

Blade Design and Manufacturing : A GE Perspective

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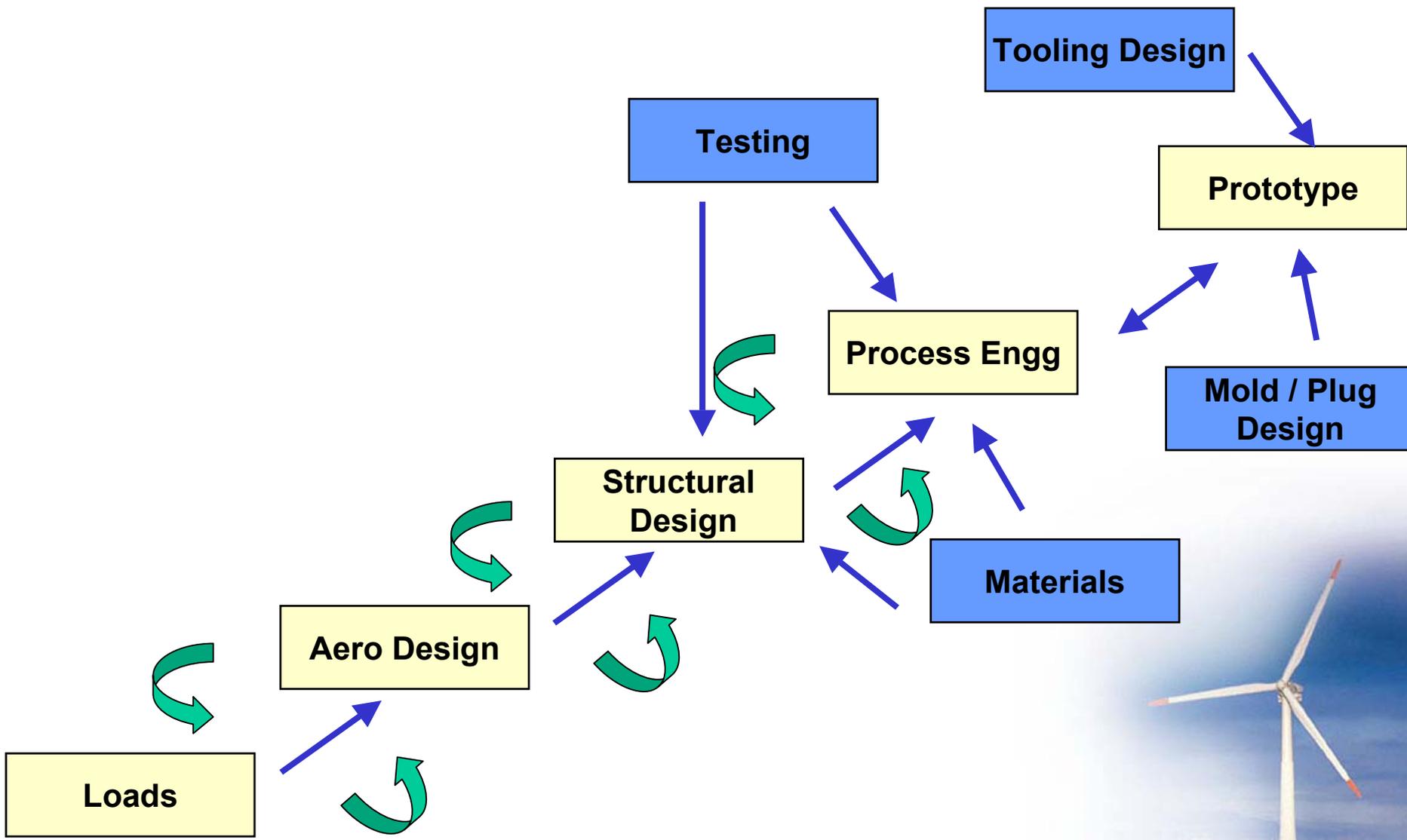
- **Max Length for given load envelope**
- **Min Weight for given length**
- **Min Lifetime Cost**
- **Simple Design for Manufacturability**
- **Reliable Design – should last 20 years**
- **Optimized Performance / Load level for Wind turbine system**
- **Minimum Noise**

