Evaluation of Aged Structural Bonds on Rotor Blades

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Project Overview

Background and Motivation:
- Long-term durability under operational environments must be understood and the aging mechanism must be investigated to support maintenance practices and to establish criteria for structural retirement
- Detailed nondestructive inspections (NDI), teardown inspections, and laboratory testing of bonded repairs on aircraft components that have been retired from service provide vital information related to the aging mechanism and any undetected material degradation
- Concerns related to process sensitivity of the bondline as an improperly accomplished in-service repair could become a safety threat
  - Potential for weak bond to degrade in an unpredictable manner when subjected to operational environments and ground-air-ground (GAG) thermo-mechanical loads
- Concern that unique dynamic loads for rotor blades yield complex history-dependent behavior for products with shifting missions

Objective:
- Evaluate bondline integrity and durability of adhesively bonded composite rotor blades for understanding the aging mechanisms with respect to various operational conditions.

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Project Goals:
- Compare “state of adhesive” or “state of resin” on old blades to the initial state of these polymeric materials on new blades
  - Teardown and evaluate bondline performance parameters
- Compare existing repairs on old blades and new repairs on old blades to new repairs on new blades
  - Use existing repairs or perform repairs → mechanical performance evaluation
- Compare accelerated aging protocols to real life
  - Structural testing based on lower building block findings
- Demonstrate improved accelerated testing in rotor blade bench tests
Objective: Establish the capability, and enhance subject matter knowledge, for rotorcraft main rotor blade structural testing efforts at FAA Technical Center and NIAR ATLAS.

• Loading Requirement Definition
  — Centrifugal Force: 120.0 kip
  — Lift Force: 44.4 kip
  — Drag Force: 14.2 kip
  — Damper Force (Not on all rotor types): 9.8 kip
    ▪ Considerations Required: [Fully Articulated, Semirigid, Rigid]

• Fixture Definition
  — FAA Technical Center: Standalone
  — NIAR ATLAS: Incorporation into Existing Multipurpose Test Rig

**Centrifugal Force**

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**Objective:** Establish the capability, and enhance subject matter knowledge, for rotorcraft main rotor blade structural testing efforts at FAA Technical Center and NIAR ATLAS.

- **Fixture Overview**
- **Centrifugal Force Application**
  - Class 2 Lever: *Pressurized Air Spring*
Objective: Establish the capability, and enhance subject matter knowledge, for rotorcraft main rotor blade structural testing efforts at FAA Technical Center and NIAR ATLAS.

- **Force Application**
  - Lift: **28.4-kip**
    - 2 x Servohydraulic Actuators
  - Drag: **14.2-kip**
    - 1 x Servohydraulic Actuators
  - Centrifugal: **100-kip via Airbag**

- **Cyclic Rate Capacity**
  - 6.0-inch Displacement: **0.44-Hz**
  - 1.1-inch Displacement: **1.0-Hz**
Structural Test Rig Development

Objective: Establish the capability, and enhance subject matter knowledge, for rotorcraft main rotor blade structural testing efforts at FAA Technical Center and NIAR ATLAS.
Rotor Blade Acquisition

**Objective:** Acquire rotorcraft main rotor blades exhibiting same construction materials and methods while exhibiting varying environmental/operational applications.

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**A. Sikorsky S-76A**

- **Blade Details**
  - Quantity: Two main rotor blades
  - Historical Information: Hours: 3,274

- **Status**
  - Inspections:
    - Shearography: Complete
    - Thermography: Complete
    - Ultrasonics: Complete

- **Path Forward**
  - Teardown
  - Root-end extraction
  - Preparation for F.S. testing
  - Testing
  - Strain surveys
  - Fixture validation

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**B. Leonardo AW109**

- **Blade Details**
  - Quantity: One main rotor blade
  - Historical Information: Hours: 4,352

- **Status**
  - Inspections:
    - Shearography: On-Hold
    - Thermography: On-Hold
    - Ultrasonics: On-Hold

- **Path Forward**
  - Holding
    - Focusing efforts on other blade sets that exhibit same material systems with various service histories

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**C. Eurocopter HH-65**

- **Blade Details**
  - Quantity: One main rotor blade
  - Historical Information: Hours: 10,457.7

