Inspection and Teardown of Aged In-Service Composite Structures

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WICHITA STATE UNIVERSITY

Evaluation of Aged Structural Bonds on Composite Rotor Blades

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NIAR®
Wichita State University

Federal Aviation Administration

SIKORSKY
A LOCKHEED MARTIN COMPANY

Program Overview

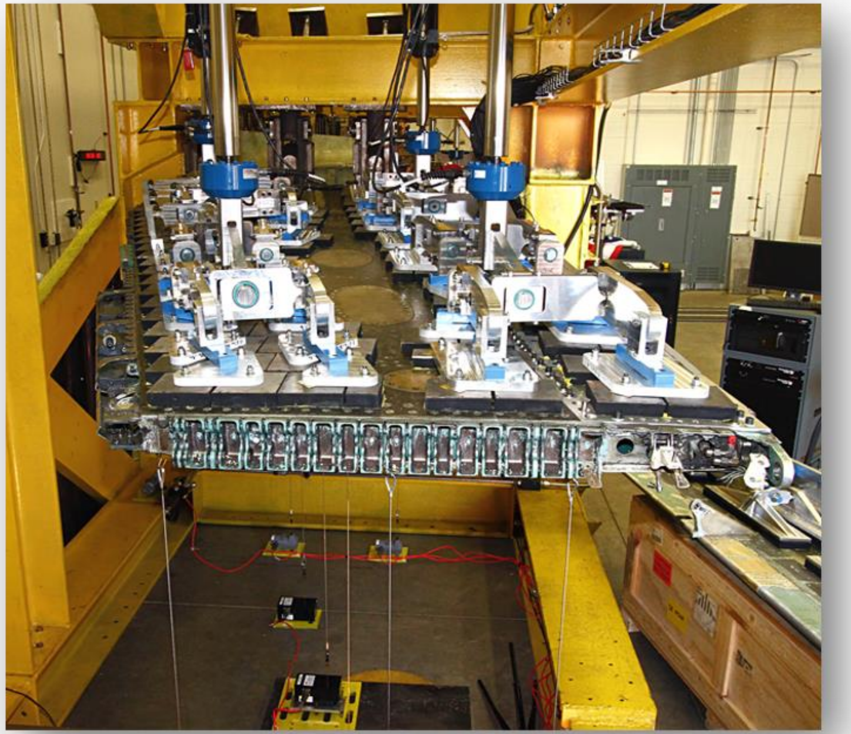
Nondestructive Inspections

Fixture Development and Fatigue

Teardown Testing Techniques

Trial Run

F-18 Testing



Background

- Evaluation of bond line integrity and durability of adhesively bonded composite rotor blades is imperative to the safe operation.
- Retired blades from aged aircraft are will be
  - Thoroughly Inspected with numerous NDI techniques.
  - Physically tested with high-stress low-cycle loading conditions.
  - Torn apart to perform small scale coupon level tests on structural adhesives.
- Long term durability of structural adhesives must be investigated to observe critical aging mechanisms and ultimately support the airworthiness or retirement of helicopter blades

The primary goal of this task is to investigate the unknown behaviors of aged bonded composite rotor blades and field repairs to gain a fundamental understanding of the aging mechanism of bonded dynamic structures. These investigations will provide guidance towards testing of composite rotor blades.

