Phased Array Ultrasound

Initial Development of PAUT Inspection of Self-Reacting Friction Stir Welds

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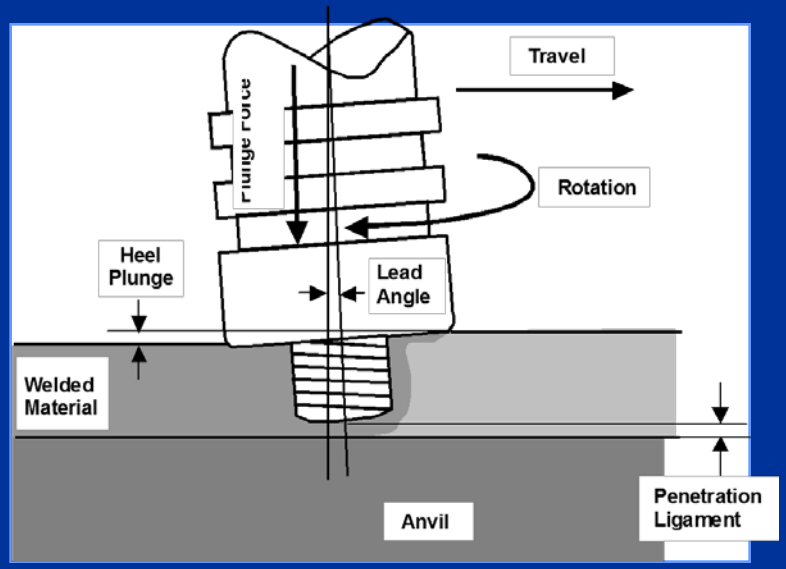
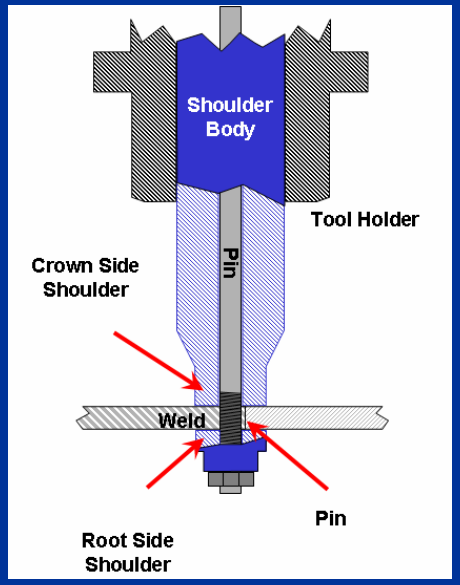
Background

Conventional Friction Stir Weld (FSW)



- Uses fixed or retractable pin tool
- One shoulder and an anvil
- Requires more tooling force

Self Reacting Friction Stir Weld (SR-FSW)



- Uses self reacting pin tool
- Two shoulders. No anvil.
- Uses less tooling force and lower rpms.

Previous Work

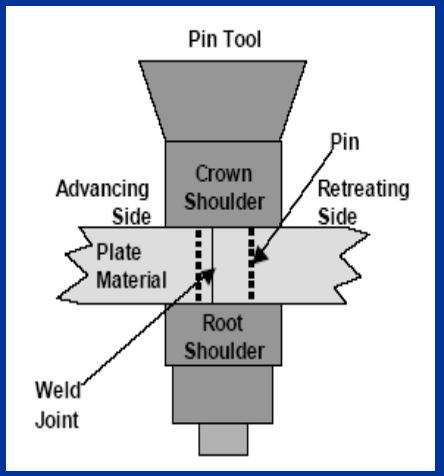
- 2003-2004
  - NDE development for inspection of SR-FSW in 0.320-inch-thick 2219-T87/2195-T8M4.
  - Develop volumetric techniques for residual oxide defects (ROD) and other void type flaws via phased array ultrasonic testing (PAUT) to assure the acceptable quality of SR-FSW.
  - Multiple techniques were evaluated: visual (VT), penetrant (PT), X-ray radiography (RT) and phased-array ultrasound (PAUT).

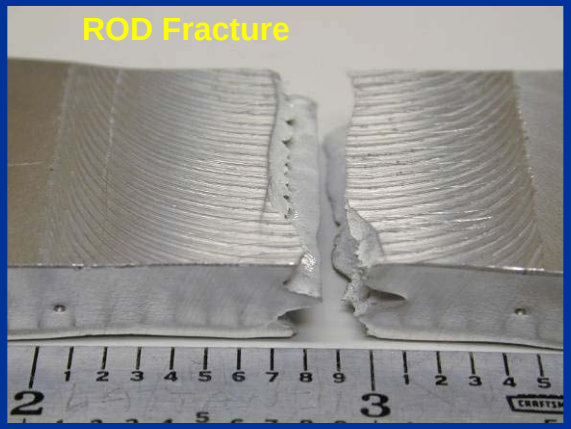
Weld Defect	Possible Cause
Defect free (clean)	
Residual Oxide Defect (ROD)	Improper weld joint cleaning/Unconsumed interface
Voids / Wormholes	Insufficient forging of weld nugget
Tears – surface and subsurface	Excessive forging force
Undercutting	Excessive heel plunge

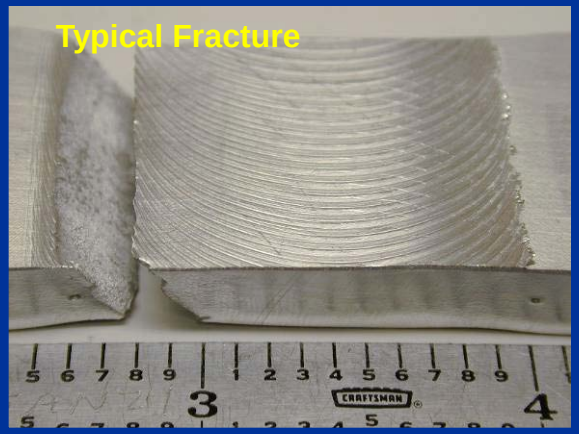
Table 1. Defects studied

Residual Oxide Defect (ROD)

- PAUT is the only NDE method which has been shown to detect detrimental levels of ROD.
- Detrimental ROD results in significant decrease in weld strength.
- Several process control countermeasures exist
  - Pre-weld prep including cleaning of weld area and dwell time.
  - Offset of centerline of weld.
  - Type of pin tool?







