Residual Stress Process Simulation Committee Progress Report

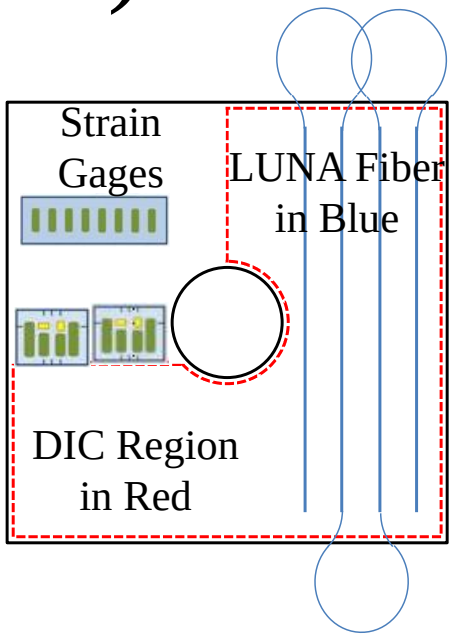
Engineered Residual Stress Implementation Virtual Workshop 2020

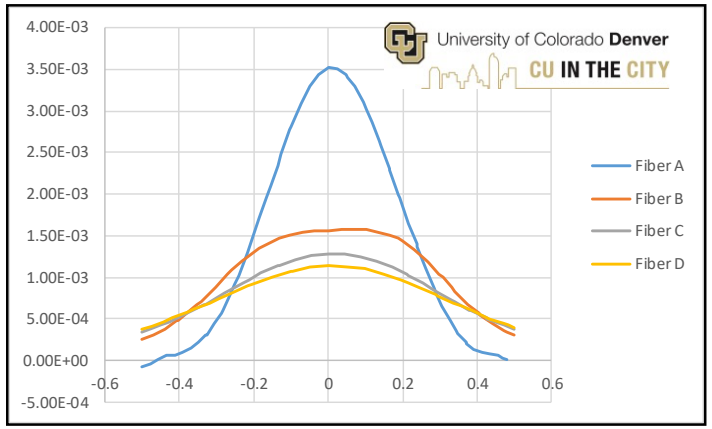
Location: The Ether

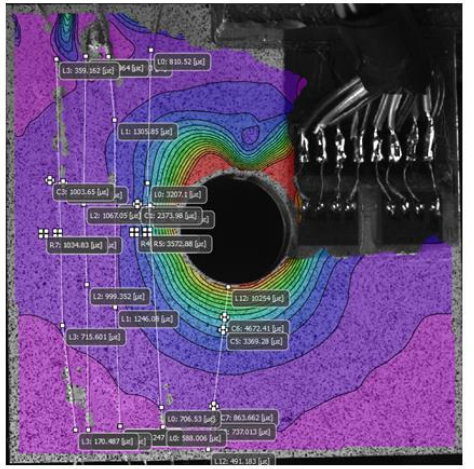
December 2020

Outline

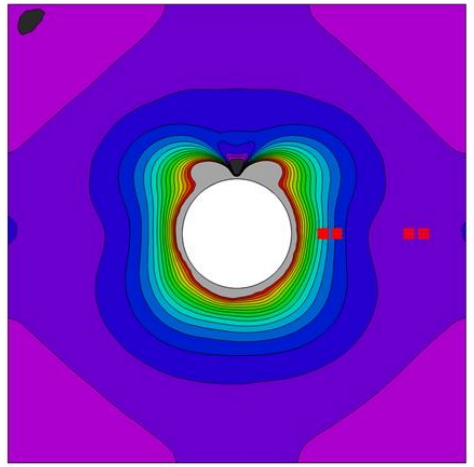
- Committee Activity
- Material Testing Update – 7075
- Process Simulation Round Robin Update
- Other items of interest (2x2 specimen status, future RR plans)







DIC Hoop strains



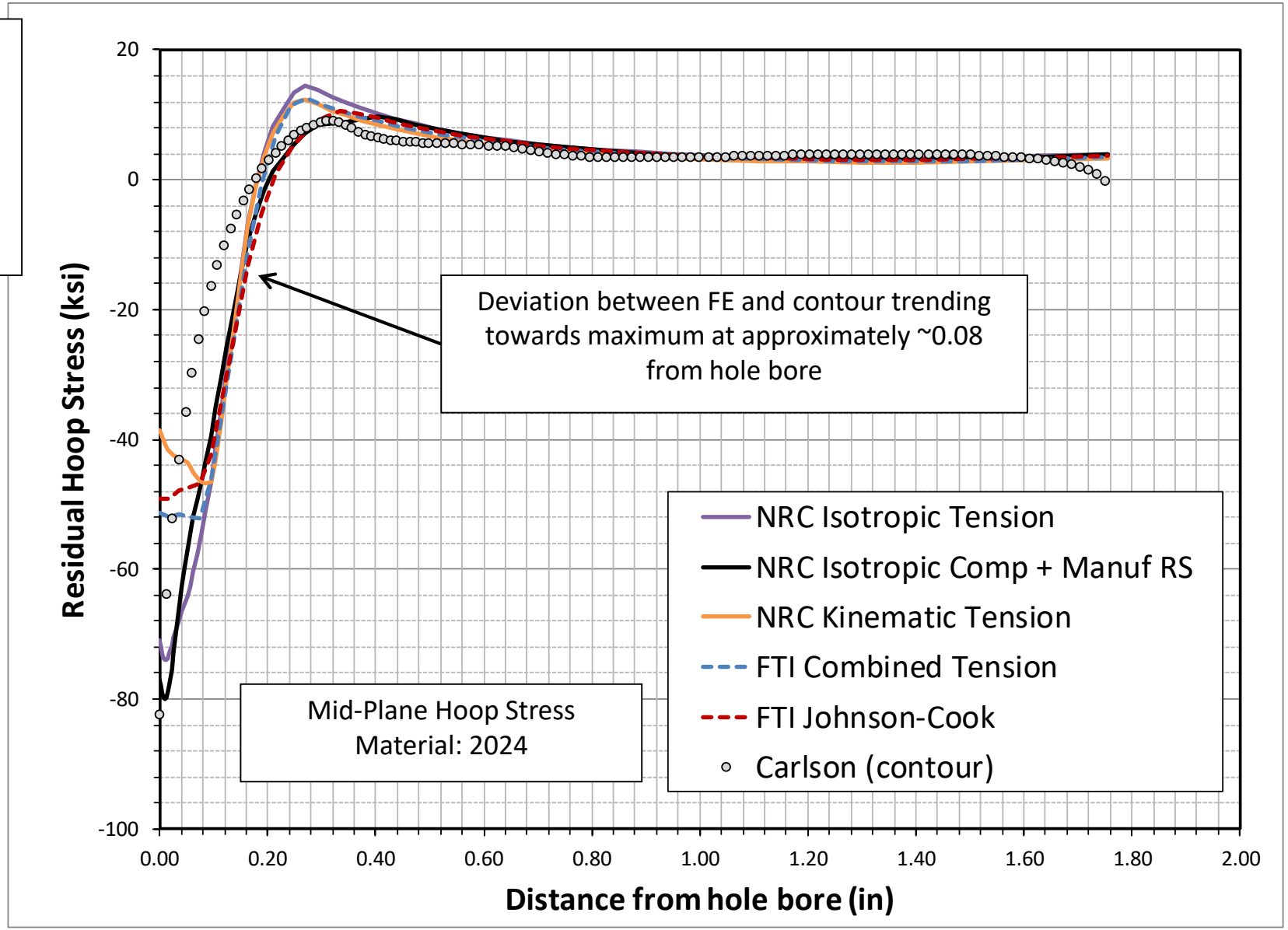
FEA Hoop strains
Chaboche Hardening

Committee Activity & Roster Updates

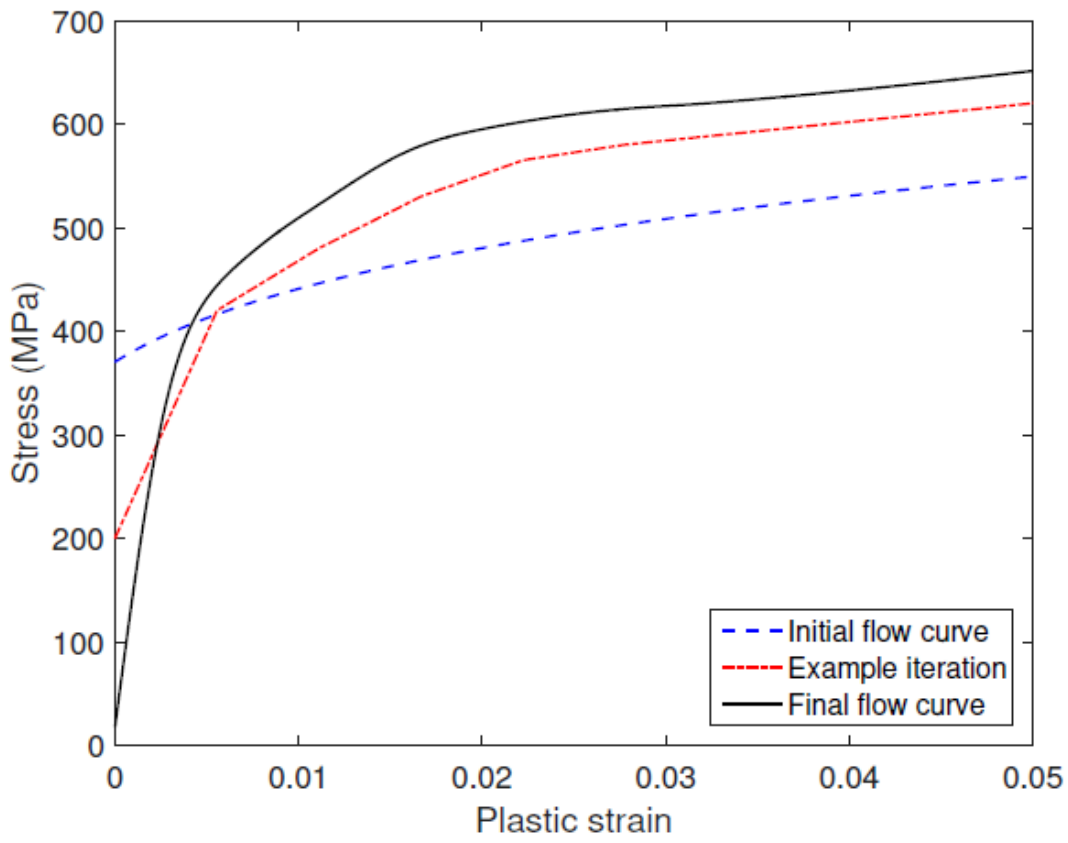
- Excellent Participation
  - Monthly Meeting 3rd Friday of each month, all are welcome!
  - Total of 13 monthly meetings
- Round Robin Data Reduction Crew
  - Gavin Jones
  - Scott Prost-Domasky
  - Keith Hitchman
  - Total of three sidebar meetings

