JAMS
JOINT ADVANCED MATERIALS & STRUCTURES
CENTER OF EXCELLENCE

Evaluation of Aged Bonded Rotor Blades

JAMS 2021 Technical Review

September 22nd, 2021

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CMH-17
COMPOSITE MATERIALS HANDBOOK

NIAR
WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

ATLAS
ADVANCED TECHNOLOGIES LAB FOR AEROSPACE SYSTEMS

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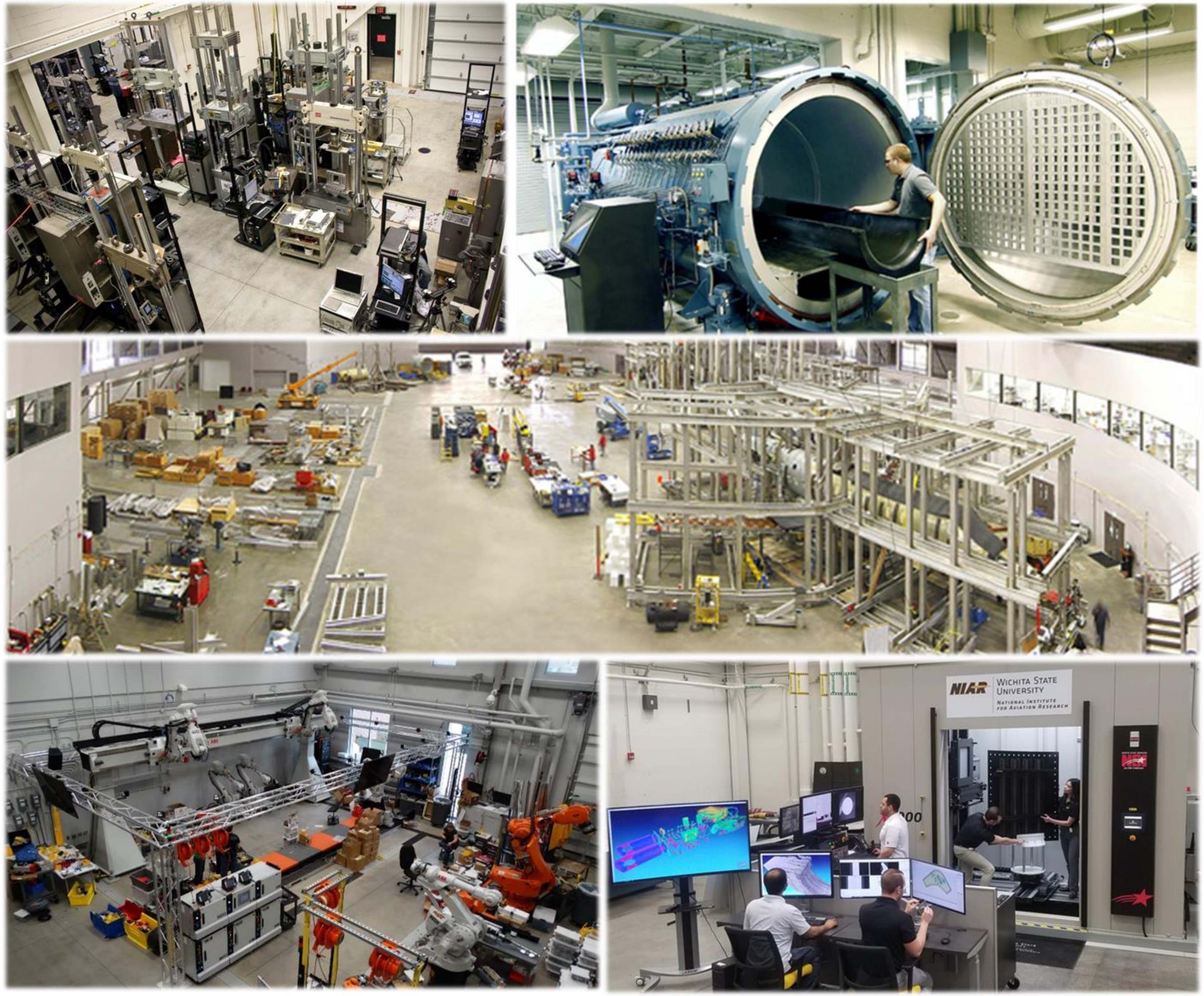


Motivation

- **Current Certification Method of Composite Aircraft Structures**
  - Relies on development of safe usage life through fatigue testing
  - Required to design with environmentally compensated static loads with considerable analytic reductions in strength
  - Rare that full-scale fatigue testing of aircraft components exercises the full capability of the composite structural members
    - The expense of fatigue testing rarely permits continued testing past the original design goals for the program
    - These factors combine to prevent composite structures from being failed during the fatigue test
    - As a result, there is little capability over the course of the aircraft life to relate in-service events to known fatigue limitations of the original certification test and no mechanism to employ engineering principles for the extension of life

Motivation

- **Increased use of Bonded Applications in Critical Structures**
  - 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
  - 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

Program Tasks

Investigate unknown behaviors of aged bonded composite rotor blades and field repairs to gain a fundamental understanding of the aging mechanism of bonded dynamic structures.