Previous Work

- Conclusions
  - RT was inadequate for inspection of ROD
  - PAUT
    - ROD from high to mild severity, but non-relevant indications (NRI) were also noted
  - Surface breaking flaws were detected by visual and PT but PT produced multiple NRI. RT and PAUT found severe surface breaking flaws.
- Recommendations
  - Continue PAUT development to encompass ALL internal and volumetric flaw types.
  - Establish NDE thresholds for worst case flaws, and develop interpretation criteria based on these thresholds to include ROD, void and internal flaws.

Orion PAUT Development

- Initial Development
  - Based on previous work to develop PAUT as the primary NDE method for SR-FSW
  - Ground Test Article (GTA)
    - First complete engineering article of the Orion Crew Module (CM)
    - GTA provides the opportunity to test and qualify the baseline PAUT process.
    - Qualification of GTA inspection will serve as input for qualification of flight hardware inspection.

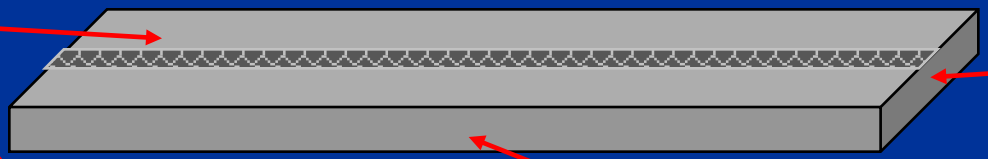
Development Defects

- Two Classes
  - Out of Schedule Defects (e.g. depend on weld temperature, mixing, etc.)
    - Galling
    - Lack of Adequate Forging (LAF)
    - ROD
    - Wormholes
  - Contamination Defects
    - Heavy Inclusions
    - Organic Material

Phased Array Ultrasound Analysis

C scan

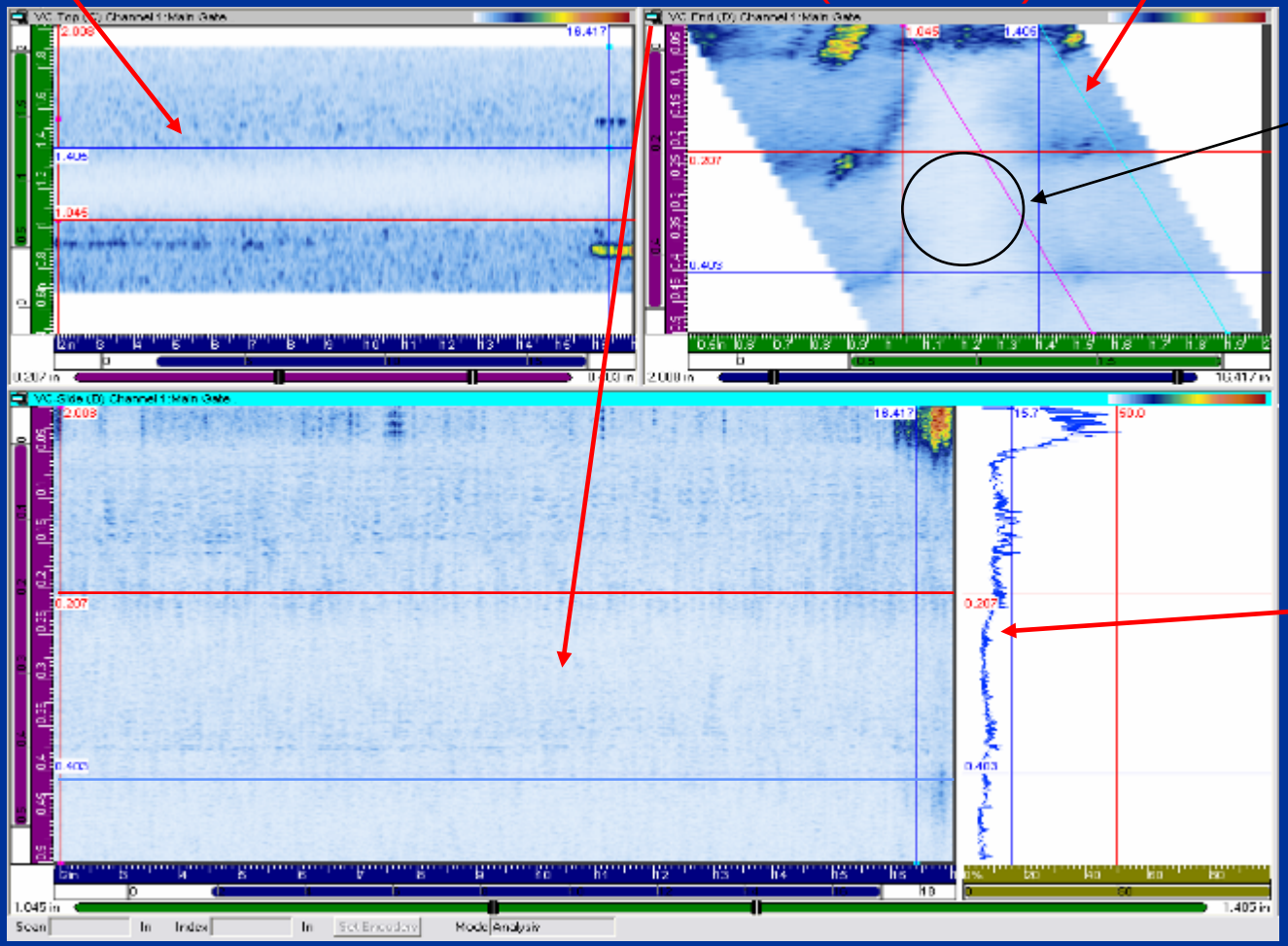
(top view)



D scan

(end view)

B scan (side view)