Rotorcraft Blades for Testing

1

Sikorsky S-76

Blade Details
* Two main rotor blades
* Flight Life ≈ 3,300 Hours

Sikorsky S-92

Blade Details
* Two main rotor blades
* Flight Life ≈ 12,000 Hours

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4

Blade Details
* One main rotor blade
* Flight Life ≈ 4,400 Hours

3

Blade Details
* One main rotor blade
* Flight Life ≈ 10,500 Hours

2

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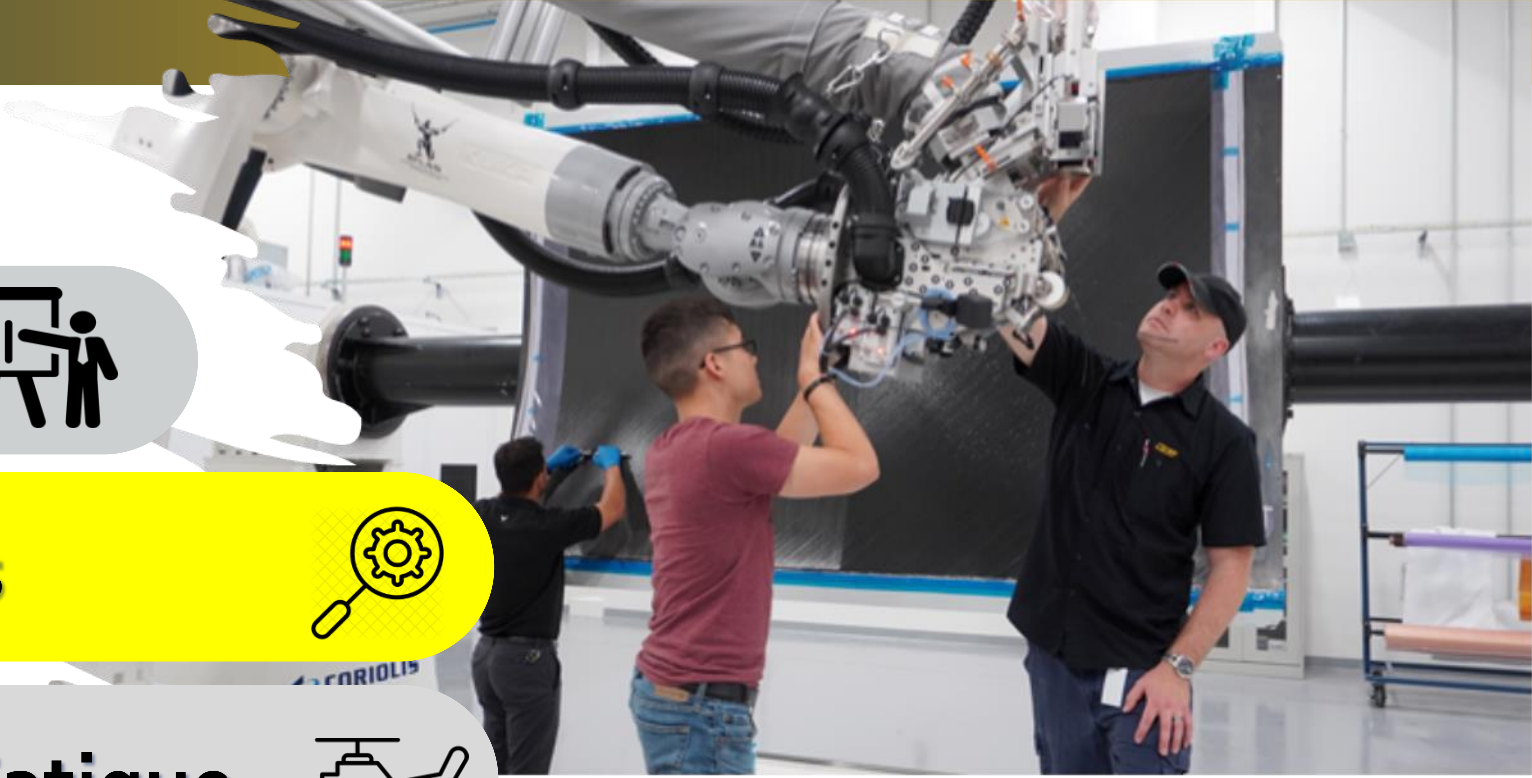
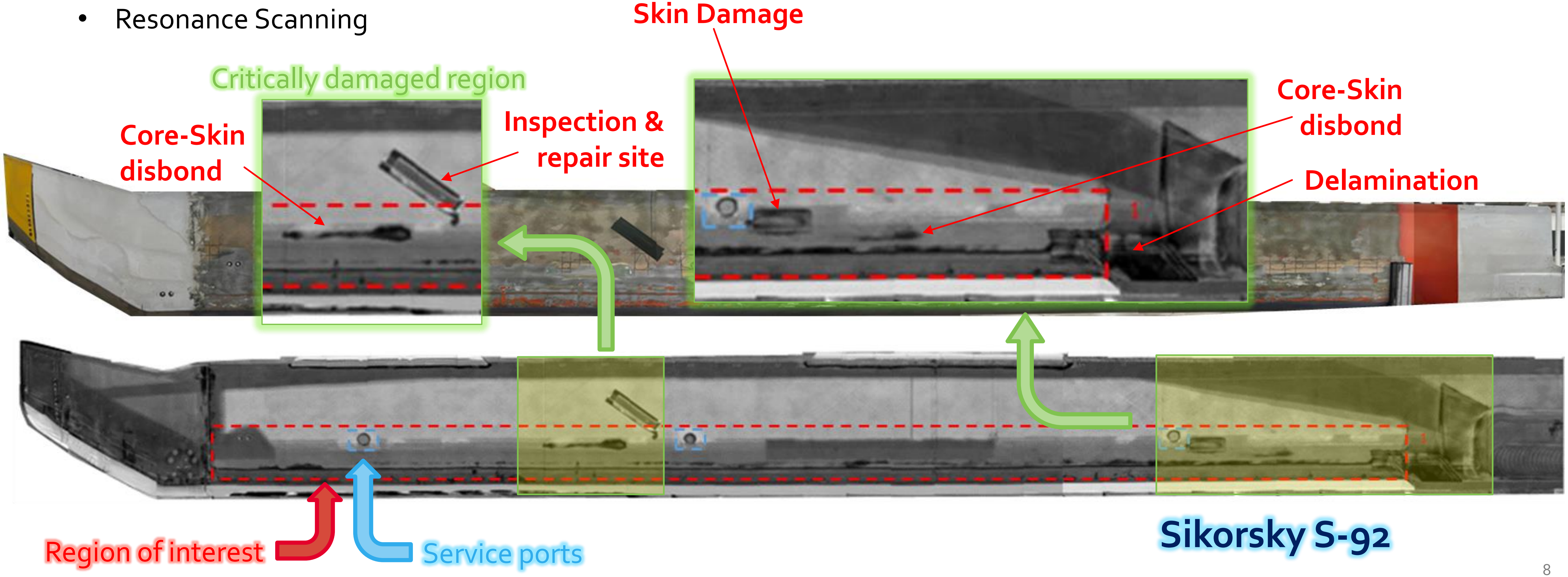


Component Level Nondestructive Inspections

- **Nondestructive Testing System Mobile Automated Scanner System (NDTS MAUS V)**
  - Mechanical Impedance
  - Ultrasonic Pulse-echo
  - Resonance Scanning
- **Laser Technology Inc. (LTI)**
  - Laser Shearography
- **Thermal Wave Imaging (TWI)**
  - Pulsed Thermography



Sikorsky S-92

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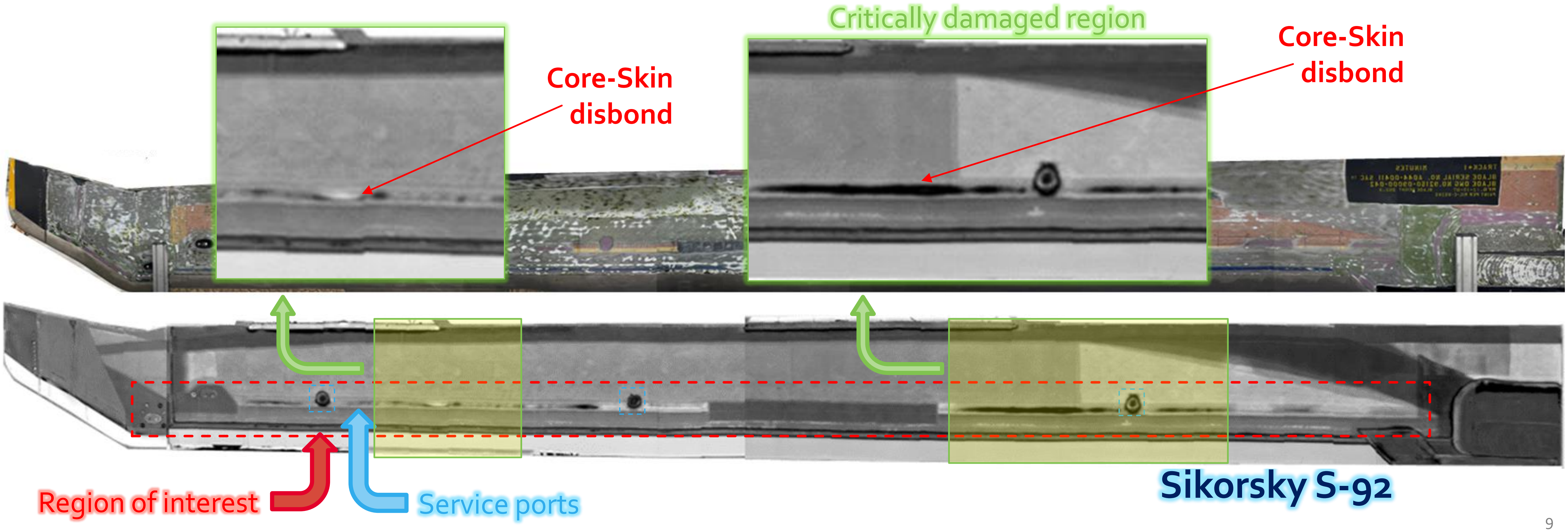

