C-130 Inspection Development

Ryan Mooers

AFRL/RXSA 27 October 2020

Acknowledgments

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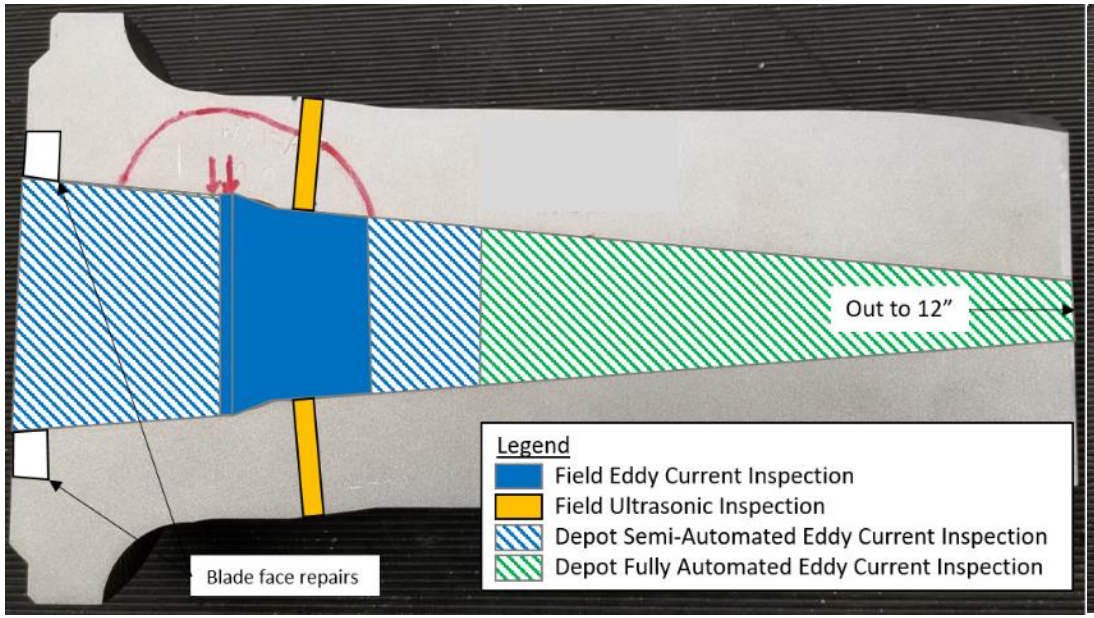
  - Kentucky Air National Guard
  - Hurlburt Field
  - West Virginia Air National Guard

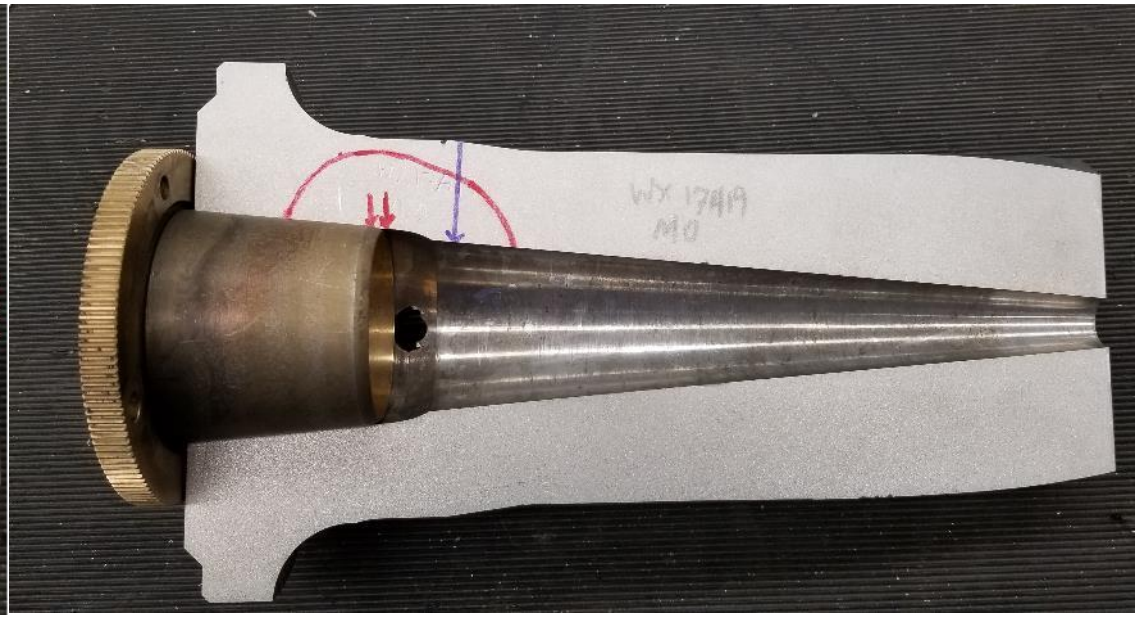
Outline

- Introduction/ Background
- Field Level Eddy Current Inspection
- Depot Level Eddy Current Inspection
- Automated Eddy Current Scanner
- On-wing ultrasonic Inspection

Introduction and Background

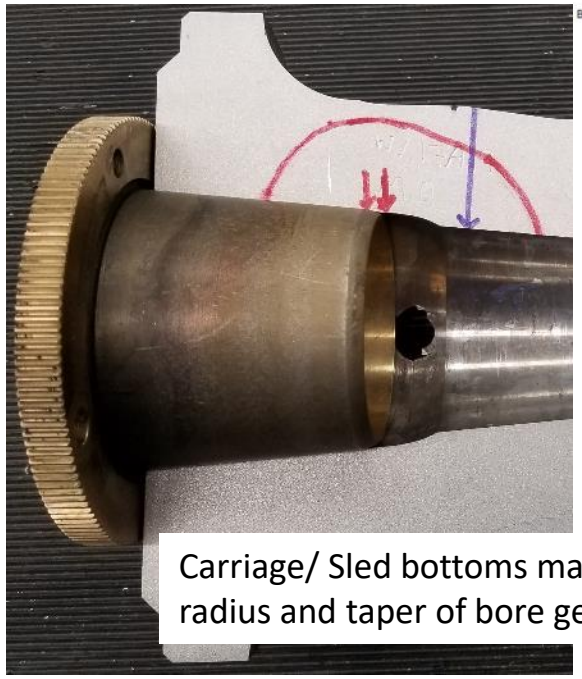
- Loss of KC-130T and 16 lives in July 2017
- Liberation of propeller blade was cause of crash
  - Stress corrosion cracking leading to fatigue failure
- AFRL expertise requested to support depot and field inspection solutions



