USAF NDI Reliability Improvement: Lessons Learned

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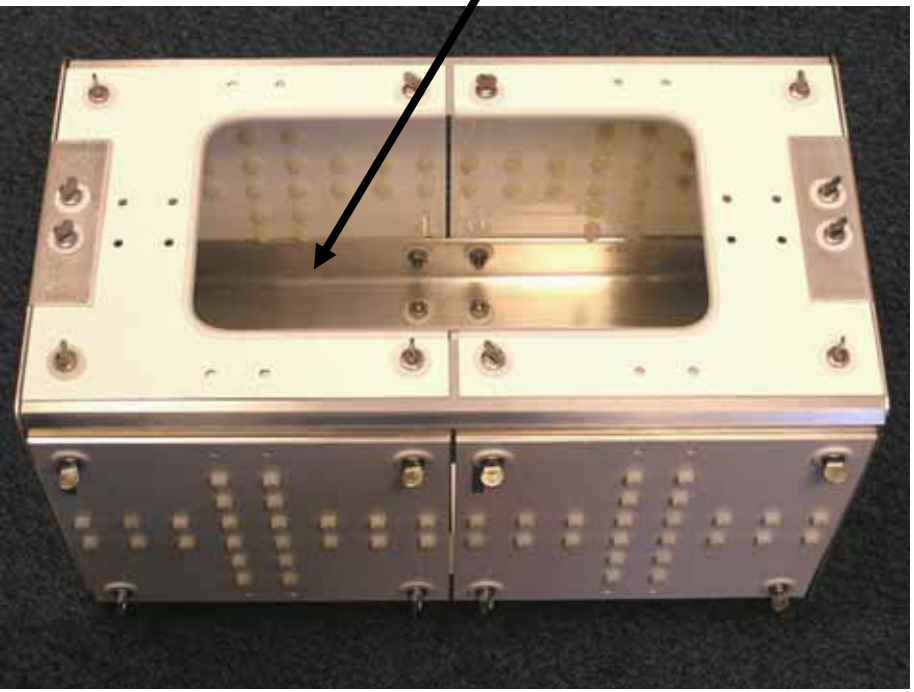
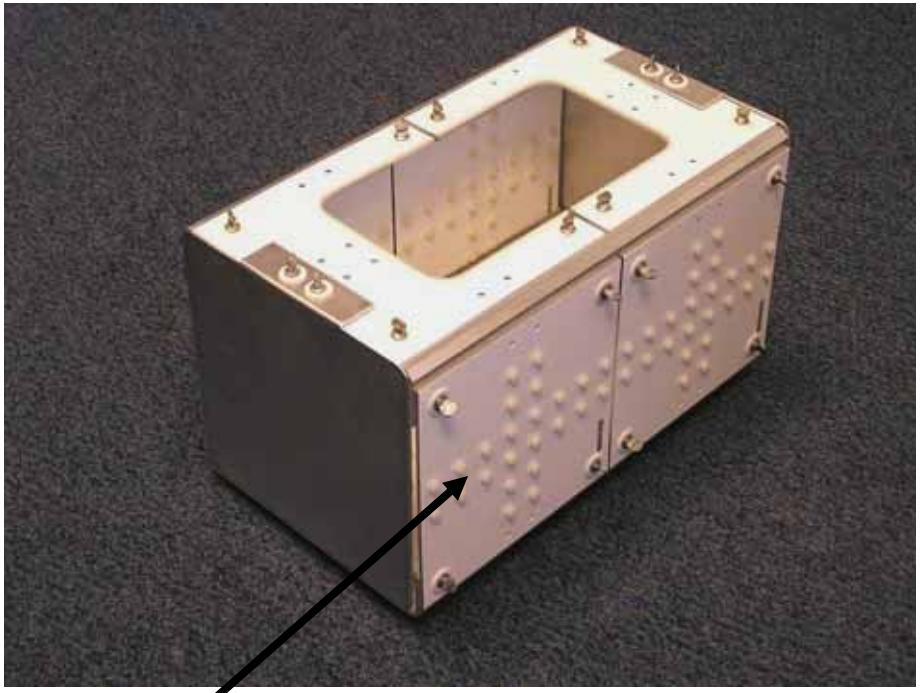
AFRL/RXSST

U.S. AIR FORCE

Shoebox

4 Angles/Box





6 Plates/Box, 24 Fasteners/Plate

Overview

- **Probability of Detection (POD) Experiment Summary**
- **Comparison**
- **Lessons Learned**
- ***Moving Forward***
- **Summary**

POD Experiment Summary

	Field 1	Depot 1	Field 2	Depot 2
Dates	2004	2005-06	2005-06	2006-07
Bases	16	3	6	3
A/C		Various		Various
Fighters	12		5	
Cargo/bombers	4		1	
Inspectors	64/62	30	26	92

POD Equipment Summary

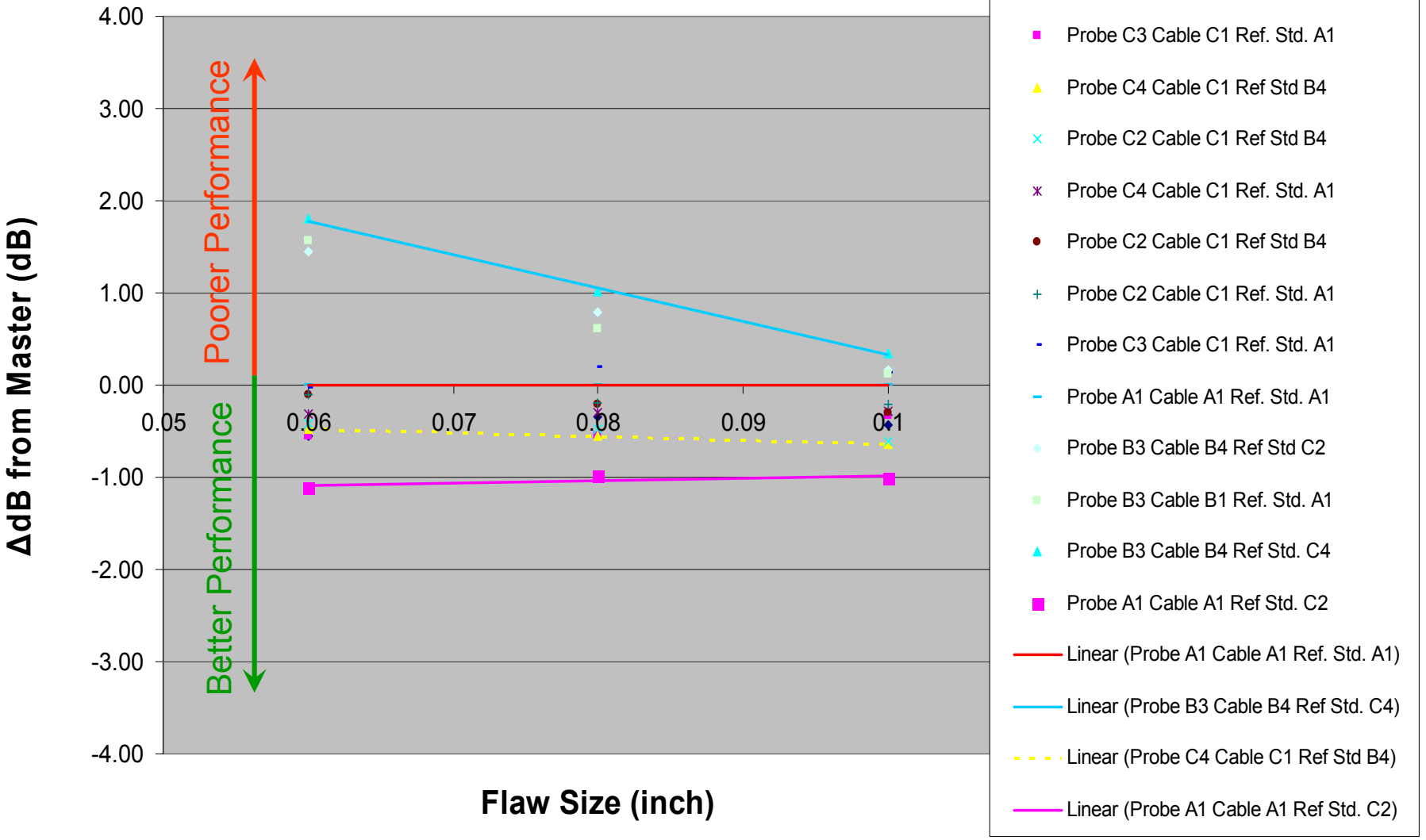
Equipment	Field 1	Depot 1	Field 2	Depot 2
Instrument	Local (19eII or 2000D)	Local (2000D)	Local (2000D)	Provided (2000D+)
Standard	Local	Local	Local	Provided
Probe	Provided	Provided	Provided	Provided
Cable	Provided	Provided	Provided	Provided

Equipment Variability Study

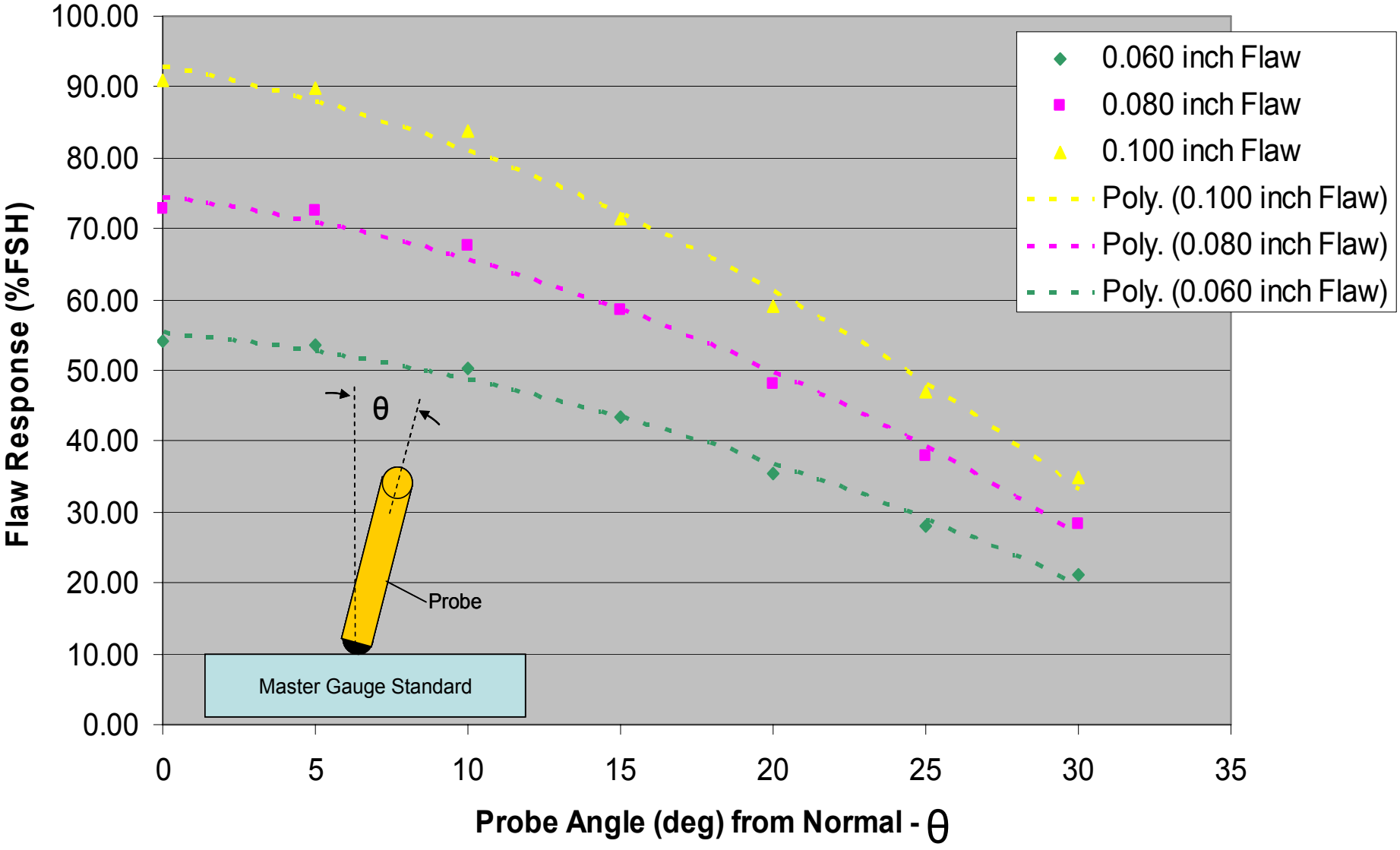
- **Minimal instrument-to-instrument variation observed**
  - **Oscillator Frequency Output**
  - **Receiver Linearity**
  - **Voltage Output**
- **Less than +/- 2dB response variance observe for all tested probe, cable, and reference standard combinations**
- **Results support human induced variance as dominant factor in manual scan eddy current inspection performance variability**