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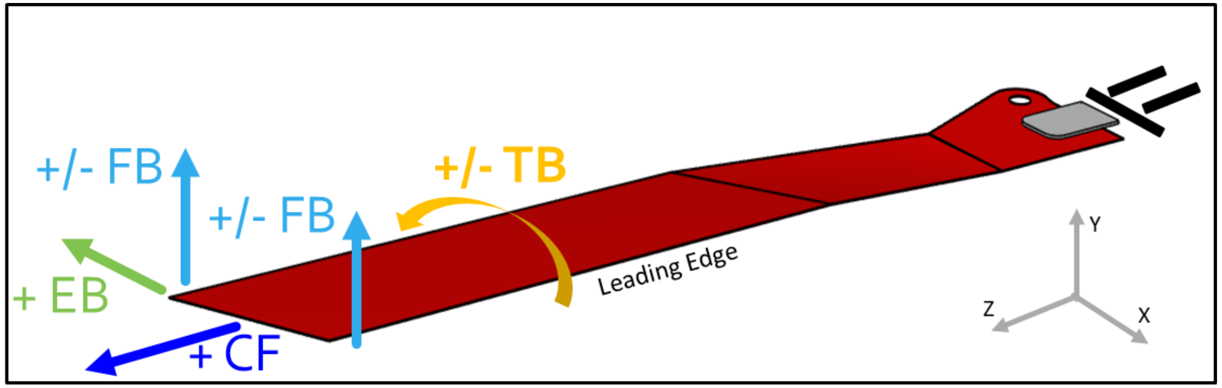
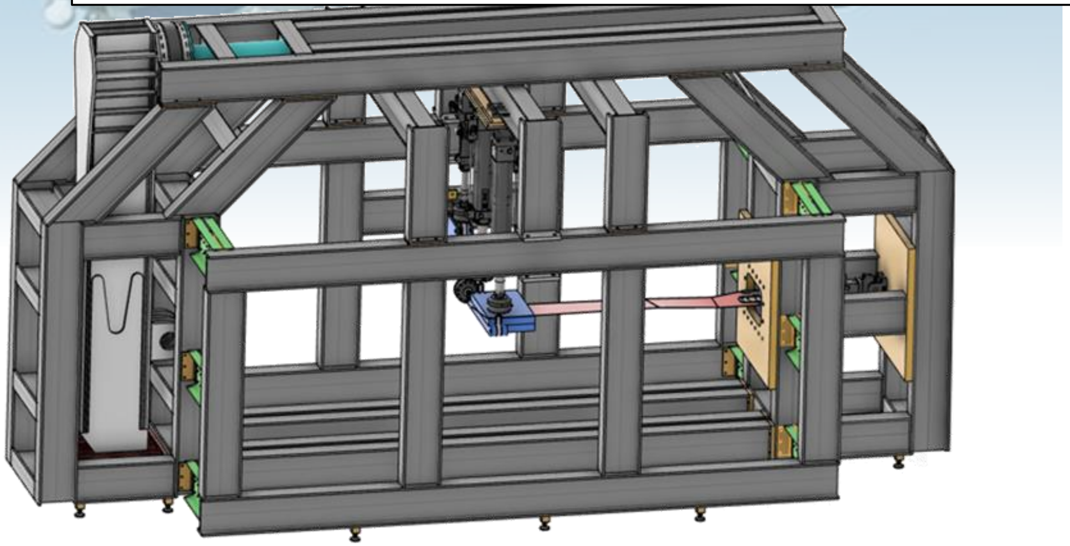
Structural Testing Apparatus NIAR & FAA Tech Center

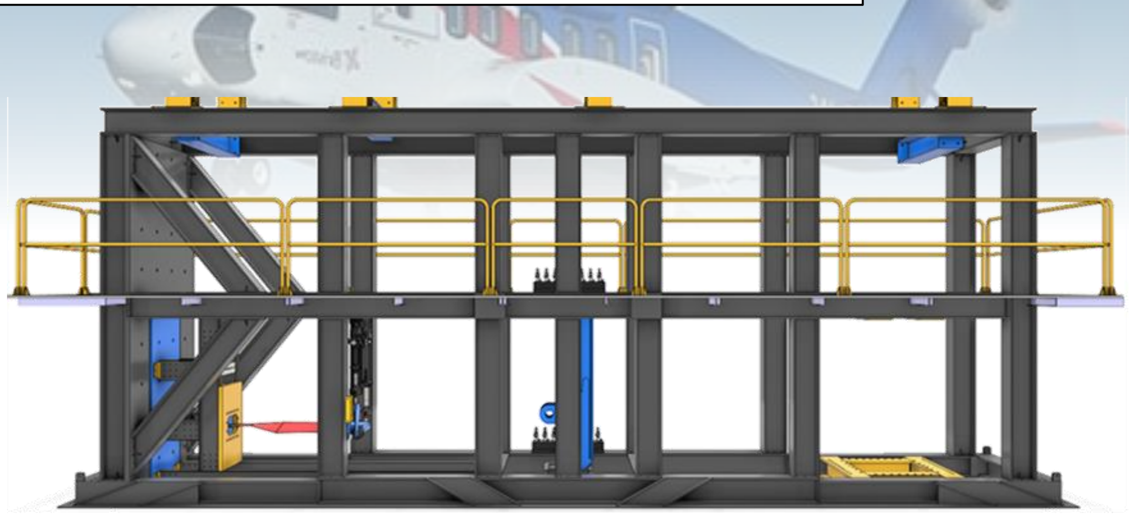
External Forces

- Centrifugal + (CF)
- Torsional Bending +/- (TB)
- Flatwise Bending +/- (TB)
- Edgewise Bending + (EB)





