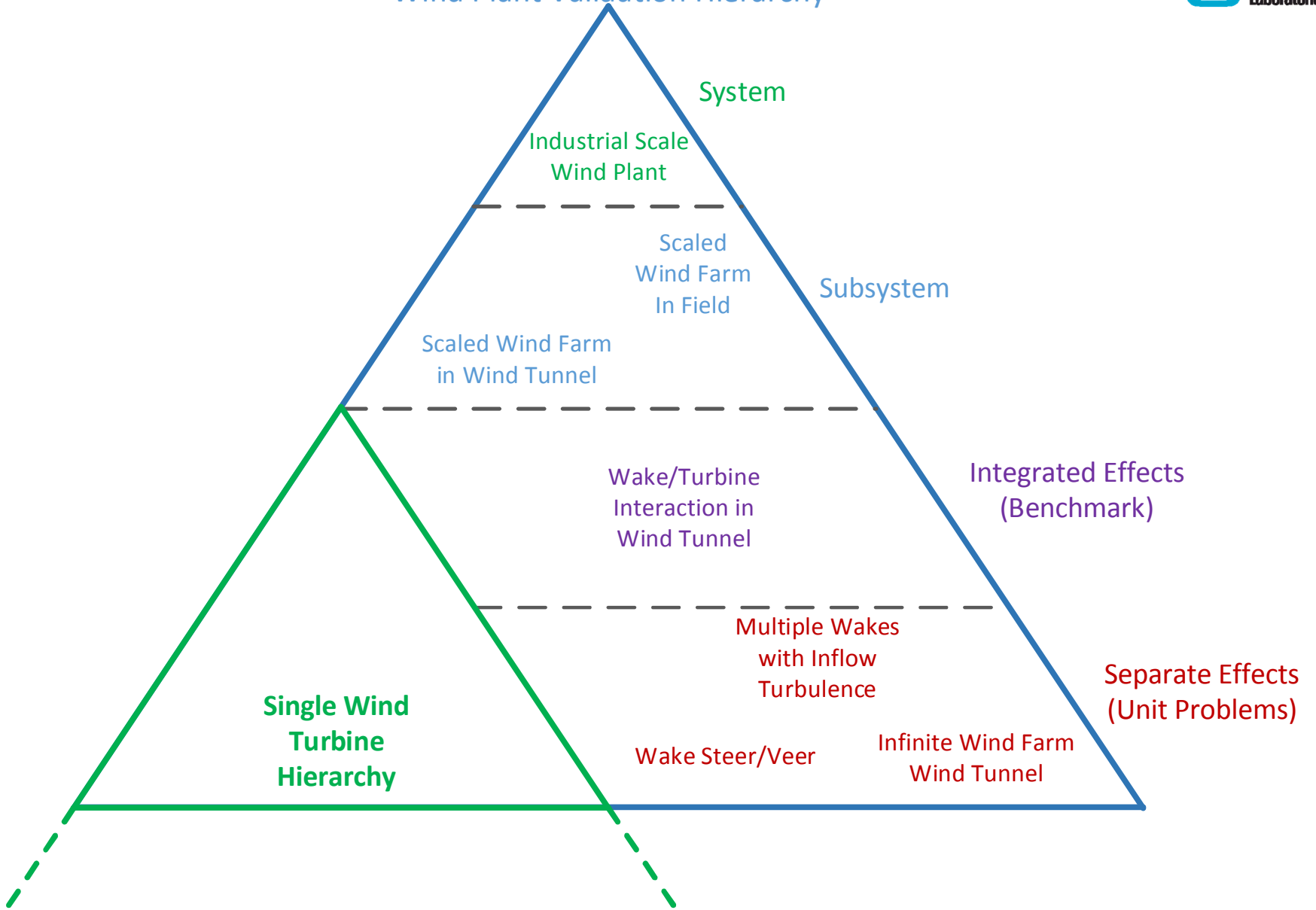
Validation Hierarchy



Single Turbine Validation Hierarchy



Wind Plant Validation Hierarchy



































































PPEM (Prioritized Phenomenon Experiment Mapping)

