# Model-Assisted POD for Ultrasonic Detection of Cracks at Fastener Holes


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Australia

# Overview

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- F-111 Lower Wing Skin Inspections
- Requirements for POD validation
- Application of POD modelling to F-111 Lower Wing Skin

# F-111 Lower Wing Skin

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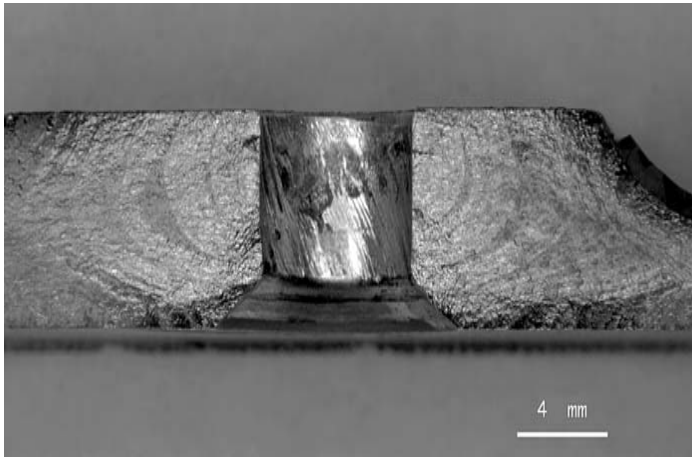
## F-111

- 1960's aircraft
- RAAF sole operator of type

## Catastrophic failure during wing fatigue life extension test

- Crack initiated from taperlok fastener hole
- Previously uninspected location
- Possible widespread build quality problem
- Interim safelife imposed pending introduction of safety-by-inspection



# Automated UT for F-111 Lower Wing Skin

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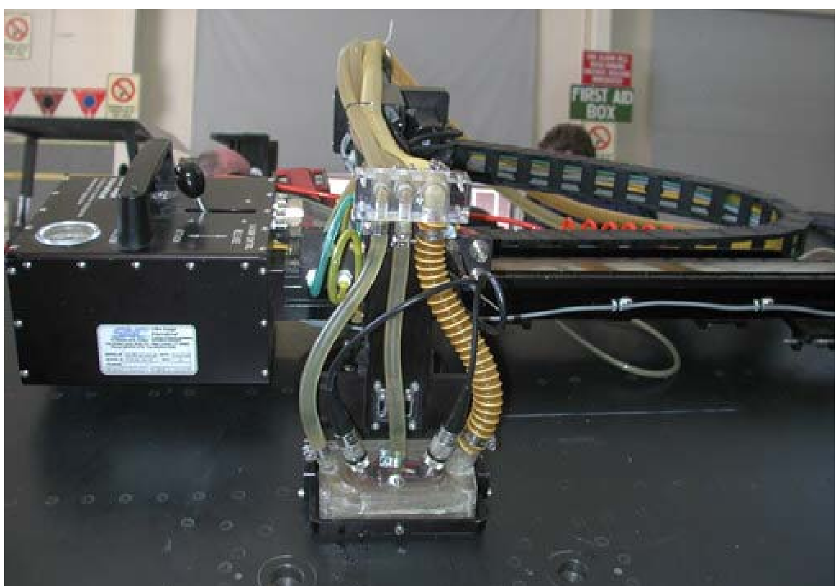
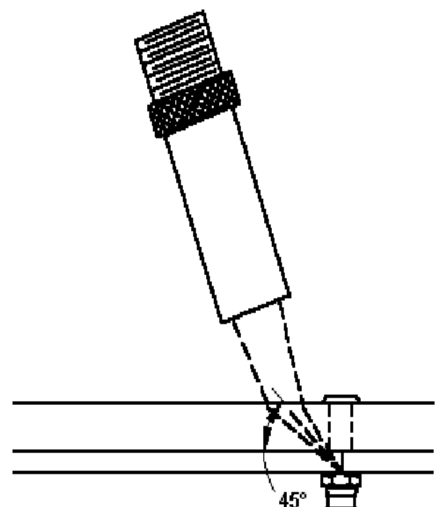
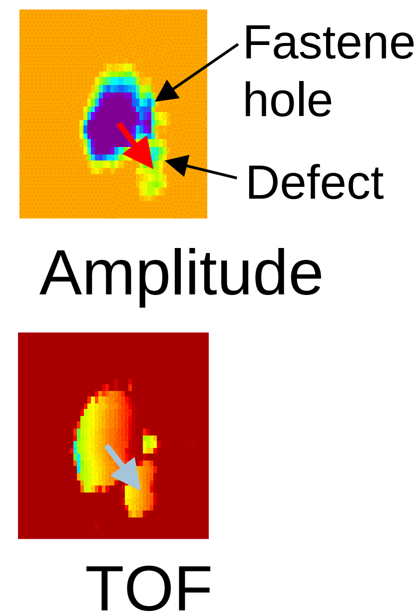
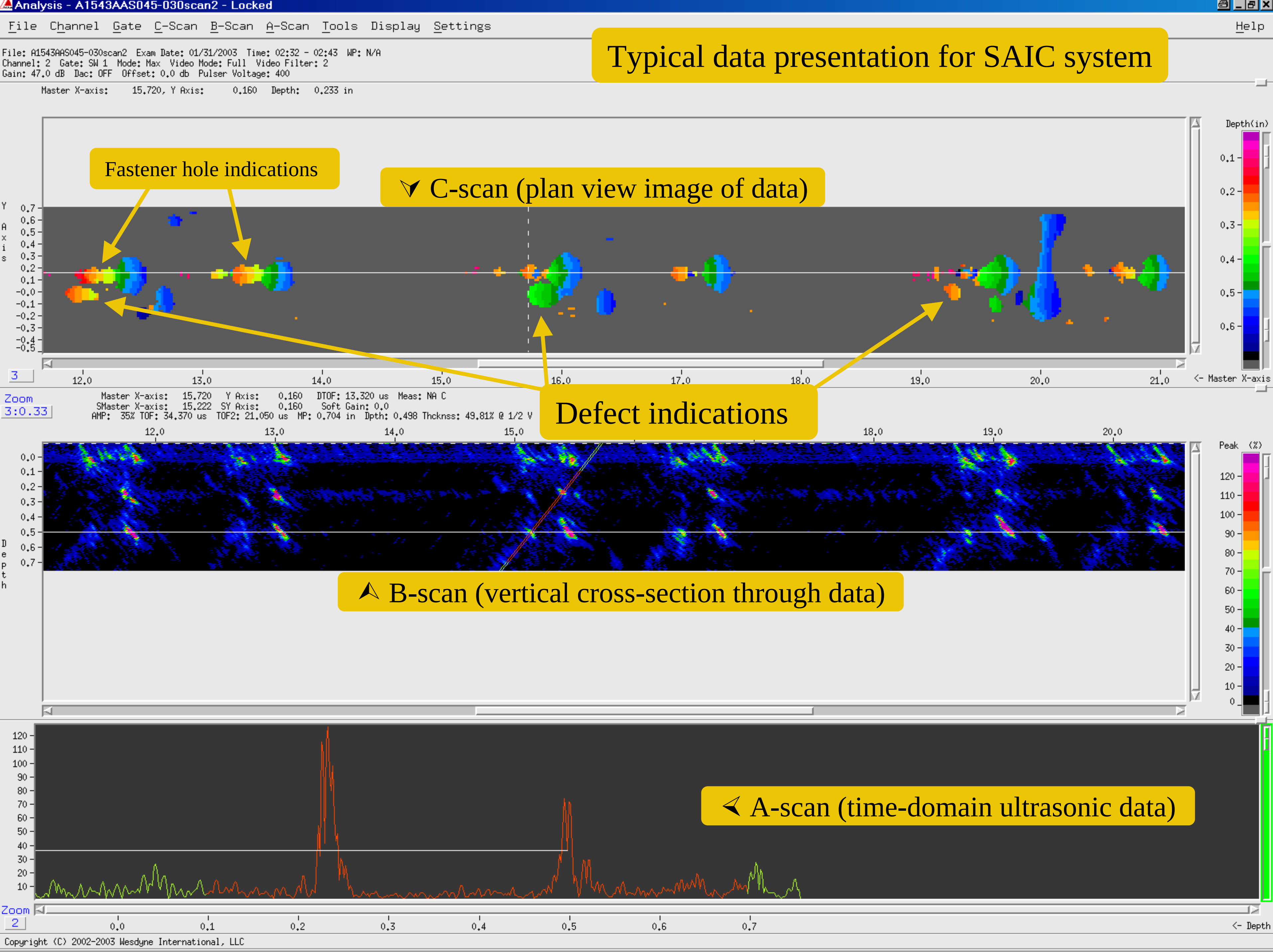
## Inspecting for cracks at fastener holes