1. Compare accelerated aging protocols to real life
2. Demonstrate improved accelerated testing in rotor blade bench tests
3. Compare “state of adhesive” or “state of resin” on old blades to the initial state of these polymeric materials on new blades.
4. Compare existing repairs on old blades and new repairs on old blades to new repairs on new blades

* Concern that unique dynamic loads for rotor blades yield complex history-dependent behavior for products with shifting missions *

Support Key Initiatives of the FAA AVS Composite Plan: *1) Continued Operational Safety (COS) A: Bonded Structure; 2) Certification Efficiency (CE) E: Bonded Structure Guidance; 3) Workforce Education (WE) B: Composite Structures Technology*

Roadmap of Technical Approach

Phase I:
Main Rotor Blade Acquisition


S-76A
3,274-hrs


AW109
4,352-hrs

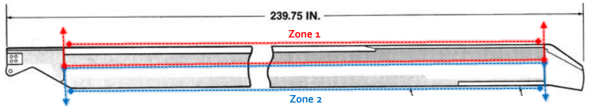

HH-65
10,458-hrs

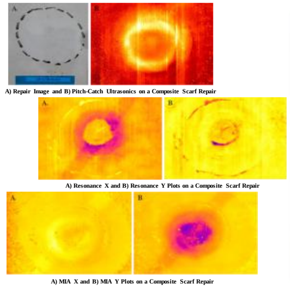
Phase II:
NIAR Inspections

Receiving Inspection:
Defect and Damage Evaluation

- Visual
- Resonance
- Mechanical Impedance
- Phased Array
- Laser Shearography
- Pulsed Thermography

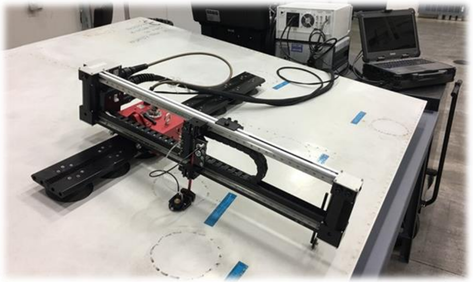
NDI Report:
Damage Maps, Repairs, etc.




A) Repair Image and B) Pitch-Catch Ultrasonics on a Composite Scarf Repair

A) Resonance X and B) Resonance Y Plots on a Composite Scarf Repair

A) MIA X and B) MIA Y Plots on a Composite Scarf Repair



Phase III:
Teardown / Detailed Inspections / Testing

Inboard:
Cuff / Pocket

Leading Edge:
Abrasion Strip

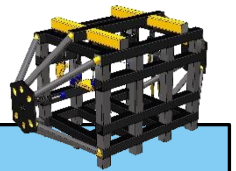
Pocket
Mid-span

Teardown: ROI Determines Testing

Mechanical Testing
- Specimen: SCB, FRP
- Element: 4PT Flex, etc.

Physical Testing
- Porosity
- Tg
- DOC

Detailed NDI
- XCT
- Photomicrographs



Full Scale Testing
Focus on Initial NDI and Areas Found in Element Tests

Component Testing:
Inboard Section

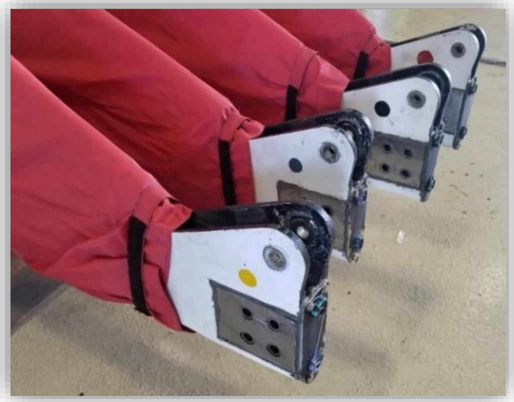
Teardown:
Outboard Section

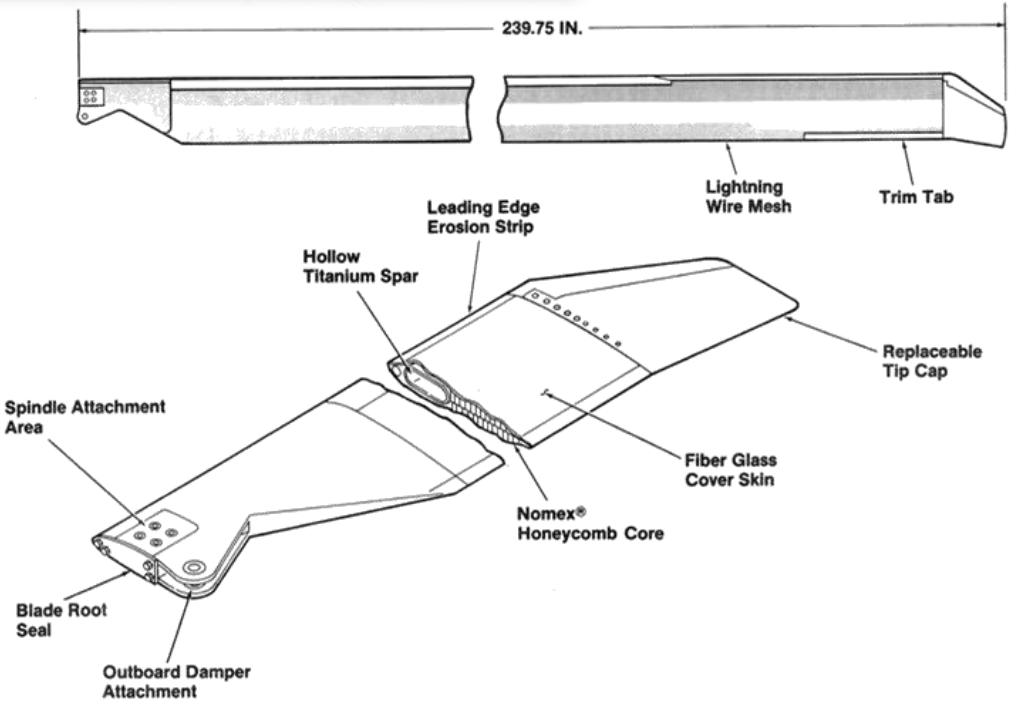
- Strain Survey
- Fatigue

Final Report:
Document Findings

Phase I: Main Rotor Blade Acquisition

- **Sikorsky S-76A**
  - Tail Number: N38
  - Aircraft Time: 3,274-hrs
  - Landings: 10,322
- **Four Main Rotor Blades**
  - Two have been acquired at NIAR
  - Two remain with the FAA





