Reliability Considerations for Large Off-Shore Blades

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Sandia Reliability Workshop
03 August 2011
Albuquerque, New Mexico
WEI 5-year Experience

• Blades in production at our clients:
  – 3.2, 4.2, 10, 13, 43, 45.3, 50.5, 56m

• Additional blades in design/development:
  – 26.3, 43.5, 48, 54, 55, 60, 73.8, 80, 90-100m

• Forensics work for blade failures (not our designs!)
  – Problems are growing as blade size grows
  – 20% of blades returned for warranty work
  – Blades are the worst components in a wind turbine
WEI 5-year Experience

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Reliability: Engineering –vs– Manufacturing

• Field failures of blades are almost always blamed on manufacturing failures
• But do blade design and engineering fail to reflect the realities of blade manufacturing?
• Improving blade reliability requires that the engineering and manufacturing reflect common specifications.
Common Blade Manufacturing Issues

• Adhesive Bond Defects
  – Thickness out of Tolerance
  – Voids (to the point of missing adhesive)

• Laminate Defects
  – Ply Wrinkling & Waviness
  – Misplaced Laminates
  – Fiber Orientation Issues

• Fiber Fraction Problems
  – Resin-Rich Regions
  – Dry Spots

• Etc.

Nominally 5mm Bond Gap Measured at 15mm
Worsening Problems With Larger Blades

• The tolerance requirements do not change as blades scale, so on a percentage basis, the tolerances become tighter
  – Adhesive bonds
  – Material placement
  – Fiber waviness and wrinkling
  – Laminate Thickness
Worsening Problems With Larger Blades

• Tolerances on molds are becoming worse as the molds grow in size
• Biggest problems we see are growing out-of-plane and in-plane mismatch between the two main shells
• Long Molds are more flexible
• This leads to larger bond gaps on blind bonds
Worsening Problems
With Larger Blades

• Thicker laminates mean
  – more dimensional variation in thickness, which translates into more variation in bond gaps
  – Variation in resin content – more resin rich regions, fabric floating, waviness, voids, etc.

• Thicker sandwich core construction –
  – quality problems infusing very thick core
  – High interlaminar shear and delamination problems
Challenge of Off-Shore

- Blades are not easily repaired
- Reliability must be improved dramatically for off-shore machines
Worsening Problems
With Larger Blades
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With Larger Blades

1/4700 Leading edge
108x30

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Worsening Problems
With Larger Blades
Worsening Problems With Larger Blades

Severe Delamination

Cracked Lam
Worsening Problems
With Larger Blades
Worsening Problems With Larger Blades
Evolution In Design for Large Off-Shore Blades

• Industry can design a conventional blade for an off-shore machine
• Based on prior research and experience with aviation systems, we expect that
  • Such blades will present severe manufacturing challenges
  • Excessively thick UD laminates with degraded properties
  • Excess quantities of balsa or foam core for buckling
  • Tolerance and matching issues during assembly of extremely large parts
  • Adhesive bond quality issues
• The weights of such blades will prove to be a source of uniquely high fatigue on the rest of the turbine system.

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Concepts for Large Blades

- Use of multiple spars, stringers, and ribs to produce a structure of significantly reduced weight and improved quality
- Modular approach to manufacturing
  - Parts are molded in more Manageable Sizes – reduces manufacturing overhead
  - Parts are assembled in open assembly fixtures
  - Bonds can be inspected before final assembly
  - Higher quality control
  - Lends itself to either factory assembly or field assembly
## Evolution In Design for Large Off-Shore Blades

<table>
<thead>
<tr>
<th></th>
<th>Conventional Wind Turbine Blade Design</th>
<th>Alternative Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Load Carrying Structure</strong></td>
<td>1 or 2 Spars centrally located</td>
<td>Several spars more distributed</td>
</tr>
<tr>
<td><strong>Outboard Skins</strong></td>
<td>Thin skins of sandwich core construction</td>
<td>Thinner skins with less core and strategic use of light-weight carbon stringers and ribs to prevent buckling</td>
</tr>
<tr>
<td><strong>Inboard Skins</strong></td>
<td>Thick skins for transferring loads from spars to root</td>
<td>Direct transfer of load from multiple spars to root</td>
</tr>
<tr>
<td><strong>Construction Approach</strong></td>
<td>A few full-length parts</td>
<td>Multiple shorter parts assembled in the factory</td>
</tr>
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Evolution In Design

• Alternatively – borrow from aircraft wing design
• Load is carried by a larger number of spars and stringers
  – Design is more fault tolerant
  – Strength and buckling both addressed more efficiently
• Buckling is resisted with much less weight using ribs and stringers
• The manufacturing is more modular
  – Smaller mold parts produce higher tolerances and higher QC and QA
  – More versatility regarding factory and field assembly
Evolution In Design
Evolution In Design
To Better Blades

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