- 45º shear wave UT C-Scan
- SAIC Ultra Image International Ultraspect-MP Scanning system
- 5MHz 1.5 inch spherical focus immersion transducers





Analysis - A1543AAS045-030scan2 - Locked
File Channel Gate C-Scan B-Scan A-Scan Tools Display Settings Help
File: A1543AAS045-030scan2 Exam Date: 01/31/2003 Time: 02:32 - 02:43 WP: N/A
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Gain: 47.0 dB Dac: OFF Offset: 0.0 db Pulser Voltage: 400
Master X-axis: 15.720, Y Axis: 0.160 Depth: 0.233 in
Typical data presentation for SAIC system
Fastener hole indications
C-scan (plan view image of data)
Depth(in)
Y Axis
<- Master X-axis
Defect indications
Zoom 3:0.33
Master X-axis: 15.720 Y Axis: 0.160 DTOF: 13.320 us Meas: NA C
SMaster X-axis: 15.222 SY Axis: 0.160 Soft Gain: 0.0
AMP: 35% TOF: 34.370 us TOF2: 21.050 us MP: 0.704 in Dpth: 0.498 Thcknss: 49.81% @ 1/2 V
Peak (%)
Depth
B-scan (vertical cross-section through data)
A-scan (time-domain ultrasonic data)
Zoom 2
<- Depth
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# Challenges of F-111 Wing Inspection

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- New technology in RAAF
- Flight critical structure
- Fastener removal to confirm indications using bolt-hole eddy-current not viable
- Formal POD assessment sought by RAAF Aircraft Structural Integrity Unit

# F-111 Lower Wing Skin

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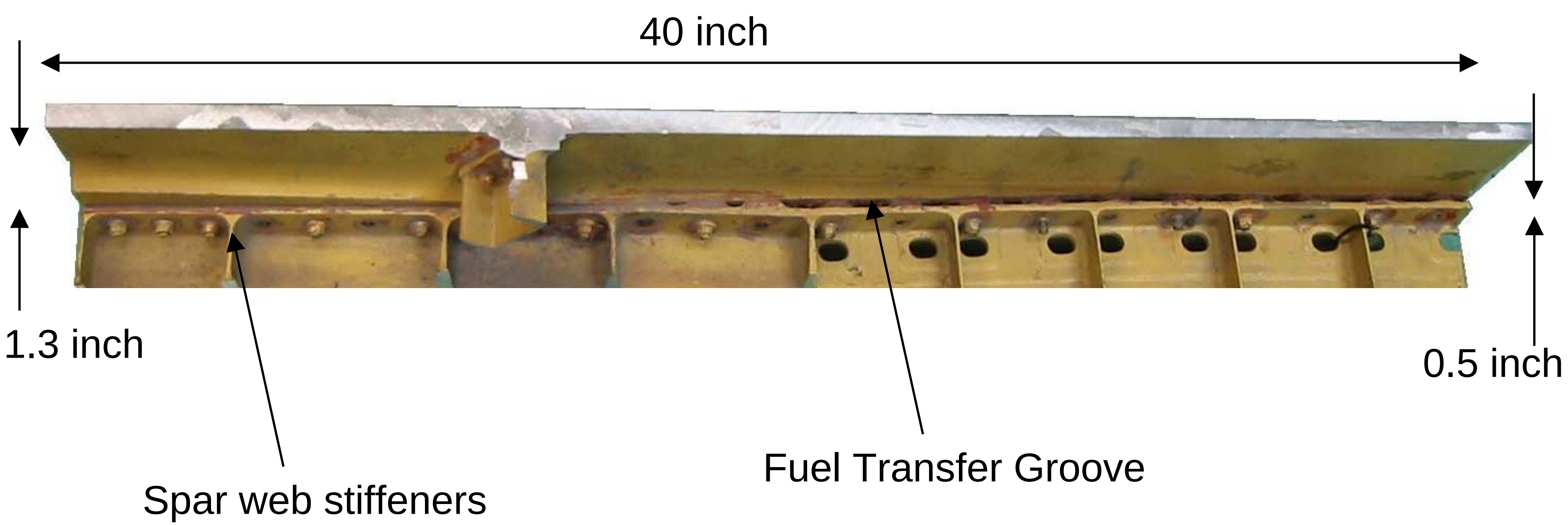
## Complex Geometry

- Skin thickness variation from 0.2” to 1.3” over whole inspection region
- Fuel transfer grooves in skin and spar
- Spar web stiffeners




Example of inboard region of F-111 wing skin

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# Requirements for POD validation

# POD for Aircraft Structural Integrity

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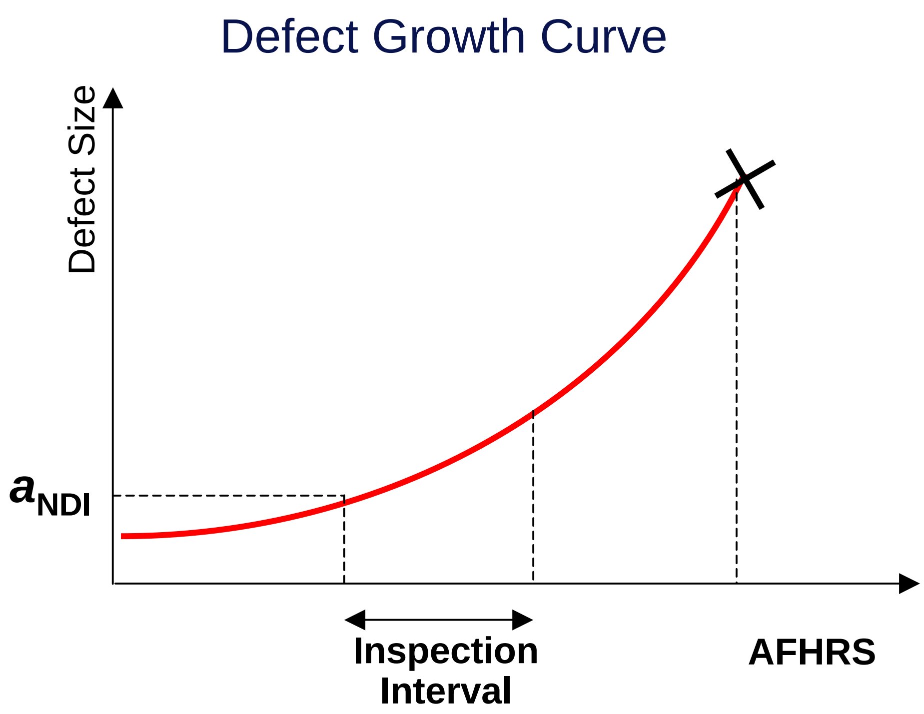
Inspection intervals are based on the largest defect that might be missed by an inspection method, $a_{NDI}$.



