478th Aeronautical Systems Wing

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U.S. AIR FORCE

F-22 Non Destructive Inspection; Challenges, Successes, and a Path To the Future

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Outline

- **Challenges coming out of EMD**
  - **Materials**
  - **Geometries**
  - **No supporting data for flaw size assumptions**
- **ACC Goal for F-22 Organic Capability**
- **Path to Establishing Effective Organic Capability**
  - **Equipment**
  - **Procedure Verification**
  - **Capability Demonstrations**
  - **Training/Testing**
- **Current and Future Challenges**
  - **Balance of FSMP inspections**
  - **Inspection Access**

EMD Closure Background

- **F-22 closed EMD activities December 2005 with 59 delivered aircraft**
- **Initial Operating Capability (IOC) declared for Langley AFB in December 2005**
- **EMD development identified location of inspections only:**
  - **Relied on legacy flaw size assumptions (F-16 and F-15)**
  - **Relied on legacy tools (EC pencil probes)**
  - **No tech order data existed for inspections**
  - **All inspections performed by contractor**

Multiple NDI Challenges After EMD Closure

Challenge: *Material*

- **Bulk of legacy Air Force NDI experience is on Aluminum metallic structure**
- **F-22 structure is primarily Titanium**
  - **Cast and forged products**
  - **Machined and cast surface textures**
  - **Large Beta-grains**

Titanium NDI Capability Unknown!!

Challenge: *Geometries*

- **F-22 tracks over 1100 control points with 730 requiring inspection**
- **Multiple Geometries requiring inspections**
  - **Bolt Hole, Flats, Radii, Edges, Hole Bores**
  - **Restricted Access**
- **Legacy tools (probes) made complete coverage difficult**
- **Legacy Tech Orders often lacked clear and concise inspection locations and scan procedures**

Better Tools and Procedures Required

Challenge:
Detectable Flaw Size Assumptions

- **F-22 Damage Tolerance and Durability Reinspection intervals based on legacy fighters (F-16 and F-15)**
  - **Surface Eddy Current,**
    - **Titanium - 0.100”**
    - **Aluminum - 0.050”**
  - **Bolt-Hole Eddy Current**
    - **Titanium - 0.060”**
    - **Aluminum - 0.030”**

Most assumptions not supported by or traceable to documented studies

Challenge:
USAF Institutional NDI Issues

- **USAF conducted EAGLE LOOK Tiger Team in 2005/2006 to assess health of USAF NDI community**
- **Findings indicated institutional concerns with procedures, equipment, and detectable flaw size assumptions**
- **Multiple examples of inspection escapes illustrated the need for more comprehensive and tailored NDI development**

F-22 Needed to Reassess Traditional NDI Approaches to Ensure Safety of Flight

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ACC Goal For Organic USAF NDI Capability

- **In August 2006, ACC issued requirement to achieve organic field level NDI capability**
  - **F-22 program had relied on complete contractor NDI support**
  - **F-22 NDI Requirements Review Board committed to providing organic capability by 1 January 2008**
- **Requirements for organic capability identified:**
  - **Equipment Delivery**
  - **Procedures Val-Ver'ed**
  - **Capability Assessments**
  - **Inspector Training**
  - **Proficiency Testing**

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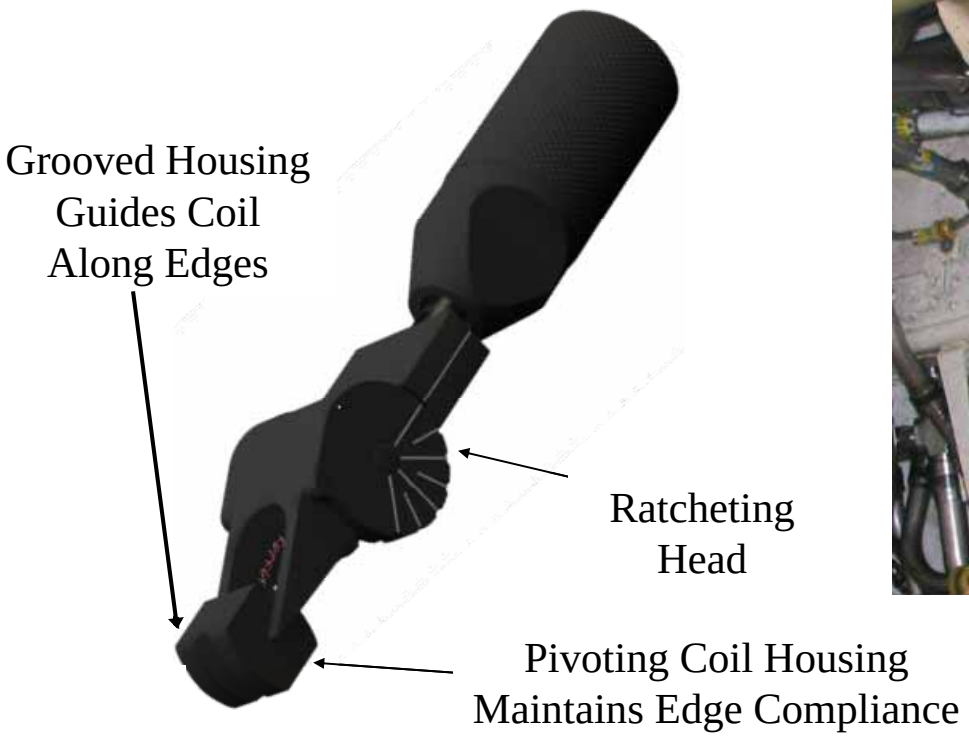
Requirements Achieved
Equipment Development

