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POD Study Challenges for Aerospace

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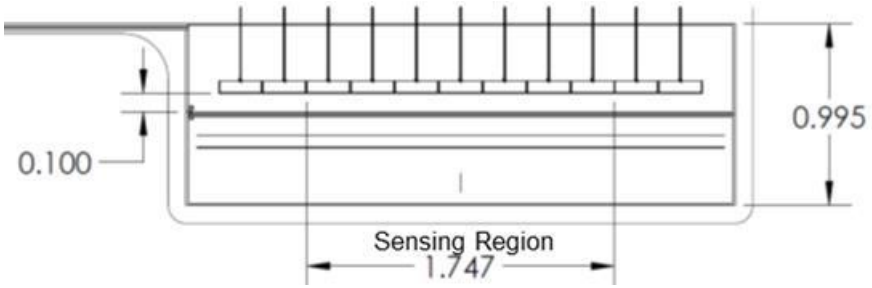
Jenteksensors.com

POD Study Challenges for Aerospace

Eddy Current Array Testing (ET-Arrays) POD Challenges

- **Brief Background on ET-Arrays and MWM-Arrays**
- **Example Applications, Challenges, & "POD Study" Results**
  - **Surface breaking cracks in simple flat plats**
  - **Engine components with complex surfaces and/or coatings**
  - ***Space Shuttle leading edge Reinforced carbon-carbon composite***
  - **Subsurface cracks in curved and complex parts**
  - **Cracks at bolt-holes in multiple layered structures**
  - ***Other Examples***
    - *Ferrous metal (steel alloys) cracks and crack clusters*
    - *2nd layer cracks at fasteners*
    - *Corrosion in multiple layered structures*
    - *SHM sensor qualification*



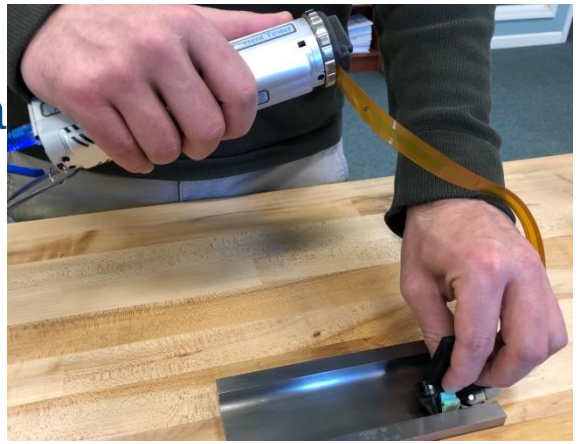
MWM-Array

jET
Eddy Current
Array Tester

Advanced ET with Flexible Arrays: MWM-Array

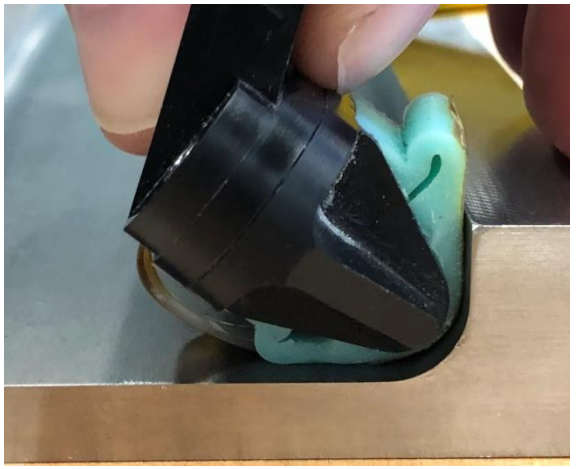
jET with GridStation Multivariate Inverse Methods (MIMs)

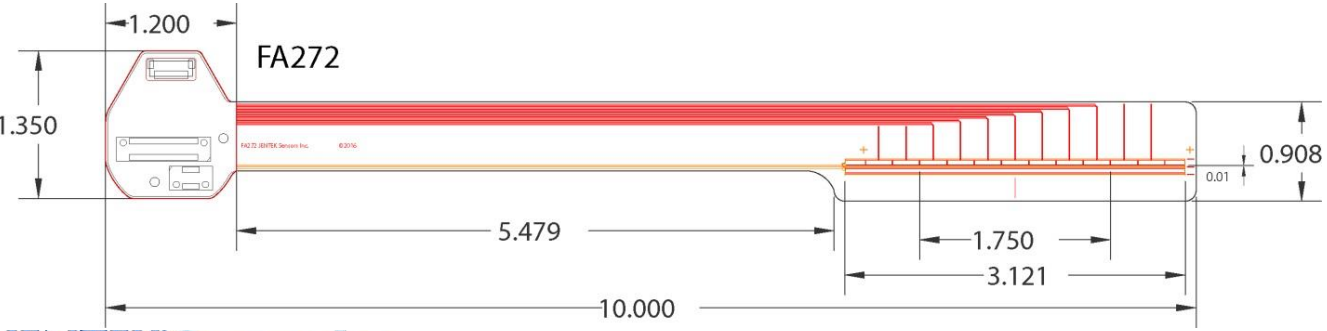
- Substantially **reduced** instrument noise
- **Simultaneous** complex impedance real and imagina at three frequencies
- **Rescaling** of crack response for varied lift-off
- **Rescaling** for position of defect within array
- **Rapid** scanning



MWM-Array

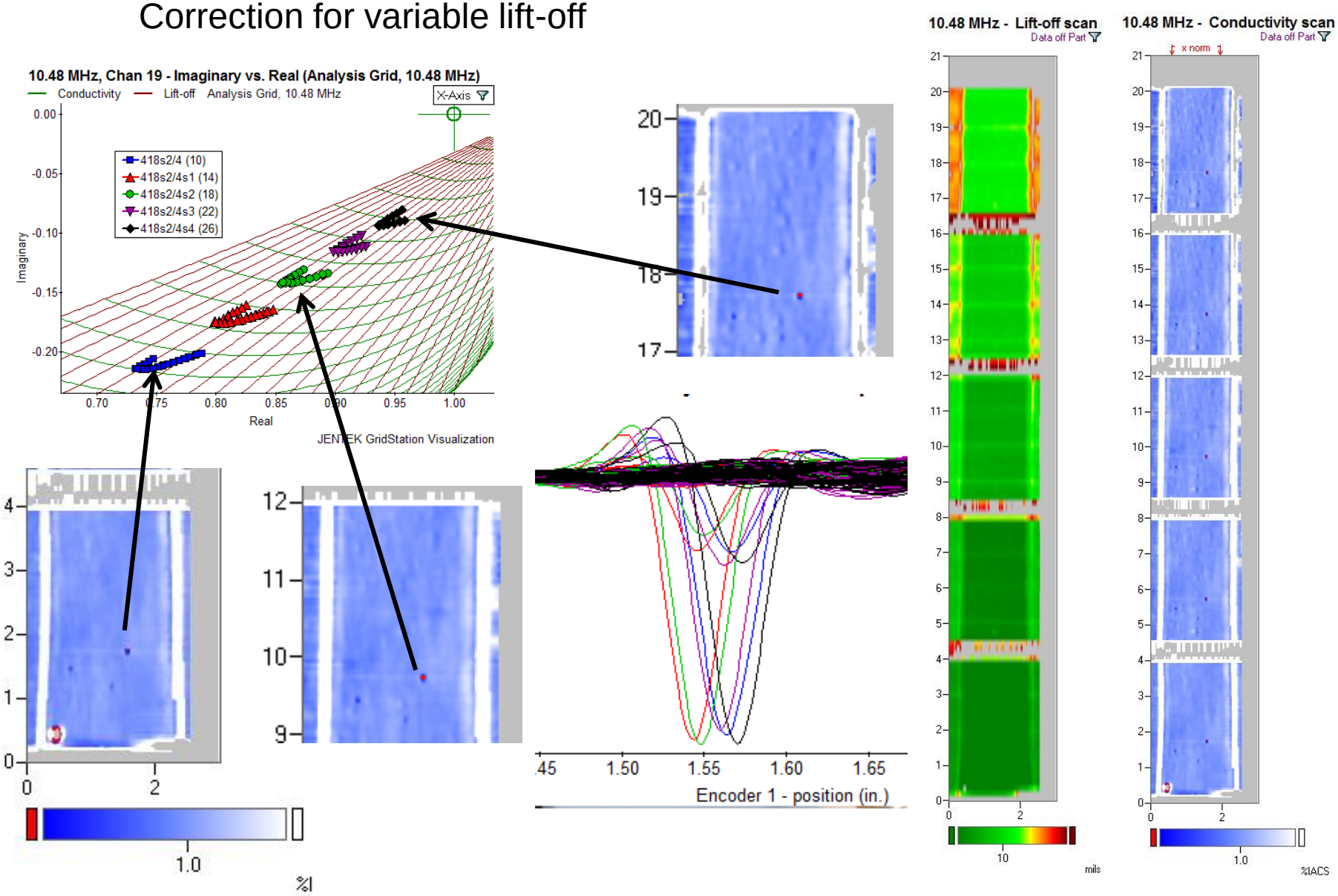
- Linear drive (**no crosstalk**, **increased crack response**)
- Flexible arrays to limit lift-off
- Simple lines and squares enable MIMs