Modular design for testing at FAA Technical Center



Built for testing at NIAR ATLAS

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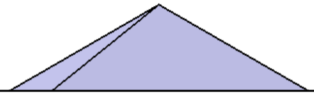
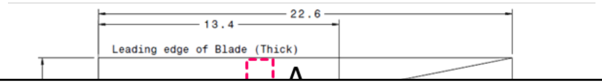
Load Introduction and Fixture Design Overview

To adequately test the helicopter blade in segments, additional support must be adhered to the skin of the blade for fixture attachment and subsequent loading.

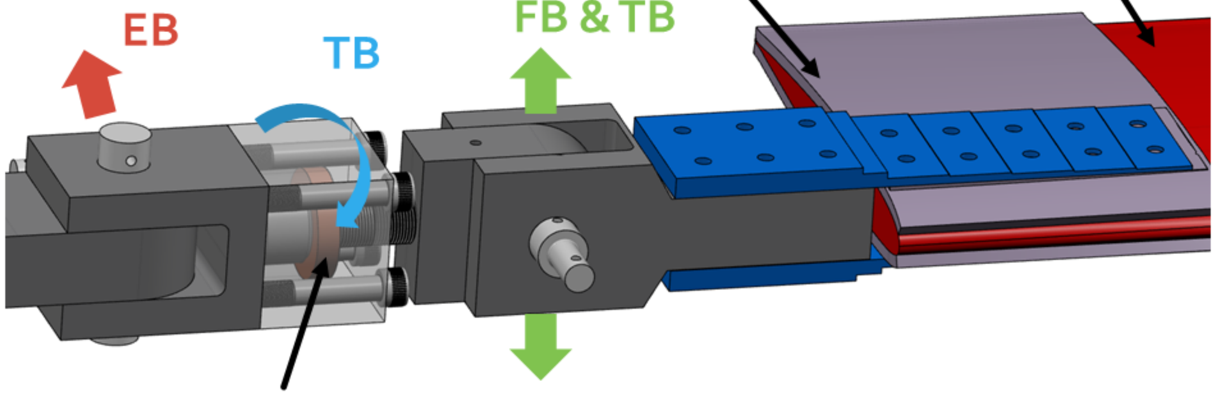
- *Laminate Pack Design ✓*

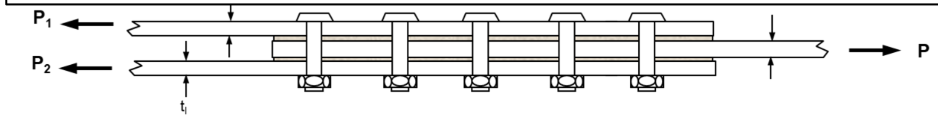




NIAR & FAA Test Fixture/Load Application

- Appling torsion, edgewise, and flatwise from the outboard end.
- Complex connections to allow for necessary degrees of freedom.





Centrifugal forces may exceed 120,000 lb!

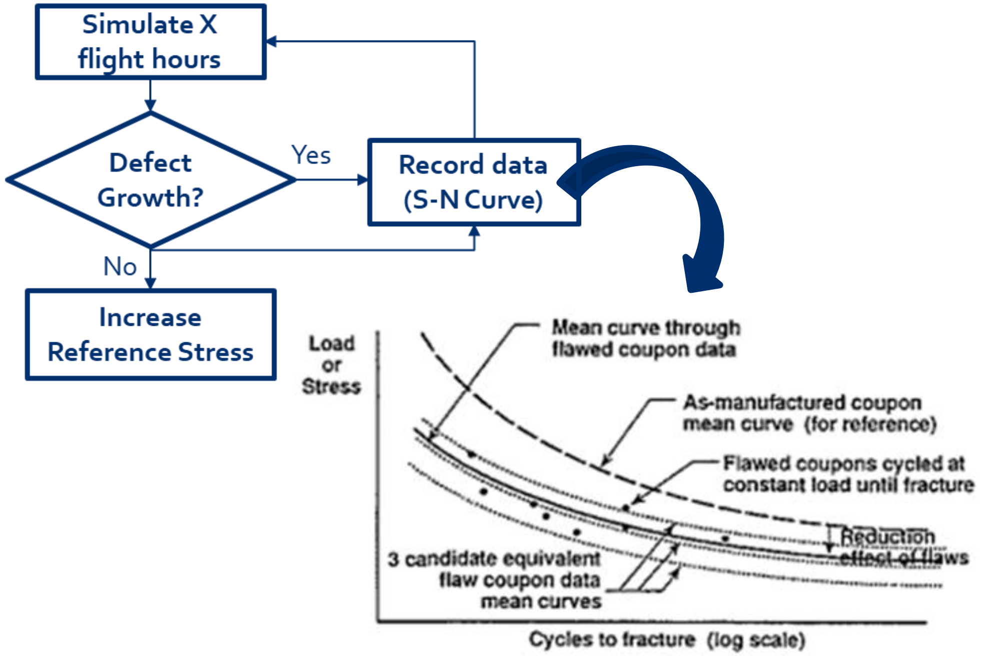
-45° Plies

Fatigue Testing of Root-End Rotor Blade Structure

- High-Cycle Low-Stress
  - Pro: Better simulates the actual fatigue wear experienced during usage.
  - Con: Difficult to simulate and accurately produce fatigue data.
- Low-Cycle High-Stress
  - Pro: Fast fatigue run-time and lower cost experiment.
  - Con: May produce unrealistic damage, not representative of actual fatigue.
- Constant Amplitude Loading
  - Pro: Easy to simulate, clean S-N curves that require no interpretation.
  - Con: Unrealistic simulations, costly to generate enough fatigue data for validation.
- Flight Spectrum Loading
  - Pro: Preserves Load sequencing effects, saves significant time and money.
  - Con: Somewhat difficult to accurately simulate loads in an accurately representative loading sequence.