Variability Results

dB Variance – Extreme Combinations



Performance Variance – Probe Angulations



Comparison

Issues	Field 1	Depot 1	Field 2	Depot 2
Time Allowed	Shift	2 days	2 days	Shift +
Boxes	3	6	6	7
Procedure (pgs)	C-17 (3)	C-130 (14)/ KC135 (11)	-2 (20)	-2 (15)
Training	None	Yes	Yes	Yes
Assist	None	None	None	first box
Cal	4 div	8 div	8 div	8 div
H-Gain	Low	High	High	High
Thresh	None	1.5 div/4 div	1 div	1 div
LO Comp	None	Yes	Yes	Yes

Plates Relative Performance

Performers	Rank (Best =10)
Depot 2: ALC2	10
Depot 1: ALC2, Depot1: ALC1, Field 2, Depot 2: ALC1	9
Depot 2 Overall	8
Depot 1 Overall, Depot 2: ALC 3	7
Field 1	3
Depot 1: ALC3	1

Angles Relative Performance

Performer	Rank (Best = 10)
Depot 2: ALC2	10
Depot 2: ALC1	8
Depot 1: ALC1	7
Depot 2: Overall	6
Depot 1: ALC2	5
Depot 1: Overall	2
Field 2, Depot 2: ALC3	1
Field 1, Depot 1: ALC3	0

Setups for Field 2, Depot 1 and 2

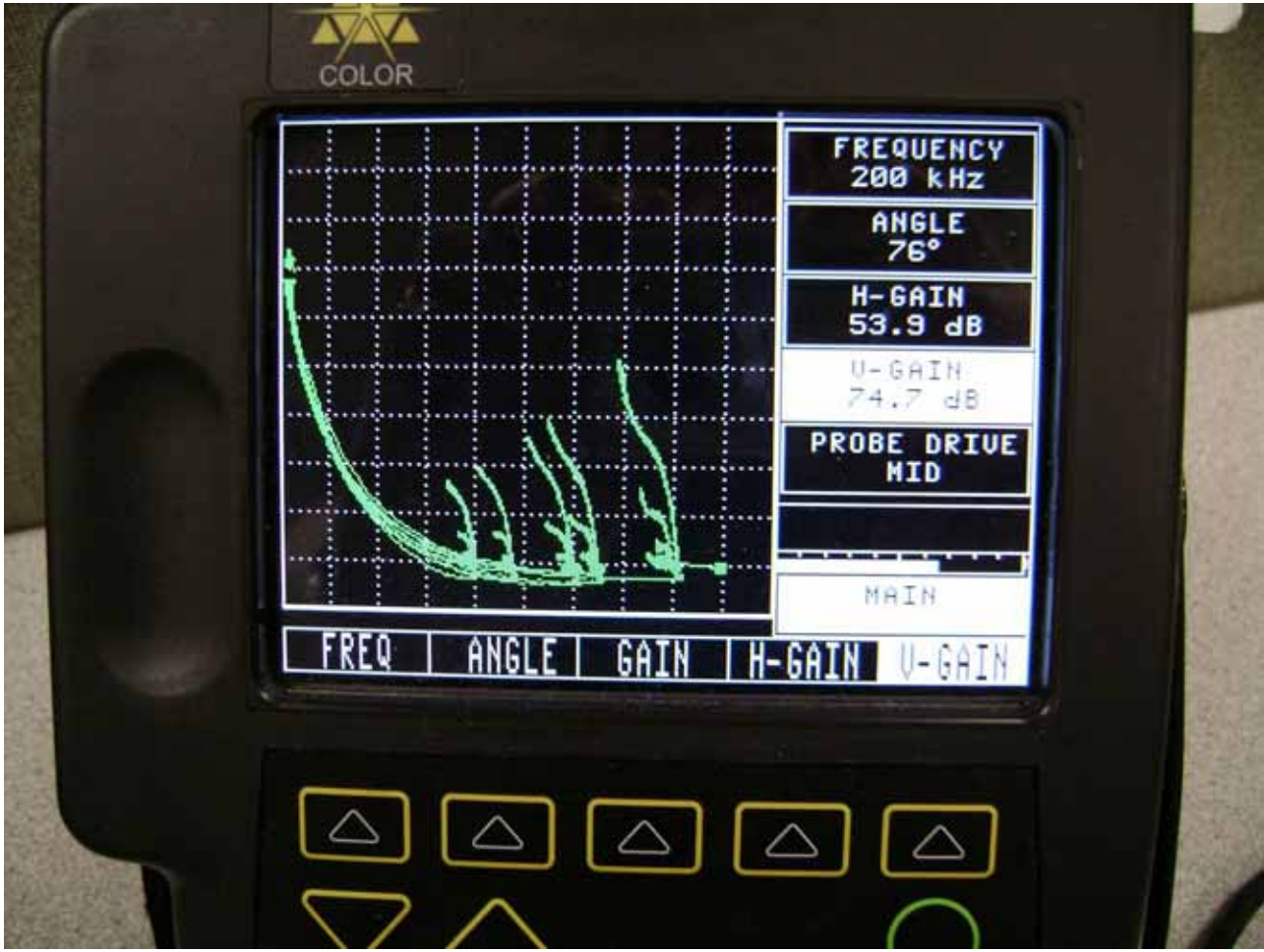
Field 1 Setup

Coating Effects and Notch Response

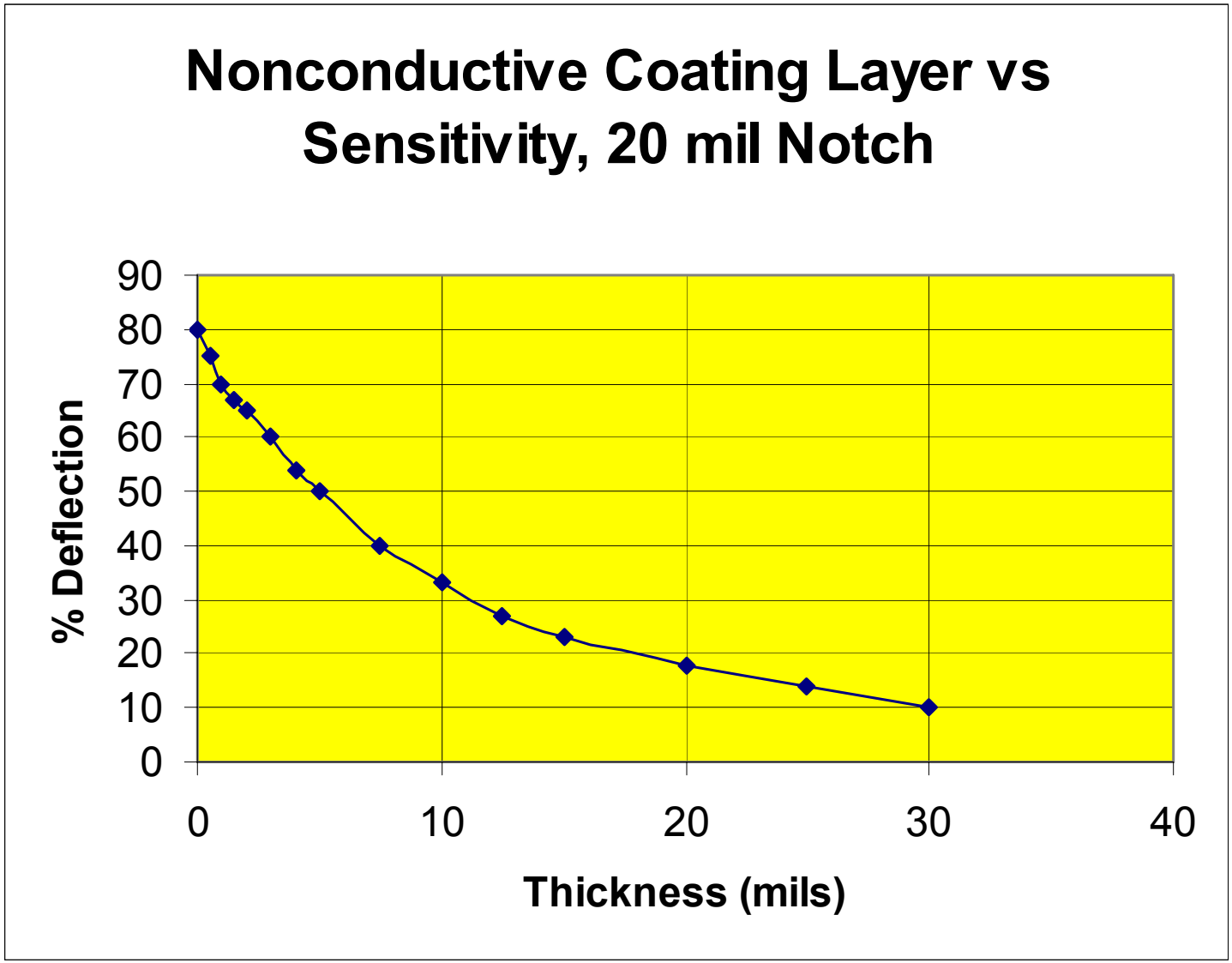
20, 10 & 5 MIL NOTCHES

Field 1 Coating Thickness Affect

- 20, 10, and 5 mil notches with Field 1 Setup
- From right to left
  - Bare
  - 3 mil coating
  - 4 mil coating
  - 7.5 mil coating
  - 10 mil coating

