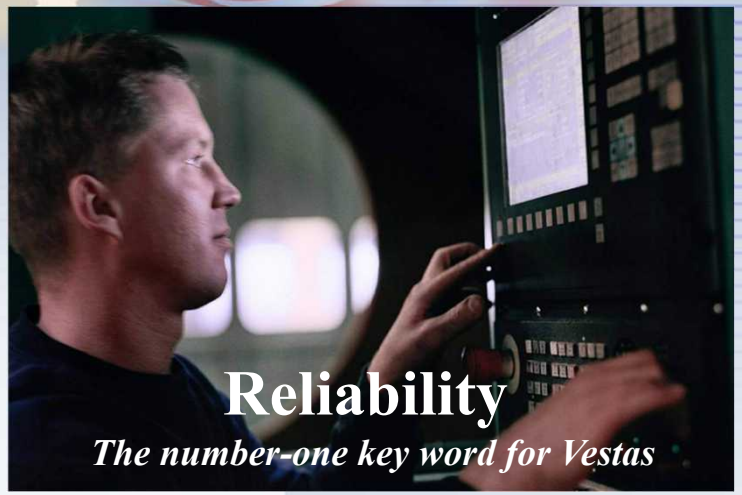
Blade Reliability Initiative

Blade Workshop
Albuquerque, New Mexico
14-May-2008

Reliability is the key focus of the industry



Vestas, 3rd quarter report, 2007

Reliability: The performance standard for a maturing industry.

Vestas CEO quote (*Windpower Monthly*):
"Our number one goal is no longer market share, it is reliability."

- At EWEC 2008, the industry CEOs spoke with a common voice that the focus would be on improving the reliability of the current product line rather than innovating on the product.
- Reliability is a system issue
- Reliability solutions are effected at the component level

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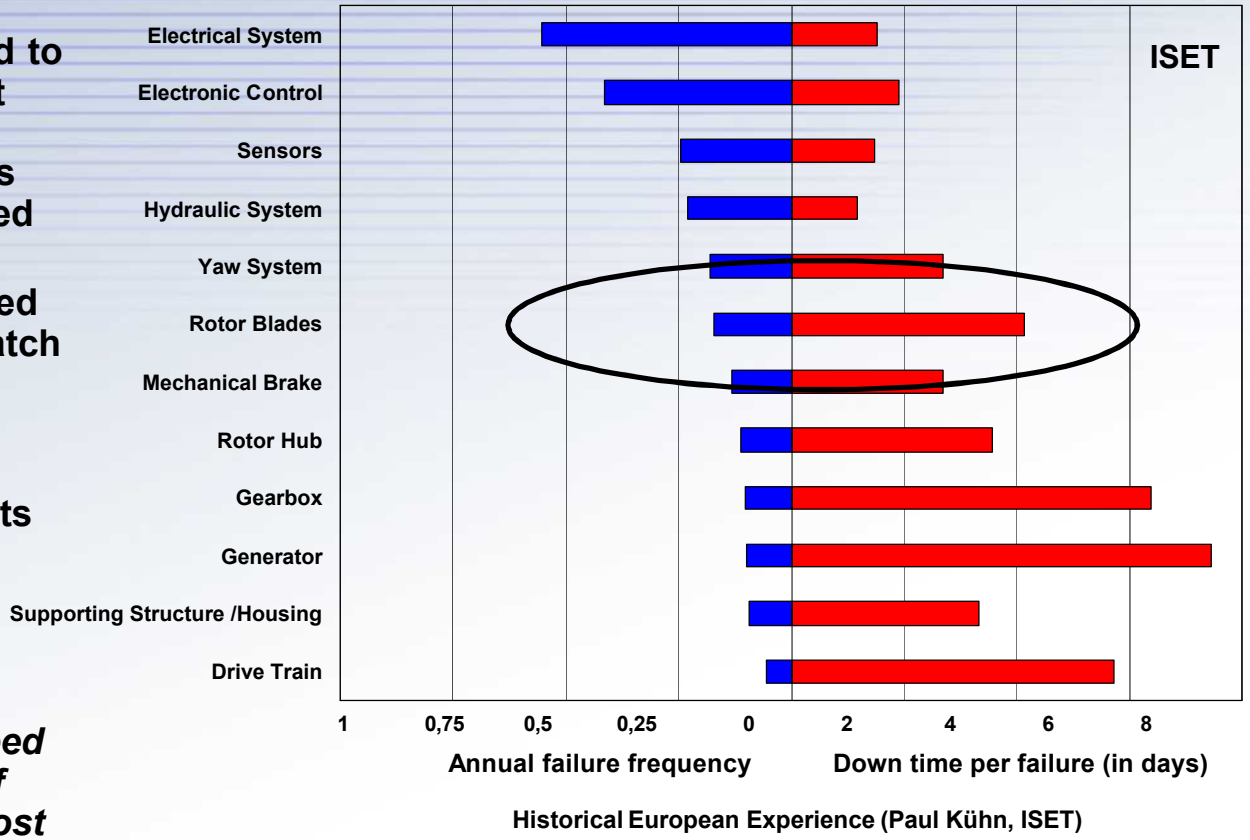
Blade Reliability

