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Reliability of Widespread Fatigue Damage Detection

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Sandia National Laboratories AANC

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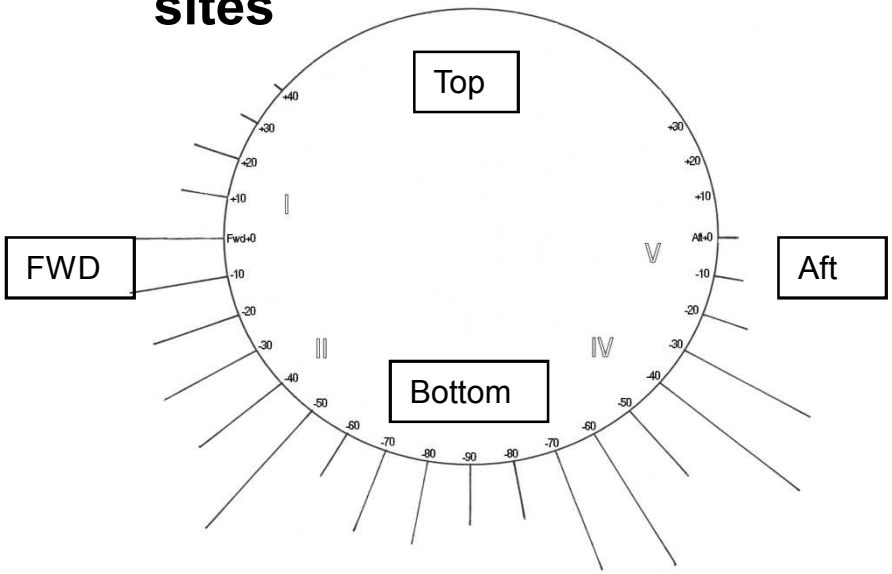
  - David Piotrowski et al
- Sandia National Laboratories Coworkers
  - Dr. Floyd Spencer – Statistical Model Development
  - Colin McConnell – Panel Disassembly
  - Ciji Nelson – NDI and Defect Characterizations
  - Bryce Smith – Defect Characterizations

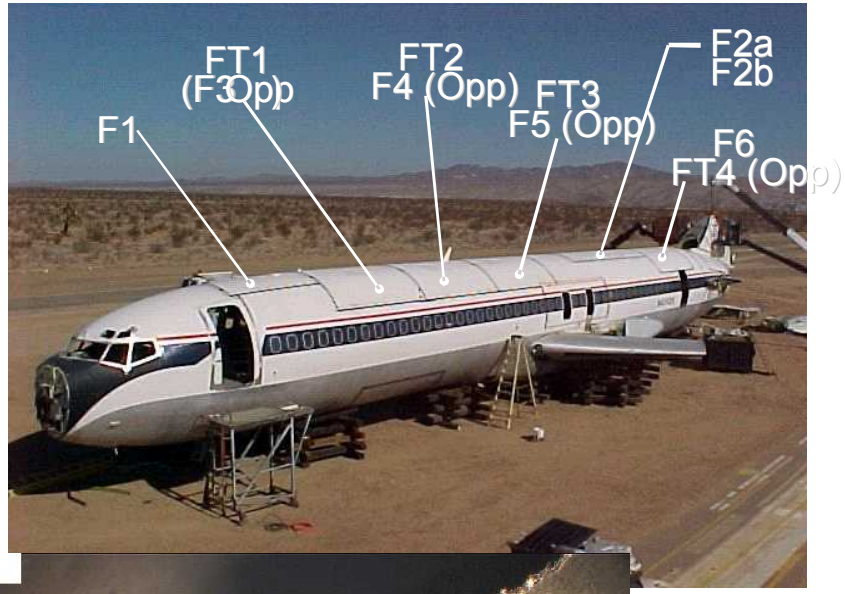
Purpose & Objectives

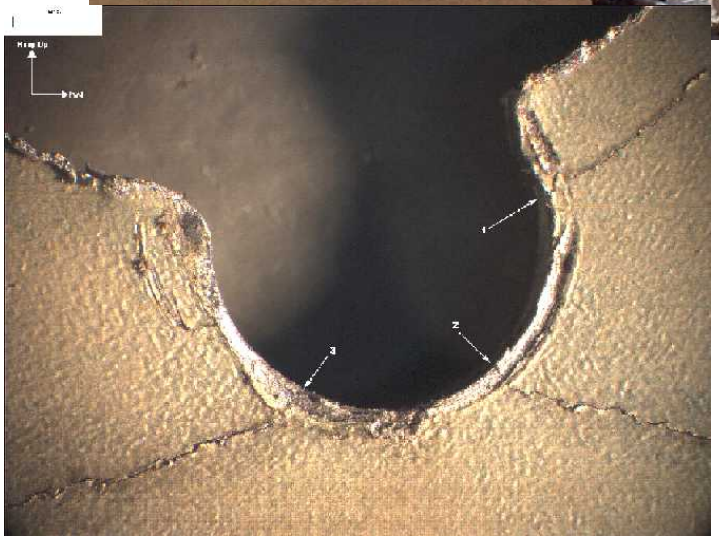
- Purpose
  - Database additions of NDI for Widespread Fatigue Damage (WFD) beyond prior work by FAA, Delta Air Lines, and AANC
    - Inner Layer Crack POD
    - Delta Panel POD
    - B727 Teardown POD
- Objectives
  - Evaluate emerging technologies not available during the initial B727 Teardown Study
  - Develop a set of lap joint WFD specimens based on real structure with natural defects for future POD determinations

B727 Teardown NDI Readiness Study
Piotrowski et al, 2005
POD Specimens from Retired Aircraft

- 20 NDT methods evaluated
- Inspections performed prior to destructive characterization
- WFD/MSD Distribution
  - 422 cracks at 270 fastener sites