Phase I: Main Rotor Blade Acquisition

- **Leonardo AW109**
  - Entered Service: 2001
  - Blade Time: 4,352-hrs
    - Lufttransport RW AS based in Norway: 2001-2012
    - PAS based in South Africa: 2012-2019
  - End of Service: 2019
- **Single Main Rotor Blade**
  - Acquired and at NIAR

Phase I: Main Rotor Blade Acquisition

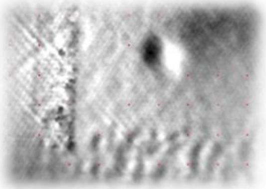
- **Eurocopter HH-65 (Coast Guard)**
  - Entered Service: 1987
  - Blade Time: 10,457.70-hrs
  - End of Service: March 7th, 2017
    - Scrapped by the USCG due to rotor over torque to 111.8% and carbon damage at trim tabs out of limits for repair – Obtained from Significant Component History Report
- **Single Main Rotor Blade**
  - Acquired and at NIAR

https://www.jetphotos.com/photo/9711

Phase II: NIAR Inspections

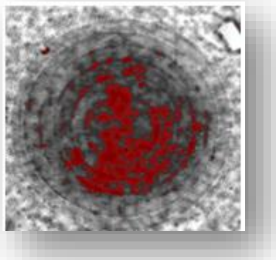
1. Laser Technology Inc. (LTI)

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



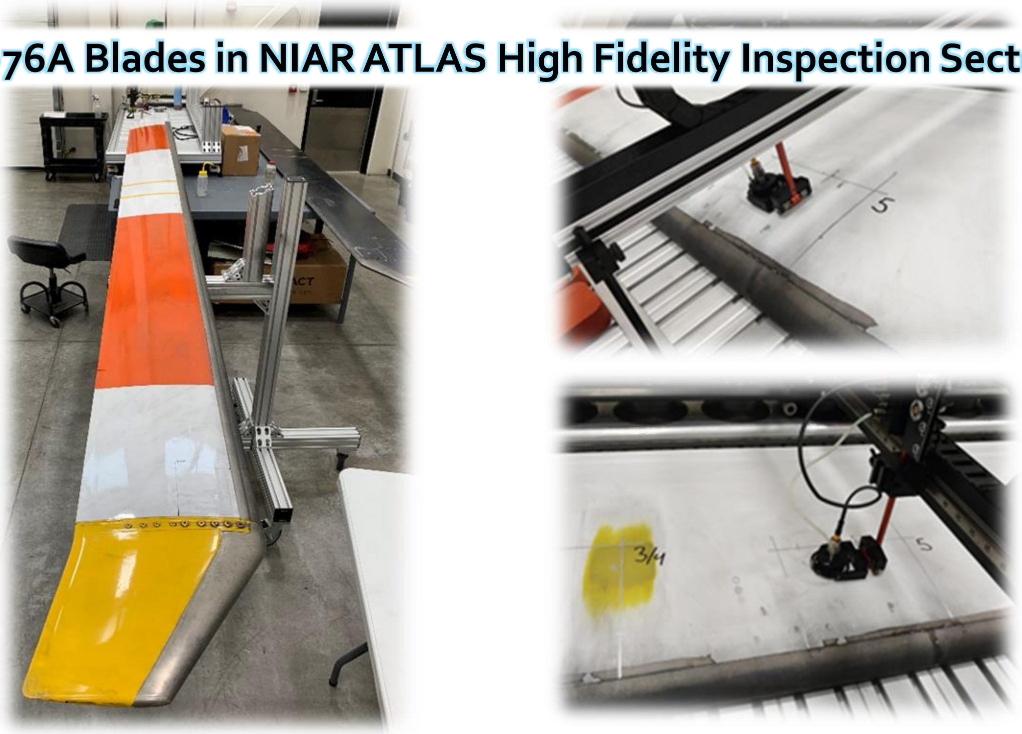
2. Thermal Wave Imaging (TWI)

- Pulsed Thermography: X8500 SC Camera
  - Resolution: 1280x1024
  - Frequency: 180-Hz



3. NDTS MAUS

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

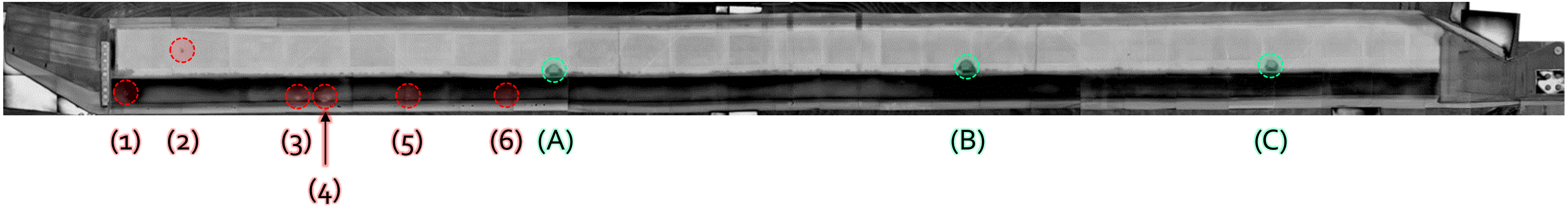


S-76A Blades in NIAR ATLAS High Fidelity Inspection Sector

Phase II: NIAR Inspections

Sikorsky S-76 (S/N: A086-00686)

