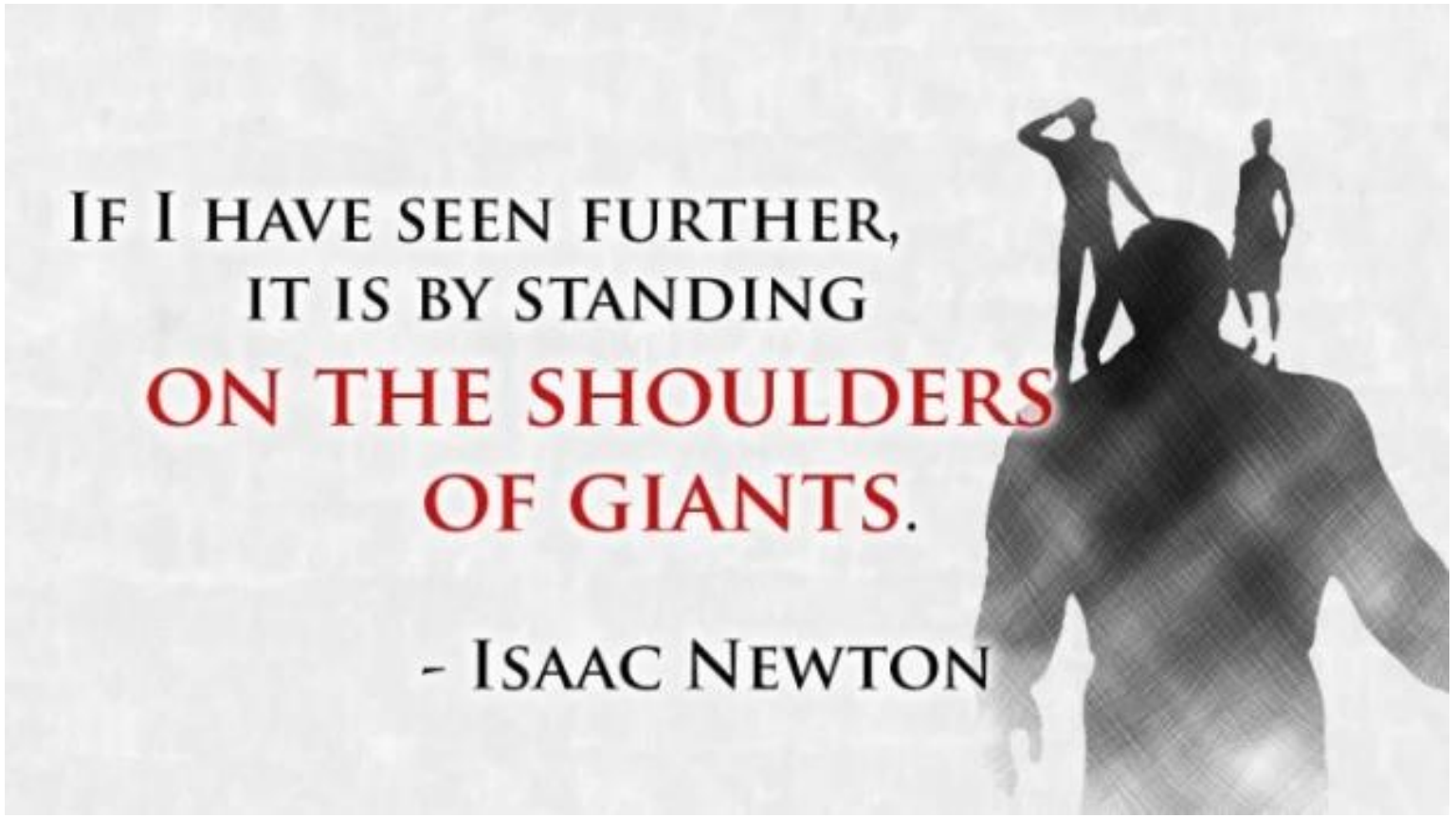
THE A-10 WARTHOG: DAMAGE TOLERANCE AND RESIDUAL STRESS IN TRANSITION

U.S. AIR FORCE

Jacob Warner and Dallen Andrew

We're Better Together

- **Thanks to all, I am grateful to learn and grow from your knowledge, expertise, wisdom and much more**
- **Special thanks to:**
  - **God and my family**
  - **Dallen Andrew (co-author)**
  - **The A-10 engineering group**
  - **All of you**

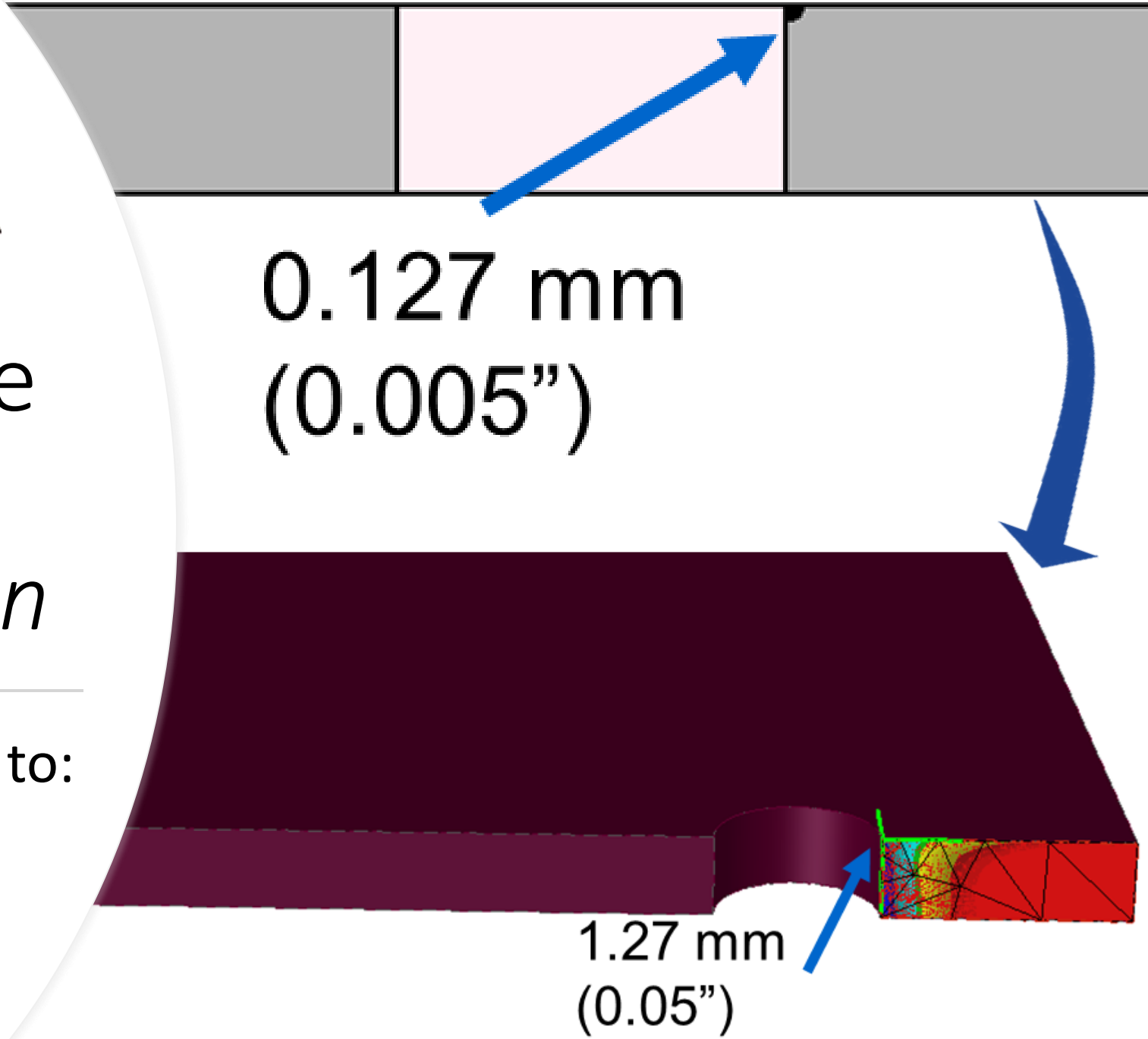


3-Star Learning Experiences
https://3starlearningexperiences.wordpress.com/2018/12/24/standing-on-the-shoulders-of-giants-an-offer-you-cant-refuse/

Damage Tolerance and Residual Stress *in Transition*

Legacy Methods in Transition to:

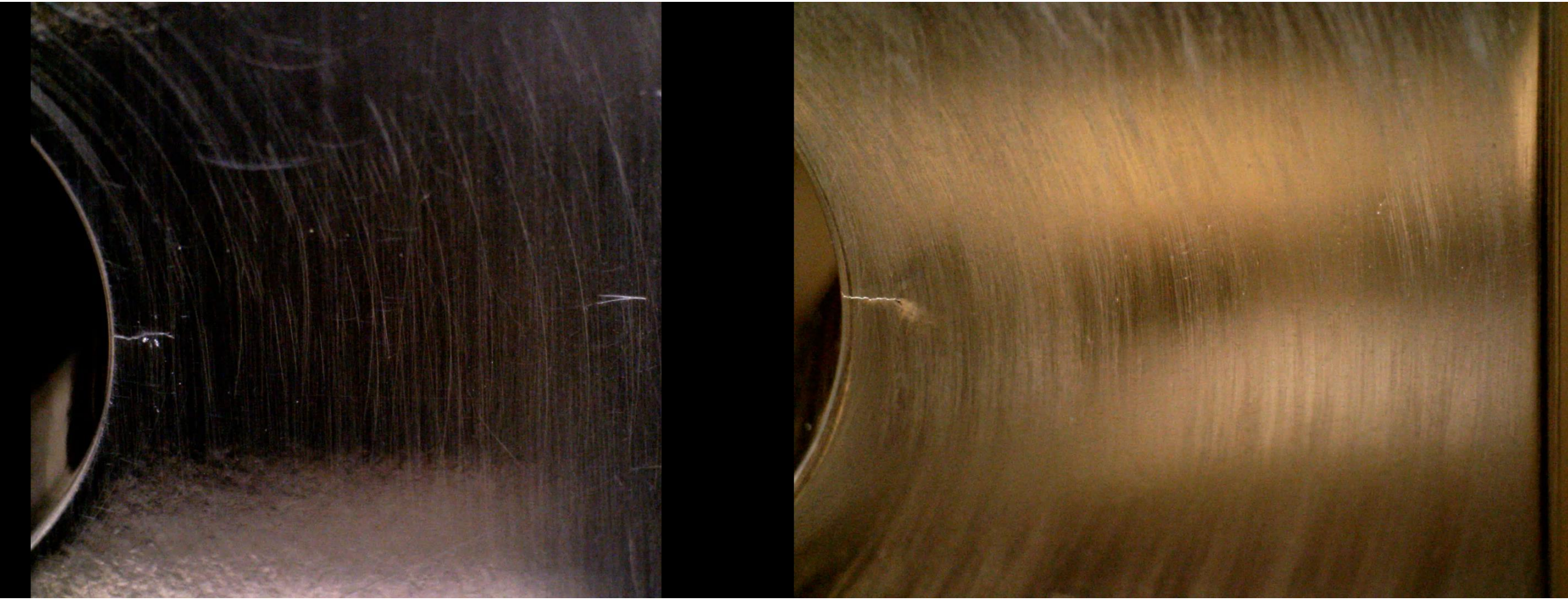
THE STATE OF THE ART



Cold Expansion (CX) Benefit

CX

Non CX



Equivalent Initial Crack Method

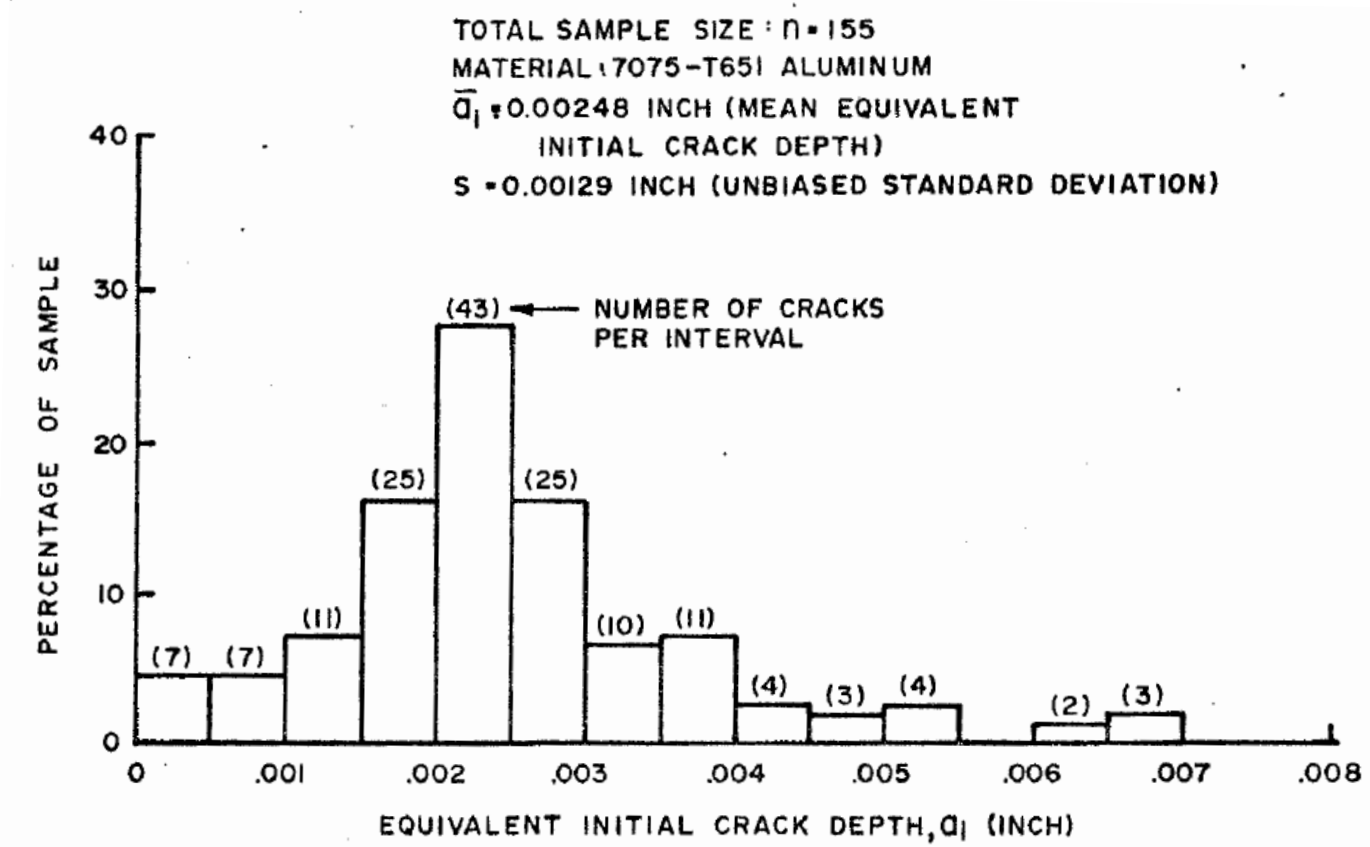
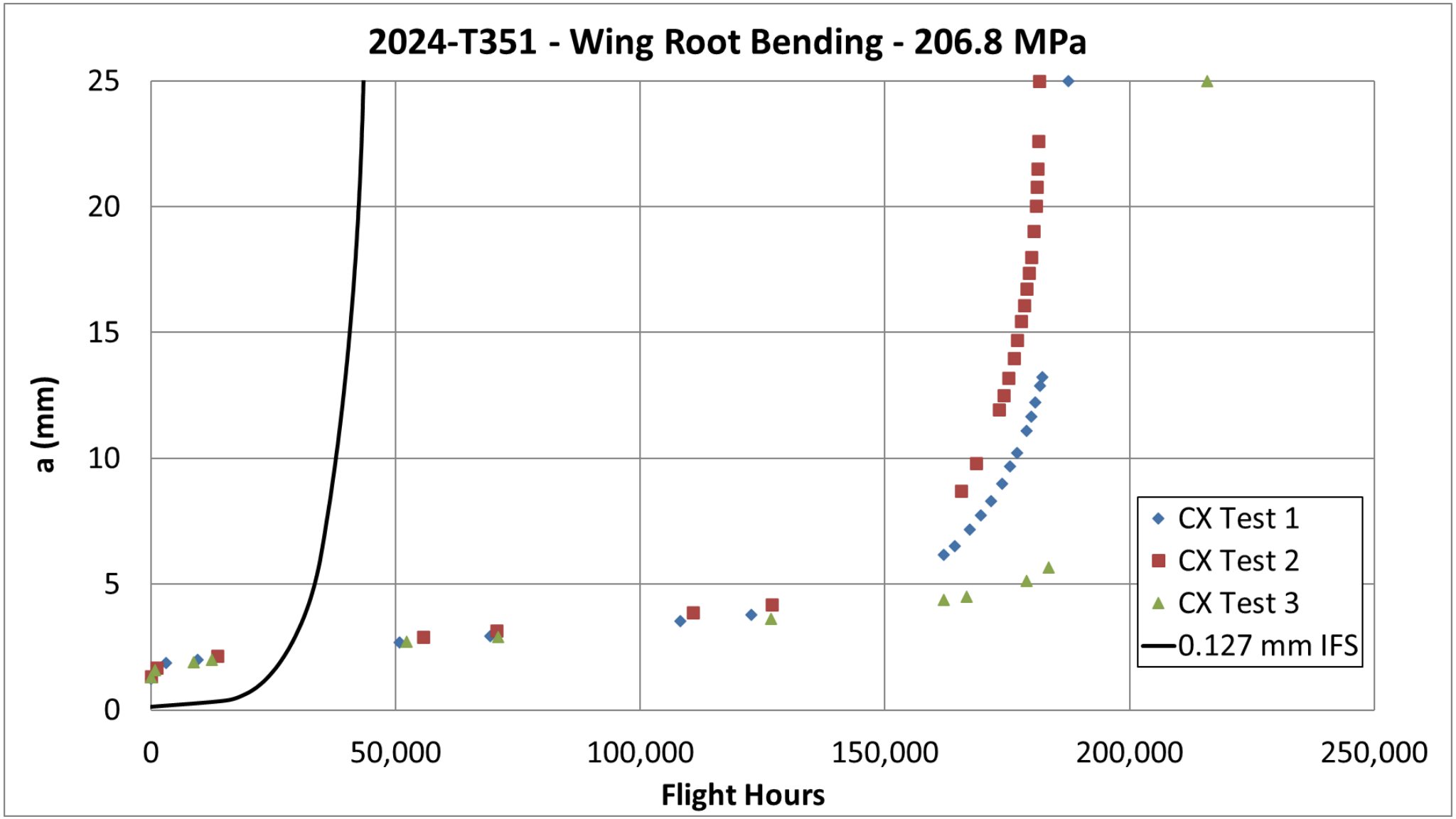


Figure 16. Equivalent Initial Crack Depth Histogram for Reamed Holes for F-4E(S) Aircraft

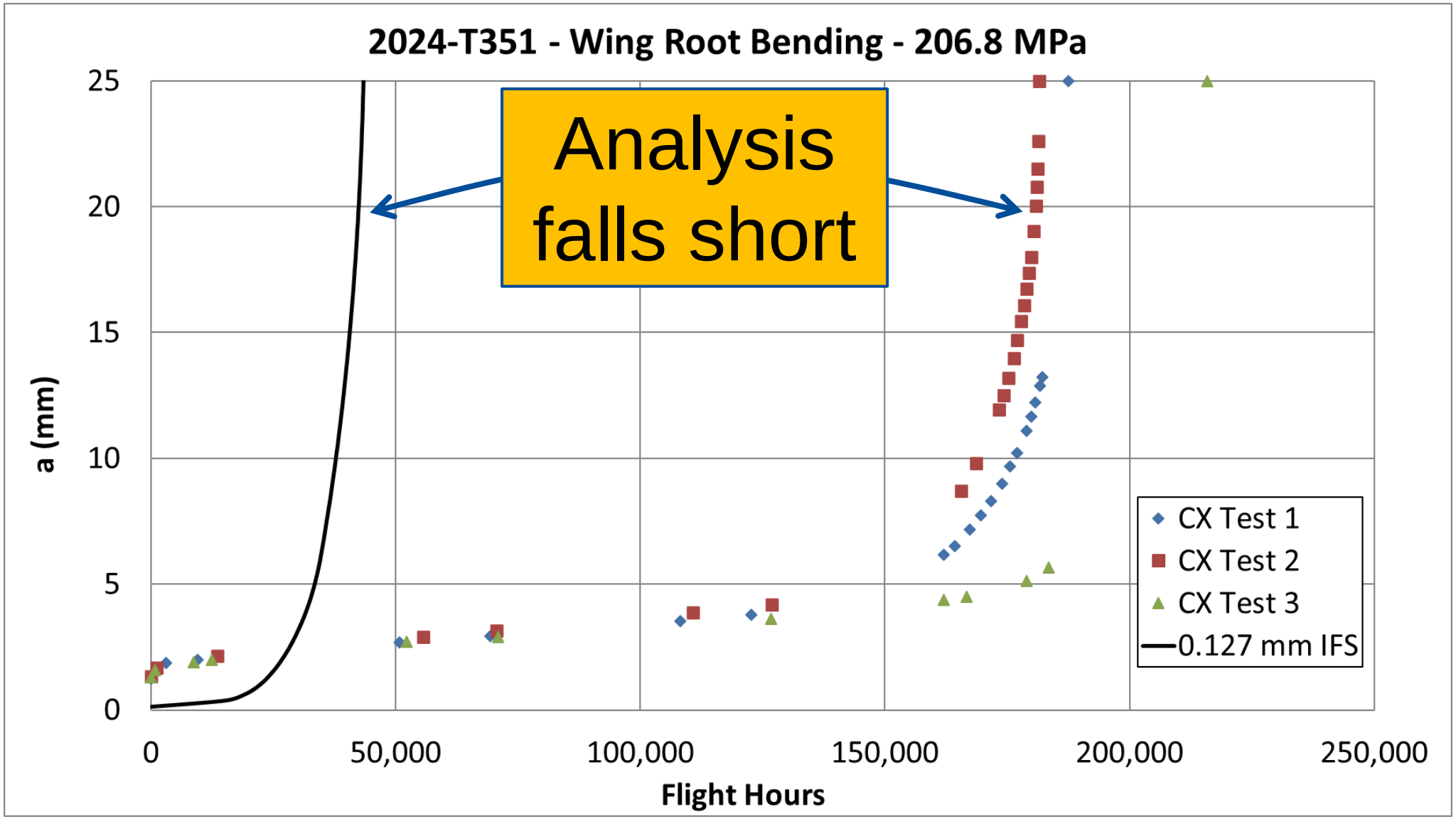
- **Standard analysis:**
  - **Lincoln: "no documented case on a service aircraft where the 1.27 mm (0.05") corner flaw was unconservative."**
- **CX benefit:**
  - **JSSG-2006: "no greater than the benefit derived by assuming a (0.127 mm) .005 inch radius corner flaw"**

Rudd, J., (1977), *Technical Memorandum AFFDL-TM-77-58-FBE*, Applications of the Equivalent Initial Quality Method.
Lincoln, J., (1985), In: Damage Tolerance – USAF Experience, Proceedings of the 13th ICAF Symposium.
US Department of Defense (1998), *Joint Service Specification Guide – Aircraft Structures*, JSSG-2006.

Equivalent Initial Crack Size Shortfalls

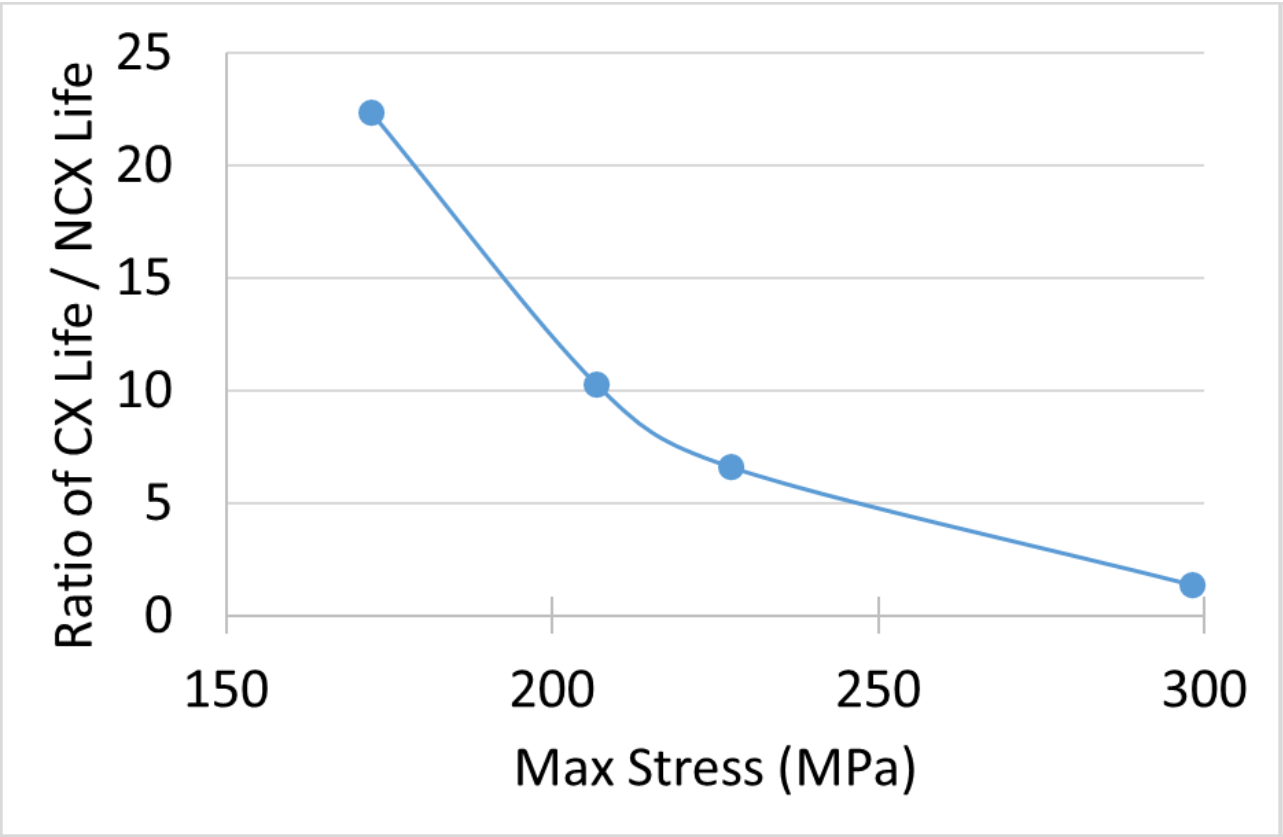


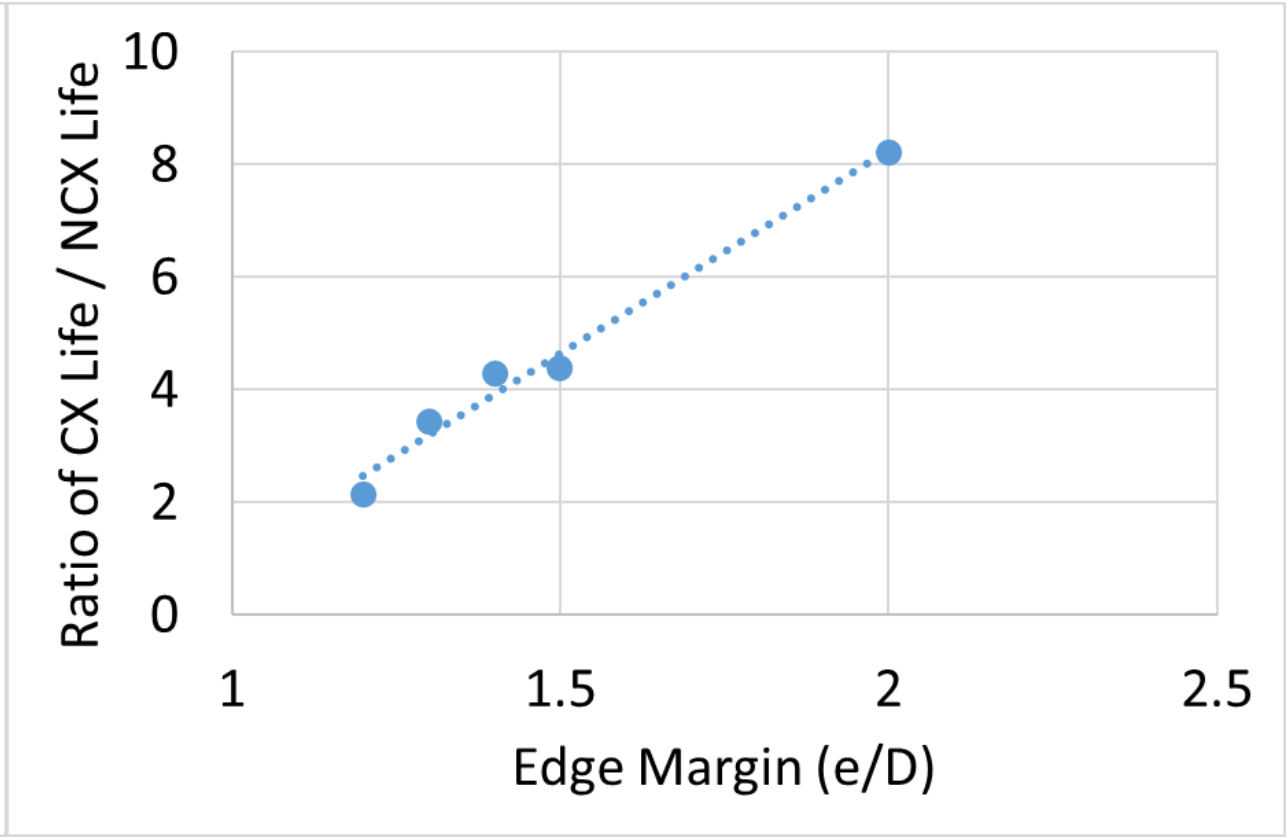
Equivalent Initial Crack Size Shortfalls