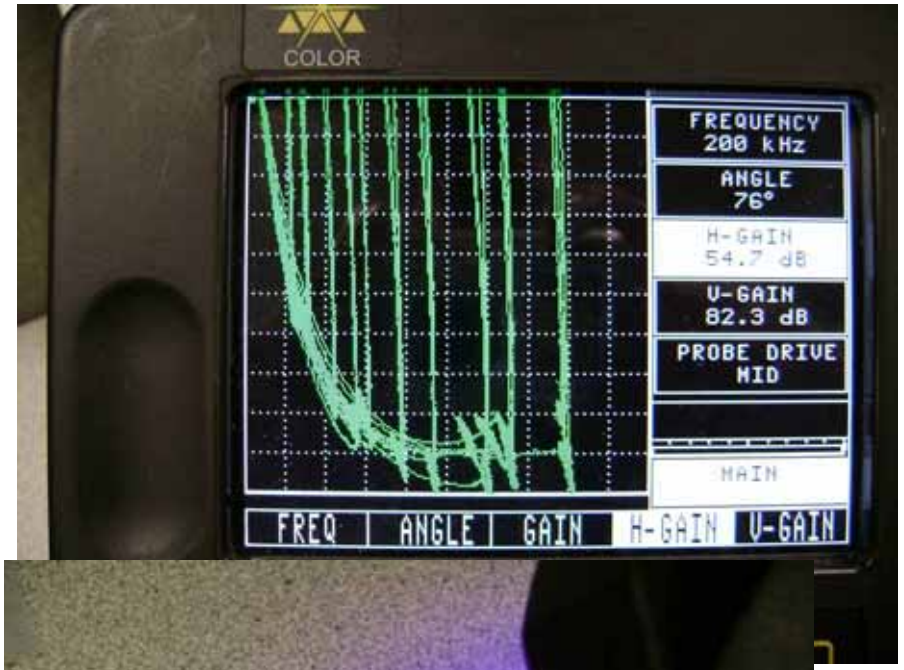


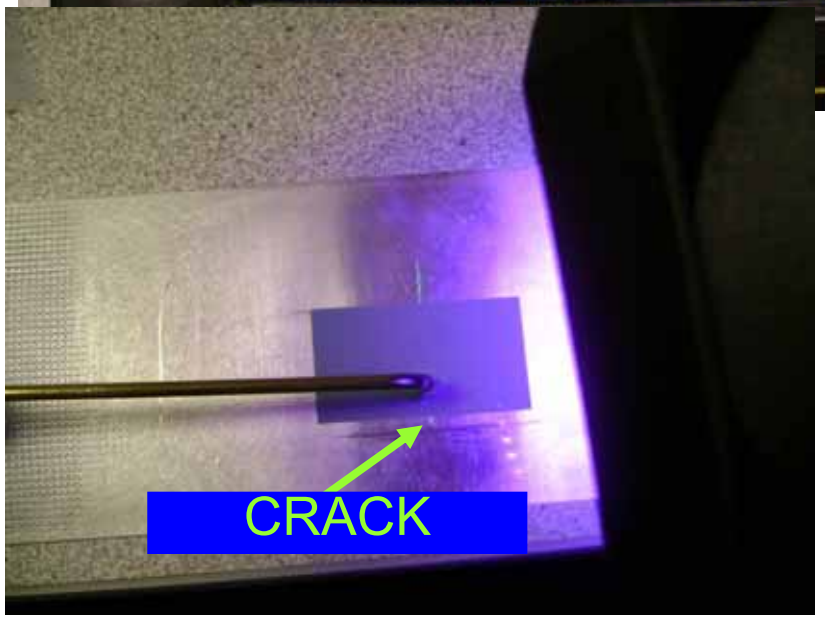
Sensitivity Reduction



Infinite Crack/Coating Thickness

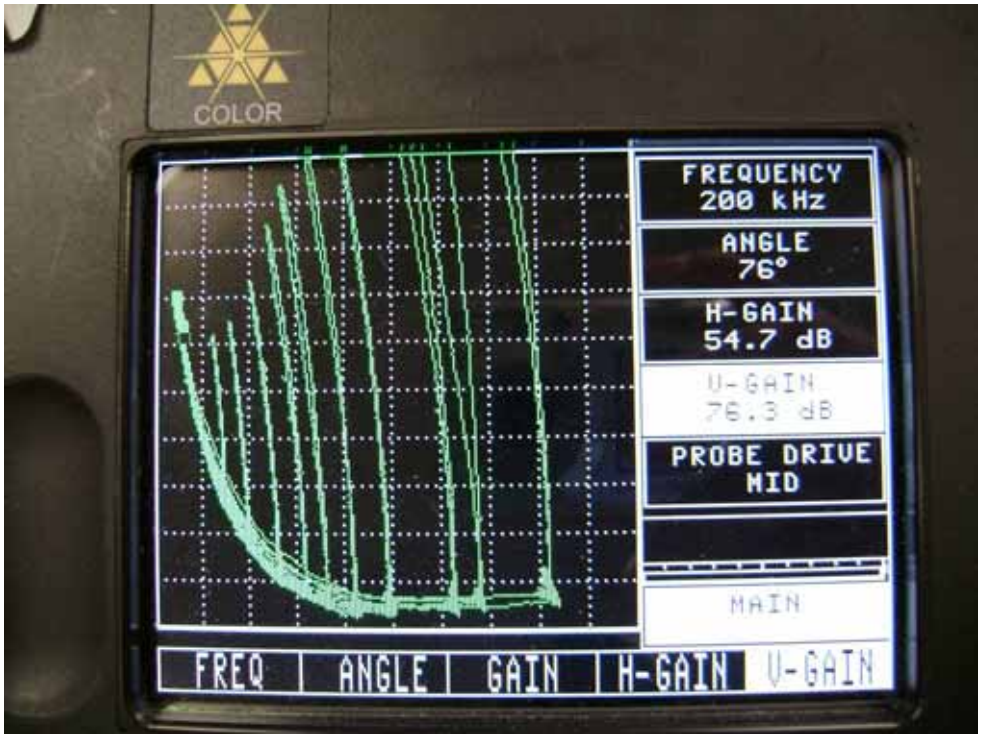
- Field 2, Depot 1 and Depot 2 Setups
- Conditions
  - 80% deflection on 20 mil notch
  - Bare Crack (right)
  - Coated: 3 to 30 mil coating (right to left)
- All indications off-scale for infinite crack
  - Crack under 25 and 30 mil coating signals actually 60 and 80% deflection





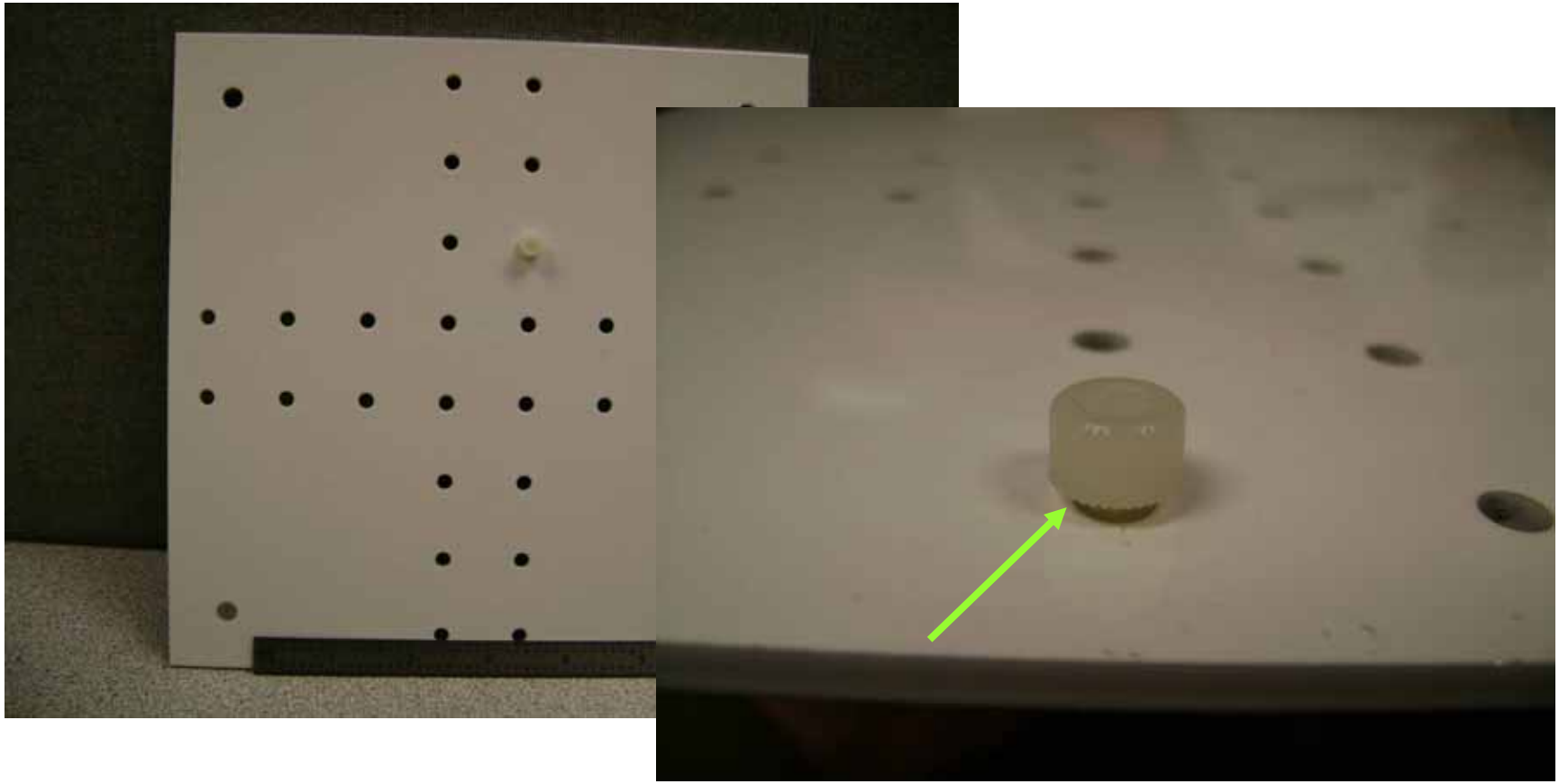
Infinite Crack/Coating Thickness

- Field 1 Setup
- Conditions
  - 40% deflection on 20 mil notch
  - Bare Crack (right)
  - Coated: 3 to 30 mil coating (right to left)
- Indications off-scale for infinite crack under up to 10 mil coating