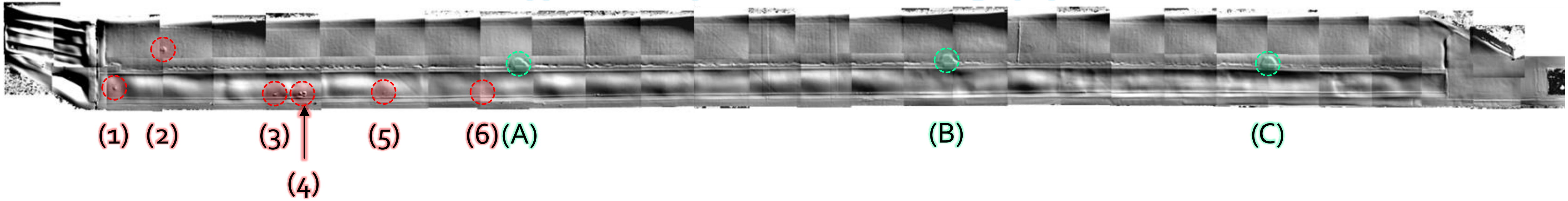
Upper Skin Inspection: Pulsed Thermography



Key

- Defect/Damage Indication
- Known Features

Upper Skin Inspection: Laser Shearography



Phase II: NIAR Inspections

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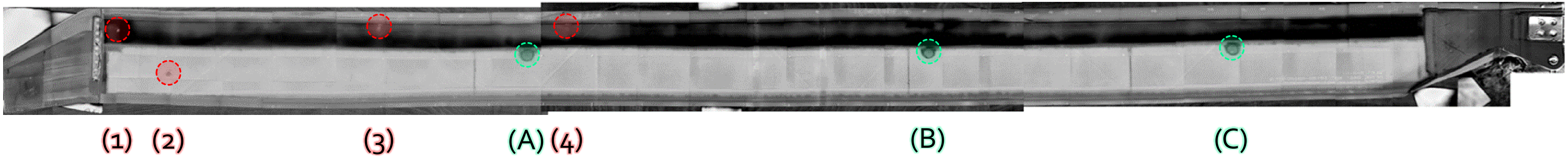

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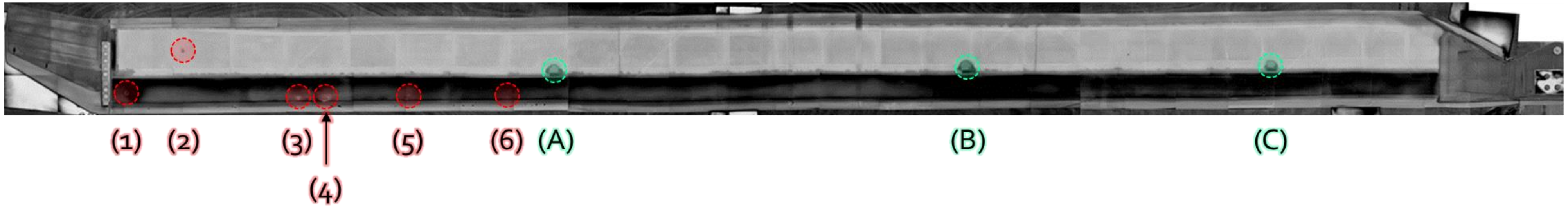

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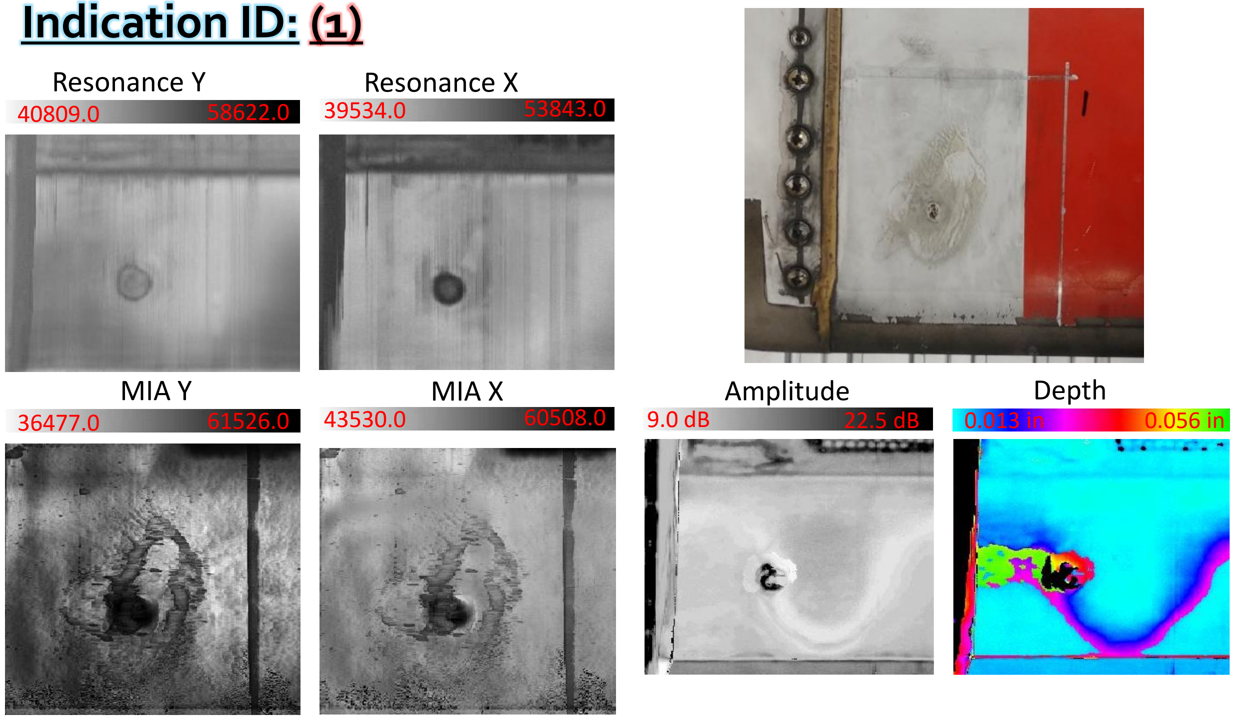

