Blade Issues, Reliability, & Innovations

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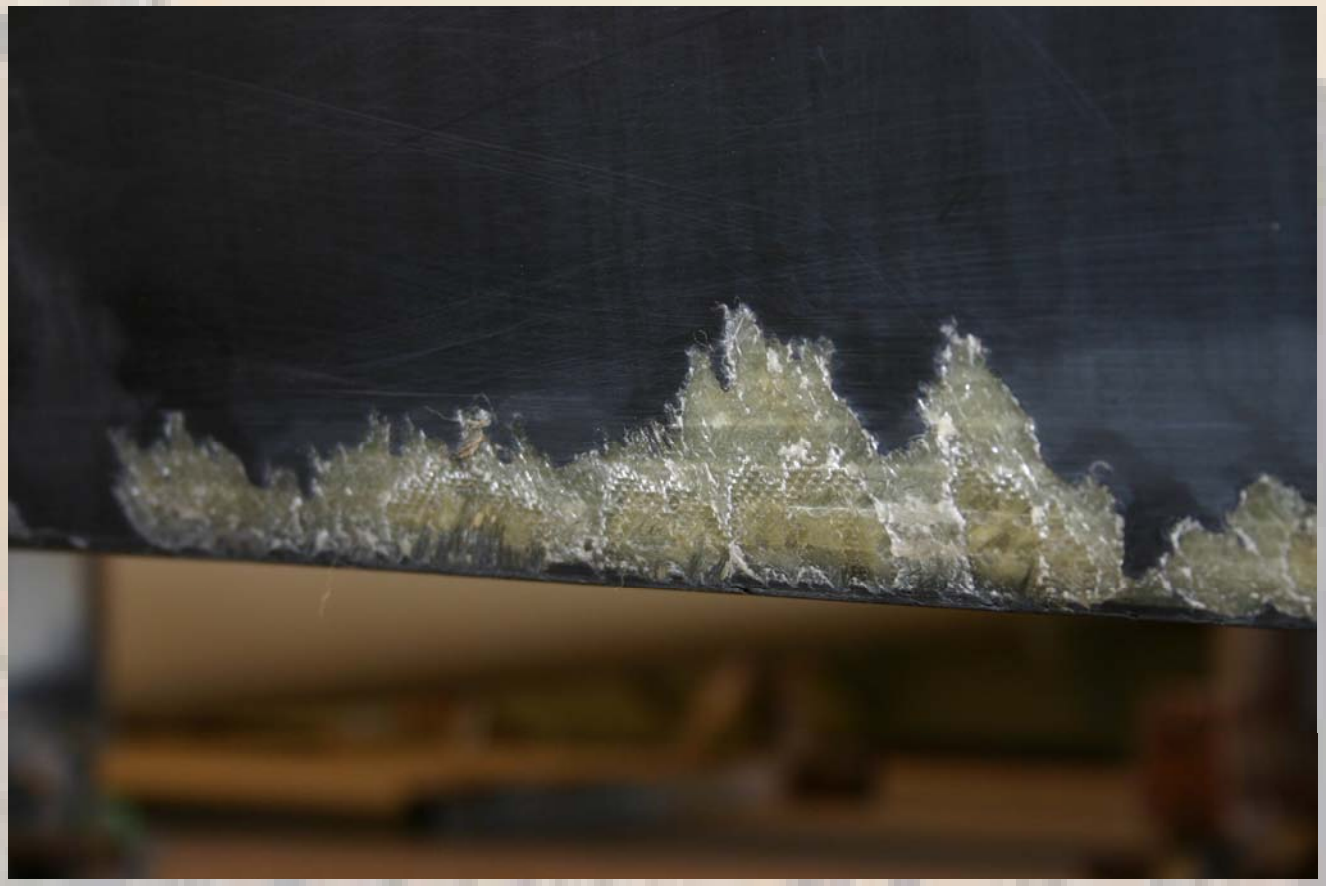
Blade Issues Related to Field Reliability

- Issues
  - **Non-structural**
    - **Leading-edge erosion**
    - **Soiling - dirt, oil**
    - **Minor damage – dings, gouges**
  - **Structural**
    - **Lightning**
    - **Fatigue**
    - **Design flaws – more severe require immediate fix (infant)**
    - **Manufacturing errors – same here**
- Understanding issues provides for more reliable blades