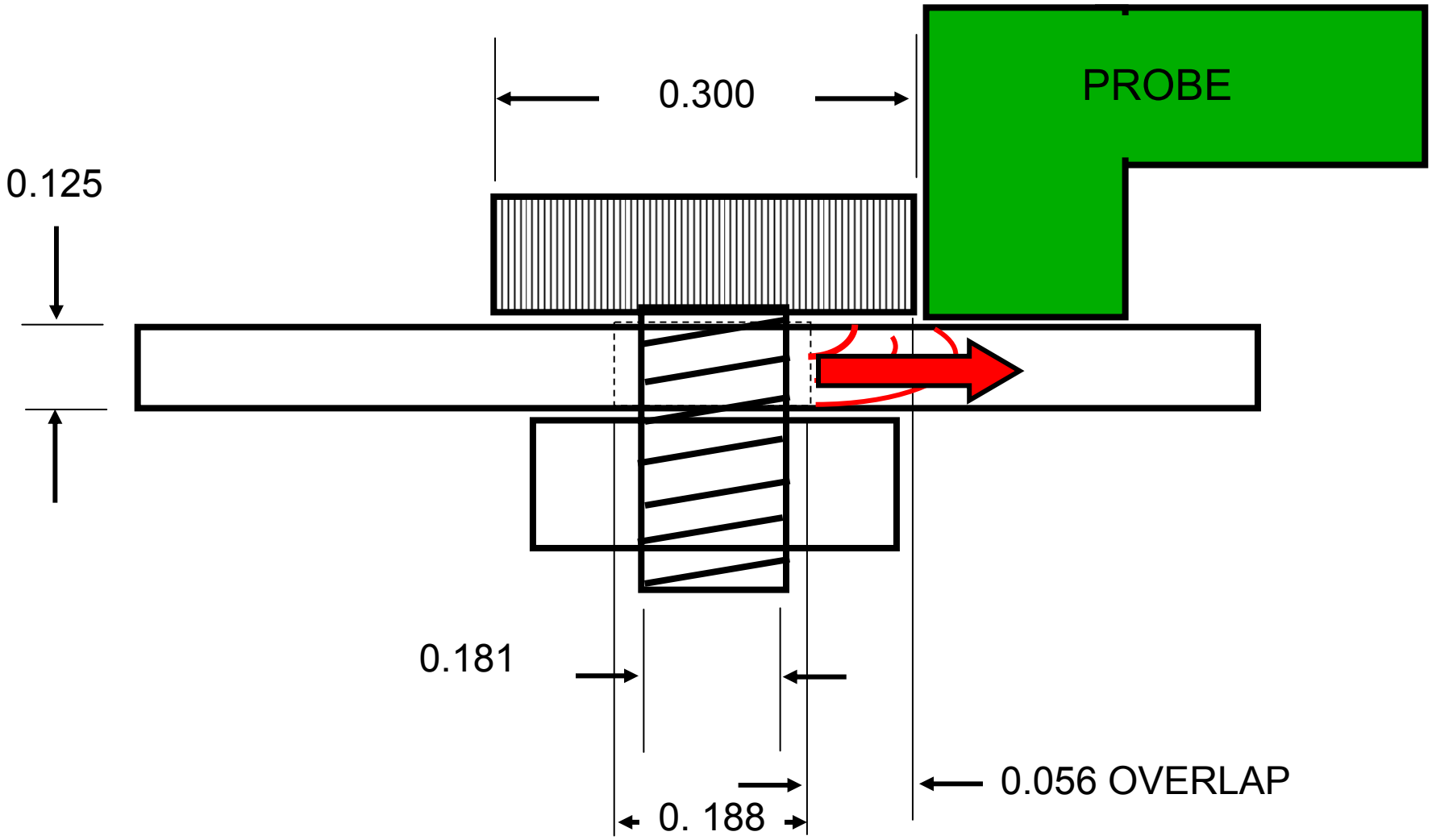


Fastener Heads

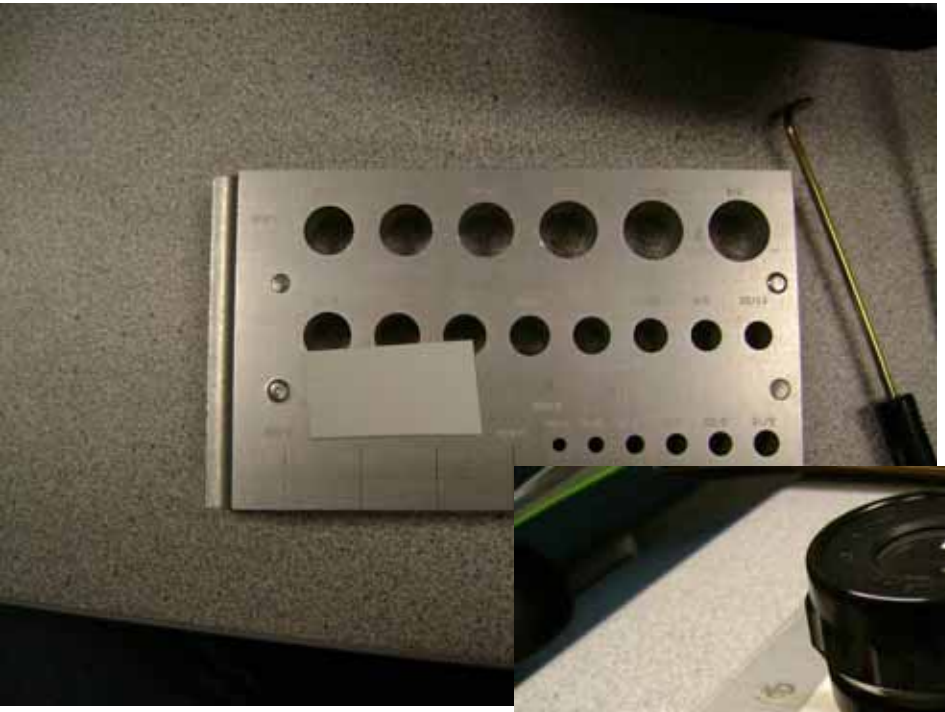
Plate POD should exclude length under fastener



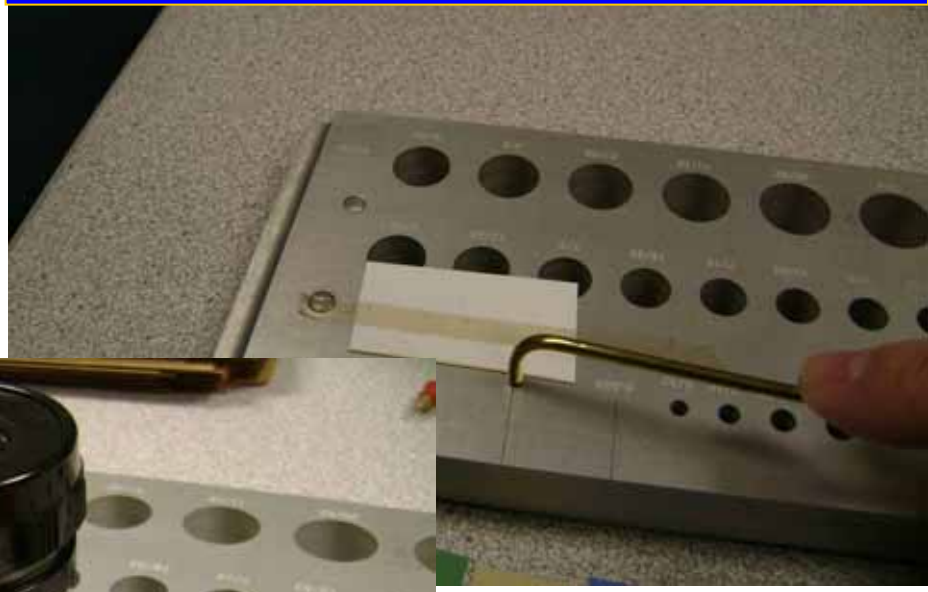
Crack Under Fastener Head Shadow

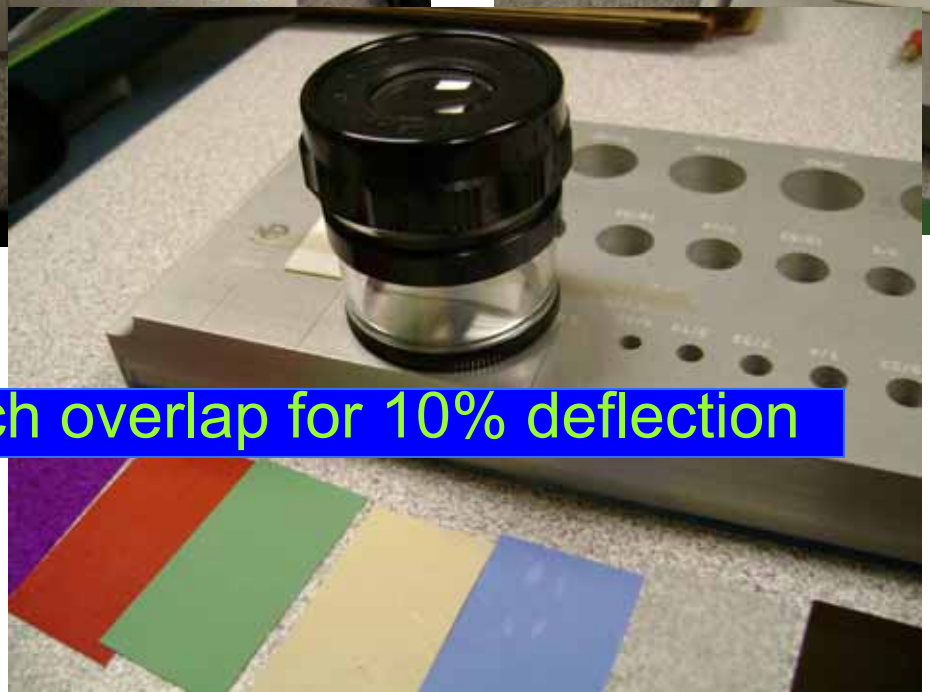


Coil Overlap for 10% Deflection



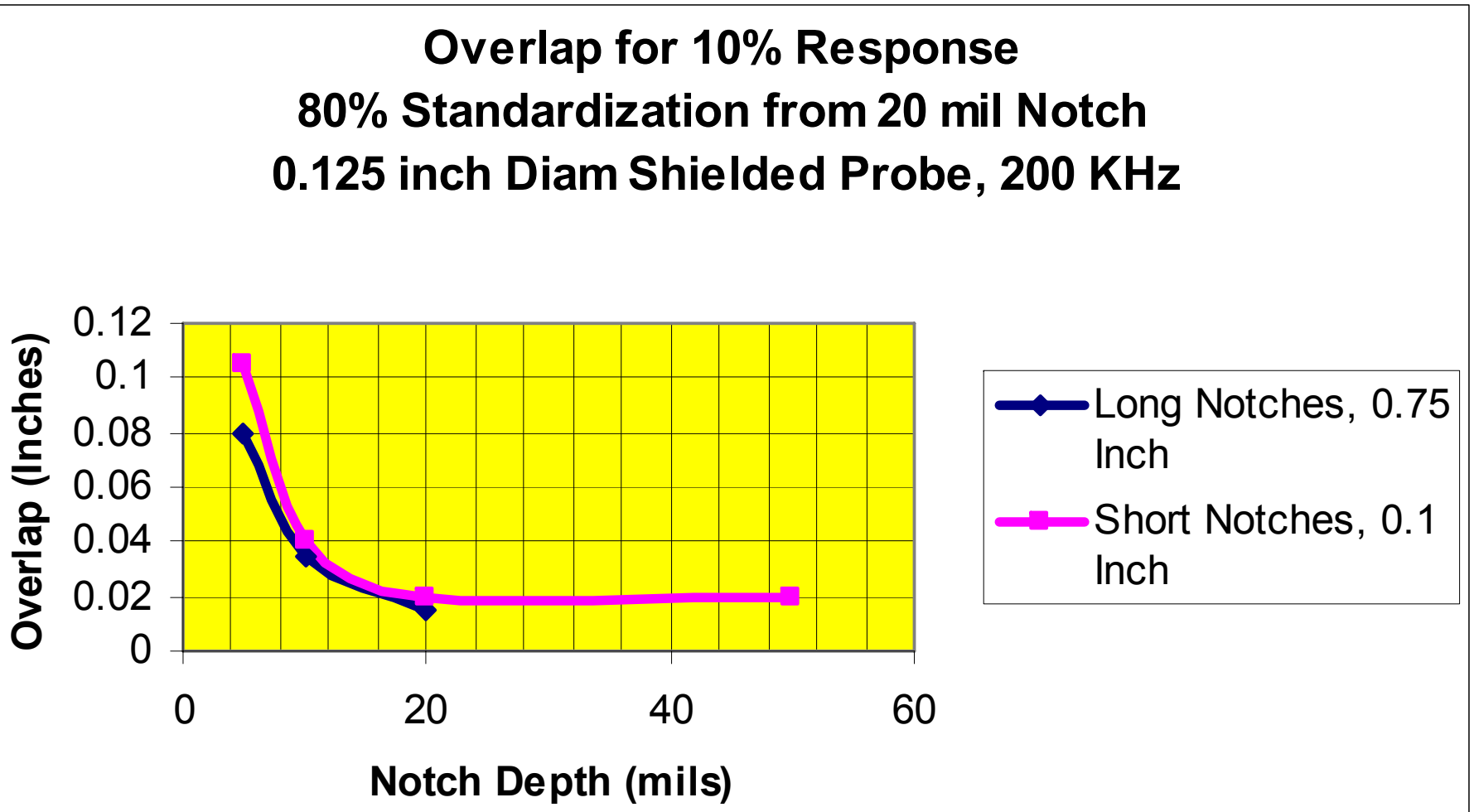
9 hits in 368 opportunities for cracks under fastener head



