SAND2006-6536C

Reliability of Emerging NDI for Widespread Fatigue Damage Detection

ASNT Fall Conference

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Michel Bode[1] & David Piotrowski[2]

[1]Sandia National Laboratories/AANC
[2]Delta Air Lines Enabling Technologies

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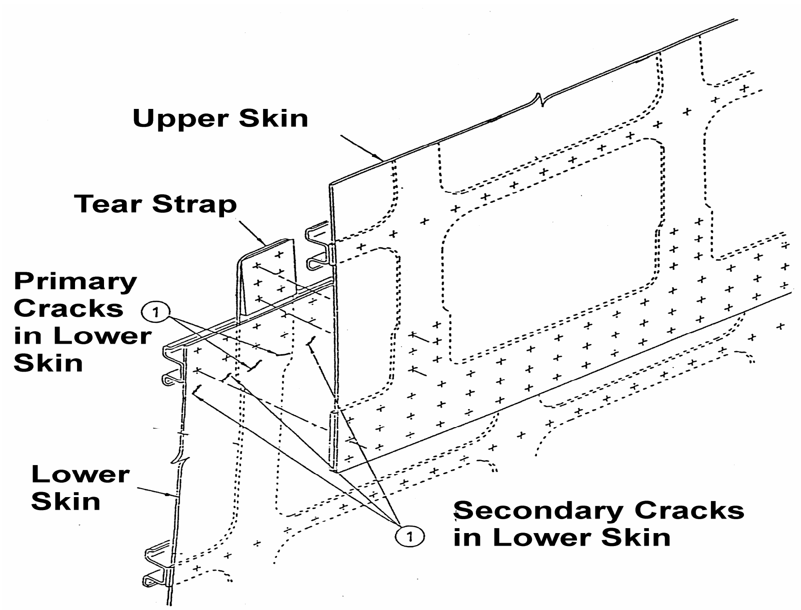
- Floyd Spencer
  - Sandia/AANC Reliability (POD) Statistician
- Participating Equipment Developers

Widespread Fatigue Damage in Lap Splice Joints

- Goal of FAA Technical Center Inspection R&D Program
  - promote development of technology that can detect cracks 0.050” long in second and third layer lap joint structures.

From Boeing

Service Bulletin SB737-53A1177

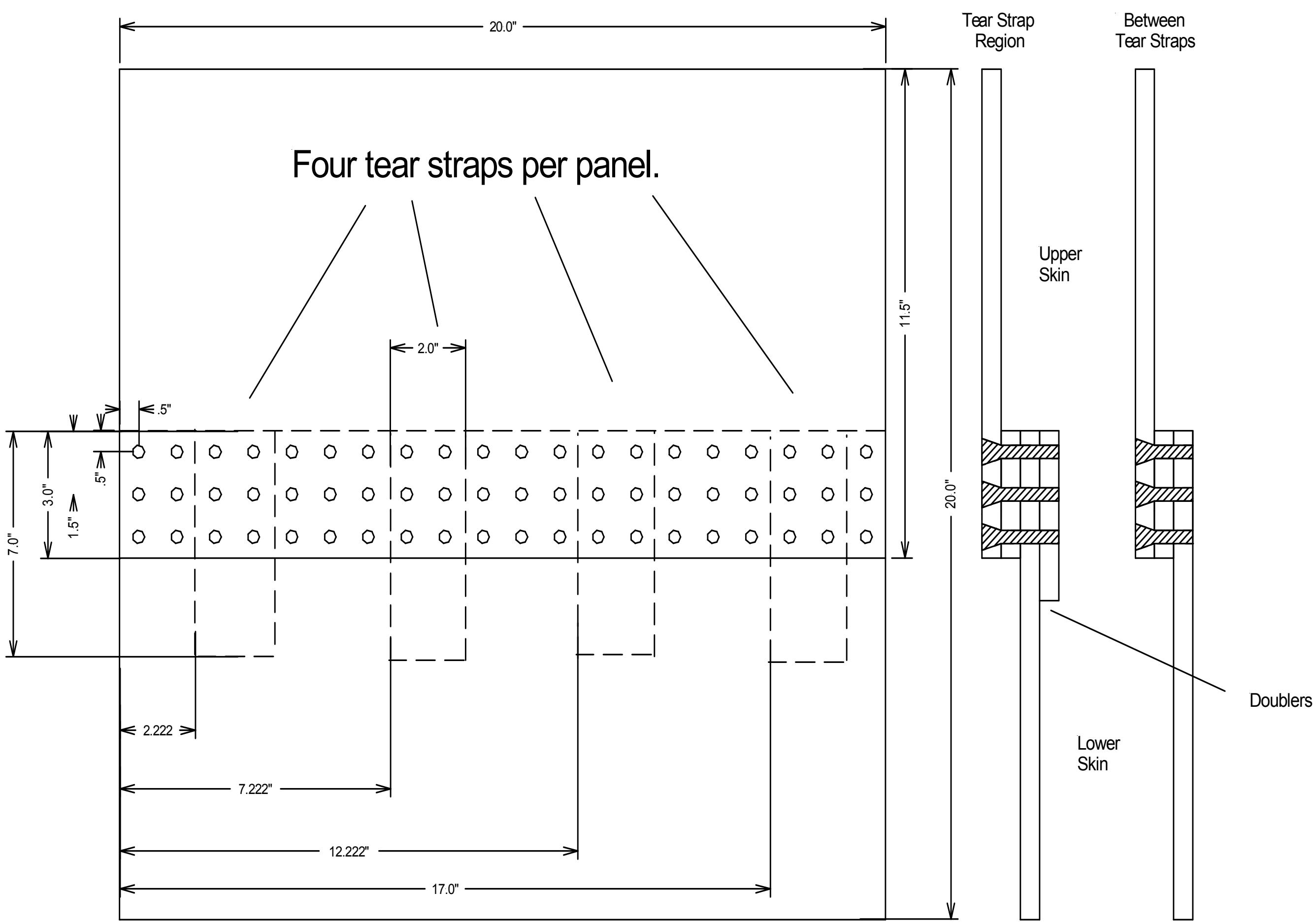


Programs Addressing WFD Detection

- AANC Inner Layer Crack Detection Experiment
  - Uses engineered defect panels
  - Assessed conventional and emerging NDI
- Delta Air Lines/AANC Industry Assessment
  - Used reassembled natural defect “Delta” panels
  - Assessed conventional NDI at field shops
- B727 Teardown Project
  - Used retired aircraft structure with natural defects
  - Assessed conventional and emerging NDI
- AANC WFD Detection Experiment
  - Developing retired aircraft structure with natural defects into reassembled panels for POD assessments