# What should $a_{NDI}$ be?

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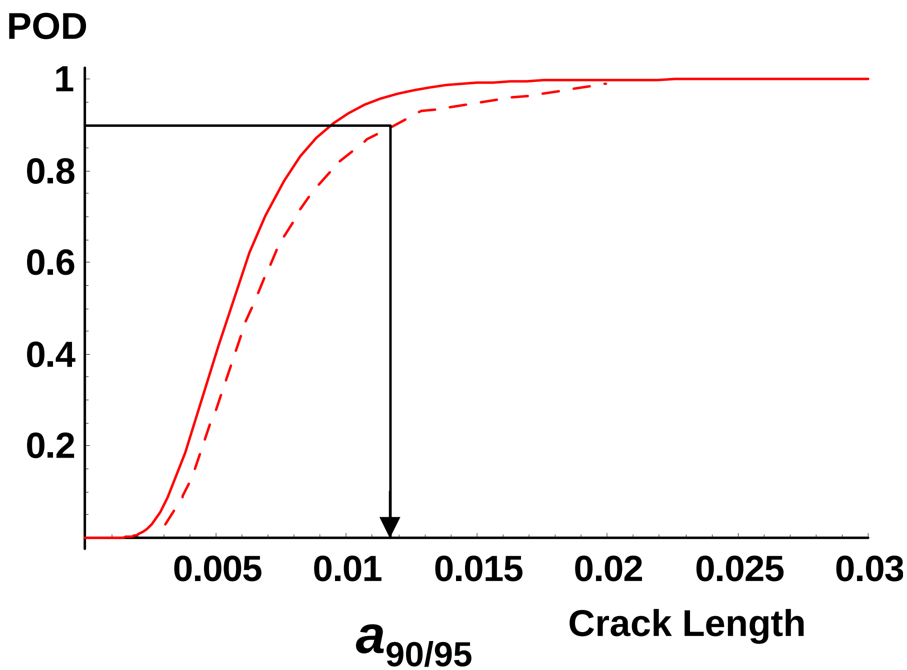
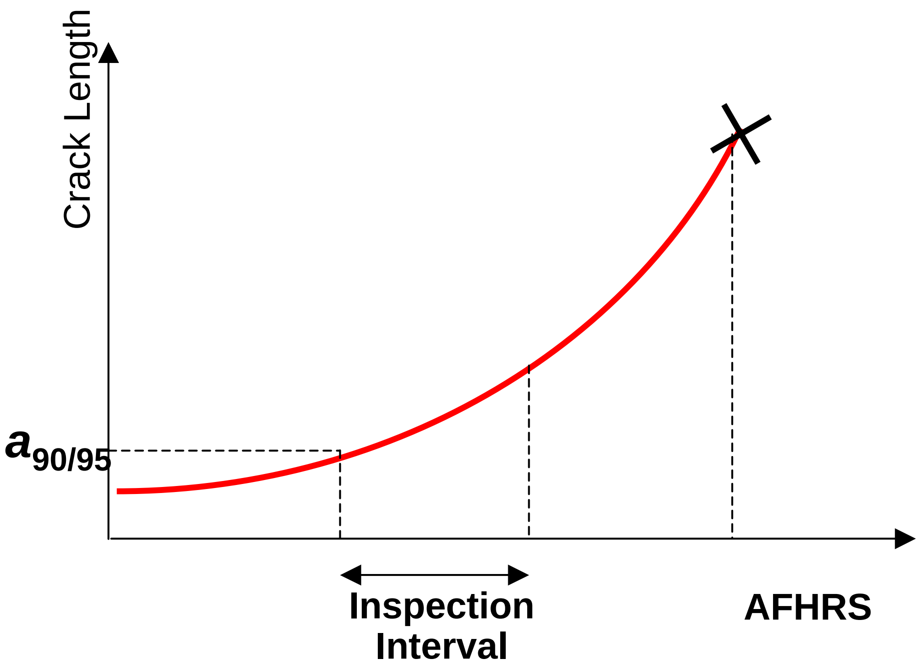
Under US Joint Service Specification Guide for Aircraft Structures (JSSG-2006):

- $a_{NDI} = a_{90/95}$ 90% POD demonstrated with 95% statistical confidence
  (JSSG-2006, paragraph 4.12.1.a Verification Guidance)
- Same as superceded MIL-A-83444 – requirement for F-111



# Current Options for $a_{NDI}$ Certification

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Two choices, no middle ground.

***99% of RAAF NDI Procedures***

**Estimated Detectable Defect Size**

… ? …

***1% of RAAF NDI Procedures***

**Representative POD trial**

- low cost
- routinely available
- limited reliability consideration

- expensive (specimens & inspection time)
- outcome applicable to specific procedure only
- comprehensive reliability measurement

# POD Modelling – Filling the Gap

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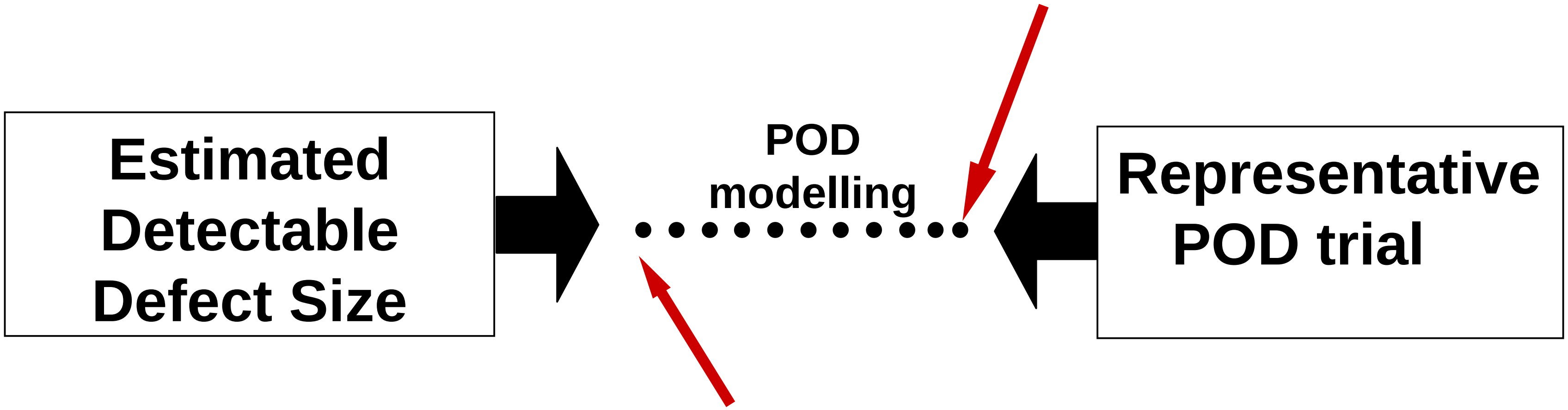
Most POD modelling effort focuses on reducing cost of high accuracy assessments




Biggest payoff for ASI is improving low accuracy end!