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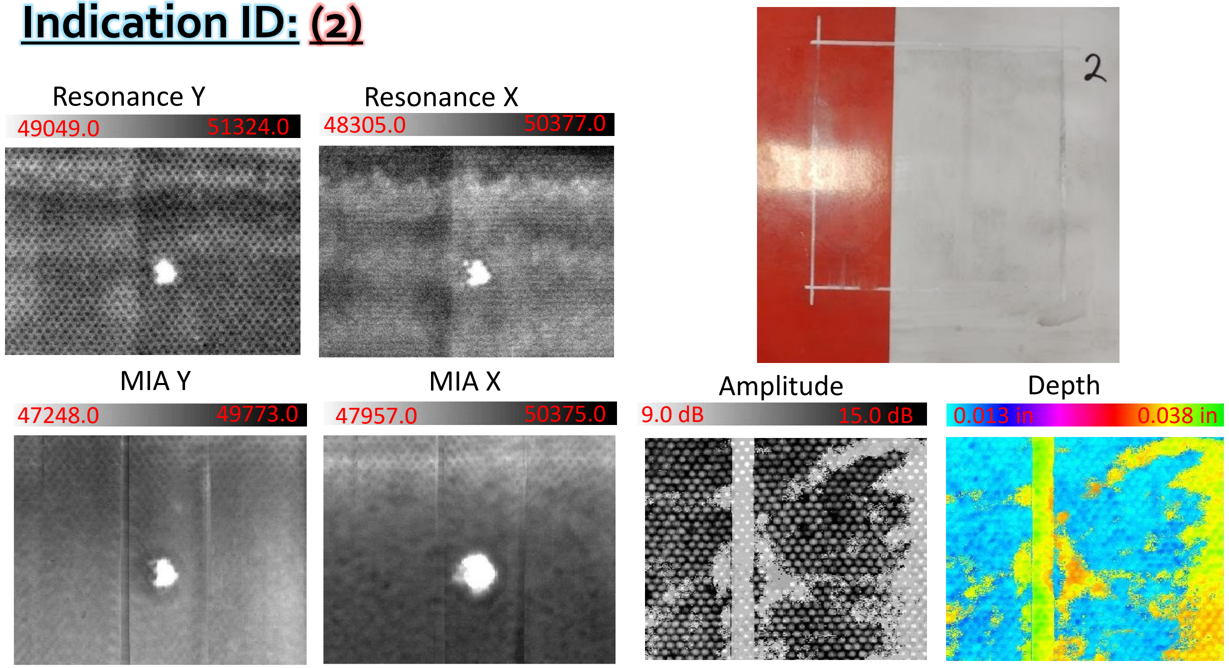

Phase II: NIAR Inspections

Sikorsky S-76 (S/N: A086-00686)

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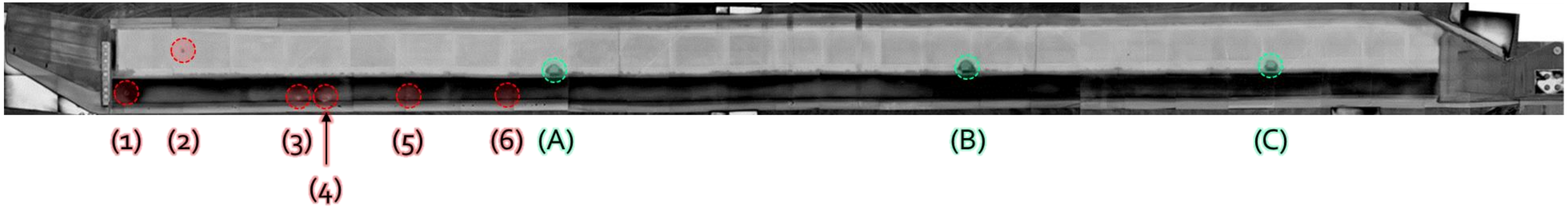

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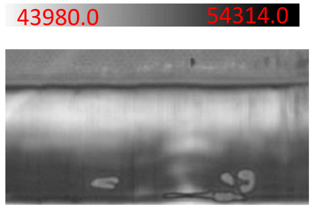
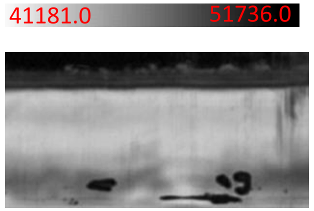
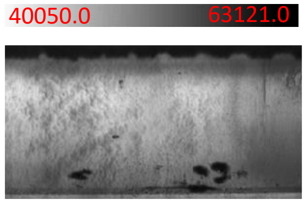
Resonance Y



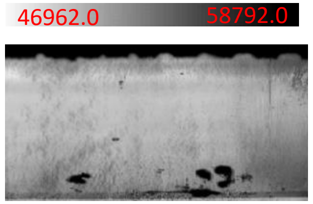
Resonance X



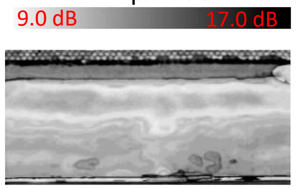
MIA Y



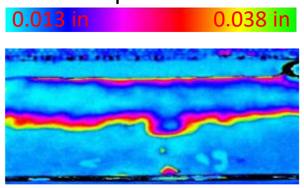
MIA X



Amplitude



Depth



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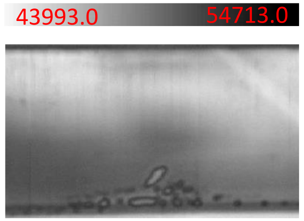
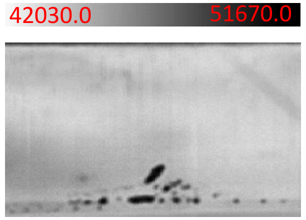
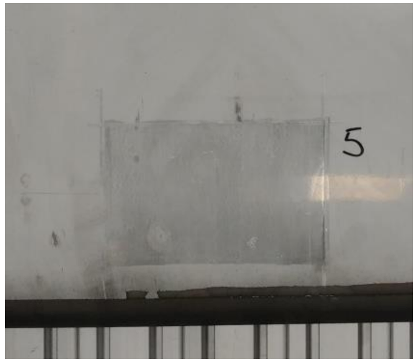
Resonance Y