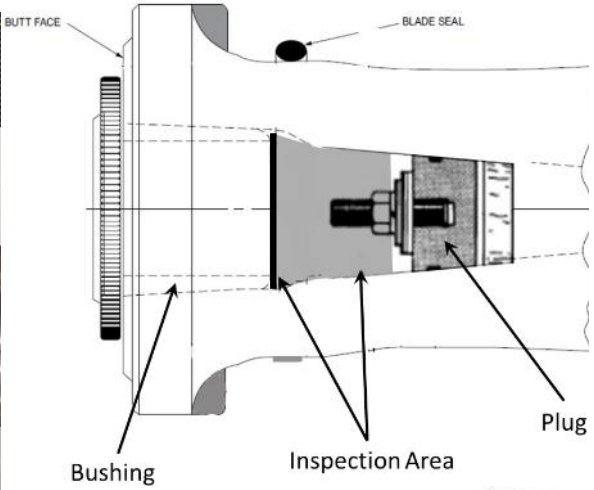


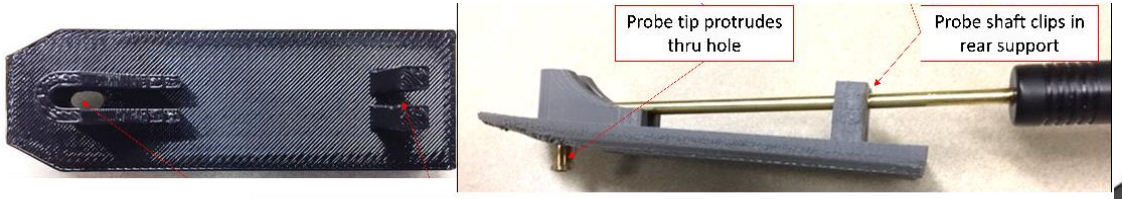
Field Level Eddy Current Inspections

- Off-wing inspection w/ bushing, gears, and coverings installed
- Two inspections:
  - Single line at end of bushing (black stripe)
  - From bushing to taper plug (gray area)
- Custom fixtures/ carriages constructed in-house
  - Ensures compliance and probe stability
  - 3D printed and sent to all C-130 field bases
- Use standard field available equipment
- Transition complete. Inspection in field use since 2018.