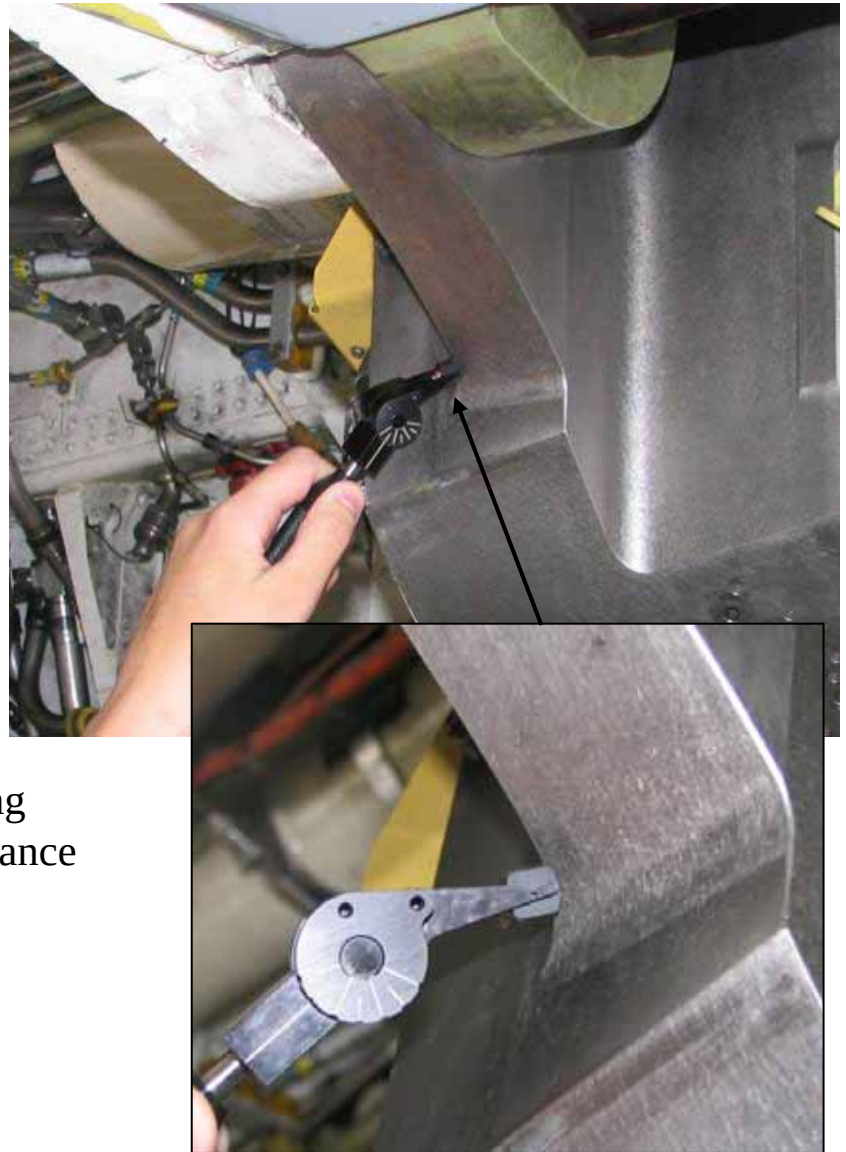
- **FSMP requires numerous Eddy Current, Ultrasonic, Fluorescent Penetrant, X-Ray inspections**
  - **Bulk of early inspection requirements are Eddy Current**
  - **Focus of initial organic development has been primarily on improved Eddy Current tools**
  - **Future years will focus on UT, FPI, and X-Ray**

- **Eddy Current Development Goals:**
  - **Develop tailored kit to improve coverage and reduce scan variability by focusing on geometry classes (flat, edge, radius)**
  - **Optimize signal-to-noise for various material product forms**
    - **Forgings versus castings**
    - **Microstructure (grain size)**
    - **Titanium and Aluminum**