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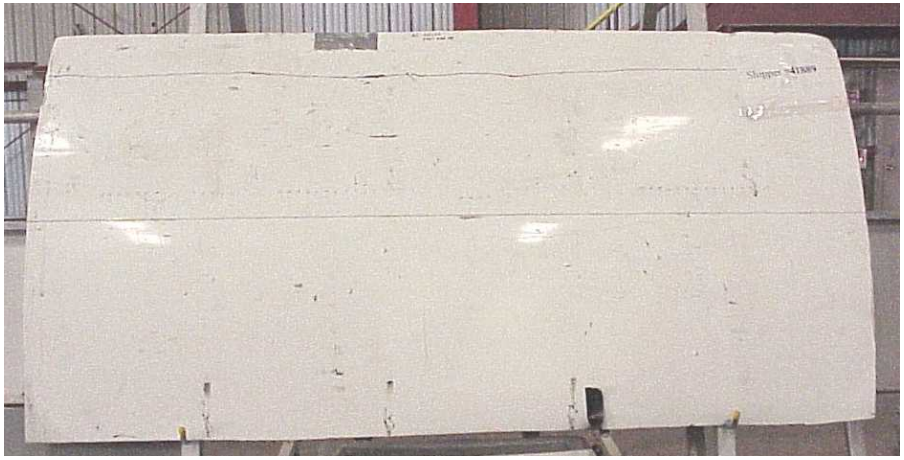
WFD POD Panel Development

- Selected 5 panels from 40 lap joints harvested from two retired B727s
- Sister ships to FAA/Delta Teardown subject aircraft
- Aircraft achieved Design Service Goal of 60k pressurization cycles
- Lap Joint design has commonality with multiple aircraft (e.g. B737)



Natural Defect - Reassembled WFD Panel Development Process

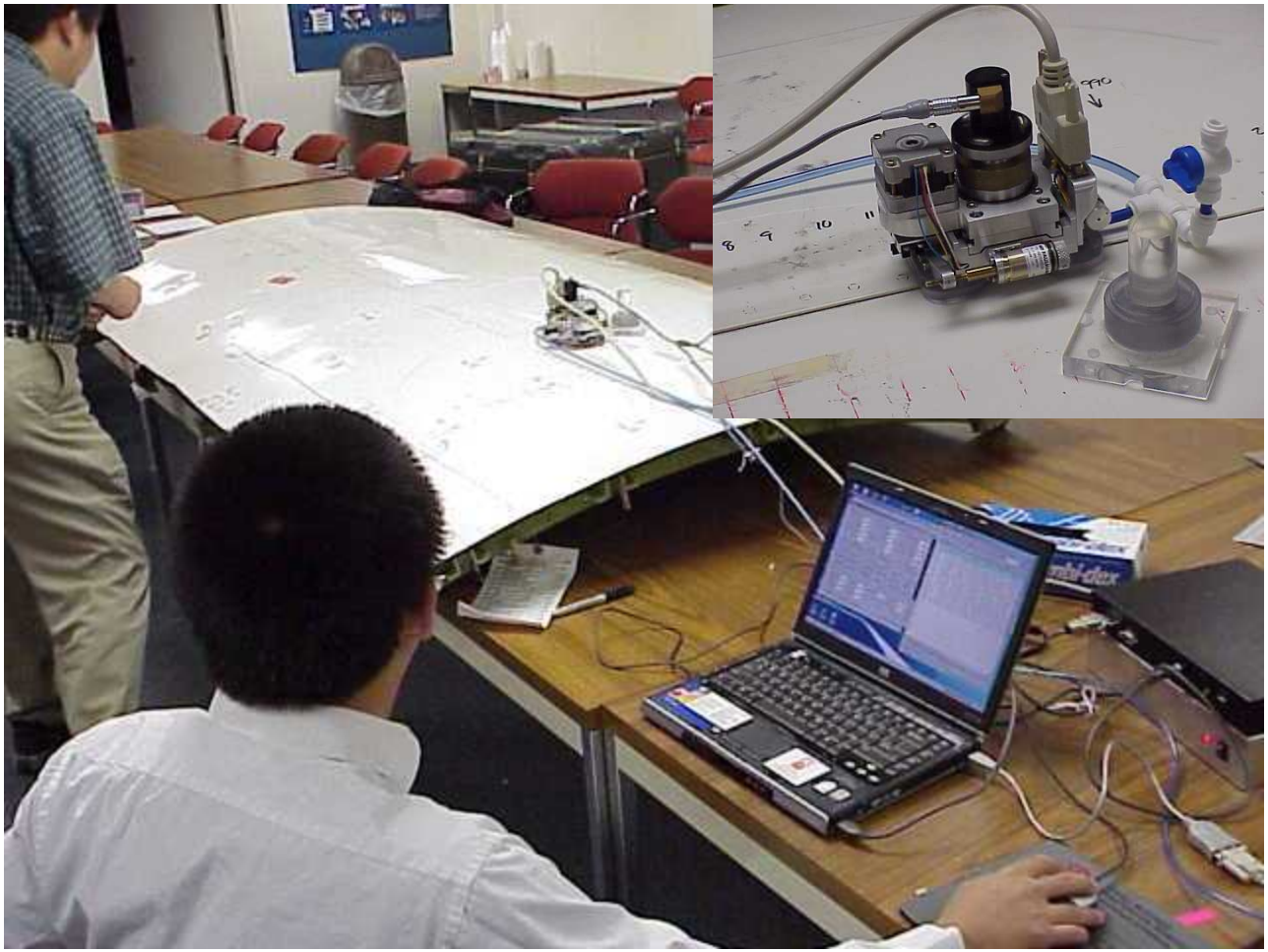
1. Blind Inspections
2. Disassemble
3. Characterize
   - Calculate POD
4. Reassemble
5. Re-characterize & Future POD Studies

Current Research
NDI Methods Evaluated

- Conventional
  - Medium Frequency Eddy Current (MFEC) Boeing Procedure – 30kHz Spot Probes & Nortec 1000 or 2000D Eddy Current Instrument
- Emerging or Developing
  - Innovative Materials Testing Technologies, Remote Field – Super Sensitive Eddy Current (RFEC)
  - USUT Labs, Ultrasonic Linear Array (USUT)
  - Olympus NDT, Omniscan Ultrasonic Linear Array (OMNI)