Surface Cracks in Flat Plates: Rescaling of Conductivity Response

Correction for variable lift-off

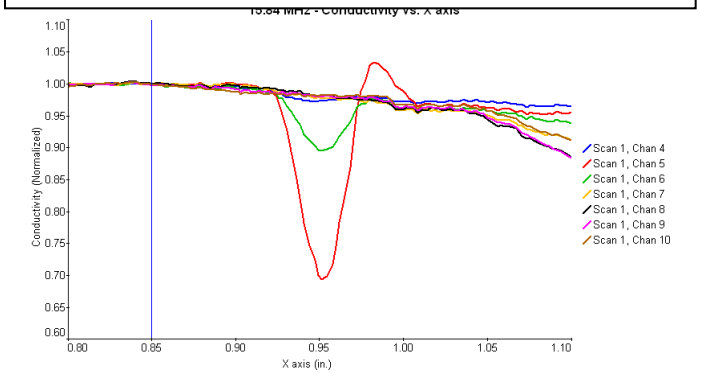


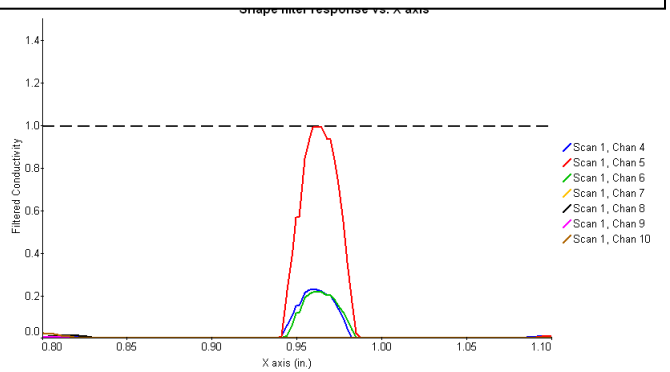
Shape Filtering Libraries Rescale for Crack Position

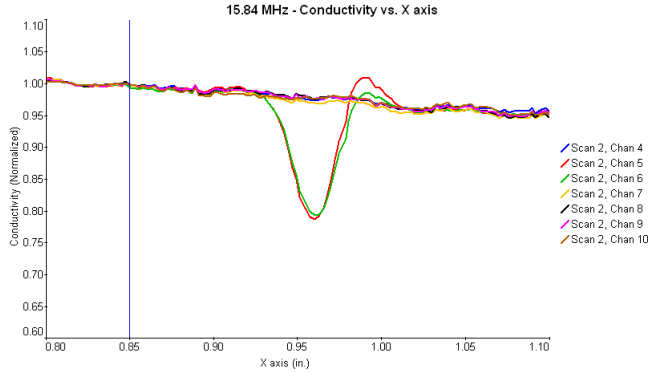
Unfiltered Crack Response

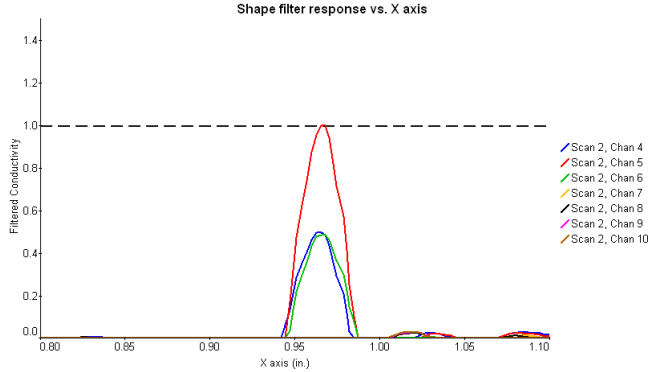
Filtered Crack Response

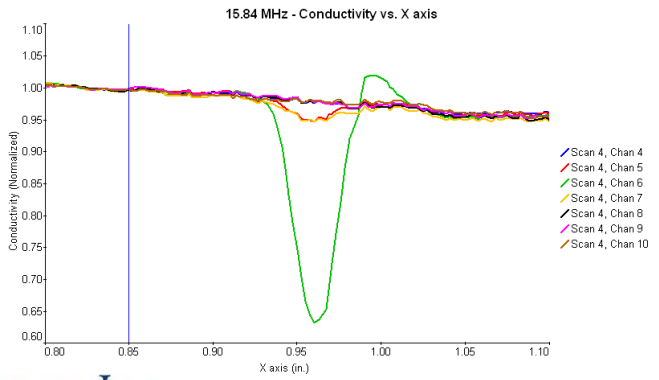
Varying Transverse Position

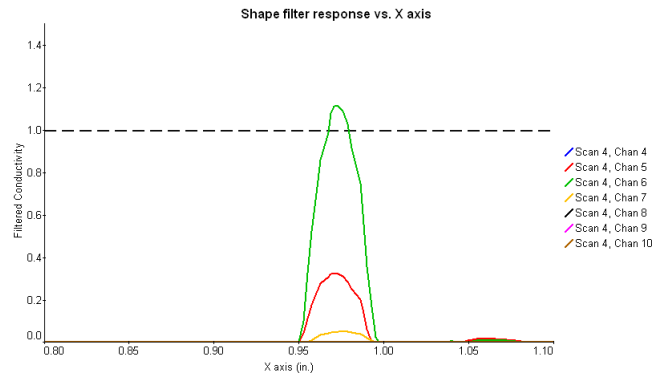






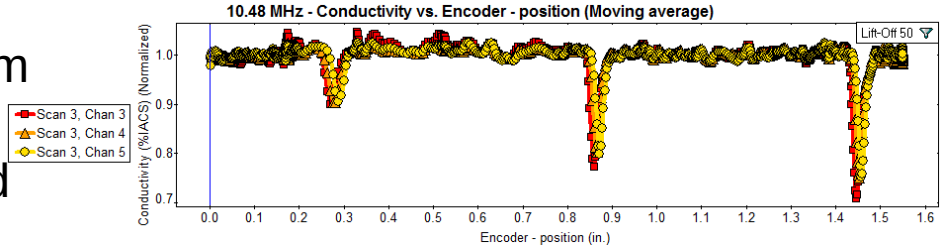


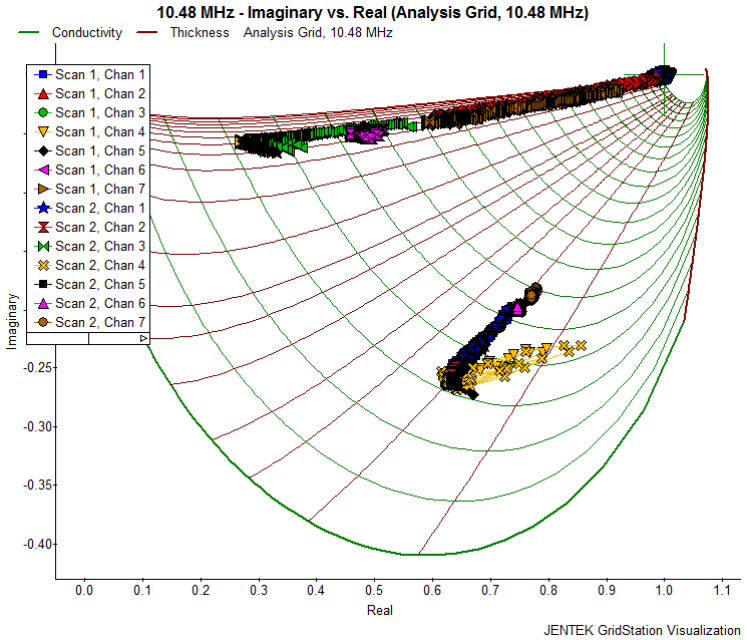


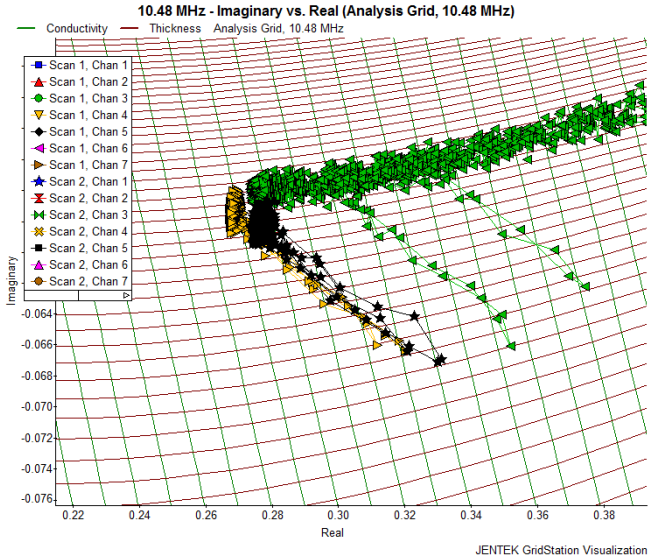


Automatic Correction for Conductivity (and Temperature)