**Maximum Swept Area, Minimum Weight and Cost
are Main Blade Design Drivers leading to
minimized system/lifetime COE**



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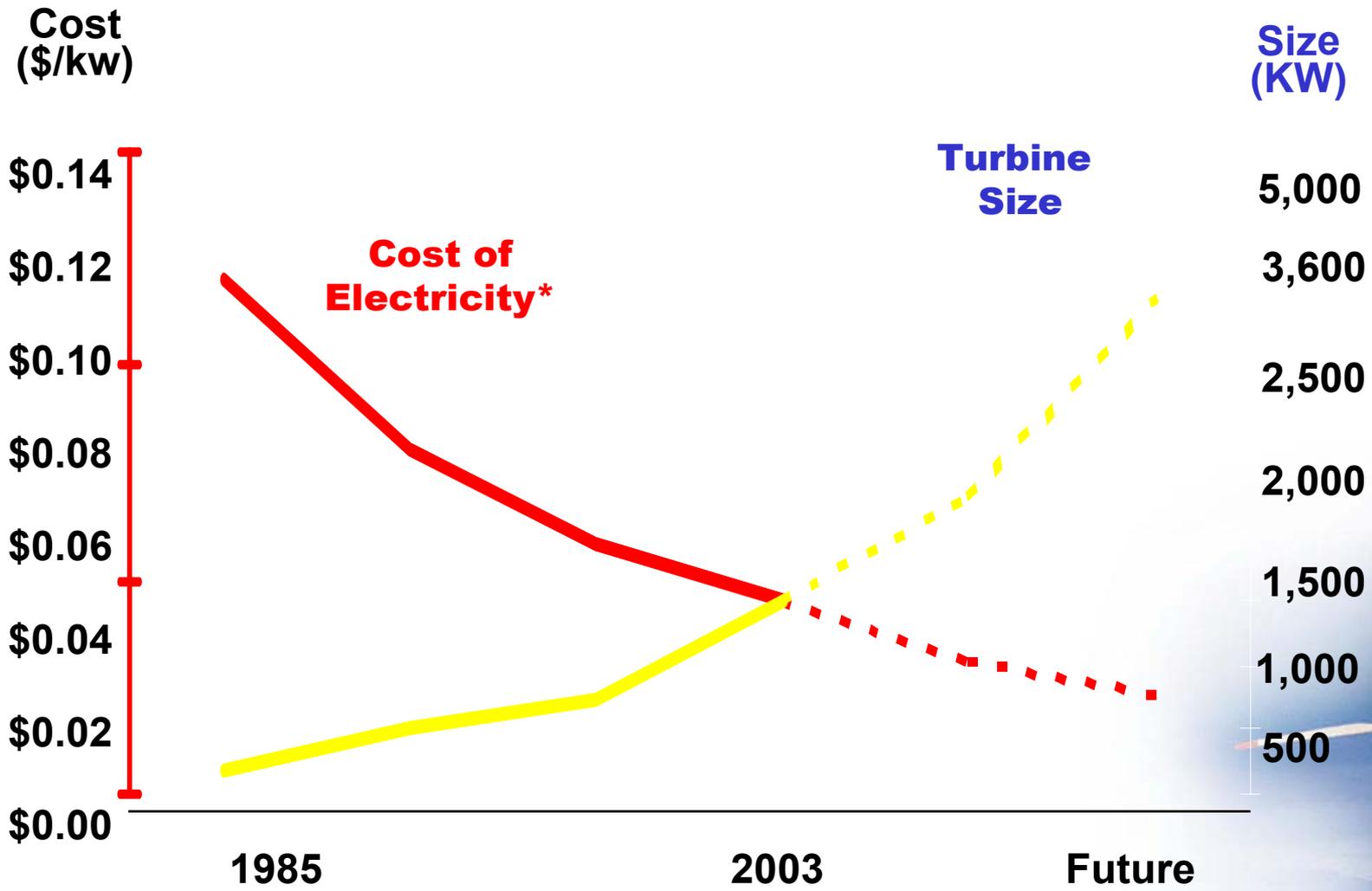
Blade Design Process



- **Loads** : Provide fatigue and extreme loads on the airfoil
- **Aero Design** : Design the external shape of the airfoil using loads and structural input
- **Structural Design** : Design the internal structure of the blade using materials, processing, manufacturing constraints
- **Process Engineering** : Infusion of blade, including curing requirements and void avoidance
- **Materials Engineering** : Material properties for structural design and process engineering
- **Testing** : Coupons and full-scale blade tests
- **Prototype Blade Manufacture**



Wind economics – driven by size



Innovation in large MW machines will enable Wind turbines to be competitive in the market