Leading Edge Erosion

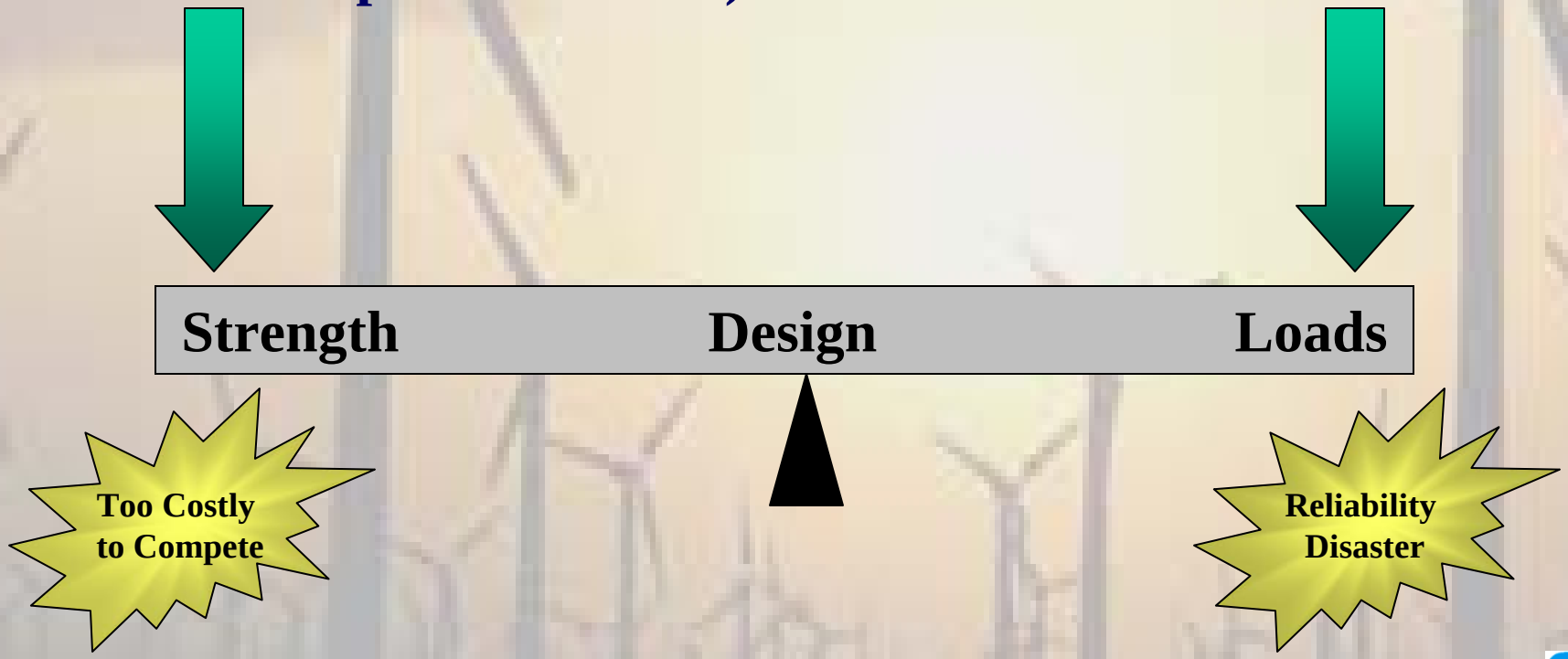


Stats on Blade Problems

- WindStats – 7% of maintenance issues related to blades
- Anecdotal – one wind farm reports 7% down time due to blades
- New reliability effort at Sandia and NREL will collect more failure and maintenance data
  - **Hopefully will be able to break this "7%" to various causes**
  - **Will help focus on major problems over entire turbine system**