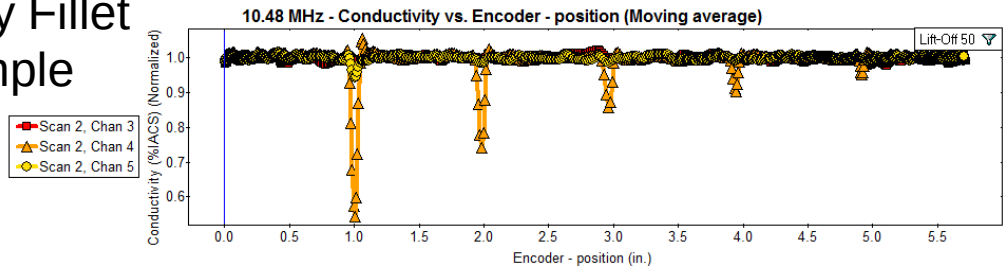
Aluminum Alloy Standard

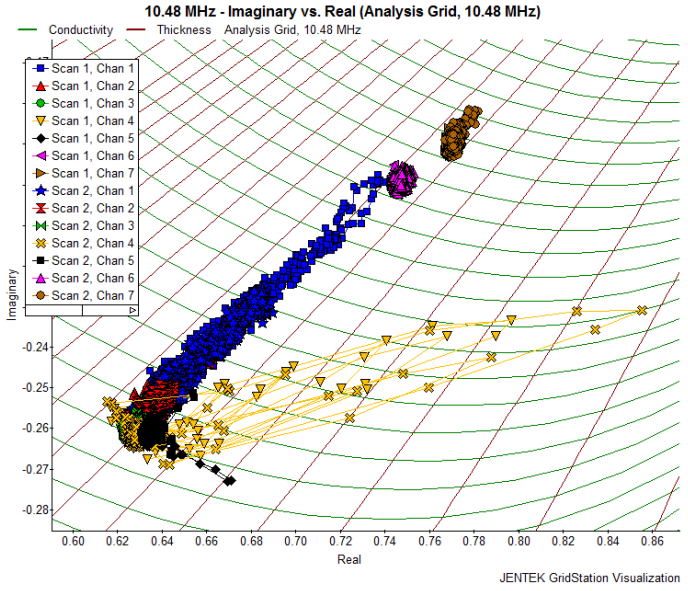






Titanium Alloy Fillet Sample

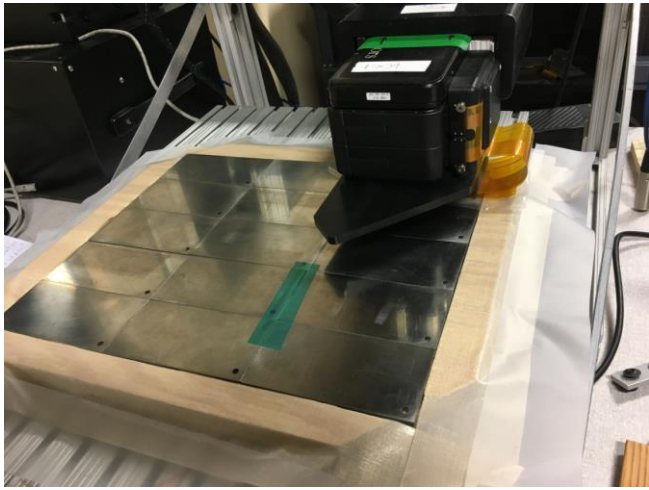




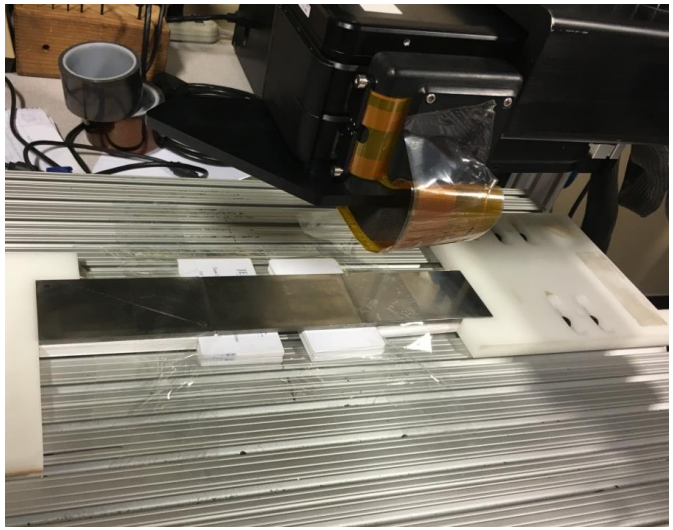
POD Study Samples: Surface Crack Detection for Titanium Alloys

Set of 29 titanium plates assessed

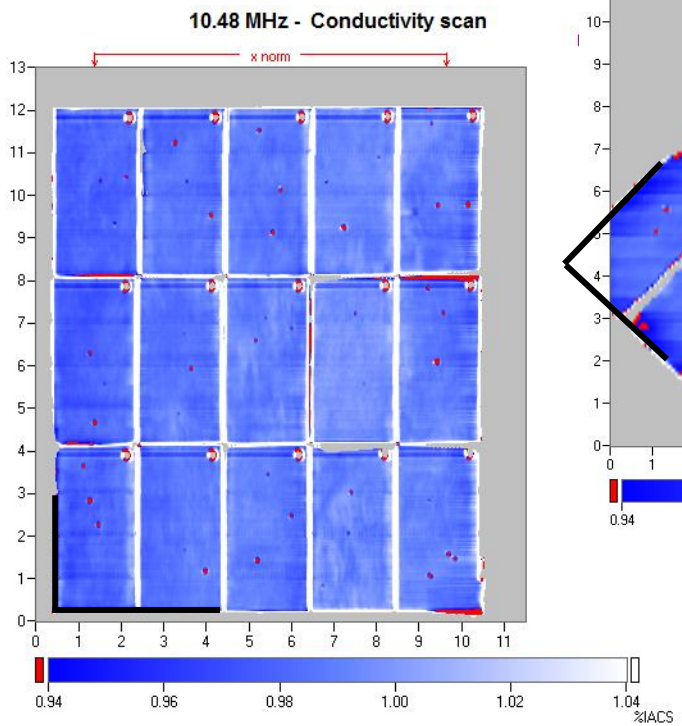
- Training set of 4 plates
- Using GS8200, 39 channel system
- POD samples provided by aerospace OEM
- Real cracks (Trueflaw and OEM sizing provided; significant variation in real crack sizing)
- Scans with MWM-Array linear drive in 0, +45 and -45 degree orientations

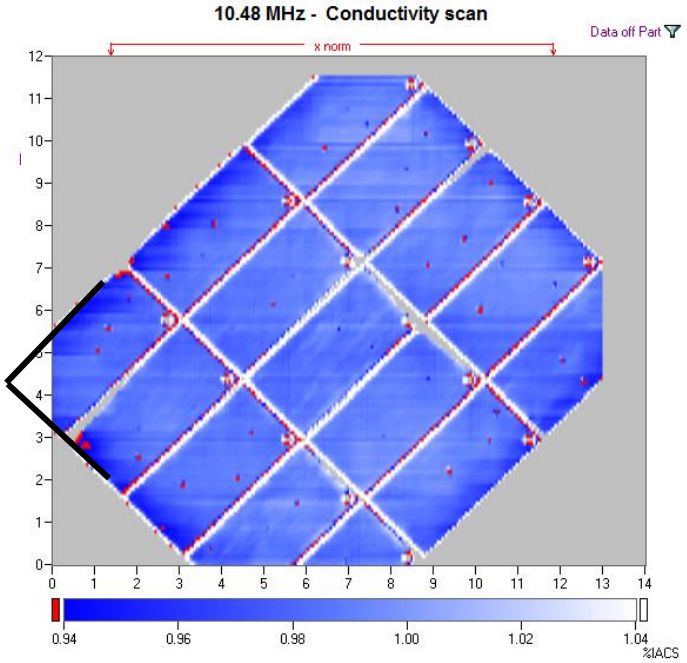


Crack	Angle	Crack Size (mm)	Crack Size (")	Keyence Measurement (mm)	Keyence Measurement (")	Trueflaw ID	Test Piece	Difference (%)
7	**90**	0.80	**0.032**	0.77	**0.031**	019BHB4368	W1403	-3%
8	**90**	0.40	**0.016**	0.53	**0.021**	020BHB4374	W1403	32%
9	90	0.30	0.012	0.73	0.029	020BHB4380	W1403	144%
34	**90**	0.60	**0.024**	0.52	**0.021**	025BHB4411	W1418	-13%
35	**90**	0.60	**0.024**	0.71	**0.028**	025BHB4417	W1418	18%
36	**90**	1.00	**0.040**	0.90	**0.036**	026BHB4423	W1418	-10%
85	90	0.50	0.020	0.52	0.021	037BHB4516	W1454	5%
86	40	0.60	0.024	0.35	0.014	037BHB4523	W1454	-41%
87	90	2.20	0.088	1.96	0.078	037BHB4528	W1454	-11%
19	45	1.70	0.068	1.26	0.050	021BHB4391	W1410	-26%
20	90	1.10	0.044	0.89	0.035	022BHB4396	W1410	-19%
21	0	1.30	0.052	1.48	0.059	023BHB4401	W1410	14%