- **Status**
  - Inspections:
    - Shearography: Complete
    - Thermography: Complete
    - Ultrasonics: Complete

- **Path Forward**
  - Holding
    - Focusing efforts on other blade sets that exhibit same material systems with various service histories

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**D. Sikorsky S-92**

- **Blade Details**
  - Quantity: Two main rotor blades
  - Historical Information: Hours: In-Work

- **Status**
  - Inspections:
    - Shearography: Complete
    - Thermography: Complete
    - Ultrasonics: In-Work

- **Path Forward**
  - Teardown
    - Extraction plan development
  - Testing
    - High level and low level
Assessment of structural bonded repairs performed during service and/or determine effects of newly bonded repairs on degraded components; additional future efforts can allow for assessments for life extension via fatigue testing beyond original certification testing.

Assessment of structural bonds related to skin-to-core performance and establishment of any correlations between NDT and Mechanical testing that may exist.

Assessment of substrates, adhesive, core, and failure modes for evaluation of influence on performance.

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Component Level NDI

Objective: Establish whether fleet blades received have traditional damage we would typically see with NDI & do they have other aging effects that we don't normally measure?

- **Laser Technology Inc. (LTI)**
  - Laser Shearography: LTI-2100HP-300
    - 300-mW @ 532-nm Green Laser
    - 2-kW Thermal Stress System
    - In-house Vacuum System and Local Chamber

- **Thermal Wave Imaging (TWI)**
  - Pulsed Thermography: X8500 SC Camera
    - Resolution: 1280x1024
    - Frequency: 180-Hz

- **NDTS MAUS**
  - Pulse Echo UT: Single-element 5.0-MHz
  - Resonance Testing: 270-kHz and 320-kHz
  - Mechanical Impedance Analysis: 19-kHz

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Component Level NDI

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• Approach for S-92 Blades

  Two identical blades exhibiting vastly different levels of skin-to-core bond strength as determined by OEM in-situ peel testing.
  
  ▪ Evaluation of operational conditions (environment, flight profiles, etc.).
  ▪ Performance of NDI for receiving condition evaluation and region of interest (ROI) determination (defects/damages).
  ▪ Evaluation of skin-to-core bond characteristics.

Initial NDI Findings: Utilizing standard inspection techniques, no change from nominal was discernable in severely aged blades.
Summary of Status

Task I: Structural Test Rig Development
1) Steering Committee Formation ✓ - Complete
2) FAA Tech Center Fixture Design ✓ - Complete
3) NIAR ATLAS Fixture Design and Manufacturing → In-progress

Task II: Rotor Blade Acquisition
4) Blade History Documentation ✓ - Complete
5) Receiving Inspections ✓ - Complete

Task III: Full-scale Structural Testing
6) Mechanical Performance Analysis of Rotorcraft Blades → In-progress

Task IV: Rotor Blade Teardown and Lower-Level Testing
7) Failure Documentation and Analysis → In-progress
8) Detailed Experimental Investigations → In-progress
Moving Forward: Full-Scale Structural Testing – Stage 1

Objective: *Risk Mitigation and Confidence.*

- **General Approach:**
  - Assumptions for Force Estimations
    - Blade Weight: **88.0-lbs**
    - Blade Speed: **300-RPM**
    - Blade Length: **19.98-ft**
    - Main Rotor Dia: **44.0-ft**
    - Takeoff Weight: **10,500-lb**
    - Disk Area: **1520.5-sqft**
  - Reverse engineer blade loft for both INBD and OTBD attach
- **Full-scale testing**: *Quasistatic strain surveys*
Objective: Establish testing methodology for laboratory aging of structural details in which a strength knockdown is observed due to environmental exposure.

- Approach
  - Two Configurations: Pristine vs. Porosity
    - Based upon dried vs. wet* core utilization when bonding
  - Use of material systems, to an extent, from rotor blade
    - Facesheet: T650/5320-1 PW
    - Adhesive: Metlbond 1113 [0.06-psf]
    - Core: HRH10-3/16-2.0
  - Baseline and Intermediate Testing
    - Peel and Flatwise Tensile
    - Hi-fidelity NDI via X-ray CT
Questions?

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