Equipment Development

Edge Probes



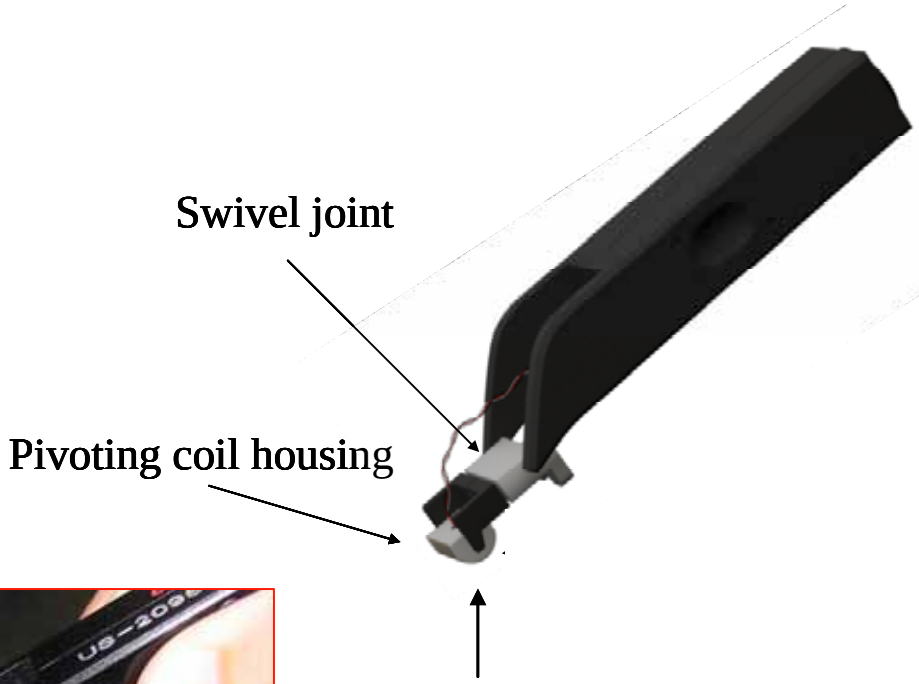


Equipment Development

Engine Thrust Mount - Radius Kit

Equipment Development

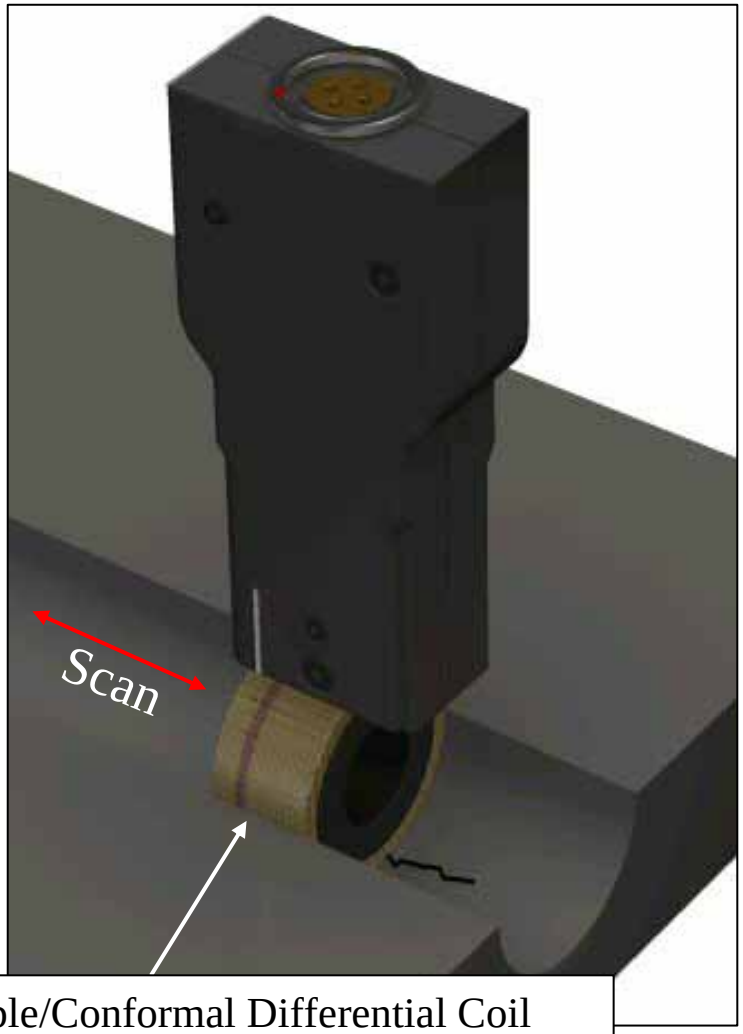
Pivoting Surface Probe



Pivot maintains coil compliance to inspection surface

Equipment Development

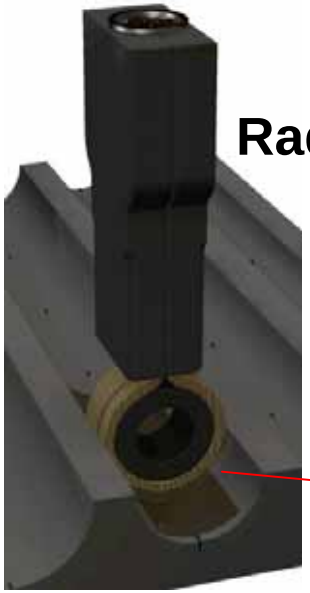
Conformal *Radii Probes*



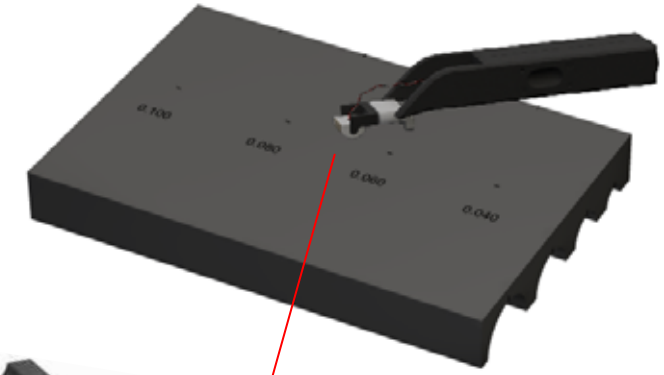
Flexible/Conformal Differential Coil
Provides Coverage of Entire Radius Surface