POD Study Samples: Surface Crack Detection for Titanium Alloys

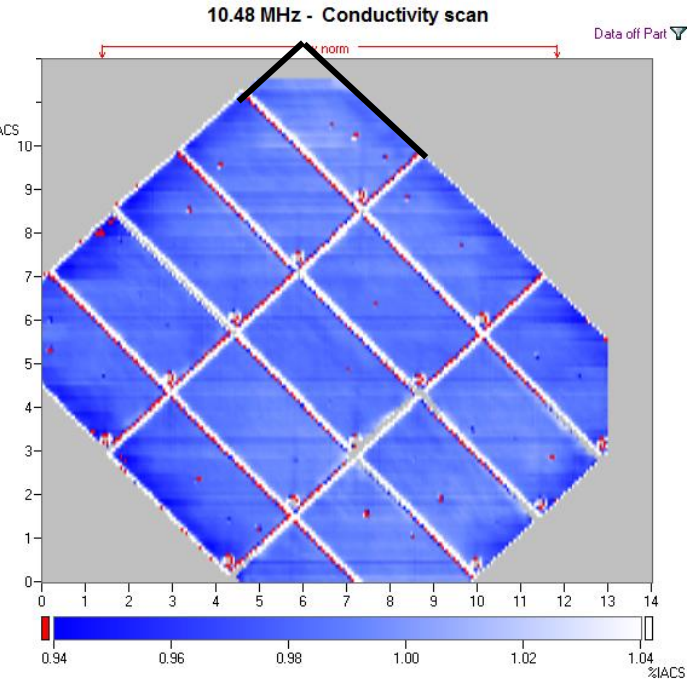




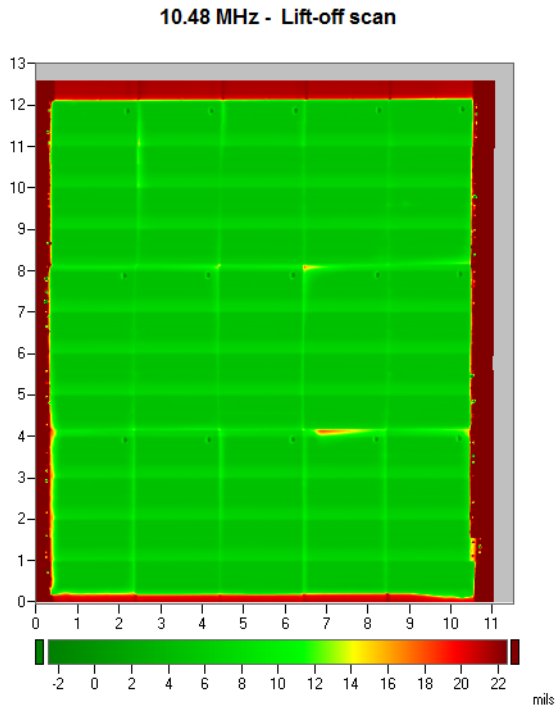
Conductivity Images

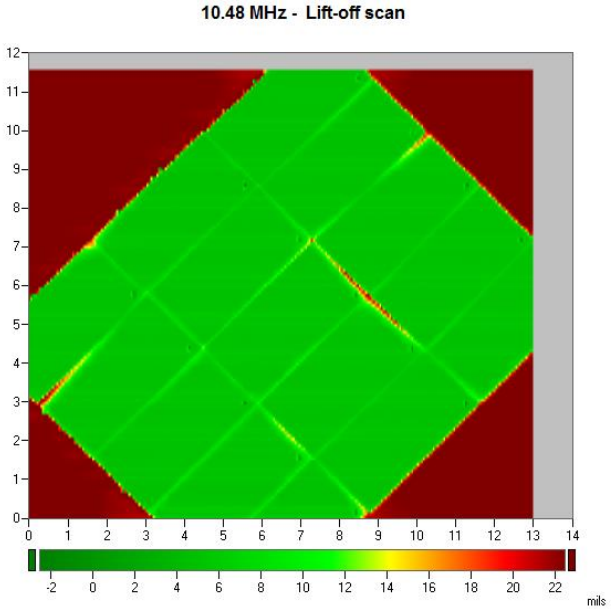
(not shape filtered)

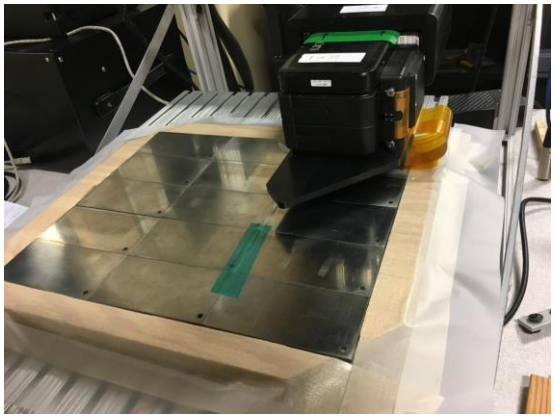
Horizontal and vertical axes units are in inches for this and the following related slides



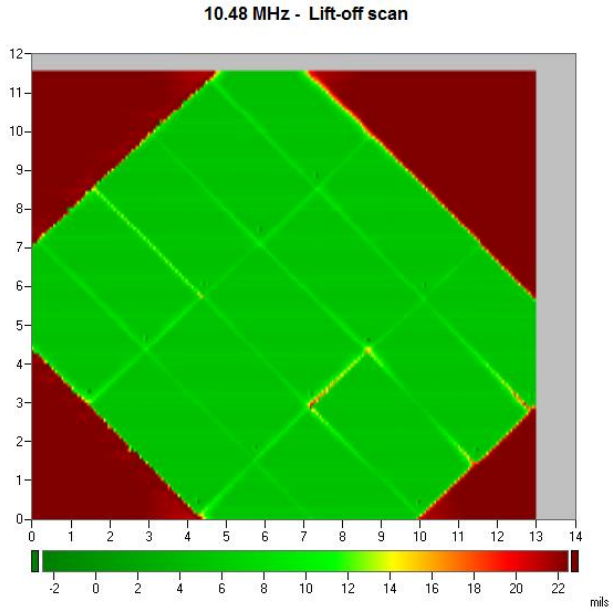
POD Study Samples: Surface Crack Detection for Titanium Alloys





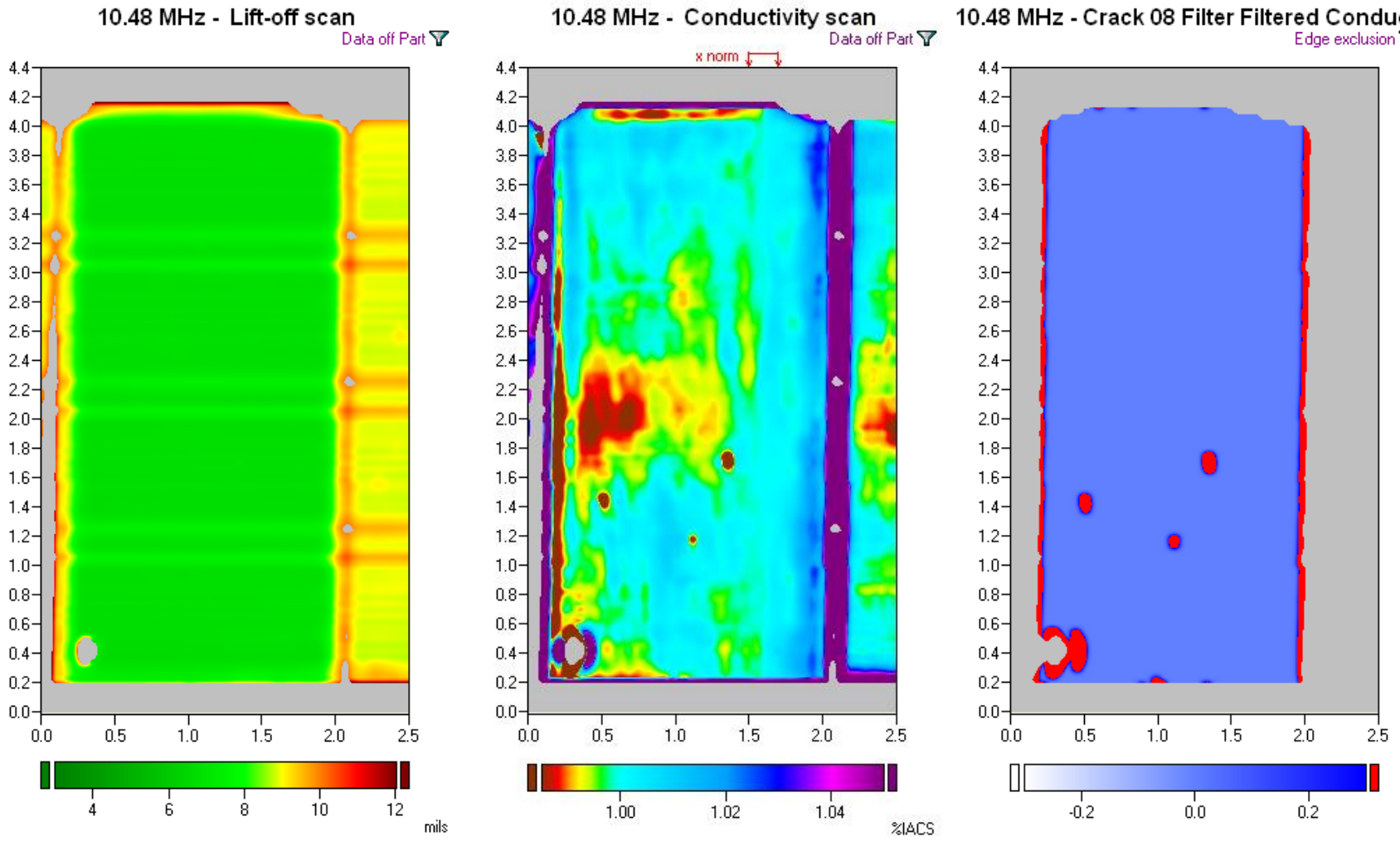


Lift-off Images



POD Study Samples: Surface Crack Detection for Titanium Alloys

Plate WXXXA (Training Set)



POD Study Samples: Surface Crack Detection for Titanium Alloys

Plate WXXXA (Training Set)

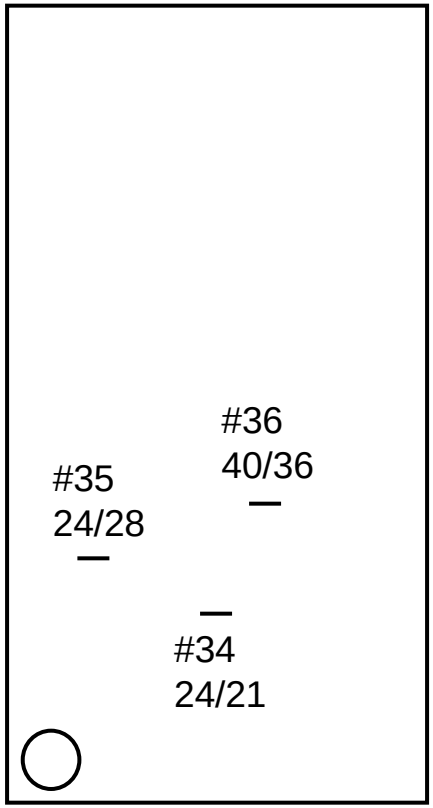
Flaw sizes (Lengths)
Trueflaw or Keyence

#34: 0.024 in. or 0.021 in.

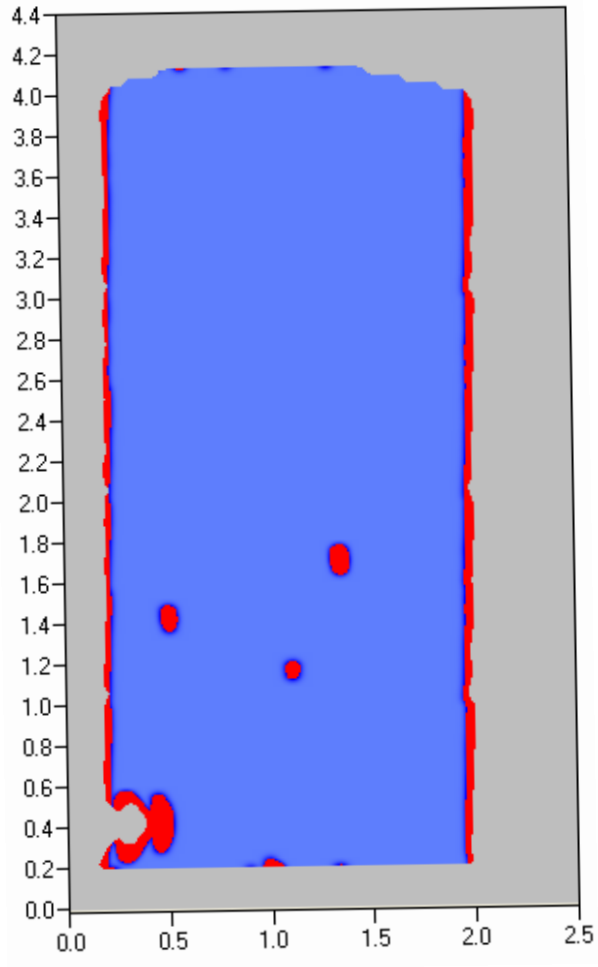
#35: 0.024in. or 0.028in.