Resonance X





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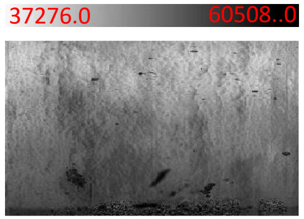

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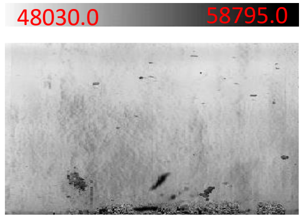

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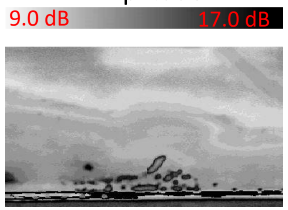

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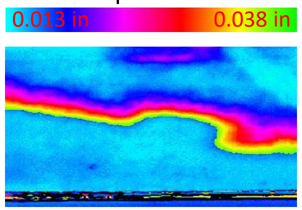
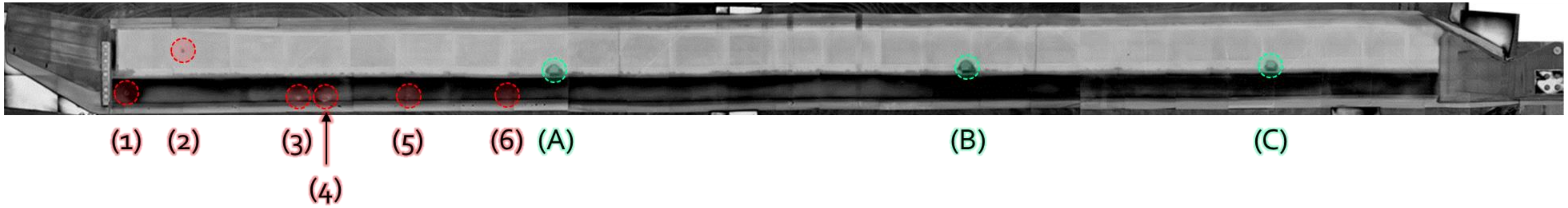


Phase II: NIAR Inspections

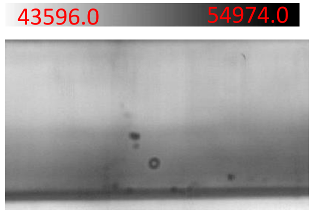
Sikorsky S-76 (S/N: A086-00686)

Upper Skin Inspection: Pulsed Thermography

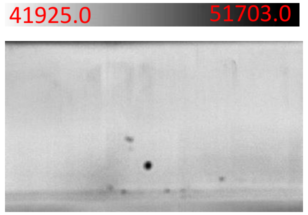


Indication ID: (6)

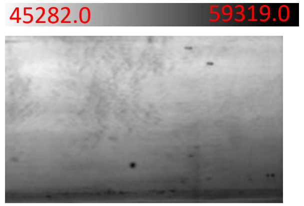
Resonance Y



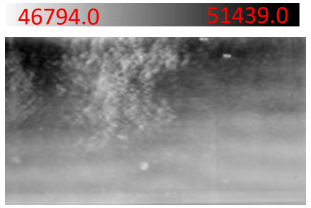
Resonance X



MIA Y



MIA X



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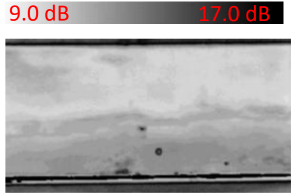

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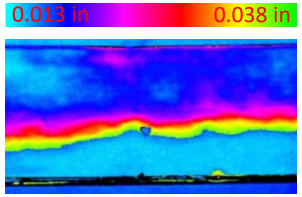
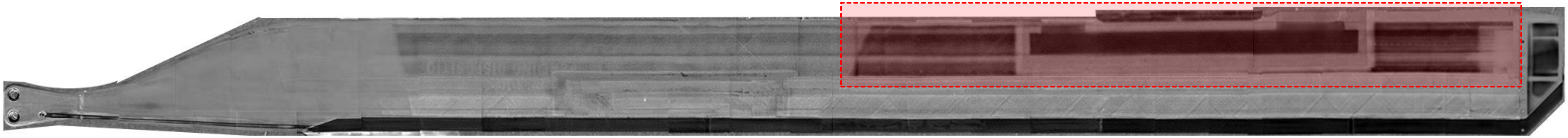