Equipment Development

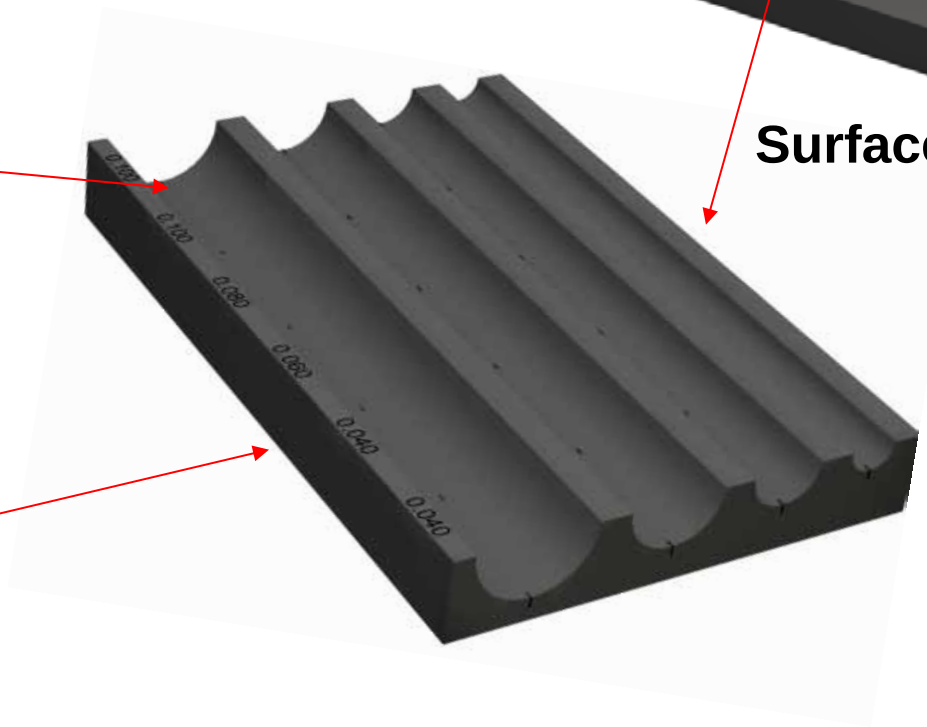
Ti and Al Reference Standards



Radii Probes



Surface Probes



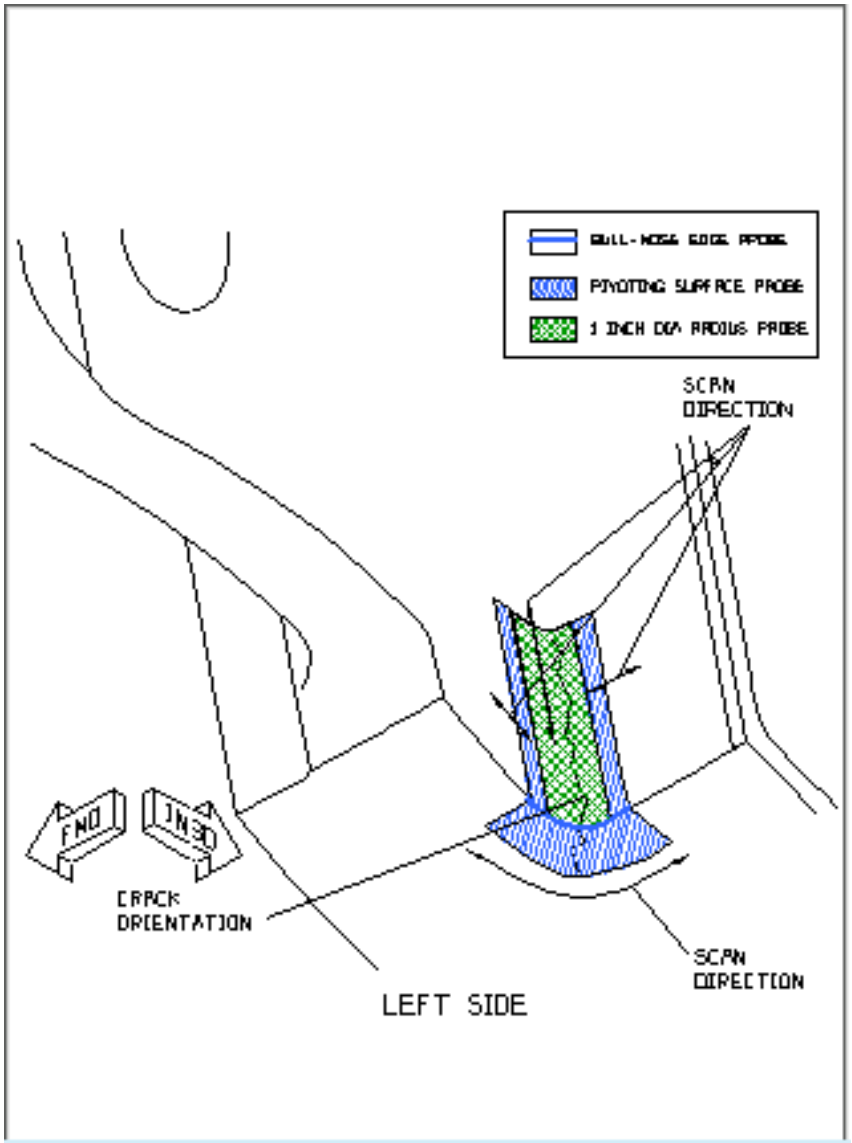
Edge Probes

Procedure Development

- **Ensure implementation of effective tech order data through…**
  - **Clearly defined inspection locations and scan zones**
  - **Limit required inspection areas only to critical zones**
  - ***Standardized procedure setup across family of probes in kit***
  - **Detailed part specific procedures defining:**
    - **Probe selection**
    - **Scan zone**
    - **Scan direction**
    - **Expected cracking location**
  - **Utilize multiple *primary* inspection methods (focused eddy current and fluorescent penetrant on critical complex details) where warranted**
  - **Rigorous review of procedures and inspection details**
    - **Field level *on aircraft* verification for every procedure**