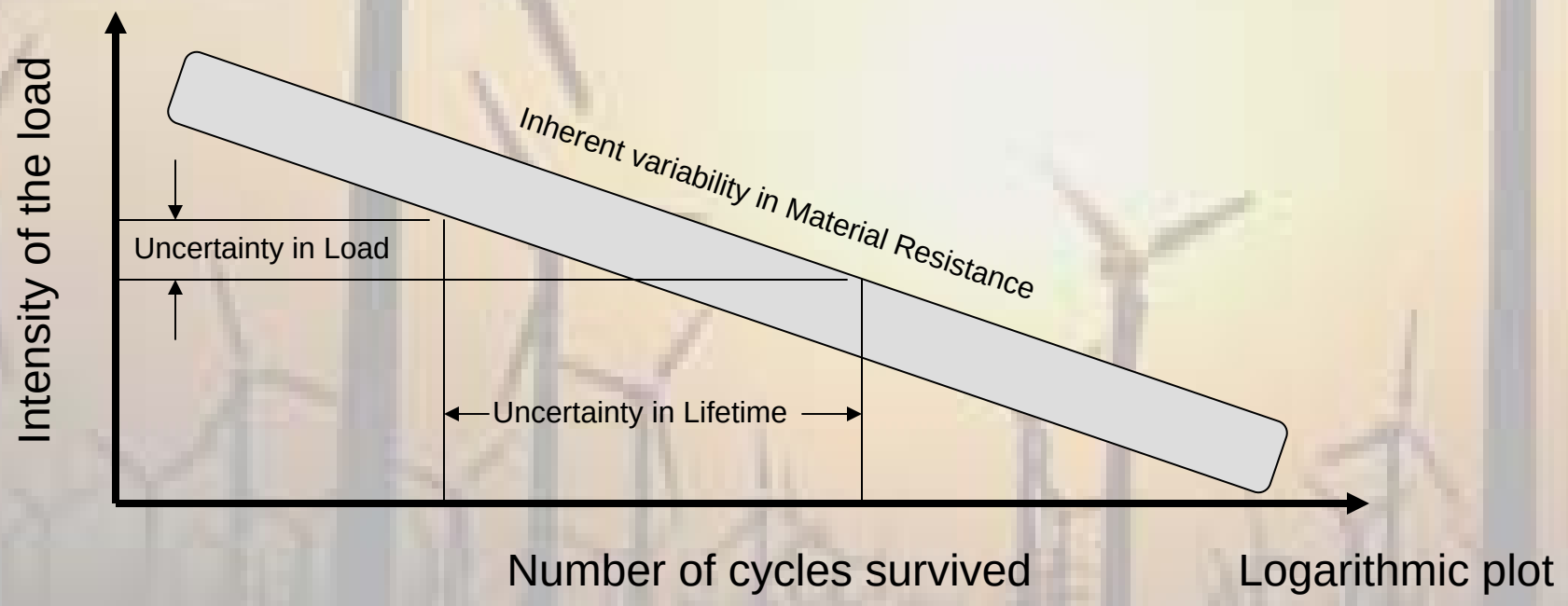
Structural Design Philosophy

- **Balancing act of Strength vs. Loads**
- **Installed Cost plays against Reliability (i.e., O&M and replacement cost)**



Things Wear Out

- **This is usually a matter of repeated loads or environmental effects. (Load, temperature, moisture, etc.)**
- **Material resistance to repeated loads is both sensitive and variable.**
- **A small load uncertainty results in an enormous lifetime uncertainty.**
- **A large margin on the mean life is required to avoid early failures.**



Things Break for Different Reasons

Environment (Loads)	Strength (Resistance)	
Loads inadequately specified (Load estimation and extrapolation)	Strength not as great as assumed (Material and manufacturing evaluation)	Design Errors
Environment outside the specification (Siting and/or Operations)	As-built strength not up to specification (Manufacturing and Construction)	Operating Errors
Acts of God – You know the design is inadequate for the environment but you assess the frequency of occurrence to low enough to absorb the loss.		

How Does Reliability Improve?

Environment (Loads)	Strength (Resistance)	
Know the environment and the response of the machine to environmental conditions including extremes	Correctly evaluate material strength and account for manufacturing variability	Design Errors
Assess the plant site and make sure it is within the design specs – Operate within design allowables	Maintain quality assurance in manufacturing and construction	Operating Errors
Acts of God – Determine the actual frequency of loss to assess the financial decision (cost of insurance)		

Improvement is not possible without sustained feedback from experience in the field.

Load and Resistance Factor Design (LRFD)

- **Can be expressed as characteristic load and resistance with appropriate safety factors.**

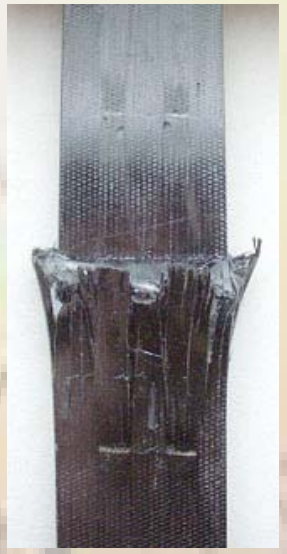
$$\varphi R \geq \alpha L$$

- **φ = safety factor for *Resistance* margin.**
  α = safety factor for *Loads* margin.
- **φ and α are calibrated to achieve an acceptably low probability that actual operational Load is greater than as-constructed Resistance.**

Variations Covered by the Load and Resistance Safety Factors

- **φ depends on**
  - Variability in material strength
  - Analysis uncertainty
  - Type and consequence of failure
  - Degree of inspection and quality control
  - Etc.
- **α depends on**
  - Dead loads
  - Live loads
  - Environmental degredation
  - Thermal effects
  - Etc.