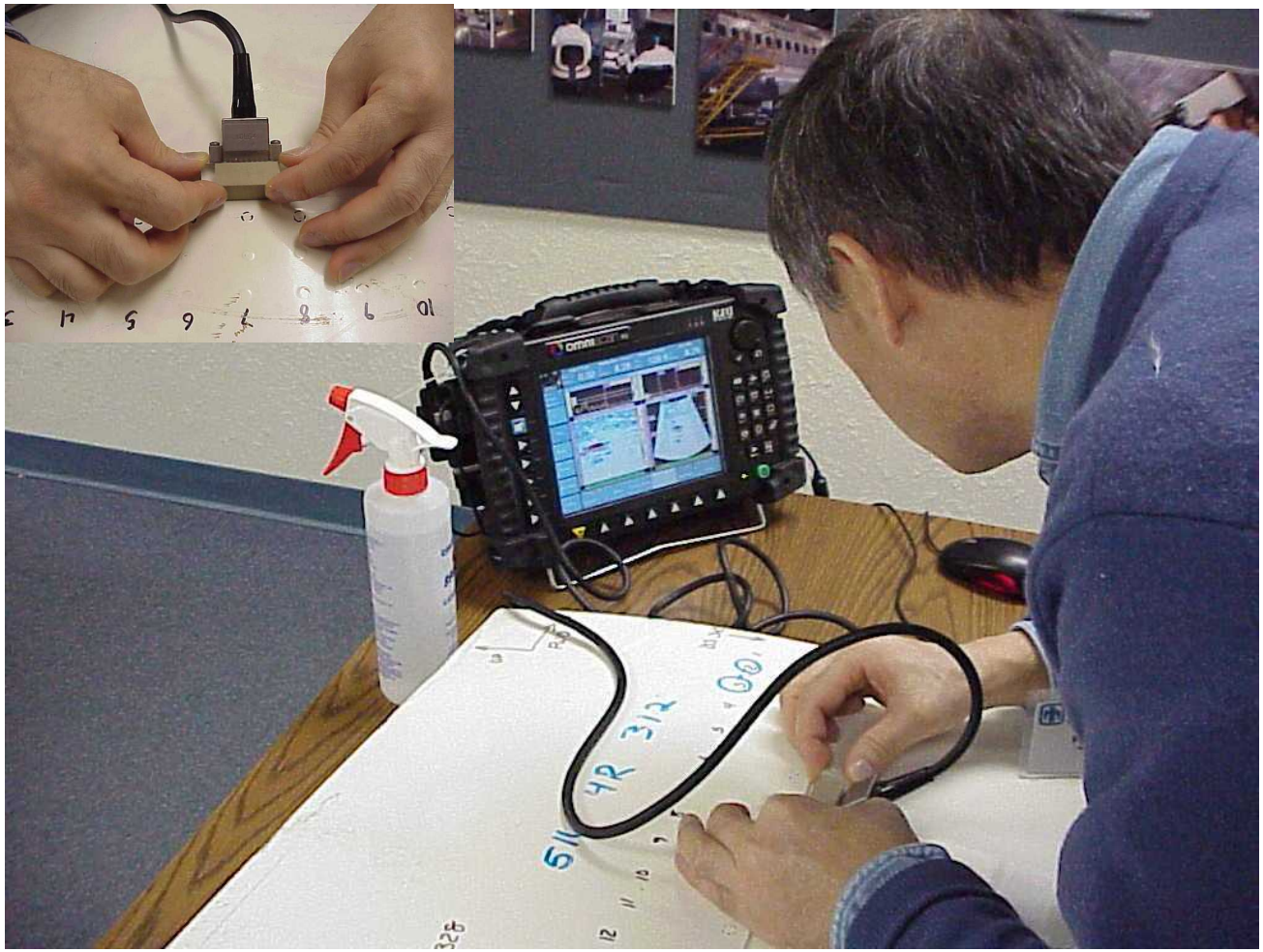
Medium Frequency Eddy Current (MFEC) Boeing Procedure 30kHz Spot Probes & Nortec 2000D Eddy Current Instrument

Innovative Materials Testing Technologies, Remote Field – Super Sensitive Eddy Current (RFEC)



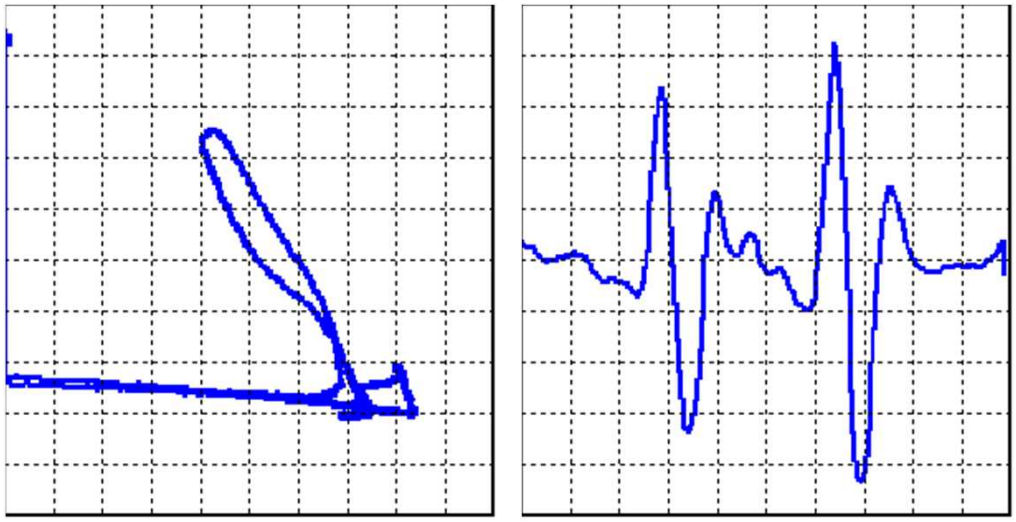
USUT Labs,
Ultrasonic Linear Array (USUT)

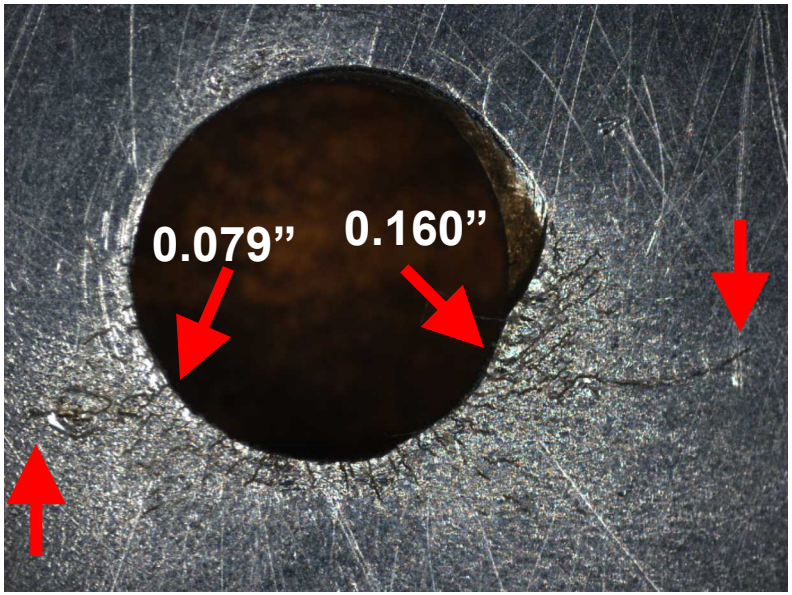
Olympus NDT, Omniscan Ultrasonic Linear Array (OMNI)