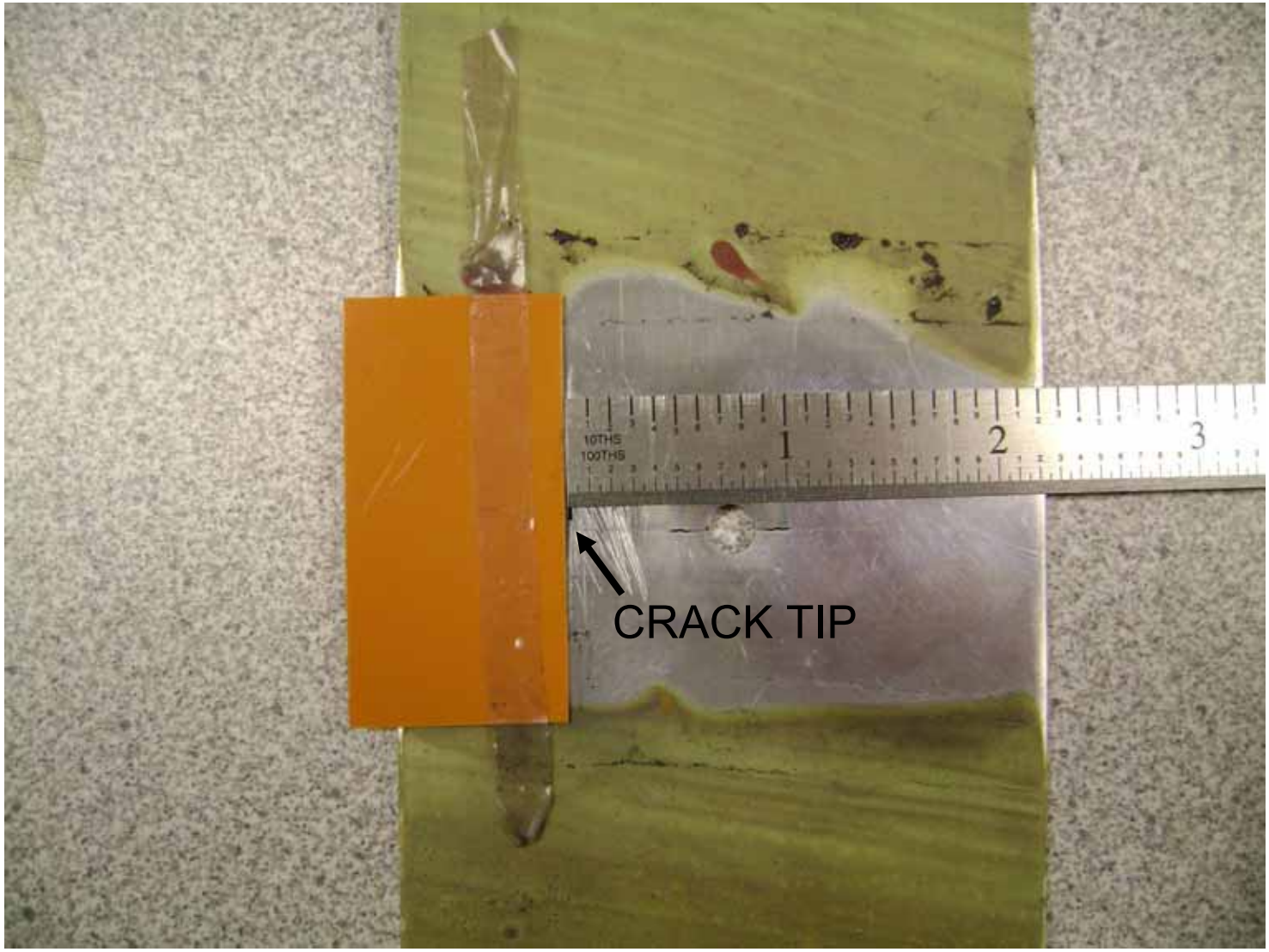


15 mil probe/notch overlap for 10% deflection

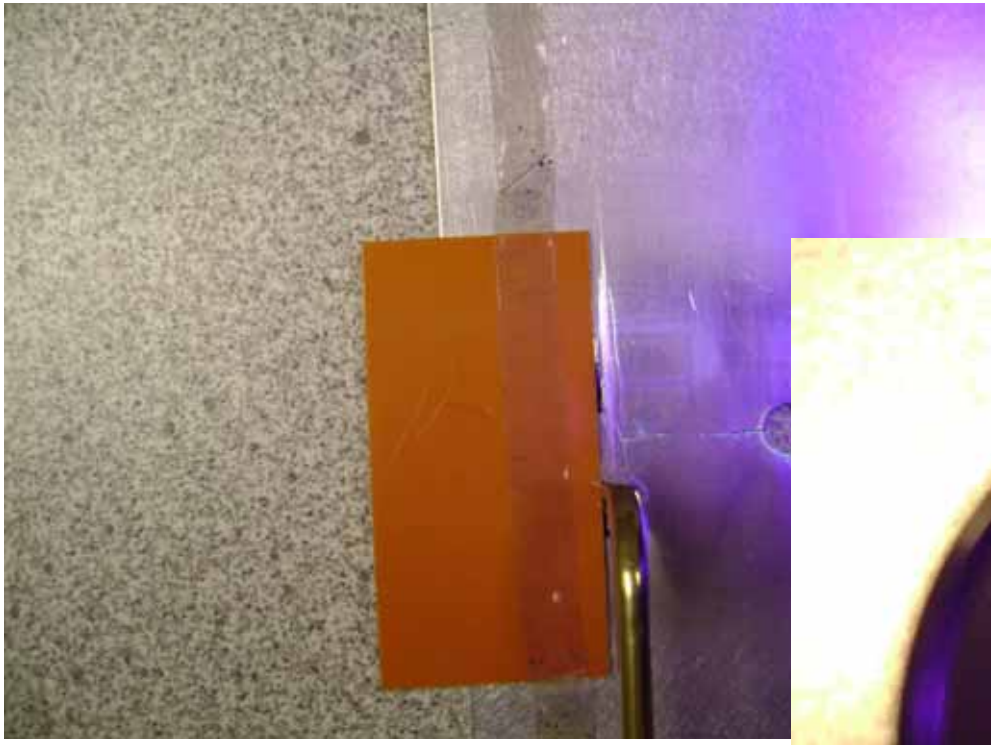
Probe/Notch Overlap

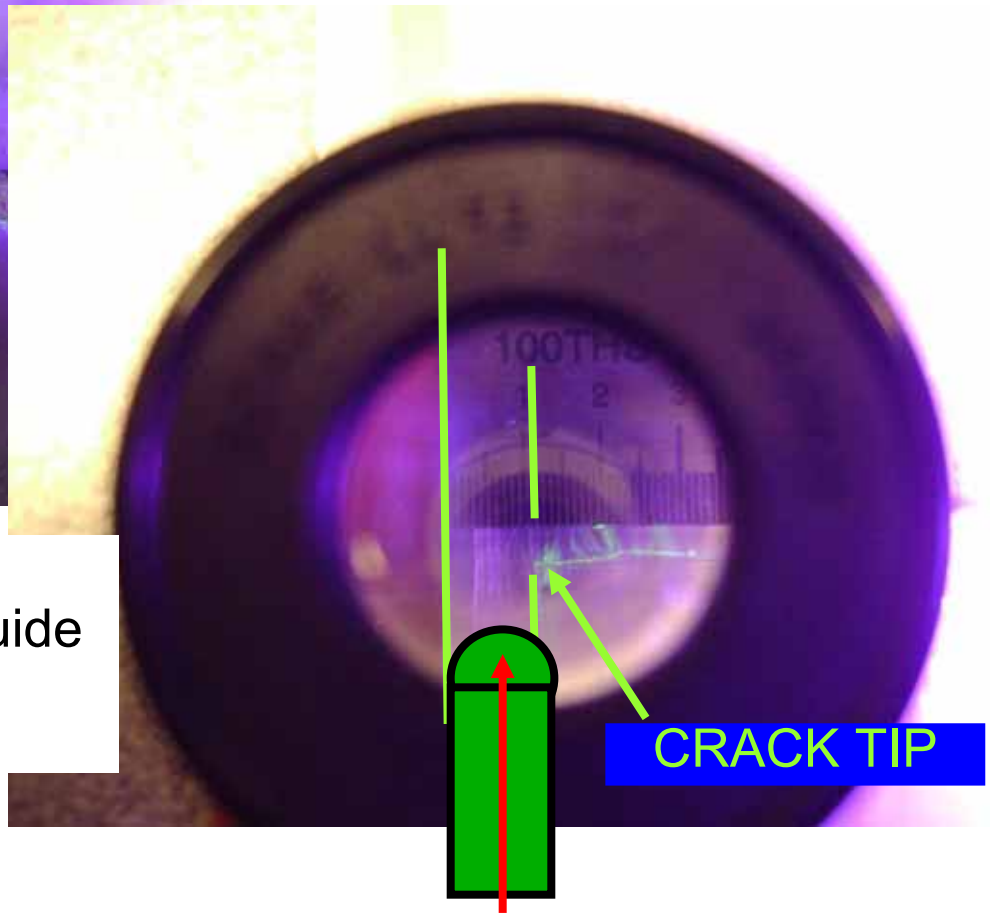


Fatigue Crack Tip Overlap



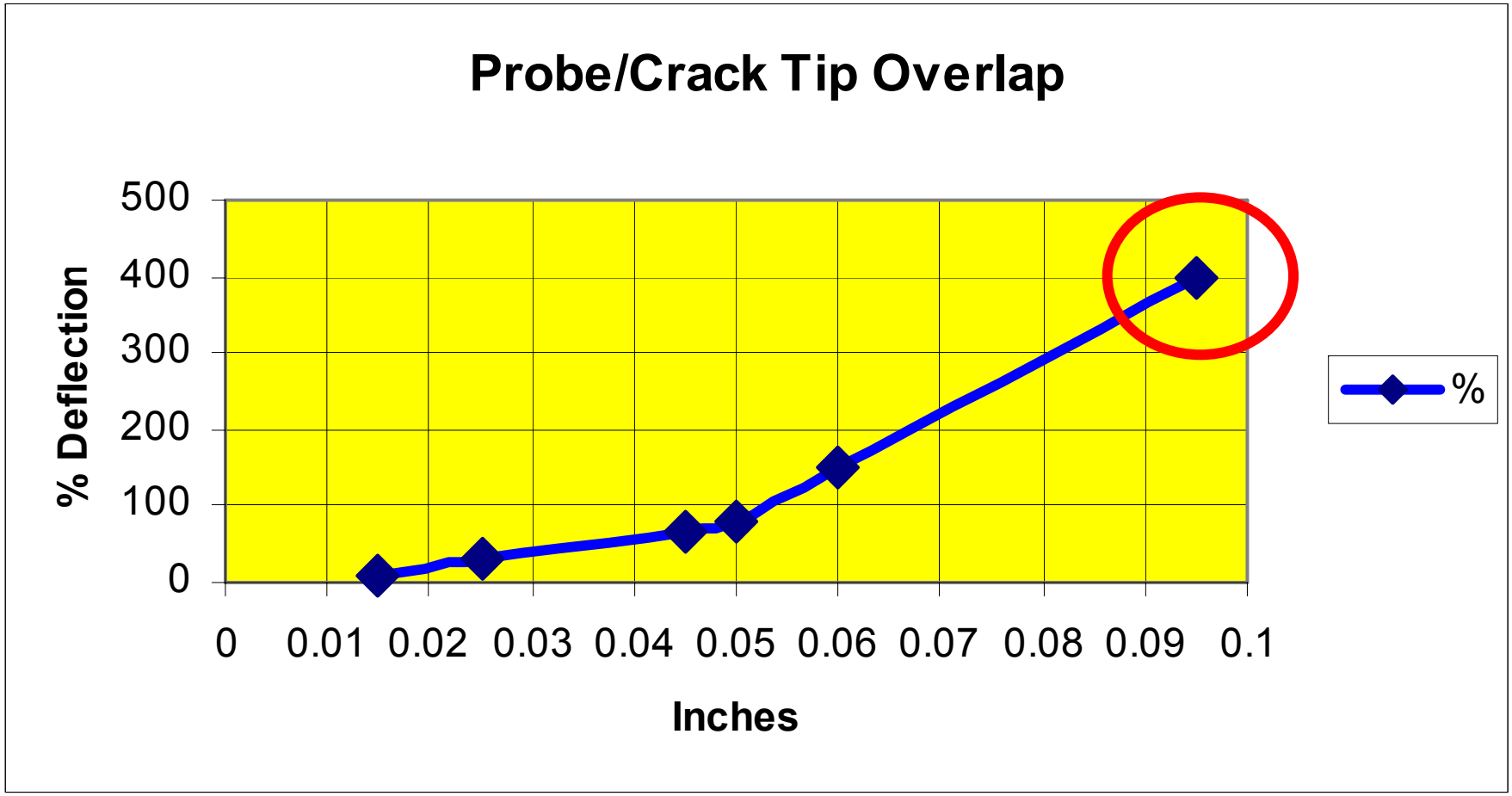
Gap Edge Guide and Crack Tip



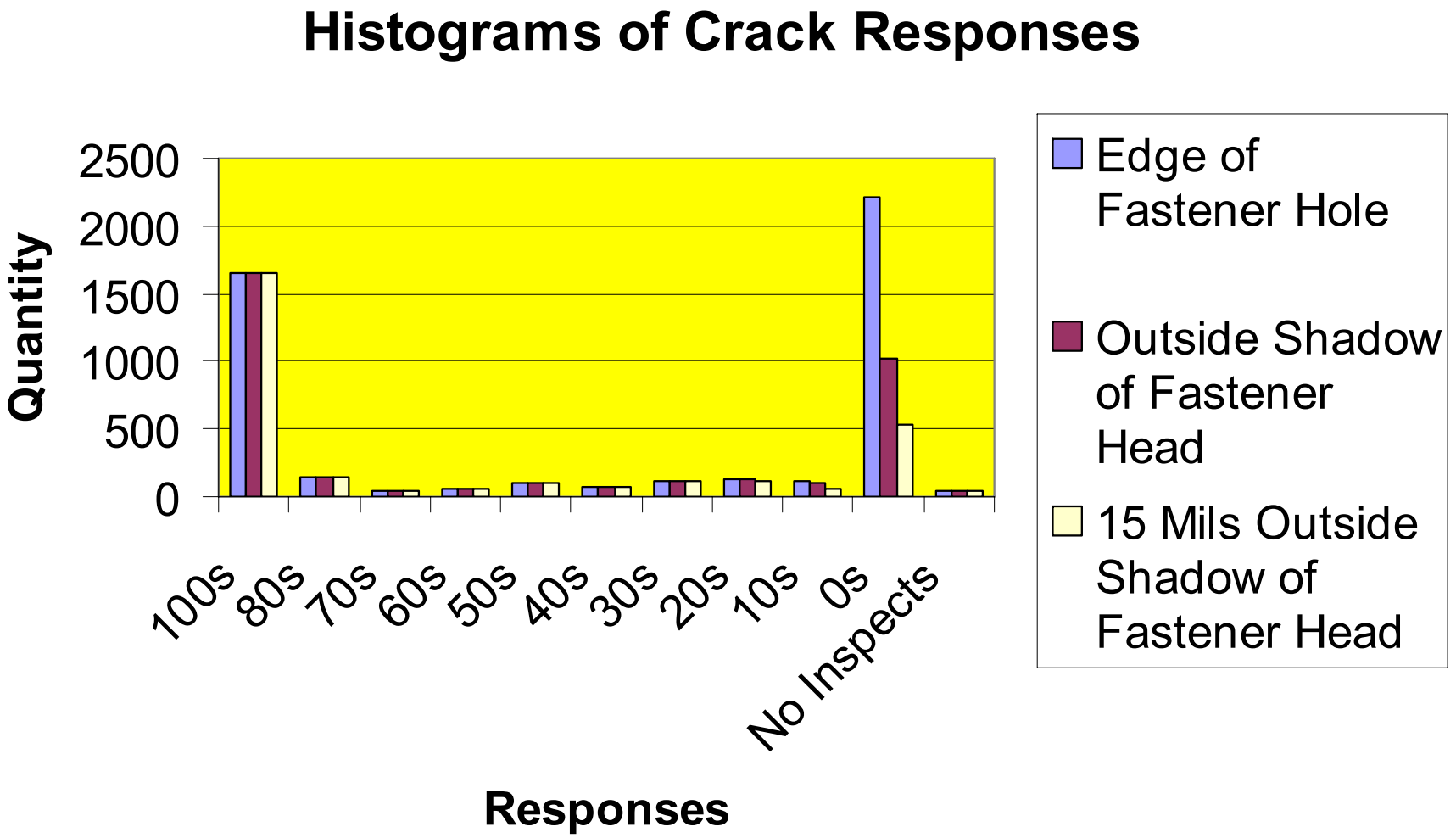


- 0.125 Inch Dia Probe
- 0.110 Gap between edge guide and crack tip
- 10% Deflection

Overlap to Saturation



Distributions of Responses

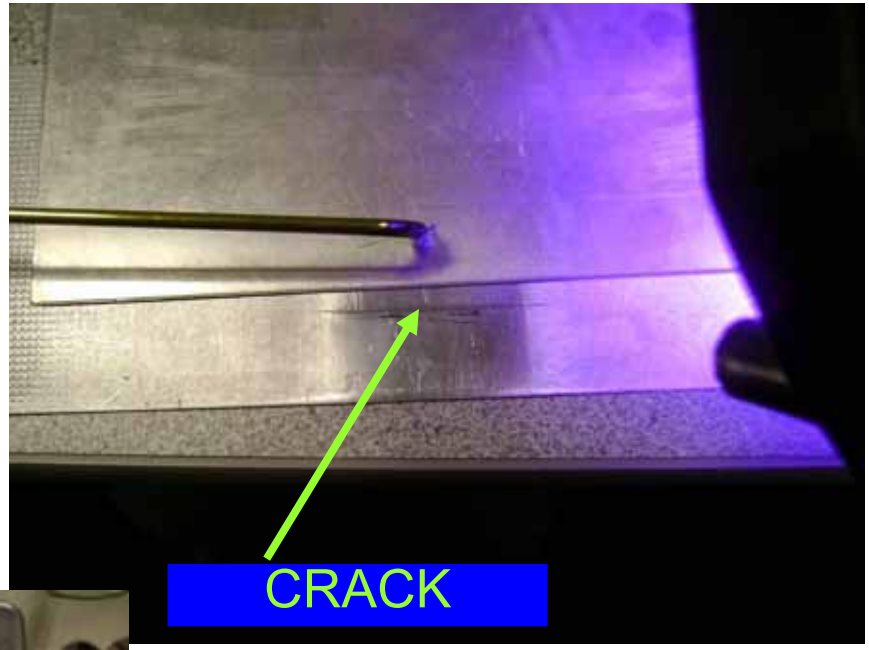


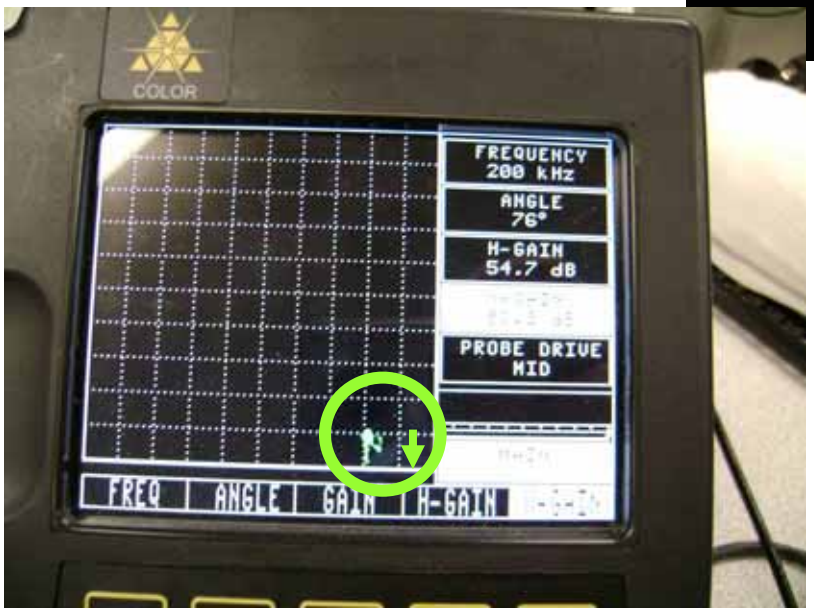
Cracks Less than 0.015 Beyond Fastener

- 19 Cracks too short to get 10% minimum based upon laboratory experiments on notches and infinite crack tip overlap requirements
  - 9 smallest cracks without one hit in 828 attempts
  - 9 hits combined from 4 largest cracks beneath heads in 368 attempts
  - 69 hits combined from next 6 cracks in 552 attempts
  - Overall of 78 hits in 1748 attempts for cracks less than 0.015 beyond fastener
  - Only ¼ of misses represented by cracks 0.015 or more beyond fastener

Subsurface Crack Simulation

- 80% Deflection Bare 20 mil notch
- Infinite crack
  - 20 mil Aluminum top cover
  - ~10% downward deflection





Common Errors

- Unfamiliar with procedure
- Read procedure once and then did not refer back to procedure for critical steps
- Unfamiliar with Nortec 2000D
- Unfamiliar with Load Default steps (rotate SmartKnob to “Confirm”)
- Not familiar with effect of H-Gain adjustment (sometimes they called it High Gain as opposed to horizontal)
- Failure to tape probe
- Failure to establish regular scan pattern
- Scanning angles in only one direction
- Failure to maintain contact with protruding fastener while scanning around holes
- Failure to scan clockwise and counterclockwise around fastener holes