Equivalent Initial Crack Size Shortfalls

- **0.127 mm approach fails to capture CX benefit dependency on stress and edge margin**





Equivalent Initial Crack Size Shortfalls

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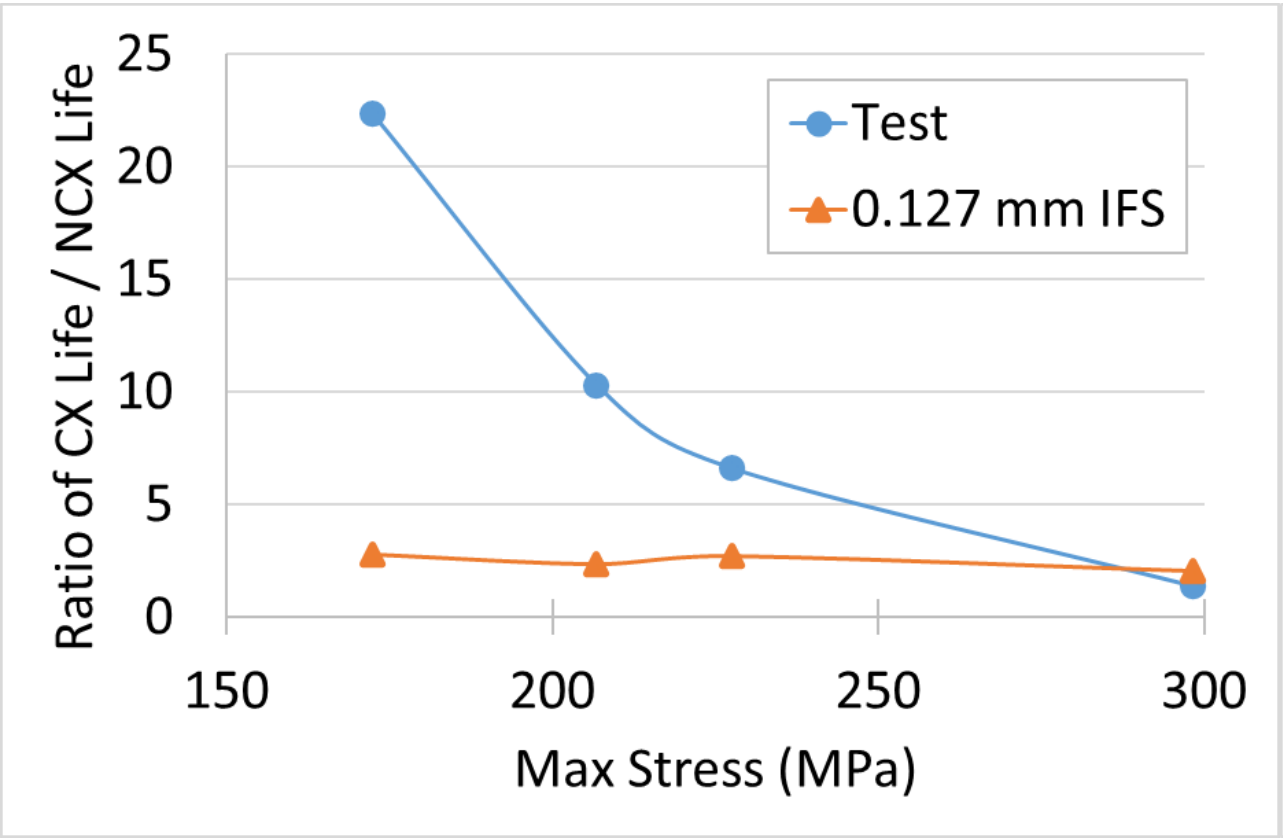
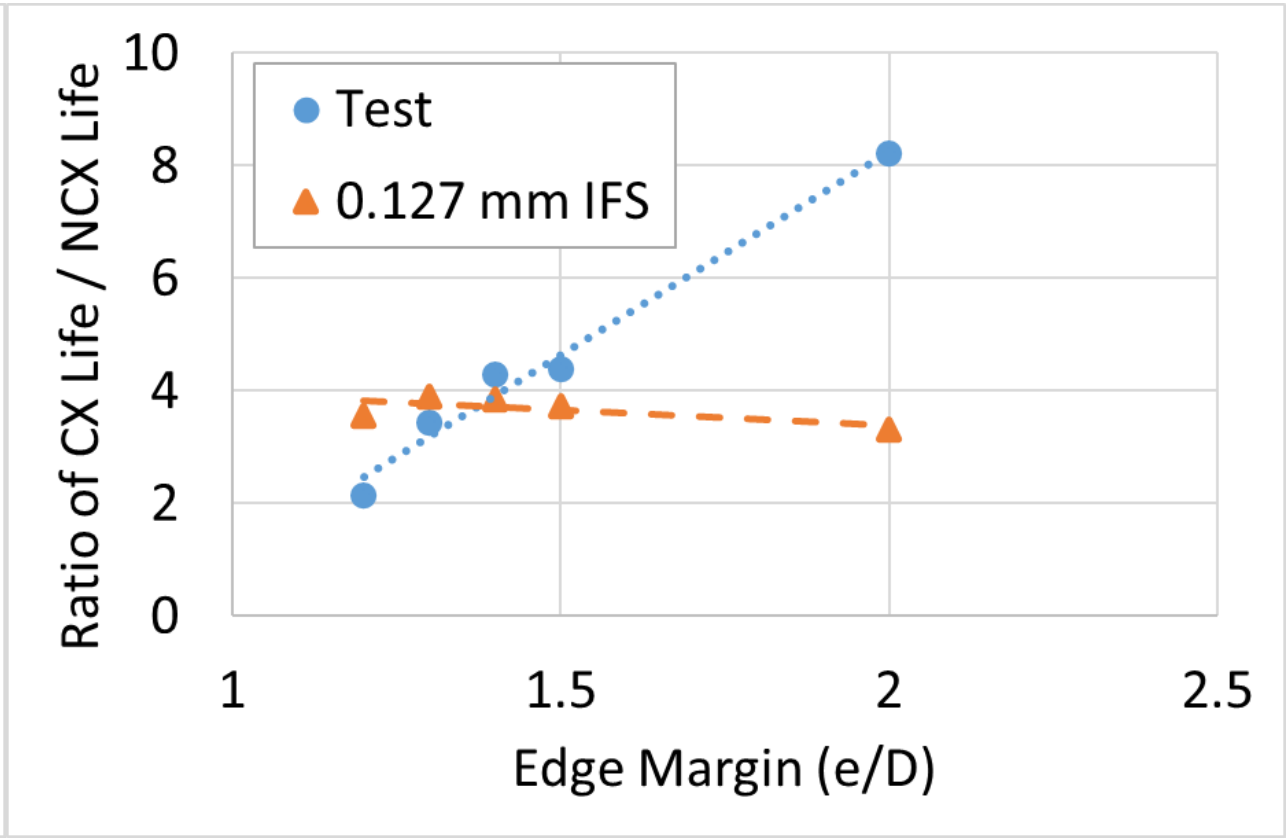
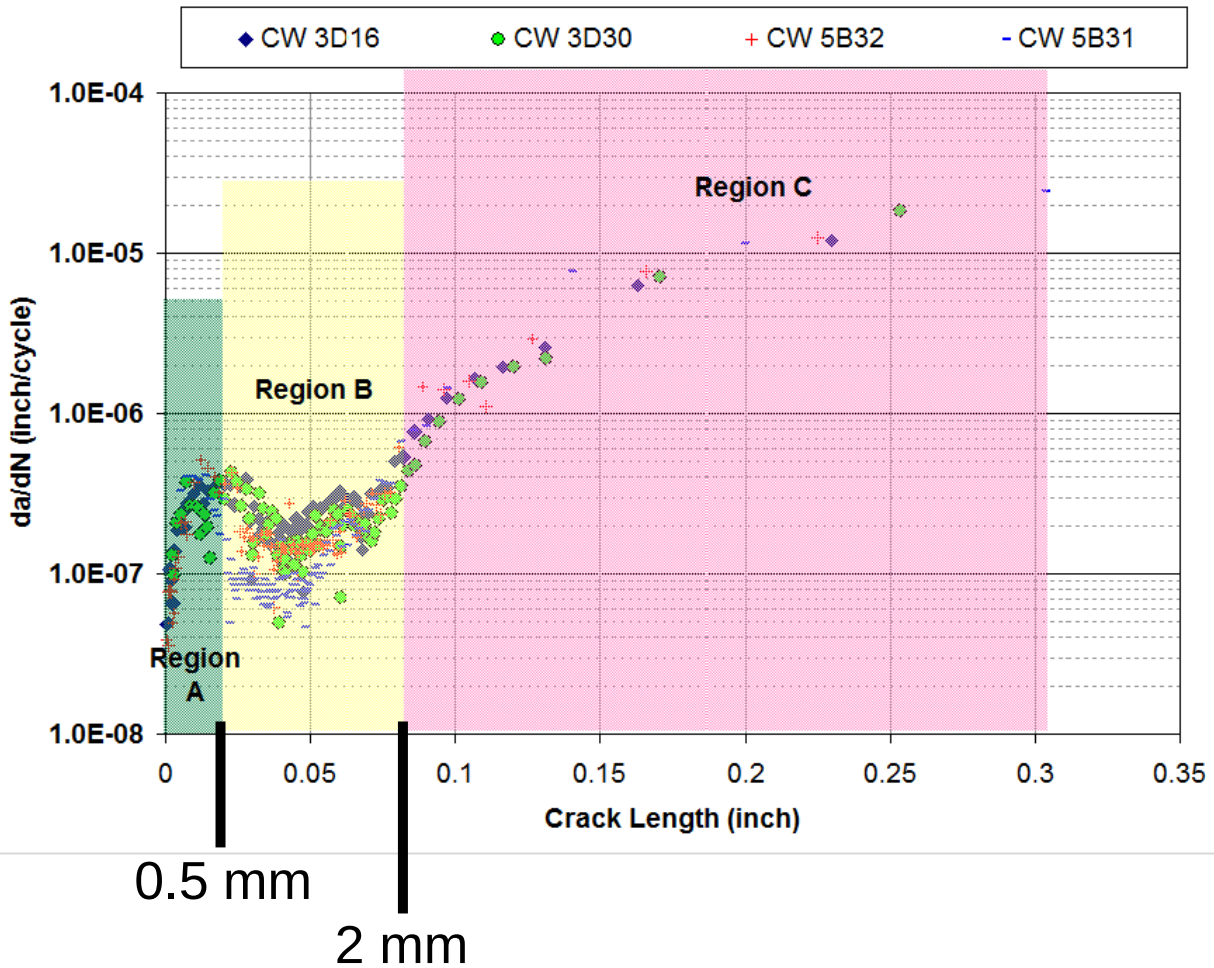
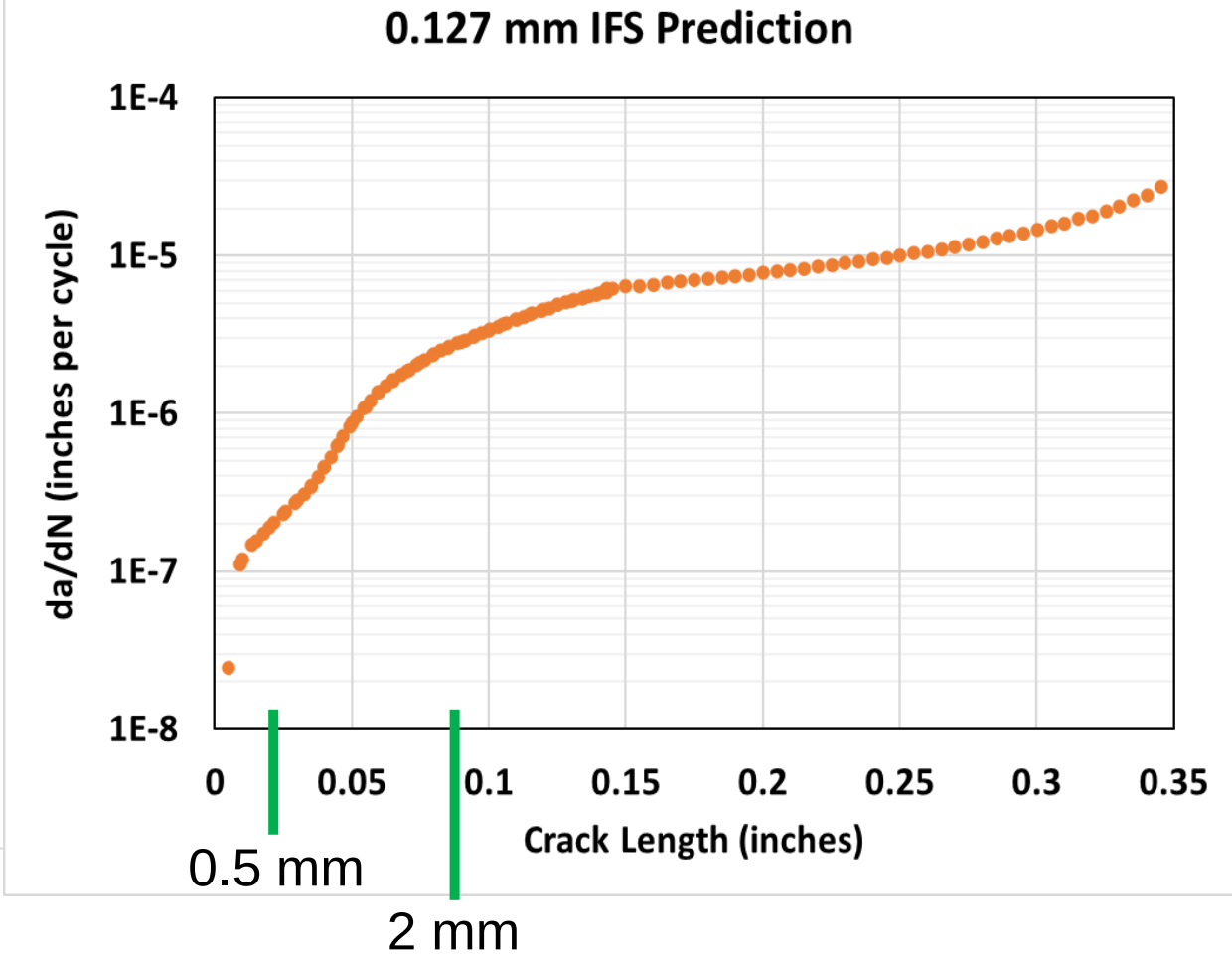