POD
AANC Inner Layer Crack
Panel Specimens

Inner Layer Crack Specimen Drawings



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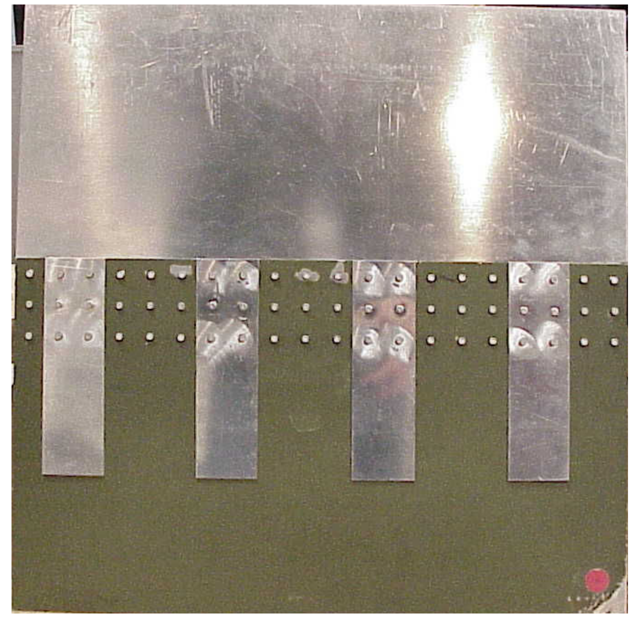
Inner Layer Crack
Panel Pictures

FRONT

LAP EDGE



BACK

LFEC Sliding Probe POD Summary

Inspectors from Airline and Third Party MROs

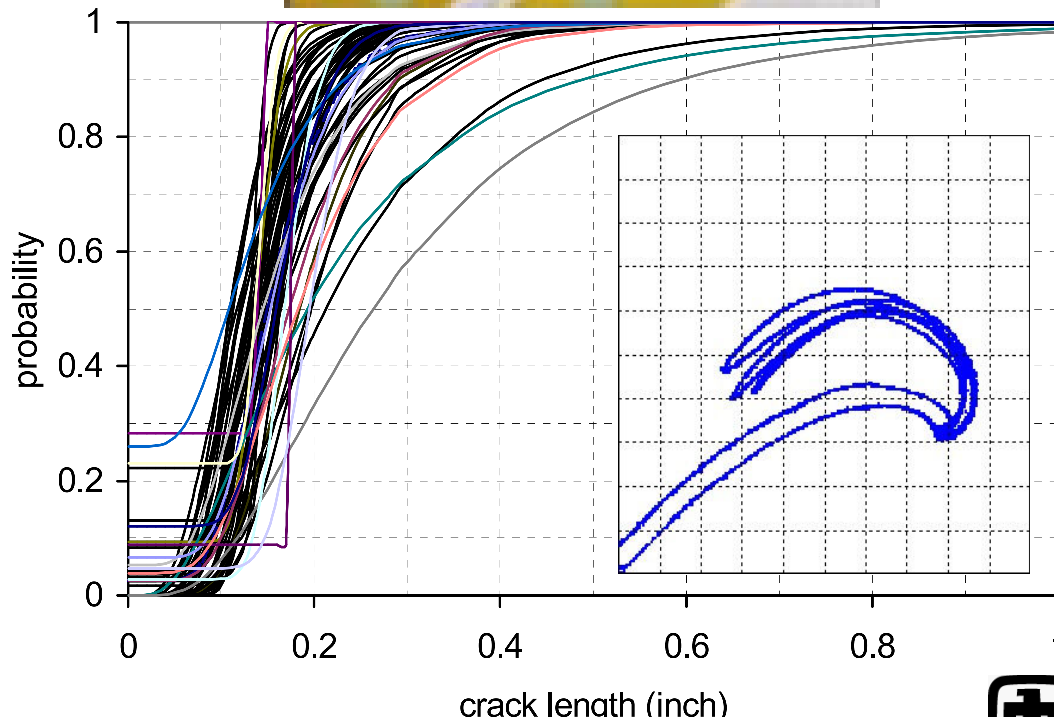
0.9 POD Range from about 0.150” to 0.500”

False Call Rates from 0 to 20%

Conventional Inspection Still in Use

Highly Dependent on Manual Signal Interpretation

Very Fast (5-10 sec)



Foerster Rivet Check POD

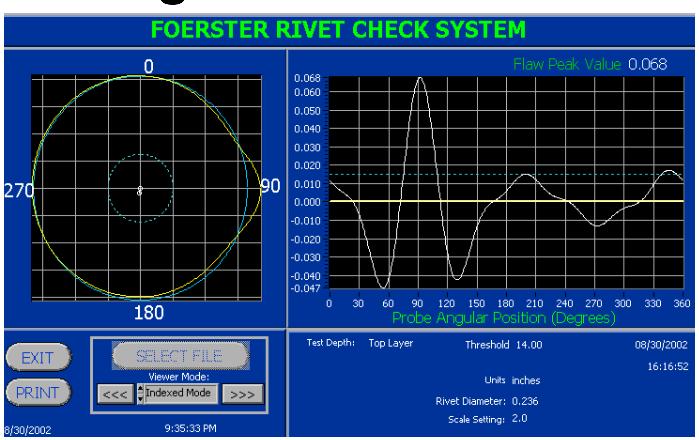
Based on NASA Self Nulling Probe

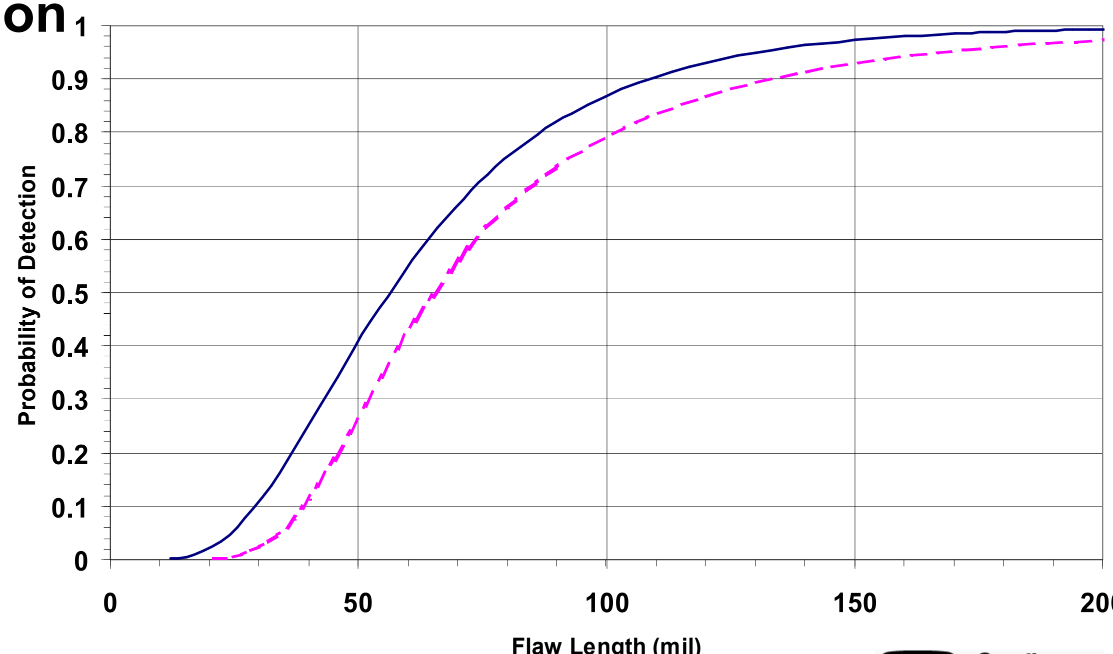
Commercially Marketed by Foerster Instruments

