Advanced Ultrasonic Testing for Cast Austenitic Stainless Steel

EPRI Preliminary Ultrasonic Results using Traditional Phased Array and Matrix Capture Techniques

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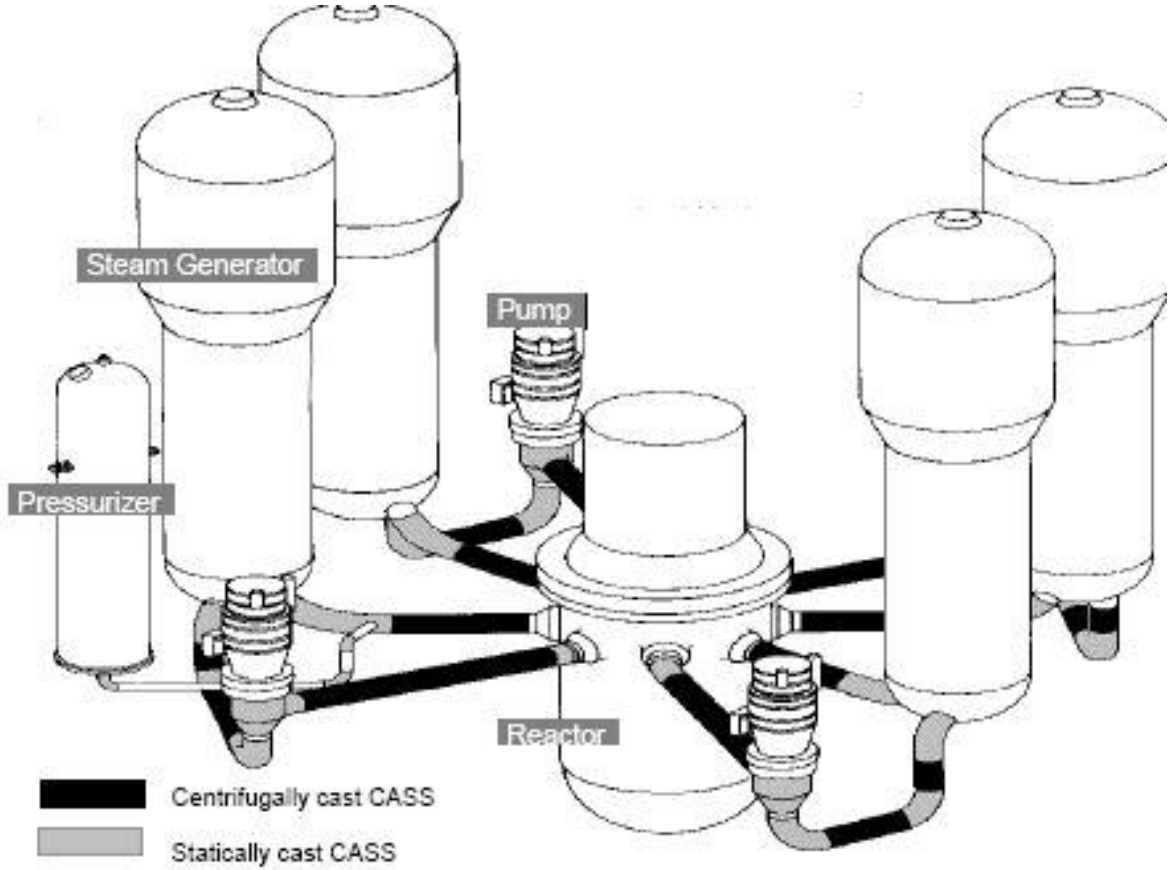
Outline

- Brief Background Information
- EPRI Preliminary Ultrasonic Results using Traditional Phased Array and Matrix Capture Techniques
- Summary
- Questions

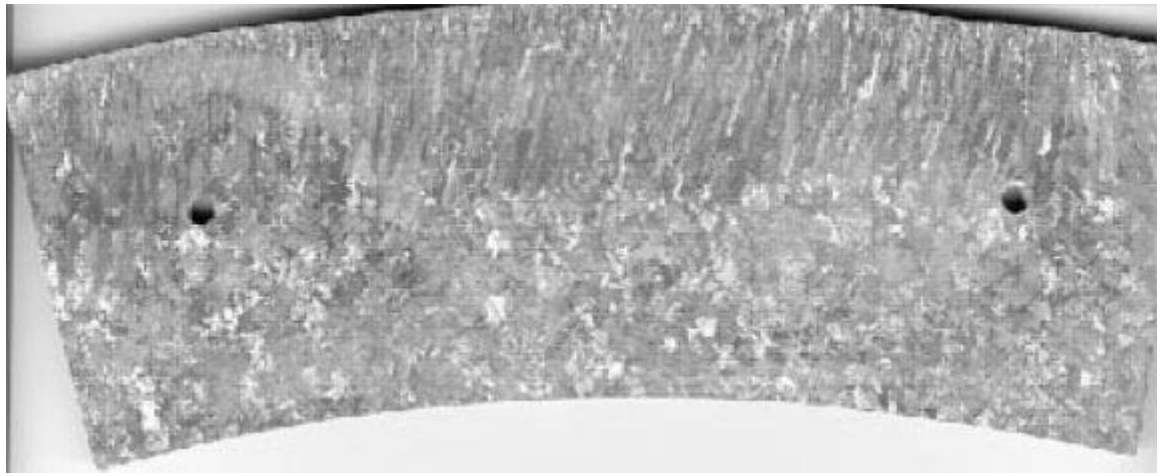
Background

- The NDE method typically deployed for RCL wrought austenitic piping is conventional ultrasonic testing (UT).
- RCL piping in PWRs contains cast stainless steel material (CASS), which has large grains that can vary in structure.



Background (cont.)