Adhesive Oriented Flaw Tolerance

1. Generate fatigue life curve for current (aged state) of blade.
2. Monitor damage growth of defects in bond lines.
3. Generate additional fatigue curves correlated with damage growth.



Ground Air Ground (GAG) Loading

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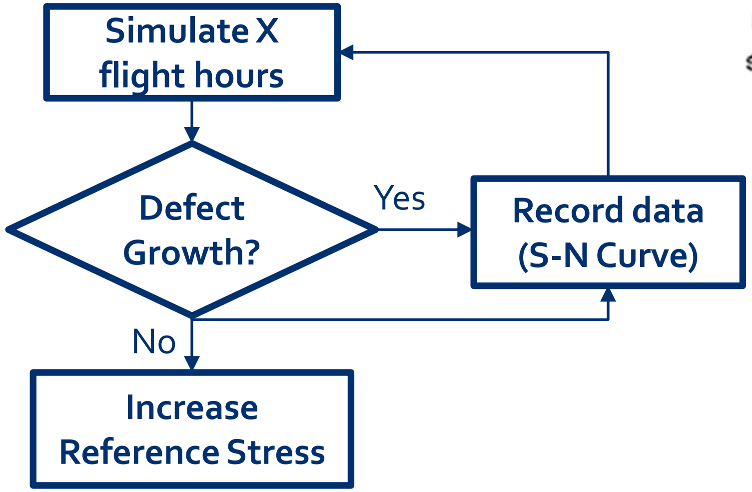
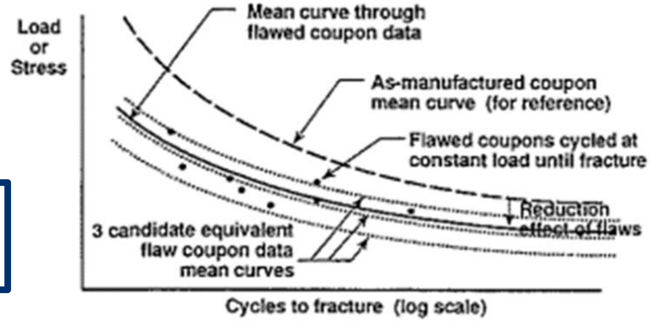




Flaw Tolerant - Safe Life Methodology[1]

- Miner's Rule used to set inspection/retirement prior to crack initiation from clearly detectable flaws (dents, scratches, corrosion, etc.).
- Inspection is for flaws based on *S-N* testing of flawed component.
- Component can be inspected for flaws and returned to service if none found or repaired if flaws found.
- Component can be retired based on crack initiation from barely detectable flaws.

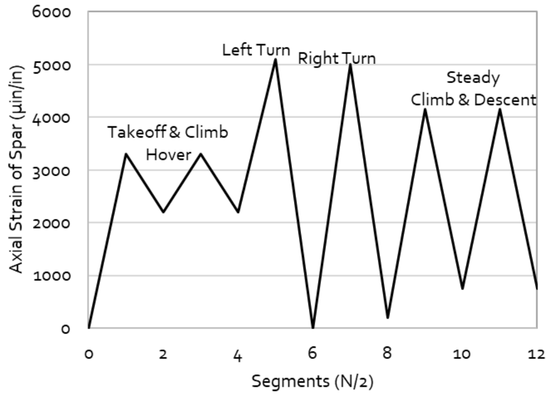
Strength Tracking Method Implementation

1. S-N Curves
2. Residual Strength Degradation Model
3. **Iterative Fatigue life Estimation**
4. **Compare to Miner's Rule**

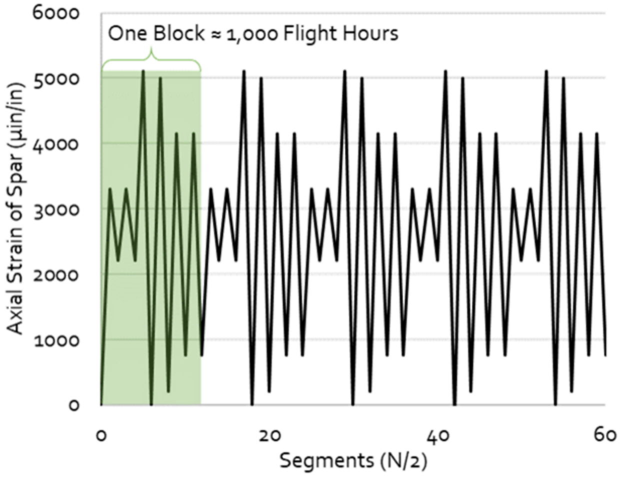
1: *FATIGUE AND DAMAGE TOLERANCE, Bill Dickson et. al*

Flight Spectrum Loading for Root-End of Blades

- **Simulated fatigue cycle count is extrapolated from legacy S-N curves.**



1. Select and group specific flight maneuvers.
2. Correlate targeted axial spar strains to calibrated engineering units for loading.