Weld Nugget

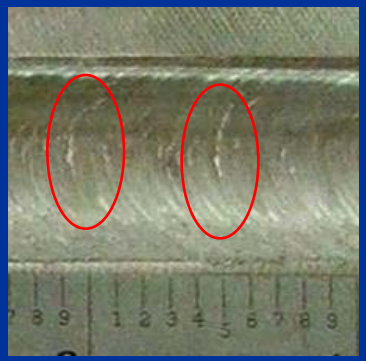
A Scan (Amplitude)

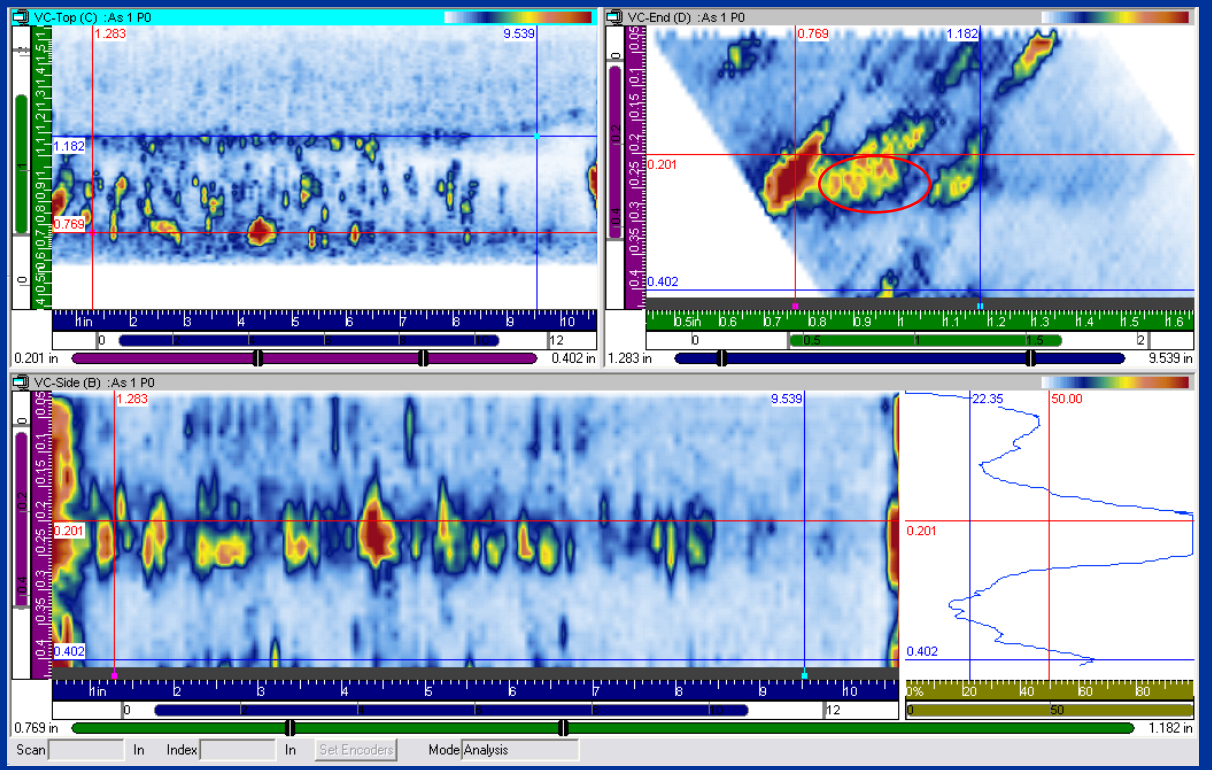
PAUT Process

- Inspection Methods
  - Phased Array UT
    - Focus
      - Reference Standard: 0.020” Side Drilled Hole (SDH)
      - 10L64 (10 MHz, 64 element) probes with water wedge
      - 0° skew angle (perpendicular to direction of pin travel)
      - Dual probe, one each on advancing and retreating sides of weld, automated track encoder
      - 45° shear wave, electronic scan
    - OmniScan
      - 0.020” SDH Reference Standard
      - 5L 64, 10L 64 and 17L 100 probes with contact wedge
      - 0° skew angle
      - 45° shear wave, electronic scan
      - Hand scan on advancing and retreating sides with mini-encoder