WFD Panel Defect Characterization

- After Disassembly
  - High Frequency Eddy Current on Faying Surface
  - Rotating Probe Eddy Current in Rivet Hole
  - NaOH Etch and Direct Visual Stereomicroscopy



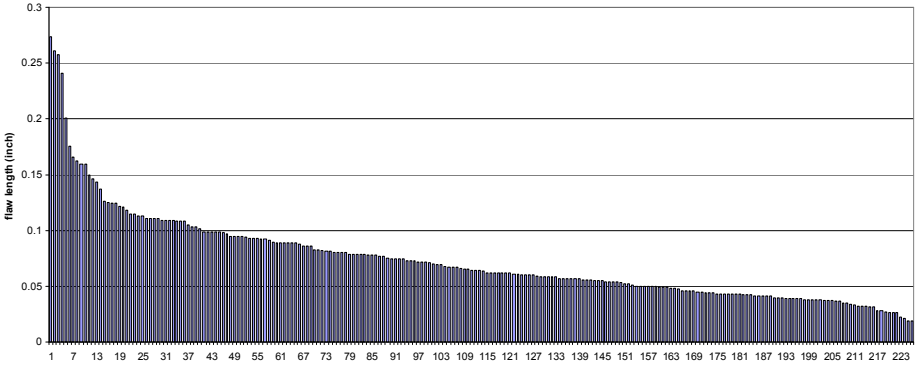


WFD Panel Defect Distribution

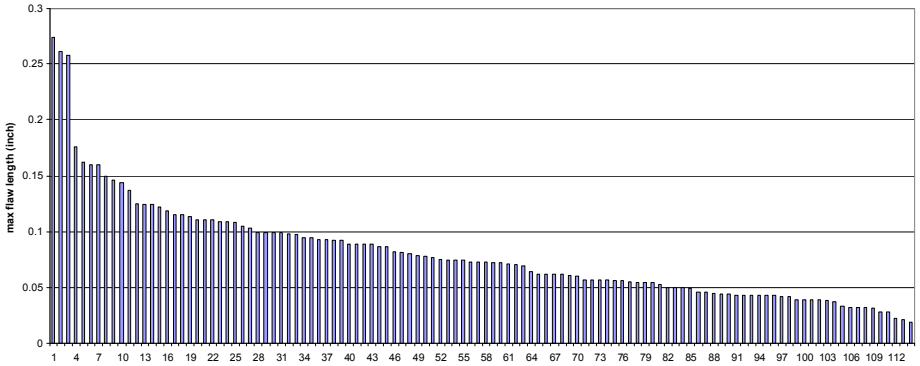
- 357 “Inspectable” Rivet Sites
  - 243 Unflawed Sites
  - 114 Flawed Sites

#Cracks/ Site	#Sites	Max Flaw Lengths/Site
5	2	0.099 – 0.060
4	7	0.258 – 0.071
3	19	0.261 – 0.037
2	45	0.274 – 0.038
1	41	0.108 – 0.019
226 Cracks Total		

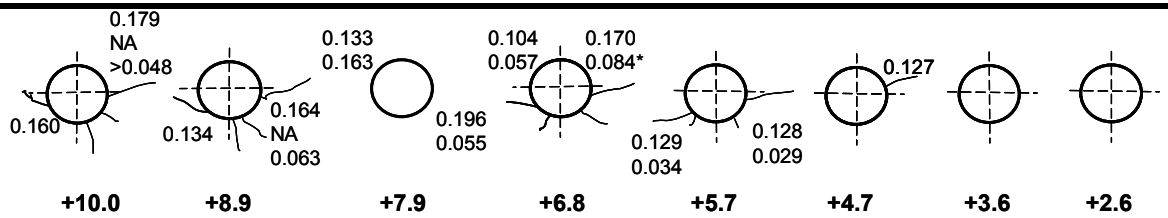
All Flaw Length



Maximum Flaw Length



Panels are Representative of Typical WFD



- **Flaw lengths and locations are consistent with prior work by FAA and Delta Air Lines**
  - **Certain sections of the aircraft prone to cracking**
  - **Certain sections of panels (bays) tend to have more cracks and other bays have little or none**
  - **Larger cracks occur within clusters of cracked sites**
  - **Individual or scattered cracks tend to be smaller**
  - **Multiple cracks at a single rivet site are common**
  - **Cracks known to tunnel under clad layer for up to 0.200 inch or more (Ramakrishnan & Jury)**

Methods of Data Analysis - POD

- All Results in Binary Format
- Spencer Multi-flaw Model
  - 2- and 4-Parameter POD Model Fits
  - Accounts for Multiple Flaws/Site
- Berens POD SS Probit Model
  - If Used for Maximum Flaw/Site
  - Then Overly Optimistic POD Estimate

$$\alpha+(\beta-\alpha)\cdot\left[1-\left(1-\Phi\left(\frac{\ln a_1-\mu}{\sigma}\right)\right)\cdot\left(1-\Phi\left(\frac{\ln a_2-\mu}{\sigma}\right)\right)\right]$$