Understanding CX Crack Growth

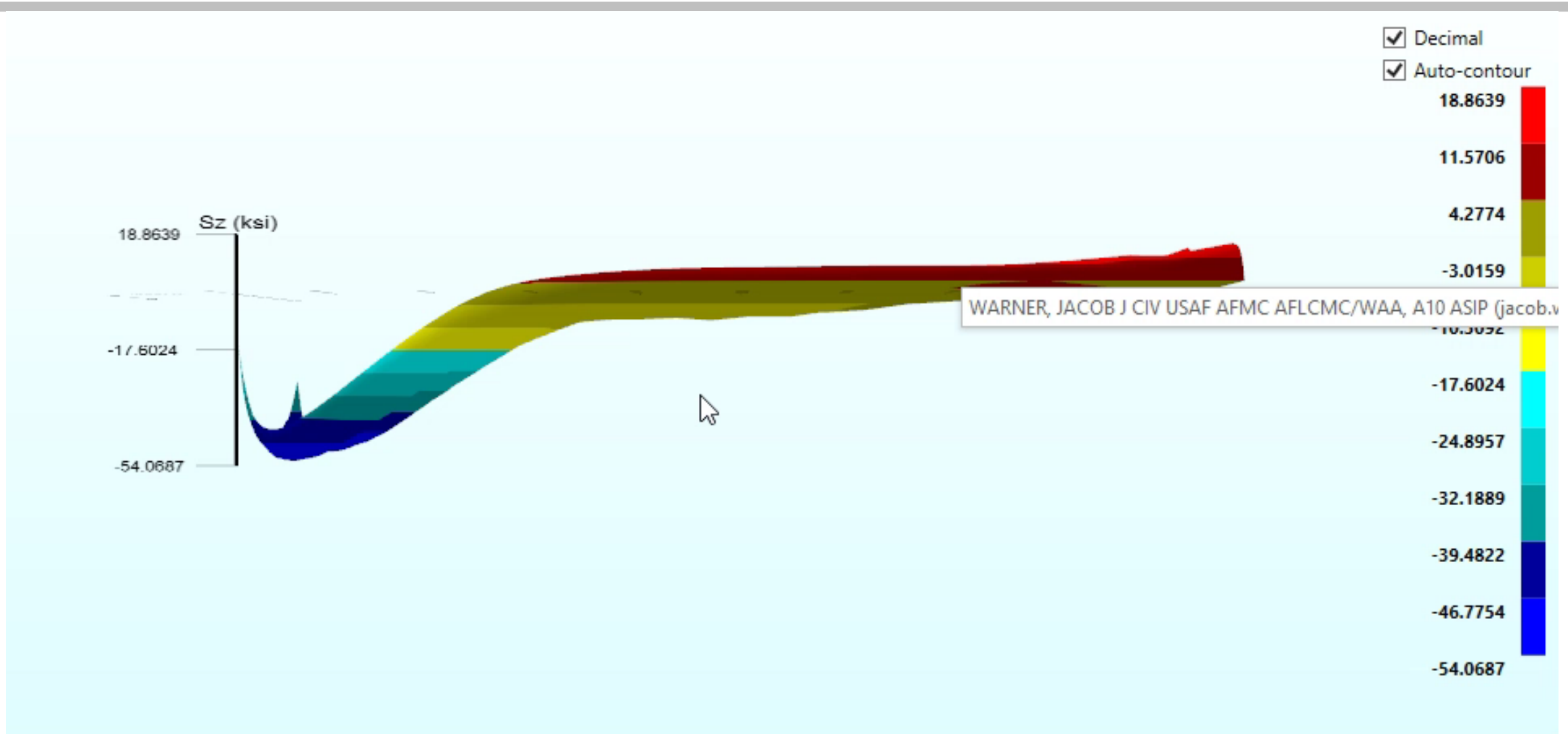
- **CX influence not characterized by equivalent initial crack method**





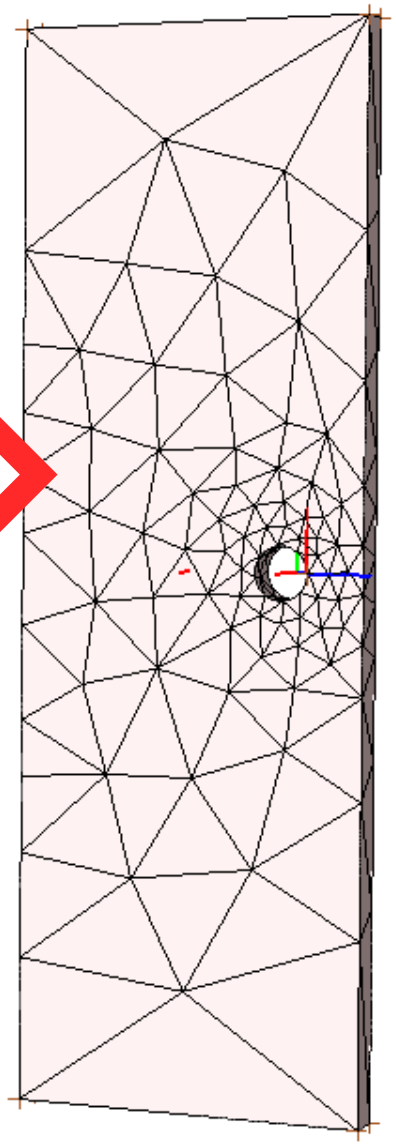
Mills, T., Honeycutt, K., Prost-Domasky, S. and Brooks, C. (2009), *Verification of Cold Working and Interference Levels at Fastener Holes*, AFRL-RB-WP-TR-2009-3045, Contract No.: FA8650-08-M-38.

Characterizing Residual Stress (RS)



RS Analysis Without Full Stress Tensor

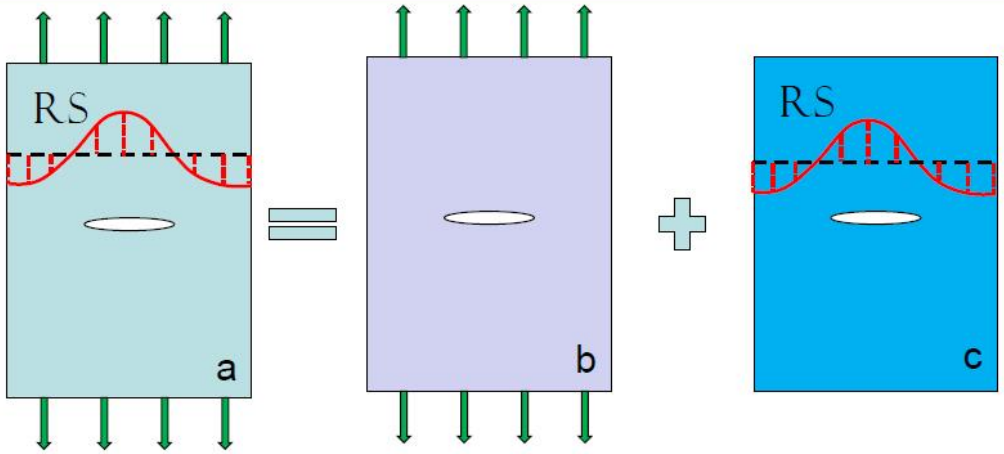
?



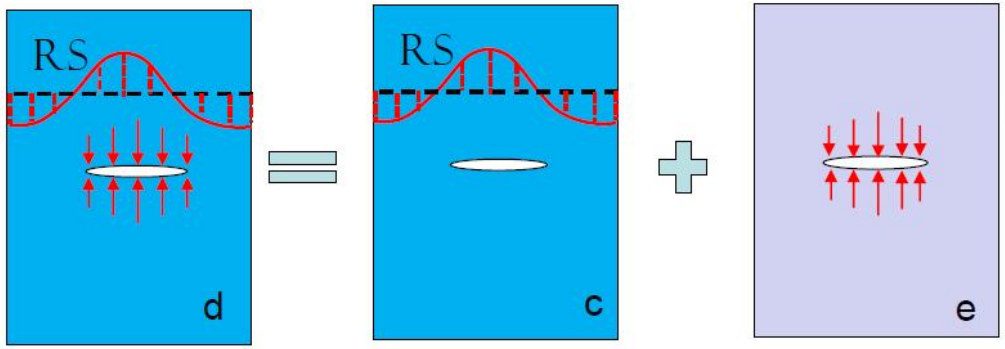
RS as a Crack Face Traction Load

SIFs by Superposition
Approach for K_{RES}

STRESSCHECK

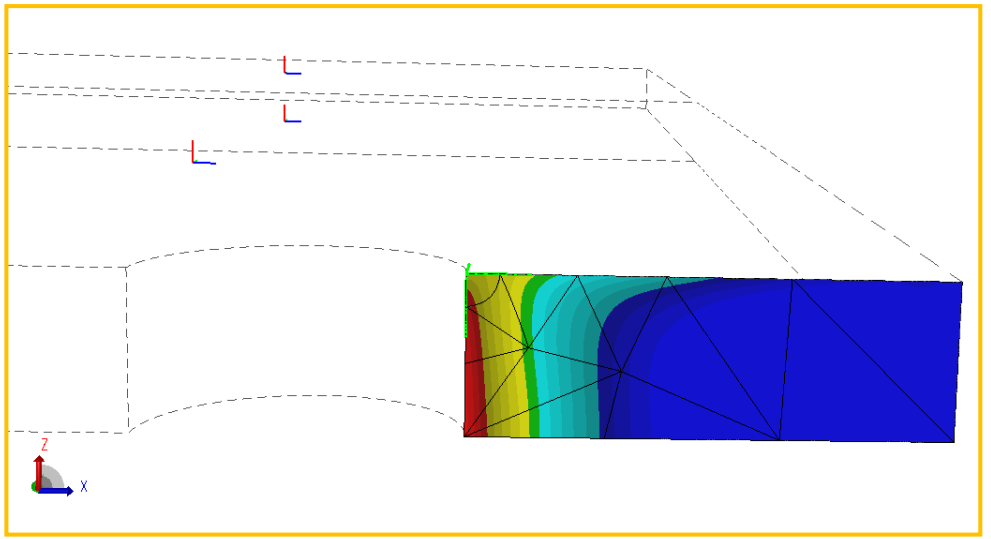


$$K_{1a} = K_{1b} + K_{1c}$$



$$K_{1d} = K_{1c} + K_{1e} = 0$$

$$K_{1c} = -K_{1e}$$



Actis, R., Watkins, M., Prost-Domasky, S., Hodges, J., (2013), ASIP Conference Proceedings, Computation of SIFs for Cracks in Cold-Worked Holes.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ERSI Advancements

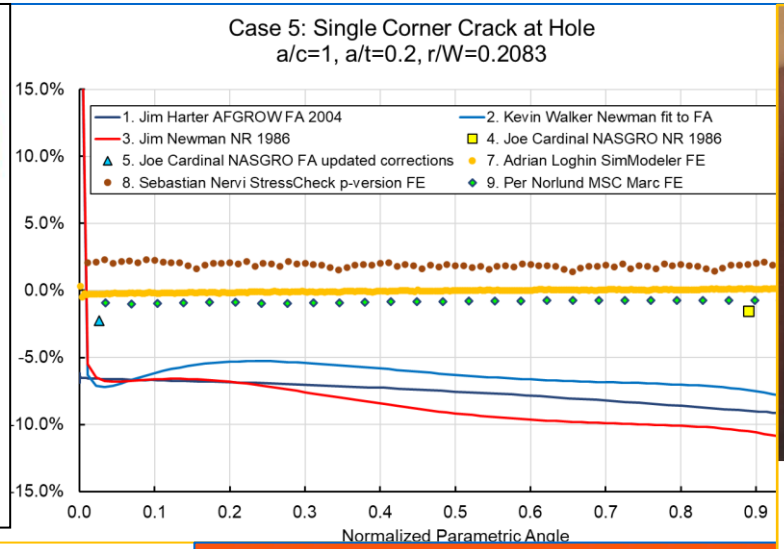
Structures Bulletin

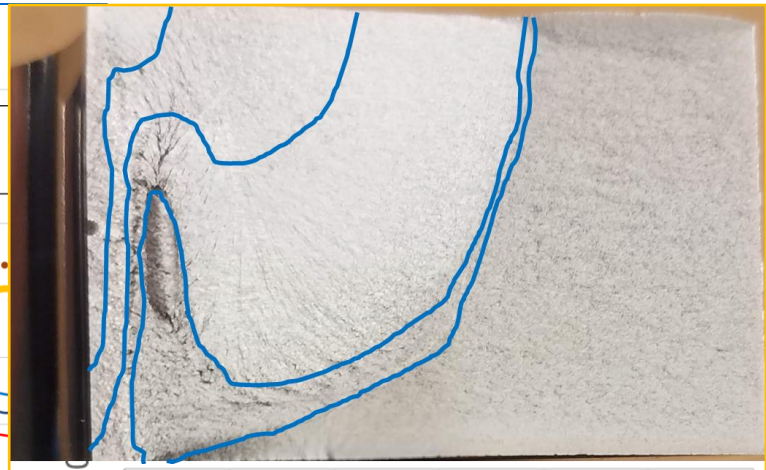
AFLCMC/EZ
Bldg. 28, 2145 Monahan Way
WPAFB OH 45433-7101
Phone: 937-255-5312