"80% of the blades that require repair have never been flown."
Gary Kanaby, Knight & Carver Wind Blade Division.

- Blades are being delivered to the site in a condition that often requires additional treatment of quality issues before they can be installed
- Rare installations need to have all the blades replaced after the discovery of a batch problem
- Many blade failures are caused by lightning and other environmental effects
- Blade failure can cause extensive down time and lead to expensive repairs.
- *Blade reliability issues need early attention because of the lost production and cost of significant failures*



Historical European Experience (Paul Kühn, ISET)

Blades are in the middle – medium failure rate, relatively high cost. US environments are more aggressive.

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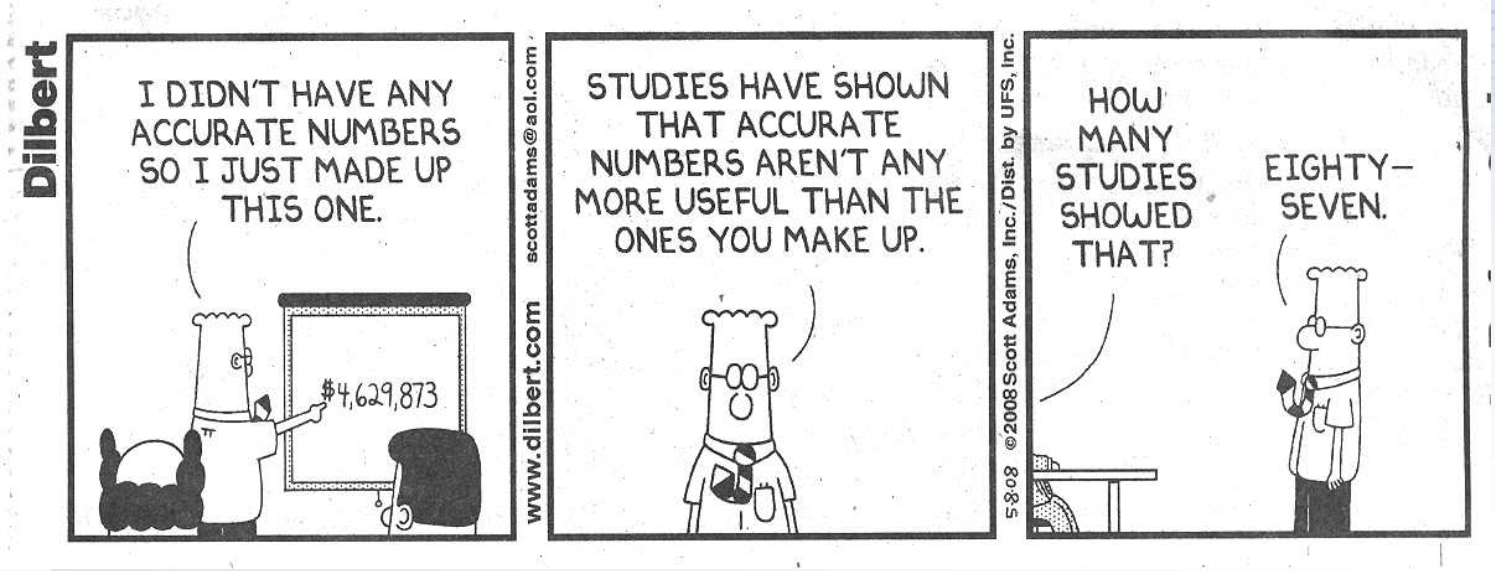
Delphi Expert's Group Assessment of Issues



- Experts from Industry, consulting, academia, and national labs convened to identify critical issues (no numbers)
- The results of that meeting are the skeleton of a plan to begin to address blade reliability needs

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Preliminary Survey of Operators - 2008