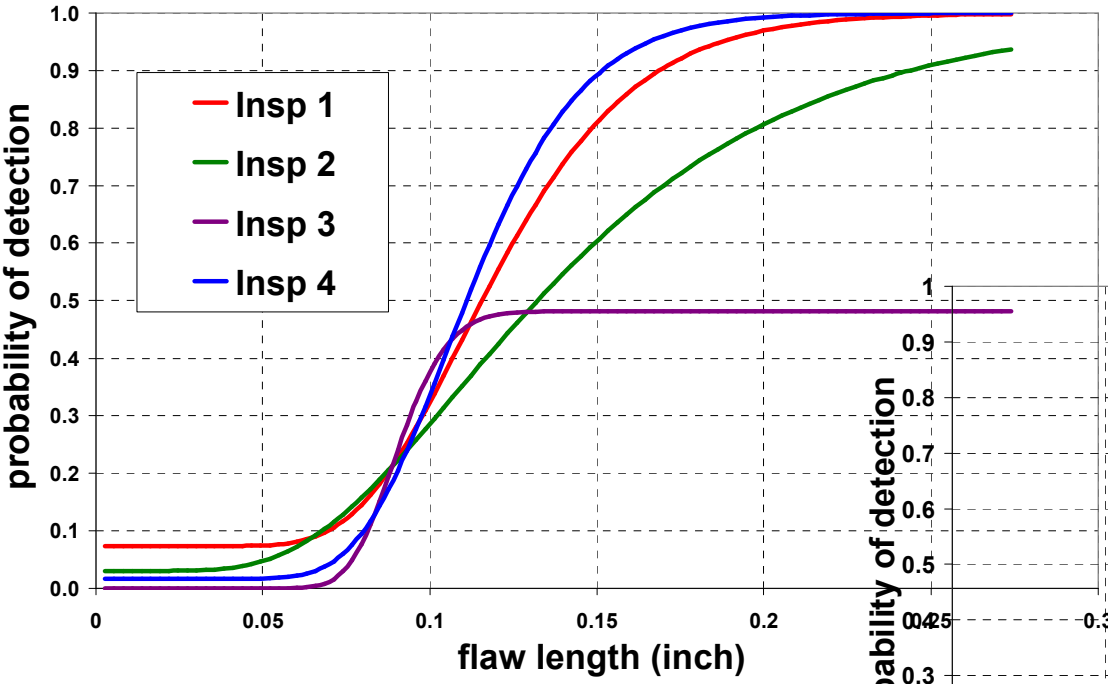
Spencer Multi-Flaw Model

$$\Phi\left(\frac{\ln a-\mu}{\sigma}\right)$$

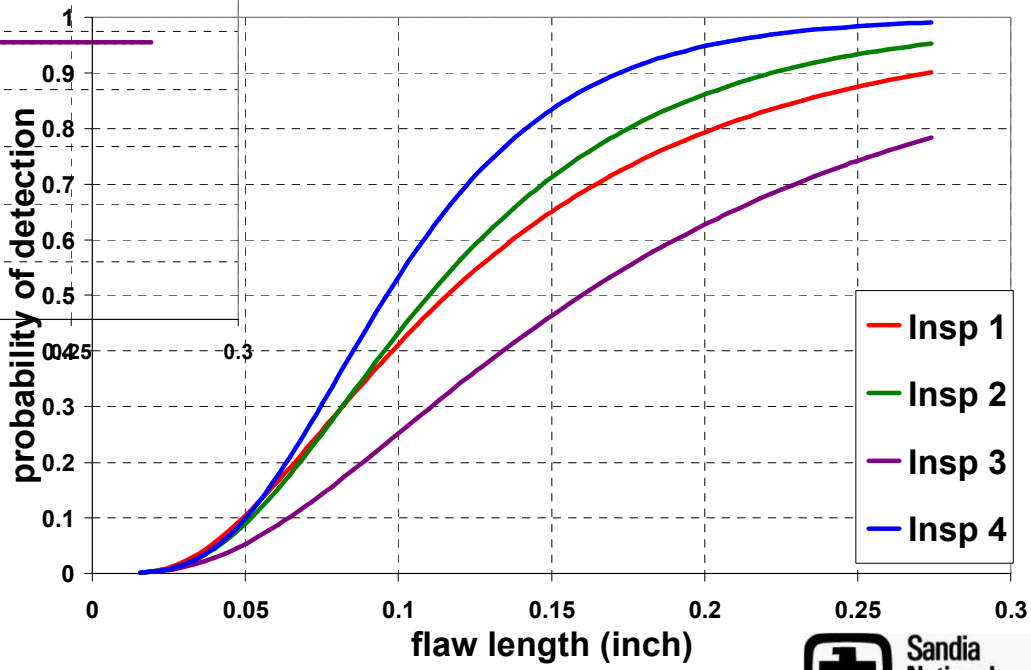
Berens Probit Model

Results of Blind Inspections – MFEC Medium Frequency Eddy Current

MFEC 3-Parameter Multi-Flaw Model POD



MFEC Probit 2-Parameter Fits



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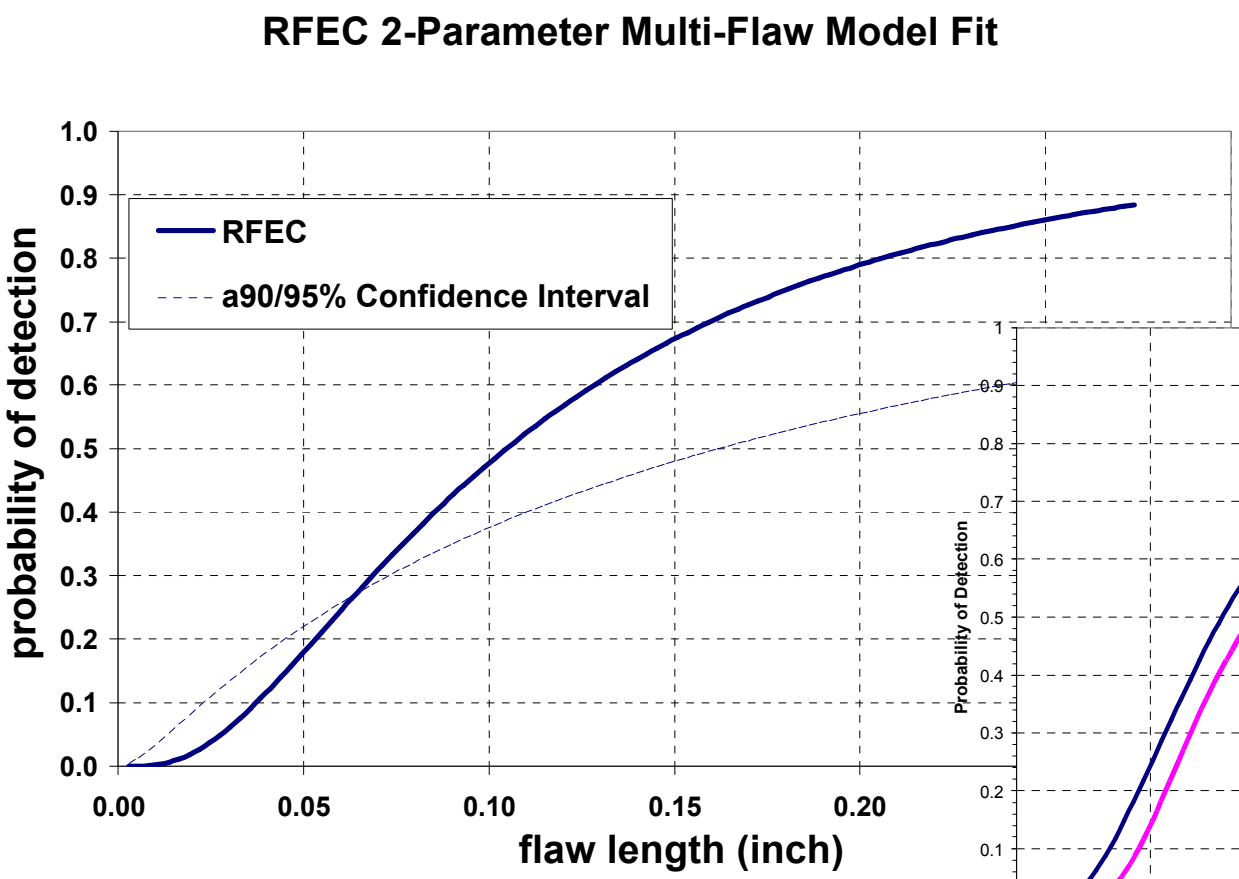