Automated Signal Interpretation

No Longer Available

False Call Rate	0.90 POD (mil)	0.90/95% POD (mil)
0.02	109	133





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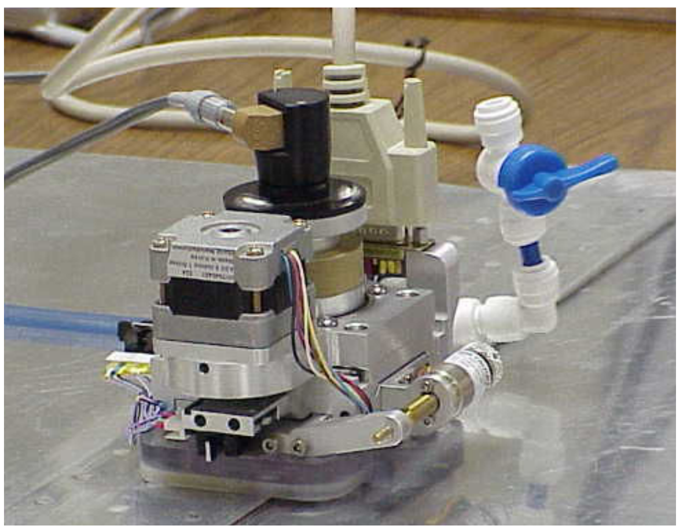
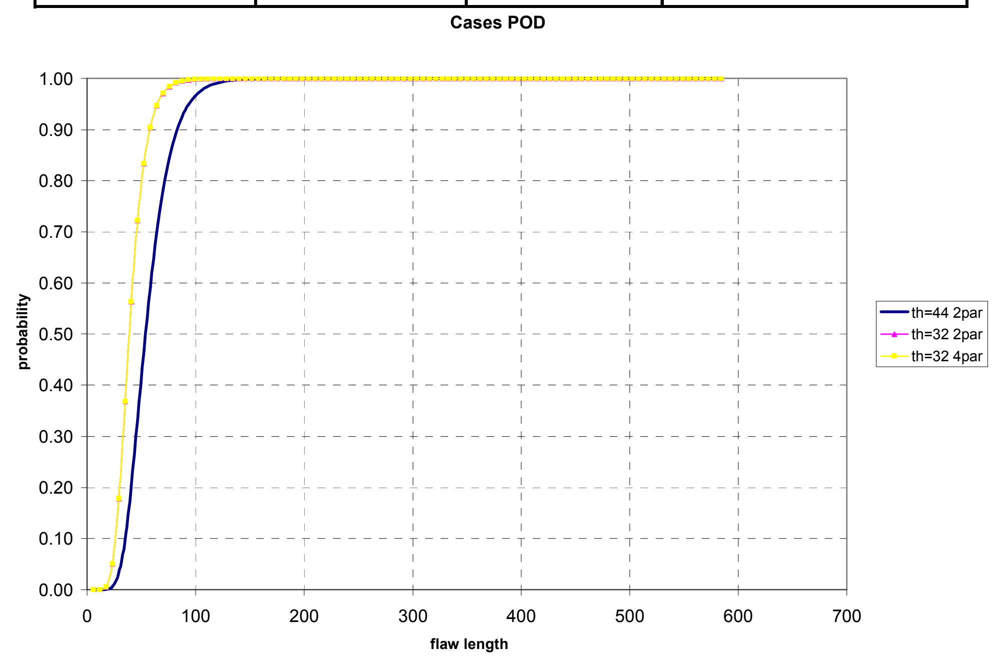
IMTT Remote Field-Super Sensitive EC POD

- Deep Penetration EC
- Relatively Inexpensive
- Automated Signal Interpretation
- Need to Increase Inspection Speed

	False Call Rate	0.90 POD (mil)	0.90/95% POD (mil)
Threshold = 44	0.017	76	86
Threshold = 32	0.107	55	62

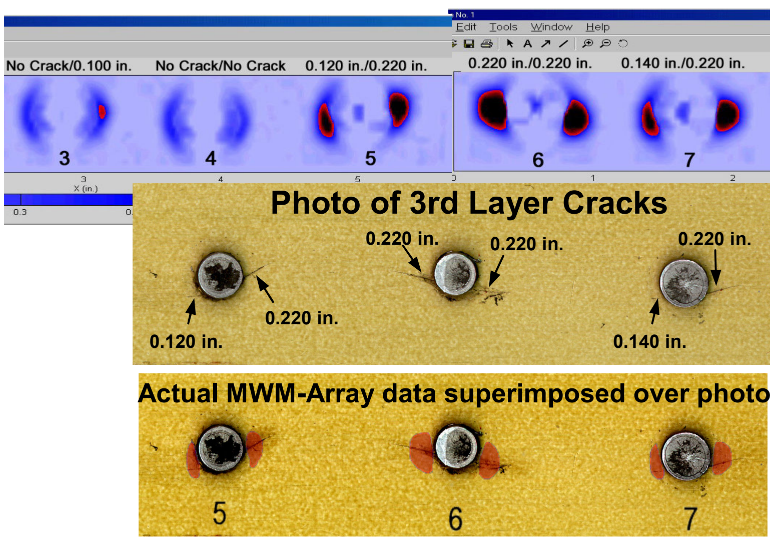


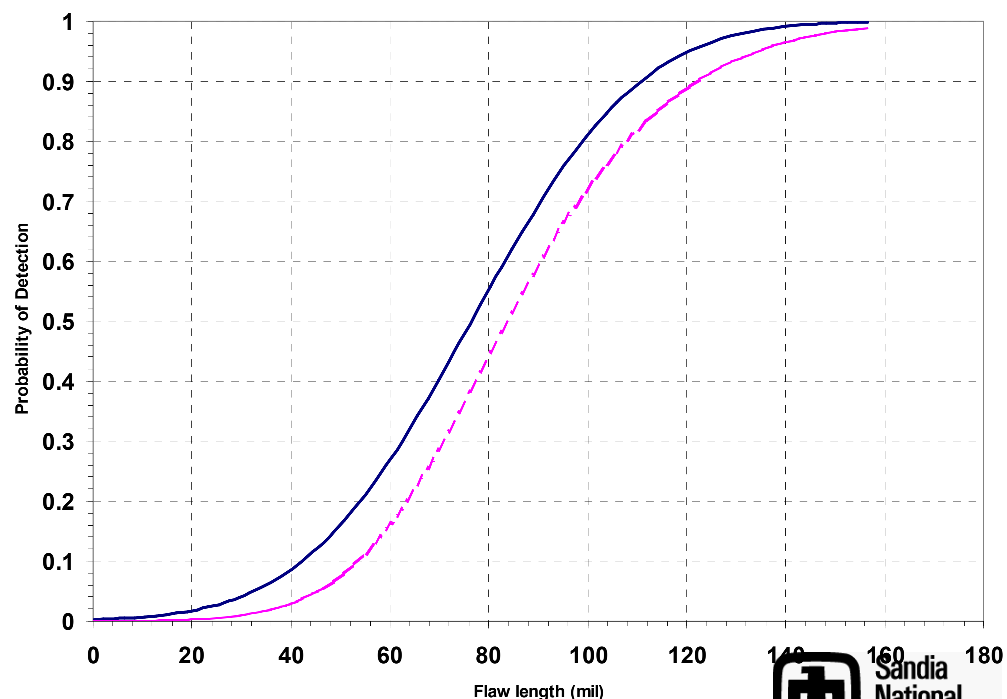


JENTEK MWM Gridstation POD

- Conformable Probe System
- Automated Signal Processing and Visual Interpretation
- Need to Increase Scan Speed
- Relatively Expensive System