Phase II: NIAR Inspections

Eurocopter HH-65

Upper Skin Inspection: Pulsed Thermography

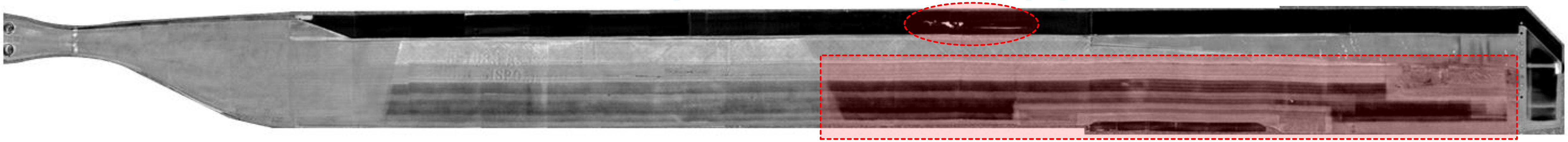


(1): Investigating to Determine Internal Structure

Key

- **Defect/Damage Indication**
- **Known Features**

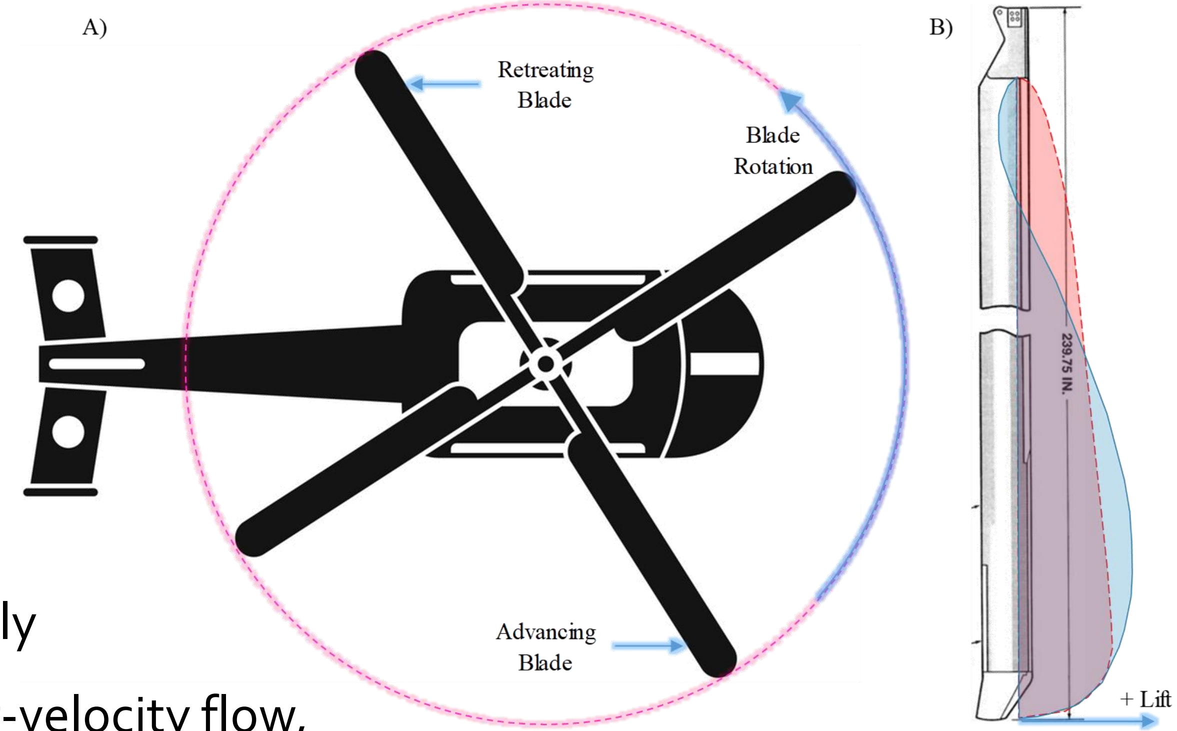
Lower Skin Inspection: Pulsed Thermography



(2)

(1): Investigating to Determine Internal Structure

Dynamics of Rotorcraft Flight



- **Airborne Rotorcraft Forces**
  - Thrust, drag, weight, and lift
- **Forces on Main Rotor Blades**
  - Lift, drag, centrifugal, and reaction forces
- **Airflow Considerations**
  - Hover: Relative wind along blade span varies linearly
  - Forward flight: Advancing blade encounters higher-velocity flow, opposite the direction of travel; Retreating blade moves with the freestream airflow
    - Backflow creates a loss of lift – rotor system compensates using flapping and cyclic feathering
- **Rotor System Considerations**
  - Rigid, Semirigid, and Fully Articulated

Overview: Fixture Design

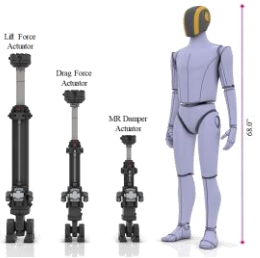
Teardown and Testing: Region of Interest

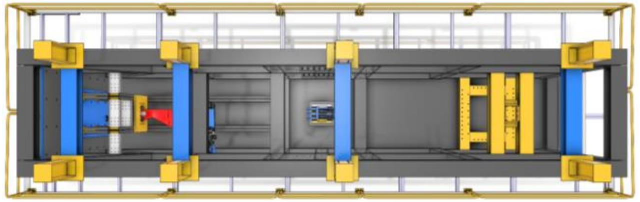
- **Shortened Test Section**
    - Less than 6.0-ft total blade length (~2.0′ to 2.5′ test section)
- **Remaining Structure**
    - Repair areas, damages, and other anomalies will be documented during NDT
    - Sub-element and specimen level studies will be conducted on assembly and constituents

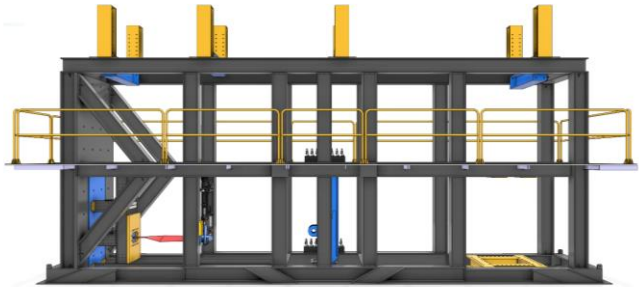
Test Rig Design Overview

- **Aero Load Simulation Through Structural Actuators and Airbag(s)**
    - Five total force inputs (Lift, drag, centrifugal, inboard lead/lag damper replacement)
- **NIAR ATLAS Fixture**
    - Incorporated into large test cell
- **FAA Tech Center Fixture**
    - Standalone for long term testing capability extension