Roger Hill


Knight & Carver

Knight & Carver

- Five Plants – over 400 turbines
- Mostly 3+ years old
- About 80 blade replacements – 40 (half) at one plant
- Replacement times from 2 weeks to 2 months
- Blade Issues Cited:
  - Manufacturing Issues – waviness and overlaid laminates
  - Bad bonds, Delamination, and Voids
  - Leading Edge Erosion
  - Trailing Edge Splits
  - Lightning – Comments:
    - At one plant - Every blade has been struck at least once
    - Many repairs and replacements
    - Scorching and splits
    - Manageable problem (relative to gearboxes)

Major Issues for Improved Blade Reliability

Six *threads* of issues

- Infusion Quality
- Bonding Quality
- Inspection Capability
- Environmental Protection
- Multiple Assembly Plants or Assembly Lines
- Certification, Tracking and Feedback

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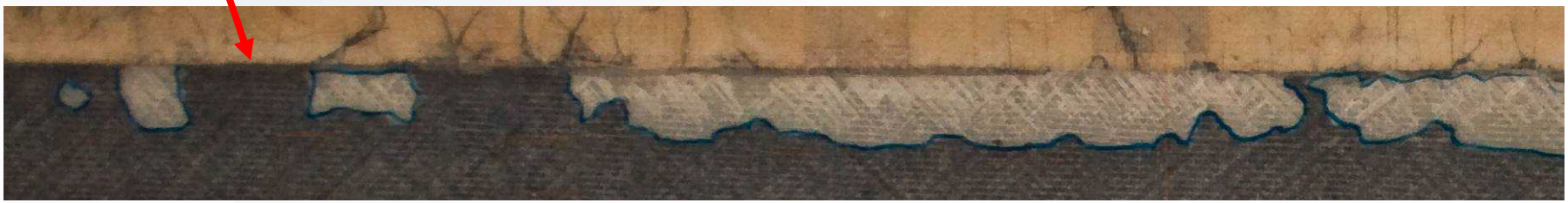
Infusion (composite fabrication) Quality

Waviness

- Speed of production creates problems
- Complete infusion, voids
- Fibers moving during infusion prior to curing
- Material drop off – Detailing
- Scaling issues

Carbon Spar Cap

Delaminations



1/2 meter

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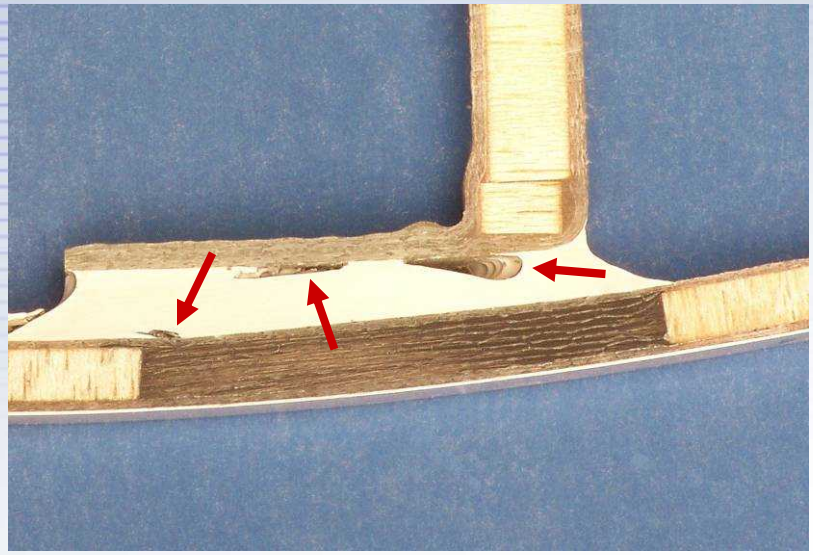
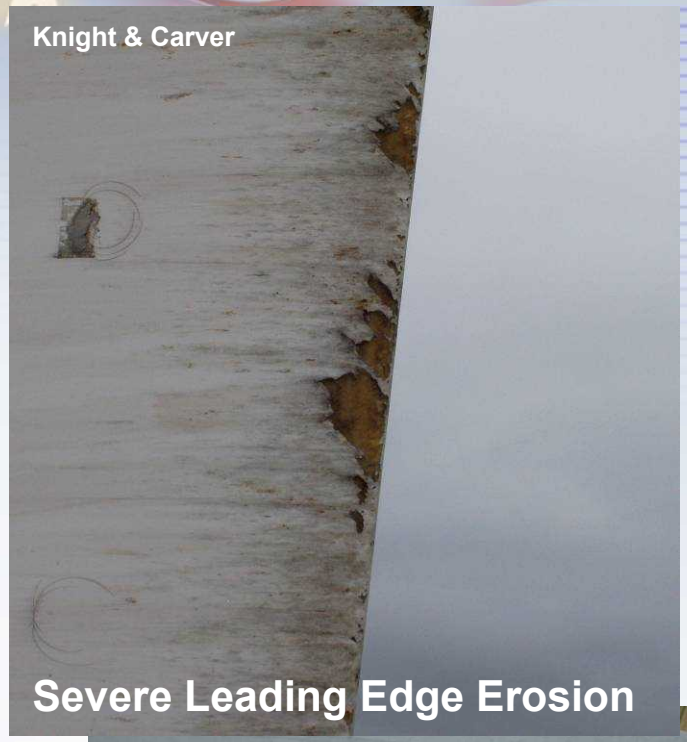
Bonding Quality