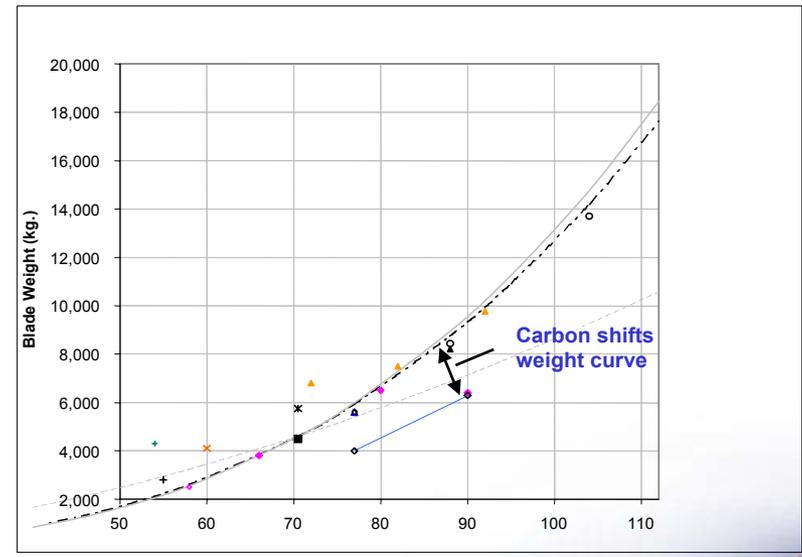


Industry moving to larger blades :

Design limits hit on many fronts :

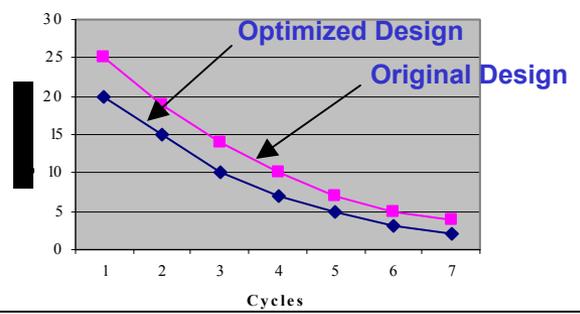
- Blade natural frequencies closer to operating range
- Increased fatigue loads due to gravity
- Edgewise damping levels decrease
- Chord limitations - transportation

Design limits prevent conventional scaling of small blades



Technology enabler - Carbon blade provides significant weight reduction from glass baseline

S-N curve



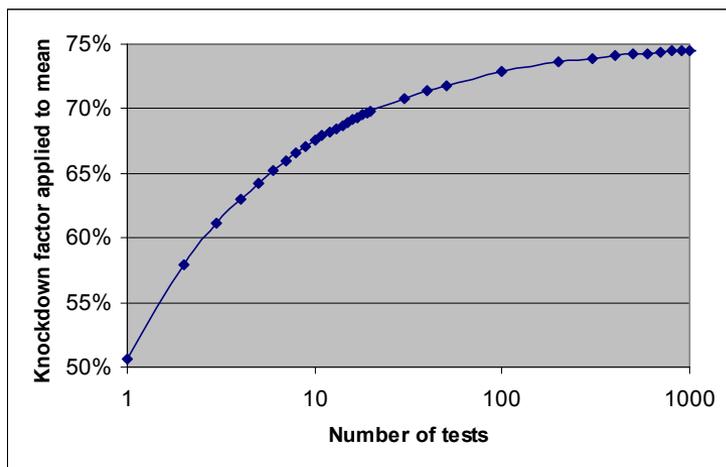
Integrated testing and Process Technology enables long life, reliable blades



Aero Technologies

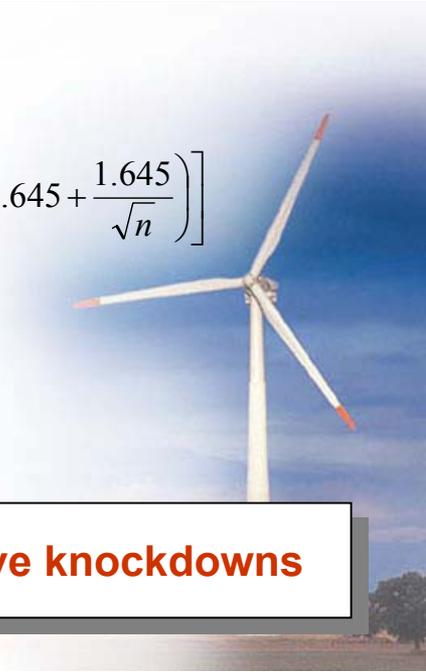
- High Lift Airfoil Design
- Tip Speed Increases
- Aeroacoustics
- Advanced Tip Shapes
- Performance enhancers

Advances in High Lift Airfoils, Acoustics and Performance Enhancers imperative for increased energy capture



$$R_k = \bar{x} \left[1 - v \left(U_\alpha + \frac{U_p}{\sqrt{n}} \right) \right] = \bar{x} \left[1 - 0.15 \left(1.645 + \frac{1.645}{\sqrt{n}} \right) \right]$$

Material characterization mitigates dependence on conservative knockdowns



Subarticle Testing

- Isolates one or two features to be evaluated
- Large enough to capture process variation; not a full scale blade - inexpensive
- Simplified shape allows straightforward testing; not cutting samples out of blade with continuous contour changes
- Quicker feedback for design/process improvements