Material Model Testing - Purpose of Program

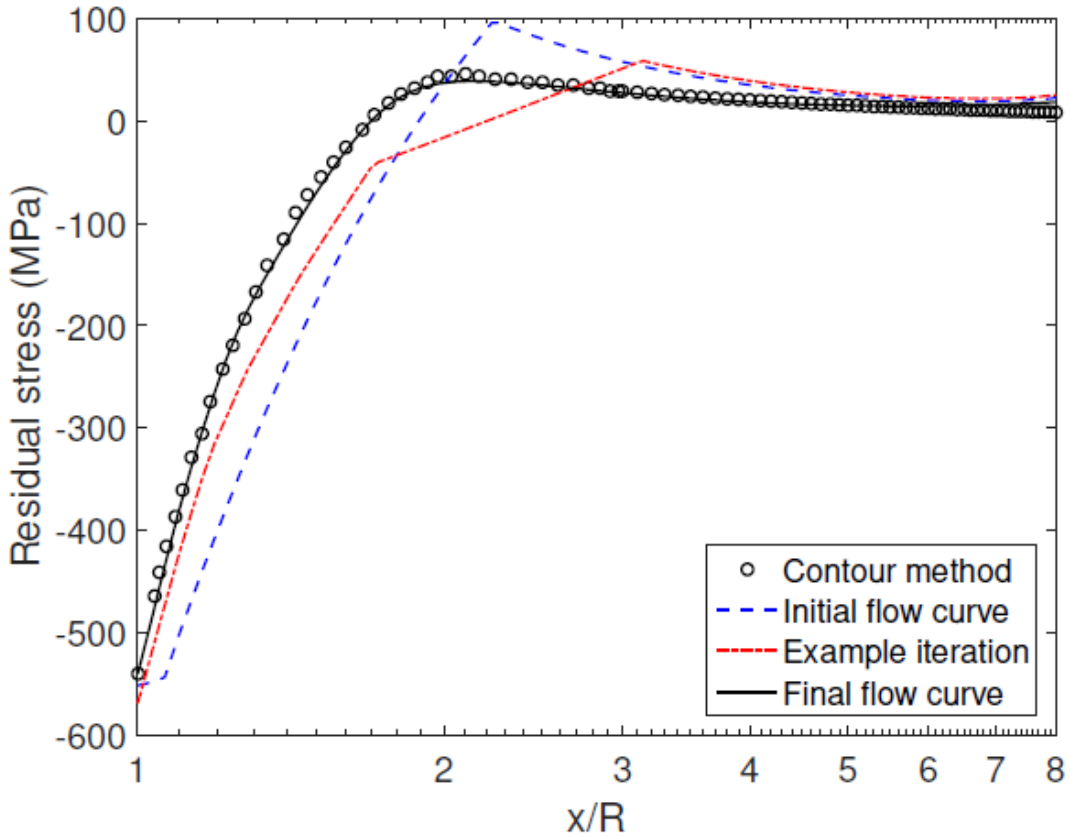
Which constitutive model is most appropriate?



Material Model Testing - Purpose of Program



(a)



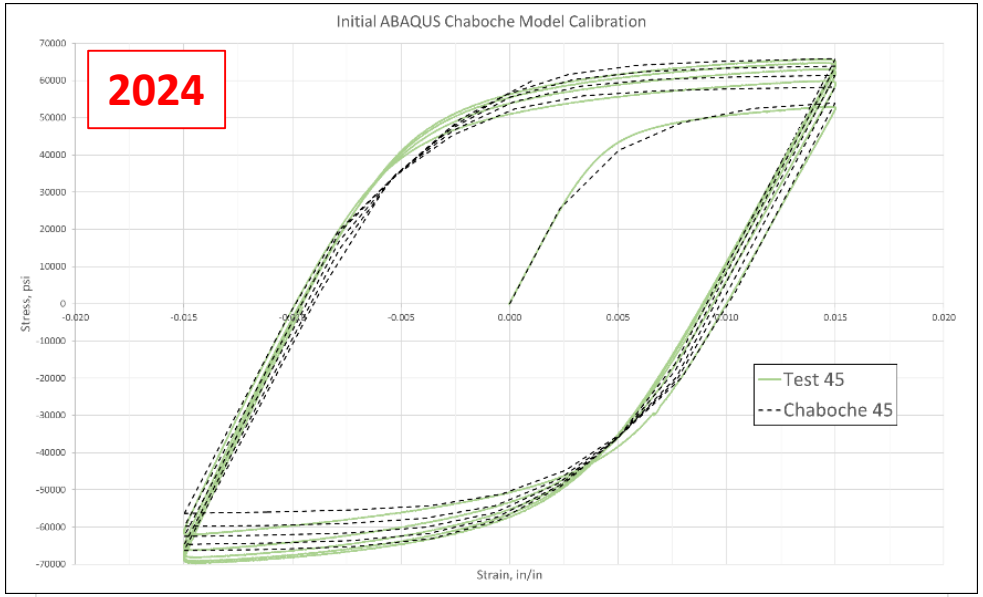
(b)

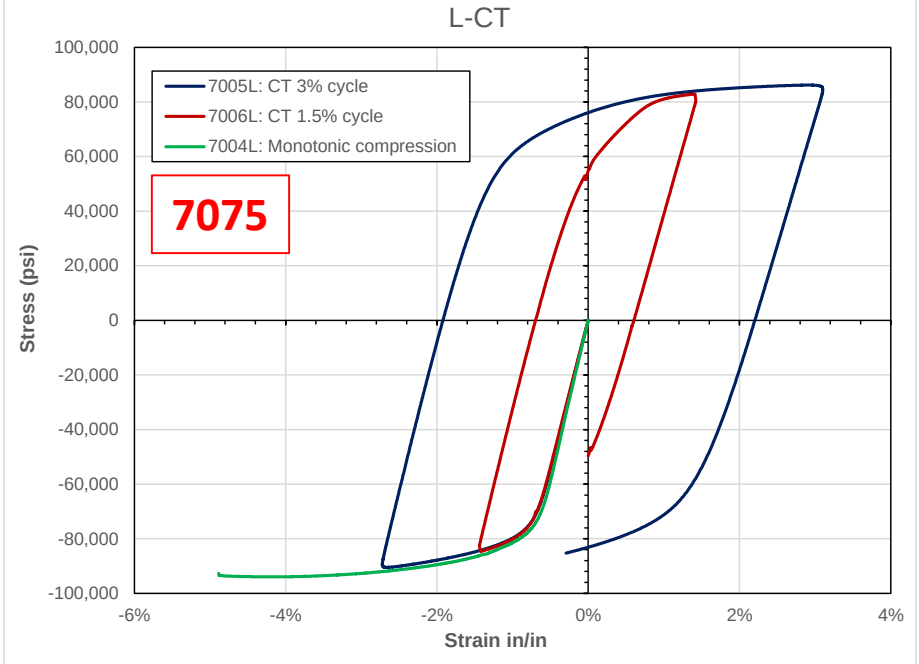
Figure 7 – (a) Flow curves tested, (b) resulting hoop residual stress ($\sigma_{\theta\theta}$); note log scale on x/R

Ribeiro, Renan L., and Michael R. Hill. "Residual Stress From Cold Expansion of Fastener Holes: Measurement, Eigenstrain, and Process Finite Element Modeling." Journal of Engineering Materials and Technology 139.4 (2017): 041012. https://doi.org/10.1115/1.4037021

Material Model Testing – General Plan

- Based upon E606 LCF, up to ±4% in./in., reduced to ±1.5%
- Isolating current investigation to orthotropy
- 2024 testing complete 2018
- 7075 testing complete 2020





Material Model Testing – Previous Results, 2024

Chaboche Parameter	NRC·CNRC Long.	NRC·CNRC Trans.	NRC·CNRC 45°	NRC·CNRC Avg.	Clausen, et. al.*
σ_{ys}, psi	30281	28942	32786	30670	31894
C, psi	7.35e6	8.69e6	8.19e6	8.08e6	9.74e6
Υ	346.88	412.96	399.09	386.31	412.0
Q, psi	21202	21042	20526	20923	23637
b	3.37	3.85	5.53	4.70	7.00
E, psi	10.56e6	10.36e6	11.10e6	10.67e6	10.62e6
ϵ	0.33	0.33	0.33	0.33	0.33

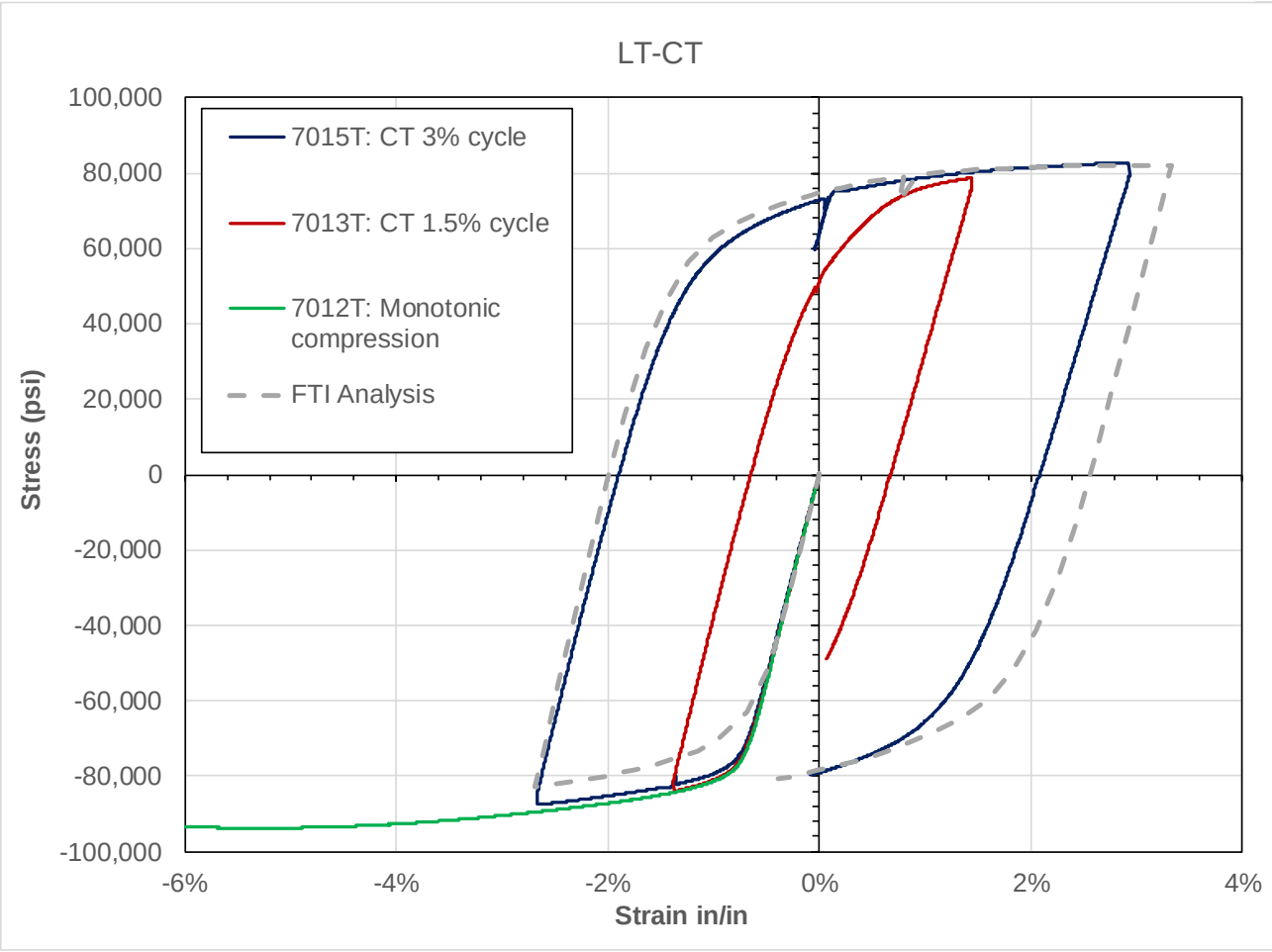
* public.lanl.gov/clausen/Clausen_et_al_PrePrint_SEM_2009.pdf