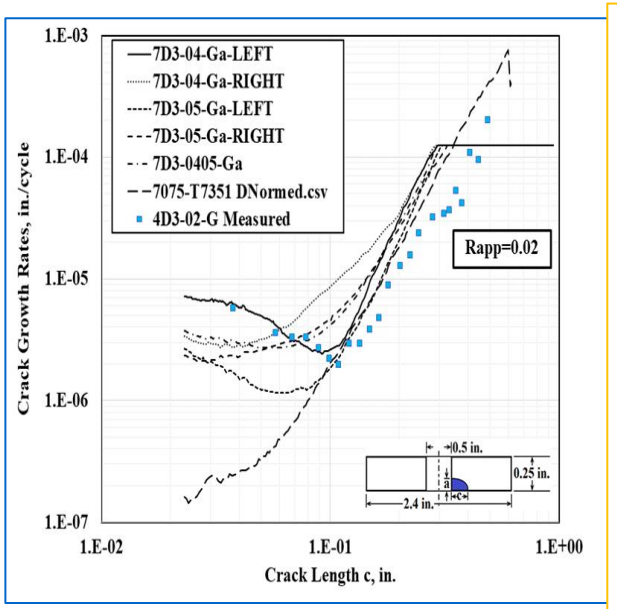
Number: EZ-SB-17-001, Revision A

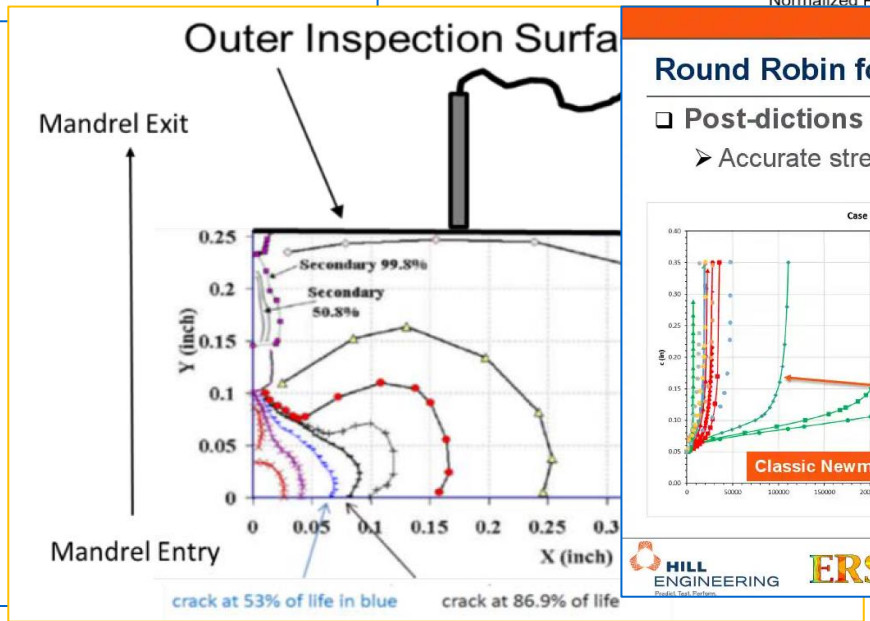
Date: December 2021

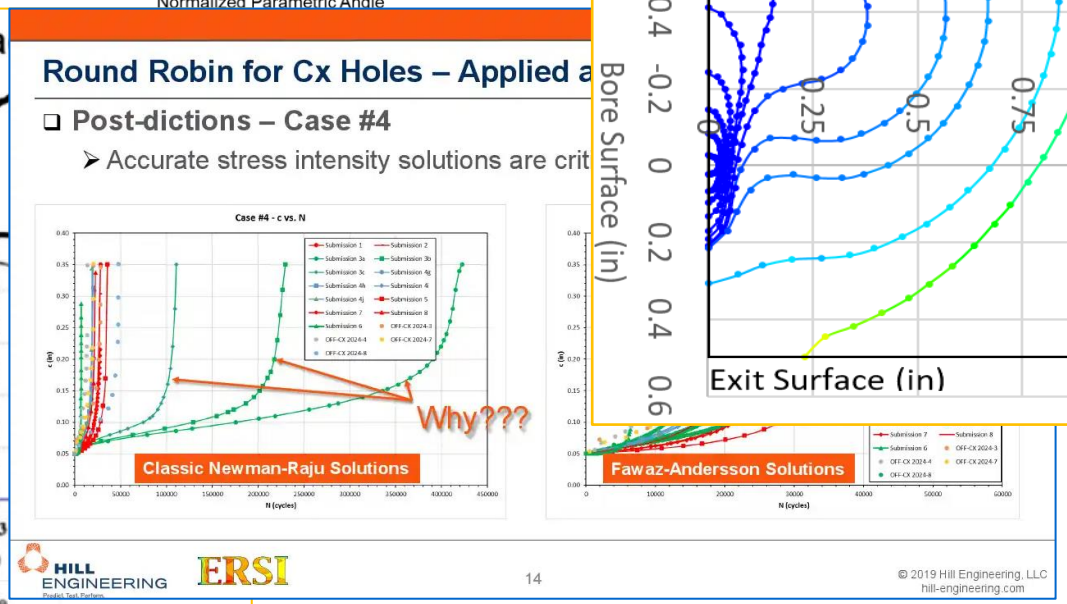
Subject: Requirements to Establish the Beneficial Effects of Cold Expanded Holes in Development of Damage Tolerance Initial and Recurring Inspection Intervals











Analysis Ground Rules

- **Requirements to validate analyses using repeatable analysis methods**

SwRI	PREPARED BY: Jacob Warner	DATE: 9/19/2022	CHECKED BY: Brian Boeke	DATE:	REV. F	PAGE: B-1
A-10 DTA RPDS Severe	Appendix B: BAMpF Ground Rules		CHECKED BY: Luciano Smith (SwRI)	DATE:	REPORT NO: SA220R0207 1 April 2023	

Appendix B: A-10 Multi-Point Crack Growth Analysis Ground Rules for Using BAMpF

The following guidelines
mechanics analysis usir
Beginning with SA220R
Analysis (DTA) on a nur
used the StressCheck C
from cold expansion.

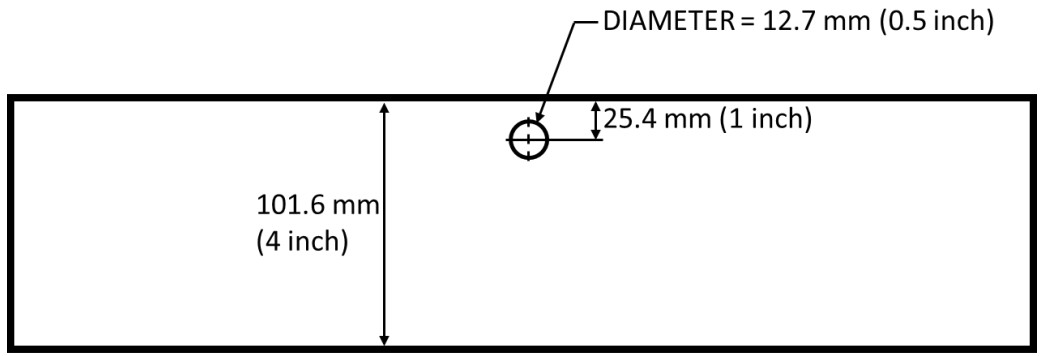
SwRI	PREPARED BY: Jacob Warner	DATE: 9/19/2022	CHECKED BY: Kaylon Anderson	DATE:	REV. F	PAGE: C-1
A-10 DTA RPDS Severe	Appendix C: Ground Rules for Including Residual Stresses from Cold Expansion in DTAs		CHECKED BY: Luciano Smith (SwRI)	DATE:	REPORT NO: SA220R0207 1 April 2023	

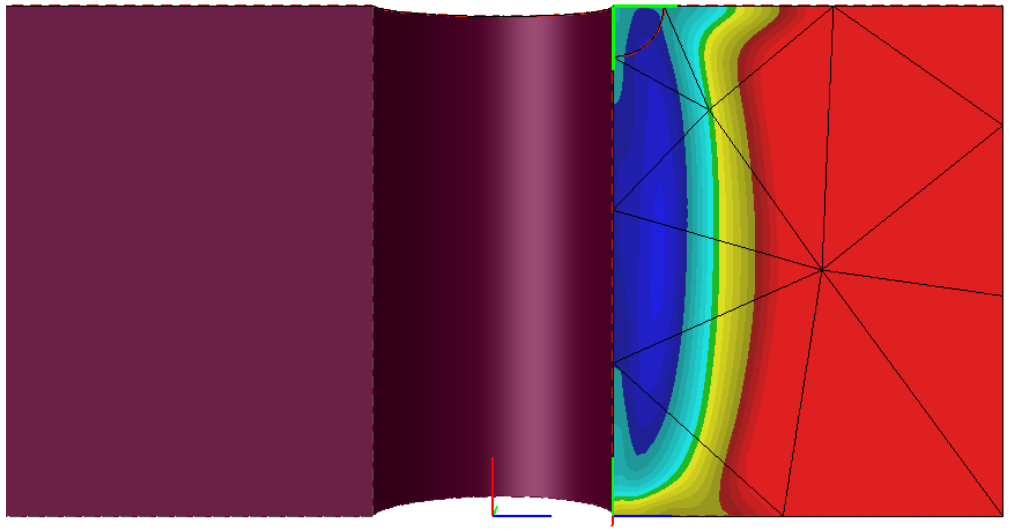
Appendix C: A-10 Ground Rules for Including Residual Stresse from Cold Expansion in Damage Tolerance Analyses

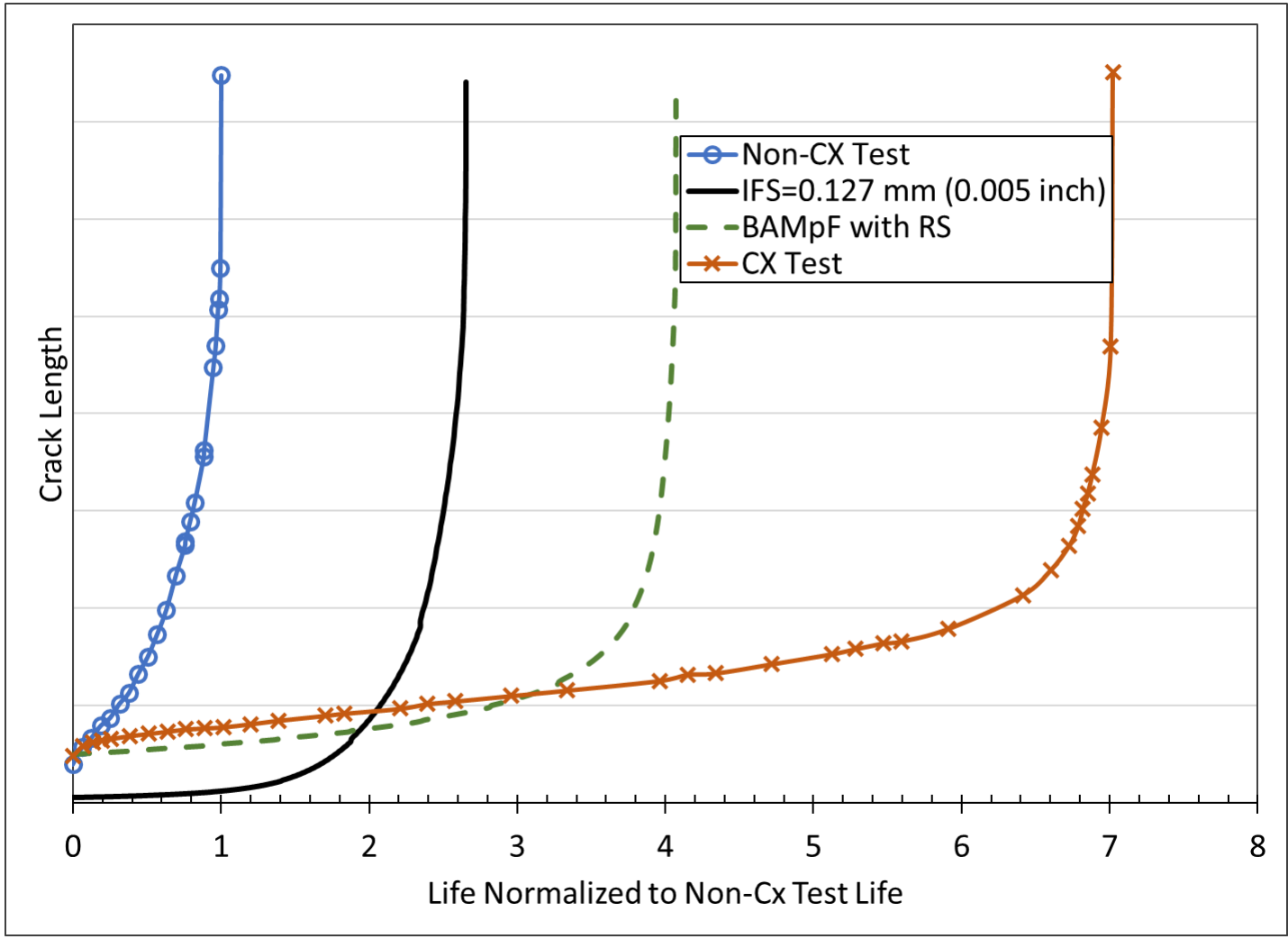
The following guidelines describe A-10 best practices for including Residual Stress (RS) in