- Calibration for angles over taped notches
- Calibration for plates over bare notches (no compensation)

Common Errors (Cont'd)

- Failure to regularly check calibration
- Failure to maintain signal between right and left sides of screen (angles)
  - Excessive H-Gain
  - Failure to maintain probe 90 degrees to surface
- Assumed tape on probe compensates for liftoff due to paint on part
- Inspected flats as well as radius of angles
- Interpreted shading meant that open area between fasteners required inspection
- Set display erase to 0.5 sec instead of 2-3 sec
  - Made it difficult to identify amplitude of signal relative to null point
  - Made it difficult for them to view display and to ensure coverage while scanning probe
- Failure to erase screen or use Display Erase regularly making it difficult to identify location of signal
- Failure to post cal

Where's the Dot?

Current Documentation

Depot 2

Inspector # _____ | Date & Shift _____ D S G | Red ☐ Blue ☐

Post Inspection Cal. Response (Lab. Standard)
20 mil slot: _____
10 mil slot: _____
5 mil slot:

Post Inspection Cal. Response (Master Standard)
30 mil slot: _____
20 mil slot: _____
10 mil slot:

How often was recalibration accomplished? _____ Note each time on comments sheet.

Does the inspector use some method to keep track of which locations have been inspected? Yes ☐ No ☐

Lighting conditions: Good ☐ Average ☐ Poor ☐

Area conditions: Comfortable ☐ Hot ☐ Dry ☐ Quiet ☐ Cold ☐ Humid ☐ Noisy ☐

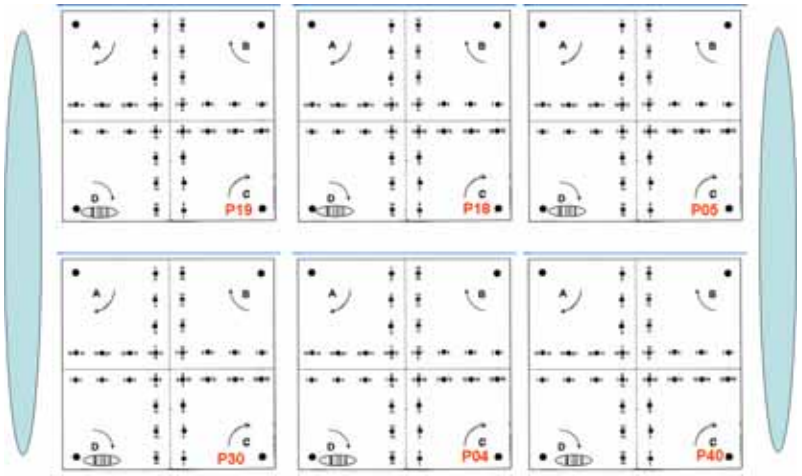
Inspectors Attention Level 10 (Focused) to 1 (Distracted or bored) _____

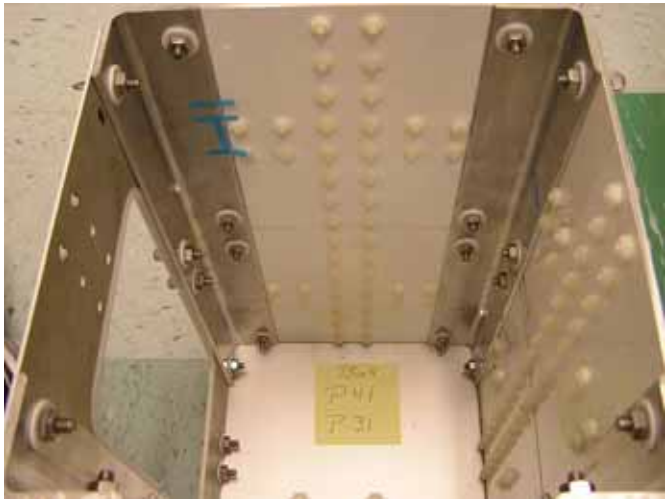
Inspectors Behavior 10 (cheerful) to 1 (Stressed) _____

Observations about the actual inspections

Other observations about the actual inspection (technique, coverage, etc.)