False Call Rate	0.90 POD (mil)	0.90/95% POD (mil)
0.01	109	124

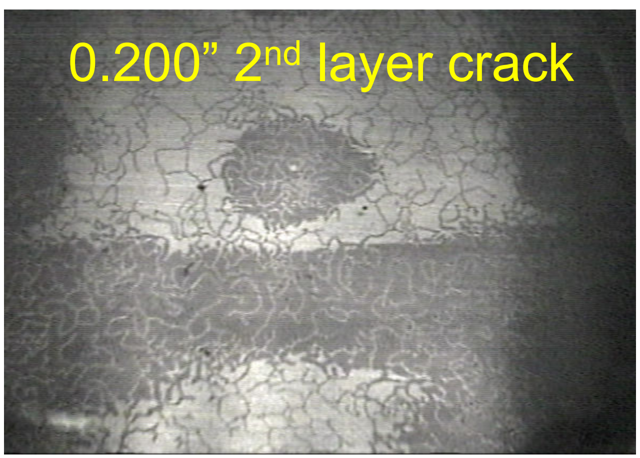


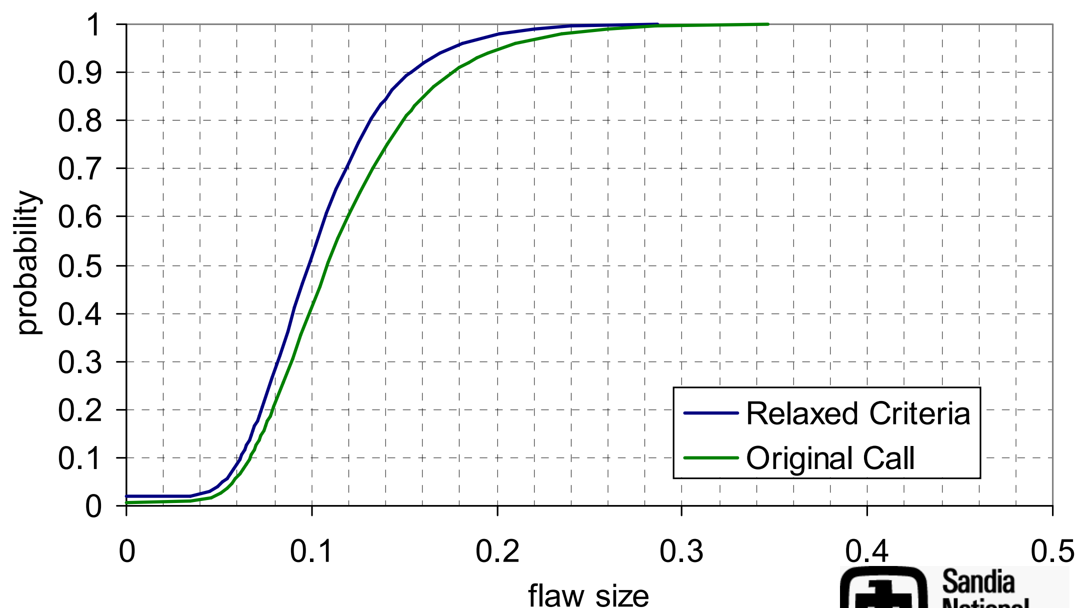


PRI Magneto Optic Imager Device

- Turbo MOI 308 (1.5-200kHz) (circular magnetic field)
- Very Fast Scan Rate
- Automated Defect Classification Methods Being Developed

	False Call Rate	0.90 POD (mil)	0.90/95% POD (mil)
Original Calls	0.003	176	220
Relaxed Criteria	0.015	153	184

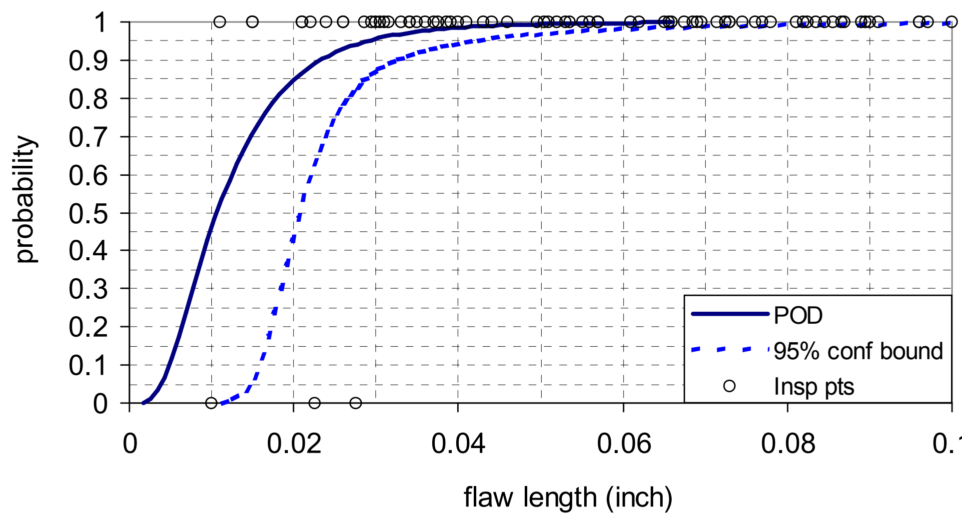




USUT Labs, Inc. with UT Linear Array

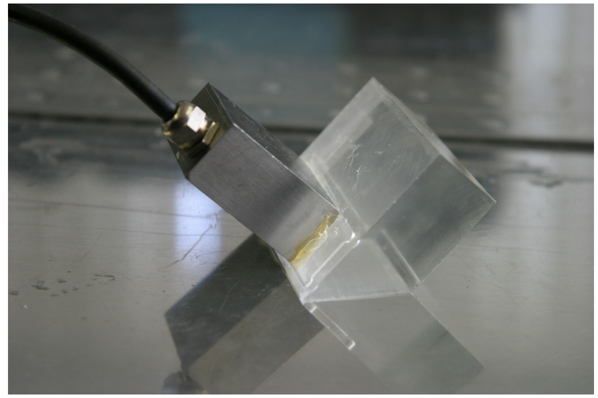
- 10 MHz Probe, 128 Elements,
- Fast Scan Speed Comparable to Sliding Probe
- 31º mode Conversion Wedge
- Relatively Expensive System
- POD from unpainted panels

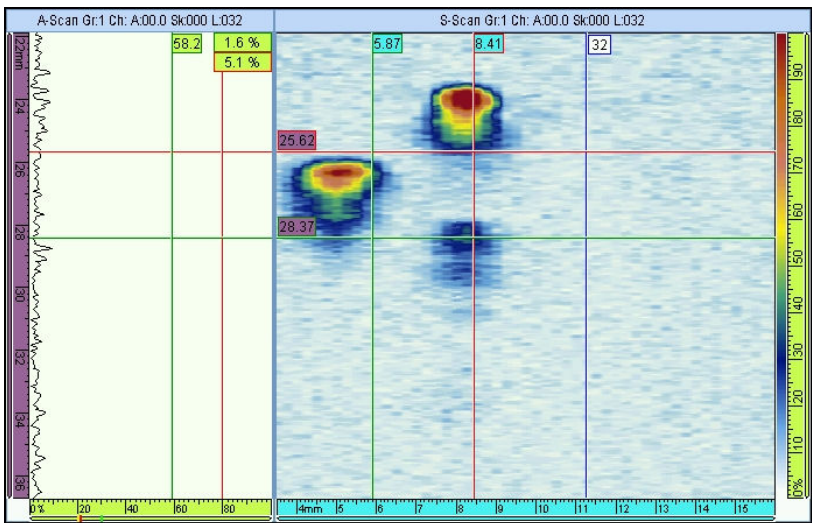
	False Call Rate	0.9 POD (mil)	90/95 POD (mil)
USUT Inspector	1.3%	23	33
AANC Tech 1	3.2%	17.5	52
AANC Tech 2	2.3%	23	34