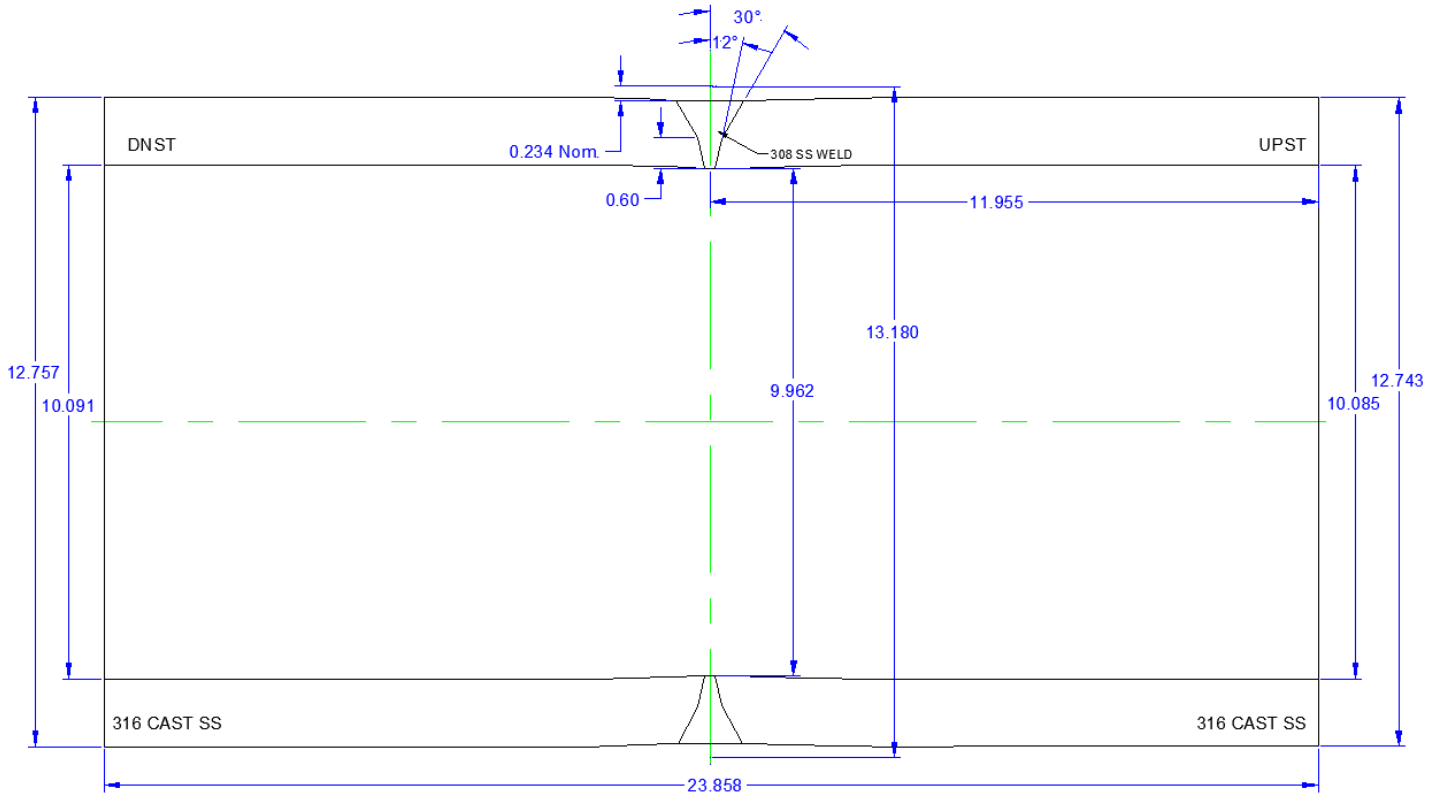
- Effect of grain structure is acoustic anisotropy
  - The sound wave is affected
    - Changes direction slightly
    - Part of it reflects
    - Part of it changes propagation mode
    - Longitudinal waves are affected less than shear waves
- The observed effects are:
  - High attenuation (the material soaks up the sound energy)
  - High noise levels
  - Beam distortion
  - Must use longitudinal waves



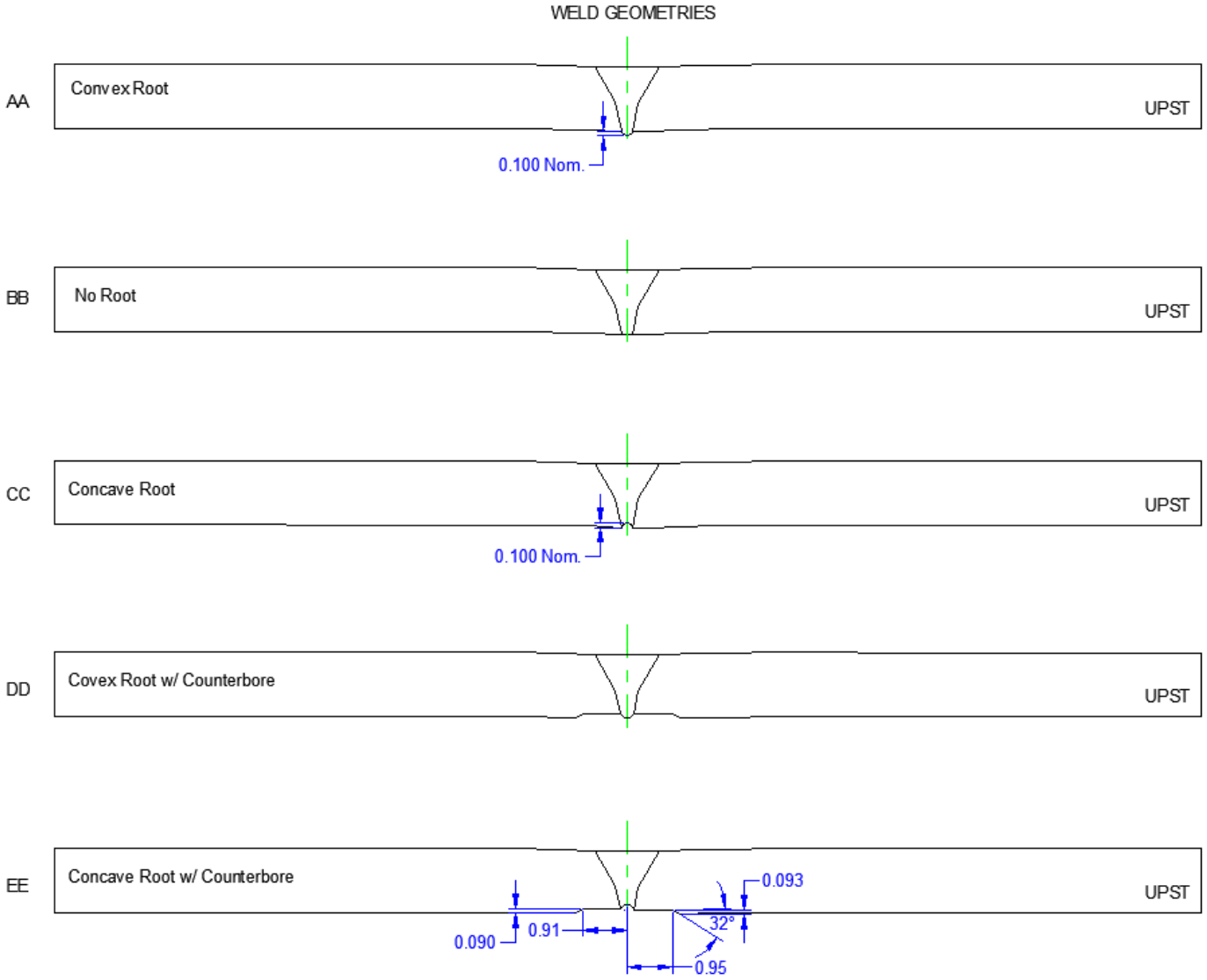
Can Advanced UT Overcome These Challenges?