#36: 0.040in. Or 0.036in.

Note **edges** and **holes** are corrected using an alternative inspection and data analysis method not applied to this data.

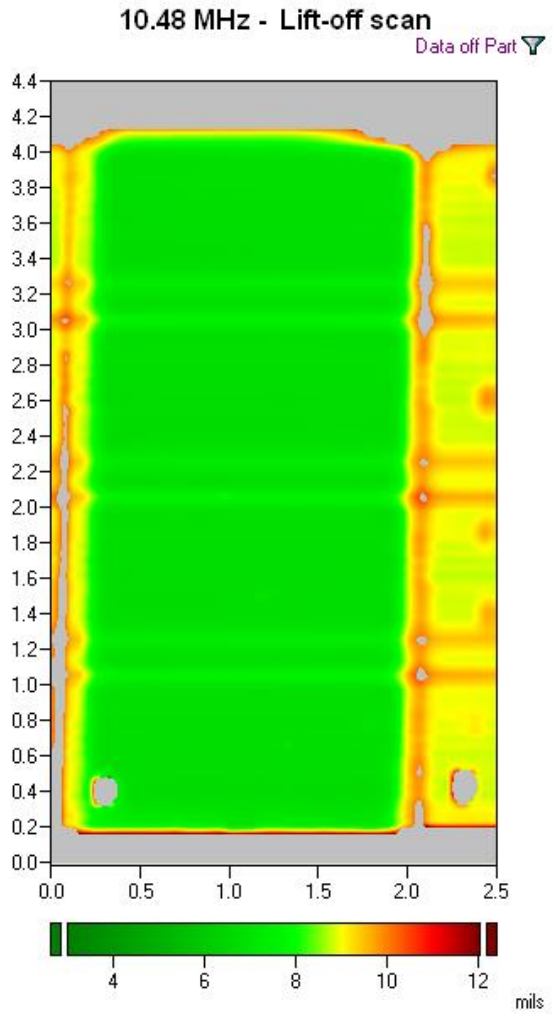


Trueflaw/Keyence lengths in mils

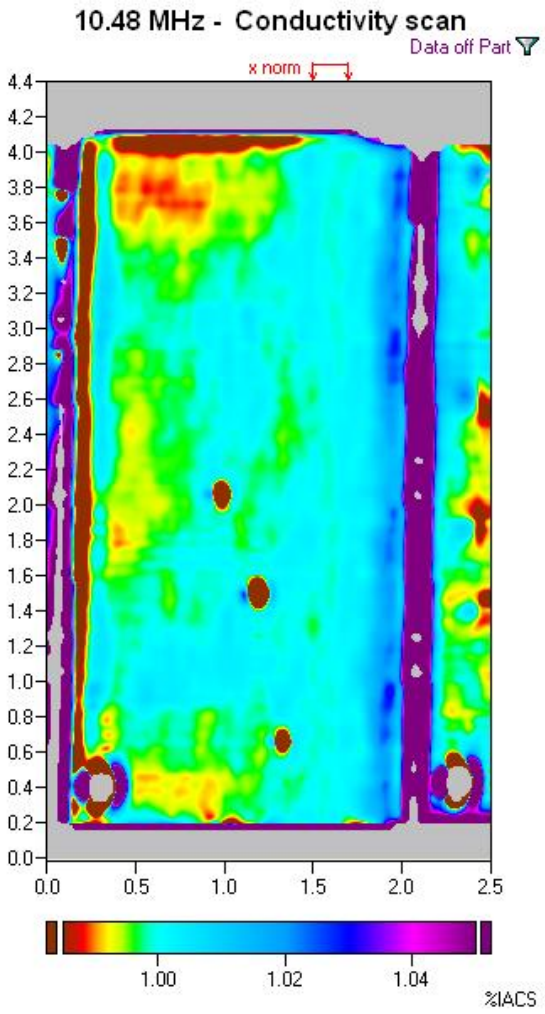


POD Study Samples: Surface Crack Detection for Titanium Alloys

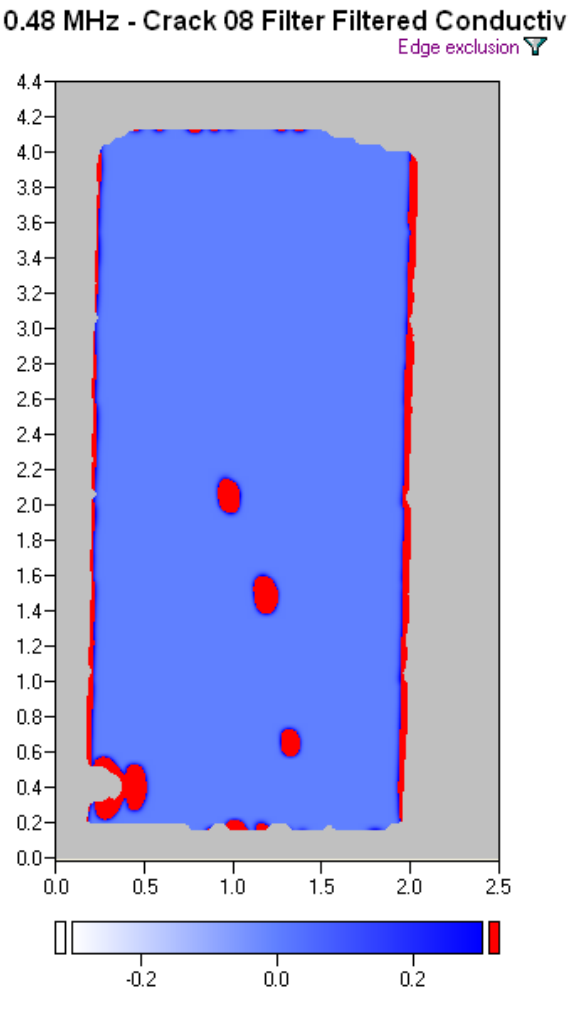
Plate WXXXB (Test Set)