Procedure Development
Frame 2 Lower Radii Example

1	Locate area requiring inspection at FS 658.63 BL 72.25 WL 85.52.
2	Scan location: Inspect lower edge of vertical radius including 0.50 inch outboard and 0.50 inch aft of radius using bull-nose edge probe, PN US-2127.
3	TASK_OPT
4	Scan location: Inspect lower aft vertical radius 1.0 inch upward from lower edge using ribbon radius probe, PN FET-3247.
5	TASK_OPT
6	Scan location: Inspect lower aft vertical radius 1.0 inch upward from lower edge, including 0.50 inch outboard and 0.50 inch aft of radius using pivoting surface probe, PN US-2098.
7	TASK_OPT
8	Scan location: Inspect lower surfaces extending 0.50 inch from edge and 0.50 inch outboard and 0.50 inch aft of radius using pivoting surface probe, PN US-2098.
9	TASK_OPT
10	Perform level 4 sensitivity penetrant inspection on lower aft vertical radius 1.0 inch upward from lower edge and 0.50 inch below edge, including 0.50 inch outboard and 0.50 inch aft of radius.
11	TASK_OPT
12	TASK_OPT
13	TASK_OPT



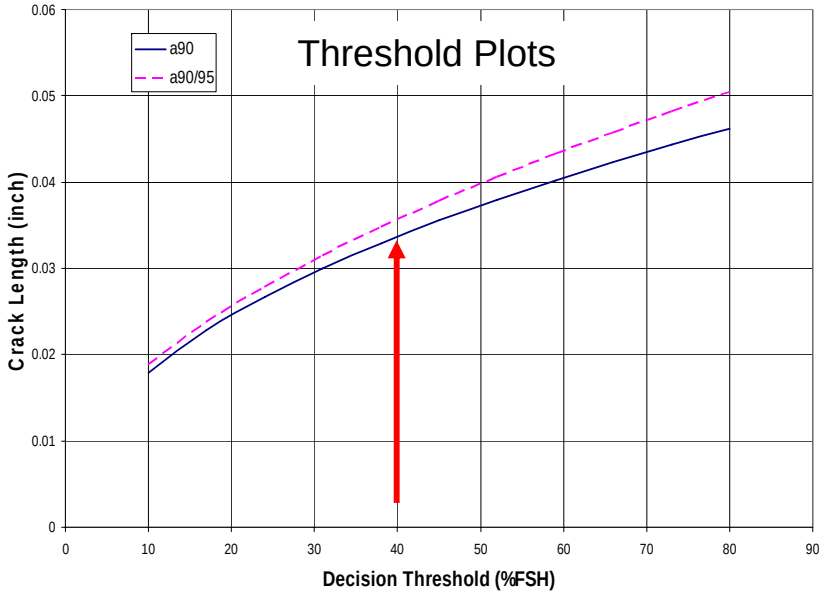
Demonstration of Detectable Flaw Size Assumptions

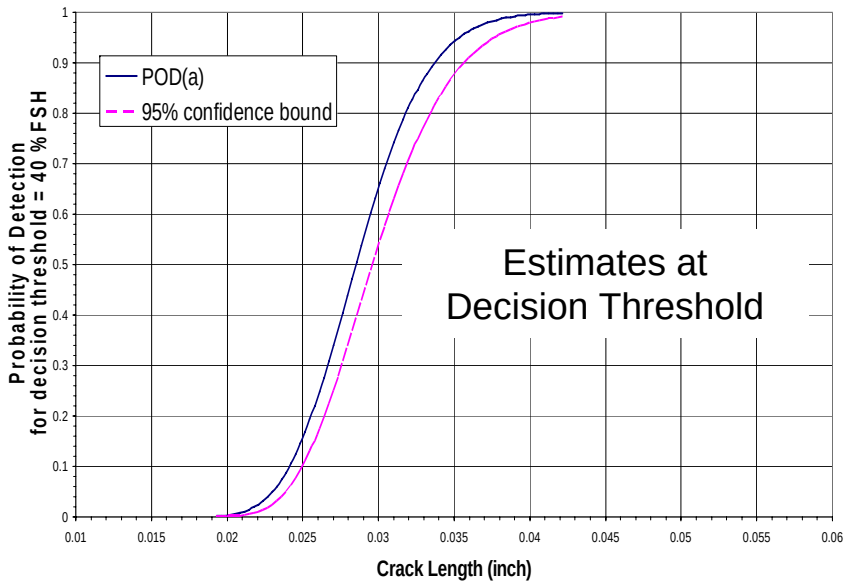
- **F-22 goal to develop data to support FSMP flaw size assumptions**
  - **Ensure detectable flaw sizes used in analysis did not need to be increased**
  - **Establish confidence in capabilities for both Ti and Al structure**
- **Limited capability estimates conducted (AFRL/RXS, 809, MXSS/MXRL**
  - **Surface eddy current, using new tools, for geometry classes (edges, flats, radii)**
  - **Bolt-hole eddy current on aluminum and titanium**
- **Data not considered statistically sufficient to establish a(90/95) but sufficient to evaluate margin above or below current assumptions**
  - **Provides near-term confidence check of assumptions without cost of full blown POD studies**
  - **Full Mil-Hdbk-1823 approach too costly for multiple materials and geometries**