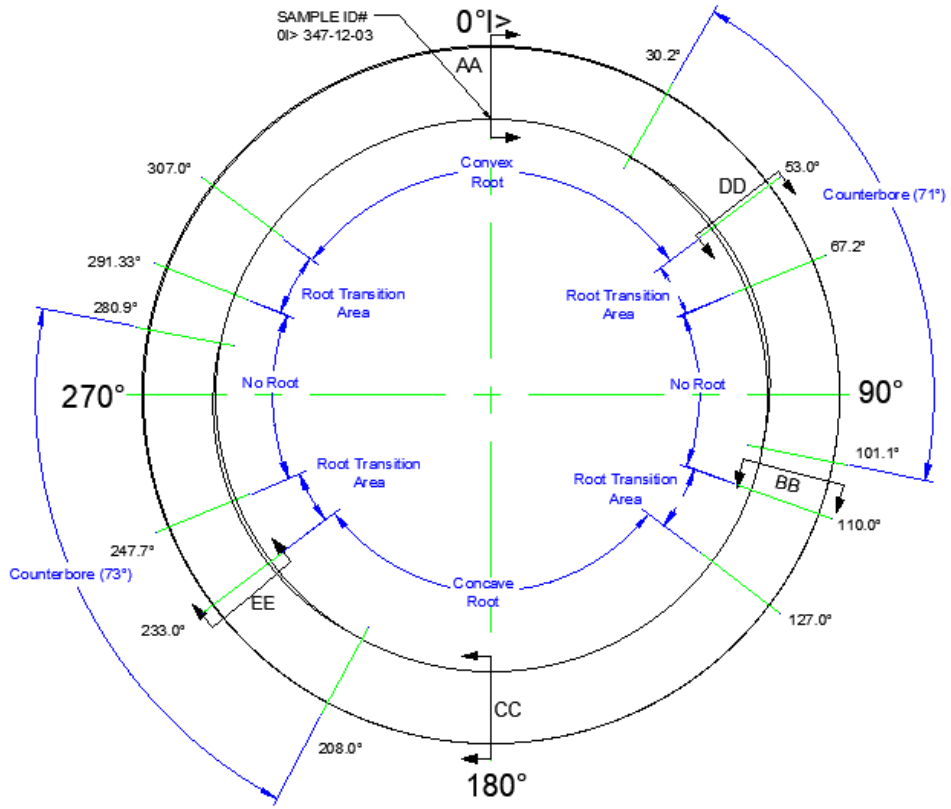
EPRI CASS Specimen 347-12-03-AB

- Diameter: 12.75in (323.8mm), Thickness: 1.333in (33.9mm)