- Reduced risk of structural failure
- Reduced incidence of over inspection

# Options for POD Modelling



Two approaches identified by Model-Assisted POD Working Group:

## Transfer Function Approach

- 3 Specimen types
  - Artificial defects in complex geometry
  - Representative defects in simple geometry
  - Artificial defects in simple geometry
- POD trial on complex geometry
- Regression analysis to adjust for representative defects

## Full Model-Assisted Approach

- Identify factors
- Develop and validate model
- Simulation tool to predict response to well-understood factors
- Experimental assessment for uncontrolled or un-modelled factors
- Compute POD

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# Application of POD modelling to F-111 Lower Wing Skin

# POD Validation for F-111 Lower Wing Skin

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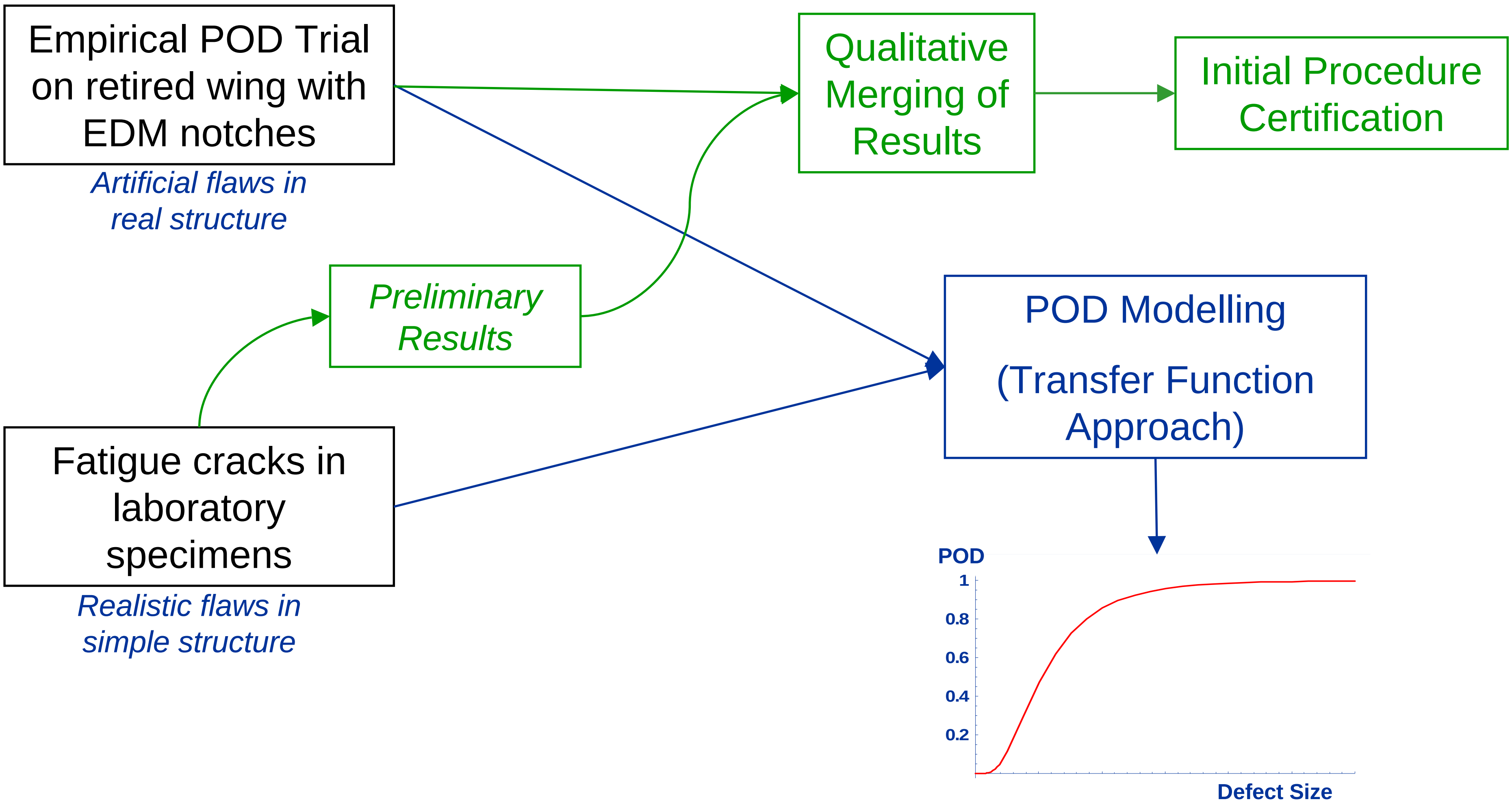

# Defect Types

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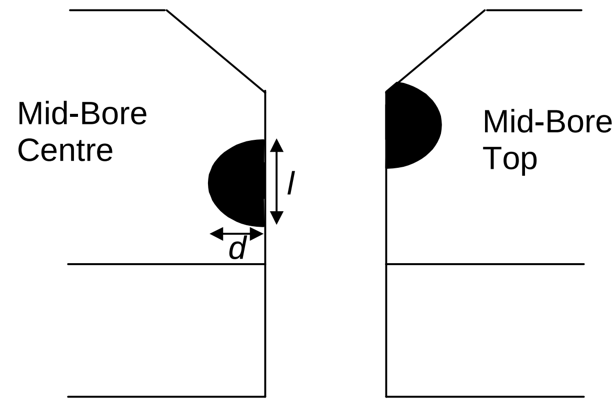
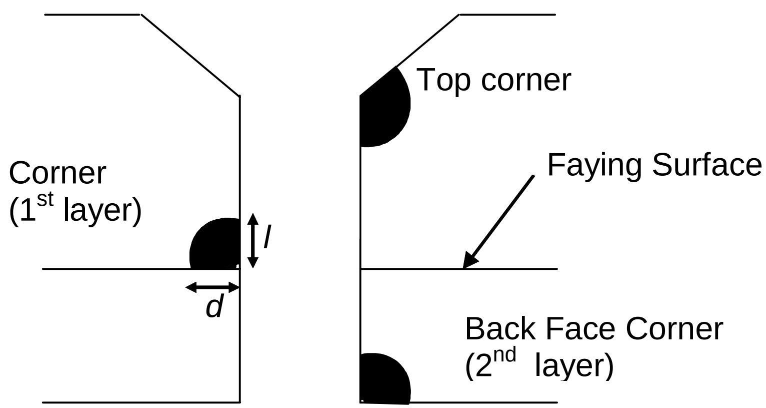
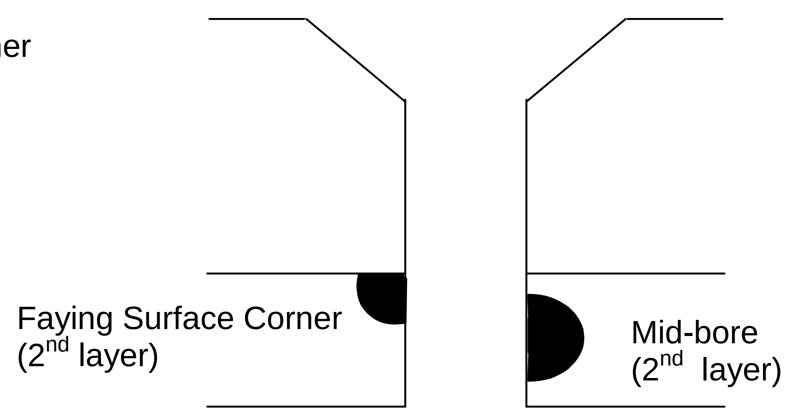
Defects can occur at any depth in hole bore and 1st or 2nd layer.