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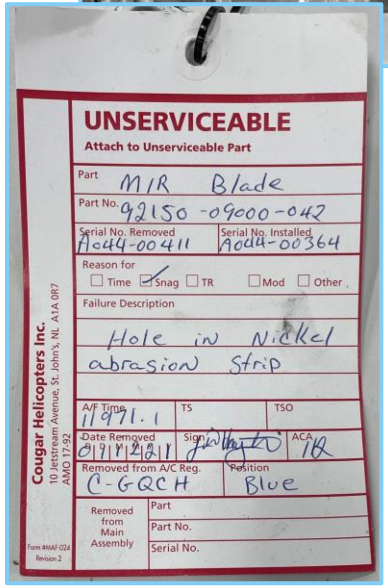
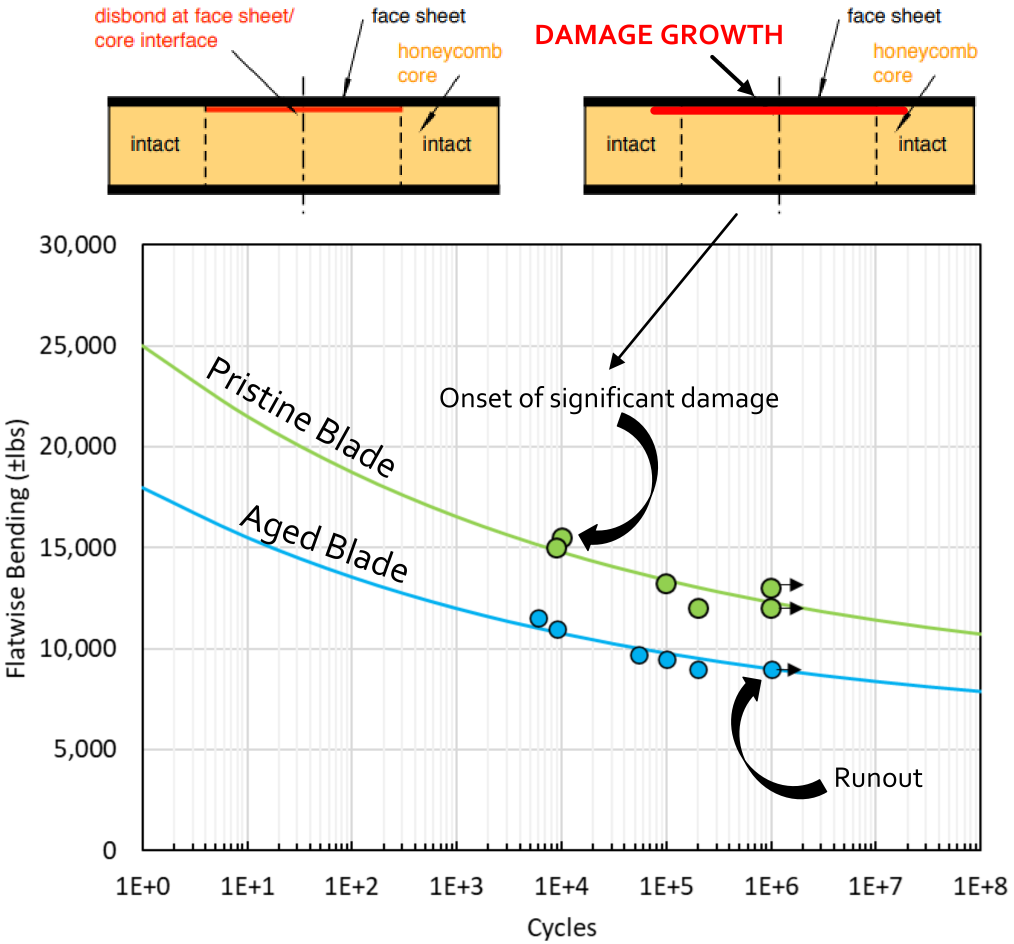
Rotor blade Fatigue Evaluation | Damage Growth Observation

Damaged & Aged Rotor Blades



Pristine Rotor Blades

- The onset of damage (Facesheet Disbonding) will be monitored with in-situ NDI Techniques