Lower Wing Skin Example

- 228 MPa max stress
- No load transfer







Lower Wing Skin Example

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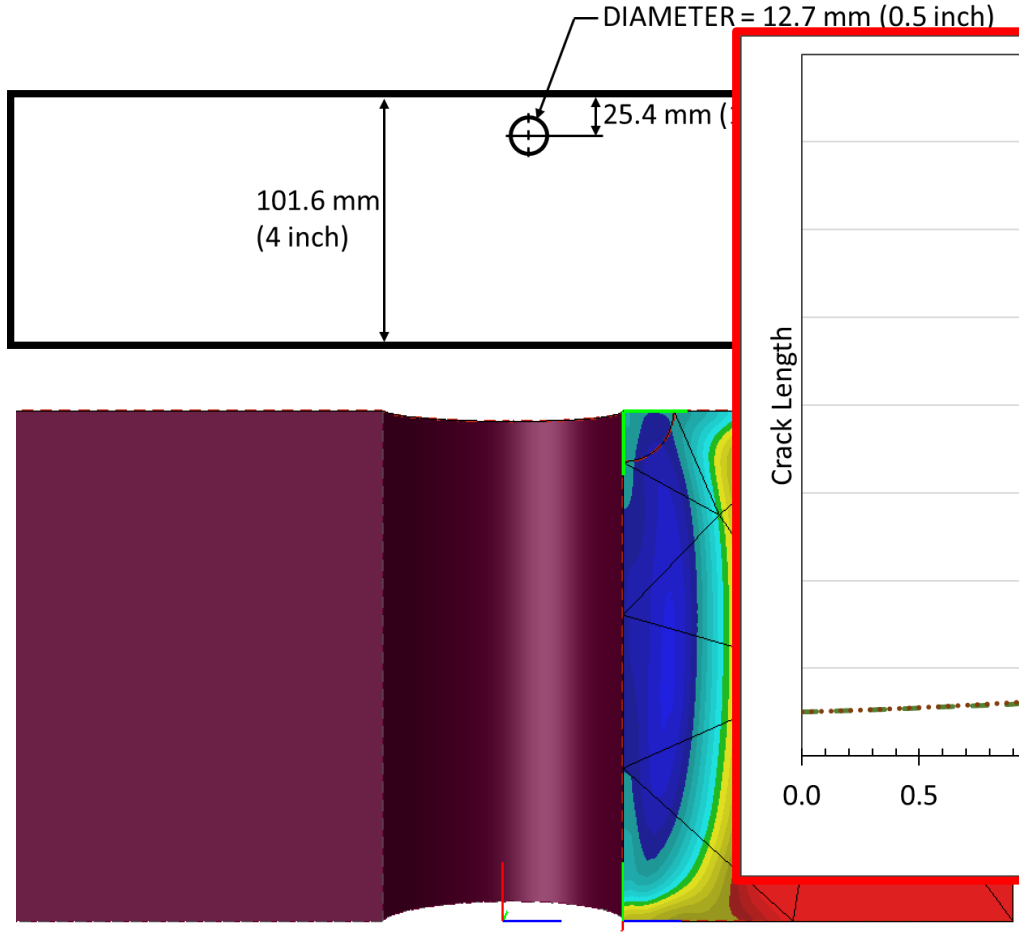
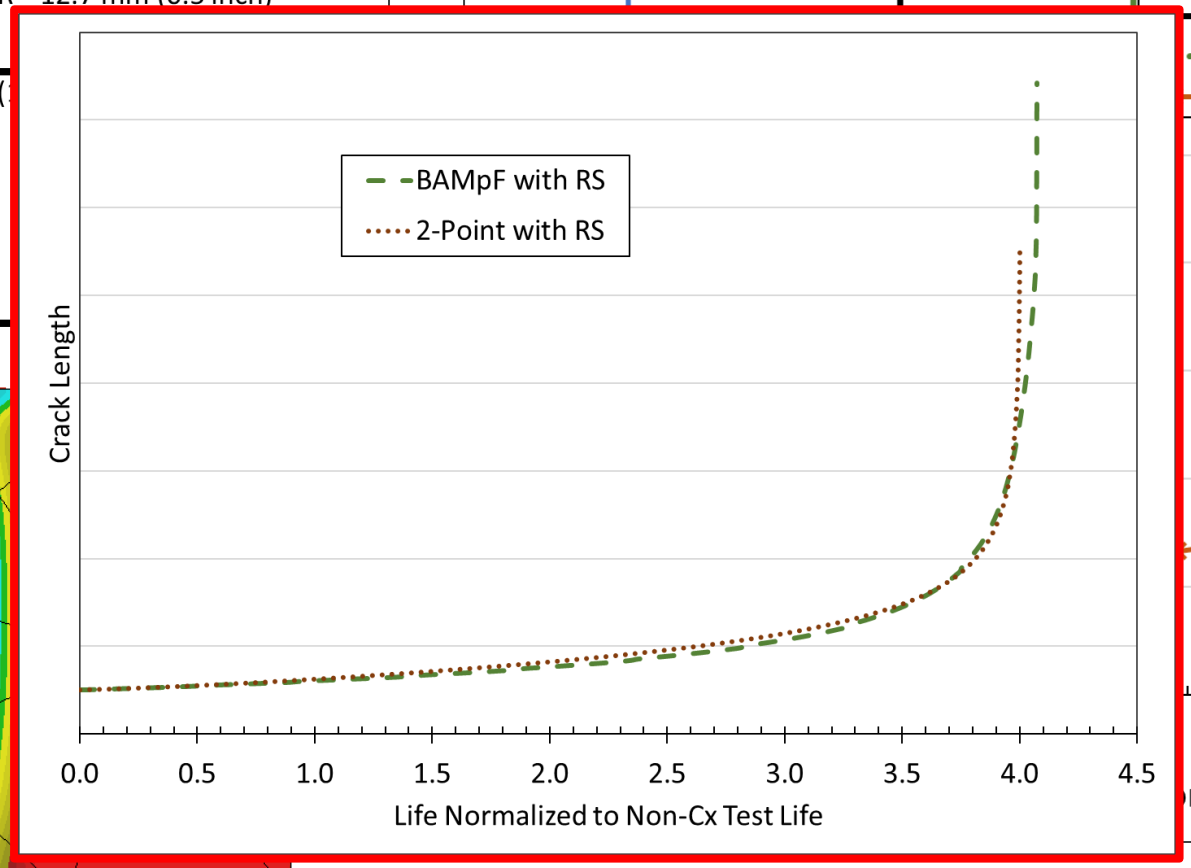
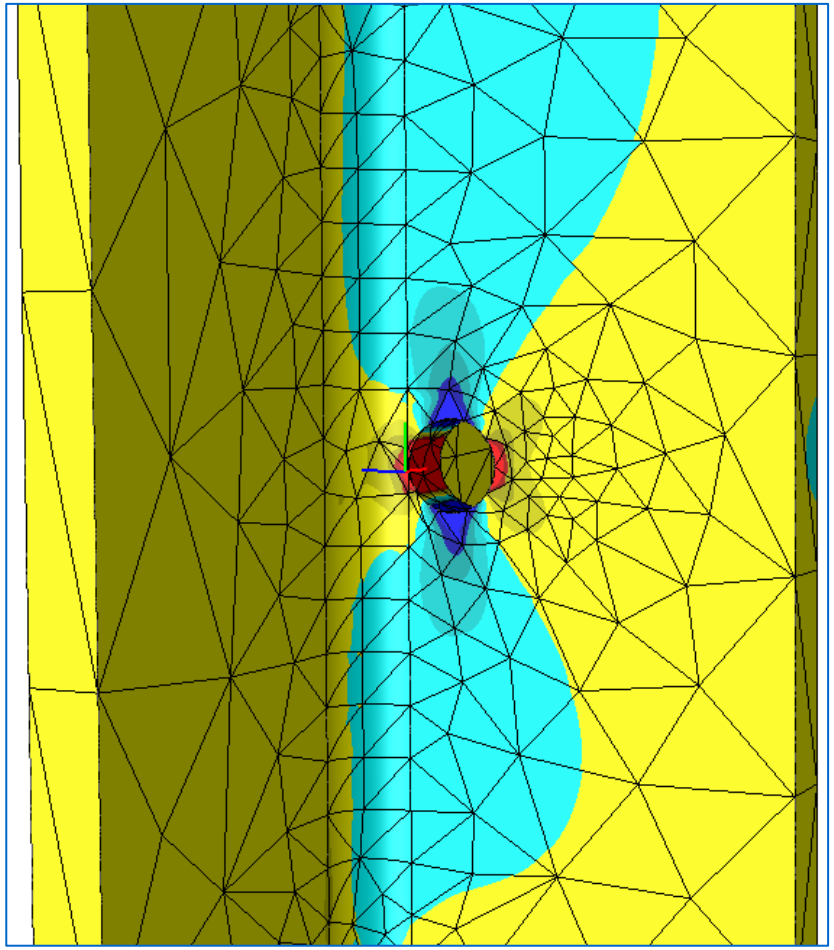
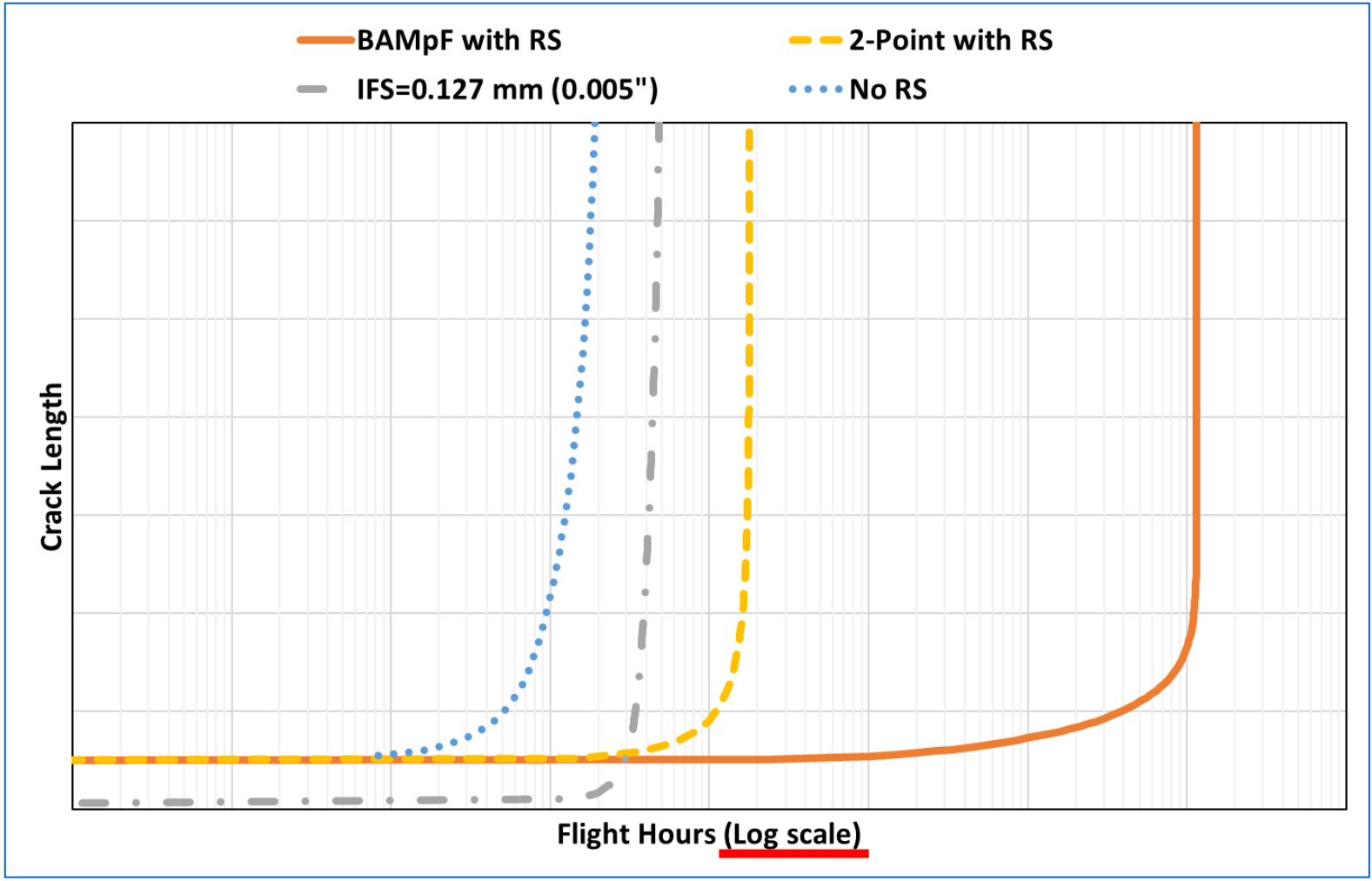




Advantage of Multi-Point

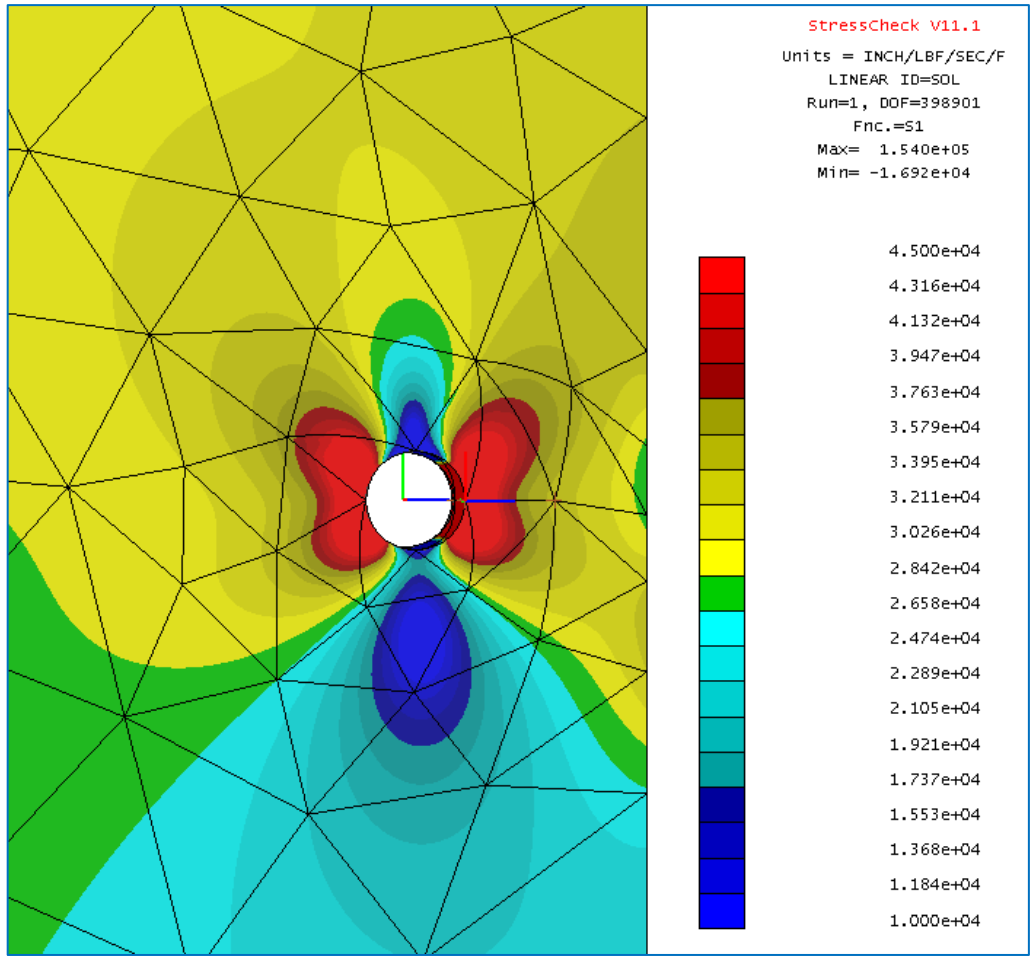
- 180 MPa far field stress
- Spar cap fuel transfer hole