Wind Plant

Physics Present/Physics Measured

-  Entirely
-  Mostly
-  Somewhat
-  Limited
-  Missing

	Multi-Turbine Wake Effects				Inflow Turbulence Wake Interaction			
	Interaction, Merging, Motion	Steering (Yaw/Tilt Effects)	Wake Dissipation	Wake Impingement (Full/Half/Near)	Wind Direction	Surface Conditions	Turbulence Statistics	Momentum Transport
Industrial Scale Wind Farm in (60 m rotor)								
Physics Present								
Physics Capture by Measurements								
Scaled Wind Farm in Field (20 m rotor)								
Physics Present								
Physics Capture by Measurements								
Scaled Wind Farm in VL WT (2 m rotor)								
Physics Present								
Physics Capture by Measurements								
Wake/Turbine Interaction in WT (2 m rotor)								
Physics Present								
Physics Capture by Measurements								

Test Objectives: Mapping Validation Exercises to Phenomena



Wind Turbine Phenomena

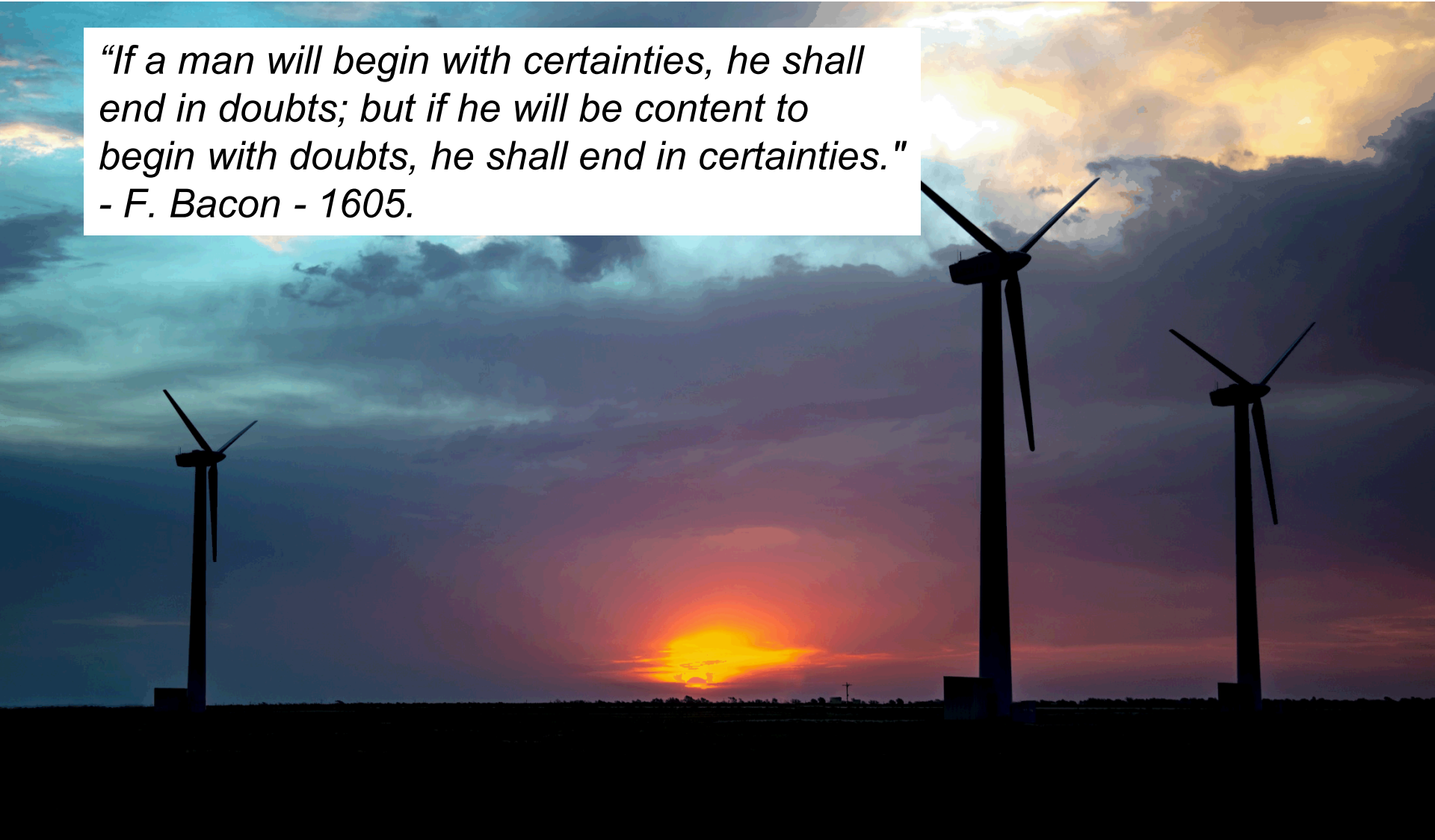
	Wake Closed Loop Control Farm Edge Wake Aero Structure, Interaction, Control Farm Interior Wake Aero Structure, Interaction, Control Wake Dynamics and Control, Two-Turbine Array Wake Sensing, Closed Loop Control Rotor and Wake Flowfield Details in Atmospheric Inflow Rotor and Wake Flowfield Details - Controlled Inflow Non-Rotating Blade and Blade Section								
	FS.1	FS.2	FS.3	SW.1	SW.2	SW.3	WT.1	WT.2	WT.3
Blade Aero/Wake Generation									
Blade Load Distribution Effects					✓		✓		✓
Tip & Root Vortex Evolution					✓		✓	✓	✓
Vortex Sheet Evolution					✓				✓
Blade Generated Turbulence					✓		✓	✓	✓
Root Flow Acceleration					✓				✓
Boundary Layer Development					✓		✓		✓
Surface Roughness Effects									✓
Boundary Layer Near LE and TE									✓
Rotational Augmentation					✓		✓		
Dynamic Stall					✓		✓		✓
Unsteady Inflow Effects *					✓				✓
Blade Flow Control									