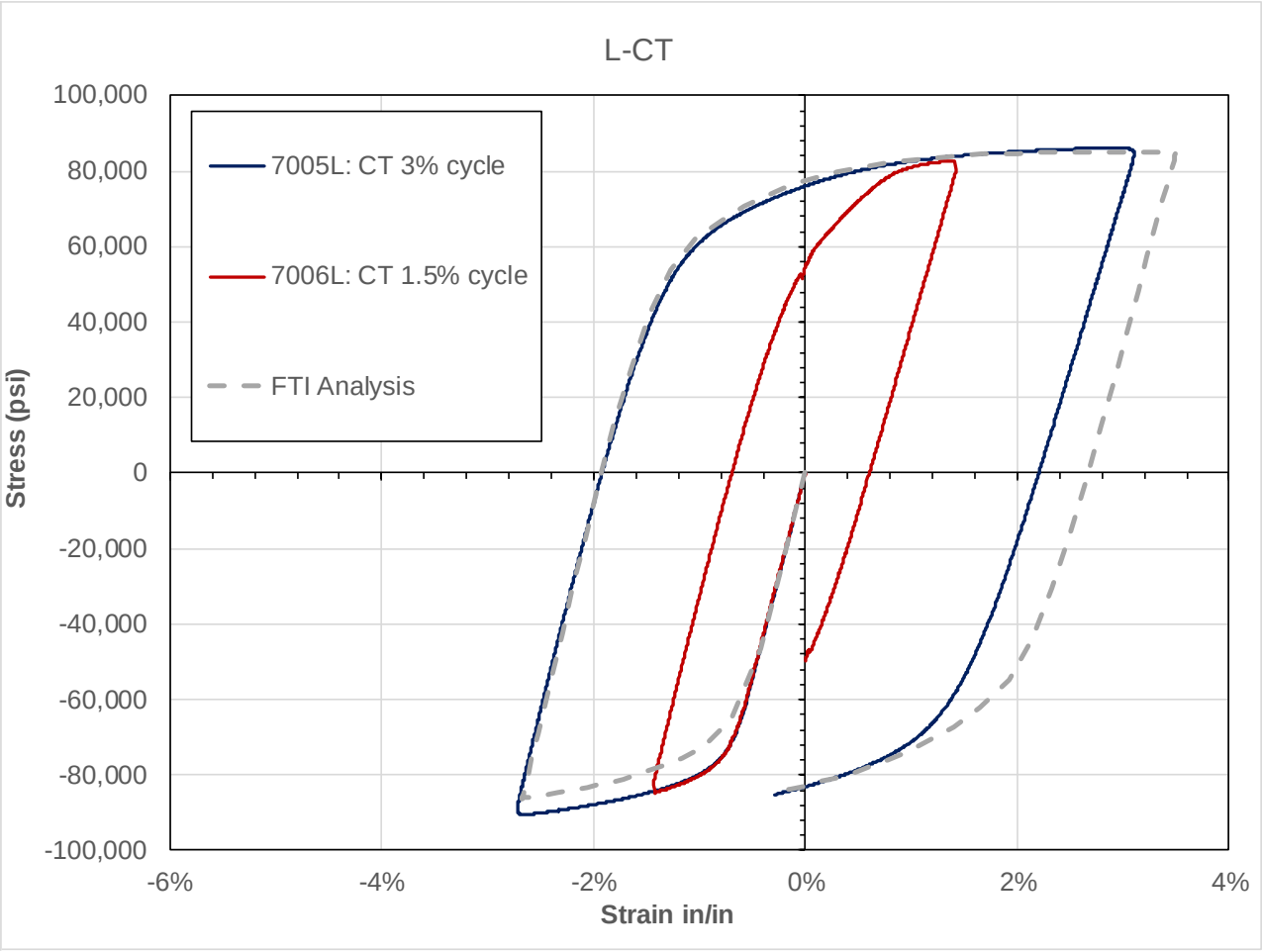
Material Model Testing – New Results, 7075

Chaboche Parameter	NRC 3% L-TC		NRC 3% L-CT		NRC 3% LT-CT			Zehsaz, et. al.*
σ_{ys}, psi	49993		45720		42321			60000
C, psi	1.99e6	3.50e7	2.21e6	3.25e7	3.65e7	1.32e7	1.52e6	7.72e5
γ	95.57	1795.80	113.79	1546.80	4845.10	782.45	90.37	31.06
Q, psi	1226		866		2574			19957
b	209.09		56.68		25.68			6.82
E, psi	9.992e6		1.149e7		1.128e7			1.06e7
ϵ	0.33		0.33		0.33			0.33

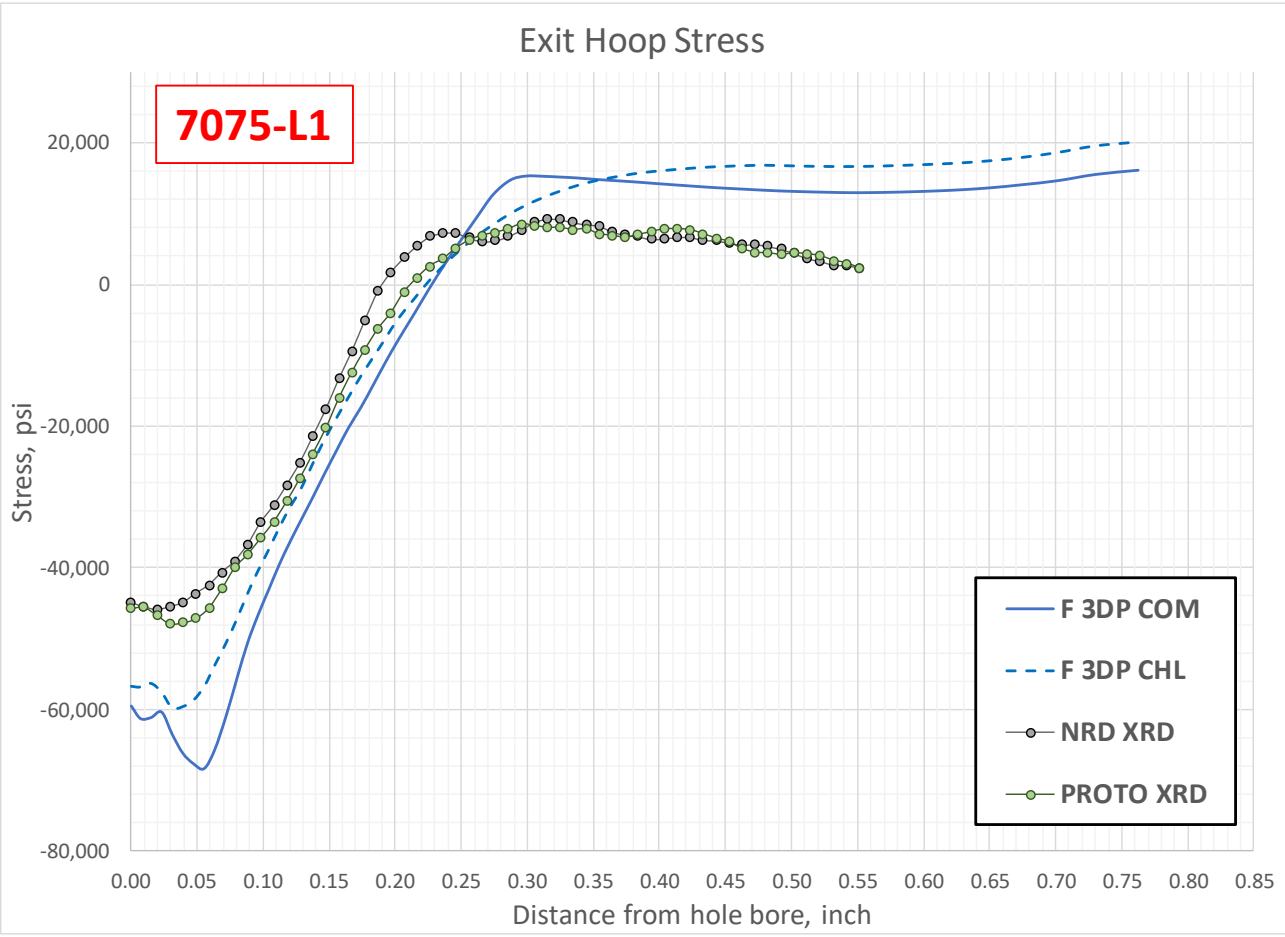
* 7075-T6 @ RT, see https://paginas.fe.up.pt/~m2d/Proceedings_M2D2017/data/papers/6567.pdf

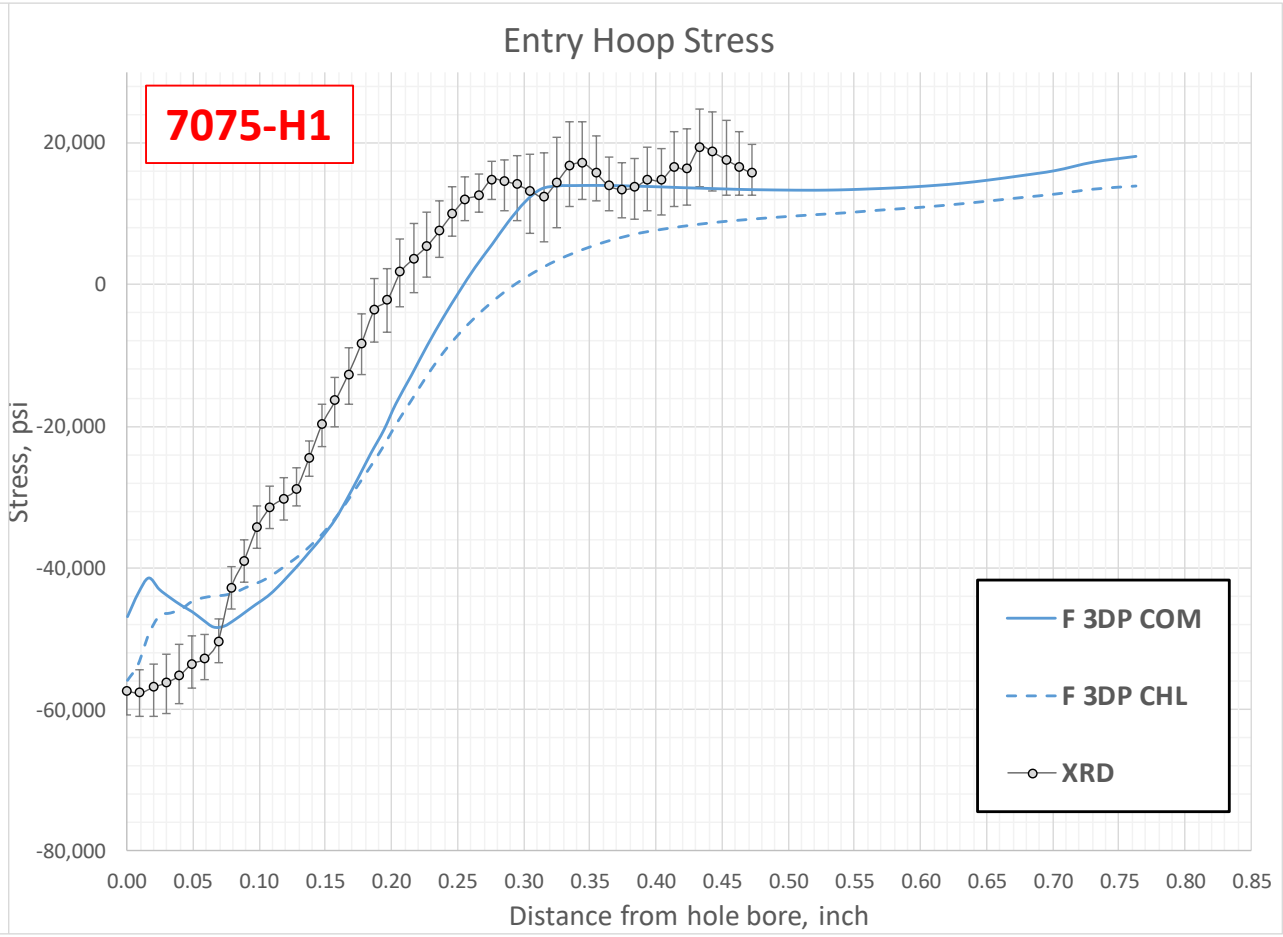
Material Model Testing – New Results, 7075