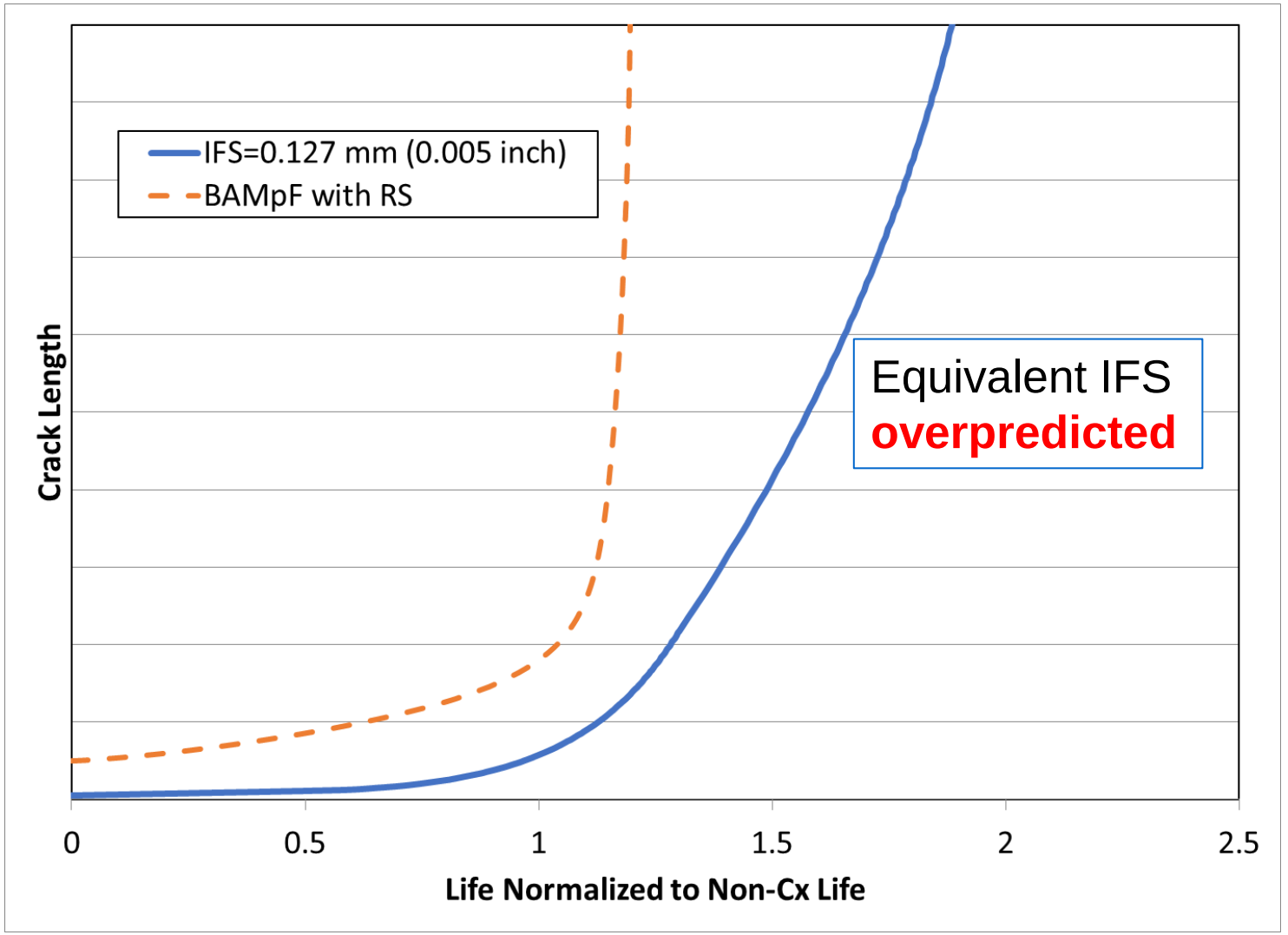




Equivalent IFS Method Shortfall

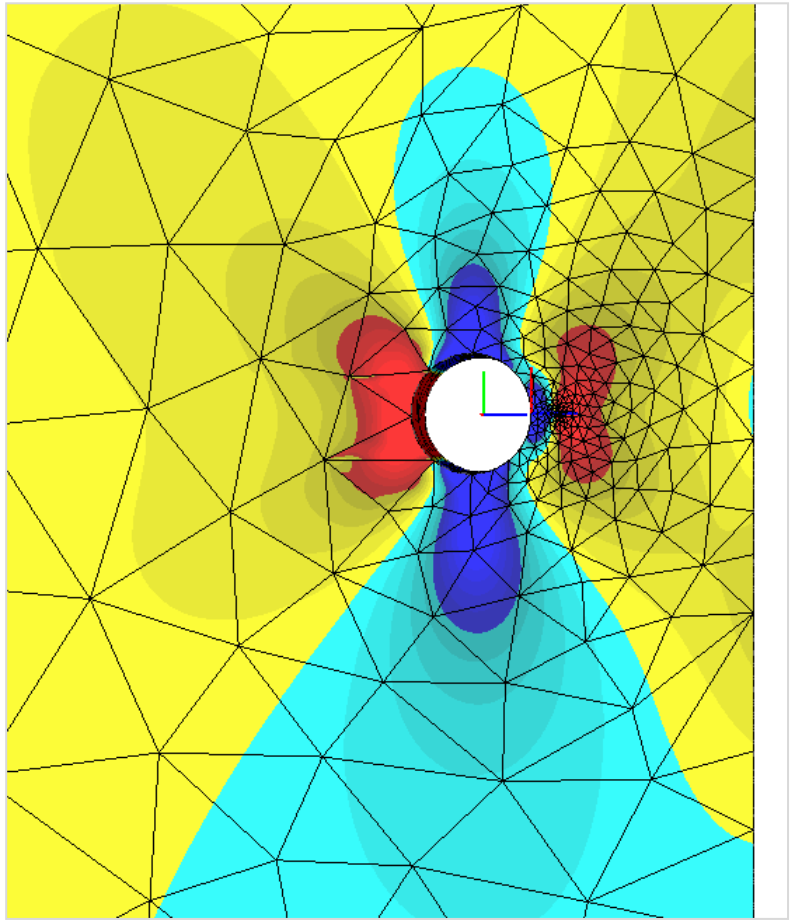
- 210 MPa far field stress
- 20% load transfer

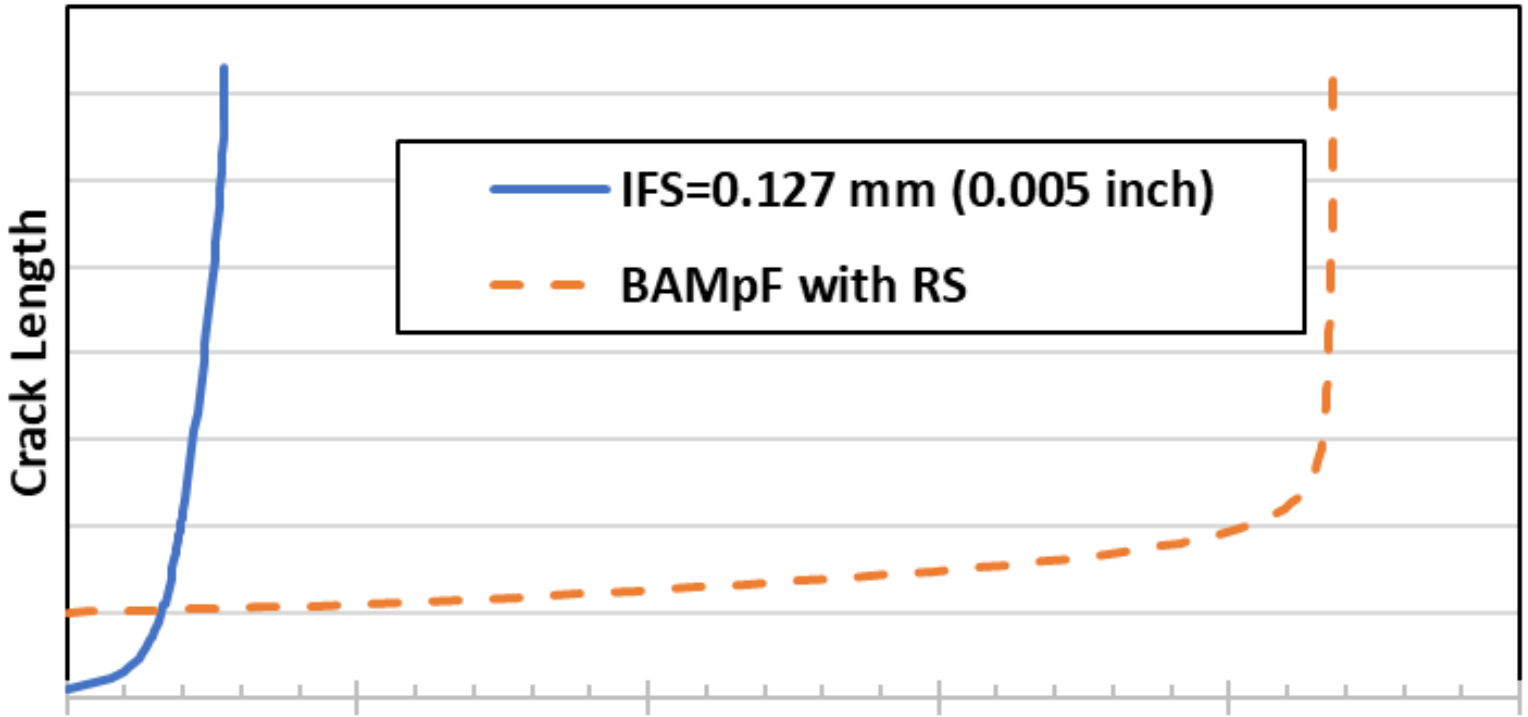




Mild Load Transfer Example

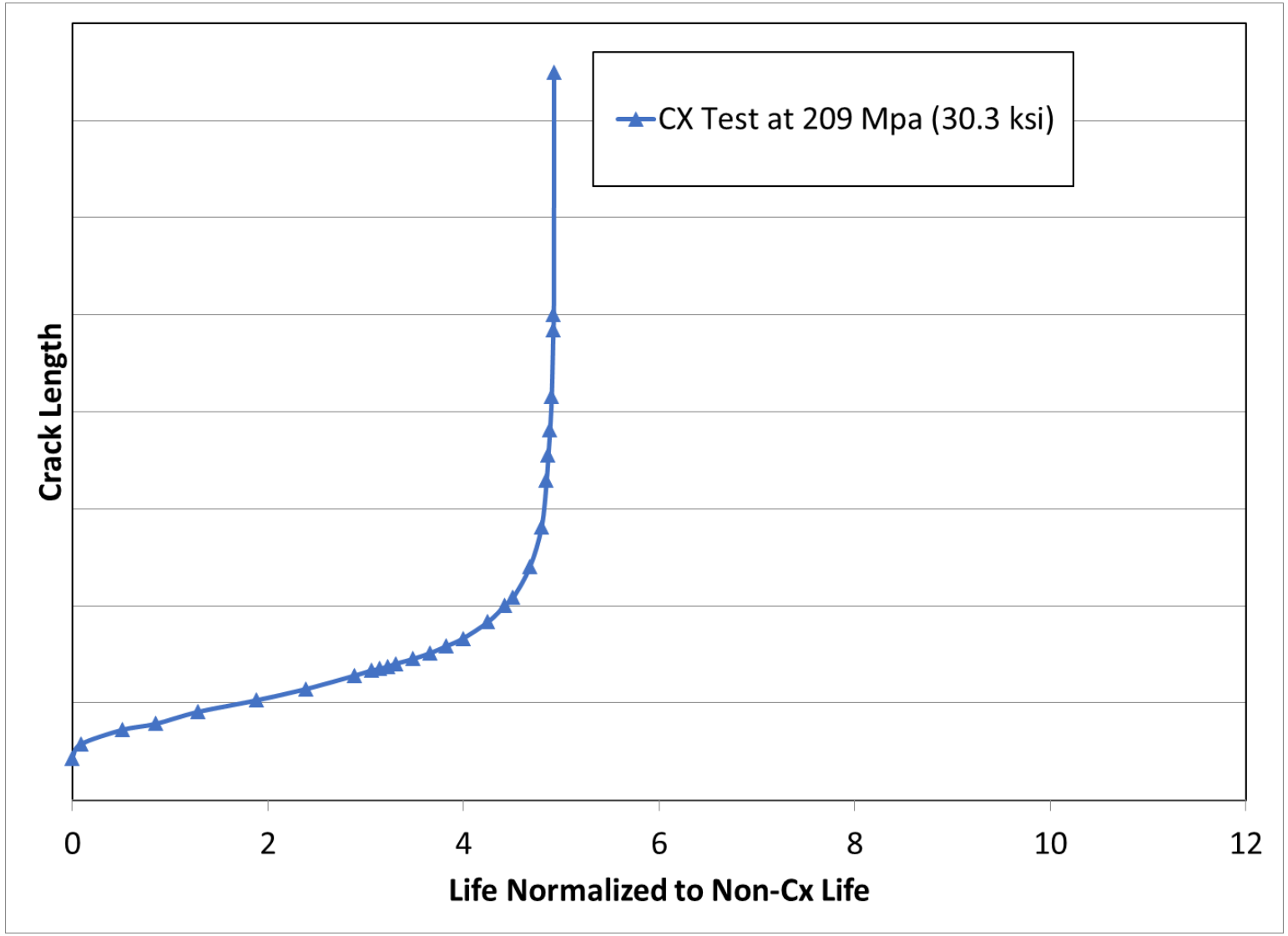
- 200 MPa far field stress
- 8% load transfer