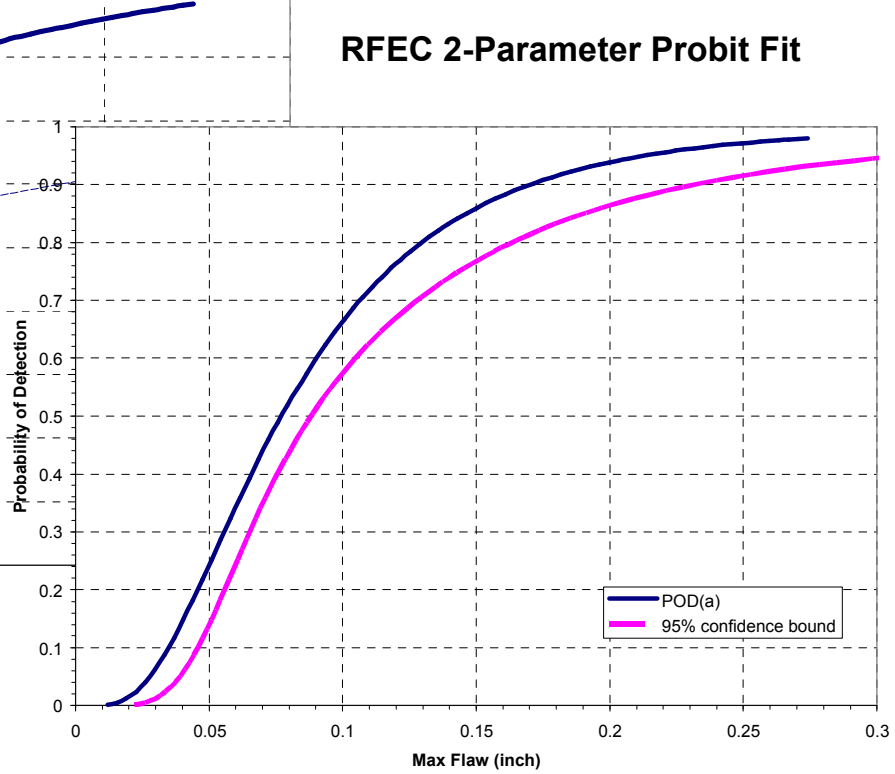
Results of Blind Inspections – RFEC Remote Field – Super Sensitive Eddy Current





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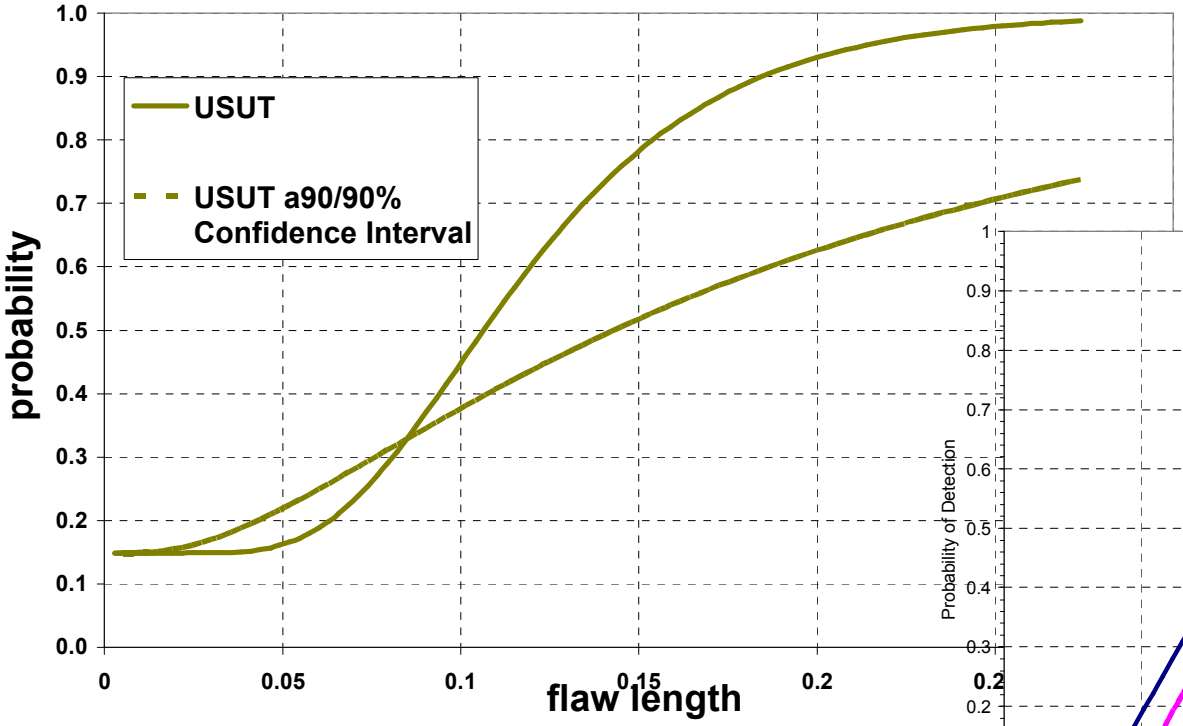
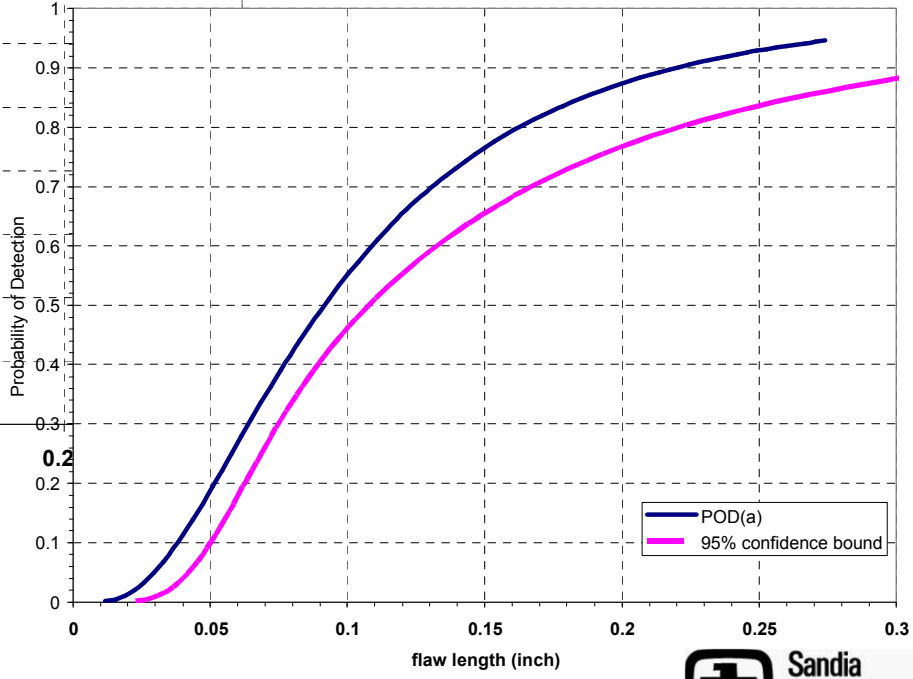
Results of Blind Inspections – USUT Ultrasonic Linear Array