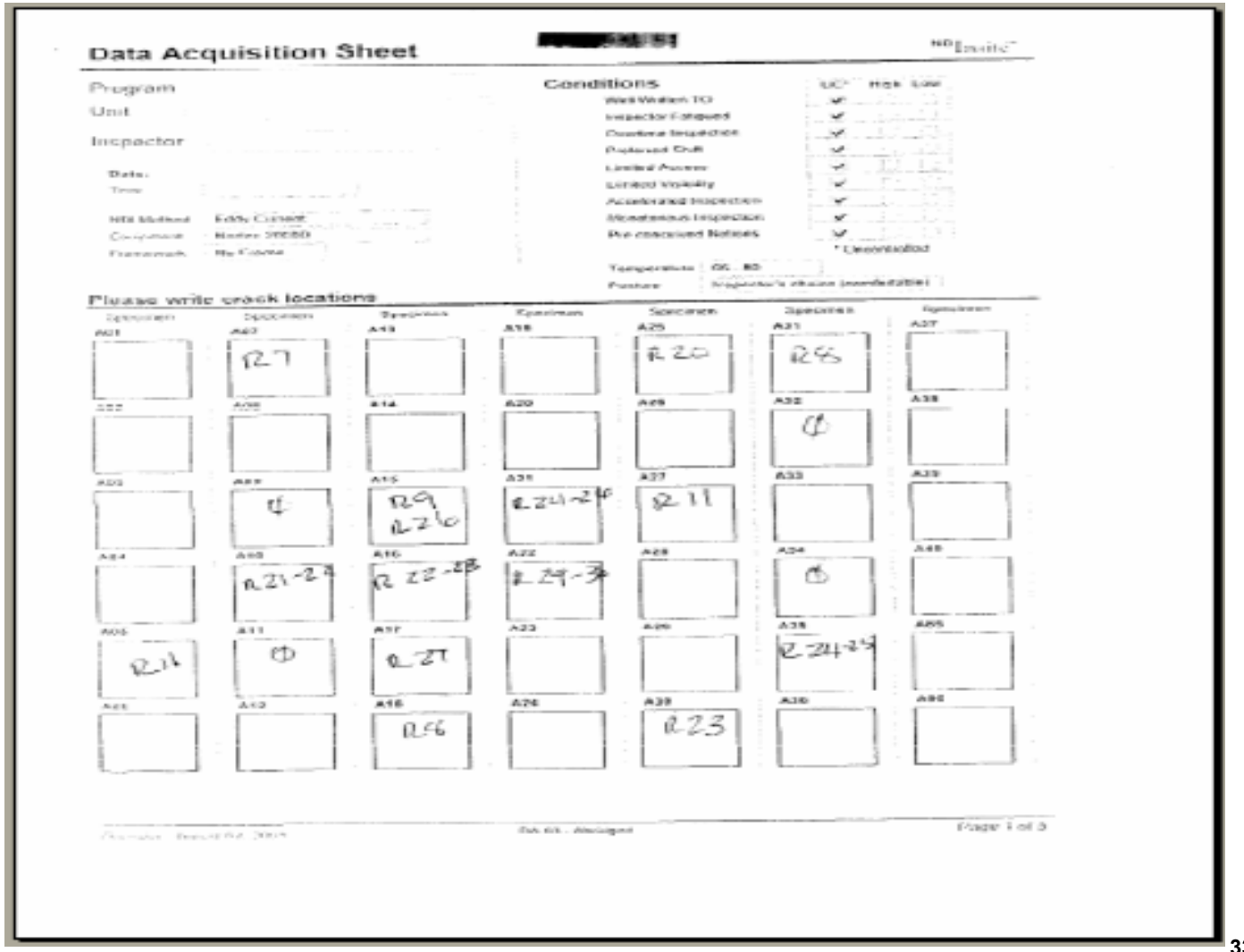
Note the Scan Plan used for:
Plates on a box - area between rivets
Rivets on a plate - order of proceeding
Circumference around rivets - coverage
Angles
Index Width
Noticeable changes during inspection
order of proceeding and tracking location





Previous Documentation

- Field 1
- Field 2
- Depot 1



Trends

- Performance improves with standardized procedures, training, and narrowing range of parameters
- Guides improve inspector performance comparing plate to angle results
- Relative performance among ALCs is consistent
- Field performance looks comparable to ALCs when provided similar experiment constraints
- Base POD on crack length available to probe (plates)
- Rogue misses occur independent of flaw size – human factors

Moving Forward

- T.O. 33B-1-2 Improvements
- Depot Inspector Development / Assessments 2008
- Command Wide Training Sep 2008
- NDI Sustainment Technology Implementation Center

T.O. 33B-1-2

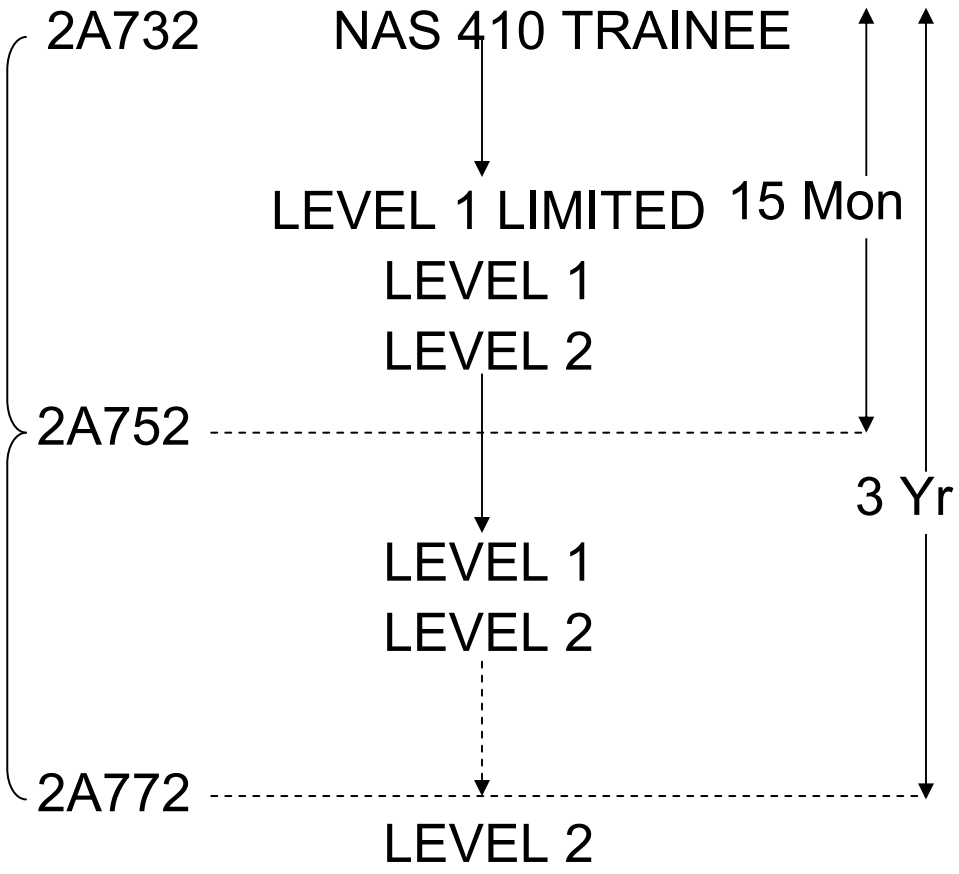
- Standardized Procedures AF wide
- New Work Package format for long term stability and ease of use
- Changes to address SECI POD results
  - Liftoff compensation (warnings/cautions)
  - Optimum screen erase (warnings/cautions)
  - Reduced horizontal gain (warnings/cautions)
  - Maintenance of signal between right and left boundaries
  - Separate work packages for scanning and liftoff
- Checklist?
- Recurring Training Recommendation
  - Annual
  - Changes
- Not intended for System Manager use without Level 3 coordination

Depot Training Issues

- Development of NDI technicians – 2865 hrs minimum / 5 Methods
- Classroom training – 304 hrs minimum
- Best POD Performance
  - Attended AETC Apprentice Course
  - Structured OJT
  - Progression: Trainee to Level 1 to Level 2
  - Certification managed for technician development
- Poorer POD Performance
  - Local Classroom Training
  - Progression: Trainee to Level 2
  - Certification managed for production flexibility

Civilian/Military Training/Experience

- **AFSC 2A732 (42732 and 45831)= NAS 410 Trainee**
  - **Primarily Level 1 Limited; potential for Level 1 and Level 2 in some methods**
- **AFSC 2A752 (42752 and 45851)= NAS 410 Level 1**
  - **Primarily Level 1; potential for Level 2 in some methods**
- **AFSC 2A772 (42772 and 45871)= NAS 410 Level 2**
  - **Likely Level 2 in all methods depending on rank – time in service**



Experience Factors

Optimum NAS 410 experience factors to obtain Level 2 in shortest time.	Method Hours	Factors %
PT	200	7
MT	265	9
ET	800	28
RT	800	28
UT	800	28

Command Wide Training

- AFMCI 21-108
- 17 NDI Courses
  - Level ½ PT and MT
  - Level 1 ET, UT and RT
  - Level 2 ET, UT and RT
  - Refreshers: PT, MT, ET, UT, RT, ST, and IR
- Sep 2008 Completion

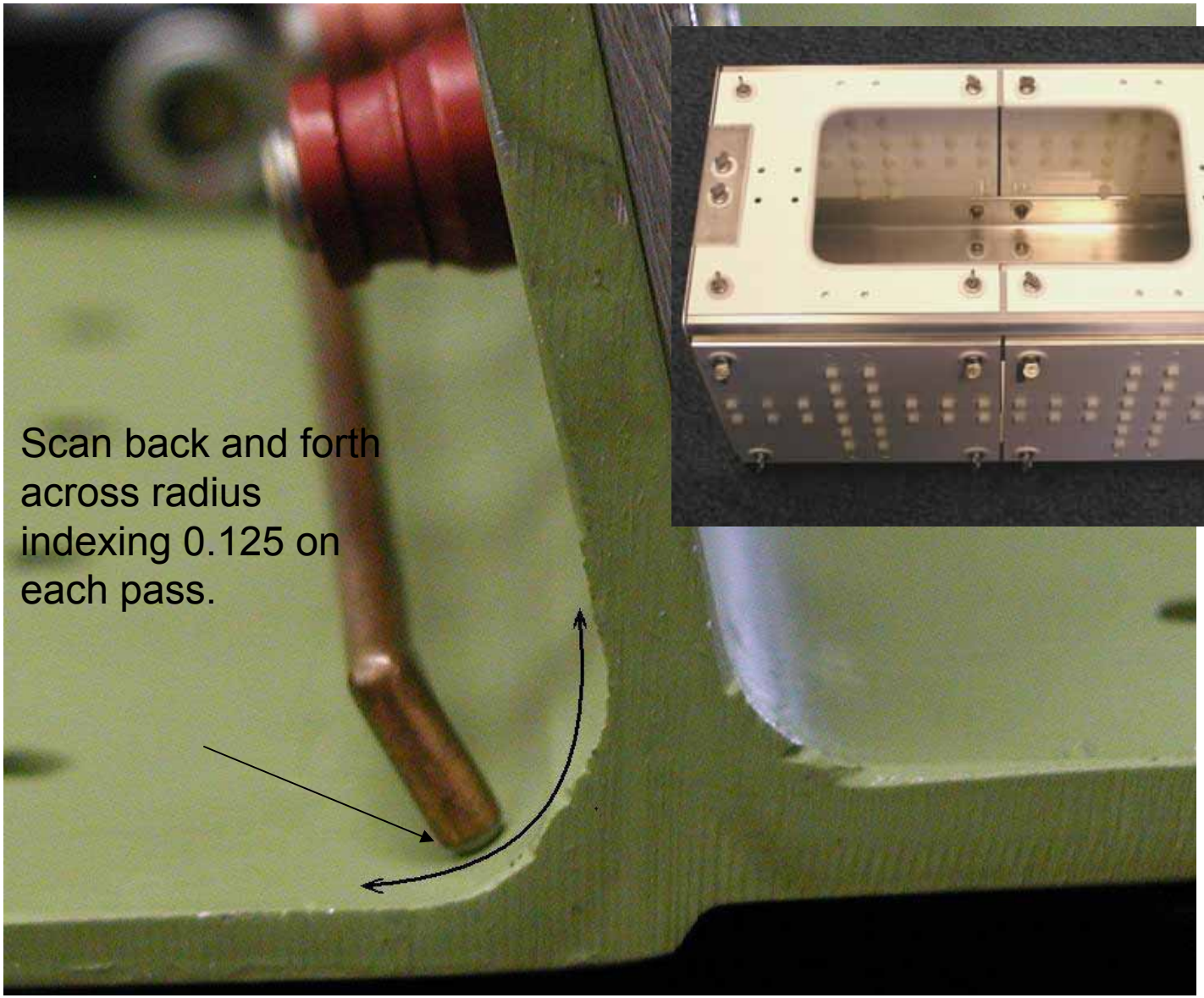
NDI STIC

- Support Sustainment Technology Process IPT
- Centrally Managed Programs: Aging Aircraft
- Transition Technology to improve NDI for AFS-TWG
- Members: AFNDIO, AFRL/RXLP, AFRL/RXSA, ALC Mgrs, and MAJCOM Functionals
- Funding
  - RXLP: $200K
  - DTMP: $1.1M