Subarticle testing obviates need for expensive full scale blade tests

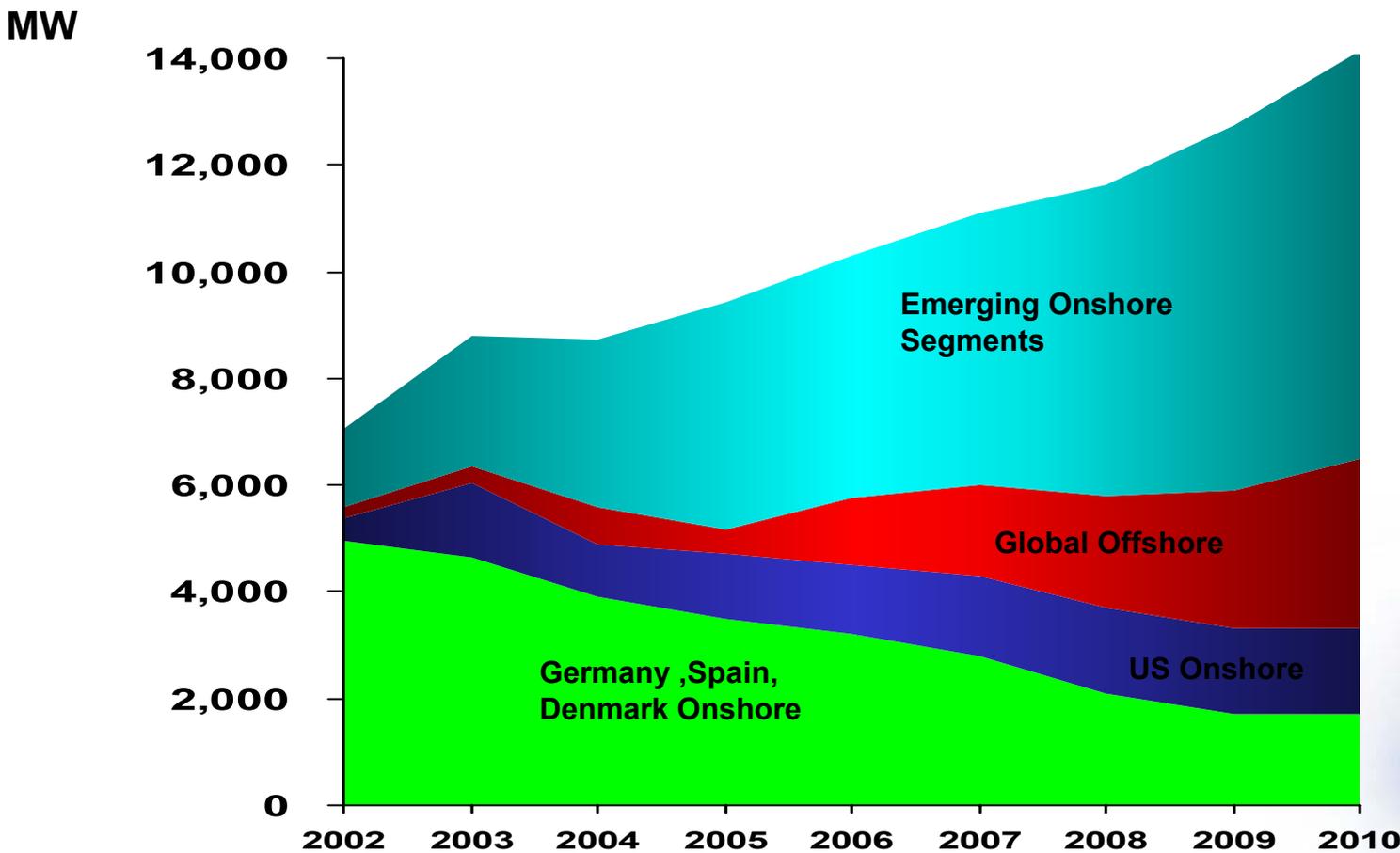
Twist Bend /Sweep coupling to attenuate dynamic operating loads :

- Needs higher stiffness fibers like carbon fibers
- Potential reduction in flap fatigue moments
- Potential reduction in extreme flap loads away from tower.



Manufacturing and Process Issues associated with twist-bend coupling must be overcome to make this a reality

Growth Dynamics



Shift from Regional to Global Markets will increase requirements for Local content – this includes local blade plants

Blade Manufacturing



- “Gypsy Manufacturing” – Portable plants
- Flexible tooling and manufacturing
- Design for manufacturability
- “One shot” production process



Automation in Manufacturing necessary to make blade plants competitive

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