USUT Multi-Flaw 3 Parameter Fit



USUT 2-Parameter Probit Fit



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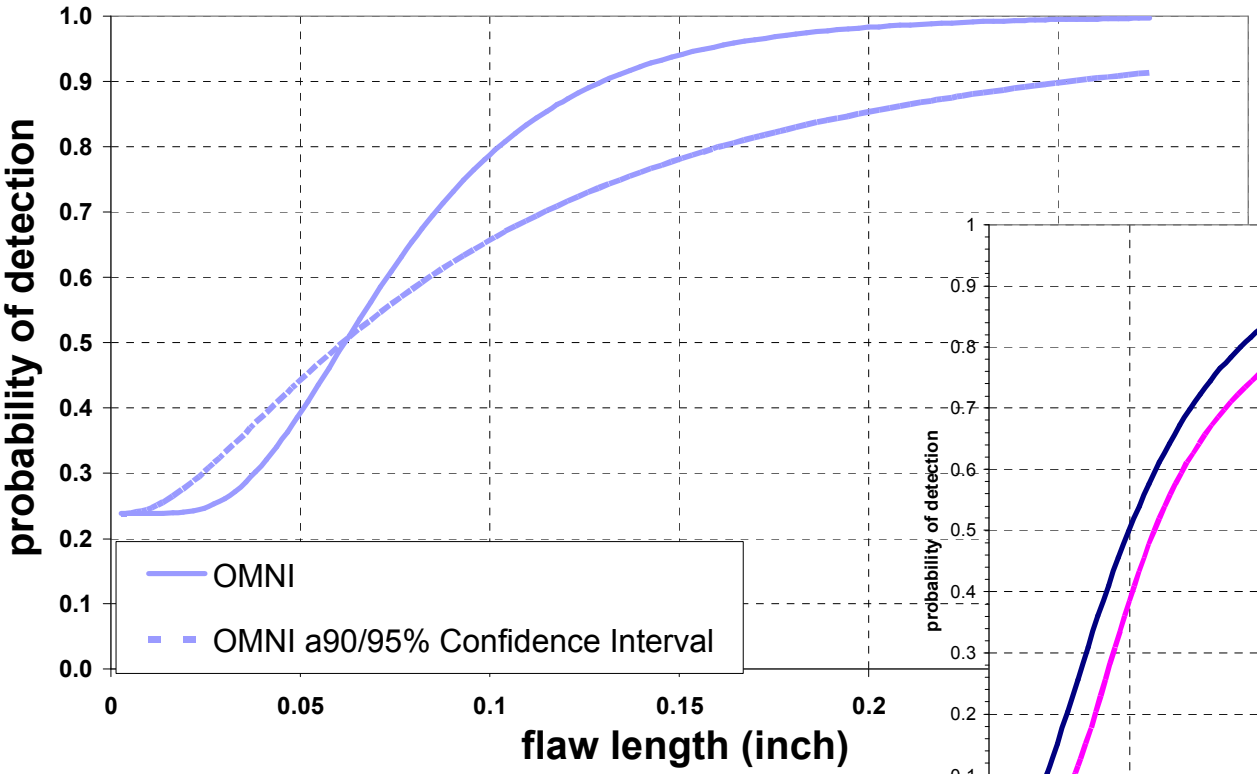
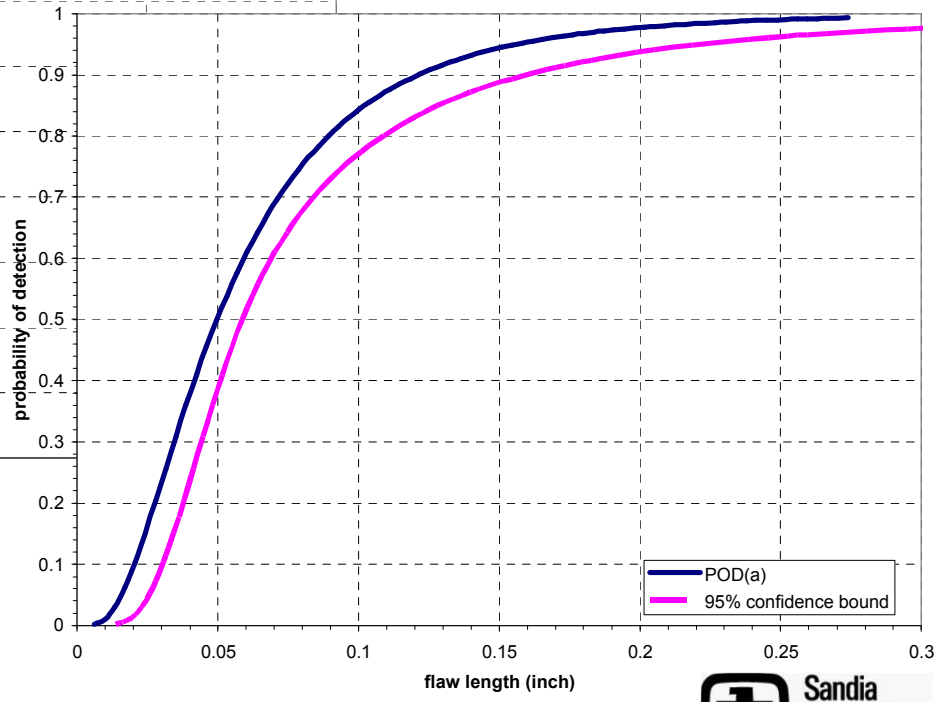
Results of Blind Inspections – OMNI Omniscan Ultrasonic Linear Array