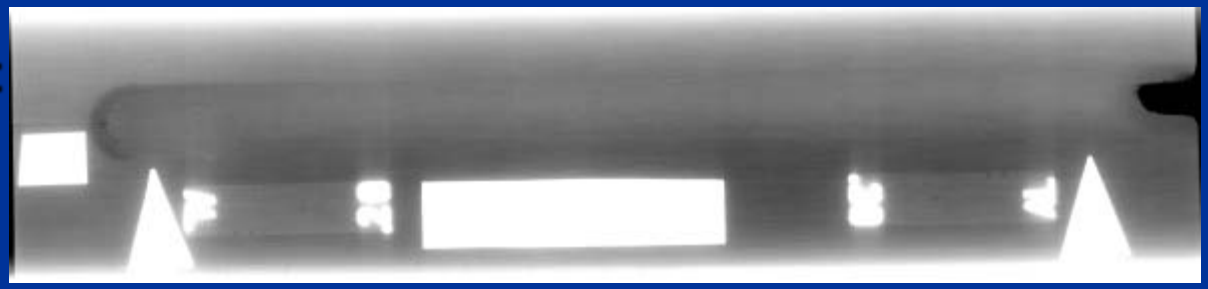
Galling

- **Tears and/or blisters on the surface (root or crown) of the SR-FSW**





No Defect Visible

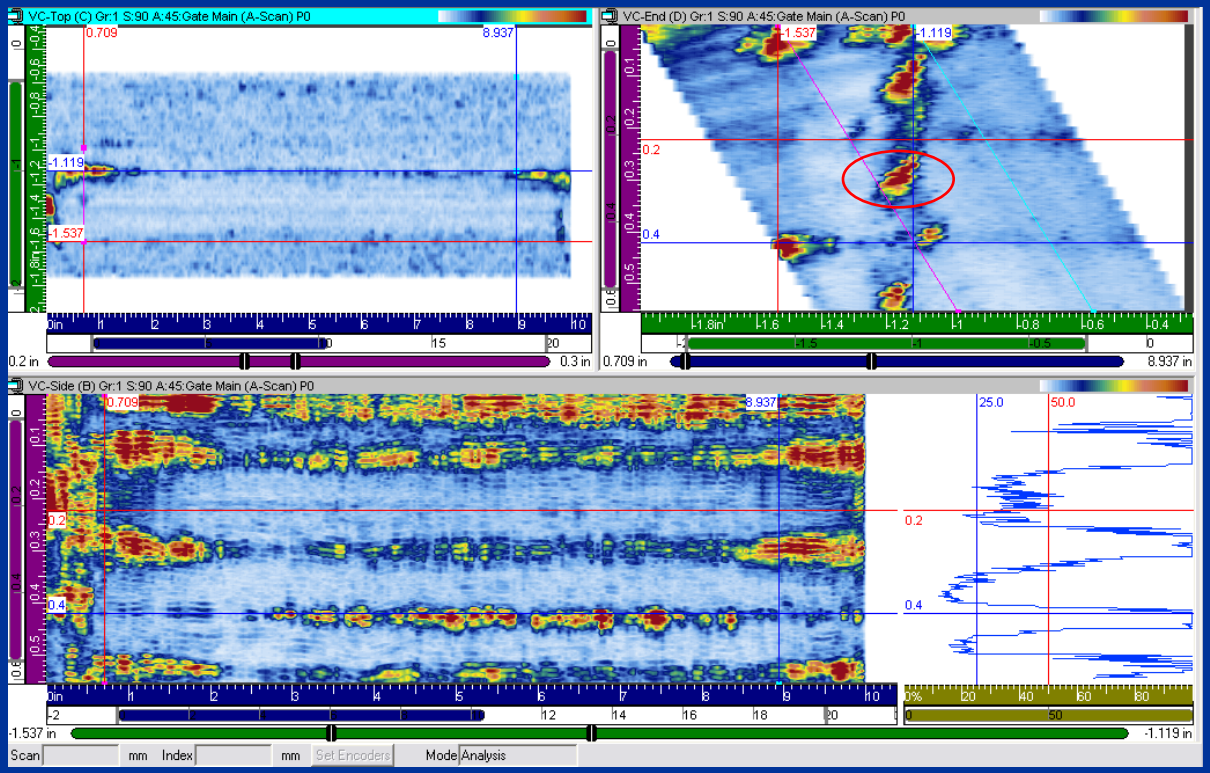


X-ray

Wormholes and LAF

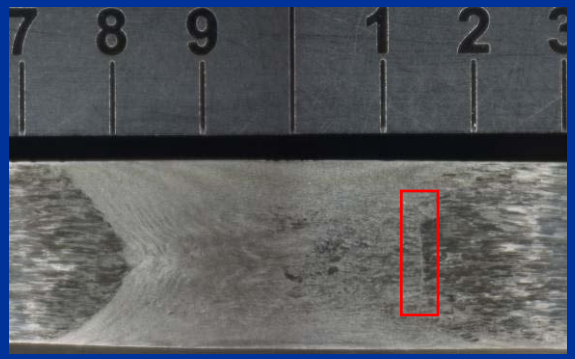
- Typically occur along advancing side of the weld midline
- Cold welds

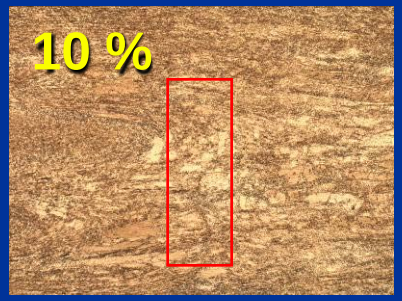
X-ray

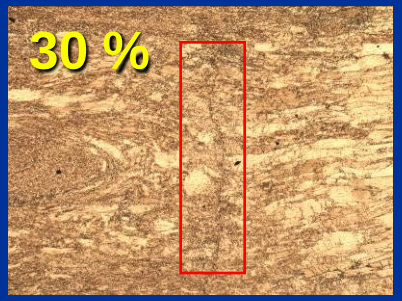


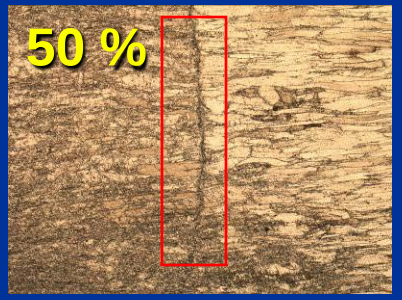
ROD/Cross Slide

- Pin tool offset to the advancing side
- Creates larger volume of unconsumed interface
- Panels with increasing degree of offset
  - 10 % → 50 %
- Can resemble LAF in extreme conditions