$$\varphi R \geq \alpha L$$



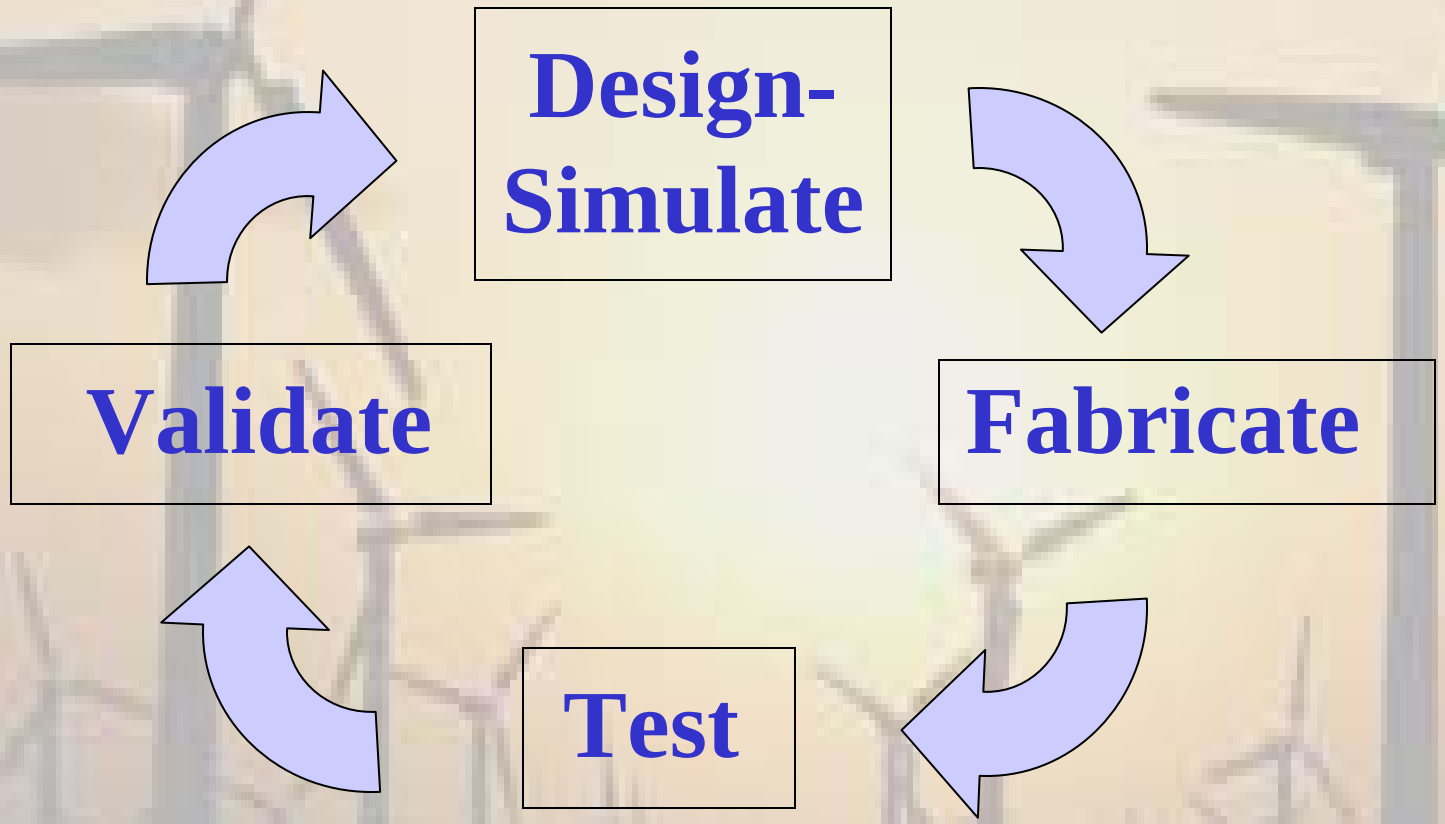
The Wind Industry is Becoming More Experienced

- **Industries that build expensive structures (e.g., high-rise buildings, offshore oil and gas production, nuclear reactors, etc.) have made large investments in calibrating appropriate Safety Factors.**
- **Wind industry initially borrowed safety factors from these industries.**
- **Wind industry now has own standards that are used for certification.**
  - Design load & safety factors guidelines are now more specific to wind.