Liftoff Image

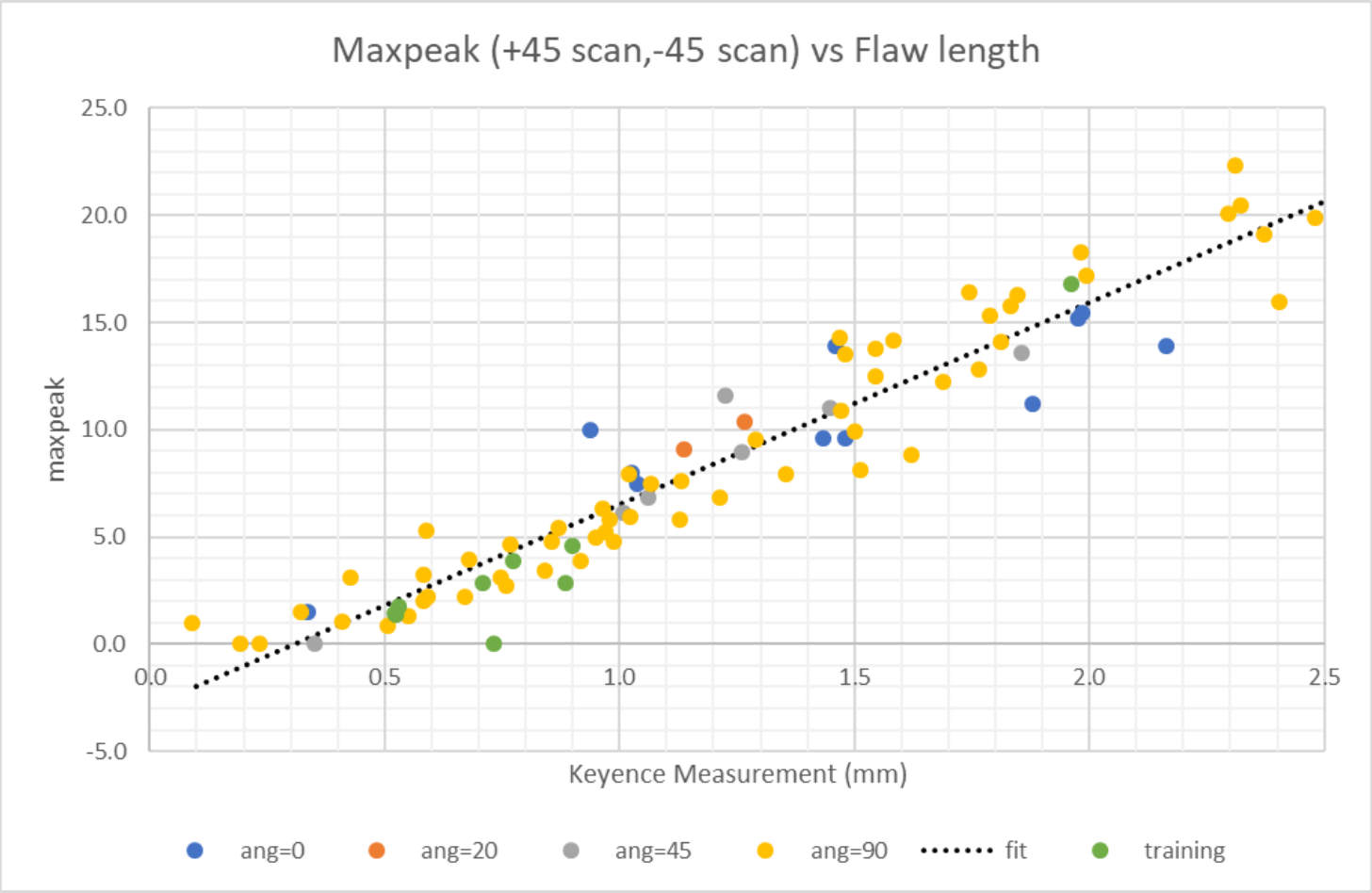


Conductivity Image



Filtered Crack Response

POD Study Samples: Surface Crack Detection for Titanium Alloys

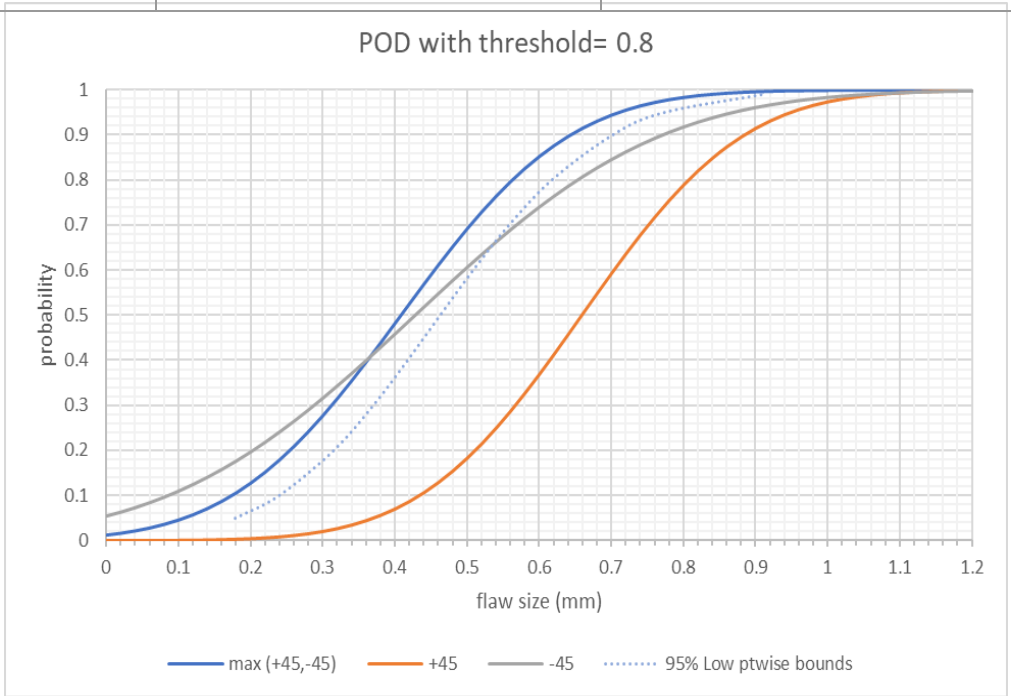


POD Study Report Figure 1

POD Study Samples: Surface Crack Detection for Titanium Alloys

Table 1. Summary of a_{90} values from Maxpeak(+45°,-45°) data with different estimation assumptions.

POD method	a_{90} flaw size mm – inch	95% confidence flaw size mm – inch
Signal regression	0.643 mm – 0.025 inch	0.701 mm – 0.028 inch length
Pass/Fail -ln(length)	0.476 mm – 0.019 inch	0.702 mm – 0.028 inch length



POD Study Report Result by Floyd Spencer

Lesson Learned: Dramatic effect of a single missed flaw if set is too small

Note this is a recent study and the missed flaw is being analyzed

Engine Component Studies

Example “POD Studies” and Performance Studies

1. FAA funded ENSIP plate POD study in 2001
2. Navy funded POD study including
   - real cracks from two service engine populations
   - fabricated real cracks from fatigue coupons
3. Engine knife seal POD Study by OEM
4. Land-based turbine blade fir tree inspection performance study with coatings, in-service
5. Navy blade dovetail crack depth measurement study

Reference available upon request

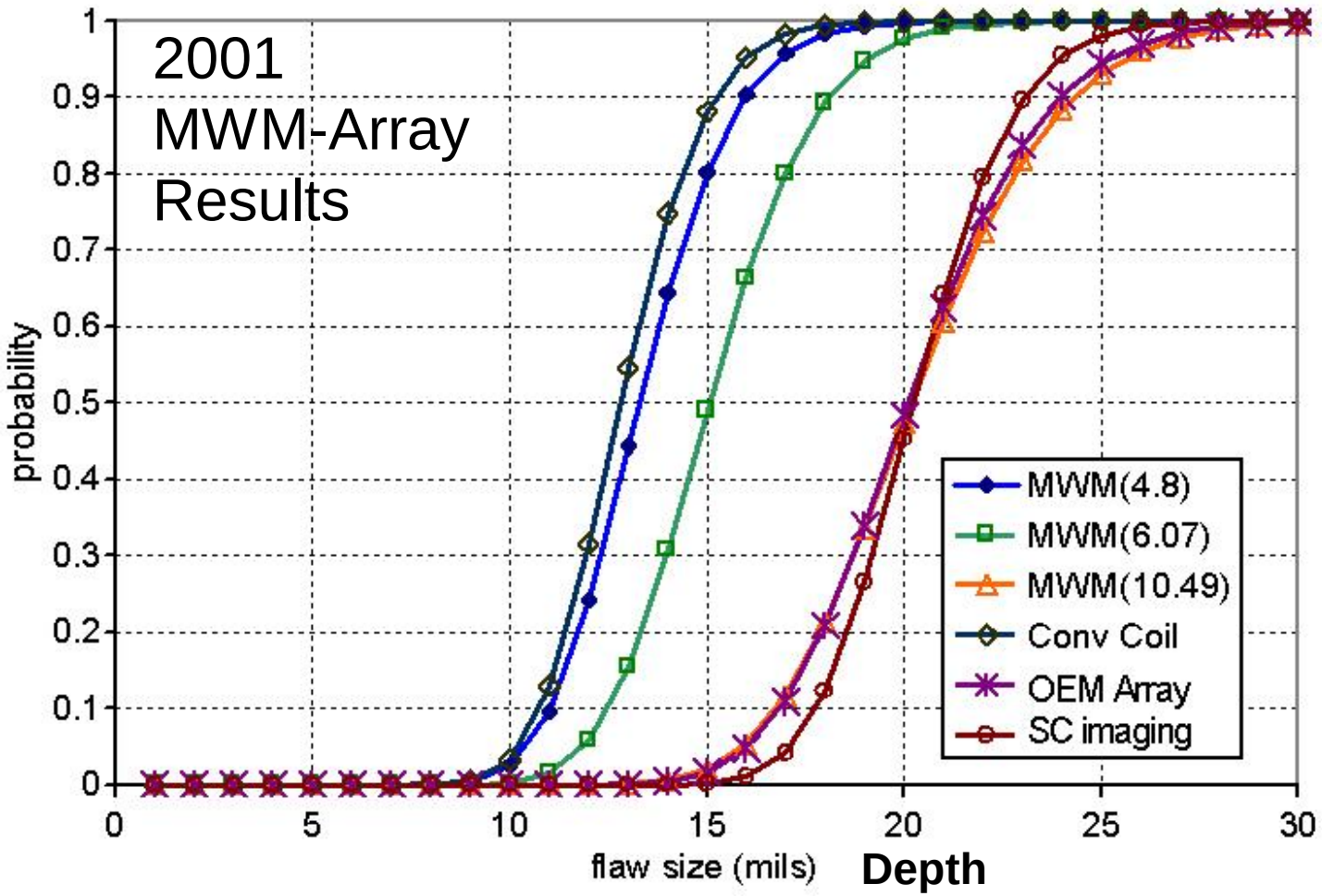
Engine Component Studies

Example Lessons Learned from these Studies

1. Eddy current arrays can match or exceed performance of conventional single channel ET
2. Lift-off range must either be controlled or measured during production/service inspections to have a valid POD Study
3. Flat plates do not capture the challenges facing an ET method on typical engine parts, and anecdotal testing is not generally sufficient.
4. Coatings and complex shapes and fretting and edges are all challenges that must be reflected in the performance evaluation
5. Real crack “knock down” factors can be used

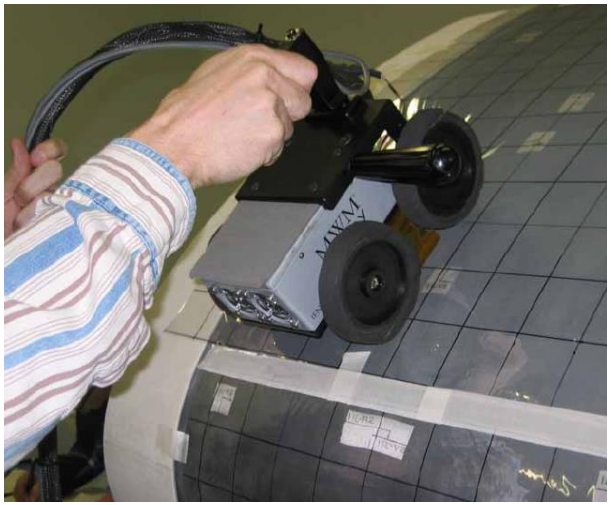
1st Funded MWM-Array POD Study (FAA)