Demonstration of Detectable Flaw Size Assumptions

Approach

- Manufacture generic fatigue specimens with geometries representing geometry classes/material (flat surface, edges, radii) (aluminum, titanium)
- Generate Empirical Signal Amplitude ***(â)*** vs. Flaw Size ***(a)***
  - **Field inspector generated** (*7 inspectors minimum*)
  - **Minimum 15 flaws per experiment** (uniform flaw size distribution)
- Calculate Threshold vs. Capability ***Estimates*** (a90 and a90/95)
  - Decision threshold established by empirically measured **on-aircraft** noise measurement
  - Estimated a(90) and a(90/95) curves generated for selected threshold

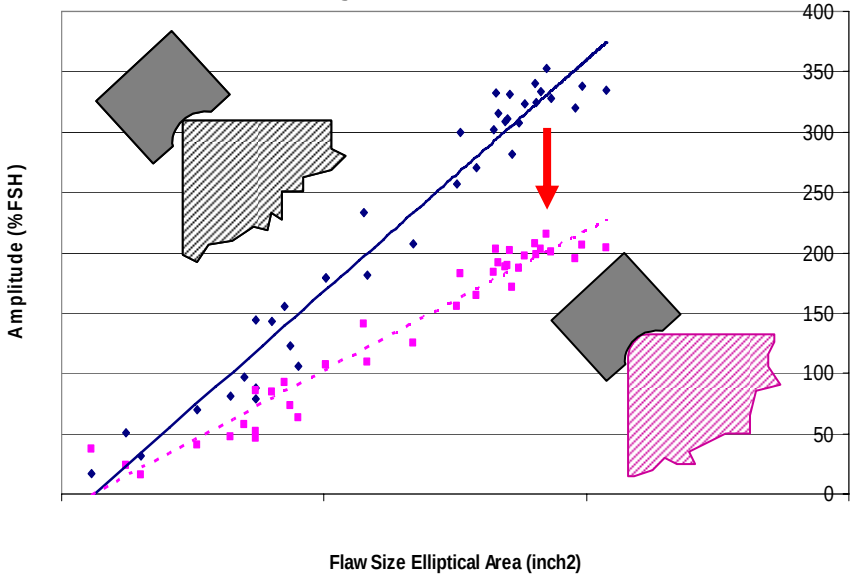




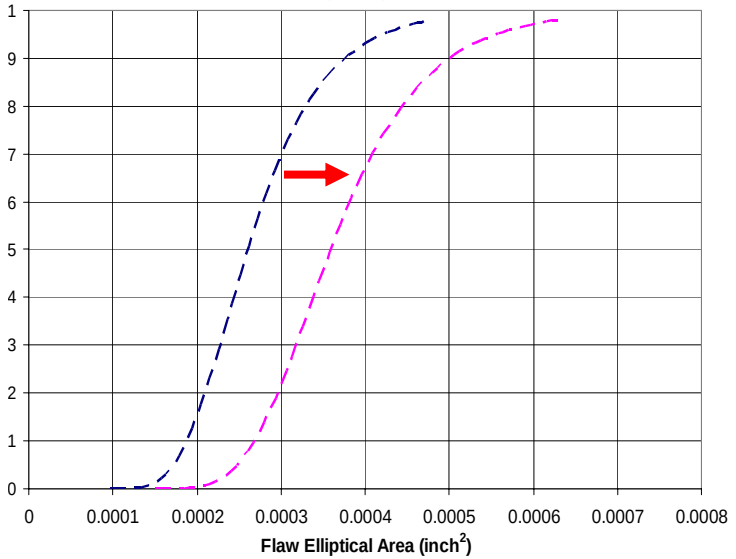
Demonstration of Detectable Flaw Size Assumptions

- Correct estimates for geometry/material variation as required utilizing transfer functions
  - Estimate and apply ***â vs. a*** shift resulting from material or geometry variance. **Can be determined utilizing EDM flaws!!**