Material Model Testing – New Results, 7075



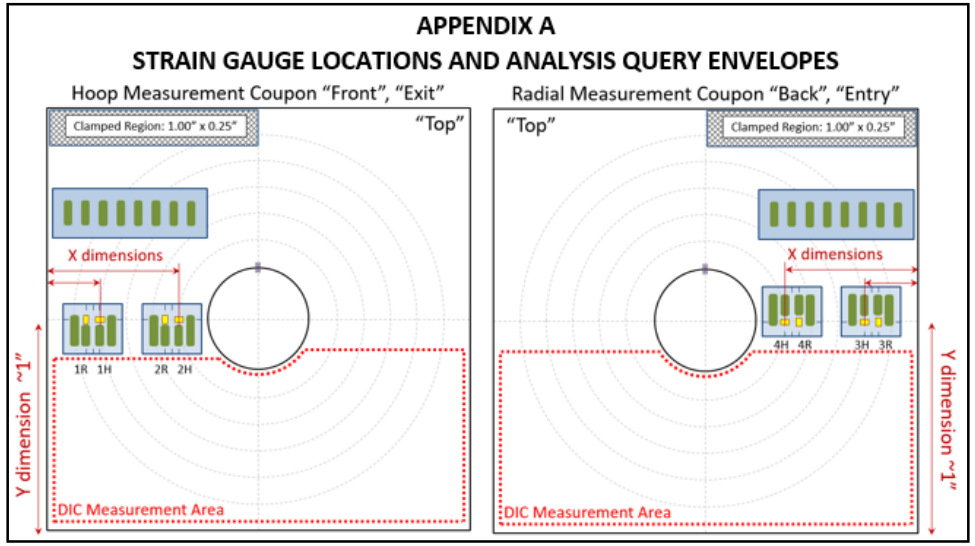


Comparisons: Combined Hardening, new Chaboche (L-TC), and XRD data

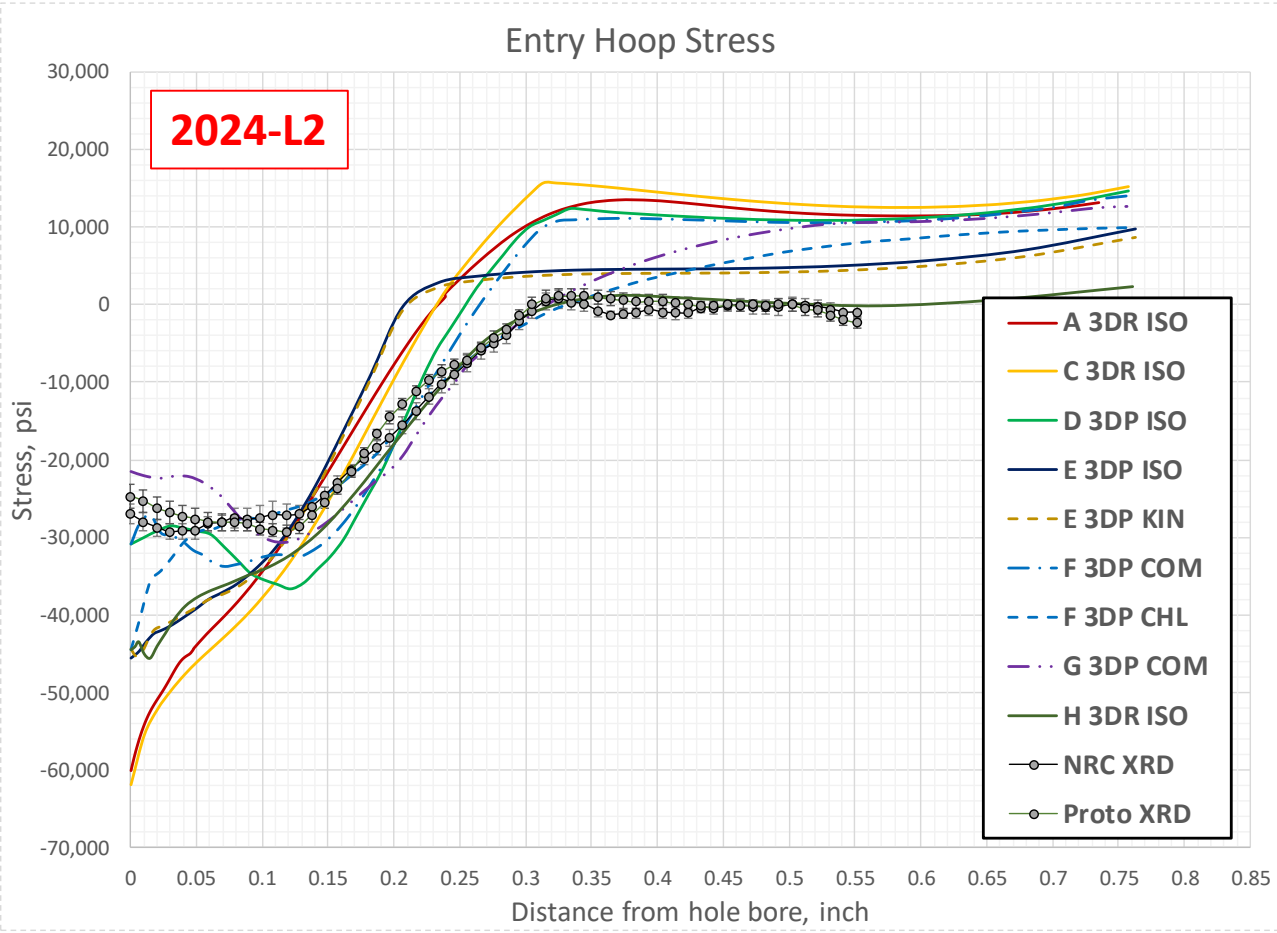
RS Process Simulation Round Robin

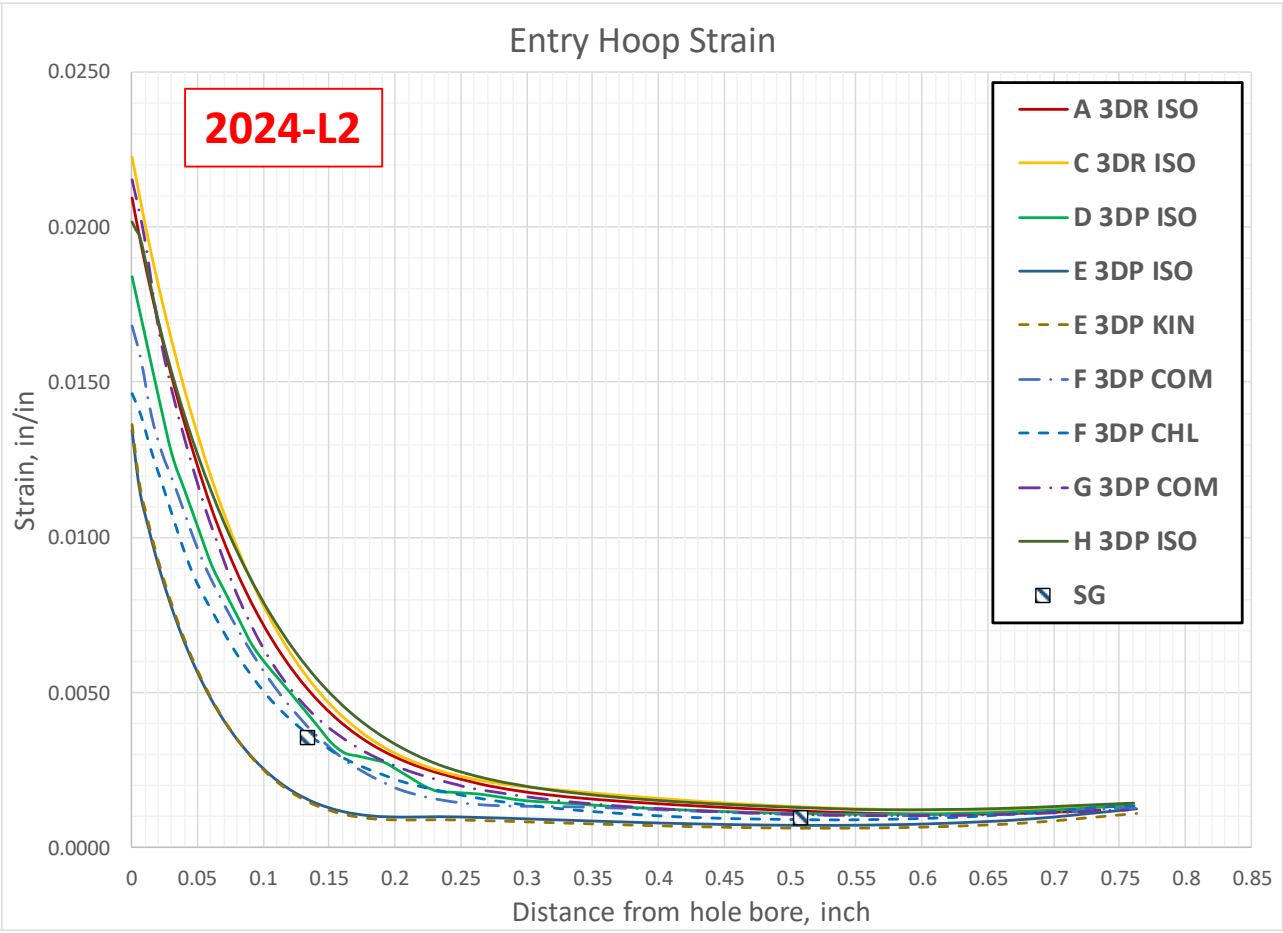
- Multiple submissions from seven participants
  - Abaqus
  - MARC
  - Nastran
  - StressCheck
- Analysis of the 2”x2” coupon cold expansion
  - Model matrix shown at right
  - Presentation limited to 2024-L2 discussion
- Multiple measurement techniques offer a unique opportunity for process simulation validation and correlation.
- Paper presenting round robin comparisons in work, lead by R. Ribeiro (Hill Engineering).

Coupon Name	Target Applied Expansion Level	Sleeve Orientation (0° = vertical)	Measured Starting Hole Diameter (inch)	Measured Plate Thickness (inch)	Mandrel Major Diameter (inch)	Sleeve Thickness (inch)	Final (Post-Ream) Hole Diameter (inch)
“2024-L2” 2024-Cx-DIC/LUNA/XRD/CM/SG-02-L2	3.16	10.0°	0.4775	0.253	0.4684	0.0120	0.5000
“2024-H1” 2024-Cx-DIC/LUNA/XRD/CM/SG-03-H1	4.16	-1.2°	0.4743	0.254	0.4697		
“7075-L1” 7075-Cx-DIC/LUNA/XRD/CM/SG-01-L1	3.16	3.2°	0.4769	0.252	0.4684		
“7075-H1” 7075-Cx-DIC/LUNA/XRD/CM/SG-03-H1	4.16	-9.5°	0.4741	0.251	0.4697		