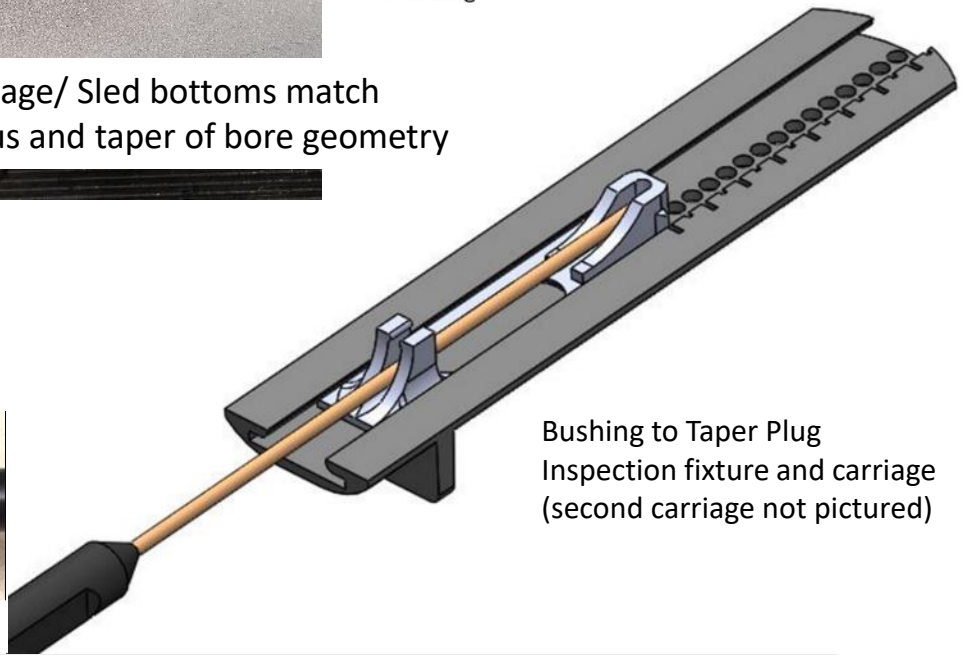


Carriage/ Sled bottoms match radius and taper of bore geometry





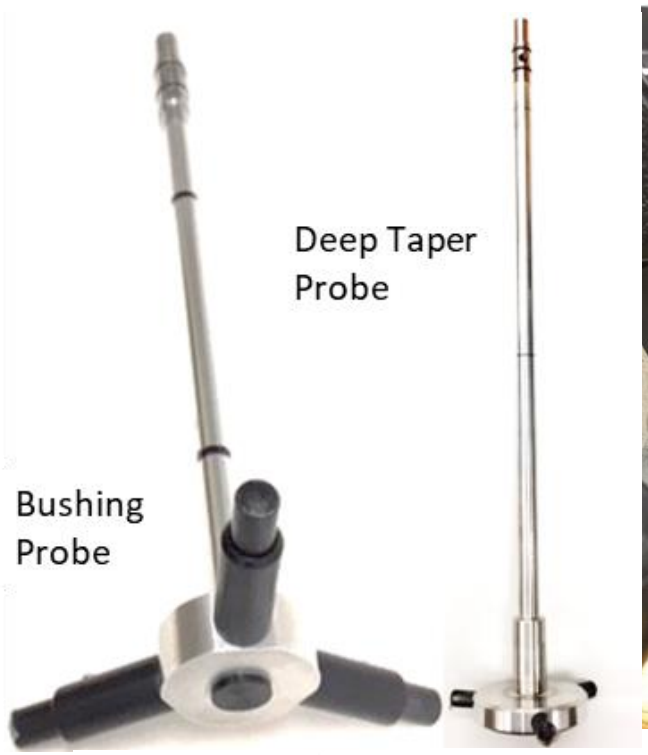
Bushing Line Inspection Fixtures

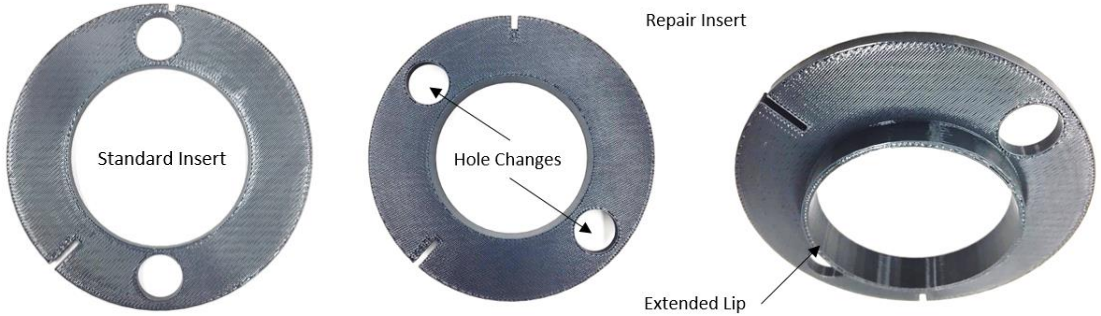


Bushing to Taper Plug Inspection fixture and carriage (second carriage not pictured)

Depot Eddy Current Inspection

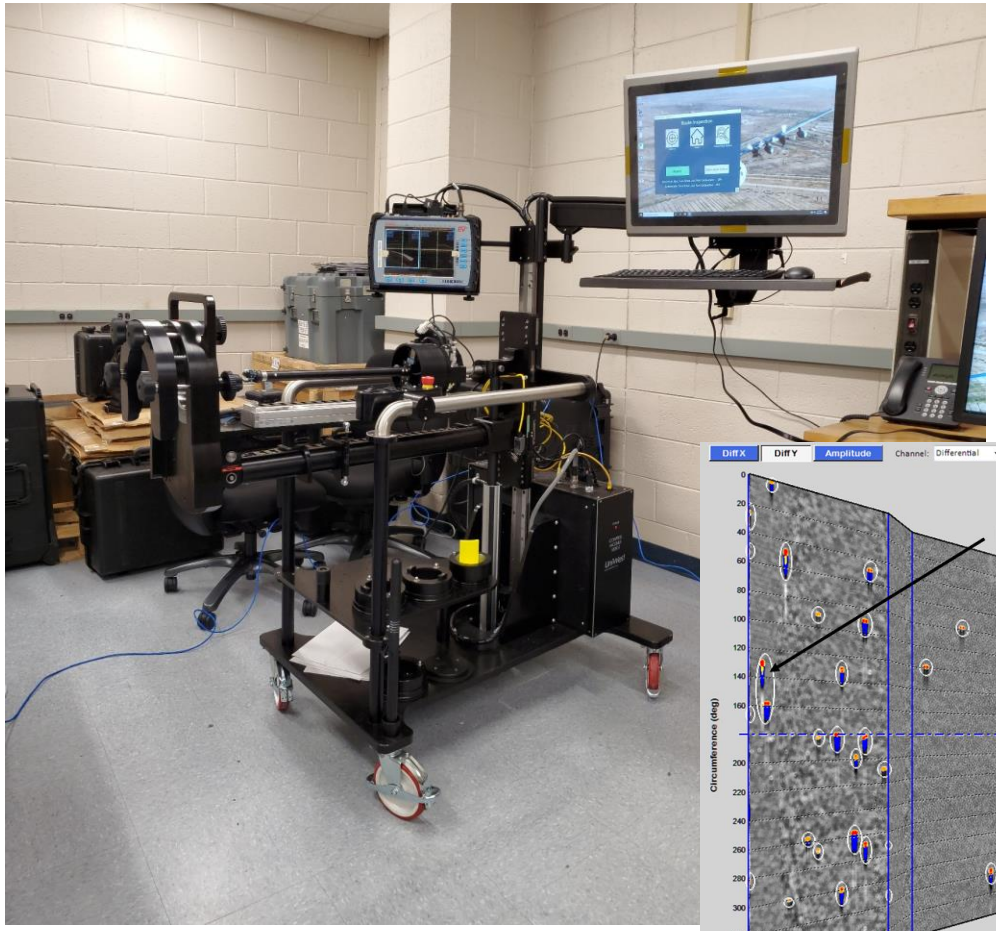
- Off-wing inspection w/ the bushing, lead wool, and coverings removed
- 2 inspection zones: Bushing area and first few inches of Deep Taper
- Custom probe, fixture, and inspection aids
  - 3 pronged, spring loaded to ensure compliance
  - Fixture provides centering, support, and aides rotation
  - Clocking ring to determine location
  - Inserts protect probe from repair locations
- Performed with standard rotary scanner and eddy current instrument
- Transition completed and currently used in blade overhaul.