- **Bond-Line Control**
  - Difficult to control
  - Blind bonds
  - Scaling effects
- **Shear-Web Bonding**
- **Bond-Line Voids**
- **Bond-Line Weakness (without major voids)**
- **Commentary from a Blade Manufacturing Manager**
  - "The most difficult part of manufacturing process is trying to bond the two shells together."
  - "Trailing edge defects can grow to full blade failure."
  - "Bonding problems are the biggest issue."



Minor Voids

Environmental Protection



Severe Leading Edge Erosion

- Root fastener corrosion
- Leading edge erosion
- Moisture intrusion
- Freeze/Thaw cycling
- Lightning
  - Big issue
  - Many blades are repaired
  - Some operators consider it manageable - when compared to other components, such as gear boxes

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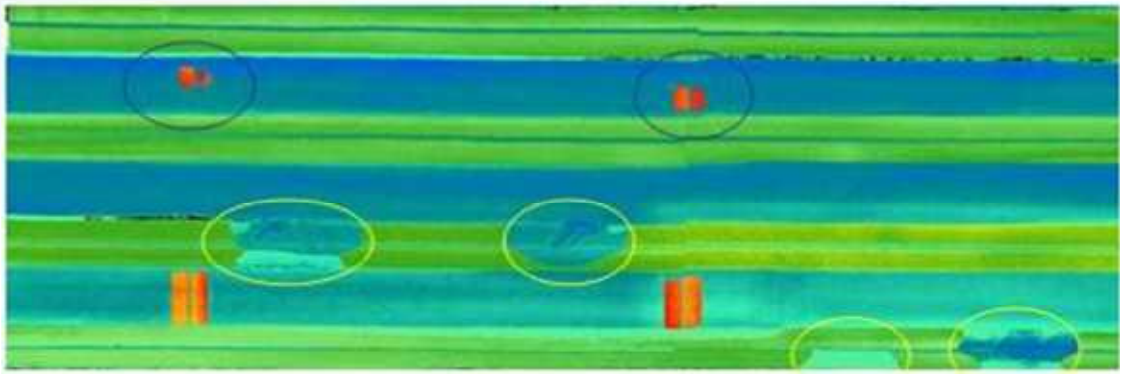
Inspection Capability: Factory and Field

- Existing inspection methods can detect bond line gaps and major delaminations
- Every blade manufacturer has inspection methods but some problems are still getting through
- Need to know what inspection methods are effective at finding the flaws that affect early failure.

Aircraft Example
Carbon Panel
(bonded ribs)