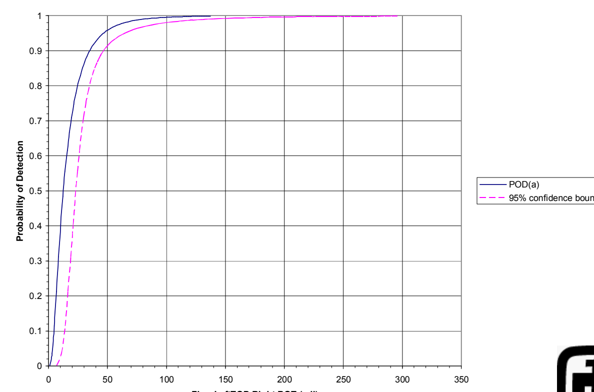
Olympus NDT Omniscan UT Linear Array Probe

- 10 MHz Probe, 64 Elements,
- 47º Mode Conversion Wedge
- Fast Scan Speed
- Relatively Expensive System
- POD from unpainted panels



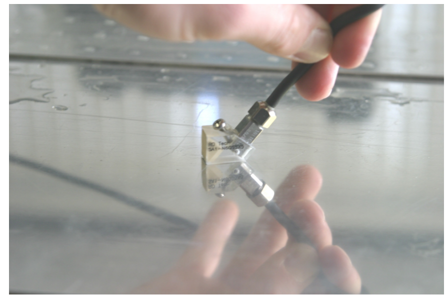


	False Call Rate	.9 POD (mil)	90/95 POD
Olympus Inspector	0.04	34.9	46.7

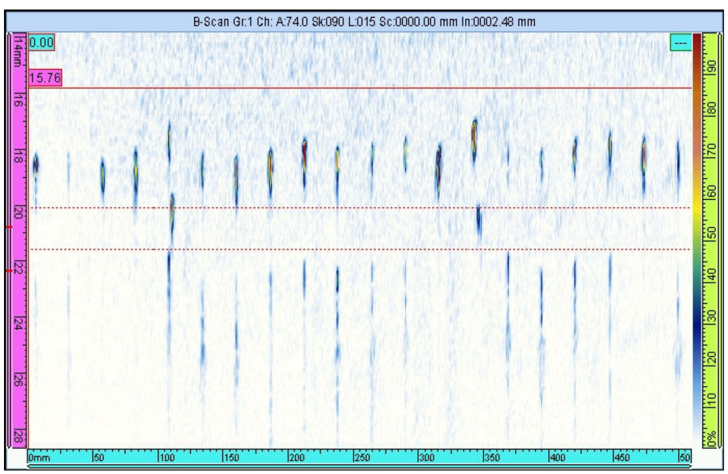


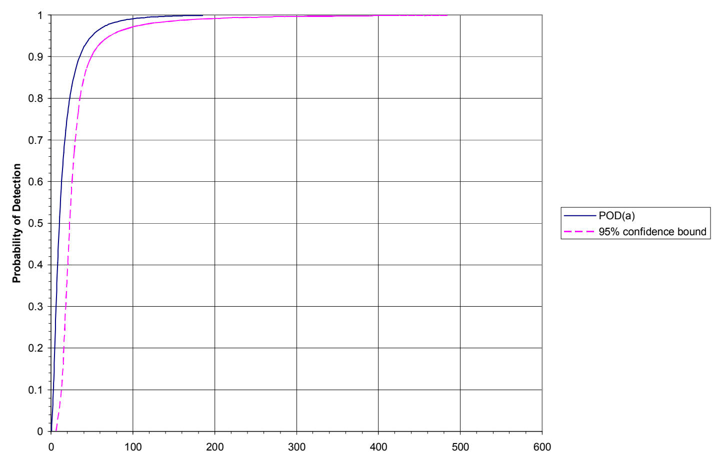
Olympus NDT Omniscan UT Small Footprint Phased Array Probe

- 10 MHz Probe, 16 Elements,
- 39º Mode Conversion Wedge
- Fast Scan Speed
- Relatively Expensive System
- POD from unpainted panels



Small Phased Array Probe	False Call Rate	.9 POD (mil)	90/95 POD (mil)
Olympus Inspector	0.025	35.1	49.2



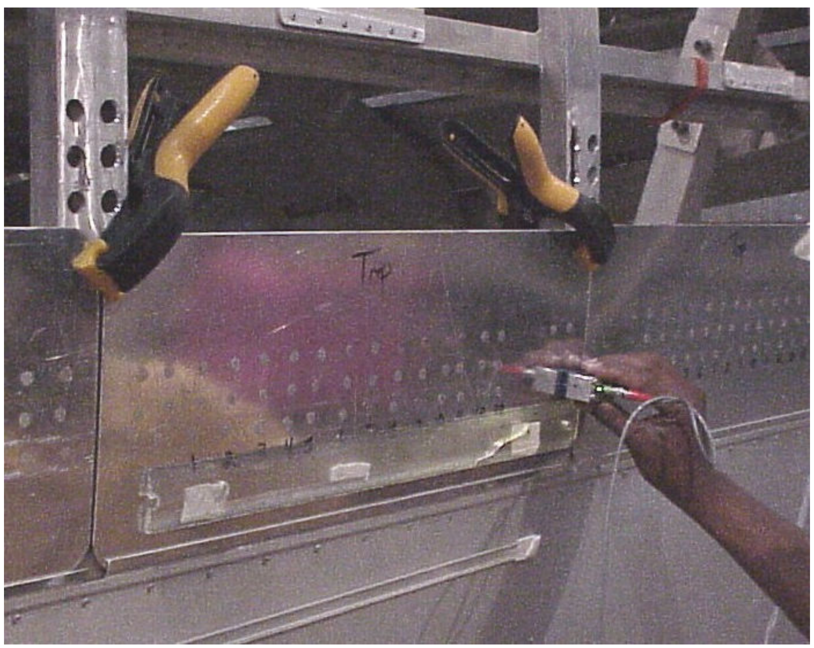


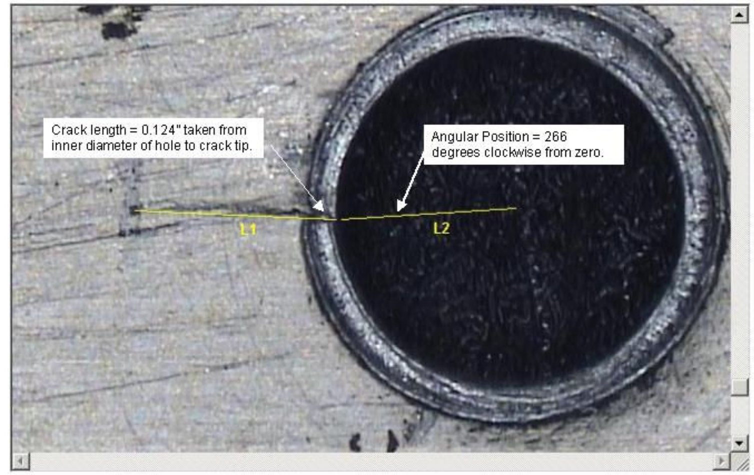
POD from Reassembled "Delta Panel" Specimens