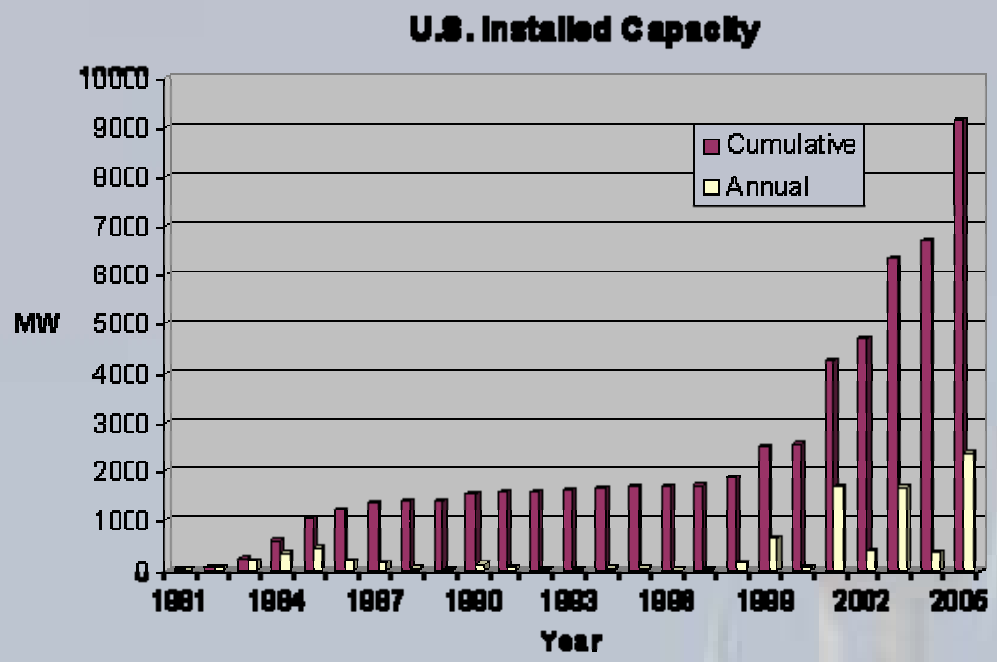
Load Analysis & Characteristic Loads

- This an area of large uncertainty & where SNL/NREL are working in reliability area
- Developing methods to estimate long term loads

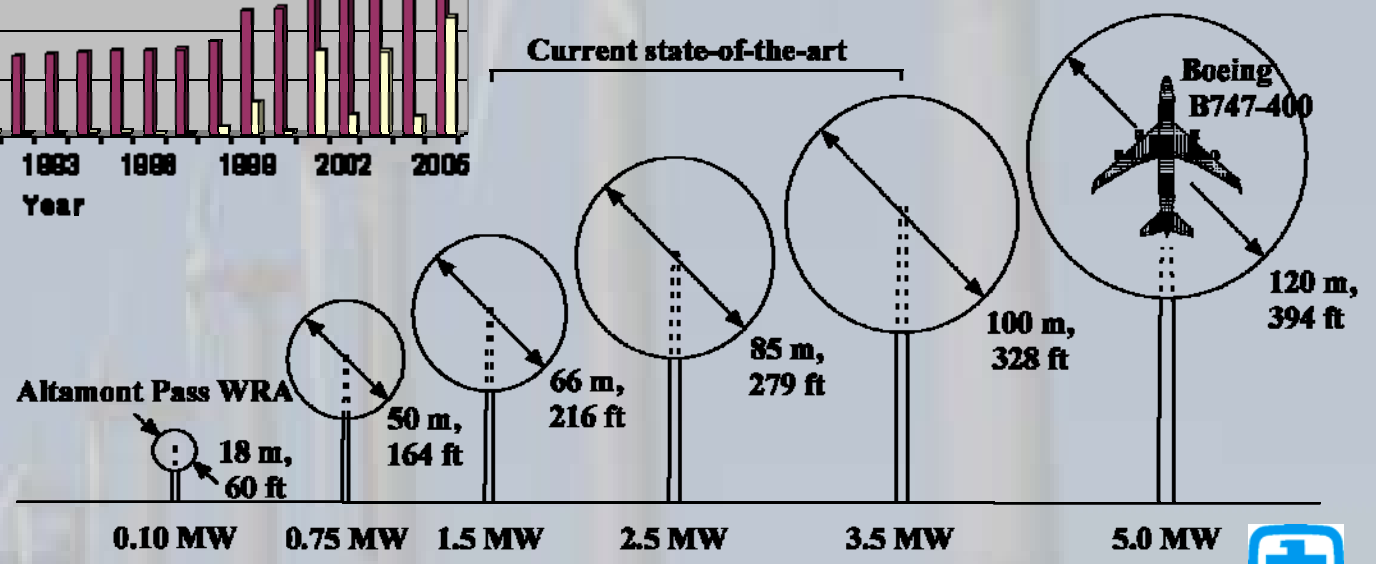
Validation Loop for Design, Models & Manufacturing Process