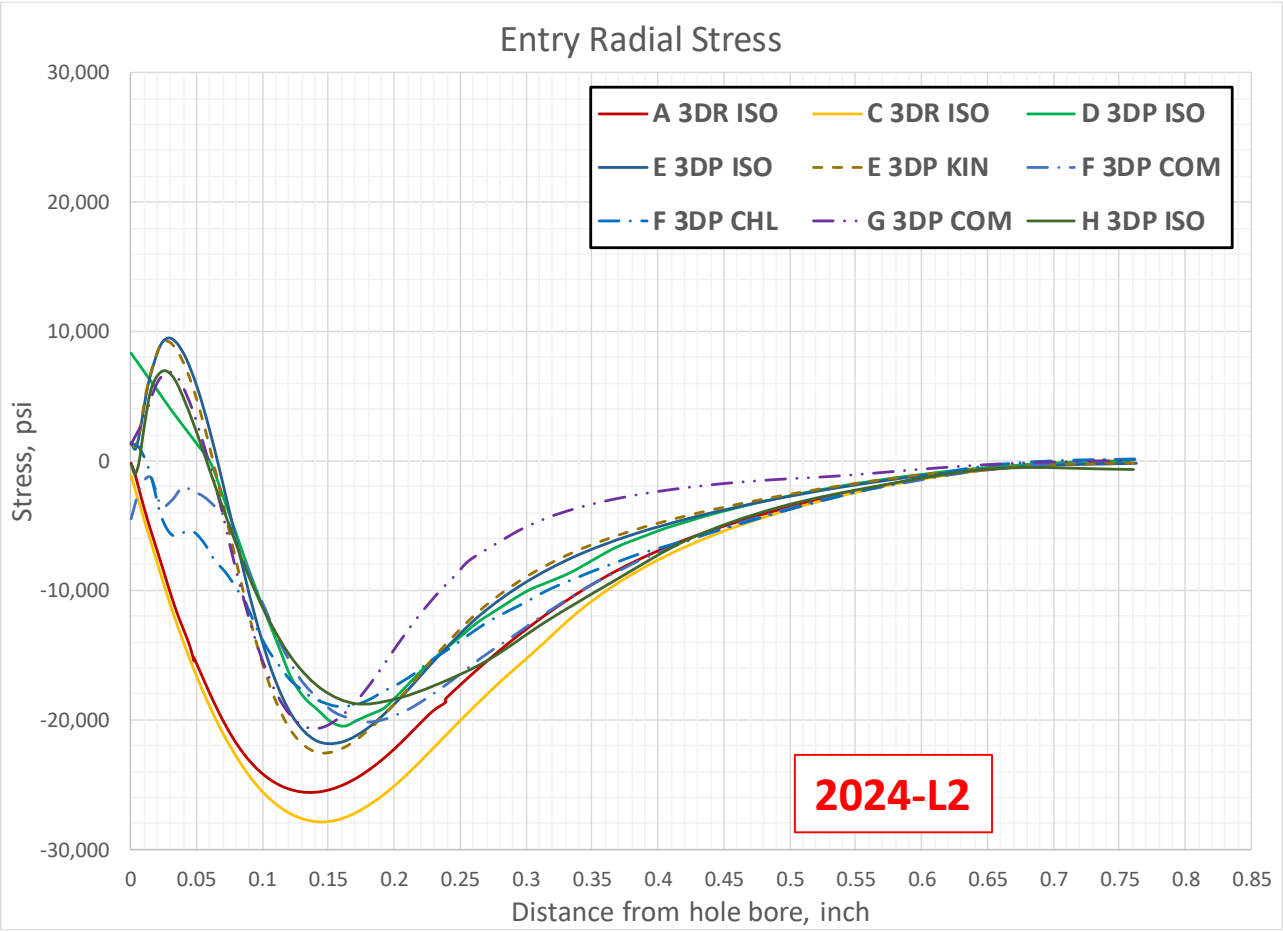
RS Process Simulation Round Robin – Results v SG

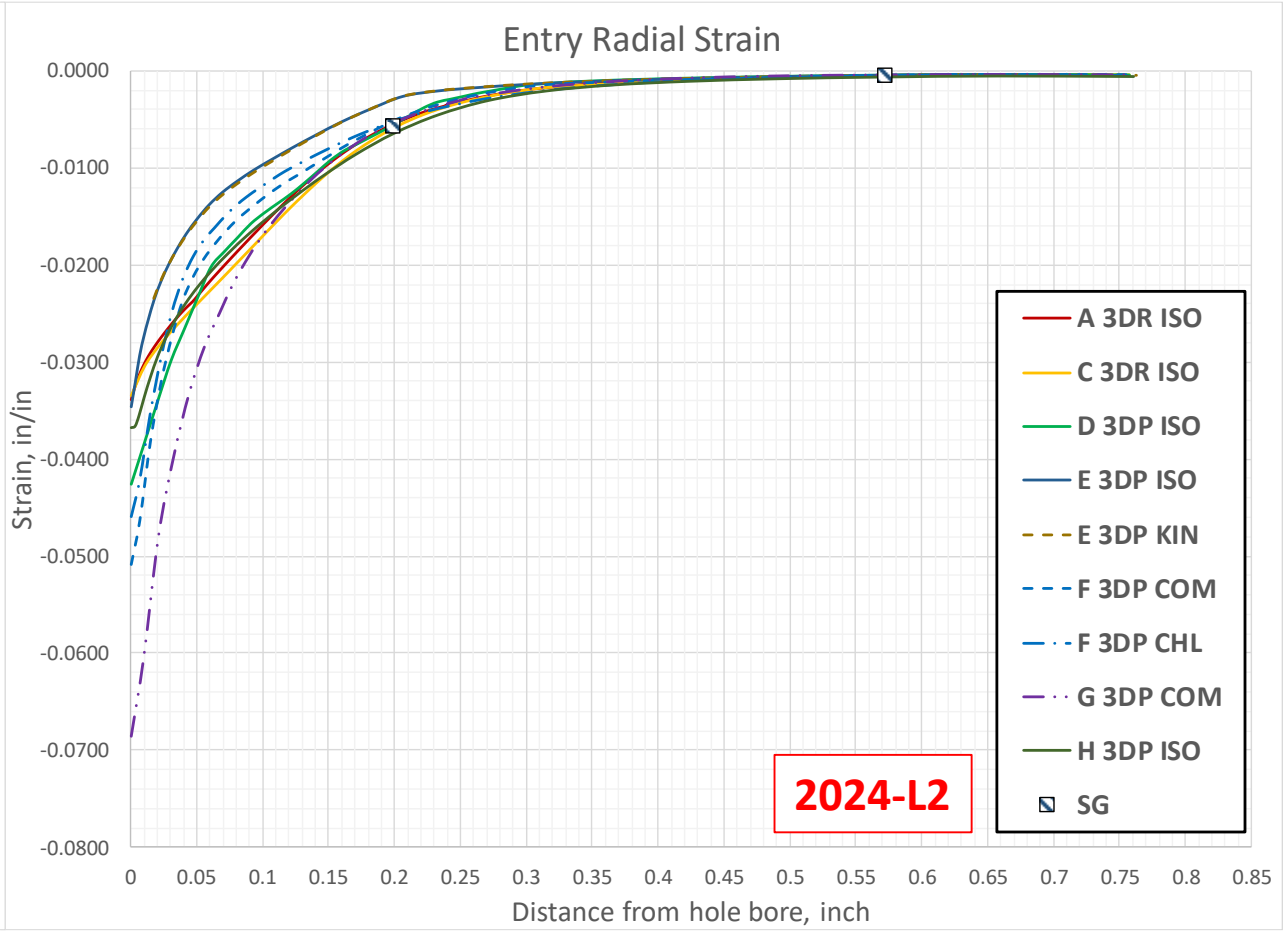




3DR – 3D Radial Displacement
3DP – 3D Mandrel Pull Through
ISO – Isotropic Hardening
COM – Combined Hardening
KIN – Kinematic Hardening
CHL – Chaboche, Longitudinal

RS Process Simulation Round Robin – Results v SG





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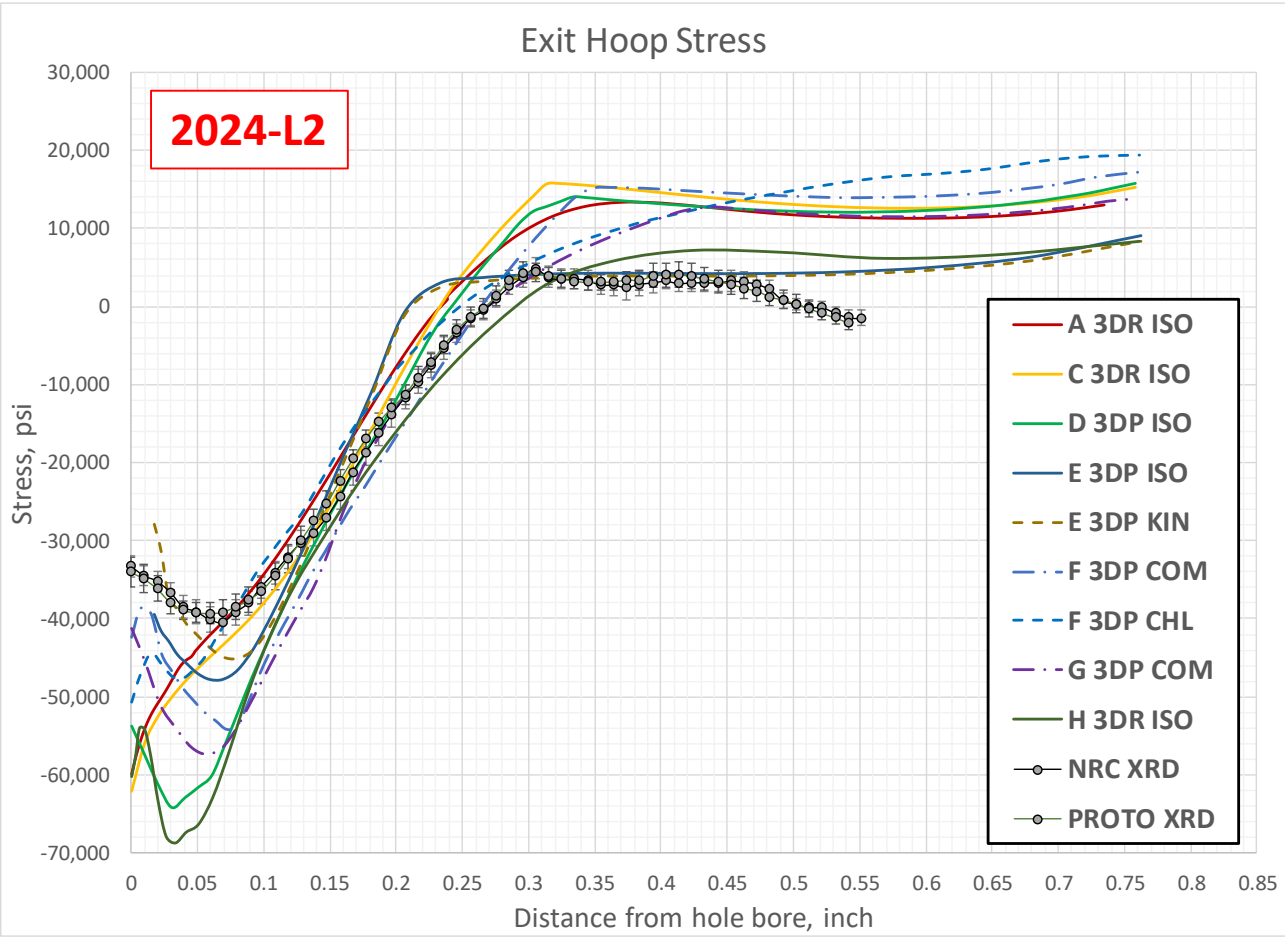