Phased Array UT Inspection of Vertical Stabilizer Specimen



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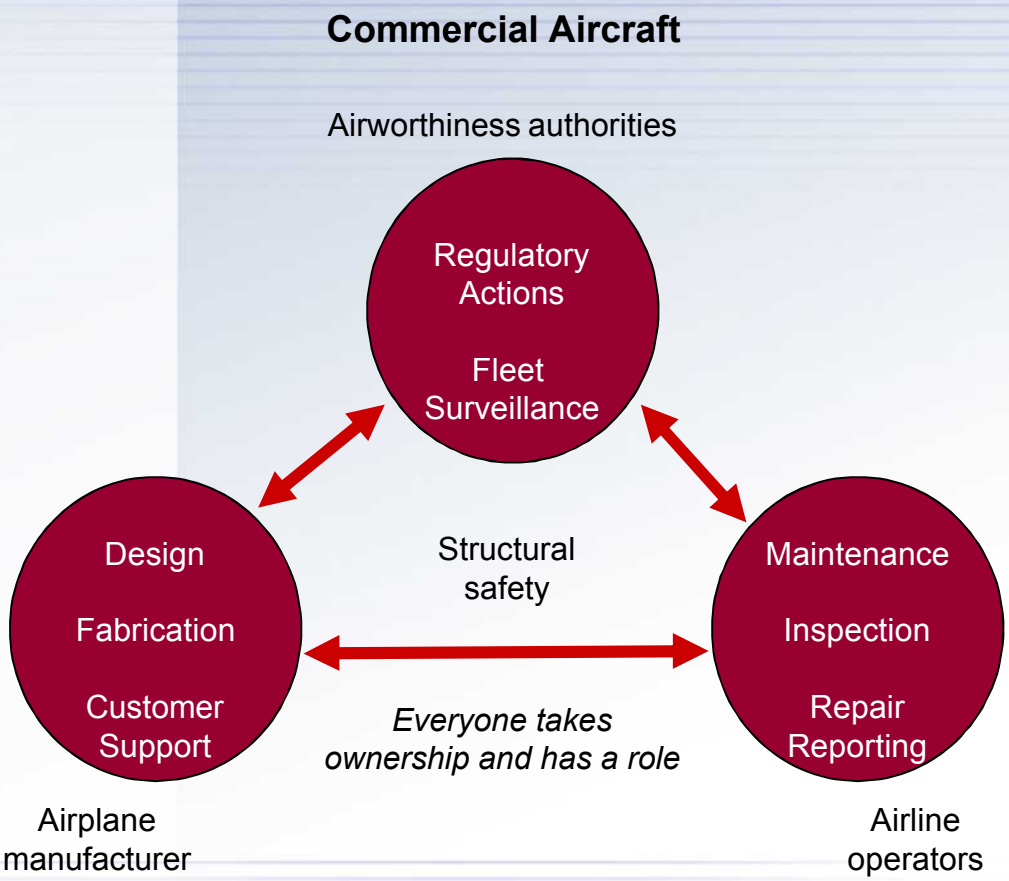
Multiple Assembly Plants

- Not covered in standards
- Production start-up (infant mortality)
- Local practices and corporate cultures
- Process qualification – metrics, procedures, etc.
- Bad batches of blades
  - lead to major plant development delays and cost overruns
  - May not be reflected in operator surveys because they are incurred before the transfer of responsibility from developer to operator

Courtesy Billy Roeseler, Boeing

Certification, Tracking and Feedback

Example of a Mature, High-Reliability, Structural Safety System



- Involves regulatory authorities in the operations of the fleet, AND …
- Specific requirements would probably be too expensive for wind turbine application, BUT…

- Continuous feedback to Manufacturers
- Drives component specification

How do we define a structure that provides the benefits without the unnecessary overhead and excessive cost?