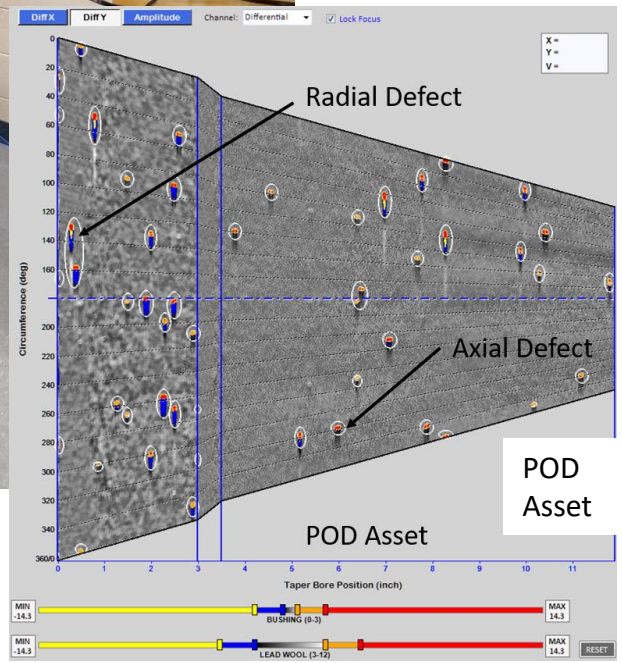




Depot Automated Eddy Current Scanning System

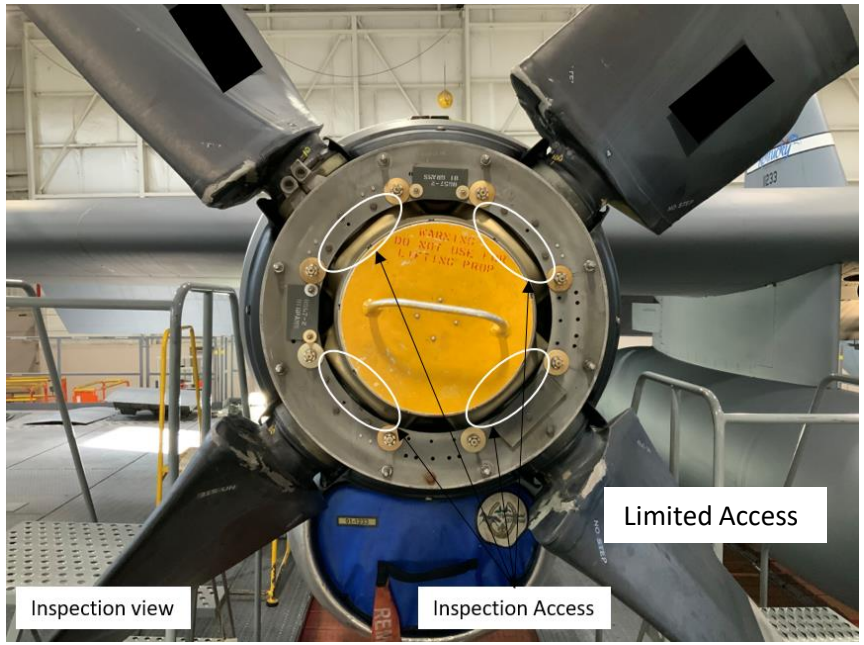
- Fully automated: calibrate, scan, report
- 12 inch scan depth
- Detection independent of crack orientation
- C-scan display: easy disposition and enhanced visualization
- Adaptable to different blade heights and configurations
- Detection capability demonstrated
  - Bushing Taper:
    - $a_{90/95}$ = 0.030” x 0.015”
  - Deep Taper
    - $a_{90/95}$ = 0.070” X 0.035”
- Transition Status
  - Final testing being completed at WRAFB
  - Ver/ Val of inspection procedure to follow
  - Implementation planned by end on CY

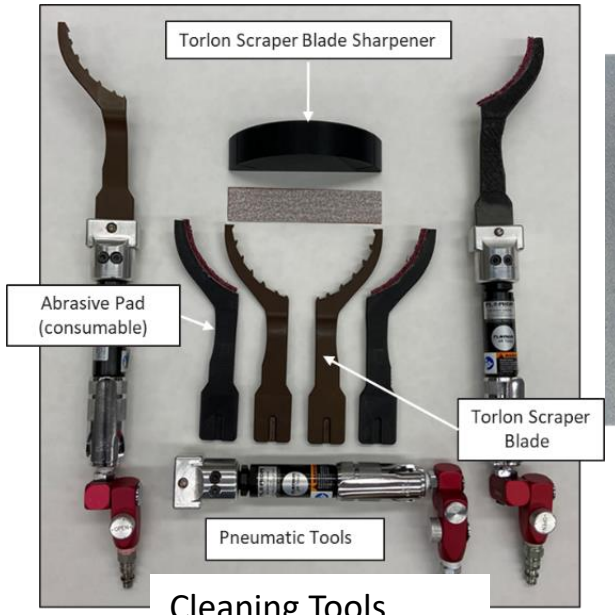




Field On-Wing Inspection

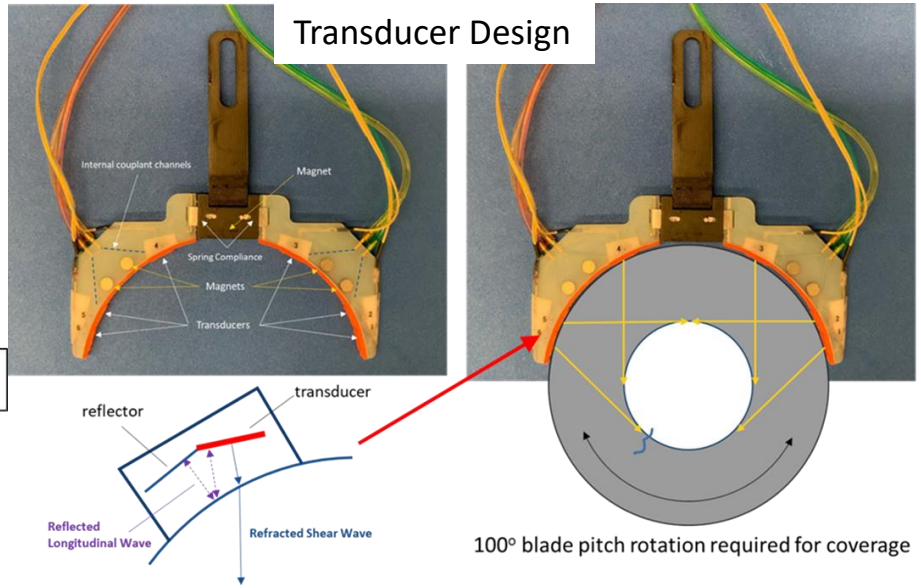
- Limited access, disassembly, and rotation
- Developed multiple-element ultrasonic transducer primarily 3D printed from multiple materials
- 2 stage cleaning kit developed
- Standalone self contained kit employs field available ultrasonic instrument
- Transition Status:
  - Kit and procedure developed, demonstrations and verification complete. Ready to transition.
  - Production sources established
  - Procurement strategy under development