Icing									
Wake Development									
Skew and Meander of Wake							✓	✓	
Swirl Instability									
Vortex Merging									
Wake Vorticity Diffusion and Dissipation					✓		✓	✓	
Asymmetry Effects									
Inflow Effects				✓	✓				

V&V Multi-year Goals

- Enable simulation and design of optimized wind plants
- Execute a simulation and modeling campaign to:
 1. Improve the research community's physical understanding of wake dynamics and turbine interaction
 2. Quantify model prediction uncertainty of wake flow dynamics and turbine interaction
- Engage with the public to disseminate results and progress on a regular basis.

Thank you

*"If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties."
- F. Bacon - 1605.*



V&V: Communication and Documentation

1. **V&V Framework** (September 2015): the development and execution of coordinated modeling and experiential programs to assess the predictive capability of computational models of complex systems through focused, well structured, and formal processes.
2. **A2e High Fidelity Modeling: Strategic Planning Meetings** (November 2015) : A report on the foundational planning for the A2e High Fidelity Modeling effort for predictive modeling of whole wind plant physics.
3. **V&V Integrated Program Planning for Wind Plant Performance** (July 2016): This document outlines the integrated program planning (IPP) process and applies it to wind plant performance prediction.
4. **Test Objectives and Prioritization for Wind Plant Performance** (July 2016): An intermediary step between the comprehensive information in the IPP document and the detailed planning needed in the integrated experiment and model planning and execution (IEMPE) stages.
5. **Integration into IEA Task 31, Wakebench.** Working toward a collaborative validation process.