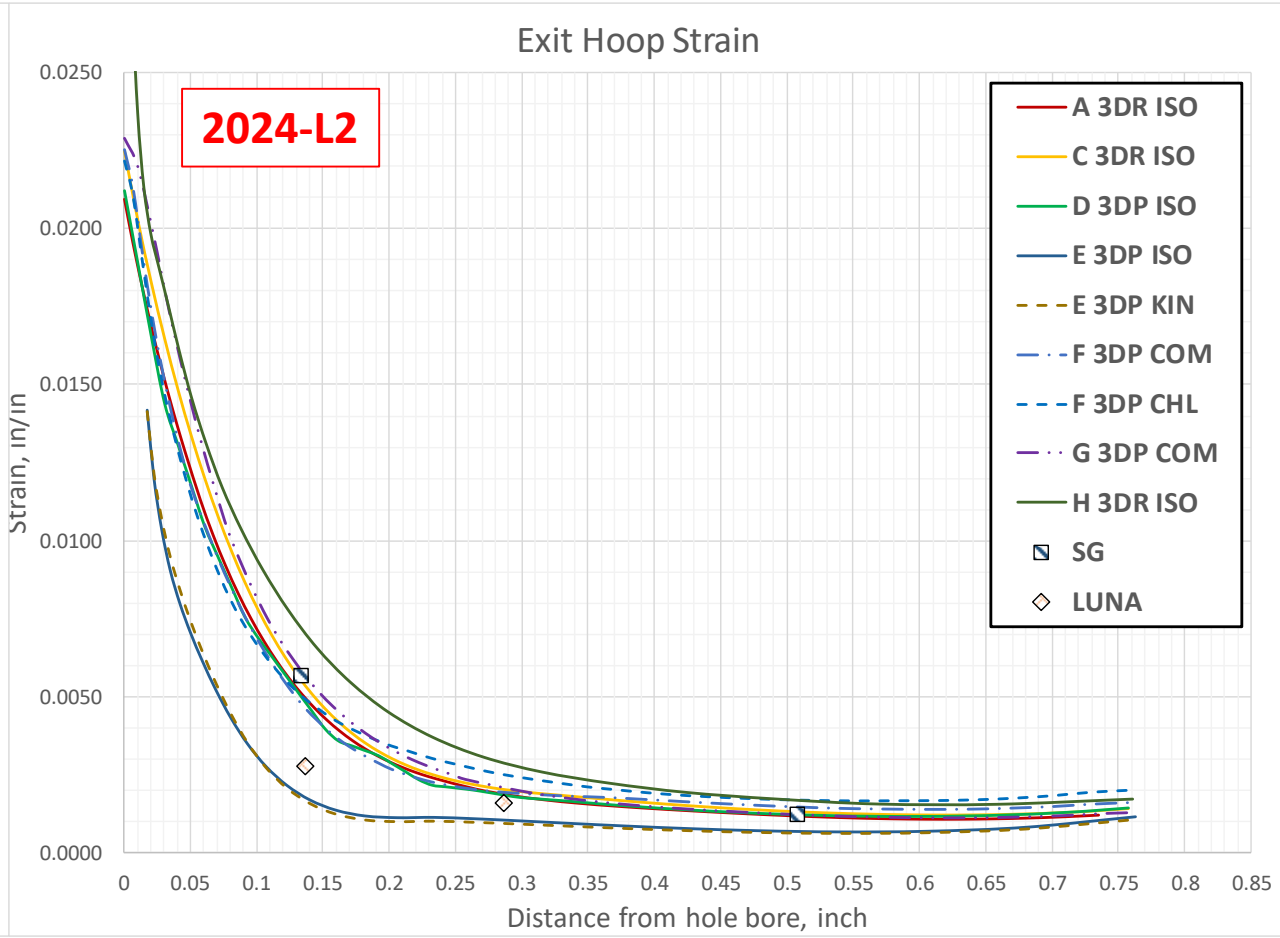

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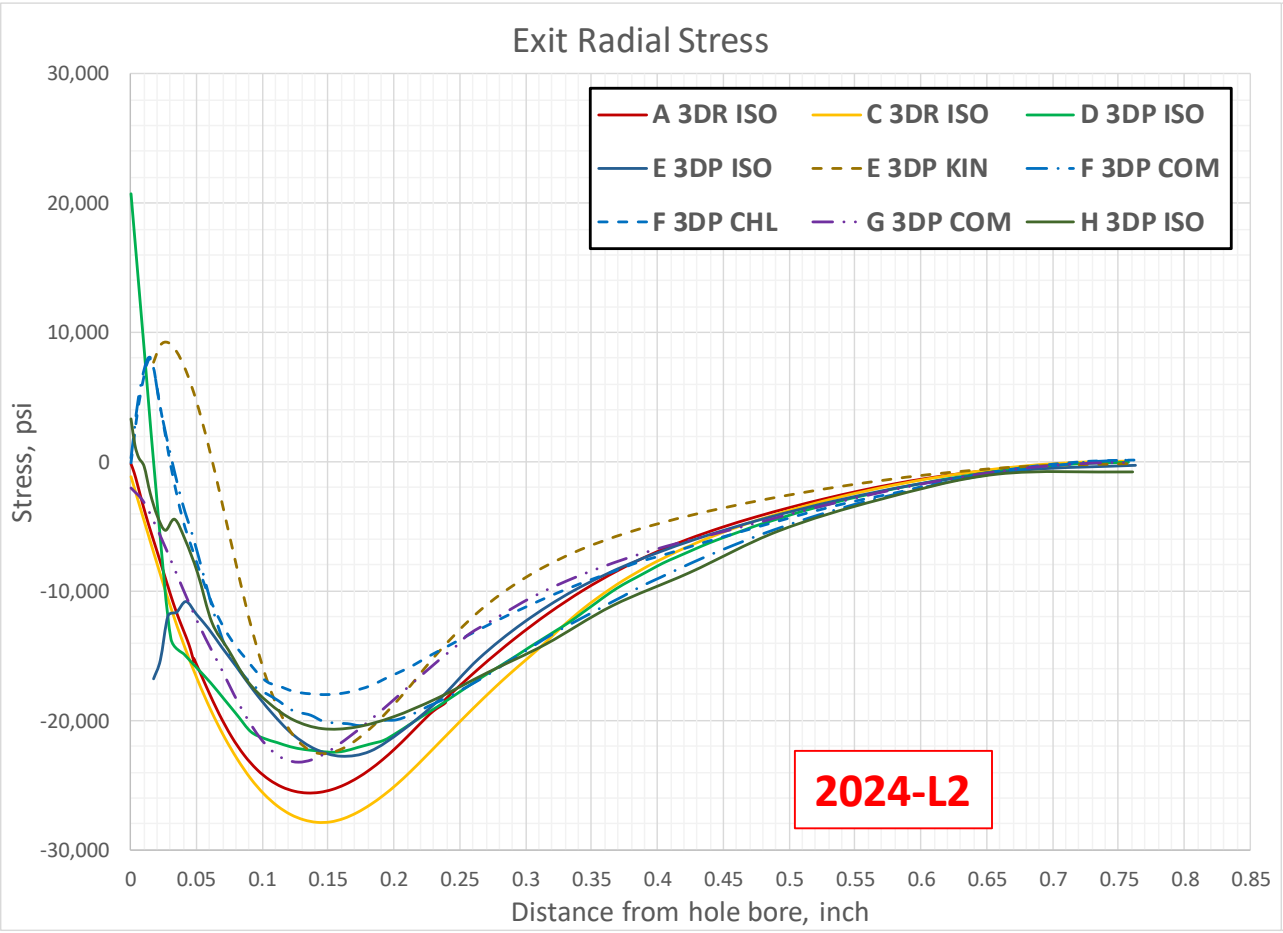

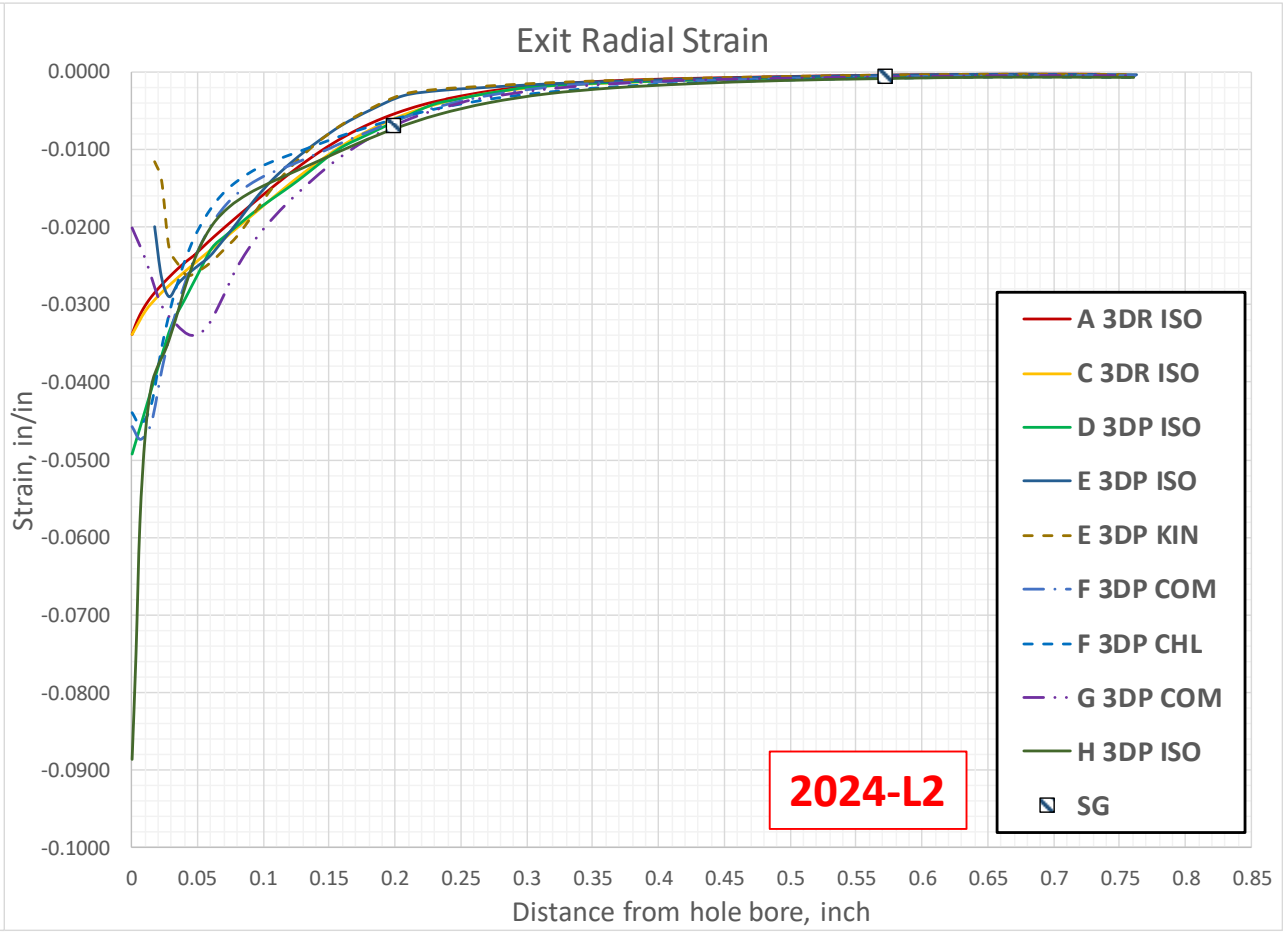

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RS Process Simulation Round Robin – Results v SG

Process Simulation Residual Strains – averaged over area subtended by strain gage.

2024 - L2			SG Value	A 3DR ISO		B 2DR KIN		C 3DR ISO		D 3DP ISO		E 3DP KIN	
			Residual	Residual	% Error	Residual	% Error	Residual	% Error	Residual	% Error	Residual	% Error
Entry	Hoop	Inner	**3570**	4436	24.2%	5316	48.9%	5659	58.5%	4341	21.6%	1407	-60.6%
		Outer	**982.8**	1187	20.8%	1529	55.6%	1306	32.9%	1089	10.8%	656	-33.2%
	Radial	Inner	**-5699**	-4417	-22.5%	-4657	-18.3%	-6042	6.0%	-5530	-3.0%	-2543	-55.4%
		Outer	**-460.8**	-487	5.7%	-733	59.1%	-567	23.0%	-467	1.3%	-386	-16.2%
Exit	Hoop	Inner	**5703**	4436	-22.2%	5316	-6.8%	5712	0.1%	5078	-11.0%	1632	-71.4%
		Outer	**1238**	1187	-4.1%	1529	23.5%	1312	6.0%	1247	0.7%	641	-48.2%
	Radial	Inner	**-6906**	-4417	-36.0%	-4657	-32.6%	-6096	-11.7%	-6402	-7.3%	-2882	-58.3%
		Outer	**-570.6**	-487	-14.6%	-733	28.5%	-570	-0.1%	-579	1.5%	-427	-25.2%

