Topics

• Blade Erosion Sheath Bonding Repair Service Experience

• Primary Blade Metal to Composite Joint Life Evaluation
Composite Blade Components

- Lightning strap
- Shield
- Hollow composite spar
- Deicing heater
Blade Erosion Shield/Sheath Bonding Repair Service Experience
Example Shield Bonding Process

• Repair: Post-bond
  – Remove shield from storage bag
  – Clean bonding surface
  – Apply adhesive
  – Assemble shield to blade
  – Cure adhesive

Note: Some manufactures use different processes for production and repair
Historical Causes of Failure

• Silicone contamination
  – Silicone transfer from masking tape to bond surface during cleaning
• Improper adhesive mixing
• Skipped process steps
  – Lack of or inadequate primer
  – Primer removal not performed
Corrective Actions

• Manual changes
  – Cautionary notes added
  – List of approved tapes added to the manual
  – Extra Inspection steps added

• Repair shop audits and training

• Removal from service of affected blades
Primary Blade Metal to Composite Joint Life Evaluation
Background Joint Information

- The blade primary joint is the attachment for the composite blade to the metallic retention

- The area is a complex construction
  Materials include: Primer, Adhesive, Resin, Graphite, Kevlar, and Glass

- Joint damage includes de-bonding, delamination, and cracking
Primary Metal to Composite Joint
Two Examples
Joint Design Philosophy

• Damage is inherent in the joint and may grow with the repeated application of high loads

• The joint may be qualified such that it requires inspection at regular interval to assess damage growth

• The joint may be qualified such that it will require retirement prior to damage reaching a defined maximum permissible size
Phases of Damage Growth

- Region I - damage initiation phase
- Region II - damage growth propagates steadily and predictably
- Region III - advanced damage state
Life Qualification Process

The life qualification process requires full scale testing

• Lab test to determine failure mechanism
• Lab test to determine flaw growth data
• Flight test to determine loading
• Life Analysis to determine inspection interval and/or retirement time
• Lab test to validate analysis
• Lab test to determine residual strength
Full Scale Test Rig

- Peak stress near the blade root
- R ratio adjusted for flight condition simulated
- Forced response test
Determine Failure Mechanism

• Test Specimen. The specimen must represent actual type design

• Loading. The blade must be loaded to simulate the predicted critical loading environment

• Monitoring Failure Mechanism using NDI
  – Flaw Initiation
  – Flaw Growth
  – Test to Failure
  – Define the failure in terms of inspection criteria
Flaw Growth Inspection Area

(Available region for inspection may be limited)
Progression of Flaw Growth

Example Flaw Growth Data

Flaw Area (% of maximum) vs. Cycles

Test performed at constant amplitude

Assigned growth rate
Develop Flaw Growth Curve

Example Flaw Growth Rate
Example Measured Blade Loads on the Airplane

Blade response follows the:
- acceleration
- airspeed
- flap angle
Sample Components of a Flight Profile

Propeller fatigue is a combination of HCF and GAG cycles
Evaluation of propeller loads using aircraft load spectra

• The aircraft load spectra is supplied by the aircraft company.

• Propeller loads are computed for each condition from flight data.

• Each aircraft maneuver or gust represents many propeller load cycles due to propeller rotation.

• Stabilized ground and flight conditions and many maneuvers are verified by flight test.

• Non-testable flight conditions (such as vertical and lateral gusts) are estimated based on test data and analysis.
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Test to validate analysis

• The damage growth model must be verified by spectrum loading for the full-scale structure using loads established from the flight test.
• The detectable damage size and location must be established and be consistent with the inspection techniques employed in service.
• The definition of failure must be based upon the inspection method employed in service.
Test to determine residual strength

• The end of life condition is established in conjunction with the service life.

• The component at the end of life condition meets all airworthiness loading requirements.
Inspection Criteria

• Inspection methods should have a POD of 90% probability with 90% confidence.

• The defined inspection interval must permit multiple opportunities, usually three, to find the damage before the component reaches the end of life condition.
Final Inspection Program

• Conduct an inspection (usually ultrasonic) of the blade retention area at each inspection interval of xxx hours.

• Retire blade when the total area of acceptable bond is less than yyy sq centimeters.