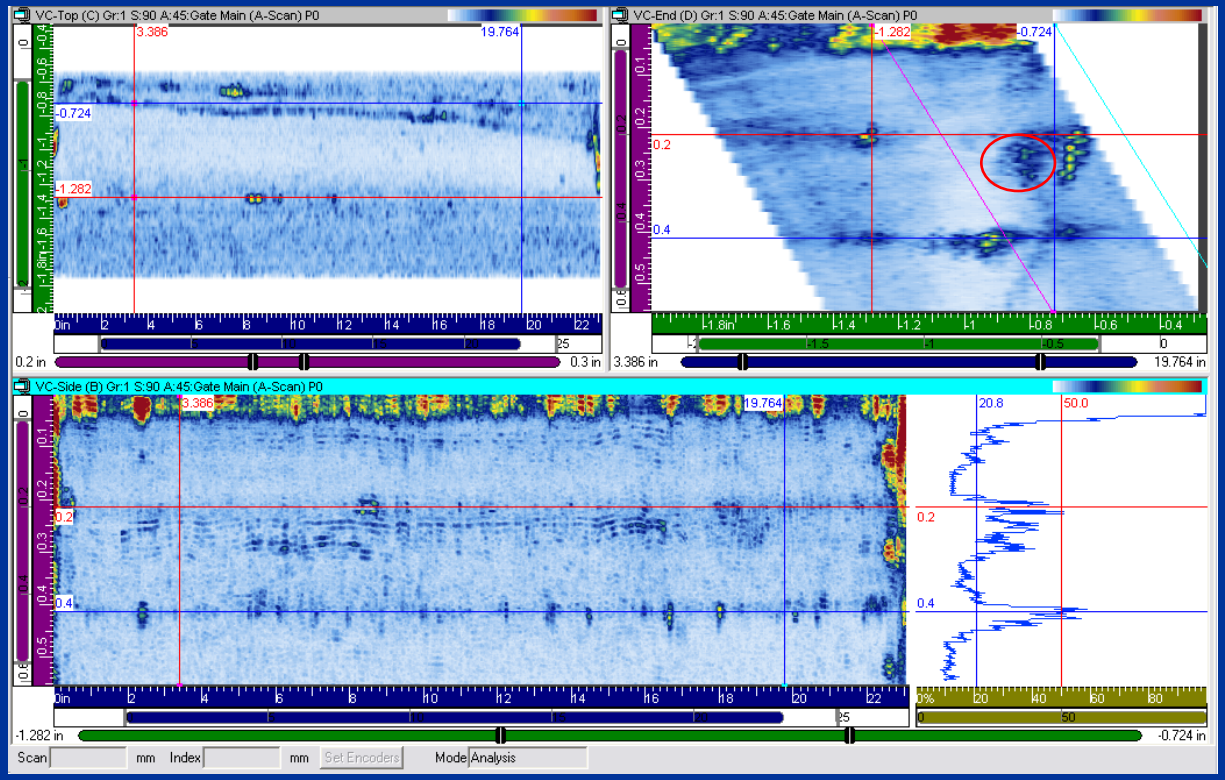






ROD

30% Offset

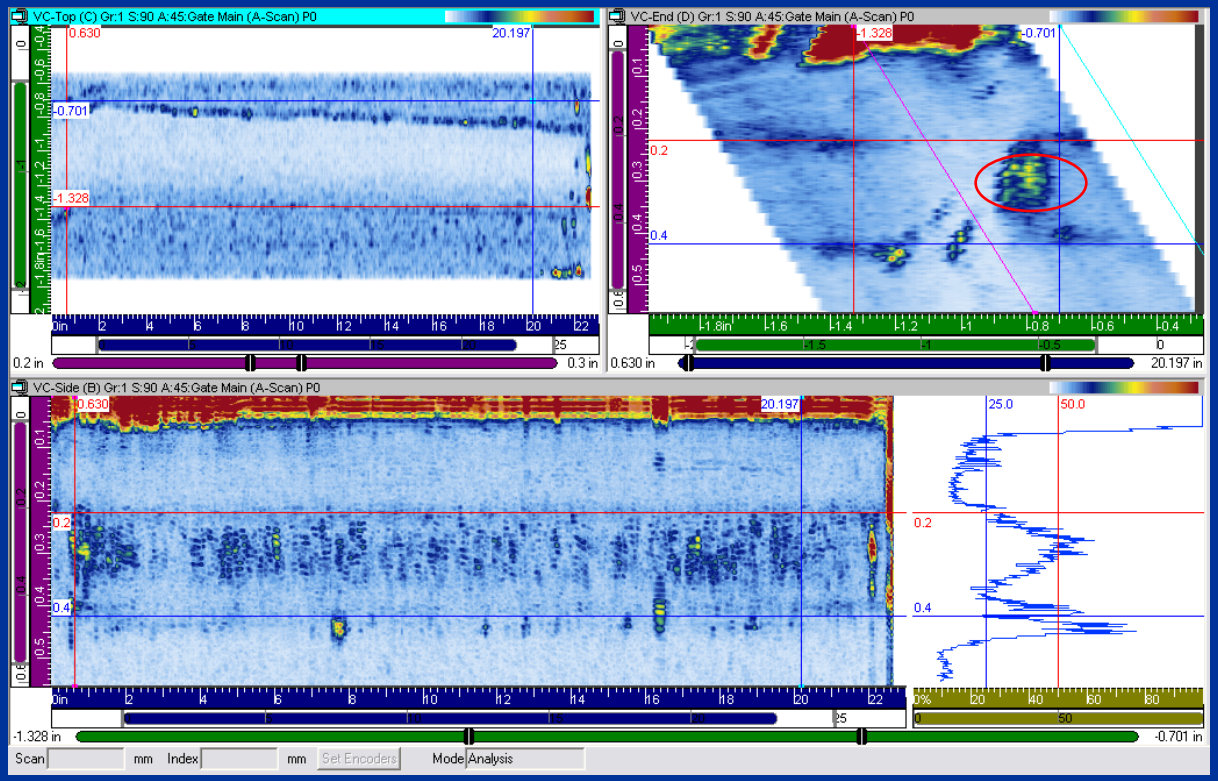


No Defect Visible

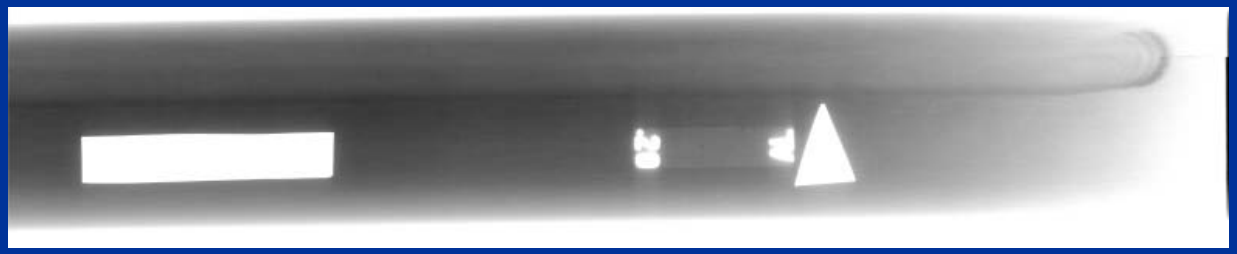
X-ray

ROD

50% Offset



No Defect Visible