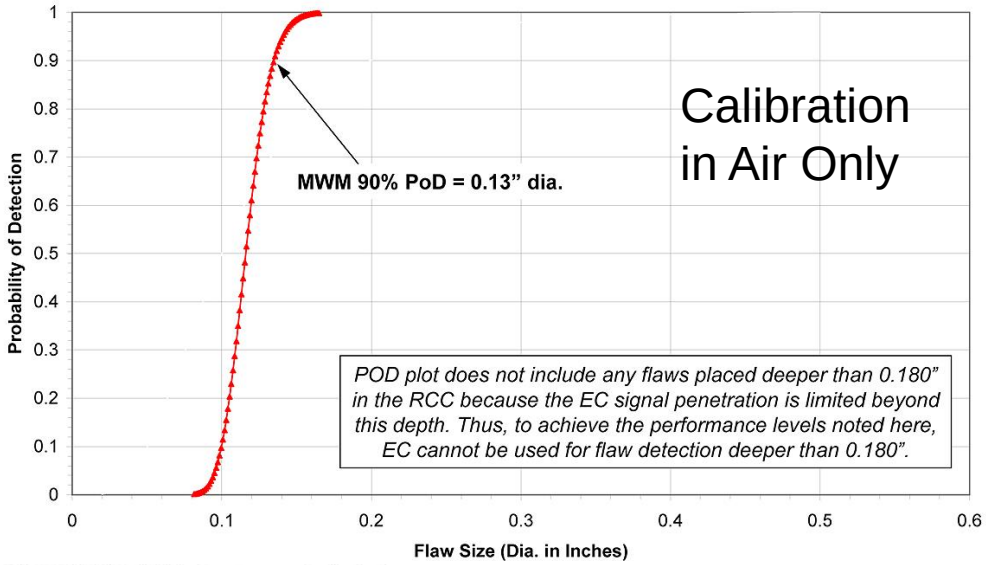
ENSIP-Type Flat Specimens (numerous other POD studies funded)

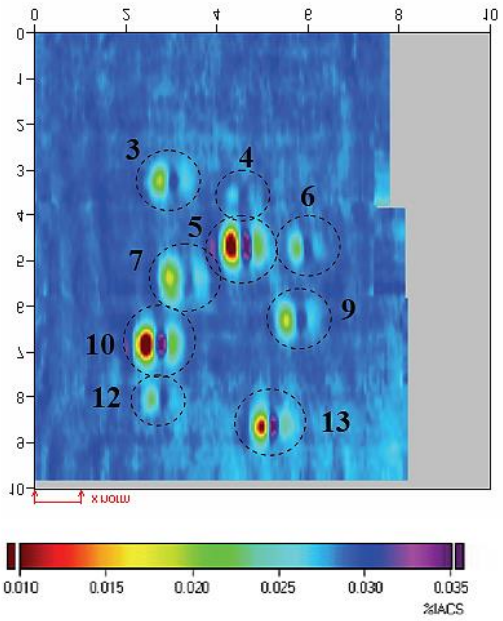


NASA Reinforced Carbon-Carbon Composite (RCC)

Full Scale Validation Panel Test, Space Shuttle Leading Edge







11LFB1 @ UPPER SURFACE				
ZONES	DRILLED FBH	LASER MEASUREMENT		
FEED BACK	∅ @ HOLE DEPTH	∅	REMAINING MATERIAL THICKNESS	THICKNESS NEAR HOLE
1	3/8 @ 0.040	0.381	0.222	0.251
2	1/2 @ 0.040	0.509	0.220	0.249
3	3/8 @ 0.115	0.383	0.138	0.247
4	1/8 @ 0.115	0.128	0.130	0.246
5	3/8 @ 0.190	0.381	0.057	0.246
6	1/8 @ 0.190	0.132	0.058	0.249
7	1/2 @ 0.115	0.512	0.140	0.249
8	1/4 @ 0.040	0.241	0.215	0.250
9	3/8 @ 0.115	0.384	0.136	0.250
10	3/8 @ 0.190	0.384	0.061	0.251
11	1/2 @ 0.040	0.507	0.212	0.250
12	1/4 @ 0.115	0.235	0.130	0.250
13	1/4 @ 0.190	0.236	0.057	0.250
14	3/8 @ 0.040	0.380	0.213	0.251

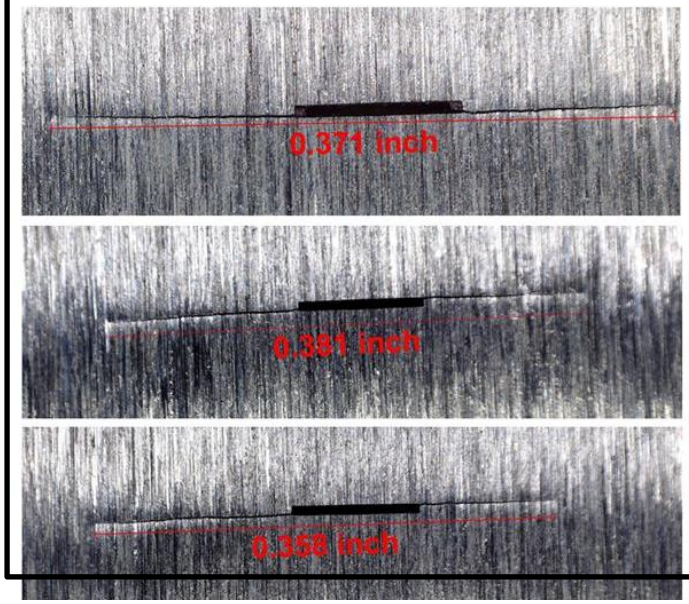
Sources:
"Global Mass Loss Characterization Through Eddy Current Analysis," Buzz Wincheski, NASA Langley Research Center; Dan Ryan, Jim Landy, United Space Alliance; and Neil Goldfine, JENTEK Sensors, Inc.
Industry NASA Partnership 2006
and
"Mapping & Tracking Properties of Next Generation Space Vehicle Materials," Goldfine, et al, ASNT Spring; Orlando, FL; March 26-30, 2007

Subsurface cracks in curved and complex parts

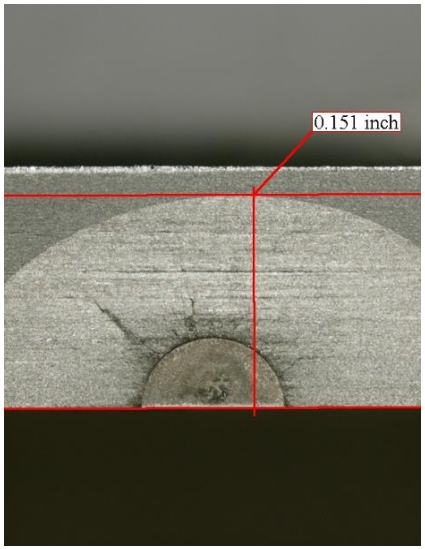
Air Force funded POD study on complex sample with curvature, holes and fillets near inspection region