Cleaning Tools

Transducer Design



100° blade pitch rotation required for coverage

Summary

- 5 new inspections developed for C-130 propeller blades
- Extensive use of 3-D printing
  - Rapid Prototyping
    - Custom fixtures/ carriages designed and constructed in house in days not weeks (Field Level EC)
    - Design optimization happens in days/weeks not months (Field Level UT/ EC)
  - Construction
    - Wedge is prohibitively expensive & time consuming with conventional methods (Field Level UT)
- Off-wing Eddy Current inspection
  - Fast inspection to provide initial details on fleet status (Field Level EC/ TCTO)
- Automated Eddy Current system
  - 2.5-5x improvement in detection capability (compared to standard pencil probes)
  - Enhanced visualization, automated reporting, and assisted defect recognition
  - Full data capture, off line post processing, and data archive
- On-wing Ultrasonic inspection
  - Provides confidence that no large cracks exist with little disassembly
  - Lead to change in how we think about rapid prototyping (new lab concept)

Questions?

Emerging Nondestructive Evaluation (NDE) for Integrity Management

Eric Lindgren, Nondestructive Evaluation Technology Lead

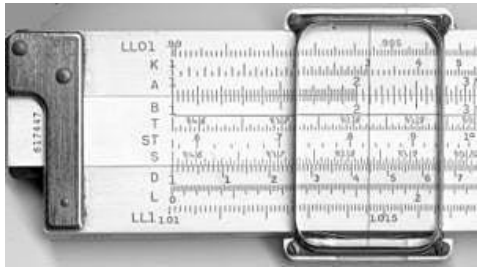
Materials and Manufacturing Directorate, Air Force Research Laboratory

October 27, 2020

Intelligence Augmentation (IA)

Intelligence Augmentation (IA): *effective use* of *information technology* to *enhance human intelligence*

- **Proposed in 1950/60s by early computer pioneers**
  - **Full 'AI' has encountered fundamental obstacles**
- **IA only uses technology as 'extra support'**

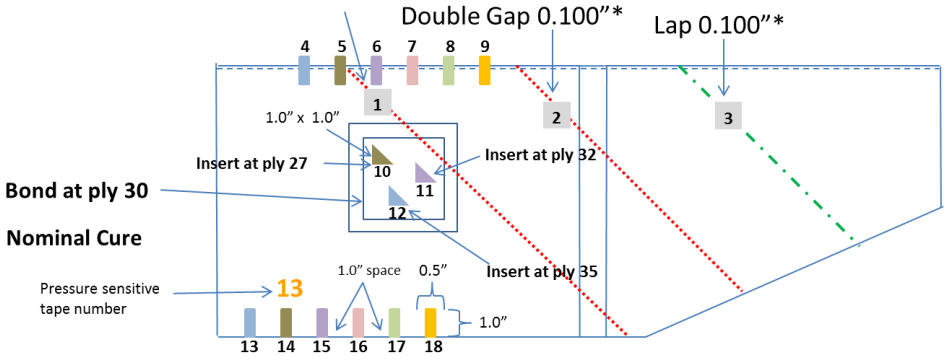


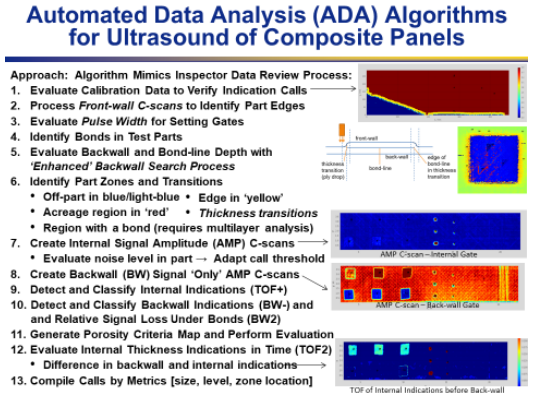
- **IA has a long history of success:**
  - **Consider history of information technology, from *writing and slide-rules to smart phones and the internet***
  - **All extend human information processing capabilities**

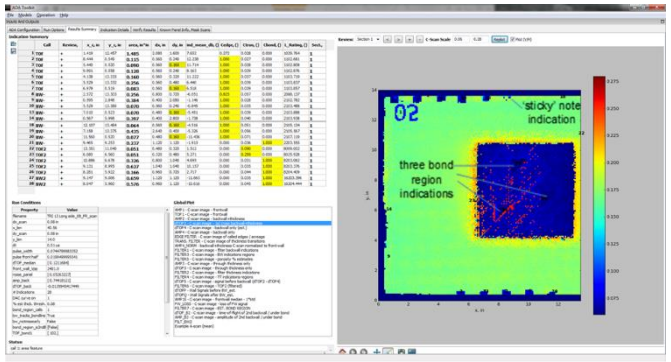
Algorithms for NDE Detection / Characterization

Data [Signal/Image/Pattern] Detection / Classification Algorithms:

- **Expert / Heuristic Based Algorithms**
  - **Approach: Implement Human Data Review Procedures in Algorithms**
  - **Example: Automated Data Analysis (ADA) for UT of Composite Panels**
- **Model-based Inversion**
- **Statistical Classifiers and Machine Learning**