Geometry Corrected â vs. a

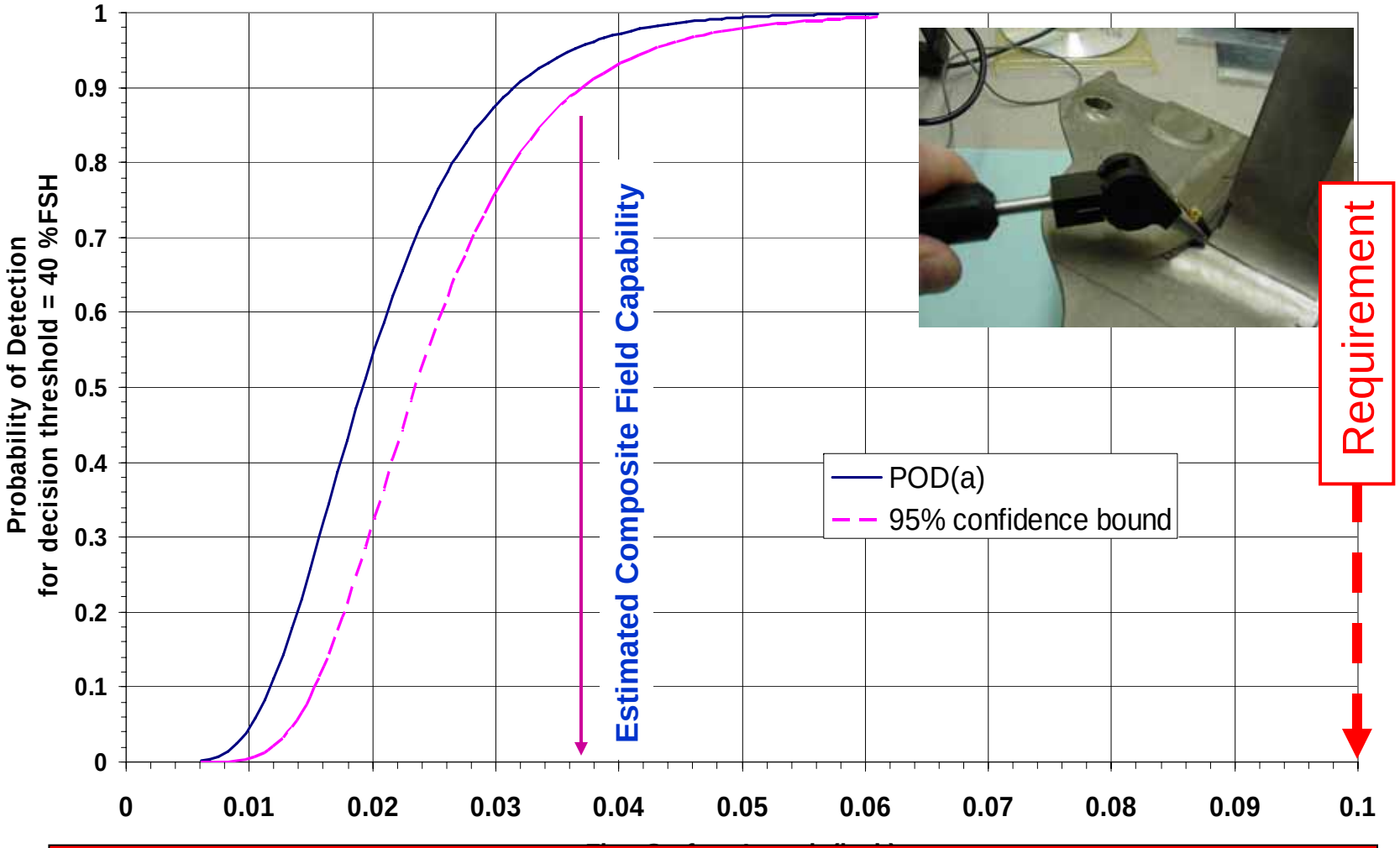


Corrected a(90) Estimates



Example: Ti-6-4 Edges

Bull-Nose Edge Probe: Composite of 7 Inspectors



Margin Sufficient to Maintain Original Assumption…This Scenario!!

Training

- **Requirement to provide hands on training to blue suiters to utilize unique tools and procedures**

- **F-22 Team Developed F-22 NDI curriculum**
  - **40hr course**
  - **Class room and on-aircraft instruction with new probes**
  - **Familiarization with new tech order data**

Training
Proficiency Examinations

- **Utilize series of representative fatigue coupons traceable to capability assessments**
- **Testing implemented to assess inspector's capability to achieve detection requirements**
- **Only qualified personnel permitted to perform FSMP defined inspections.**

Training

On-Aircraft

Proficiency Testing

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Current and Future Challenges
Additional FSMP Inspections

- **Organic capability to be provided by Jan 2008 will only include inspections up to 1200 hours**

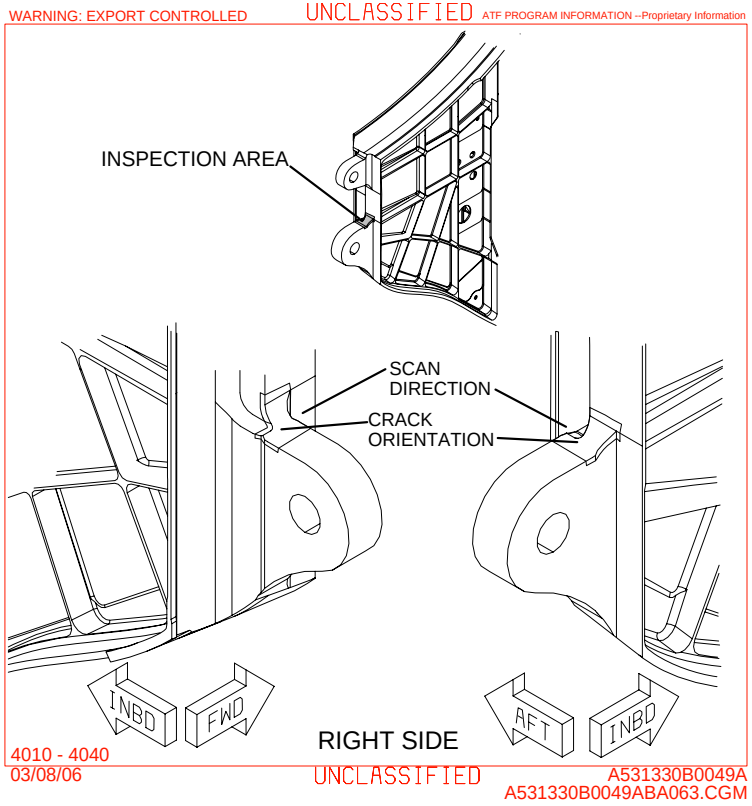
- **Balance of F-22 inspections through 8,000 hours development ongoing**
  - **Unspecified equipment and/or techniques will be required**
    - **Example: Ultrasonic Inspection of Ti Lugs**
  - **Extensive Tech Order data to be verified**