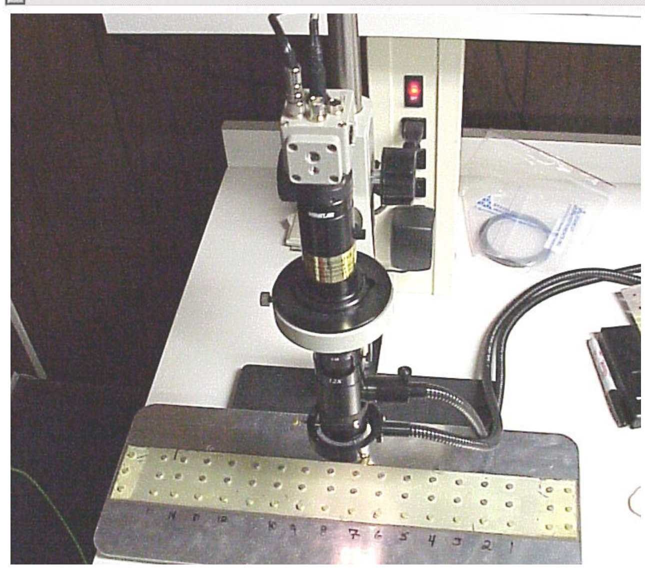
Delta Panel POD Implementation at Airline Maintenance Facilities

•Inspections on remanufactured specimen panels with actual WFD/MSD

•LFEC

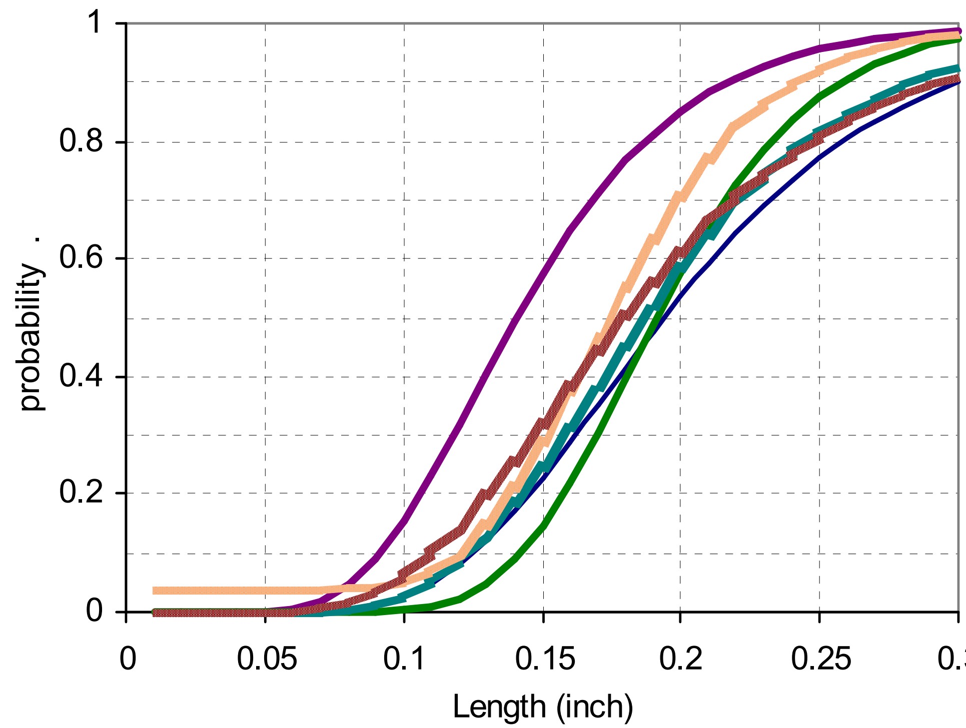






Delta Panel POD
Typical Airline Inspectors
Sliding Probe

- **Substantial variation across 42 inspectors (not unusual)**
- **Multiple flaws and varied orientations add to variation but reflect actual field conditions**
- **Inherent Capability determined from subset of 6 inspectors with 5 or fewer “false calls”**
- **0.9 detection flaw sized range from 0.220” to 0.300”**



Delta Panel POD
Airline Inspectors
Sliding Probe

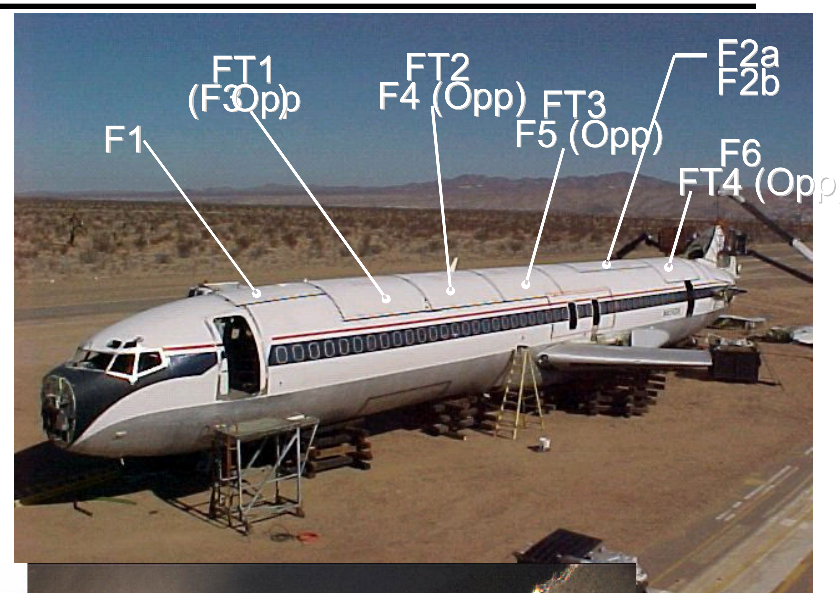
Inspector	Calls on flawed rivets	Calls on unflawed rivets	Call rate on flawed rivets	Call rate on unflawed rivets
1	31	8	0.256	0.037
2	61	38	0.504	0.174
3	24	1	0.198	0.005
4	32	13	0.264	0.06
5	49	4	0.405	0.018
6	66	37	0.545	0.17
7	55	48	0.455	0.22
8	96	135	0.793	0.619
9	31	9	0.256	0.041
10	38	15	0.314	0.069
11	11	36	0.091	0.165
12	52	98	0.43	0.45
13	48	101	0.397	0.463
14	60	89	0.496	0.408
15	47	110	0.388	0.505
16	51	88	0.421	0.404
17	49	144	0.405	0.661
18	37	135	0.306	0.619
19	19	24	0.157	0.11
20	38	37	0.314	0.17
21	77	172	0.636	0.789