RXLP Funding

- PODs
  - Depot: Angles using Wide Field Coil
  - Field: Plates and Angles (WFC) Using QAPA Protocol
- MAUS V Scanner Durability Improvement
- UT and Eddy Current Arrays

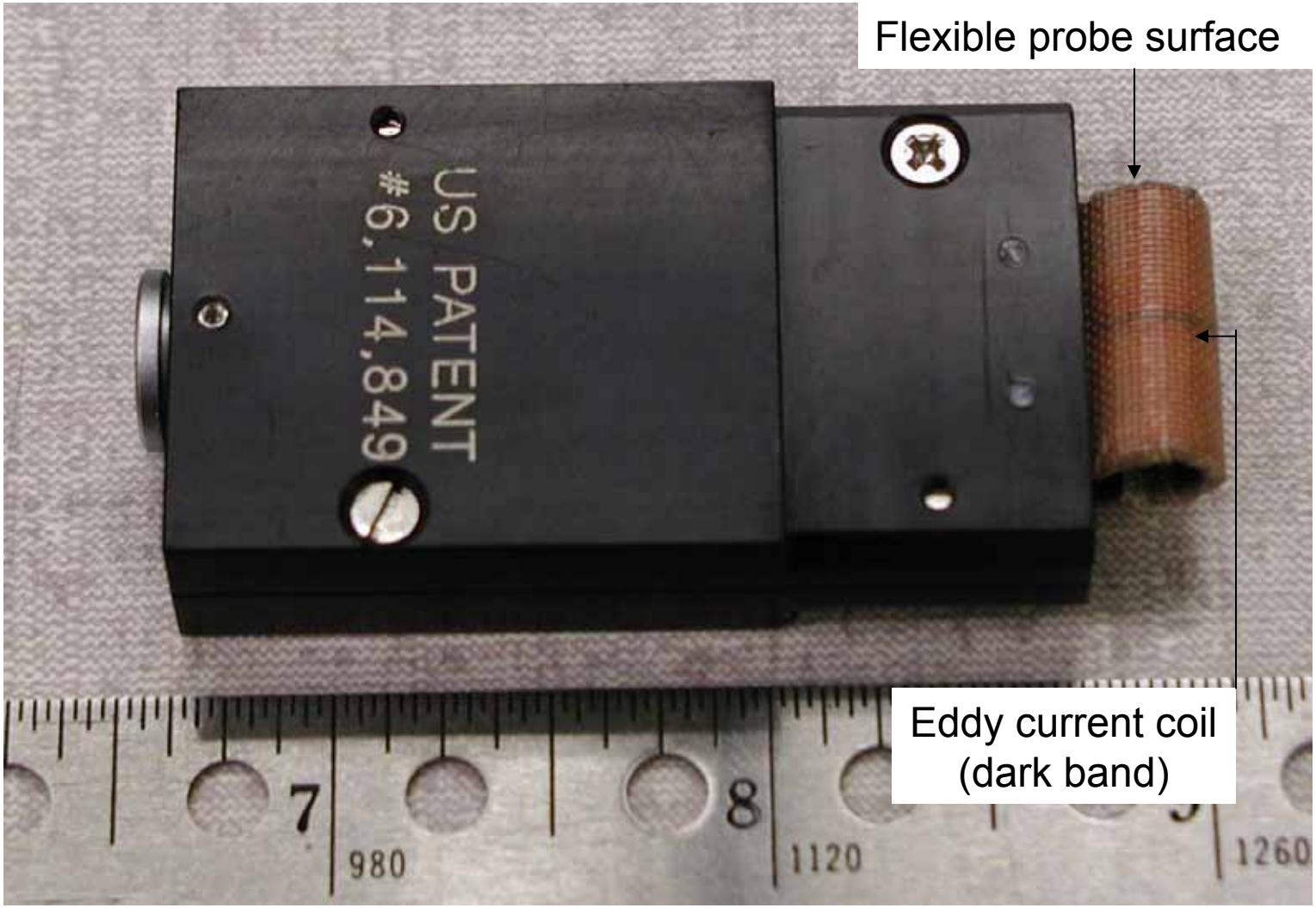
Current Approach/Probe



New Approach

Gently mash probe into radius and slide down the length of the spar.

Wide Field Probe



New generation flexible or conformal probe.

Probe Benefits

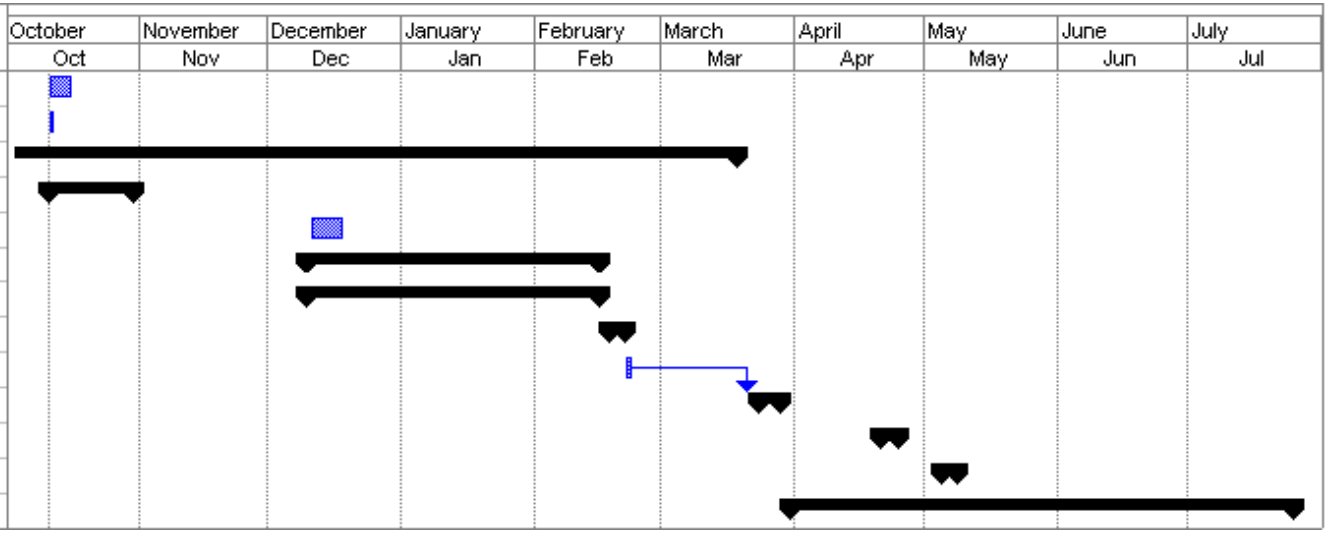
- Reduce human factors
  - Coverage
  - Probability of Inspection
- Improved POD
- Productivity
- Confidence across the board

Depot Demonstration

- Measure POD improvement using wide field coil
- Funding: FY08 $200K AFRL/RXLP
- Contractors: Universal Technology Corp and Sandia National Laboratories AANC
- When: Spring 2008
- Where: 3 depots
- Who: 10 personnel sample each ALC
- 1 Day training/practice
- 2 Days testing (2 hours/inspector)
- Needs: Depot support (facilities/labor)

Draft Schedule

ID		Task Name	Duration
1		Establish Purpose/Benefits	3 days
2		Draft Task - Contractor	1 day
3		**Coordination**	**120 days**
9		**Draft Procedure T.O. 33B-1**	**14 days**
13		TDY UniWest	5 days
14		**Standard**	**50 days**
18		**Probes**	**50 days**
22		**Training Plan**	**4 days**
25		Dry run procedure/POD	1 day?
26		**OC-ALC**	**5 days**
32		**OO-ALC**	**4 days**
38		**WR-ALC**	**4 days**
44		**Sandia Report**	**85 days**



Broader Effort

- **Purpose: Improve inspection reliability of all safety of flight structure inspections**
- **Benefits: Potential for increased productivity, reduced field level inspections and extension of maintenance intervals**
- **Applicability: Safety of Flight Inspections (SOFIs) – NDI**
- **Funding: $1.1M FY08 DTMP**
- **Critical Input: ASIP Managers identify Safety of Flight Structures and communicate requirements to NDI**

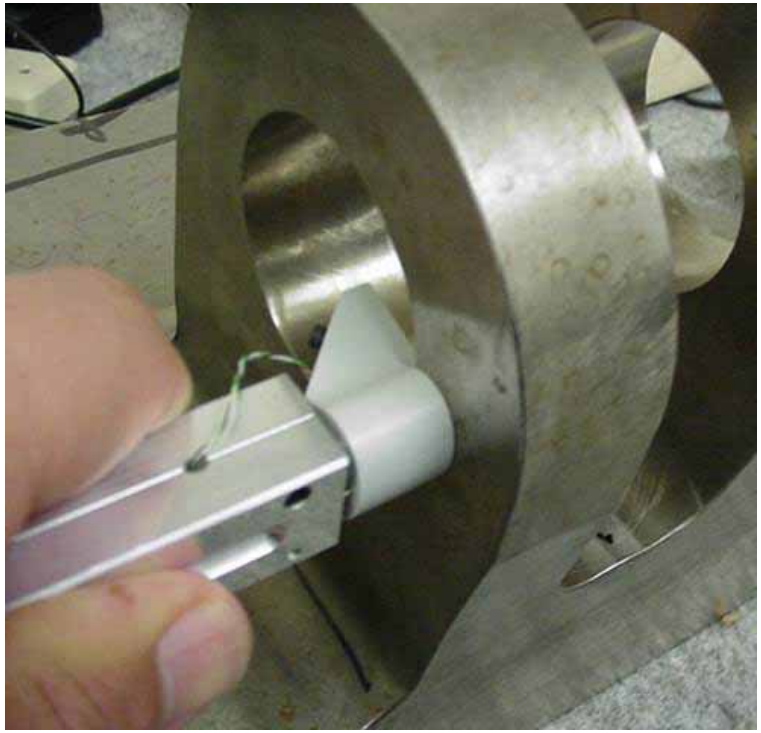
Reliability Improvement Plan

- Technical Data - Third party review
  - Written accuracy
  - Witness inspection
  - Evaluate potential inspection reliability improvement
- Utilize principle contractor / multiple probe developers
- Prototypes - validation
- Productionization – verification
- System Manager implementation
- Leverage developments for other MDS's

Other Probes

Initial Prototypes

Edges



Flat Surface

Key Performance Parameters

Parameter/ Weight (0-1)	Req,t Threshold	Req't Objective	Expected Value	How to Demo	Current Status	How Demo'd	POF
Reliability 1	**-25%**	**-60%**	**-50%**	**POD**			**0.1**
Coverage 0.7	**90%**	**100%**	**95%**	**Demo**			**0.1**
Efficiency 0.5	**25%**	**100%**	**50%**	**Demo**			**0.1**

Summary

- Field 1 is not comparable to other PODs due to many factors handicapping performance
- Results improved with standardized T.O. 33B-1-2 procedure and training
- Relative performance among ALCs is consistent
- Progressive inspector development and recurring training is recommended to establish and maintain proficiency
- Base POD upon unobstructed crack length for SECI
- Radius inspections (angles) should use wide field coil instead of right angle probe
- Support NDI STIC POD efforts and projects to reduce human factors – SOFS inspections

Questions?

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