EPRI CASS Specimen 347-12-03-AB



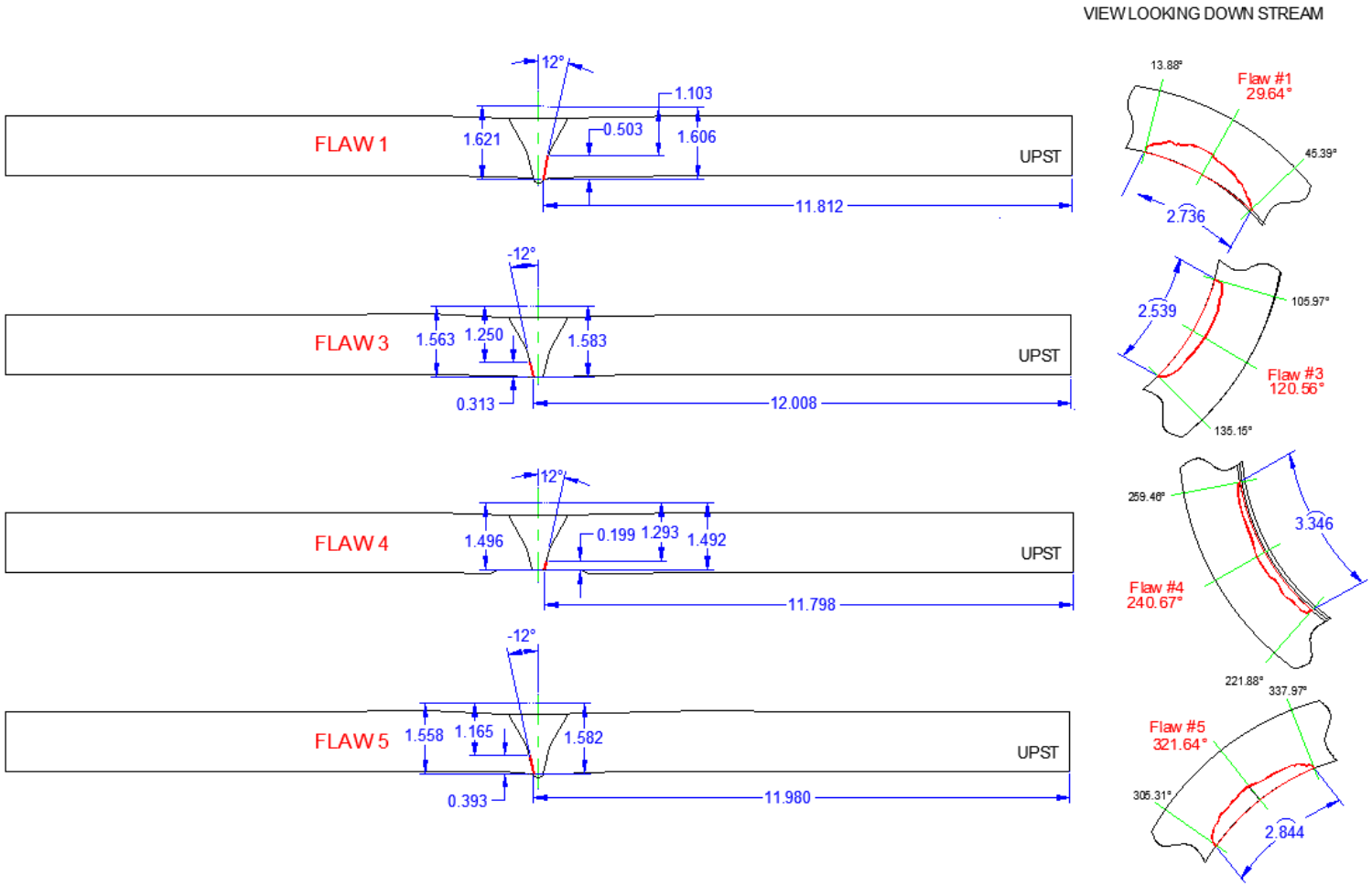


VIEW LOOKING DOWN STREAM

EPRI CASS Specimen 347-12-03-AB

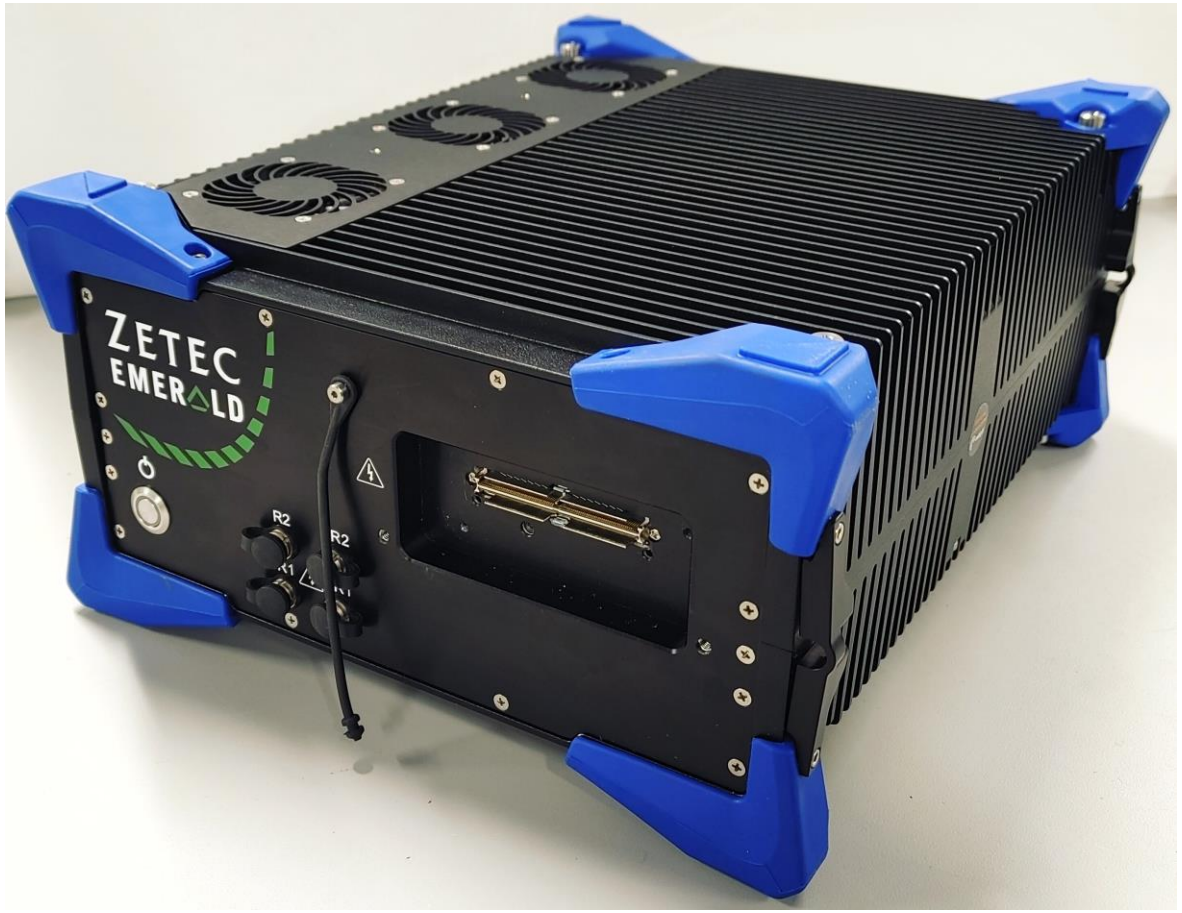
- Evaluated four inside surface connected circumferential flaws:
  - Flaw 1, Length: 2.736in (69.5mm), Depth: 0.503in (12.8mm) (38%)
  - Flaw 3, Length: 2.539in (64.5mm), Depth: 0.313in (8mm) (23%)
  - Flaw 4, Length: 3.346in (85mm), Depth: 0.199in (5.1mm) (15%)
  - Flaw 5, Length: 2.844in (72.2mm), Depth: 0.397in (10.1mm) (30%)

Each of these flaws are coincident with the geometrical conditions noted on the previous slide



Ultrasonic Equipment

- Zetec Emerald
  - Bipolar Square Wave
  - Pulse Width 500ns
- General Electric Inspection Technologies (GEIT) 115-000-603 Dual Array
  - 1.0MHz, Dual 2x16, Pitch: 0.378in x 0.142in (9.6mm x 3.6mm), Size: 0.756in x 2.283in (19.2mm x 58.0mm)
- GEIT Rexolite Wedge 115-000-497 Contoured in the Axial Direction
  - Wedge Angle: 18.5°, Roof Angle 7.3°, Diameter: 16.75in (425.5mm)
- Zetec ZMC2 motion controller with ATCO GPS-1000 Pipe Scanner



Scanning Approach

- Individual Scan Lines separated by 0.6654in (16.9mm)
- Scan Resolution 0.0394in (1.0mm)

Ultrasonic Data Collection Channels

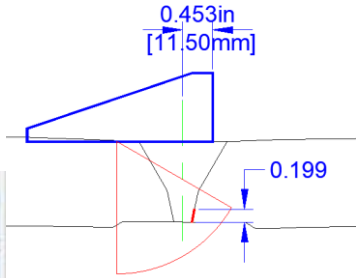
- Data Acquisition Setup #1 (0.70in/s [17.8mm/s]):
  - Joins elements such that the dual 2x16 array is a dual 1x16 array for faster data acquisition
  - Ultrasonic Phased Array Channel:
    - Longitudinal Waves 0°-70°, every 1°, focused at a half path of 1.5in (38.1mm)
  - FMC/TFM Channel:
    - L-L Mode, Frame Size: 256x256 (2.5in x 2.5in) [63.5mm x 63.5mm]
- Data Acquisition Setup #2 (0.50in/s [12.7mm/s]):
  - Ultrasonic Phased Array Channel:
    - Longitudinal Waves 0°-70°, every 1°, focused at a half path of 1.5in (38.1mm)
  - PWI/TFM Channel:
    - Transmit with 2x16 elements, Longitudinal Waves 0°-70°, every 5°, focused at a half path of 39in (990.6mm)
    - L-L Mode, Frame Size: 256x256 (2.5in x 3.0in) [63.5mm x 76.2mm]

Ultrasonic Data Analysis Channels

- Traditional Merged Ultrasonic Phased Array:
  - Longitudinal Waves 0°-70°, every 1°, focused at a half path of 1.5in (38.1mm)
- Sectorial Total Focusing (STF) with Delay-Multiply-and Sum (DMAS) and Envelope (ENV) Beamformer:
  - Longitudinal Waves 0°-70°, every 1°, using total focusing
- FMC/TFM with DMAS and ENV Beamformer
- PWI/TFM with DMAS and ENV Beamformer

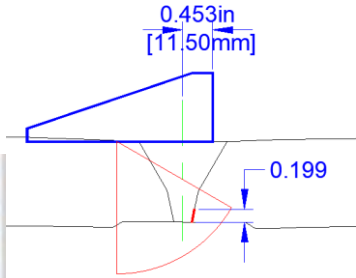
Processing times (minutes)	Laptop 16GB Ram I7-4700MQ CPU 2.4GHz	Desktop 128GB Ram I9-7900X CPU 3.3GHz
Single Line FMC	5	<1
Single Line FMC ENV	6	<1
Single Line FMC DMAS	6	<1
Single Line FMC ENV DMAS	86	10
Single Line PWI	2	<1
Single Line PWI ENV	2	<1
Single Line PWI DMAS	2	<1
Single Line PWI ENV DMAS	12	<2