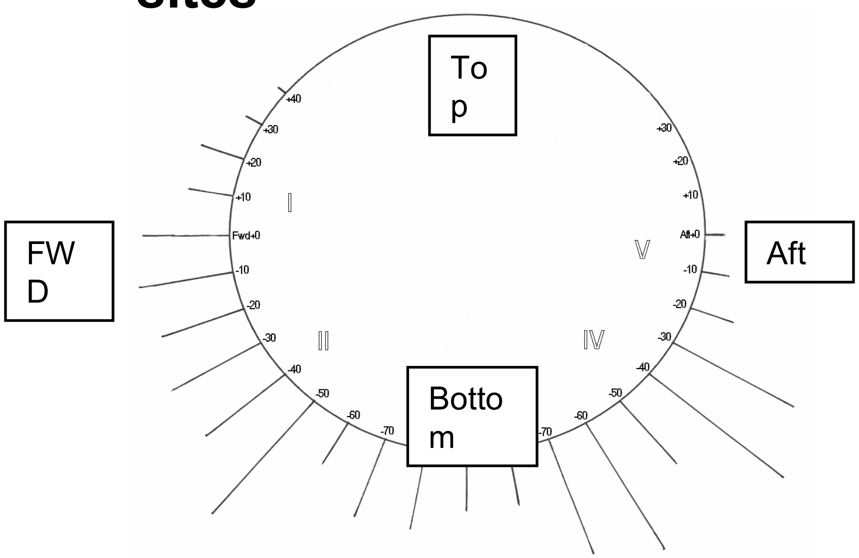
Inspector	Calls on flawed rivets	Calls on unflawed rivets	Call rate on flawed rivets	Call rate on unflawed rivets
22	51	43	0.421	0.197
23	32	22	0.264	0.101
24	40	6	0.331	0.028
25	80	83	0.661	0.381
26	39	18	0.322	0.083
27	53	30	0.438	0.138
28	73	80	0.603	0.367
29	44	28	0.364	0.128
30	44	20	0.364	0.092
31	64	24	0.529	0.11
32	56	56	0.463	0.257
33	22	7	0.182	0.032
34	30	15	0.248	0.069
35	21	0	0.174	0
36	37	15	0.306	0.069
37	26	5	0.215	0.023
38	32	4	0.264	0.018
39	36	16	0.298	0.073
40	22	6	0.182	0.028
41	30	5	0.248	0.023
42	42	11	0.347	0.05

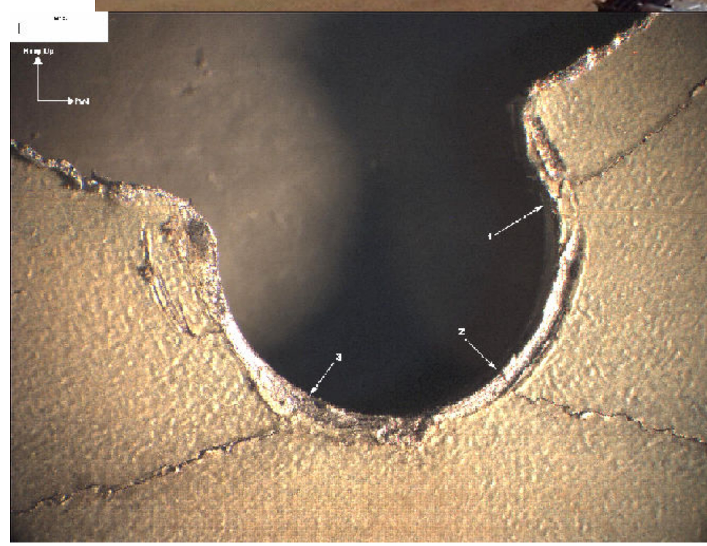
POD from B727 Teardown Specimens

B727 Teardown Study
Bakuckas et.al.
POD Specimens

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







B727 Teardown Study
Piotrowski et.al.
POD Results

Technique	2-parameter 0.9	2-parameter 90/95	Percent of detected (All flaws)	Percent of detected (>0.150)	Largest Flaw Missed	No. of false calls (rate)
Automated Couplant Ejection System (Single)	1.083	N/A	15.0	32.1	0.249	5 (4.2%)
Array Eddy-Current (Single)	N/A	N/A	16.0	17.9	0.237	0.0
Conventional Film X-ray	N/A	N/A	0.0	0.0	0.263	0.0
C-scan Eddy-Current (Single)	0.259	0.513	26.0	53.6	0.263	3 (2.4%)
Digital Radiography (Double)	0.207	0.340	62.6	70.8	0.204	0.0
Digital Radiography (Single)	0.191	0.328	57.2	66.7	0.204	0.0
DVI - Field (Double)	0.934	N/A	19.1	30.8	0.263	3 (1.4%)
DVI - Field (Single)	1.314	N/A	18.2	32.1	0.263	3 (2.4%)
DVI - Pre-Teardown (Double)	1.042	N/A	24.2	38.5	0.263	3 (1.4%)
DVI - Pre-Teardown (Single)	0.998	N/A	22.0	39.3	0.263	3 (2.4%)
Eddyscan	N/A	N/A	0.0	N/A	N/A	0.0
GMR (Single)	0.193	0.247	13.0	42.9	0.237	0.0
LFEC - Field (Single)	0.287	0.417	13.1	39.3	0.237	0.0
LFEC - Pre-Teardown (Single)	0.286	0.416	13.1	39.3	0.237	0.0
MAUS Rasterscan (Single)	0.357	0.723	22.0	46.2	0.237	0.0
MAUS Rotoscan (Single)	0.428	N/A	25.0	66.7	0.202	0.0
MFEC - Field (Double)	0.092	0.113	64.0	94.9	0.202	0.0
MFEC - Field (Single)	0.081	0.103	68.0	96.4	0.202	0.0
MFEC - Pre-Teardown (Double)	0.074	0.087	72.0	100.0	0.129	0.0
MFEC - Pre-Teardown (Single)	0.071	0.091	82.0	100.0	0.129	0.0
MOI (Double)	0.268	0.343	8.0	35.9	0.237	0.0
MOI (Single)	0.295	0.444	9.0	35.7	0.237	0.0
MWM (Double)	0.169	0.210	35.0	94.7	0.154	0.0
MWM (Single)	0.162	0.218	39.0	92.3	0.154	0.0
RFEC (Double)	0.254	0.368	20.3	64.0	0.204	0.0
RFEC (Single)	0.183	0.224	18.0	73.7	0.204	0.0
Rivet Check™ (Double)	0.457	N/A	12.8	46.2	0.214	0.0
Rivet Check™ (Single)	0.232	0.297	12.0	42.9	0.214	0.0
Structural Anomaly Mapping	N/A	N/A	0.0	N/A	N/A	0.0
Trecscan	N/A	N/A	0.0	N/A	N/A	0.0
Turbo-MOI (Double)	0.246	0.340	41.0	89.7	0.202	0.0
Turbo-MOI (Single)	0.203	0.279	44.0	92.9	0.202	0.0

Summary Comparison of POD for Certain Methods - B727 Teardown Defects vs Engineered Defects

Two-Parameter POD Fits						
Rank Ordering				Rank Ordering		
B727 Teardown Natural Defects				Engineered Defect Panels		
Method	0.9 POD	False Call %		Method	0.9 POD	False Call %
MFEC	0.071	0		USUT	0.018	3.2
MWM	0.162	0		OMNISCAN PA-UT	0.035	2.5
RFEC	0.183	0		RFEC*	0.076	1.7
GMR	0.193	0		MWM	0.109	1
T-MOI	0.203	0		RC	0.109	2
RC	0.232	0		T-MOI[+]	0.176	0.3
LFEC	0.286	0		LFEC	0.150-0.500	0-20
USUT	N/A			GMR	N/A	
OMNISCAN PA-UT	N/A			MFEC	N/A	