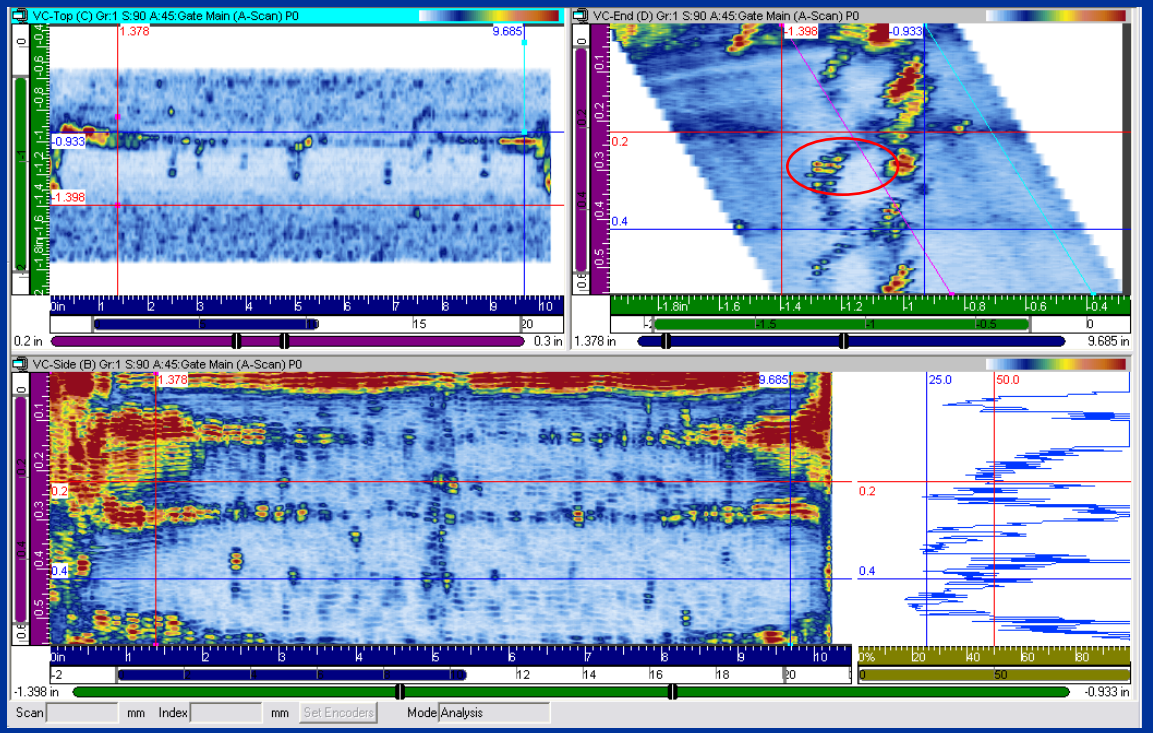


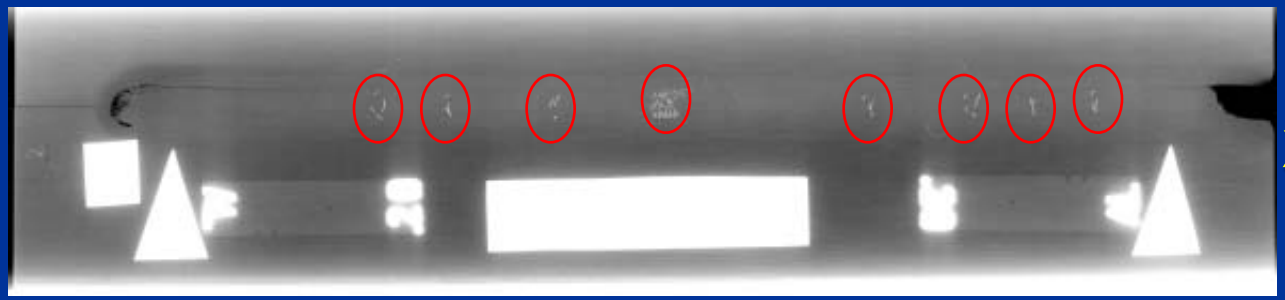
X-ray

Contamination

- Heavy Inclusions – Wire brush bristles, pin tool fragments
- Organics – Oil, hydraulic fluid