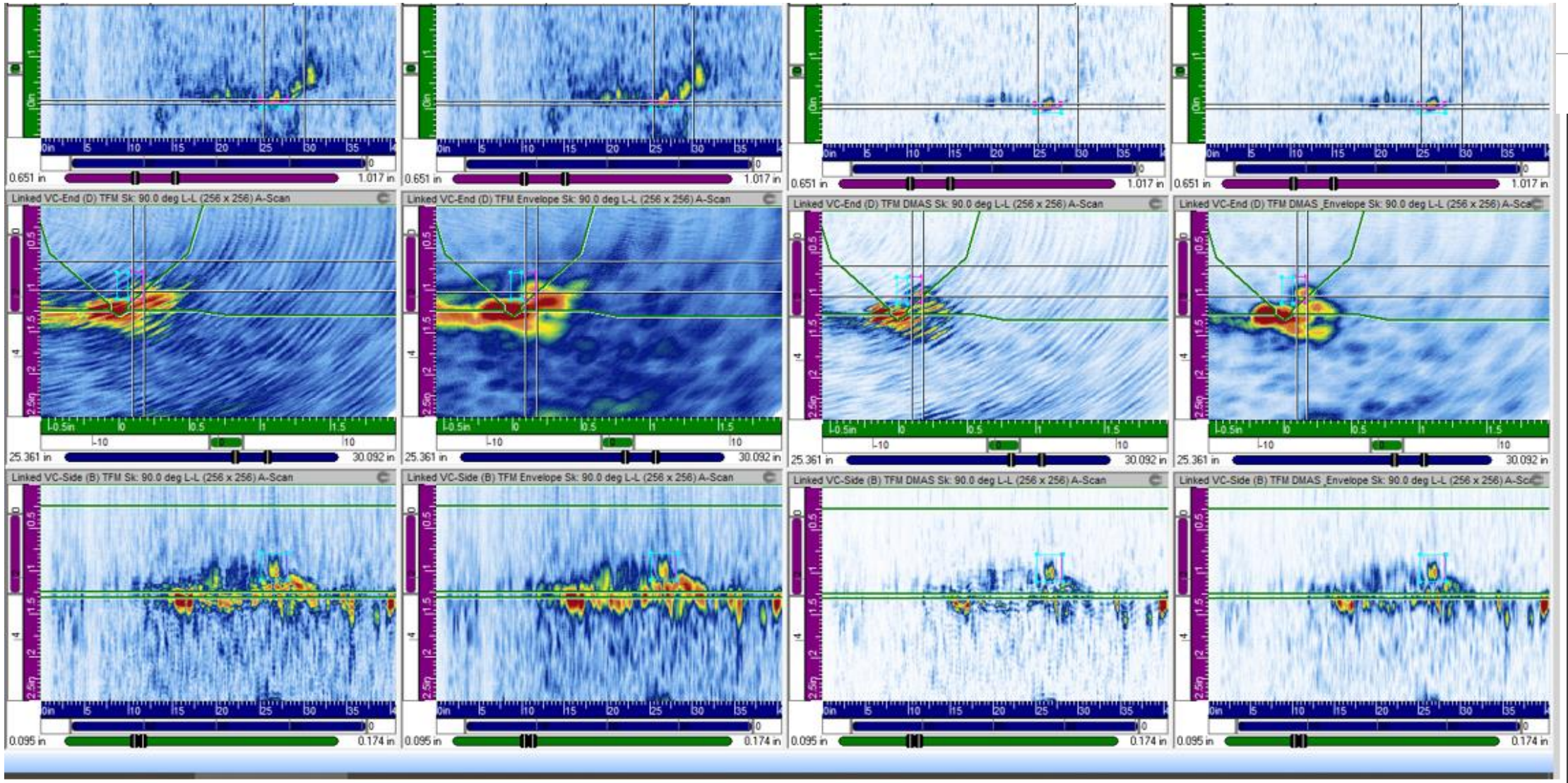
Flaw 4 Images, Far Side, Line 3 (PAUT, STF)



PAUT MERGE 0-70LW	STF MERGE 0-70LW	STF MERGE 0-70LW w/ ENVELOPE	STF MERGE 0-70LW w/ DMAS	STF MERGE 0-70LW w/ ENV & DMAS

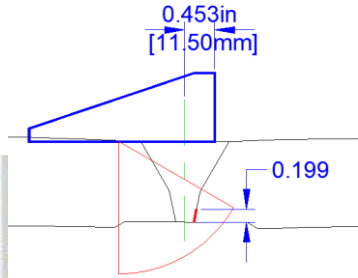
Flaw 4 Images, Far Side, Line 3 (FMC/TFM)