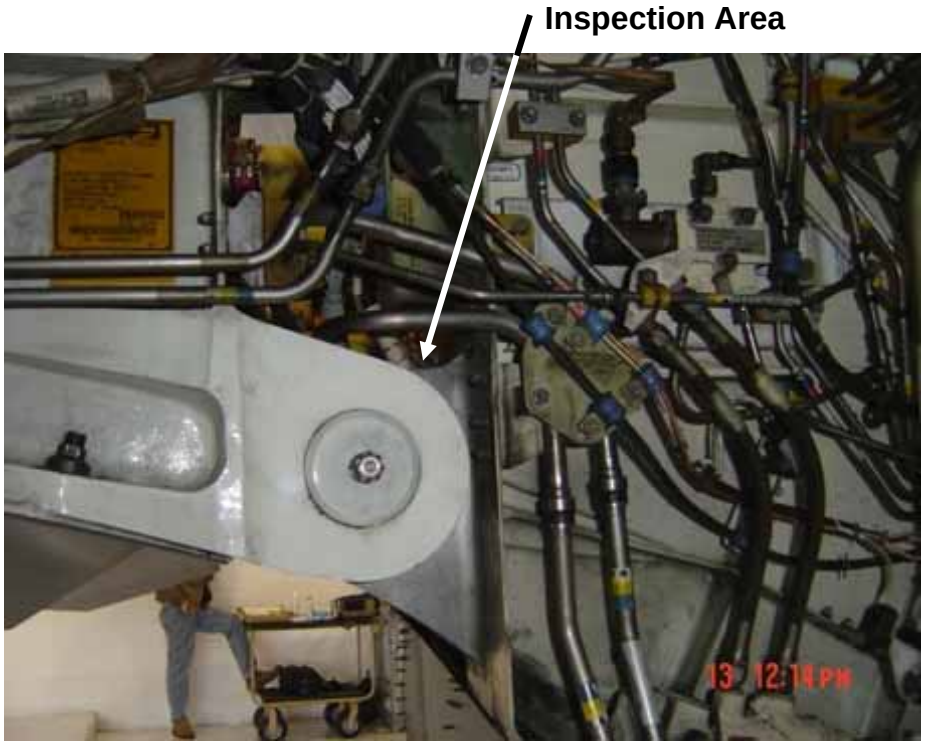
Current and Future Challenges
Inspection Access

- **Multiple inspection locations (<1200hrs) currently have restricted access**
  - **Can not achieve required inspection capability without proper access**
  - **Contractor may continue to conduct these inspections**
- **Some locations for future inspections (>1200hrs) currently have no access at all**
  - **Will require burdensome maintenance or mod to provide access**
  - **May require continued NDI probe development**
- **NDI access modification program required**
  - **Relocation of hydraulic tubes, wire bundles, etc**

Current and Future Challenges
Inspection Access Example 1

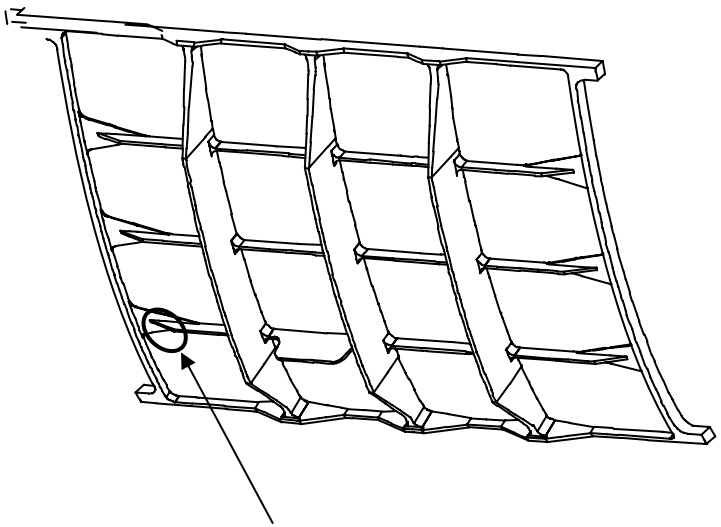
- **Frame-2 (BA063 / BW421) Lower Lug/Clevis, Upper Radius Inspection**
- **Obstruction: Three Hydraulic Tubes**





Current and Future Challenges
Inspection Access Example 2

- **Upper Skin Bay-3 (BA204) Multi. Stiffener Run outs (7000 Hrs)**
- **Obstruction: Tubes, Brackets, Actuators, Etc.**



Upper Skin aft of Frame-3, Sta.-685 – 708.5

Summary

- **Little development of NDI prior to EMD closure**
- **Multiple challenges including loss of confidence in legacy assumptions for NDI**
- **F-22 has begun robust NDI program to develop tools, procedures, assumptions and training to ensure safety of flight and to mitigate aircraft downtime**
- **Challenges still lie ahead**