Heavy Inclusions



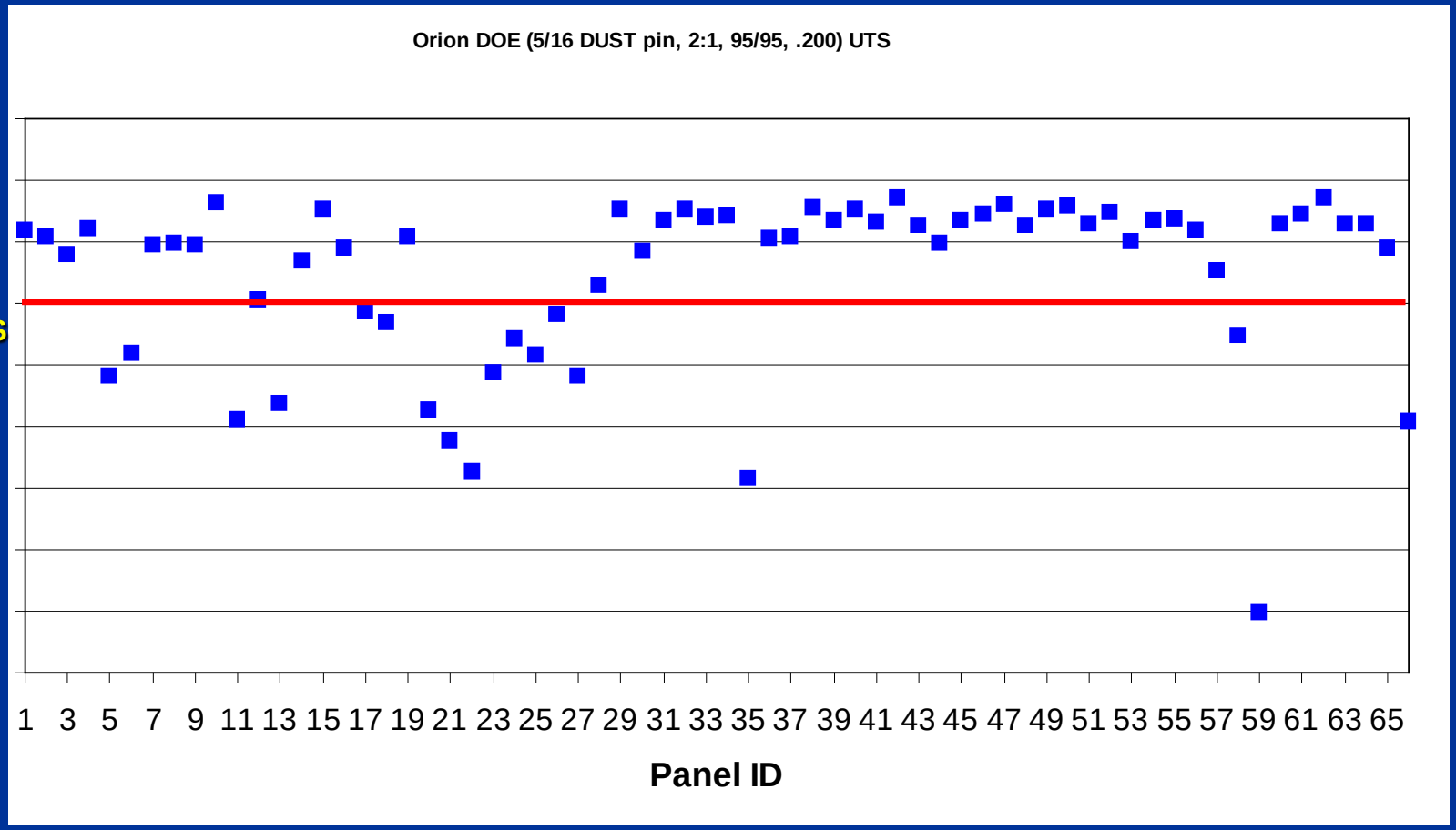


X-ray

Weld Development DOE

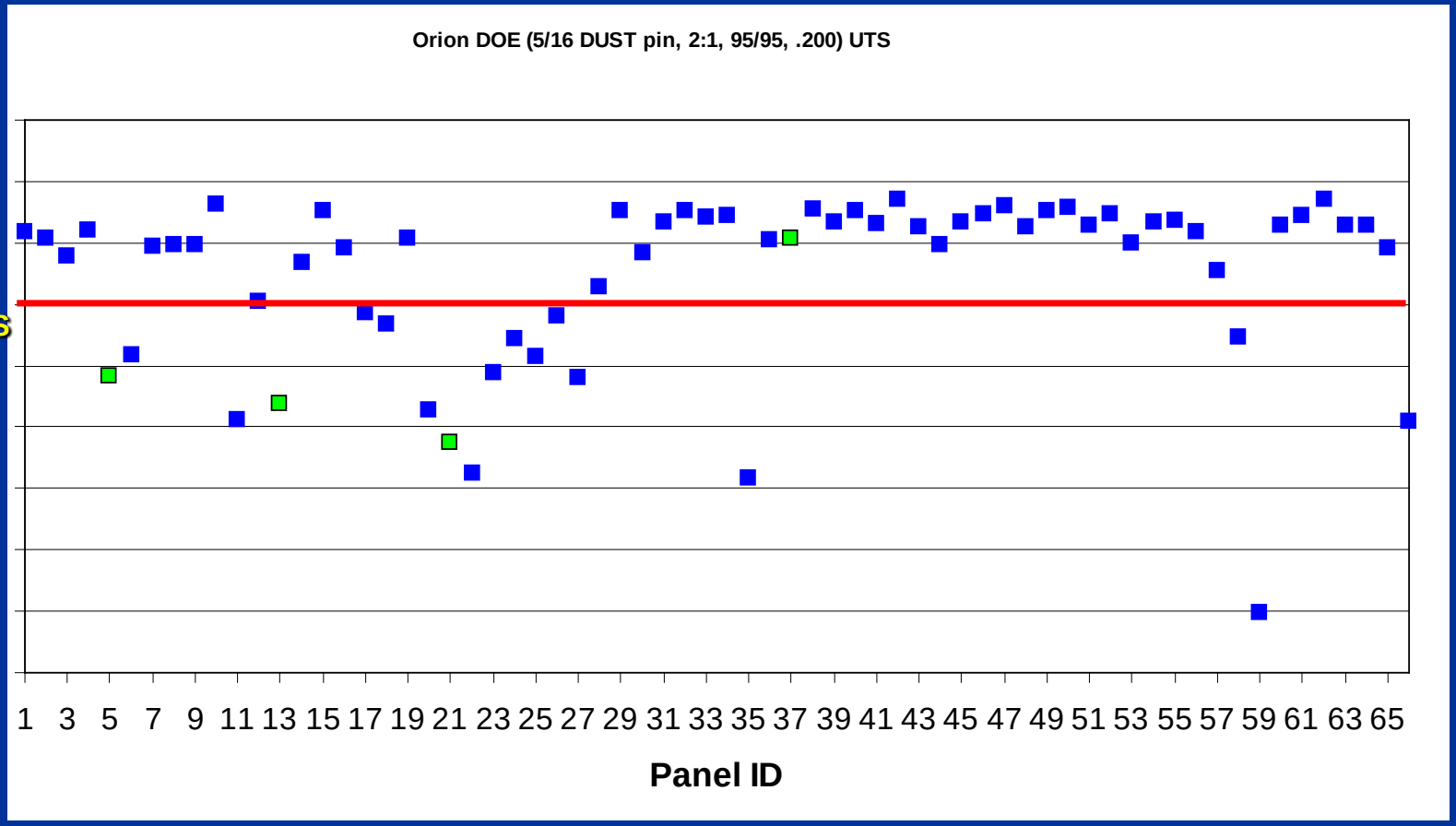
- Correlate weld strength and NDE results
- Weld Schedule for 0.200” thick Al 2195/2195
- External Tank (ET) PAUT protocols were followed
  - Reference Standard: 0.020” Side Drilled Hole (SDH)
  - 10L64 (10 MHz, 64 element) probes with water wedge
  - 0° skew angle (perpendicular to direction of pin travel)
  - Dual probe, one each on advancing and retreating sides of weld, automated track encoder
  - 45° shear wave, electronic scan