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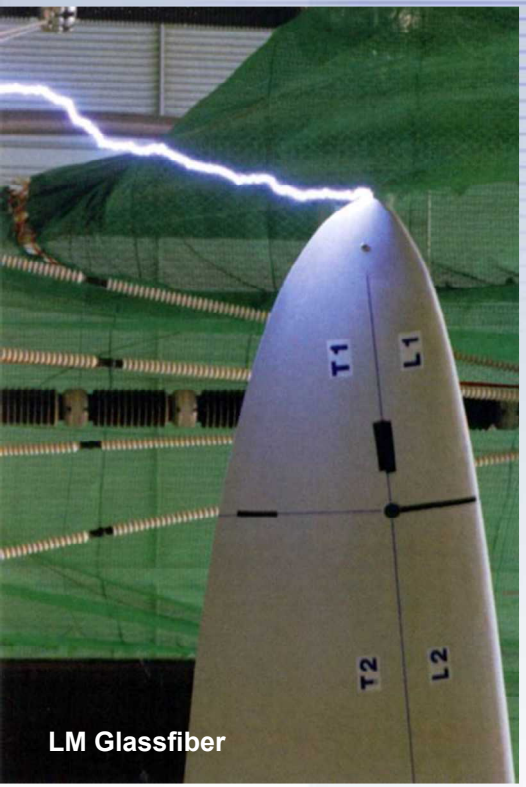
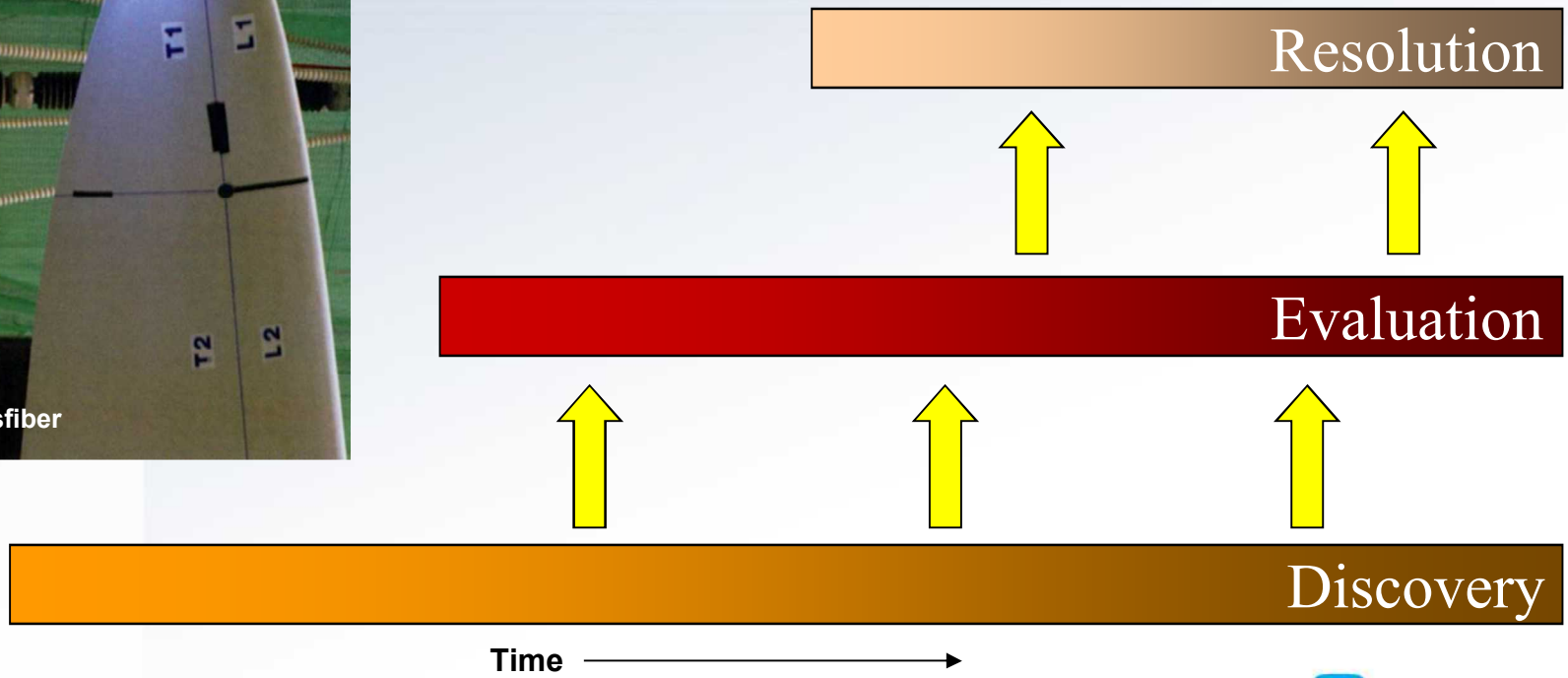
Blade Reliability Initiative – Three Phases



Discovery **– Define the nature and extent of the issues:**
Focused on field work and full-scale testing

Evaluation **– Characterize the issues and evaluate mitigation:**
Focused on laboratory testing and inspection

Resolution **– Validate the methods of resolving specific issues:**
Targeted R&D to solve specific issues



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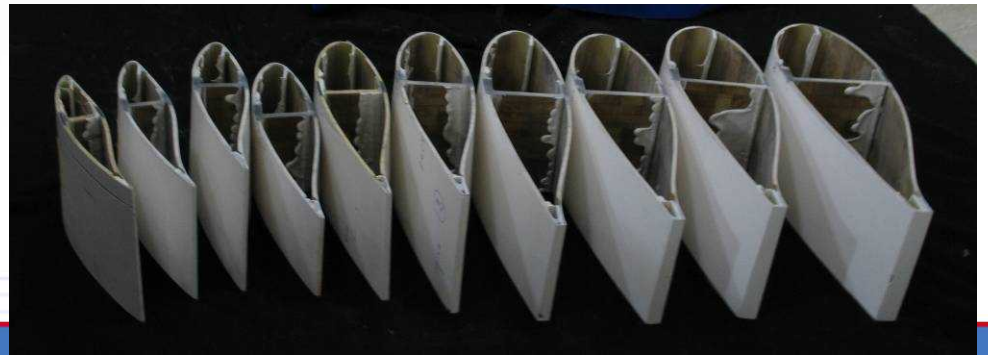
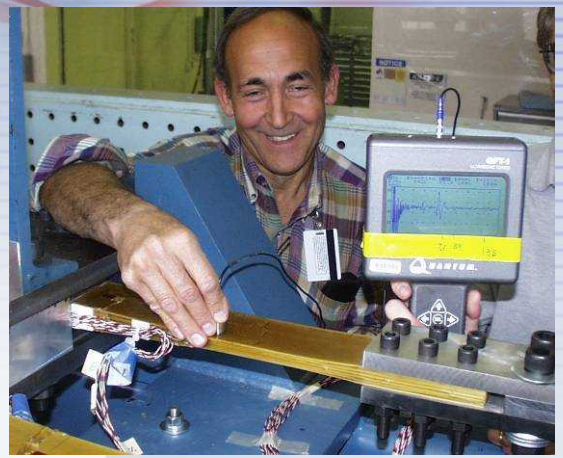
Discovery Phase