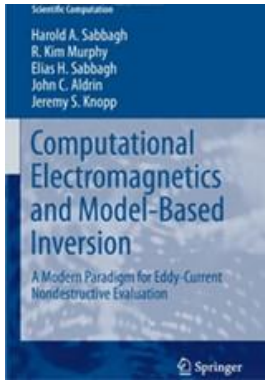


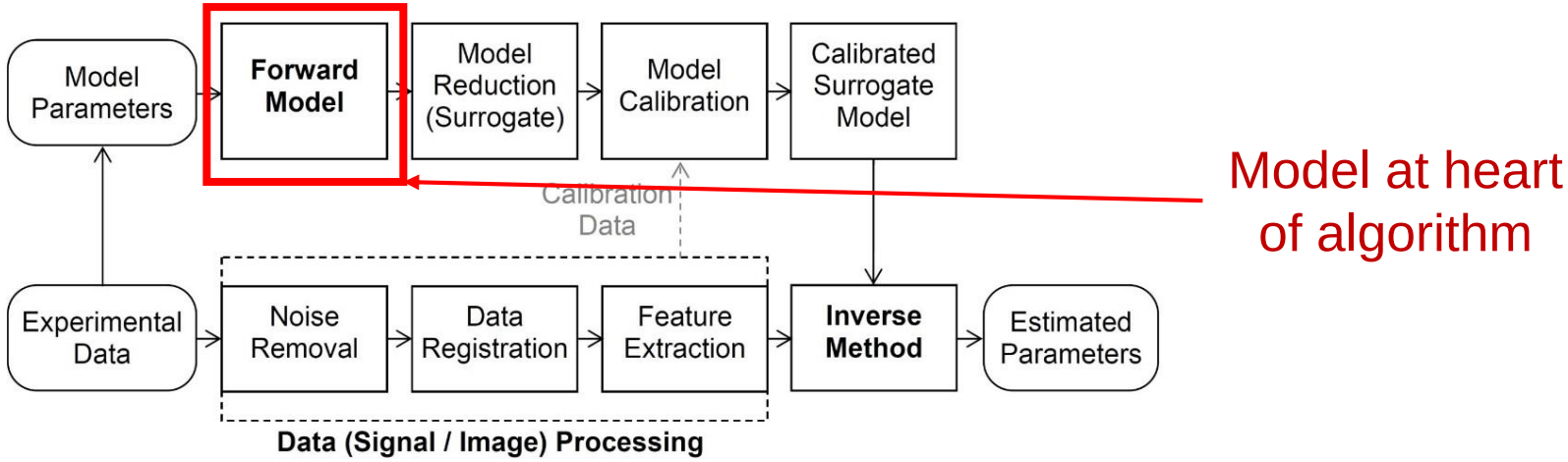
Aldrin, J., C., Forsyth, D. S., and Welter, J. T., "Design and Demonstration of Automated Data Analysis Algorithms for Ultrasonic Inspection of Complex Composite Panels with Bonds," *42nd Annual Review of Progress in QNDE, Incorporating the 6th European-American Workshop on Reliability of NDE*, Vol. 1706, p. 120006, AIP Publishing, 2016.

Algorithms for NDE Detection / Characterization

Data [Signal/Image/Pattern] Detection / Classification Algorithms:

- Expert / Heuristic Based Algorithms
- **Model-based Inversion**
  - **Model-base d inverse method: Uses first principles (physics) 'model' with optimization (iterative) scheme to solve classification problems**





- Statistical Classifiers and Machine Learning

Algorithms for NDE Detection / Characterization

Data [Signal/Image/Pattern] Detection / Classification Algorithms:

- Expert / Heuristic Based Algorithms
- Model-based Inversion
- Statistical Classifiers and Machine Learning
  - Statistical classifiers: Use statistical representation of data classes
    - Frequentist (e.g. Fisher's linear discriminant)
    - Bayesian (e.g. MCMC computations)
  - Artificial Intelligence, Neural Networks and Deep Learning:
    Layered algorithms mimics a 'network of neurons'
    - Requires large well characterized data set
    - 'Deep learning' strategies overcoming past issues with
      (1) learning complex patterns, and (2) robustness to input variability

‘Pros’ and ‘Cons’ of Artificial Intelligence (AI)

Pros:

1. Handle Laborious and Repetitive Tasks
2. Error Reduction (Complex Tasks)
3. Faster Decisions/Actions
4. Reduction in Overall Risk
5. Act as ‘Digital Assistant’
6. Repository for Human ‘Expertise’

Cons:

1. High Cost (Development, Validation)
2. Cannot Make Decisions Well for *Scenarios Not Trained*
3. Lack of Inherent Flexibility / Poor at Judgement Calls
4. Lack Moral Values
5. Unemployment
6. Degradation of Human Skills

Need Responsible Usage of Artificial Intelligence!

https://content.wisestep.com/advantages-disadvantages-artificial-intelligence/, https://www.arrkgroup.com/thought-leadership/artificial-intelligence-the-advantages-and-disadvantages/, https://www.datamation.com/applications/pros-and-cons-of-artificial-intelligence.html

Augmented Reality for Nondestructive Inspection

Dr. Eric Lindgren and Capt Joshua Lynch
Materials State Awareness Branch
Materials and Manufacturing Directorate
Air Force Research Laboratory
October 27, 2020

Common On-aircraft NDI Conditions

Limited:

- **Access**
- **Field-of-view**
- **Currency**

In both field and Depot

Could Impact Capability

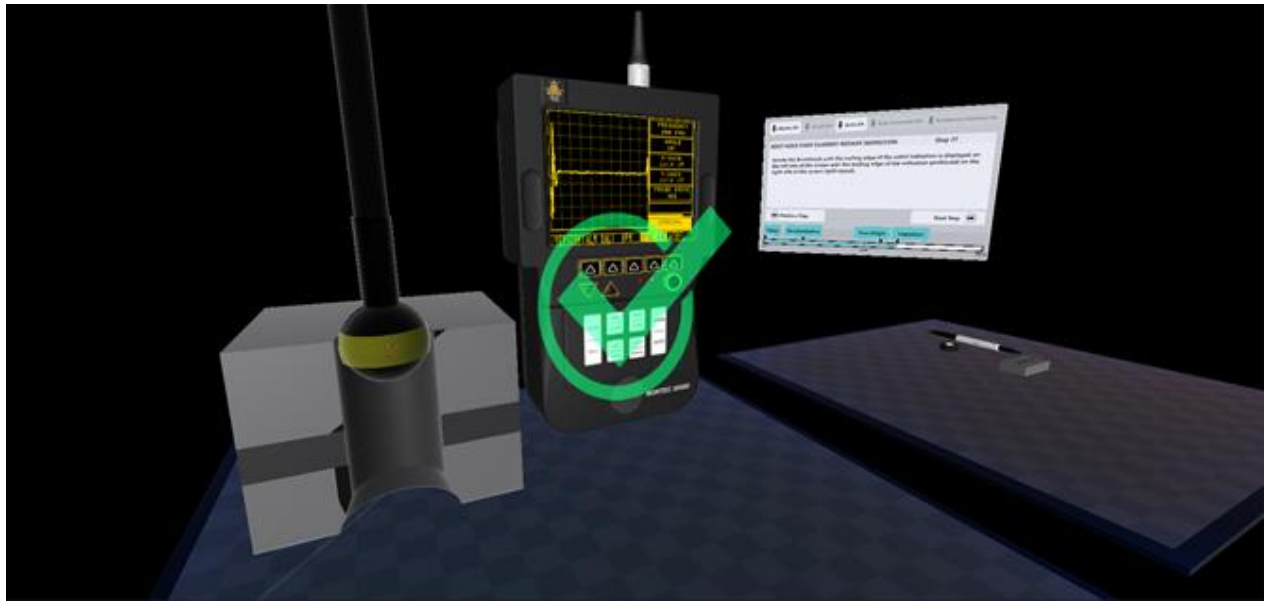
Objectives

- Refresh for infrequent NDI procedures
- Training for advanced NDI technology
- Guidance for rapid implementation of complex inspections
- Improve readiness of Airmen
  - Increased availability of aircraft
- Capture digital data for engineering
- Follow VAMRAM IPT Tenants
  - Developer's guide in publication

Refresh: Critical but Infrequent Inspections

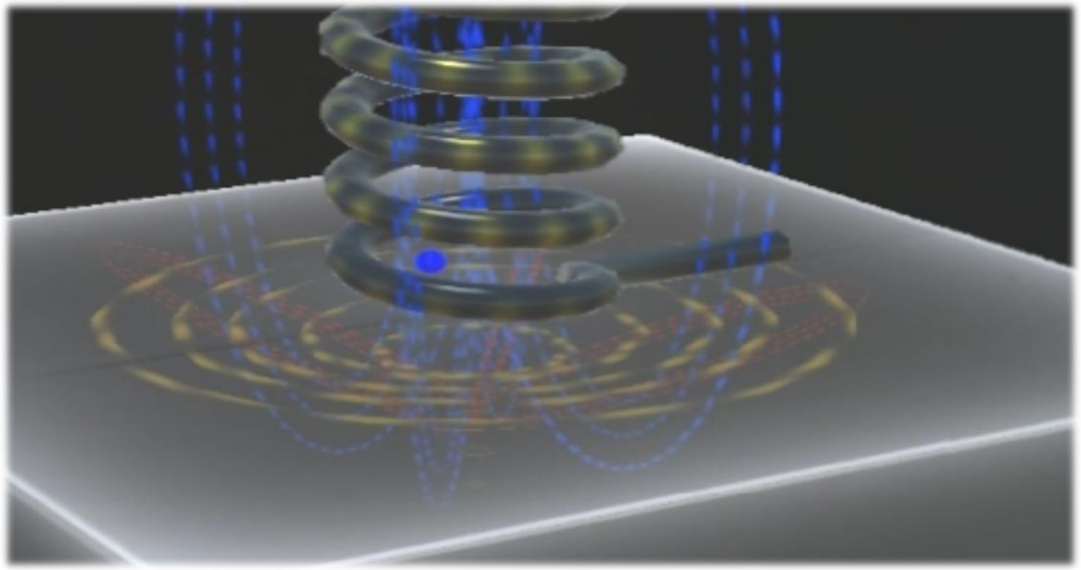
Initial Applications:

- Bolt Hole Eddy Current and Angle Beam Shear Wave
- Setup, Calibration, Inspection, Interpreting Results
- Enabling Airmen to accomplish their objectives