Mean UTS Values for DOE I & II



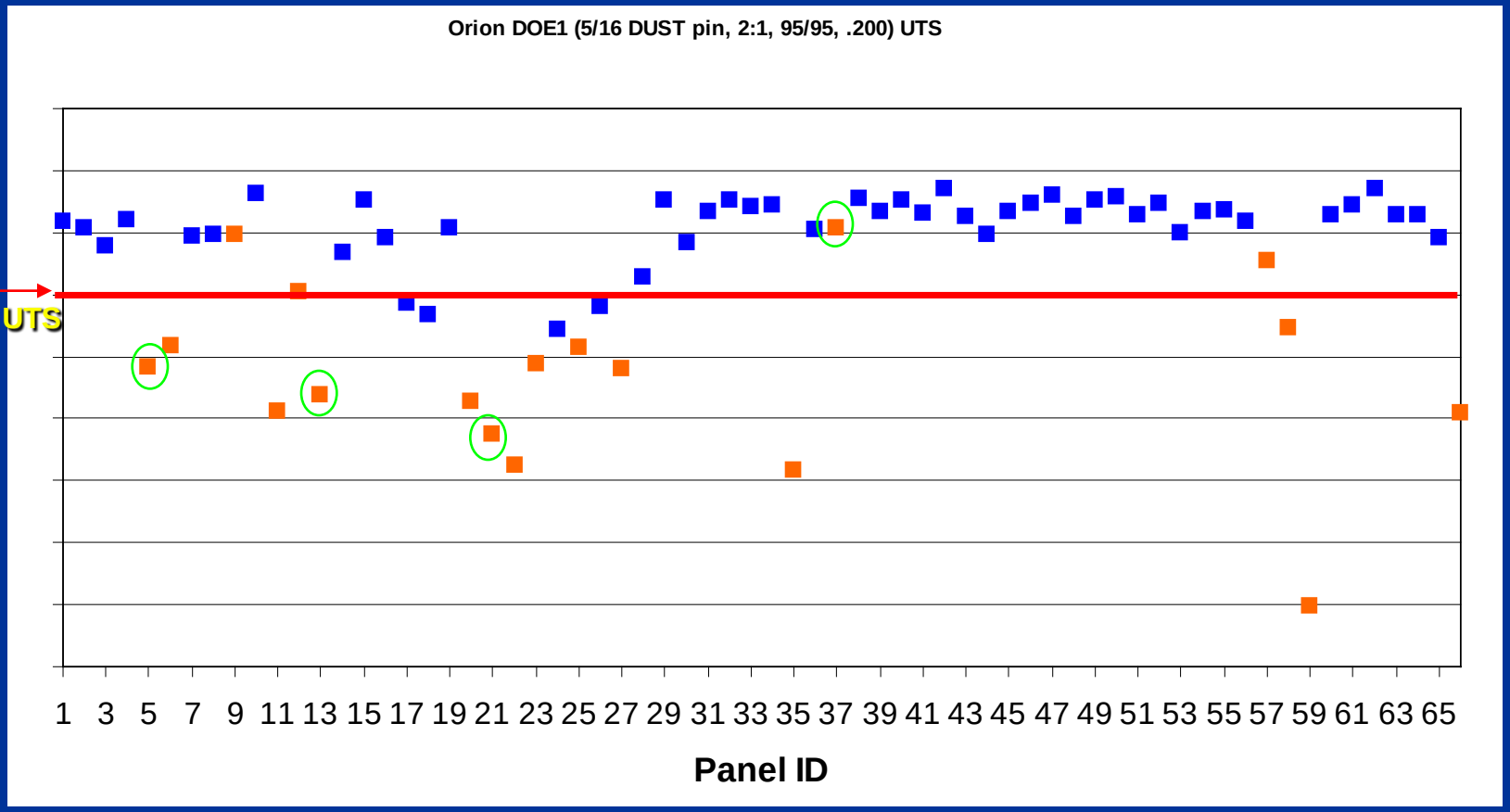
- Minimum acceptable UTS (red line above) per Engineering Process Specification

Mean UTS Values for DOE I & II



- Green squares were rejected by x-ray radiography

Mean UTS Values for DOE I & II

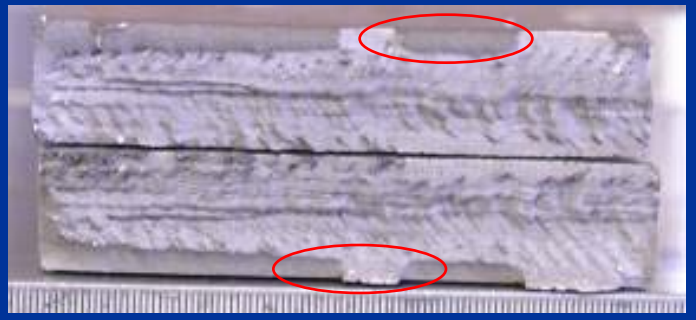


- Orange squares were rejected by PAUT
- Captured all of X-ray rejected defects (circled in green)
- False positives had localized defects and/or insufficient surface preparation

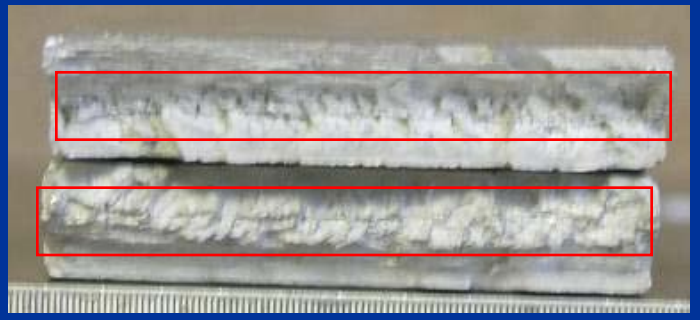
Representative Metallurgy

- **Acceptable**

- **Galling**



- **LAF**



Conclusions

- Weld DOE
  - All welds rejected by PAUT were outside the nominal weld schedule
    - Low UTS
    - Fracture Location in Weld
- X-ray was not successful at rejecting all major defects
- PAUT has shown initial success at finding all classes of defects in SR-FSW