# Empirical POD Trial on Retired F-111 Wing

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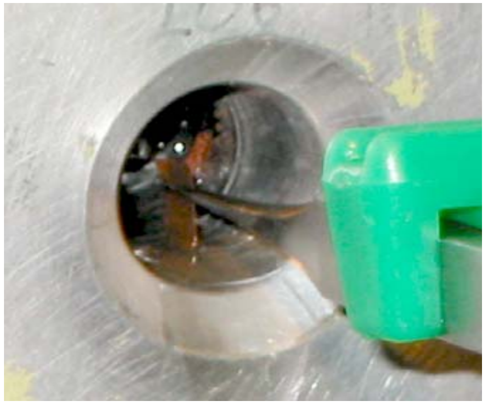
- >100 EDM notches inserted in bore of fastener holes across 2 wings
  - Range of types, sizes and locations
- 4 level 2 NDI Technicians
  - Training recently completed
  - No previous experience interpreting full-waveform c-scan data
- Treat data acquisition and data interpretation phases separately



# Empirical POD Trial on Retired Wing

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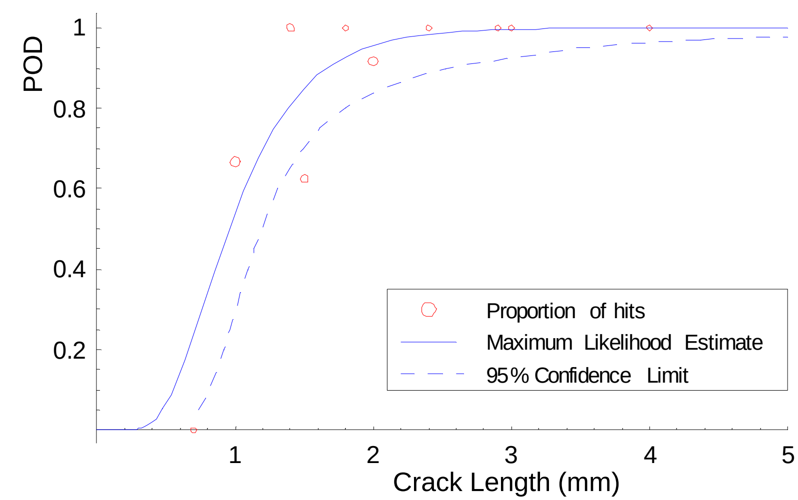
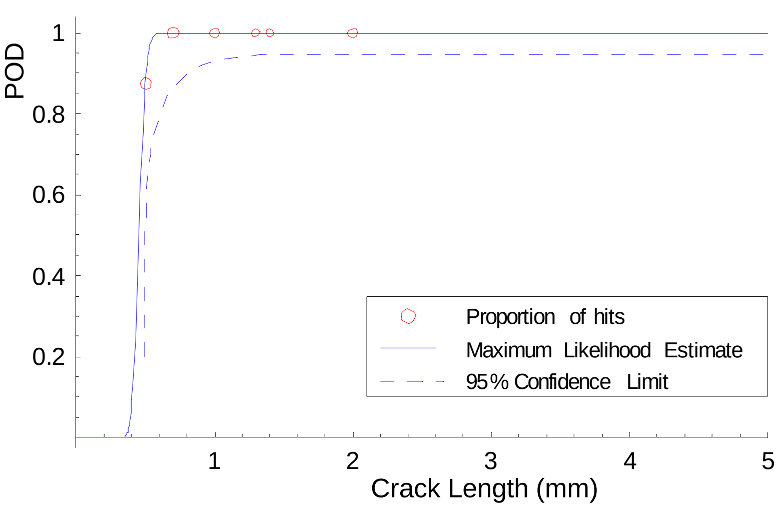
## Preliminary results for EDM notches

| | $a_{90}$ (mm) | $a_{90/95}$ (mm) |
|---|---|---|
| Corner | 0.5 | 0.7 |
| Mid-bore centre | 1.7 | 2.5 |
| Mid-bore top | 3.3 | Not achieved |

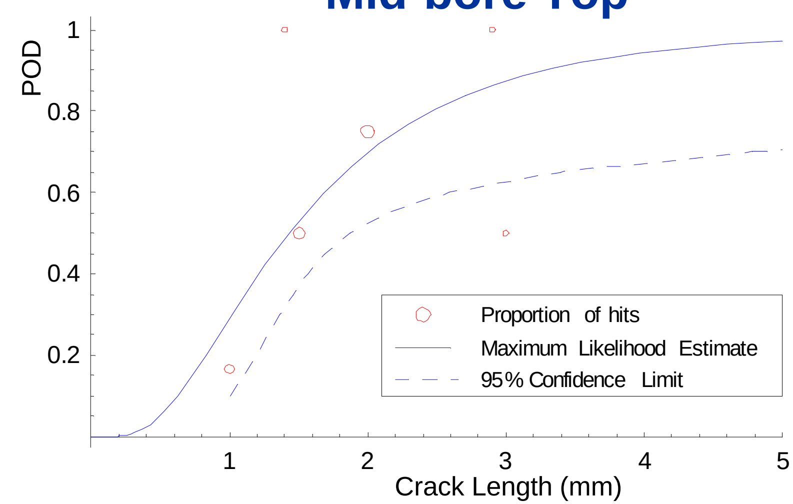
## Mid-bore Centre




## Corner




## Mid-bore Top



# Fatigue Cracks in Laboratory Specimens

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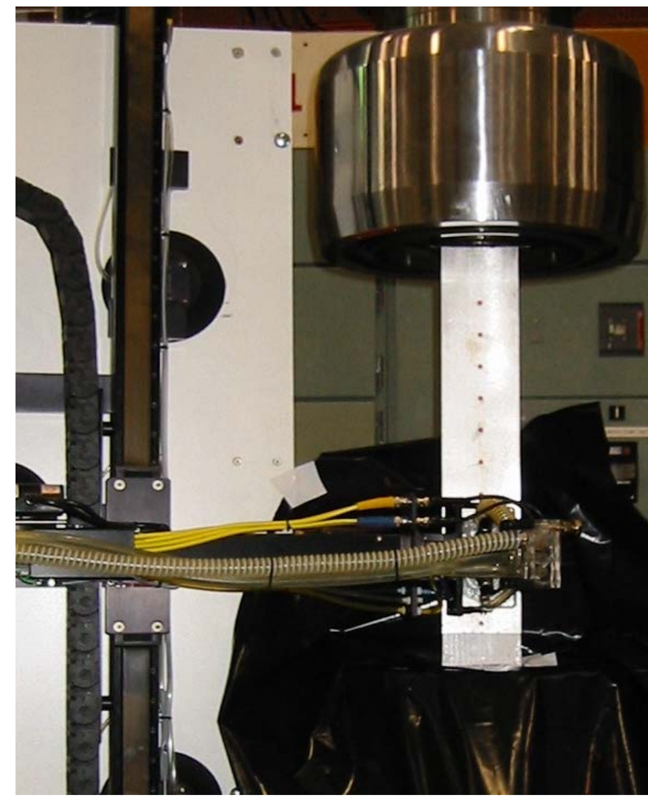
## Fatigue crack specimens

- 2 thicknesses (0.5” & 1.0”)
- 4 defect types
  - Corner, mid-bore top, mid-bore centre, top corner
- Representative spectrum loading
- Two specimens contain EDM notches

## Experimental program

- Metrics for ultrasonic response
  - Area
  - Amplitude
- Measured under varying load
  - Crack closure effects