2024 - L2			SG Value	F 3DP COM		F 3DP CHA		G 3DP COM		H 3DP ISO		E 3DP ISO	
			Residual	Residual	% Error	Residual	% Error	Residual	% Error	Residual	% Error	Residual	% Error
Entry	Hoop	Inner	**3570**	3775	5.7%	3664	2.6%	4598	28.8%	5723	60.3%	1455	-59.2%
		Outer	**982.8**	1073	9.2%	836	-14.9%	1053	7.1%	1275	29.7%	721	-26.6%
	Radial	Inner	**-5699**	-5318	-6.7%	-5333	-6.4%	-5567	-2.3%	-6273	10.1%	-2595	-54.5%
		Outer	**-460.8**	-500	8.5%	-458	-0.6%	-405	-12.1%	-561	21.7%	-416	-9.7%
Exit	Hoop	Inner	**5703**	4640	-18.6%	5010	-12.2%	5948	4.3%	7121	24.9%	1757	-69.2%
		Outer	**1238**	1446	16.8%	1826	47.5%	1225	-1.0%	1698	37.2%	708	-42.8%
	Radial	Inner	**-6906**	-6506	-5.8%	-9342	35.3%	-7069	2.4%	-7090	2.7%	-3110	-55.0%
		Outer	**-570.6**	-669	17.3%	-803	40.7%	-555	-2.7%	-765	34.1%	-481	-15.7%

All values in µinch/inch. Green: less than ±10% Red: more than ±30%

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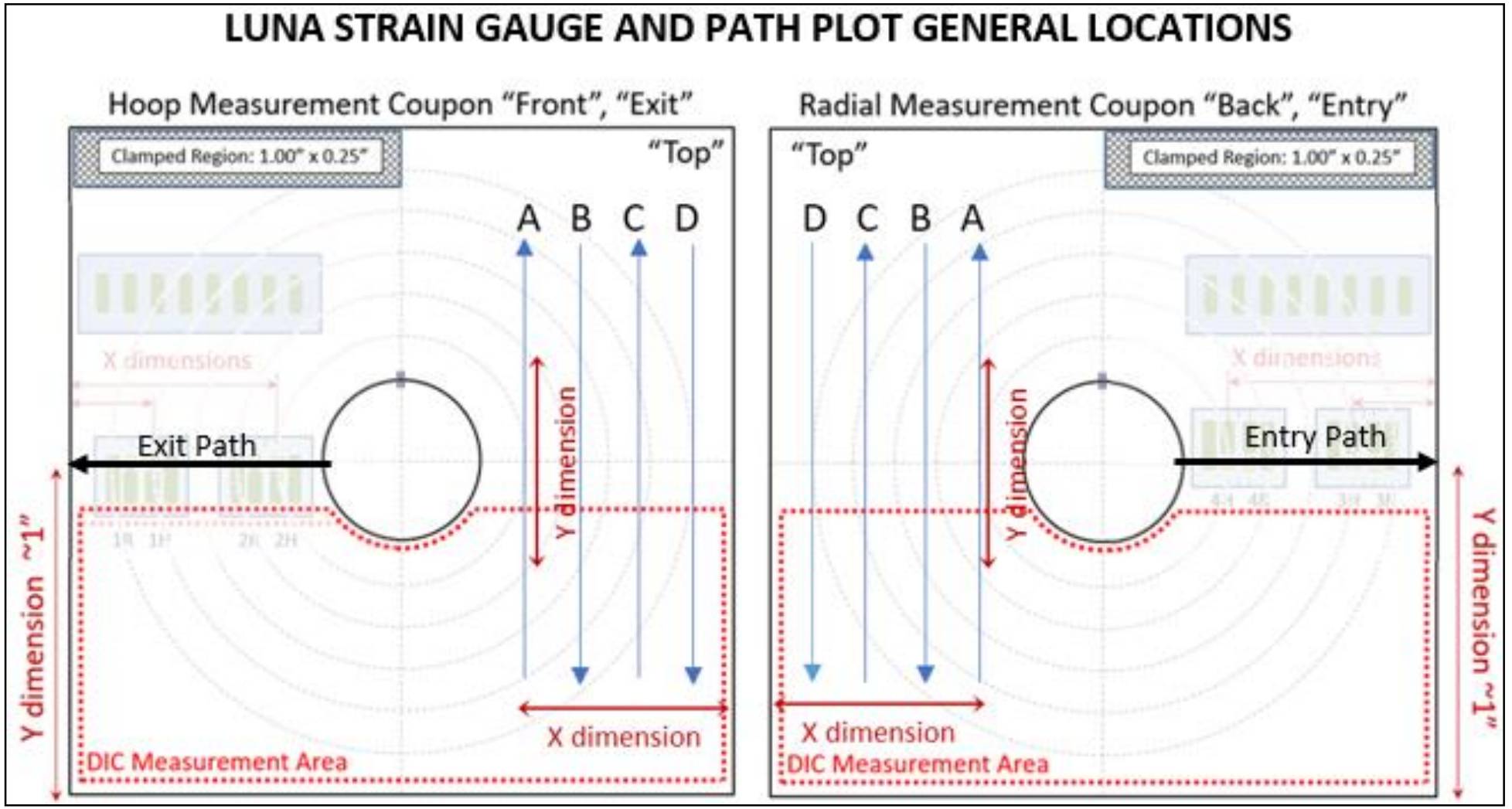
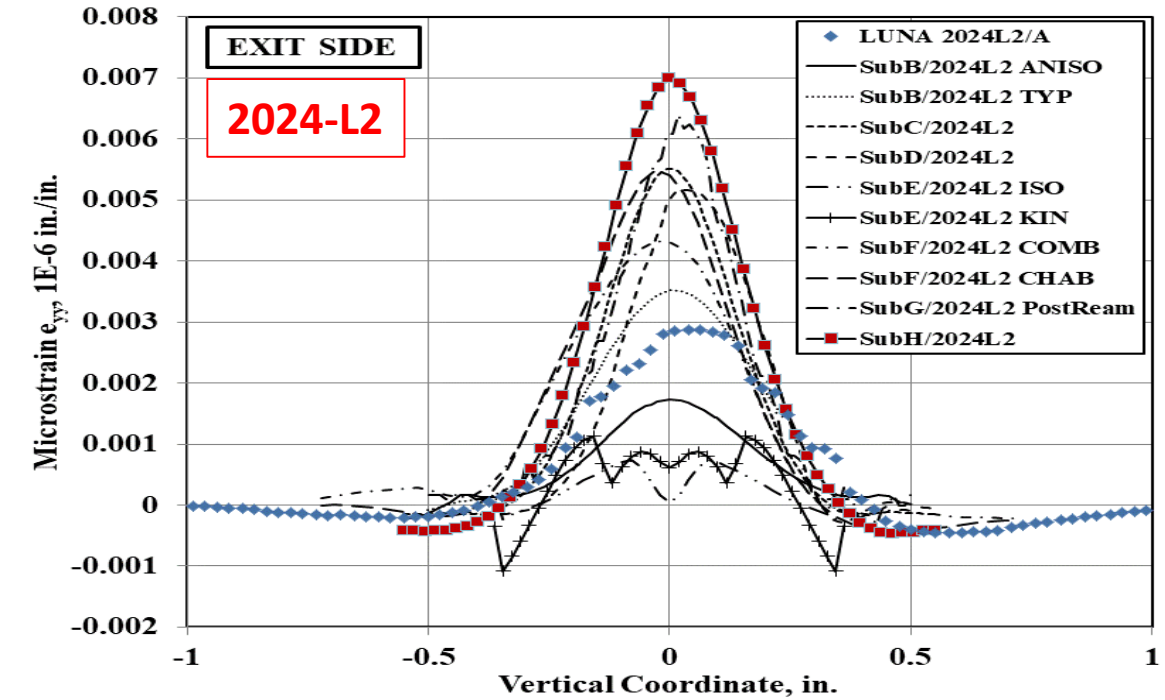
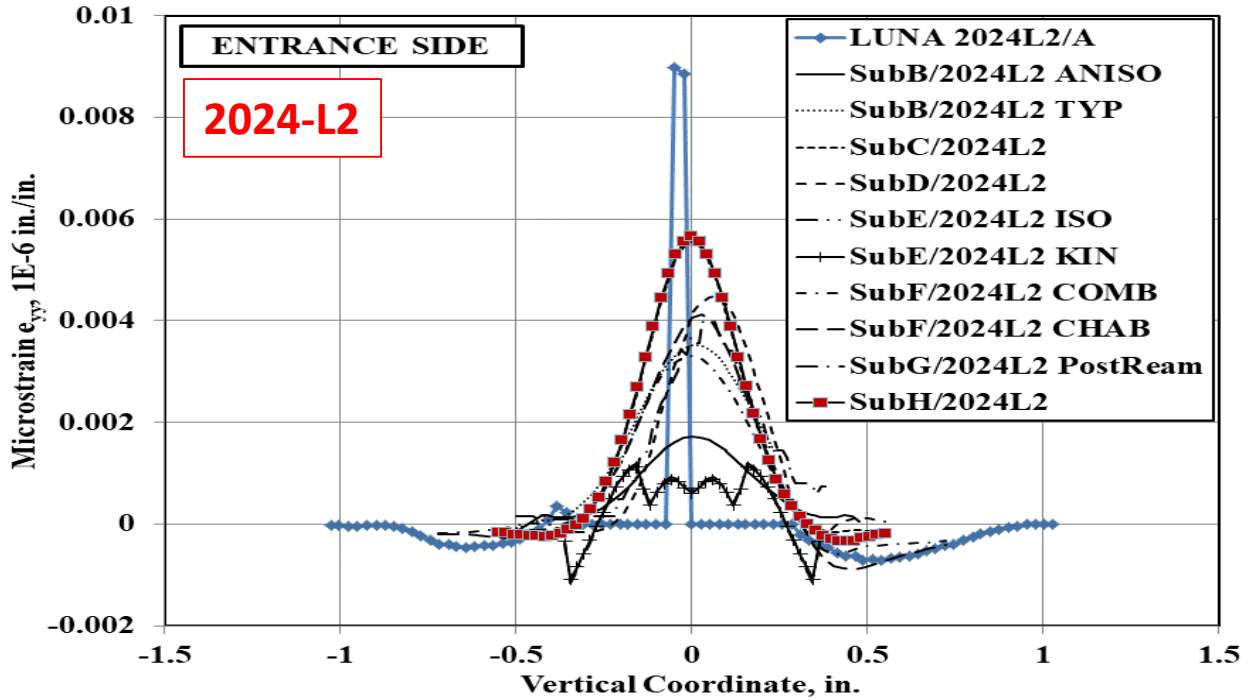
RS Process Simulation Round Robin – Results v Luna




EXIT SIDE
2024-L2
LUNA 2024L2/A
SubB/2024L2 ANISO
SubB/2024L2 TYP
SubC/2024L2
SubD/2024L2
SubE/2024L2 ISO
SubE/2024L2 KIN
SubF/2024L2 COMB
SubF/2024L2 CHAB
SubG/2024L2 PostReam
SubH/2024L2
Microstrain e_{yy}, 1E-6 in./in.
Vertical Coordinate, in.