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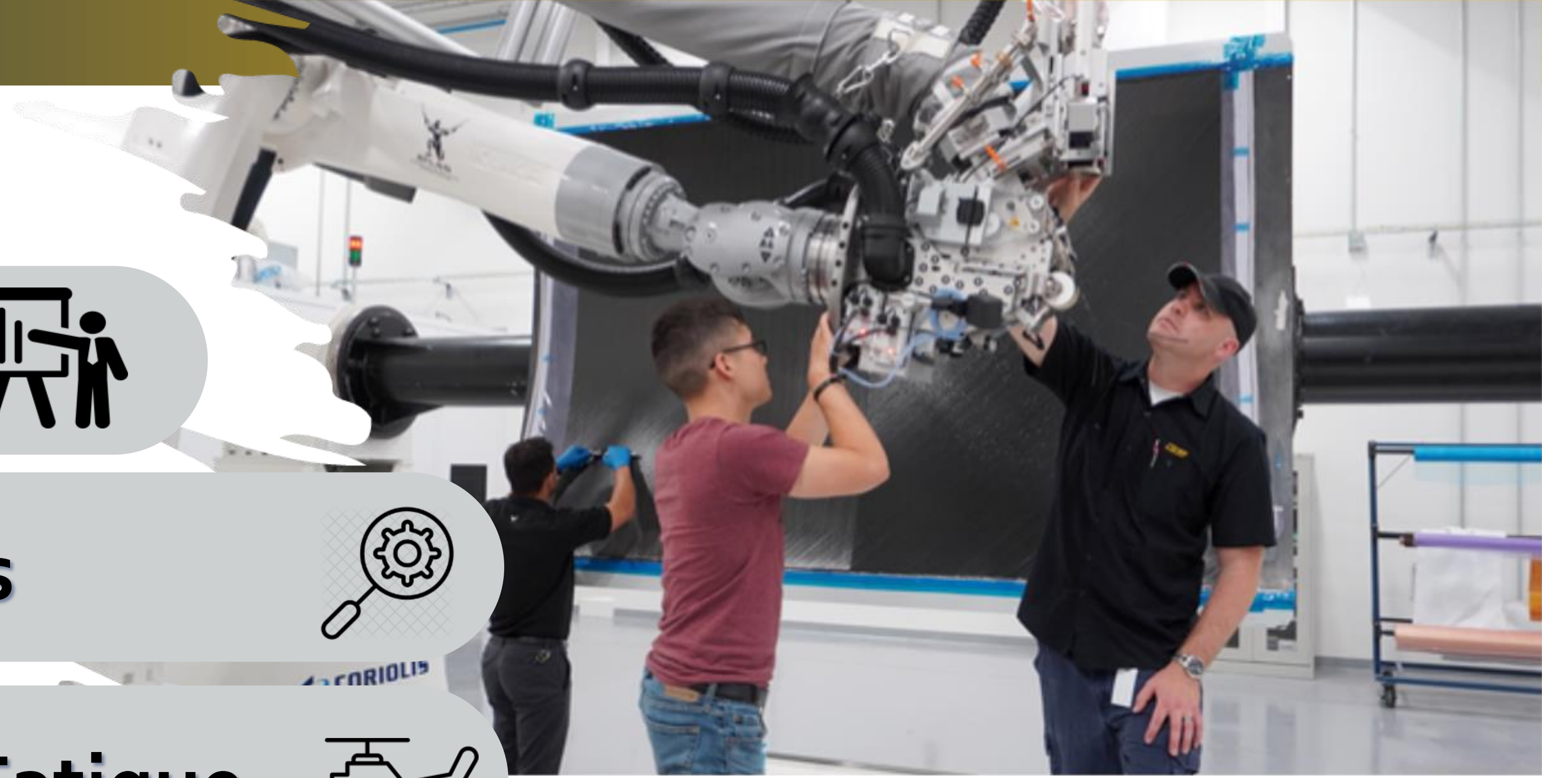
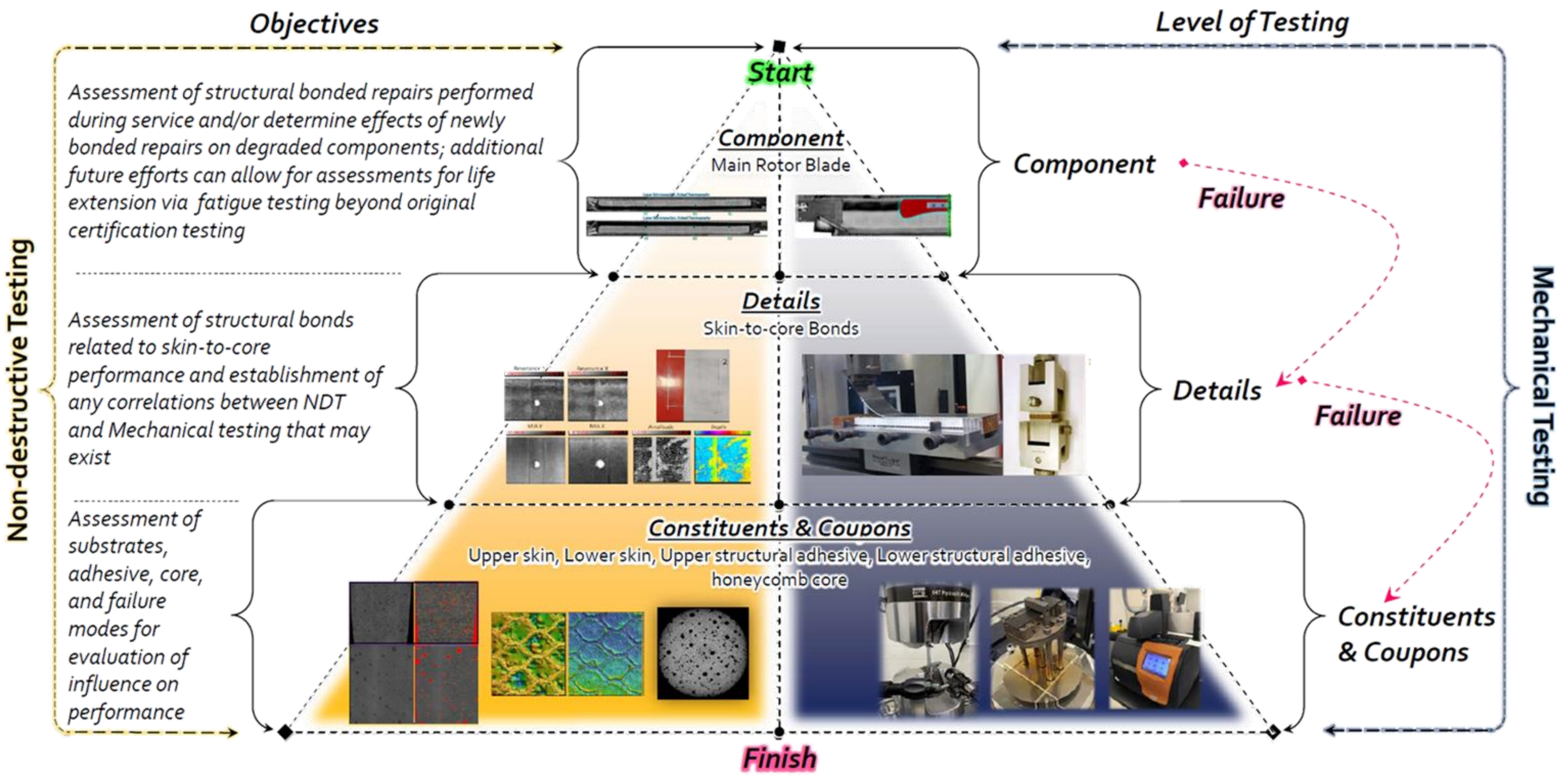
- Fixture Development and Fatigue
- **Teardown Testing Techniques**
- Trial Run