# Preliminary Results

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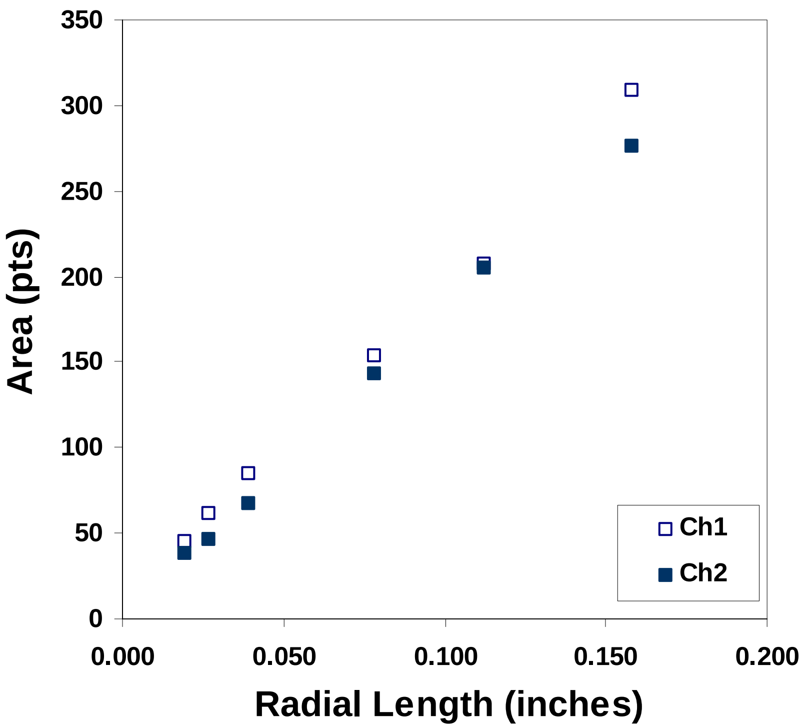
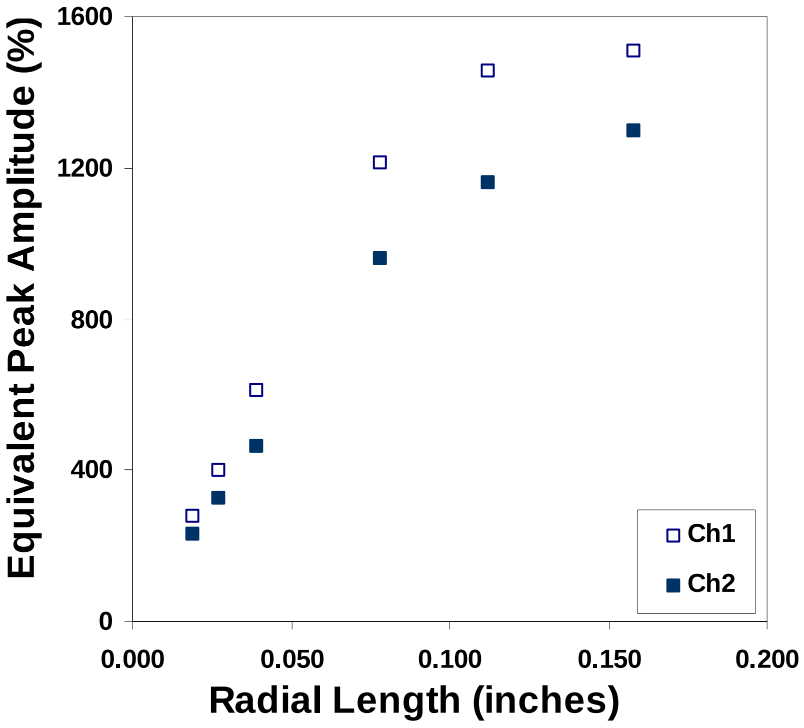
- UT response for corner EDM notches in specimens
  - Corner reflections
  - 0.5” specimen thickness



# Preliminary Results

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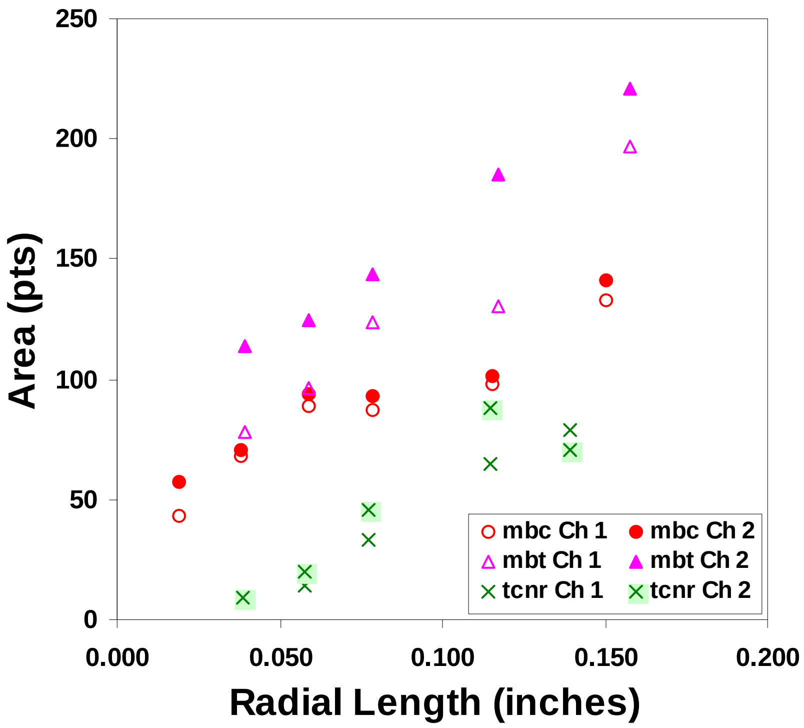
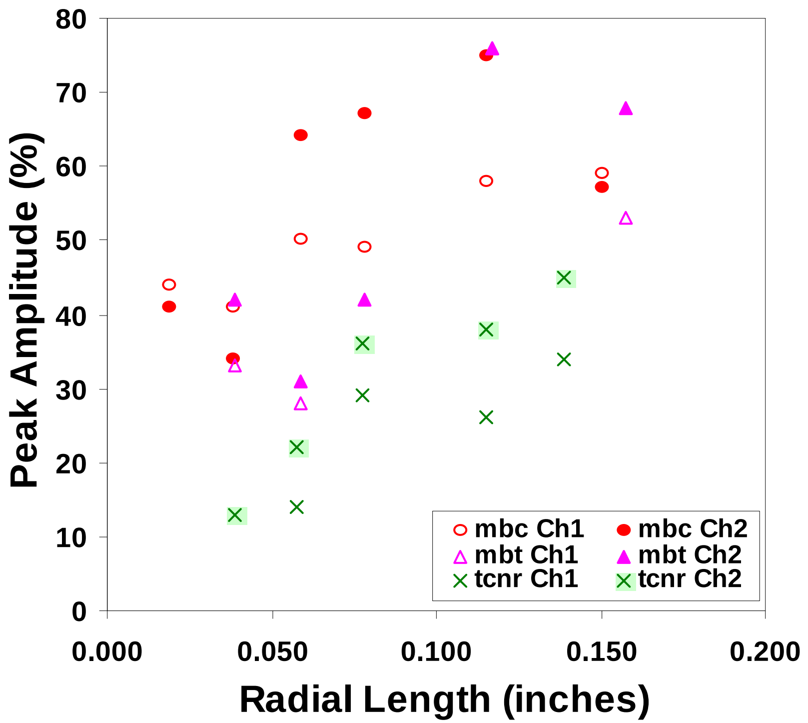
- UT response from mid-bore EDM notches
  - Direct reflection
  - Area measured at lower threshold