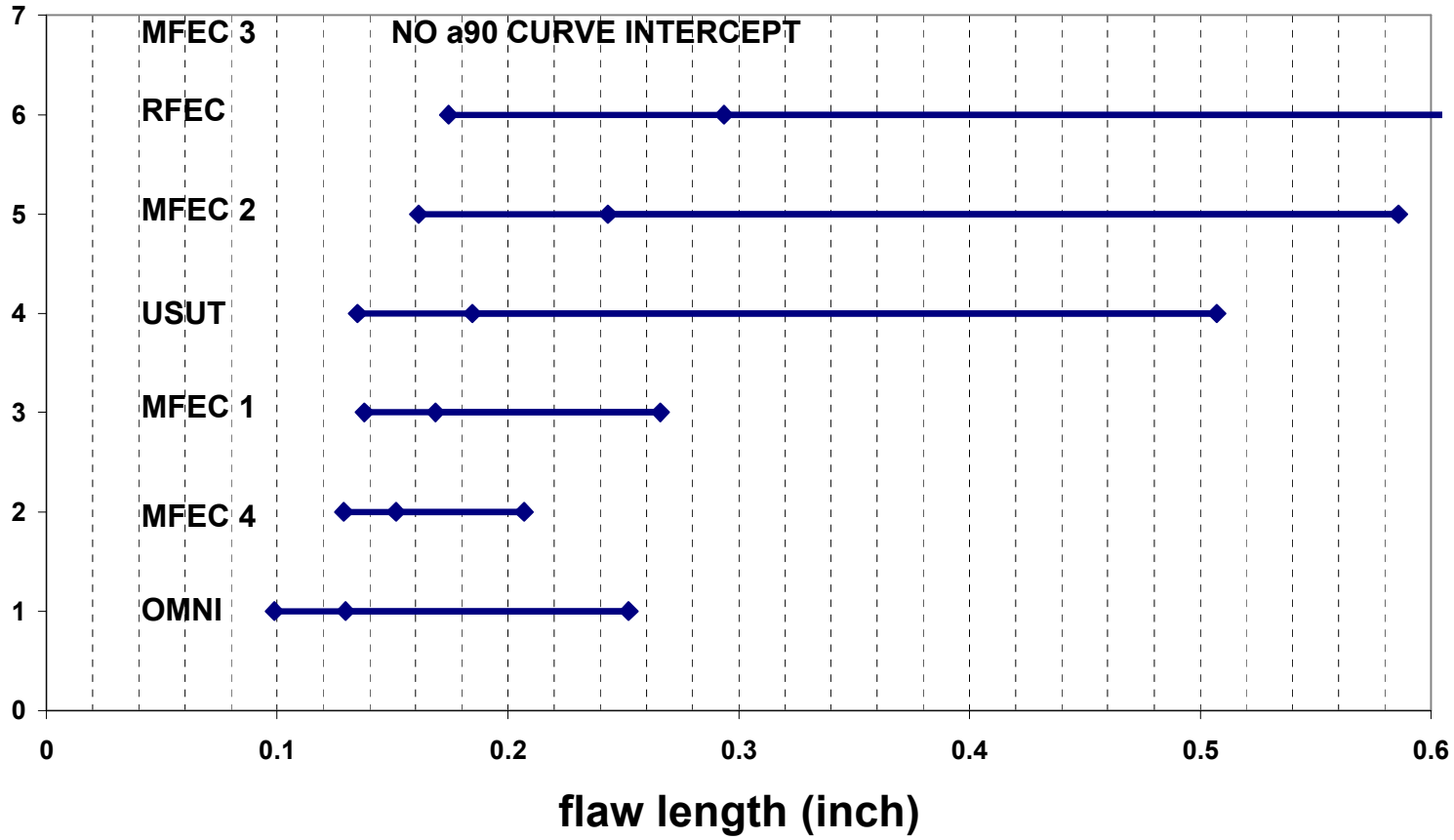
OMNI Multi-Flaw 3-Parameter Fit



OMNI Probit 2-Parameter Fit



Results of Blind Inspections – Comparison of Confidence Intervals



Results of Blind Inspections – POD Comparison Table

	Multi-Flaw Model Best Fits						Max Flaw Probit Fits	
Method	a90	a90./95	# Pars	Flaws Detected	Largest Missed	False Calls	A90	A90/95
MFEC 1	0.168	0.266	3 α=0.07	31/114	0.160	6/215	0.272	0.424
MFEC 2	0.243	0.585	3 α=0.03	28/114	0.160	15/221	0.224	0.315
MFEC 3	na	na	3 β=0.48	19/114	0.274	1/221	0.381	0.681
MFEC 4	0.151	0.207	3 α=0.02	28/110	0.144	12/165	0.179	0.227
RFEC	0.293	1.14	2	51/113	0.144	72/222	0.170	0.232
USUT	0.194	0.507	3 α=0.15	42/113	0.144	8/225	0.220	0.328
OMNI	0.130	0.252	3 α=0.24	73/113	0.113	36/222	0.121	0.160

??QUESTIONS??

- Contact us if you would like to participate in a POD exercise.

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