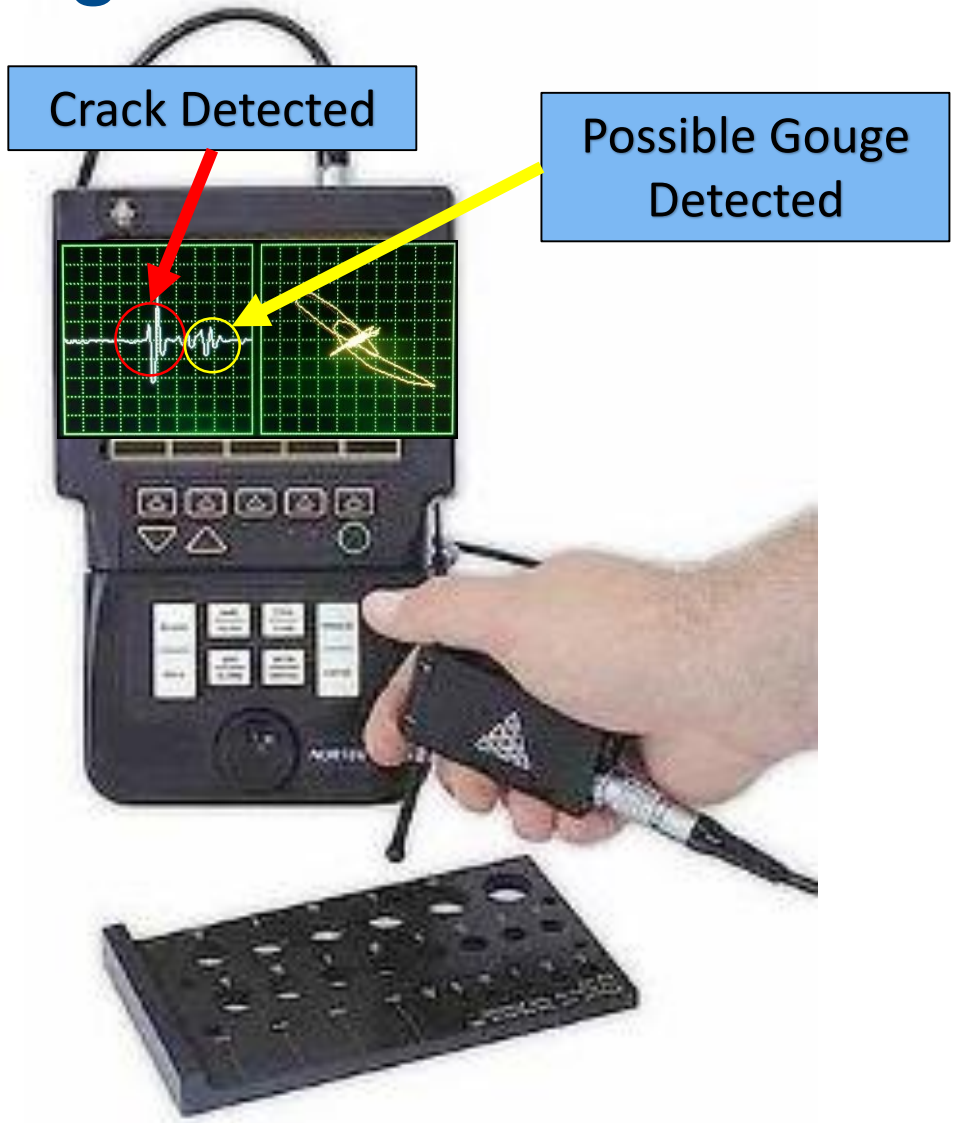
Train: Understanding the inspection

- **Integrate into NDI Schoolhouse curriculum**
  - **Strong support for instructors!**
  - **Reduces 2D teaching information**
- **Visualization of physics of inspection**
  - **Accelerates comprehension: probe/energy interaction with material**



Guidance: Higher Fidelity Coaching

- **Step-by-step guidance**
  - **Tailorable level of details for each step followed by an inspector**
- **Active feedback to user**
  - **Facilitate interpretation**
- **Object recognition to assist inspectors**
  - **Aligned with received signals**
- **Aid for interpreting results**



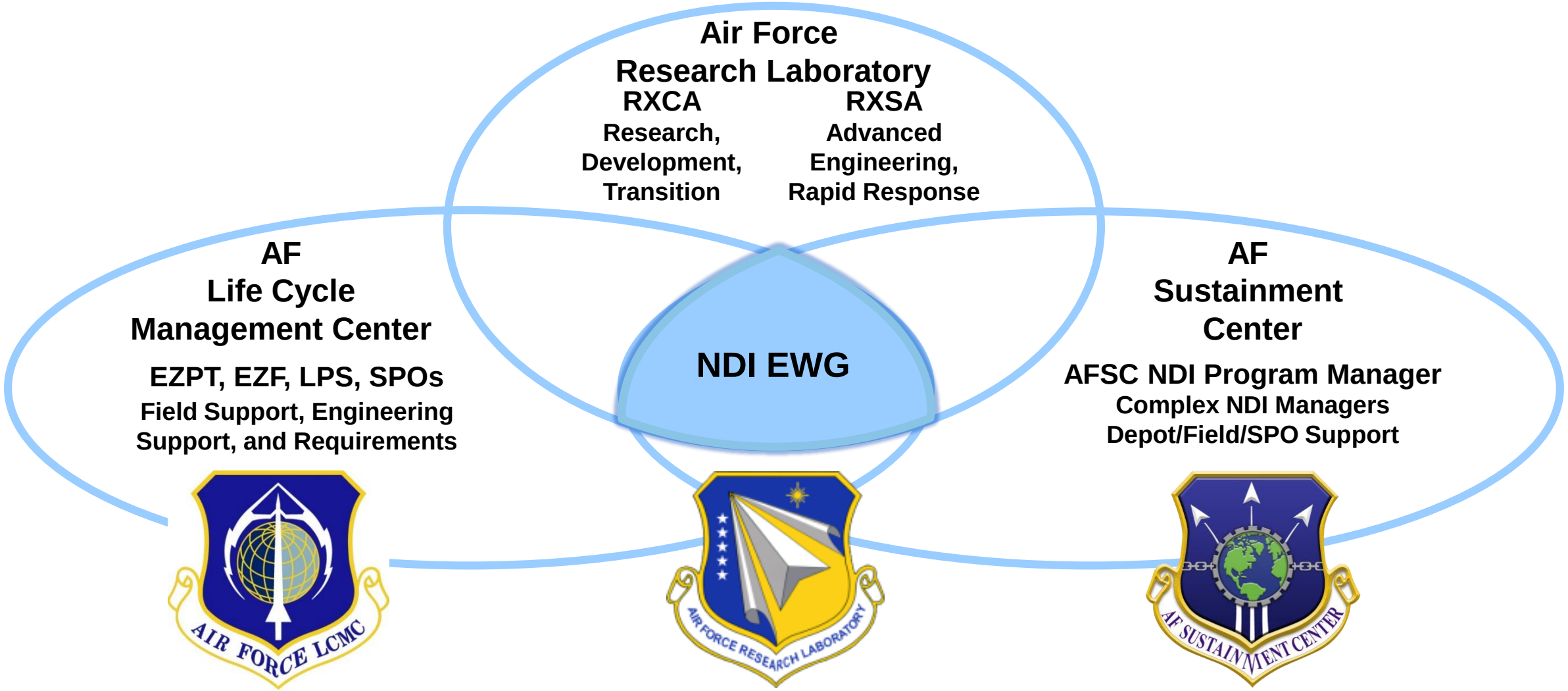
Summary

Augmented Reality can:

- Coach infrequent inspection procedures
- Accelerate / simplify training for advanced inspection technology
- Rapidly implement complex inspections
- Accelerate disposition of indications

Enhance Aircraft Availability

Nondestructive Inspection Executive Working Group



Material Assessment for Integrity Assurance

Questions / Discussion

Photograph by Author