What is causing early field failures and unreliability?

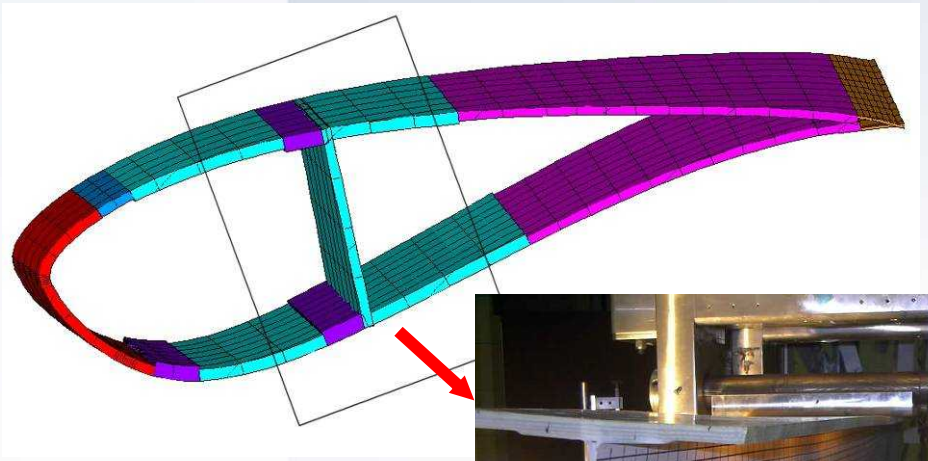
- National Reliability Database analysis
- Operator surveys
- Field failure assessments and root cause analysis
- Current inspection capability
- Manufacturer inputs
- Full-scale blade testing: Fatigue tests reveal hidden flaws
  - Production blades
  - Detailed inspection
  - Typical manufacturing quality resulting capability



Evaluation Phase



Pursuing specific findings from the Discovery Phase. Fully define the issue.



- Subcomponent testing troublesome details
- analytical modeling and failure analysis
- Evaluating the impact of defects
- Targeted Inspection method improvement
  - Specimens with well characterized flaws
  - Blind trial opportunities for commercial inspection providers and blade manufacturers

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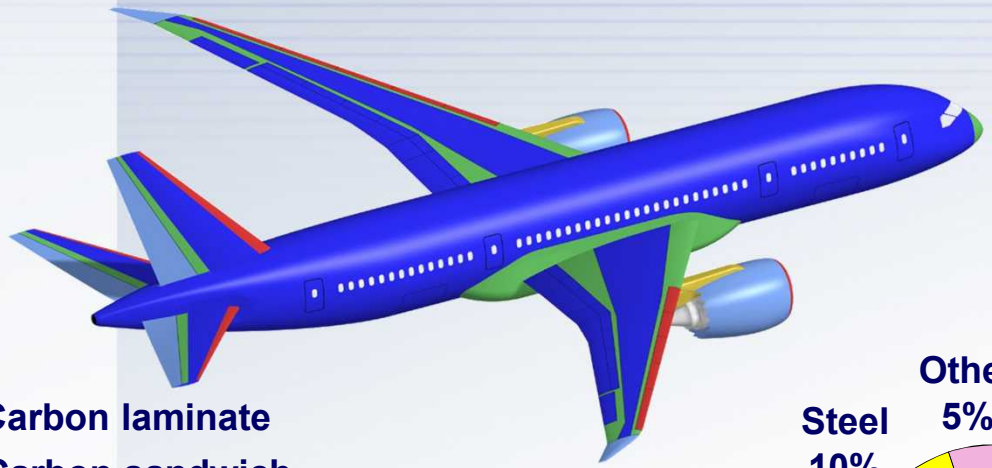
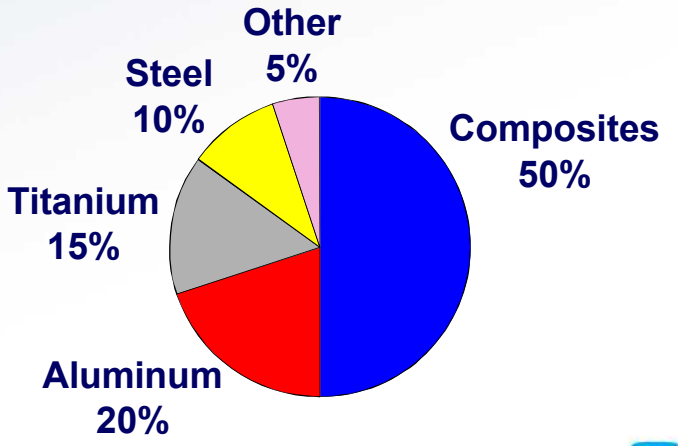
Technology for inspection is under intense development for new Composite aircraft