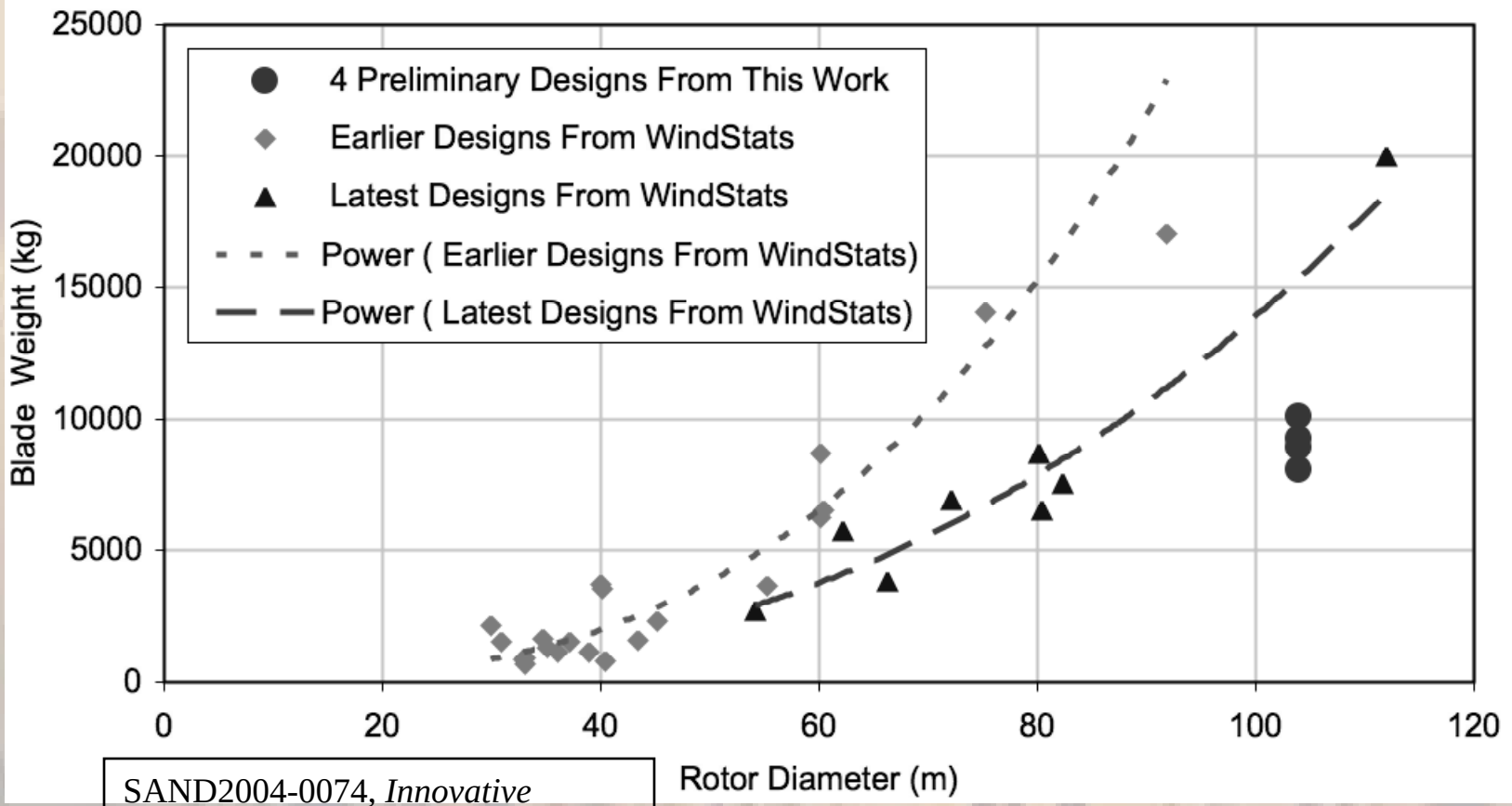
U.S. Installation and Wind Turbine Size Trends