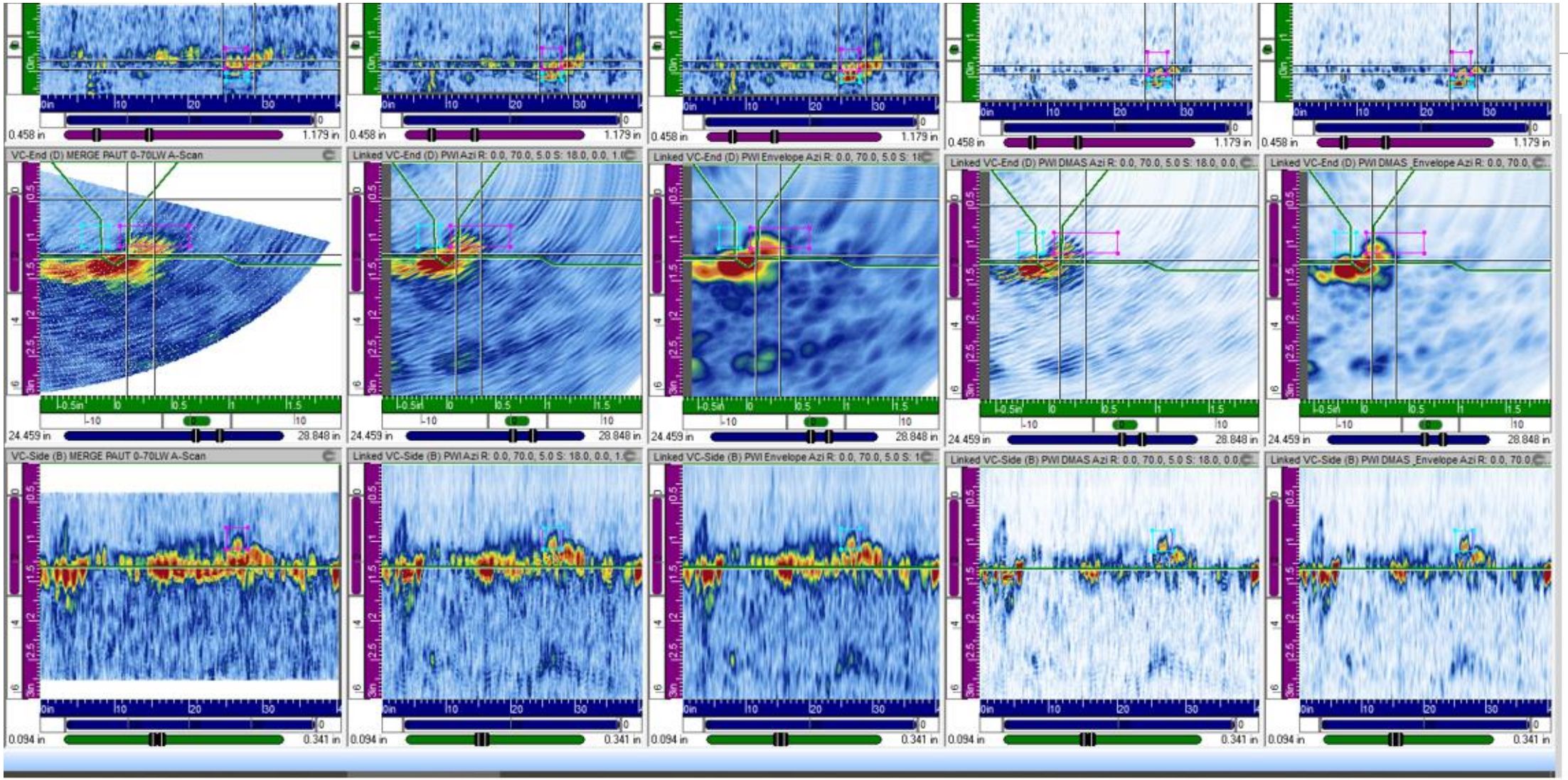




	TFM	TFM w/ ENVELOPE	TFM w/ DMAS	TFM w/ DMAS & ENVELOPE

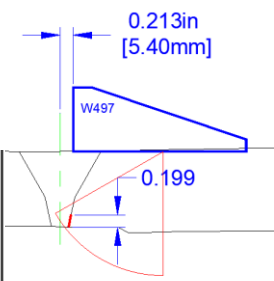
Flaw 4 Images, Far Side, Line 3 (PWI/TFM)

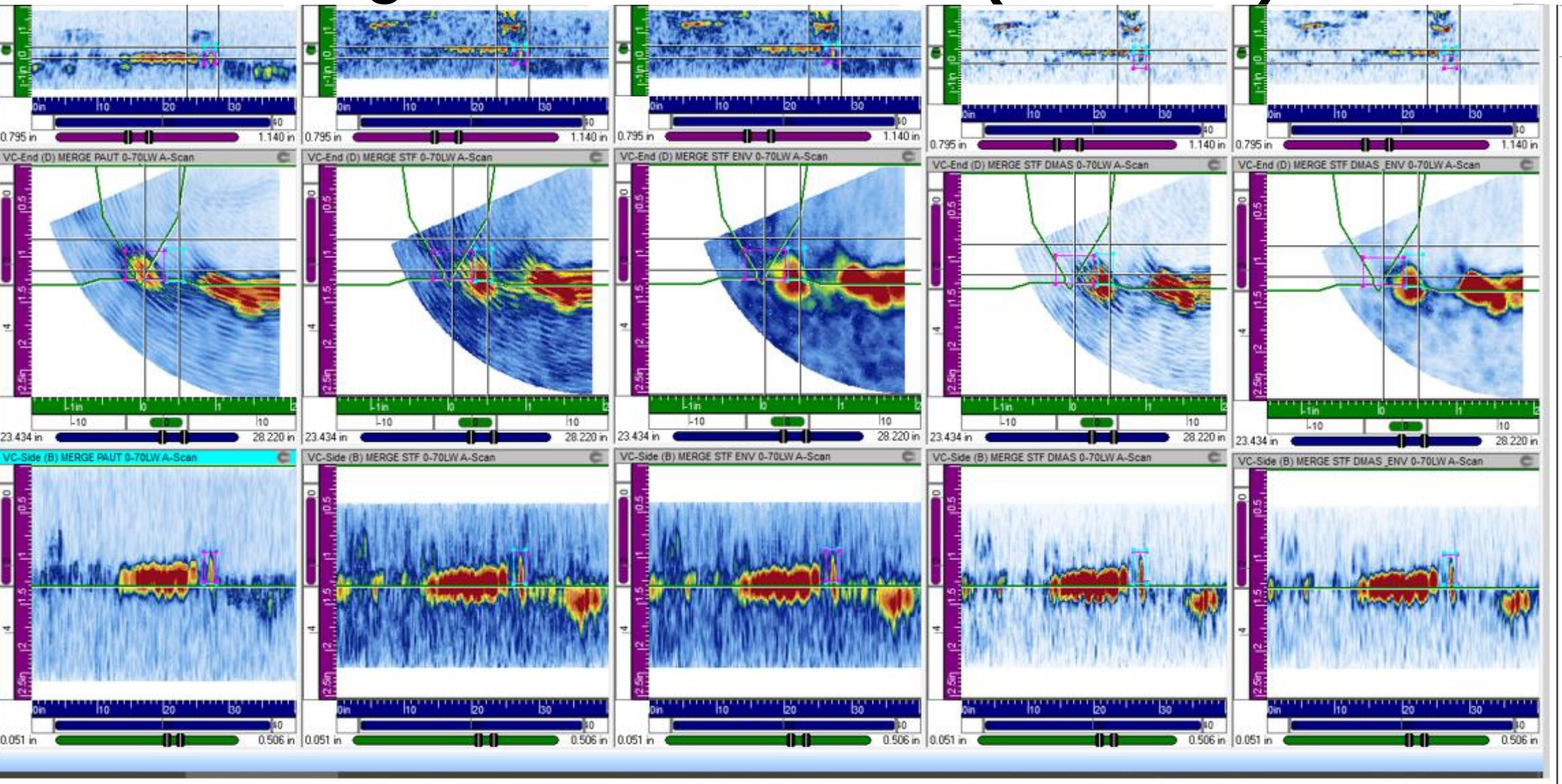




	PAUT MERGE 0-70LW (1)	PWI 0-70LW (5)	PWI 0-70LW (5) w/ENVELOPE	PWI 0-70LW (5) w/DMAS	PWI 0-70LW (5) w/DMAS & ENVELOPE

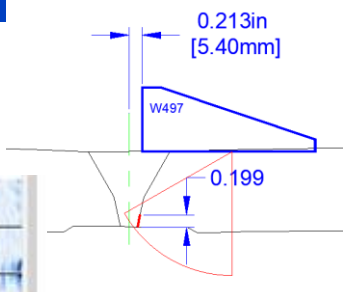
Flaw 4 Images, Near Side, Line 2 (PAUT, STF)