# Preliminary Results

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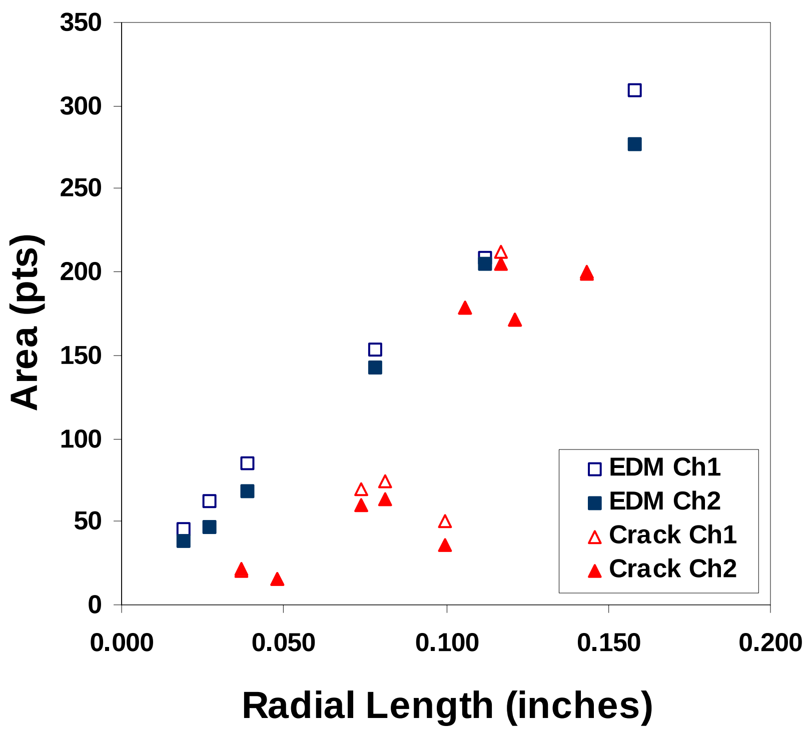
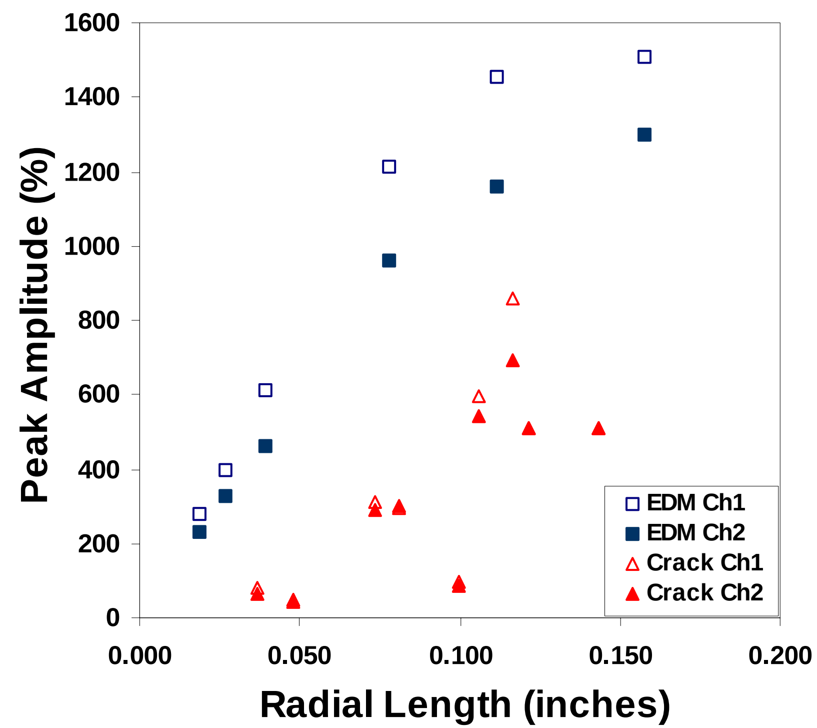
- UT response from corner fatigue cracks and EDM notches
  - Length of cracks measured by UT with specimens under load to fully open cracks
  - Cracks show reduced area and amplitude compared to EDM notches



# Preliminary Results

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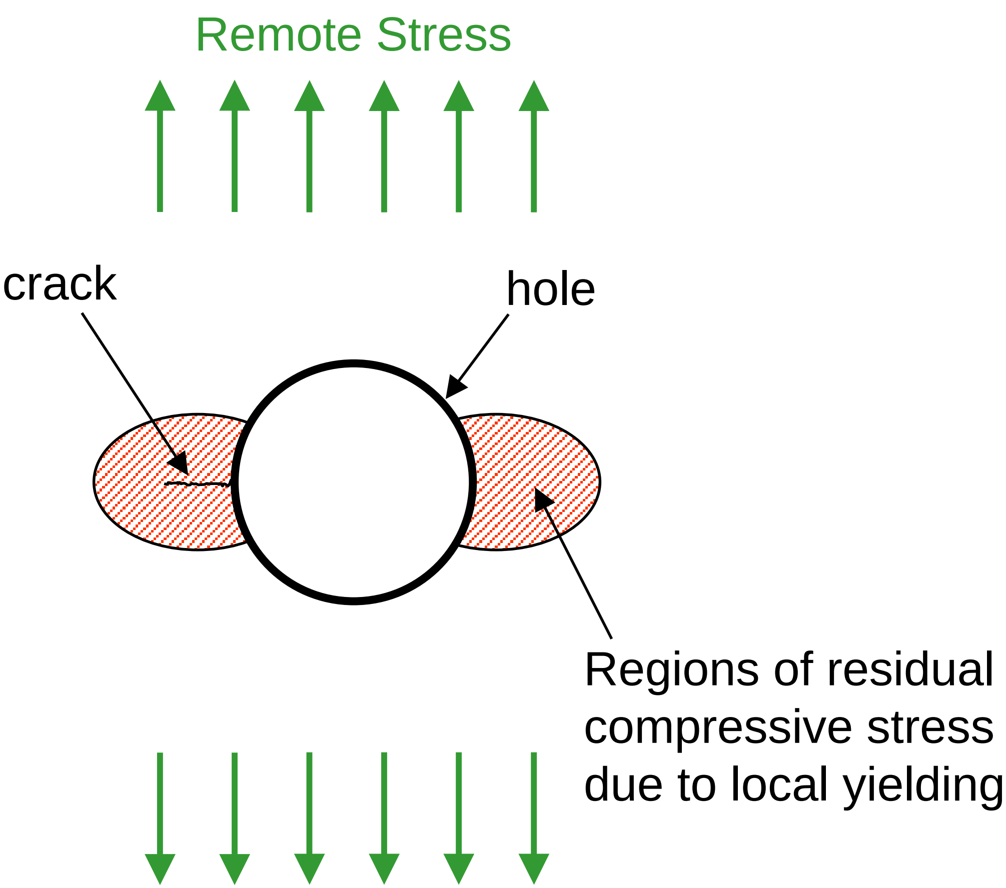
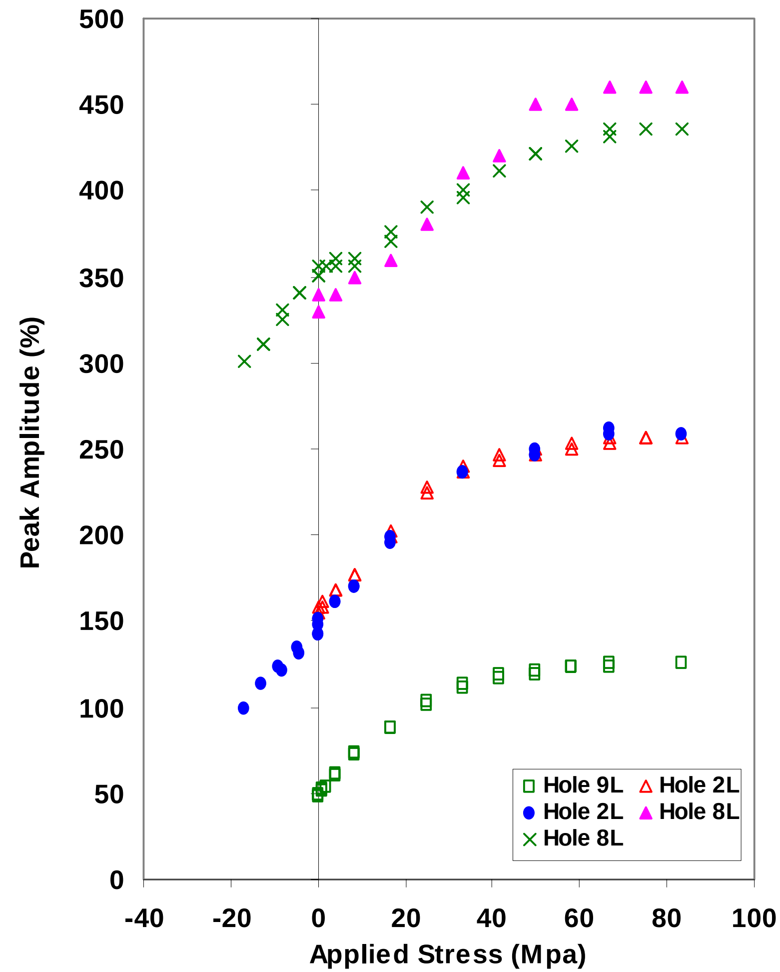
## Crack closure due to plastic strain at holes (notch plasticity)