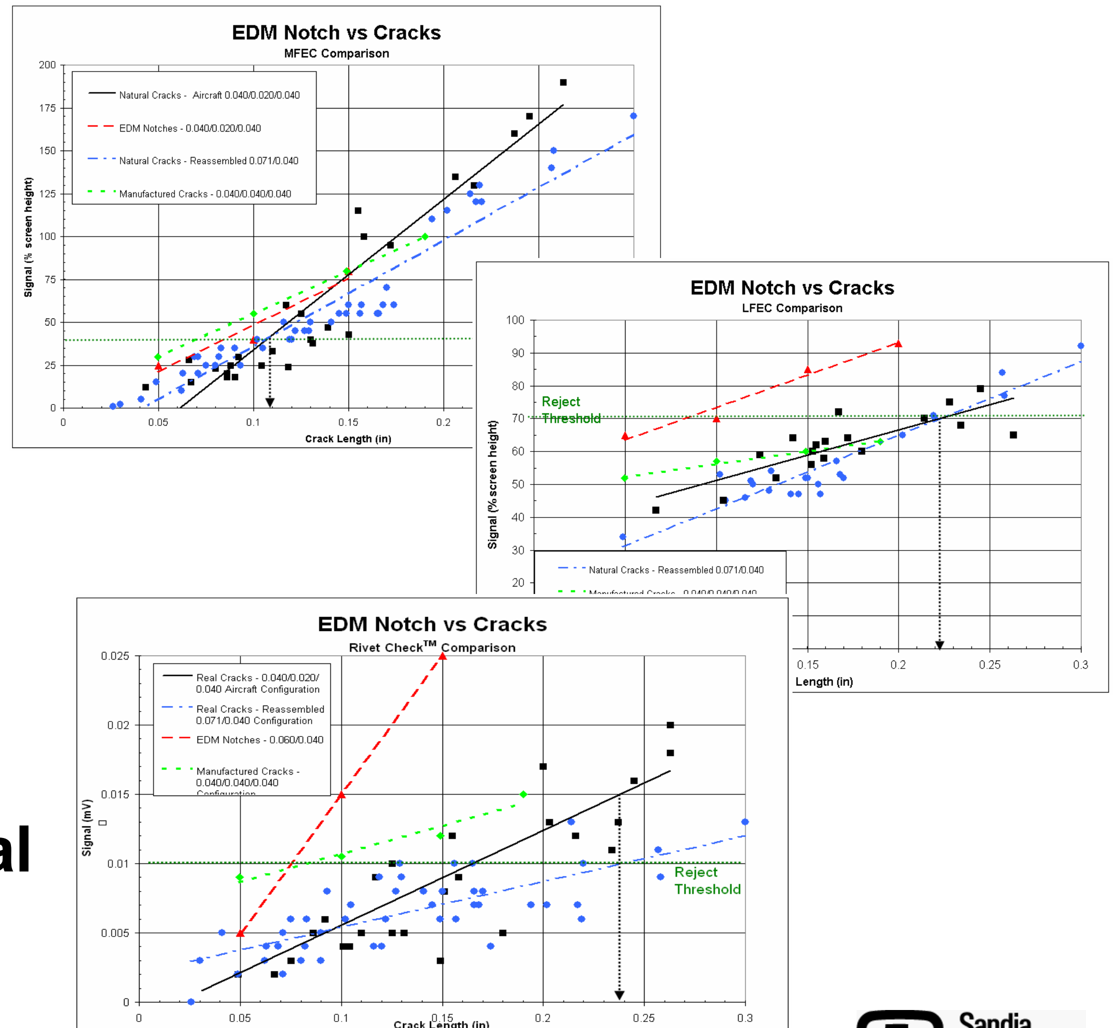
Current and Future Research Directions in Widespread Fatigue Damage Detection Reliability Assessments at AANC

FAA William J. Hughes
Technical Center

Sandia National Laboratories

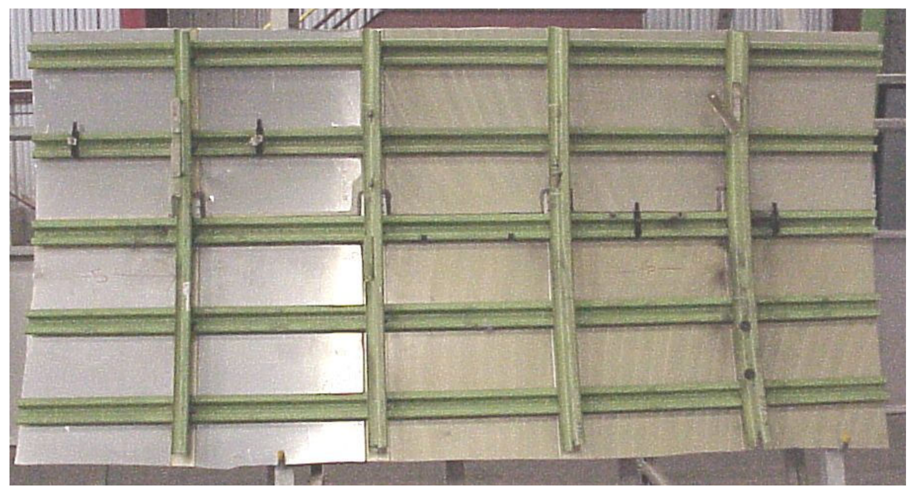
WFD POD
Reassembled Specimen Development

- Engineered defect panels are good for comparison across multiple technologies but perhaps optimistic for assessing Intrinsic Capability
- Data suggests Reassembled panels provide reasonable approximation of natural defect situation



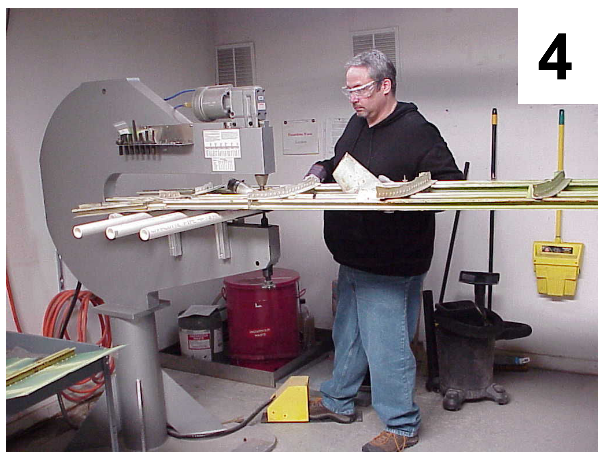
WFD POD Panel Development

- Utilize 40 lap joints harvested from two retired B727s
- Aircraft were at or near Design Service Goal of 60,000 cycles
- Lap Joint design has commonality with multiple aircraft (e.g. B737)



Natural Defect – Reassembled Panel Development Process

1. Inspect
2. Disassemble
3. Characterize
4. Reassemble
5. Re-inspect & Perform PODs



Validate Appropriate NDI Technologies on B727 Fuselage with Known WFD

QUESTIONS??

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

- Sandia National Laboratories
- Airworthiness Assurance NDI Validation Center (AANC) – Mike Bode
- Albuquerque, NM
- 505-843-8722
- mdbode@sandia.gov