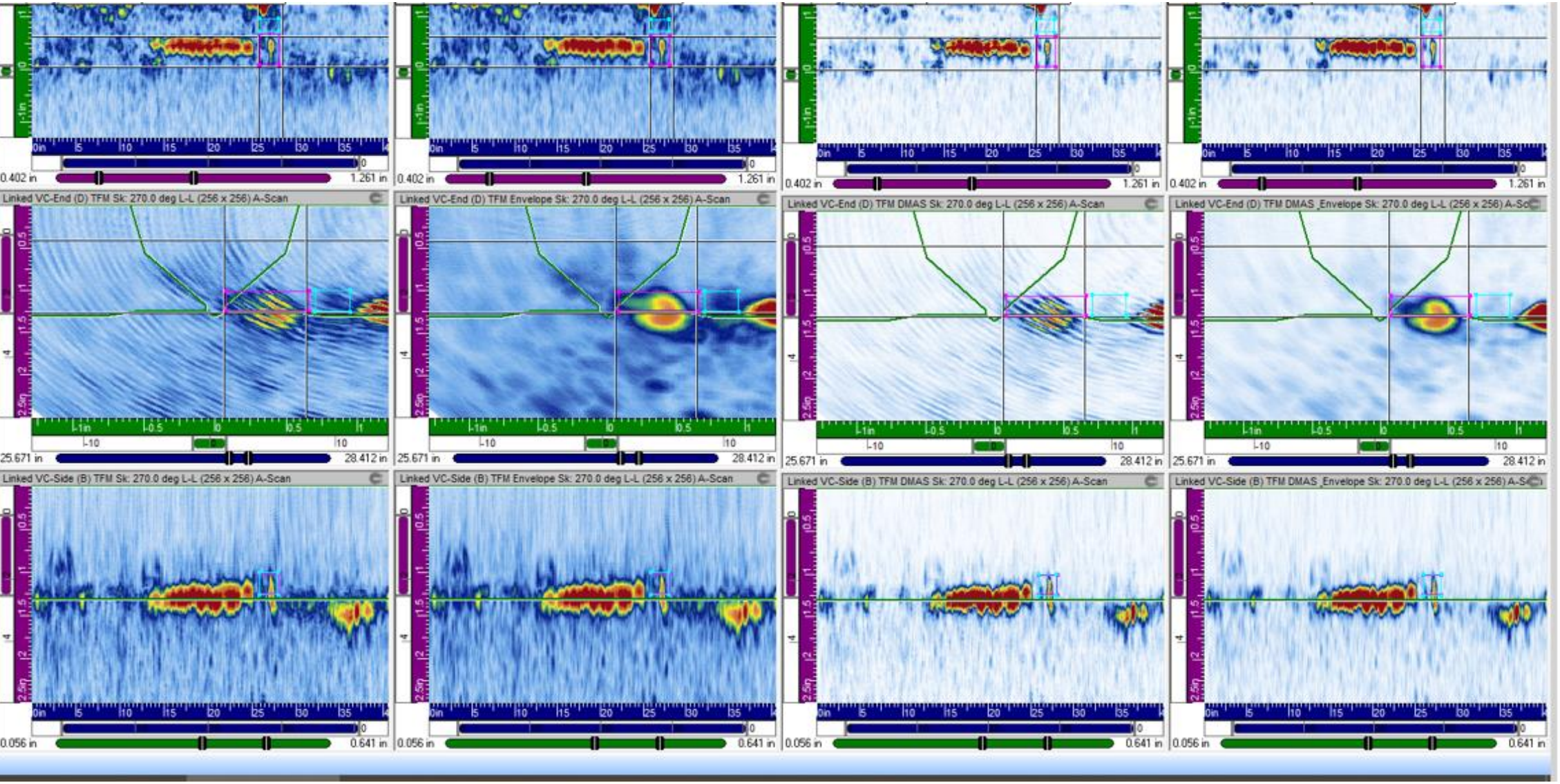




PAUT MERGE 0-70LW	STF MERGE 0-70LW	STF MERGE 0-70LW w/ ENVELOPE	STF MERGE 0-70LW w/ DMAS	STF MERGE 0-70LW w/ ENV & DMAS

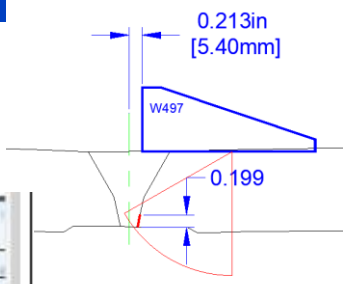
Flaw 4 Images, Near Side, Line 2 (FMC/TFM)