- Blades/Turbines continue to to get bigger and relatively lighter



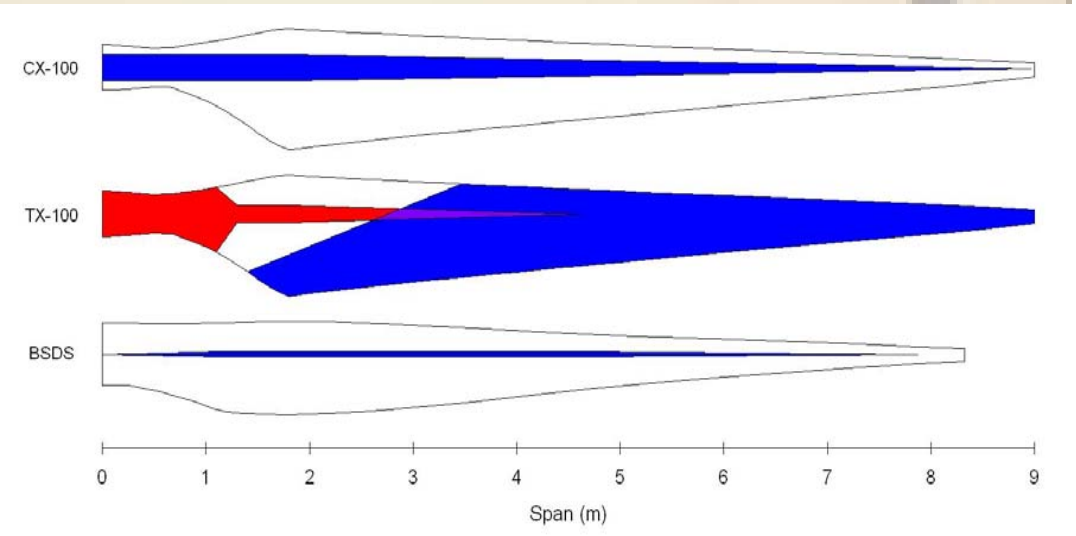
Comparison of Weight Trends, WindStats Data & Preliminary Designs

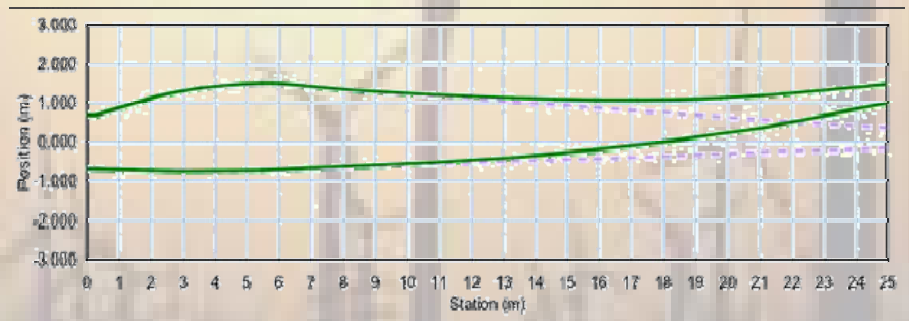


SAND2004-0074, *Innovative Design Approaches for Large Wind Turbine Blades; Final Report*, TPI

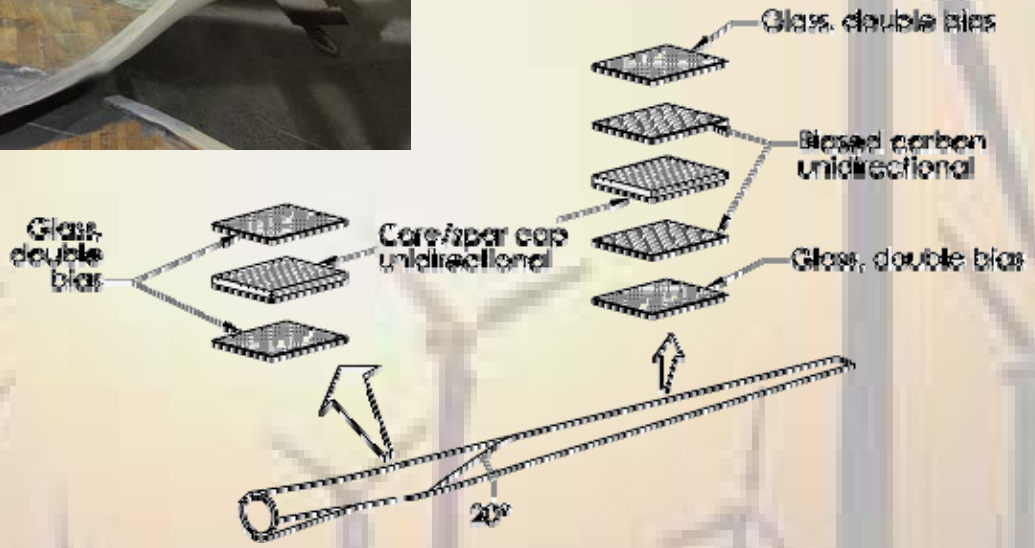
Applications of Innovations

- Types of innovations we are developing
  - **Carbon spar cap: CX-100**
  - **Bend-twist coupling w/angled fibers: TX-100**
  - **New airfoils (thickened airfoils & flatbacks): BSDS**
  - **Bend-twist with sweep: K&C 27.5 m blade**
  - **Active devices: microtabs on scaled models for wind tunnel**