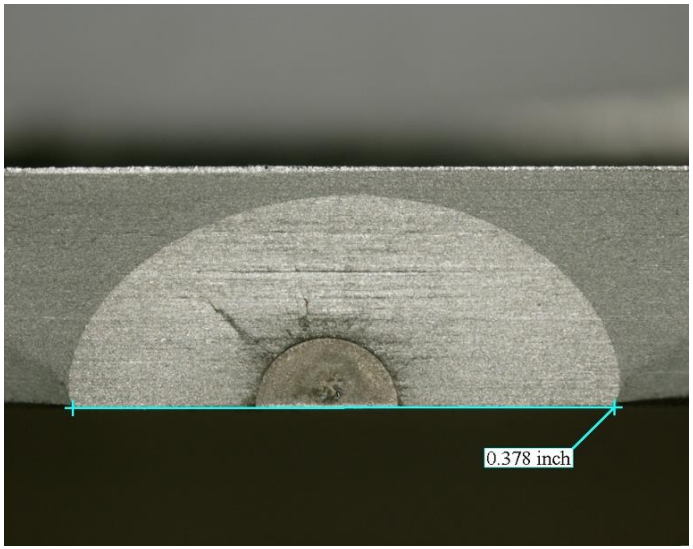
Fractography for largest defect

Crack length measurement
Specimens 1, 2, 3

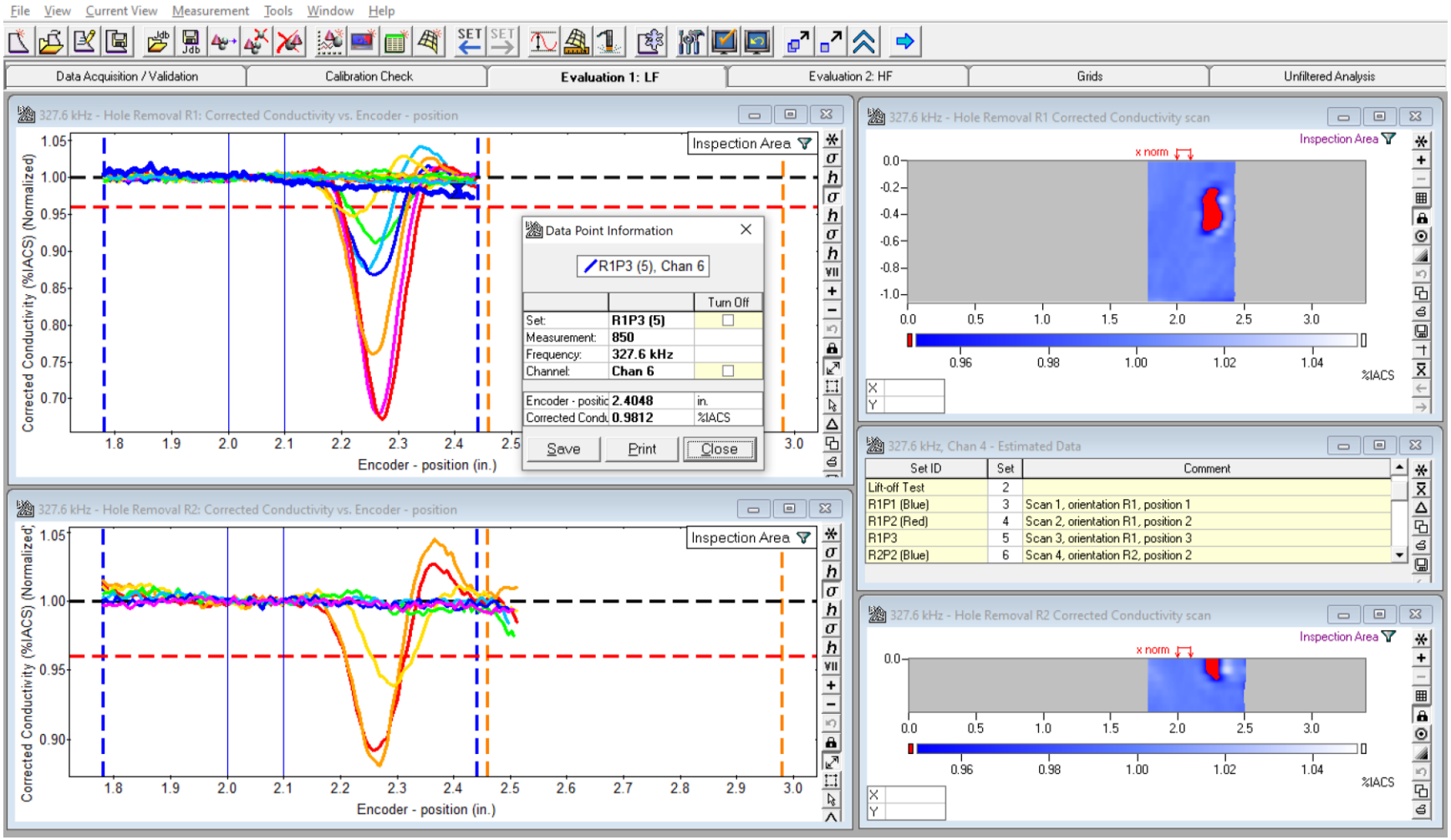


Destructive analysis of Specimen 2
Specimen thickness measured at 0.168 in.



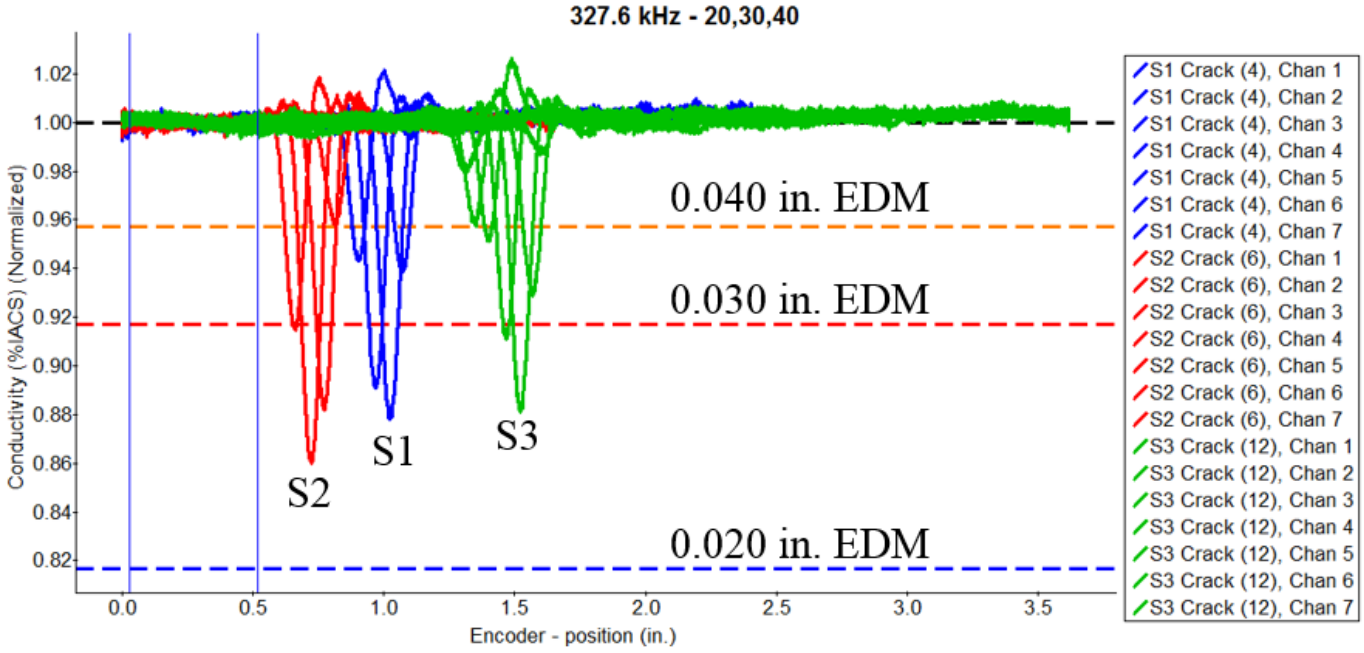


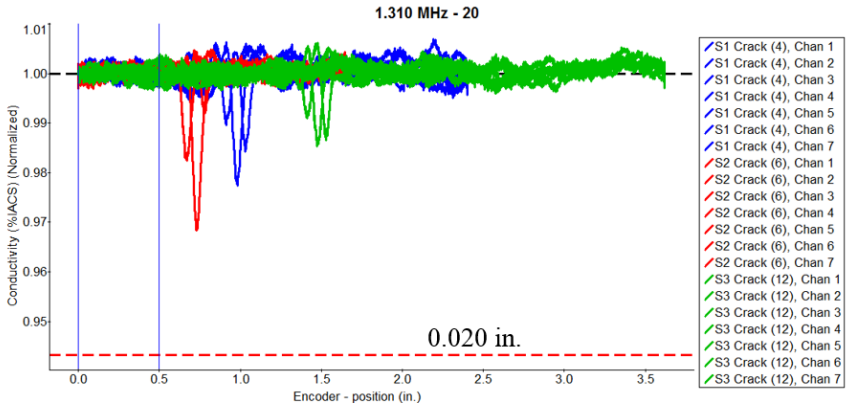
GridStation Inspector Interface with “Tabs”

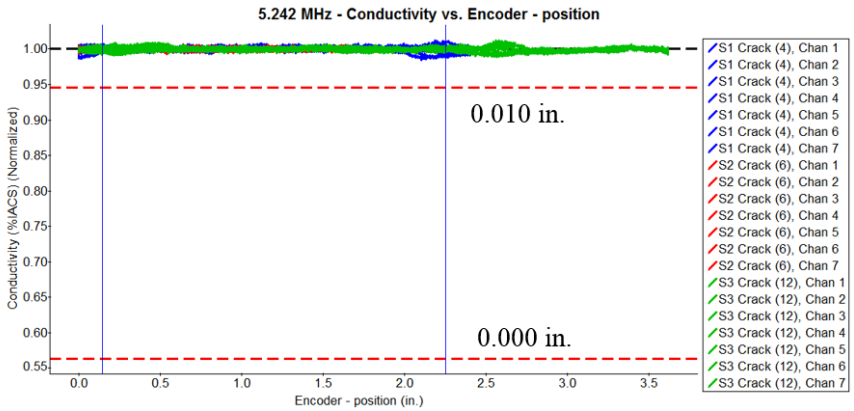


Real Crack Scan Data vs. EDM Notch Indication Levels

S1, S2 and S3 are the real cracks shown on slide 19







Cracks at Bolt-Holes in Multiple Layered Structures

Ongoing Air Force funded program with

- Large sample set
  - Multiple layers (2 to 5)
  - Two alloys (Aluminum and Titanium)
  - Multiple hole diameters
  - EDM notches and real crack samples
  - Defect positions at edges and mid-layer
  - Varied layer thicknesses
- Anomalies
  - Fretting scars
  - Corrosion pits
  - Burrs
  - Shims and debris between layers

Other Example POD and Performance Studies

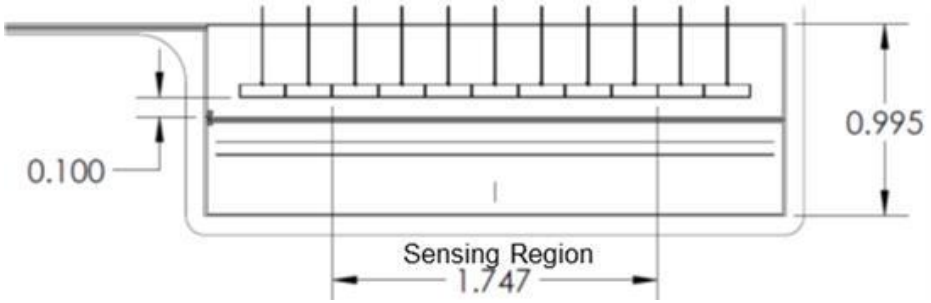
- ***Space Shuttle leading edge Reinforced carbon-carbon composite***
  - ***POD study run by NASA internally***
  - ***Solution used at NASA KSC for over 5 years on Space Shuttle***
- ***Ferrous metal (steel alloys) cracks and crack clusters***
  - ***POD study performed for oil and gas application for SCC***
- ***Corrosion in multiple layered structures***
  - ***Navy funded study for second layer corrosion imaging***
- ***SHM sensor qualification***
  - ***100s of coupon tests and numerous subcomponent and full scale tests run***
  - ***SHM with installed sensors is uniquely different than NDT and sensors must be qualified for each target geometry to replace NDT***

References Available upon request from JENTEK Sensors, Inc.

Summary: POD Study Challenges for Aerospace

Eddy Current Array Testing (ET-Arrays) POD Challenges

- **Example Applications, Challenges, & "POD Study" Results**
  - **Surface breaking cracks in simple flat plats**
  - **Engine components with complex surfaces and/or coatings**
  - ***Space Shuttle leading edge Reinforced carbon-carbon composite***
  - **Subsurface cracks in curved and complex parts**
  - **Cracks at bolt-holes in multiple layered structures**
  - ***Other Examples***
    - ***Ferrous metal (steel alloys) cracks and crack clusters***
    - ***2nd layer cracks at fasteners***
    - ***Corrosion in multiple layered structures***
    - ***SHM sensor qualification***



MWM-Array

jET Eddy Current Array Tester