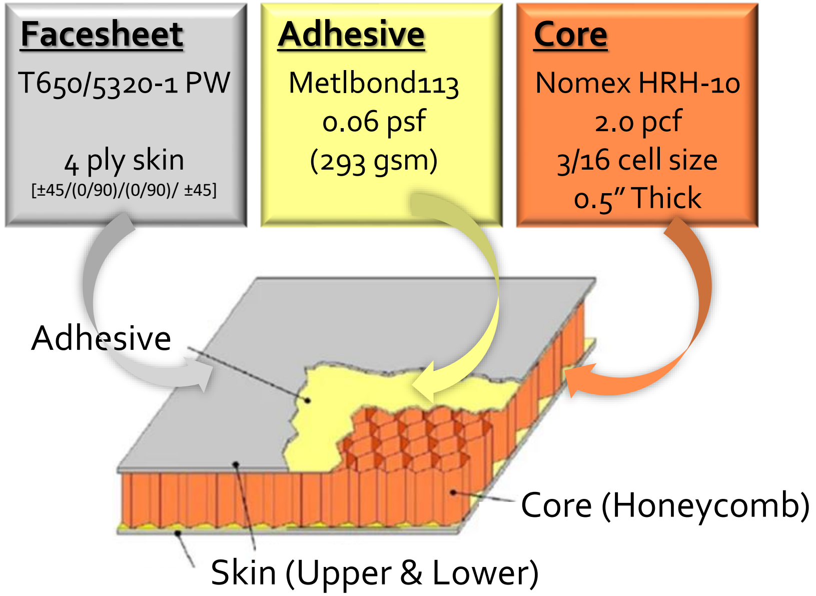


Teardown Testing Approach

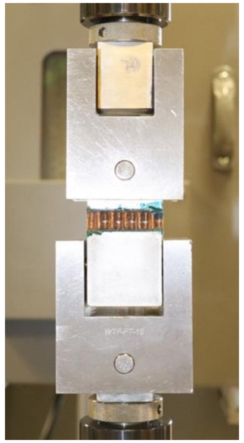


Coupon Level Testing | Artificial Aging Protocols

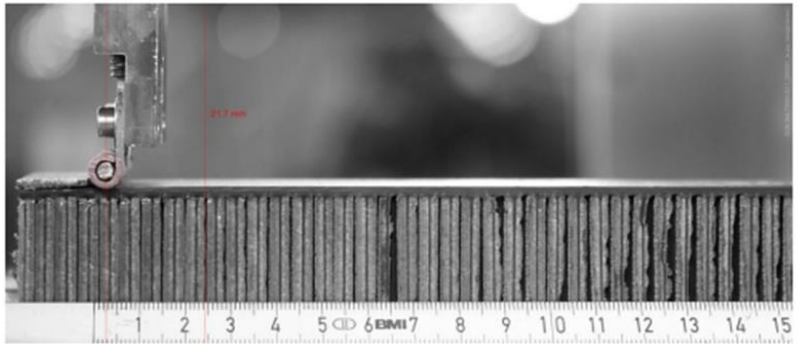
- Objective: Establish a testing methodology for laboratory aging of adhesive based details due to variable environmental conditions.



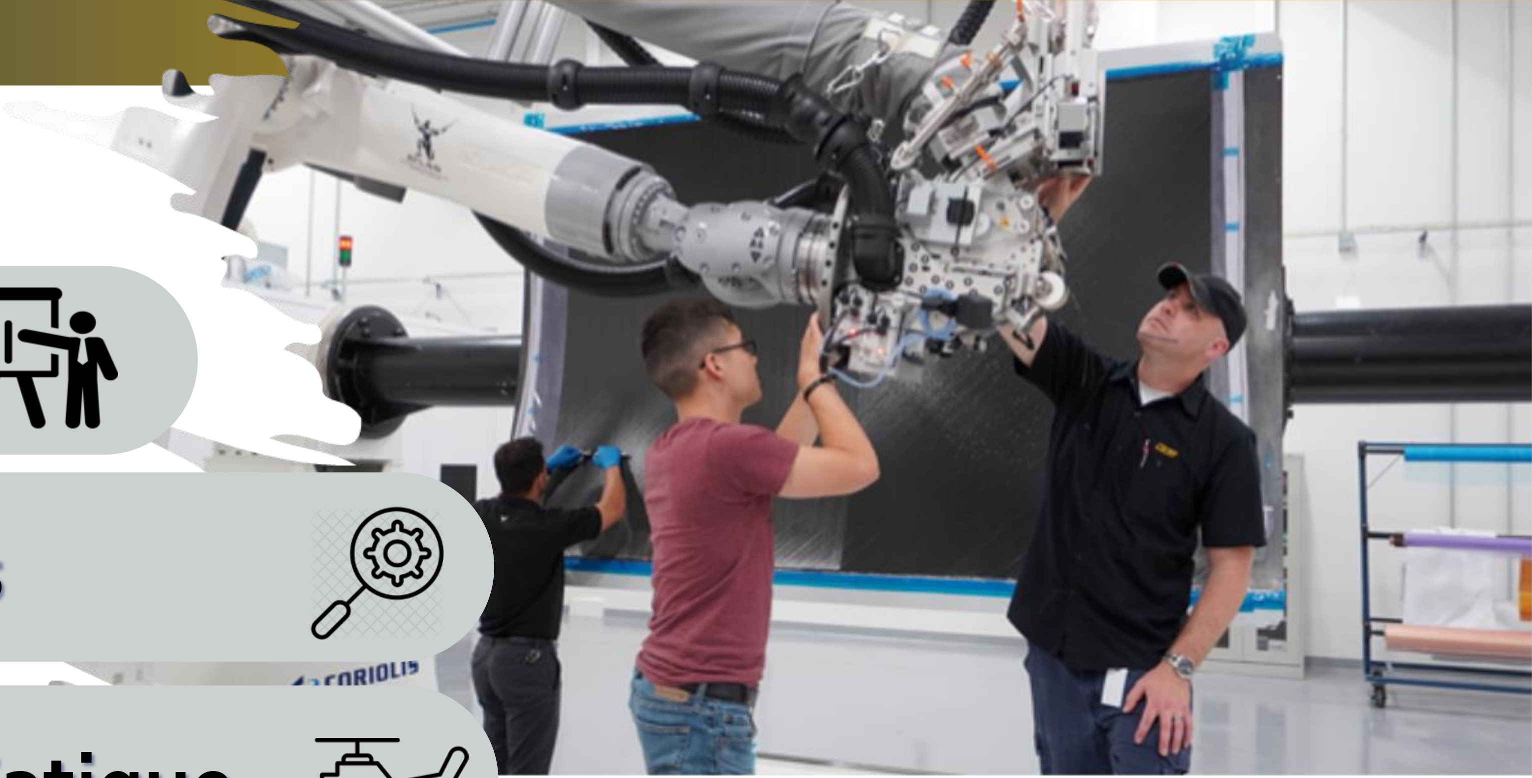
- Approach
  - Two Configurations: Pristine vs Artificially Induced Porosity
    - Pristine coupons are manufacture with dried cores, Porous with wet cores.
  - Similar materials that are used in rotor blade construction
    - Facesheet: T650/5320-1 PW
    - Adhesive: Metlbond 1113 [0.06-psf]
    - Core: HRH10-3/16-2.0
  - Baseline and Intermediate Testing
    - Peel and Flatwise Tension
    - Hi-fidelity NDI via X-ray Computed Tomography



Flatwise Tension



Single Cantilever Beam (Peeling)



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Questions?

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