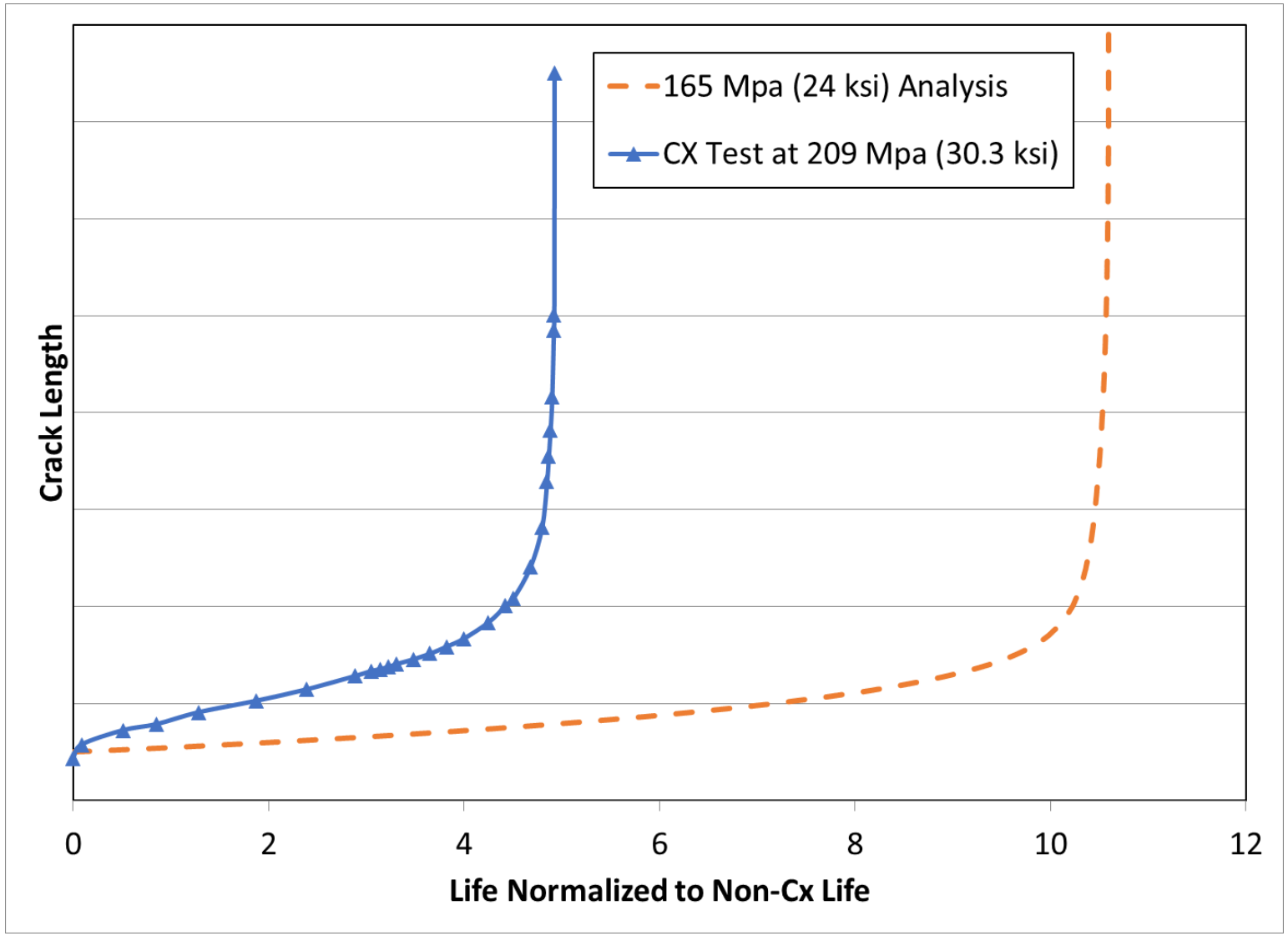
Validating Analysis with Limited Test Data

- Test most severe stress and geometry for given spectrum



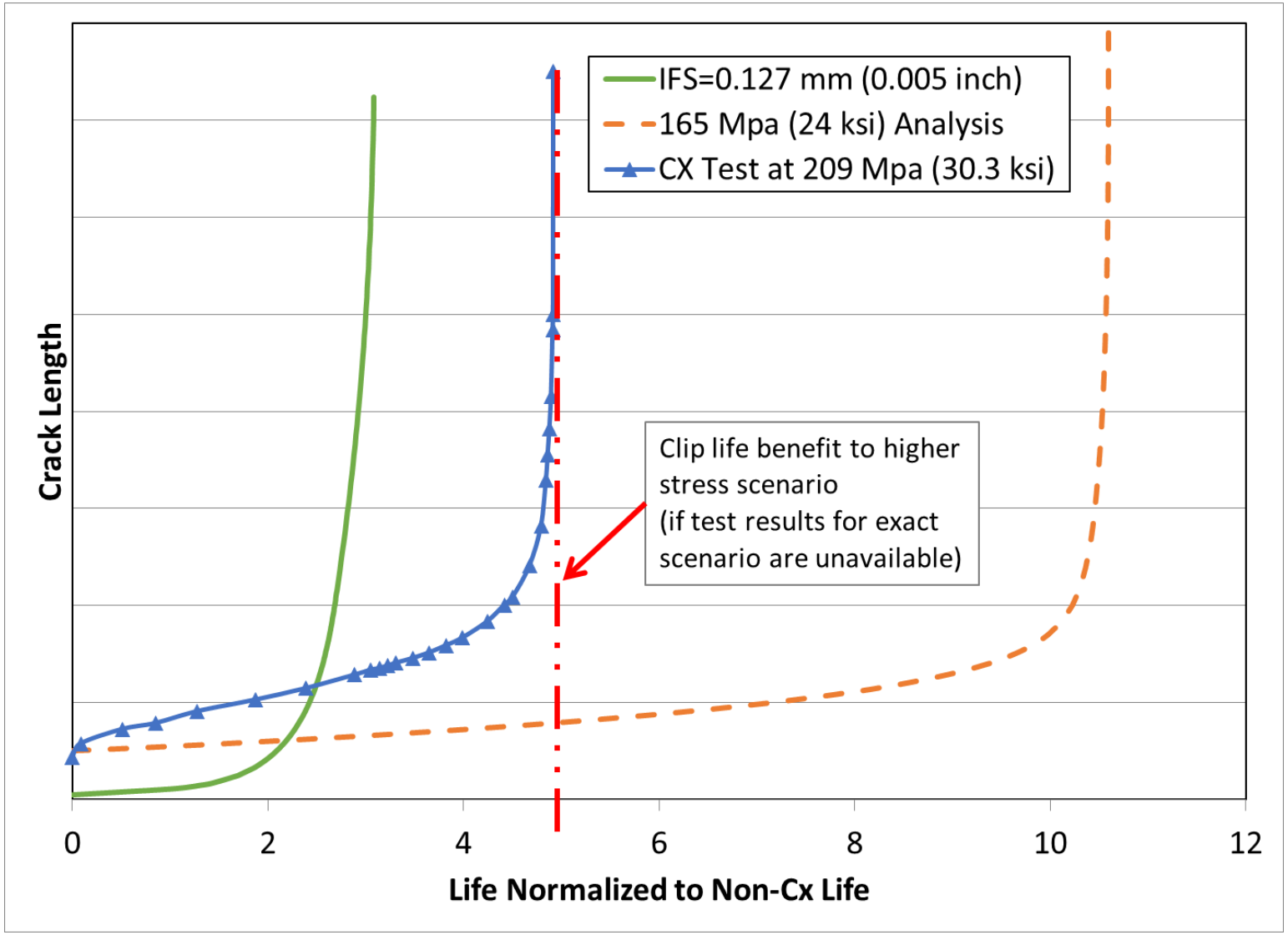
Validating Analysis with Limited Test Data

- Test most severe stress and geometry for given spectrum
- Predict less severe case(s)
  - 165 MPa shown here



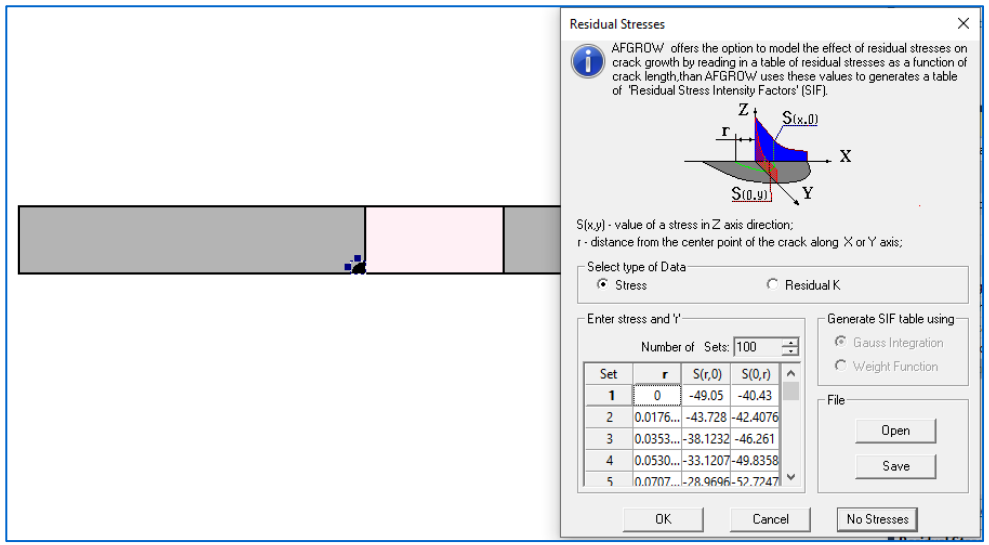
Validating Analysis with Limited Test Data

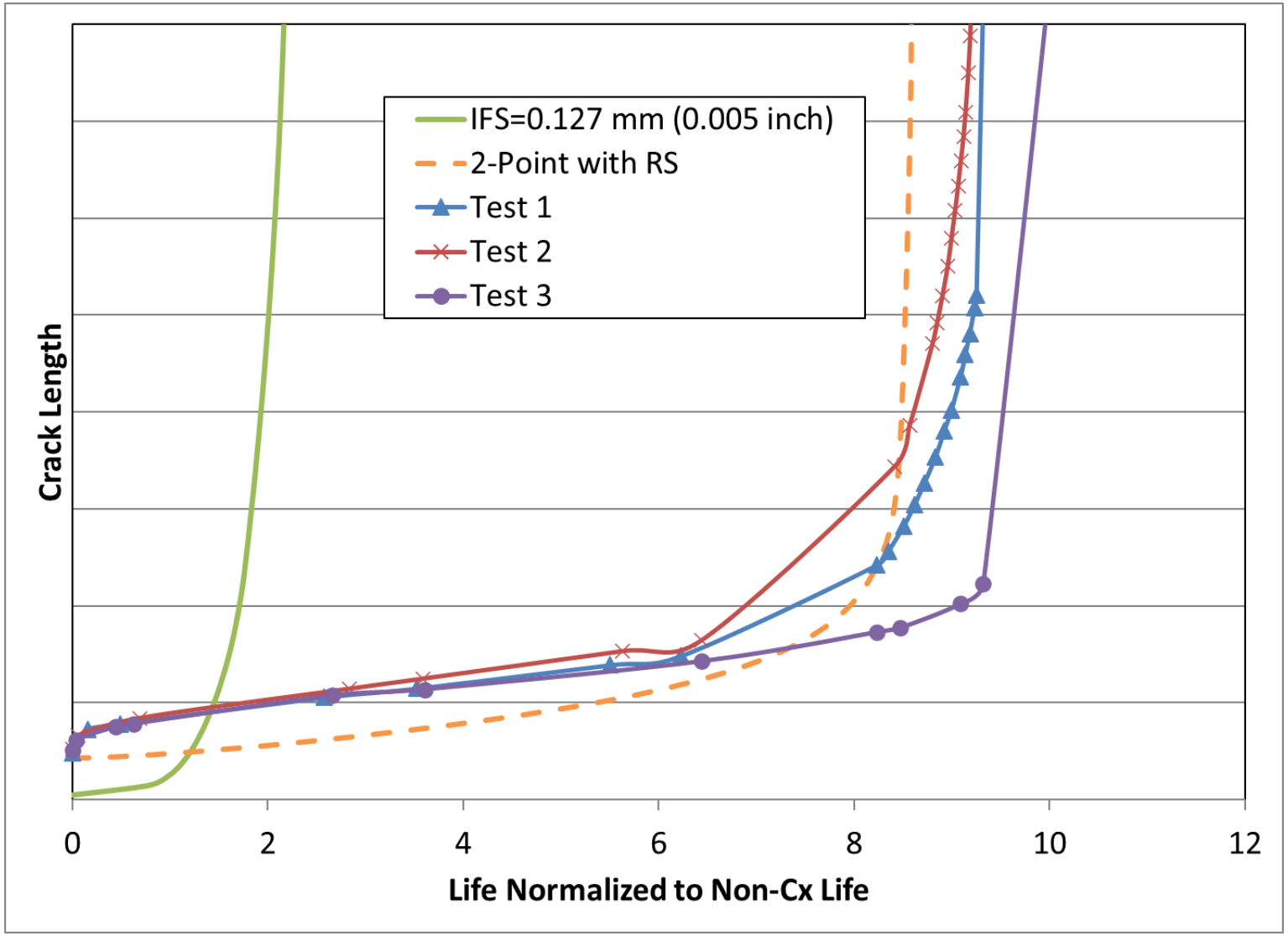
- Test most severe stress and geometry for given spectrum
- Predict less severe case(s)
  - 165 MPa shown here
- Limit benefit to the tested scenario
- If additional benefit is needed, test a less severe scenario



High Consistency and Repeatability

- 207 MPa
- No load transfer





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