ENTRANCE SIDE
2024-L2
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Microstrain e_{yy}, 1E-6 in./in.
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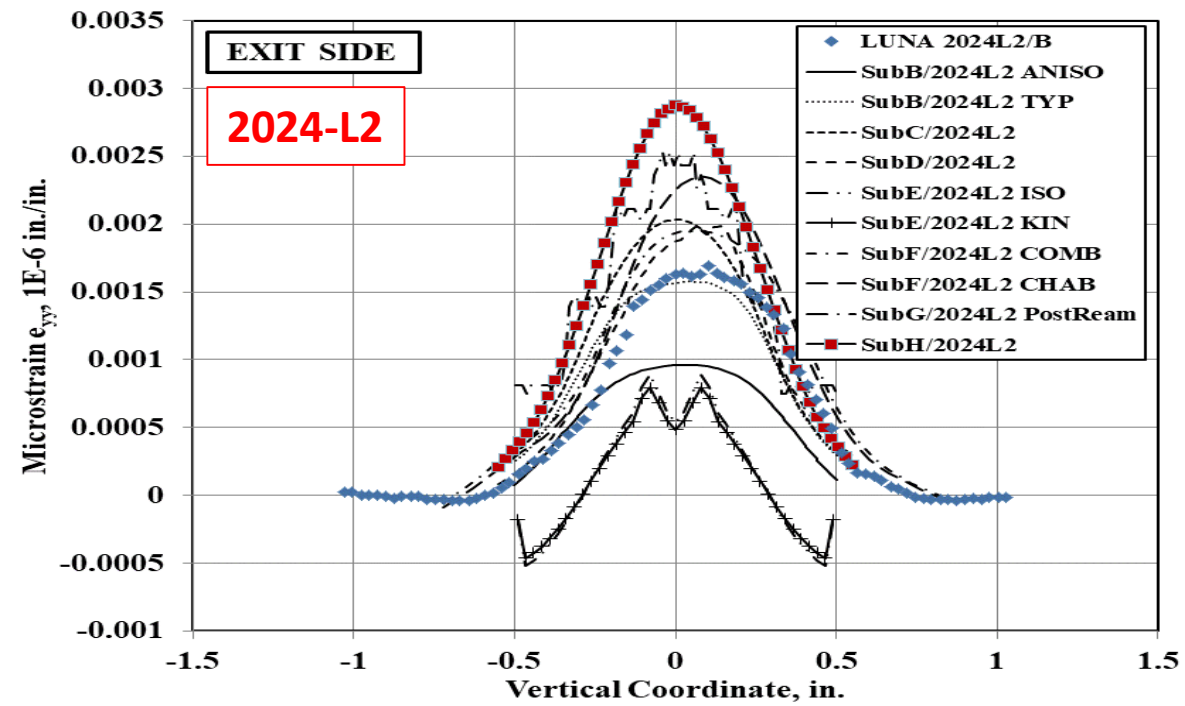
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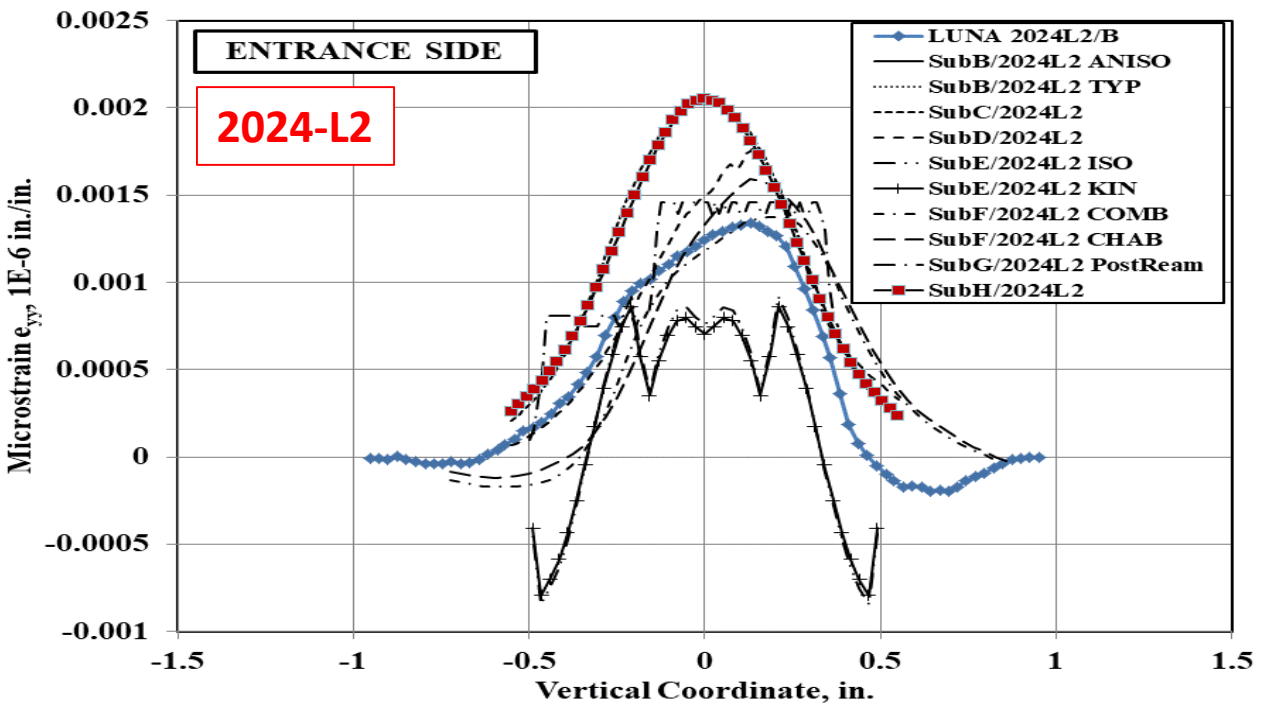
ENTRANCE SIDE
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SubC/2024L2
SubD/2024L2
SubE/2024L2 ISO
SubE/2024L2 KIN
SubF/2024L2 COMB
SubF/2024L2 CHAB
SubG/2024L2 PostReam
SubH/2024L2
Microstrain e_{yy}, 1E-6 in./in.
Vertical Coordinate, in.

Other Items of Interest

- 2x2 Specimen (Stansfield)
  - Surface Paper
  - Final Measurements
- Round Robin Last Steps
  - Complete Report Out
  - Paper Submittal
- Round Robin: GLS

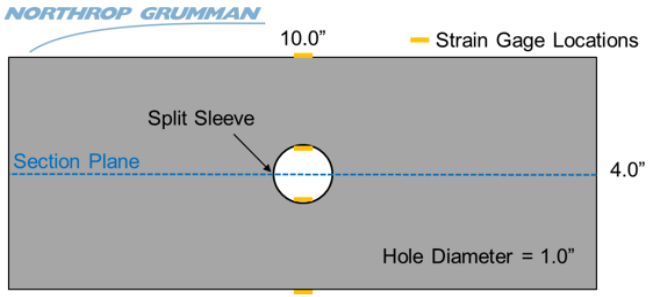


Figure 1 Geometrically "large" test coupon illustration

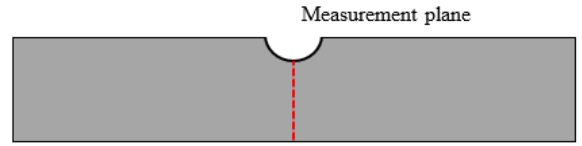
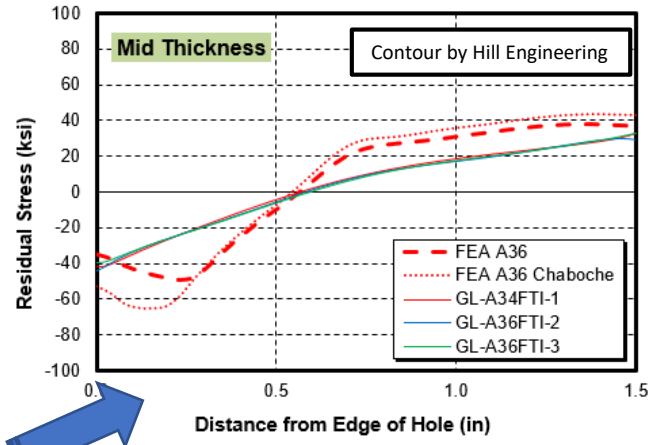
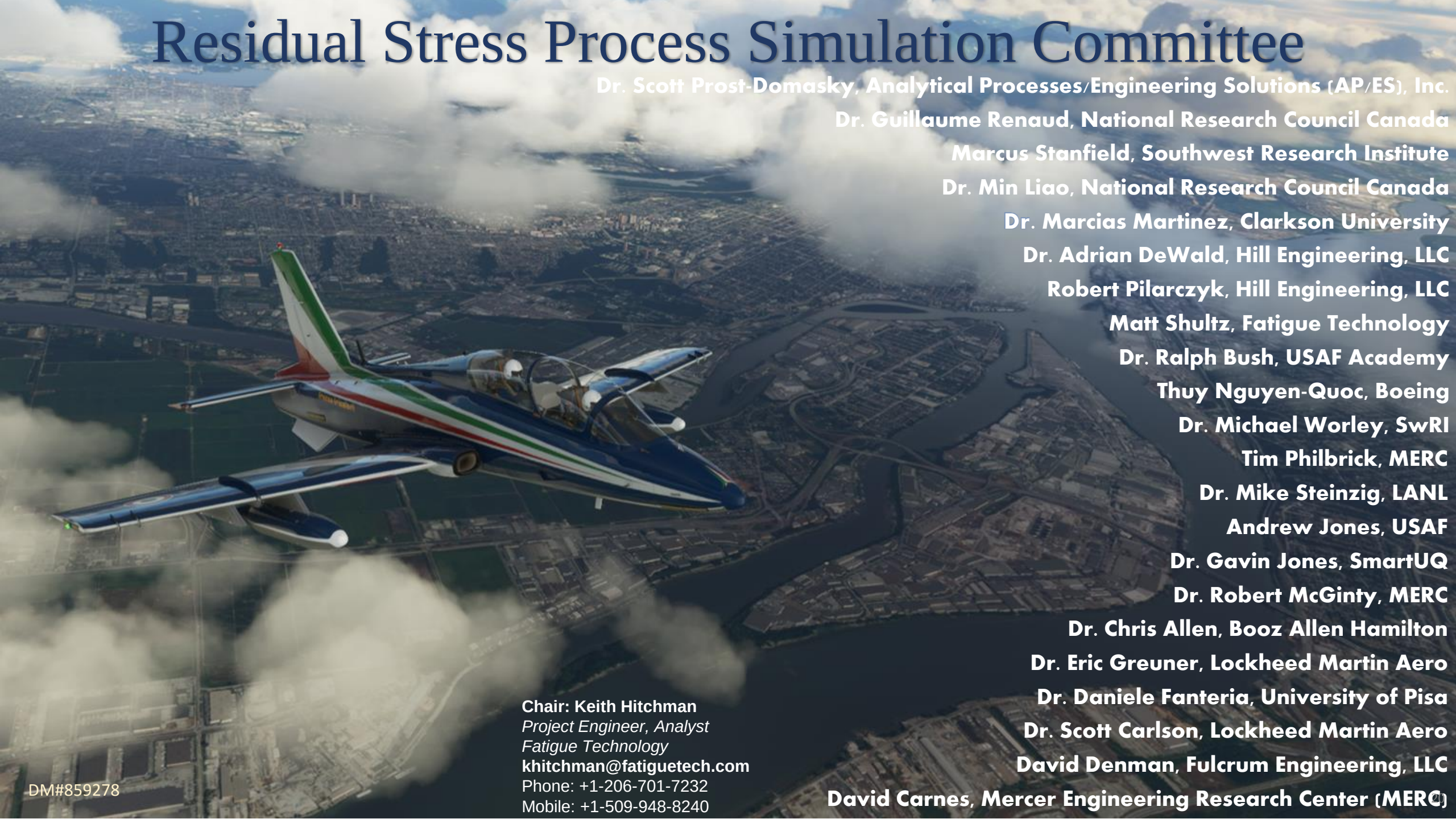


Figure 2 Illustration of contour measurement plane



Residual Stress Process Simulation Committee



Dr. Scott Prost-Domasky, Analytical Processes/Engineering Solutions (AP/ES), Inc.

Dr. Guillaume Renaud, National Research Council Canada

Marcus Stanfield, Southwest Research Institute

Dr. Min Liao, National Research Council Canada

Dr. Marcias Martinez, Clarkson University

Dr. Adrian DeWald, Hill Engineering, LLC

Robert Pilarczyk, Hill Engineering, LLC

Matt Shultz, Fatigue Technology

Dr. Ralph Bush, USAF Academy

Thuy Nguyen-Quoc, Boeing

Dr. Michael Worley, SwRI

Tim Philbrick, MERC

Dr. Mike Steinzig, LANL

Andrew Jones, USAF

Dr. Gavin Jones, SmartUQ

Dr. Robert McGinty, MERC

Dr. Chris Allen, Booz Allen Hamilton

Dr. Eric Greuner, Lockheed Martin Aero

Dr. Daniele Fanteria, University of Pisa

Dr. Scott Carlson, Lockheed Martin Aero

David Denman, Fulcrum Engineering, LLC

David Carnes, Mercer Engineering Research Center (MERC)

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Project Engineer, Analyst
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