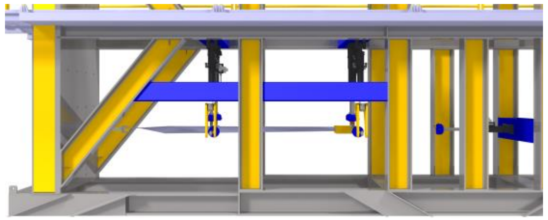
NIAR ATLAS





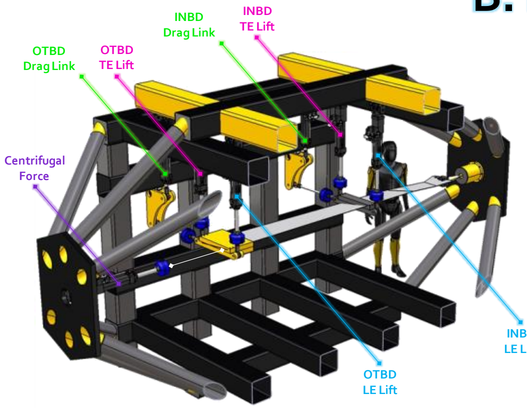


A. Conceptual Design



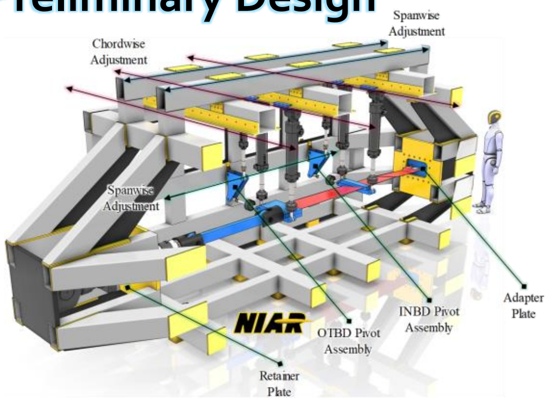
B. Preliminary Design

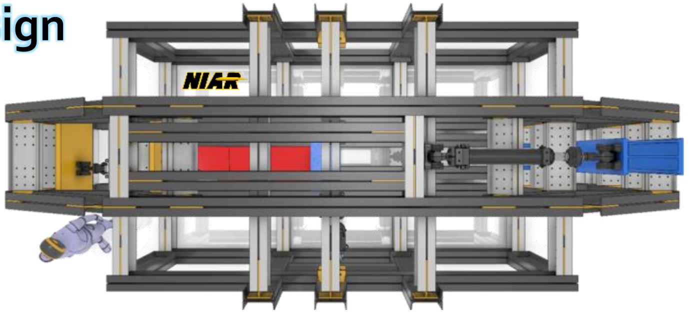
FAA Tech Center

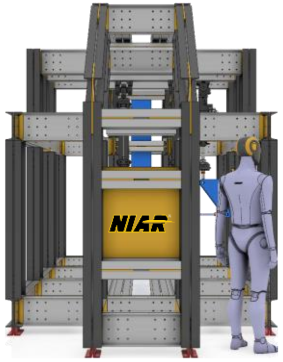


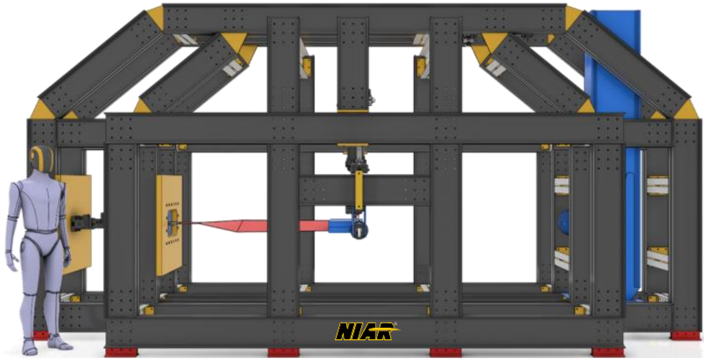
A. Conceptual Design

B. Preliminary Design









C. Detail Design

Benefits of Effort

- **Inspection and Teardown Procedures**
  - Enhancement of inspection procedures for digital data capture and improved flaw detection
  - Development of best practices associated with teardown of rotorcraft assemblies and components
- **Test Development**
  - Knowledge base enhancement in testing of rotorcraft blades/rotating components
  - Multipurpose test rig design and manufacturing for extended use into future research efforts and in support of potential industry overflow
- **Protocol Development**
  - Improvement of existing testing methodologies for acceleration of mechanical performance evaluations
  - Enhancement of rotor blade and other bonded aerostructure sustainment practices

Moving Forward

- **Additional Inspections of HH-65 Main Rotor Blade**
  - Laser Shearography (heat excitation)
  - Ultrasonics in regions of indications
- **Teardown of HH-65 Blade (Primary Focus on this Main Rotor Blade)**
  - Determine regions exhibiting defects/damage for removal from test campaign
  - Extract large region exhibiting prior in-service repair for bench testing focus
  - Extract regions just outside defect/damage area and outside of full-scale test section for specimen level investigations (compare to material specification and/or baseline material testing)
    - Skin Laminate / Skin-to-Core Adhesive / Leading Edge Adhesive

Moving Forward

- **Preparation for Bench Testing of HH-65 Blade**
  - Determination of representative flight loads
  - Design and implementation of centrifugal force reaction pad-up on blade section
- **Additional Main Rotor Blade Acquisition**
  - Current blade assets exhibit relatively low hours and zero replicates – aging effects and subsequent comparisons are limited
  - Access to DoD blades with structural adhesive aging effects present
    - Would benefit from additional work and would provide extreme value to program deliverables
    - Difficulty with sanitization of data and findings for release
    - Evaluating path forward
  - Still on the lookout for blade assets exhibiting higher hours and documented operating environments and usage

Questions

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