- The Boeing 787 is 50% composite material in structural elements
- Composite Inspection is growing in technical sophistication
- Tied to damage tolerance

Composite Structures on Boeing 787 Aircraft



- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons



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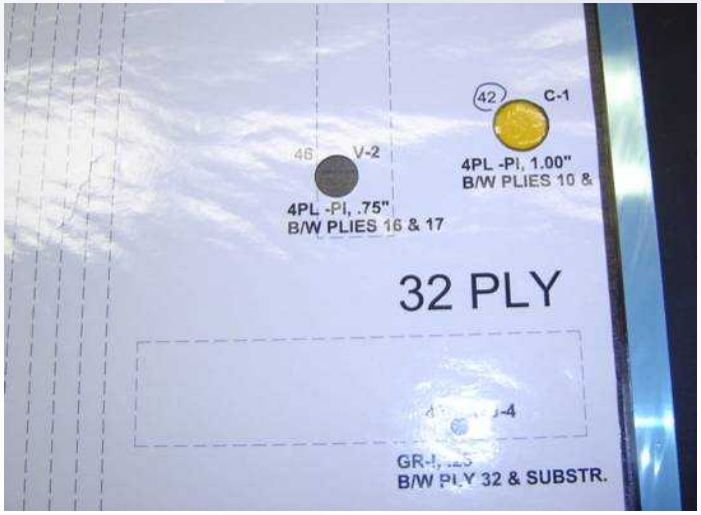
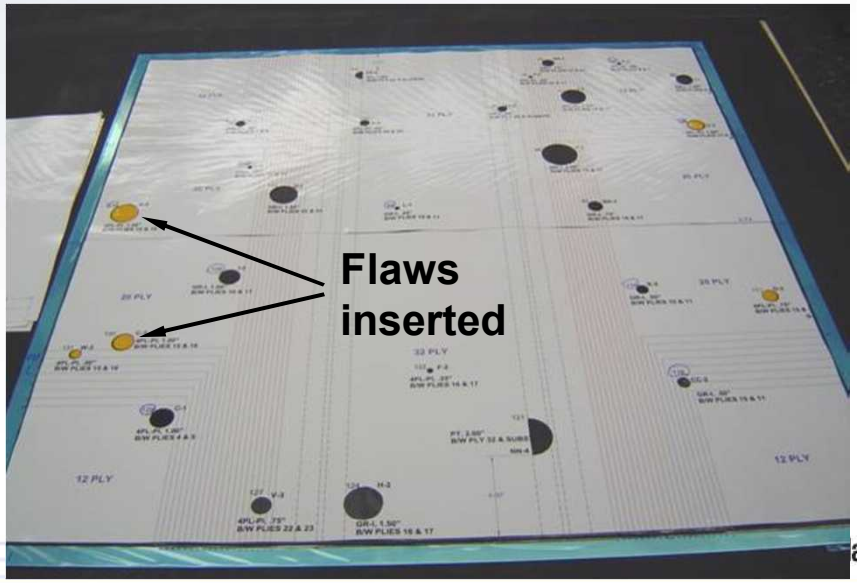
Example: Fabricated flaws for validation of inspection

Flaw templates - ensure proper location of flaws





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Resolution Phase

Pursue design changes to eliminate the issue "Failure Modes and Effects *Avoidance*"

Outcome: Definition of the Critical Issues

- Confirm the level of quality required to preempt the delivery of flawed blades to the field
- Validate the inspection methods capable of certifying the required quality

- R&D will be issue specific and led by manufacturers
- Innovation will have a reliability driver

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