TX-100 Carbon Tri-ax Skin & Glass Spar-Cap



Manufactured by TPI Composites

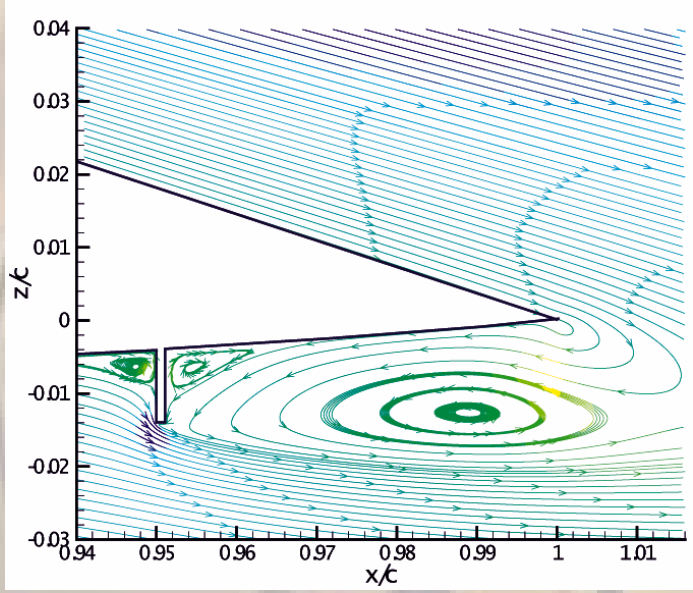
Passive Bend-Twist Coupling – Off Axis Carbon Fiber

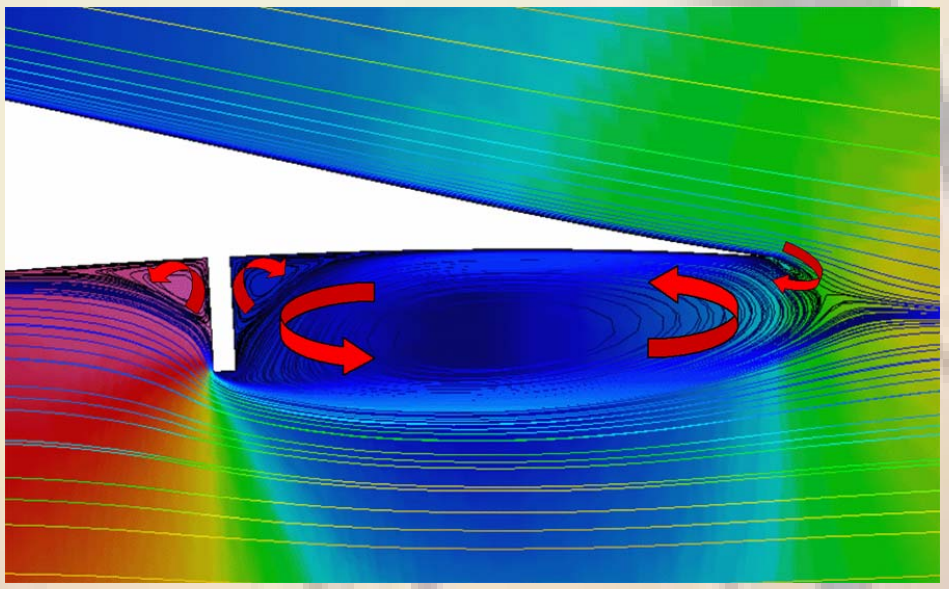
BSDS – Flatback Airfoils

Manufactured by TPI Composites

Knight & Carver Swept Blade

Active Blade Control





Summary

- **Plan on gathering more data on kinds of blade maintenance issues.**
  - Recommendations will be made on how to address blade maintenance issues and "Design for Maintainability"
  - Blades are not failing structurally in massive numbers
- **Wind standards are now addressing wind-specific design, materials & manufacturing safety factors.**
- **Work in reliability will focus on understanding extreme & maximum operating loads and exercising the Design Loop.**
- **Innovations are adding more uncertainty.**
  - Test and validation will lower for industry applications – the "Design Loop"
  - Innovative materials will require specific calibration