## Effect of applied stress on UT



# Cracking at Fuel Transfer Groove in Wing Skin

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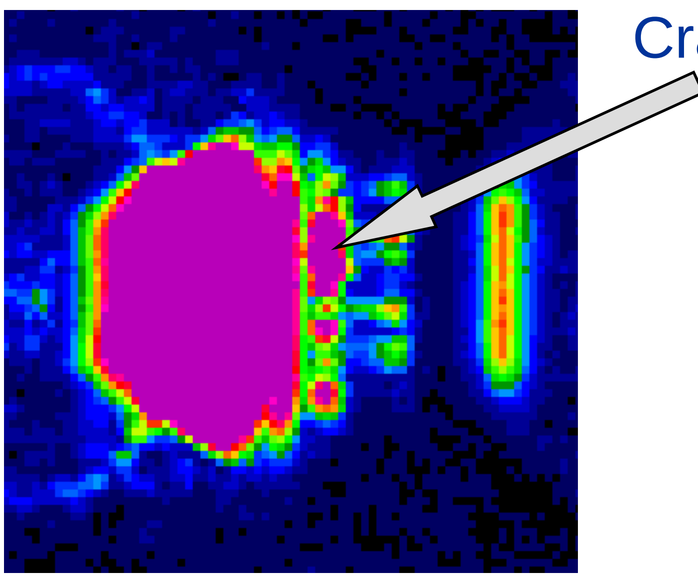
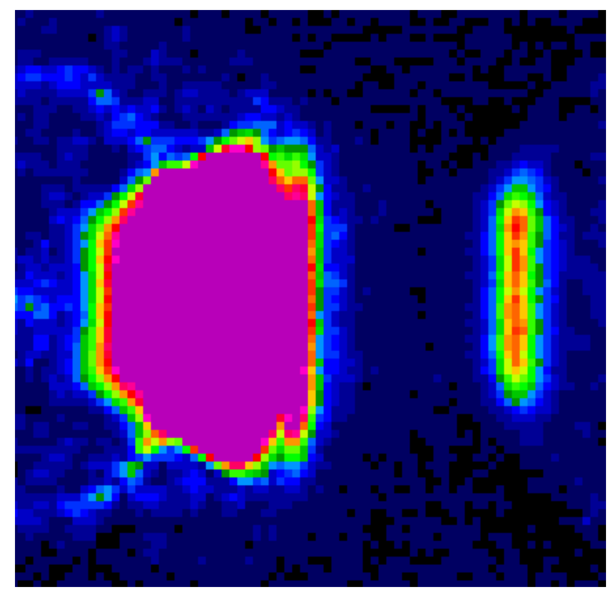
Specimen containing real crack at fuel transfer groove inspected by 45º shear wave UT with and without applied load

Applied stress 120MPa (~50%MSS)




Amplitude C-scan

No applied load



Amplitude C-scan

# Cracking at Fuel Transfer Groove

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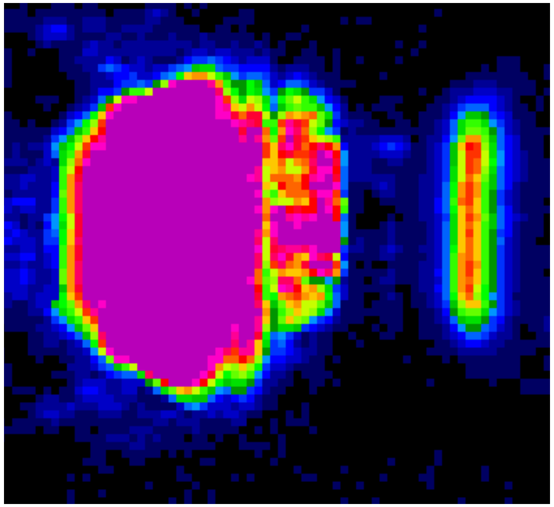
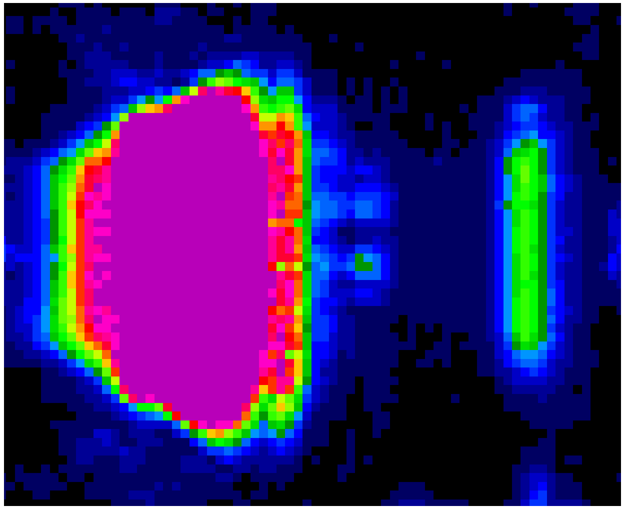
Larger crack at fuel transfer groove, with and without fuel ingress

No applied load
Dry crack



Amplitude C-scan

No applied load
With fuel ingress



Amplitude C-scan

# Conclusions

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- Accurate assessment of POD for F-111 lower wing skin inspection is required for continued operation of RAAF F-111 fleet through to planned withdrawal date
- Full POD trial on representative defects is not feasible for this application
- Transfer function approach to POD modelling will be applied
- Significant difference between response from EDM notches c.f. cracks
- Crack closure is a significant factor