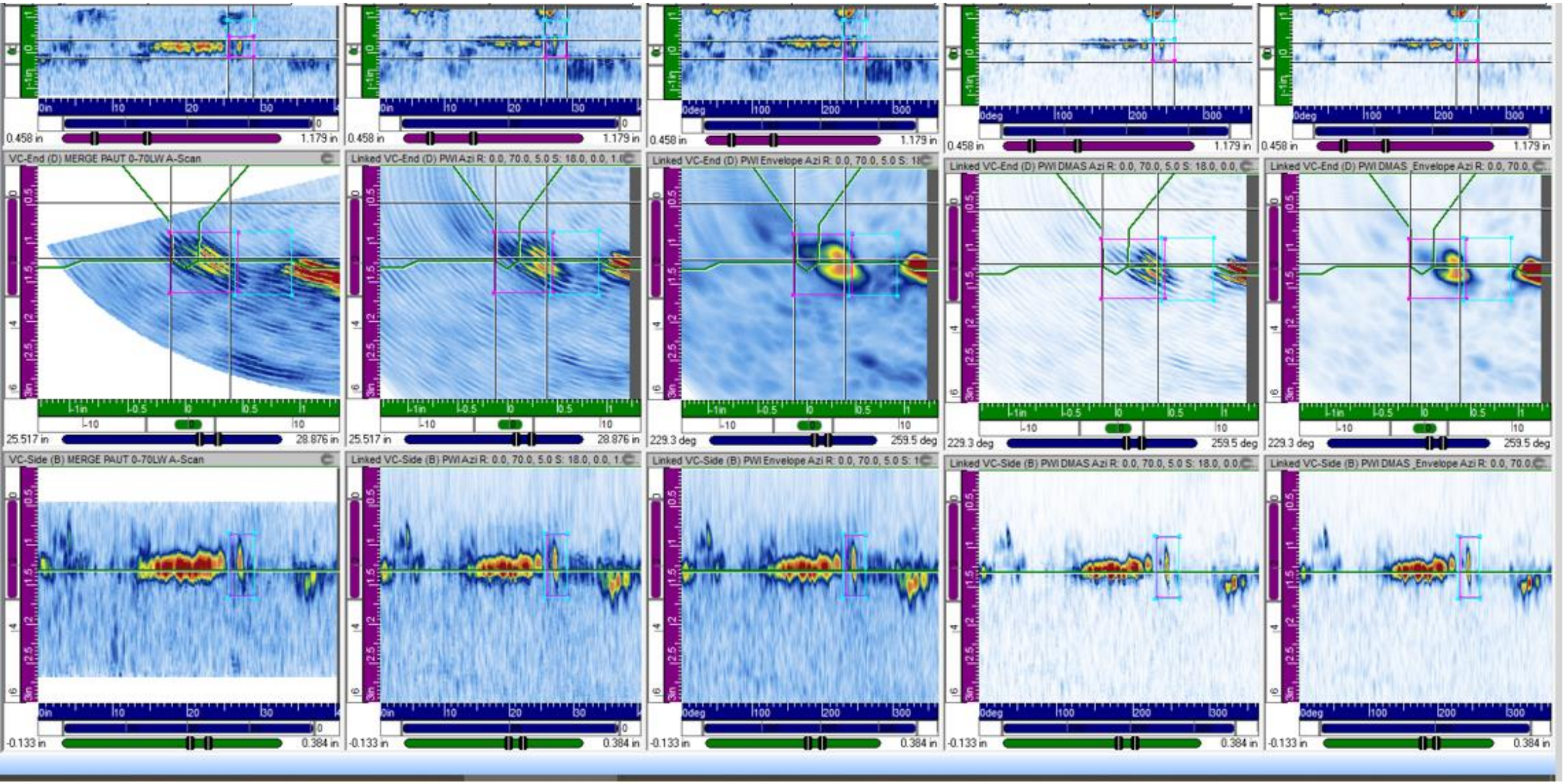




TFM	TFM w/ ENVELOPE	TFM w/ DMAS	TFM w/ DMAS & ENVELOPE

Flaw 4 Images, Near Side, Line 2 (PWI/TFM)





	PAUT MERGE 0-70LW (1)	PWI 0-70LW (5)	PWI 0-70LW (5) w/ENVELOPE	PWI 0-70LW (5) w/DMAS	PWI 0-70LW (5) w/DMAS & ENVELOPE

Signal-to-noise Ratio (SNR) Results in dB

Worst SNR
Best SNR
Worse SNR than PAUT
Better SNR than PAUT by 12dB

General Info			SNR (C/Avg)					SNR TFM - PAUT			
Flaw	Location	Line	PAUT MERGE	TFM	TFM ENV	TFM DMAS	TFM DMAS ENV	TFM	TFM ENV	TFM DMAS	TFM DMAS ENV
1	Far Side	4	23.6	21.1	17.3	38.1	33.9	-2.5	-6.3	14.5	10.3
3	Near Side	2	23.3	18.5	15.1	32.0	26.6	-4.8	-8.2	8.7	3.3
4	Far Side	3	27.1	18.1	14.2	31.3	25.0	-9.0	-12.9	4.2	-2.1
5	Near Side	2	26.6	23.9	20.1	40.2	36.9	-2.7	-6.5	13.6	10.3
1	Near Side	3	28.3	23.3	19.8	40.1	35.3	-5.0	-8.5	11.8	7.0
3	Far Side	3	23.4	21.7	18.1	36.4	32.0	-1.7	-5.3	13.0	8.6
4	Near Side	2	23.5	20.0	16.4	37.8	31.7	-3.5	-7.1	14.3	8.2
5	Far Side	2	12.8	29.0	25.5	49.8	44.5	16.2	12.7	37.0	31.7

General Info			SNR (C/Avg)					SNR STF - PAUT			
Flaw	Location	Line	PAUT MERGE	STF	STF ENV	STF DMAS	STF DMAS ENV	STF	STF ENV	STF DMAS	STF DMAS ENV
1	Far Side	4	23.6	21.6	18.5	36.6	34.0	-2.0	-5.1	13.0	10.4
3	Near Side	2	23.3	20.2	17.0	33.8	31.6	-3.1	-6.3	10.5	8.3
4	Far Side	3	27.1	20.8	18.7	29.6	24.5	-6.3	-8.4	2.5	-2.6
5	Near Side	2	26.6	22.0	18.3	35.7	31.8	-4.6	-8.3	9.1	5.2
1	Near Side	3	28.3	23.9	20.4	40.6	36.1	-4.4	-7.9	12.3	7.8
3	Far Side	3	23.4	20.0	16.6	33.3	29.6	-3.4	-6.8	9.9	6.2
4	Near Side	2	23.5	14.0	11.2	21.6	17.3	-9.5	-12.3	-1.9	-6.2
5	Far Side	2	12.8	19.2	15.6	35.5	29.6	6.4	2.8	22.7	16.8

General Info			SNR (C/Avg)					SNR PWI - PAUT			
Flaw	Location	Line	PAUT MERGE	PWI	PWI ENV	PWI DMAS	PWI DMAS ENV	PWI	PWI ENV	PWI DMAS	PWI DMAS ENV
1	Far Side	3	17.1	17.1	14.1	27.0	20.5	0.0	-3.0	9.9	3.4
3	Near Side	2	22.3	22.2	18.6	36.5	32.0	-0.1	-3.7	14.2	9.7
4	Far Side	3	25.9	23.8	20.3	38.9	32.8	-2.1	-5.6	13.0	6.9
5	Near Side	2	24.0	23.4	19.6	38.6	33.3	-0.6	-4.4	14.6	9.3
1	Near Side	3	21.7	21.3	17.6	37.2	30.6	-0.4	-4.1	15.5	8.9
3	Far Side	3	20.6	21.3	17.4	34.4	27.9	0.7	-3.2	13.8	7.3
4	Near Side	2	22.4	24.1	20.4	40.2	34.2	1.7	-2.0	17.8	11.8
5	Far Side	2	23.7	27.7	24.1	47.4	41.7	4.0	0.4	23.7	18.0

Signal-to-noise Ratio (SNR) Results in dB (DMAS)

Worst SNR
Best SNR
Worse SNR than PAUT
Better SNR than PAUT by 12dB

General Info			SNR (C/Avg)			SNR Difference from PAUT		
Flaw	Location	Line	TFM DMAS	STF DMAS	PWI DMAS	TFM DMAS	STF DMAS	PWI DMAS
1	Far Side	4	38.1	36.6	27.0	14.5	13.0	9.9
3	Near Side	2	32.0	33.8	36.5	8.7	10.5	14.2
4	Far Side	3	31.3	29.6	38.9	4.2	2.5	13.0
5	Near Side	2	40.2	35.7	38.6	13.6	9.1	14.6
1	Near Side	3	40.1	40.6	37.2	11.8	12.3	15.5
3	Far Side	3	36.4	33.3	34.4	13.0	9.9	13.8
4	Near Side	2	37.8	21.6	40.2	14.3	-1.9	17.8
5	Far Side	2	49.8	35.5	47.4	37.0	22.7	23.7

Summary

- All techniques detected flaws with adequate SNR:
  - Minimum SNR: 11.2dB
  - Average SNR: 26.1dB
- Adding Envelope greatly increased the post-processing time (2-14 times) and consistently yielded worse SNR
  - Average SNR for PAUT versus TFM_ENV, STF_ENV, and PWI_ENV was 22.0/18.3dB, 20.0/16.8dB, and 23.4/19.7dB
- DMAS provided the best SNR improvement versus PAUT
  - FMC/TFM DMAS on average was 14.6dB better than PAUT
  - STF DMAS on average was 9.8dB better than PAUT
  - PWI/TFM DMAS on average was 15.3dB better than PAUT