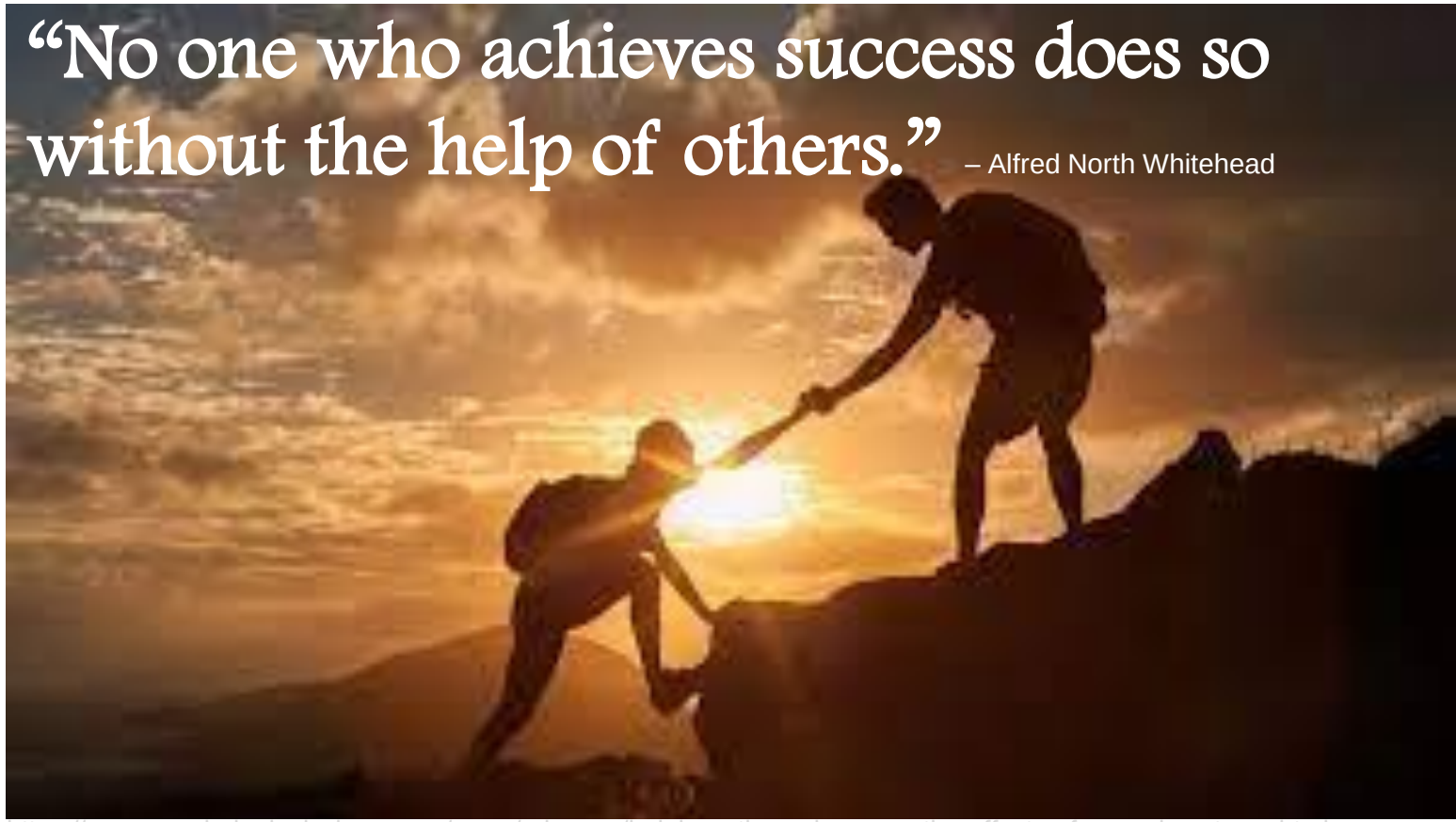
Ground Rules on Multi-Point and Residual Stresses

Jake Warner, DAF
Jacob.Warner@us.af.mil
A-10 ASIP

Acknowledgements

- Together we can move mountains

- Special thanks to:
  - God and my family
  - Teachers and mentors
  - The A-10 engineering group
  - All of you



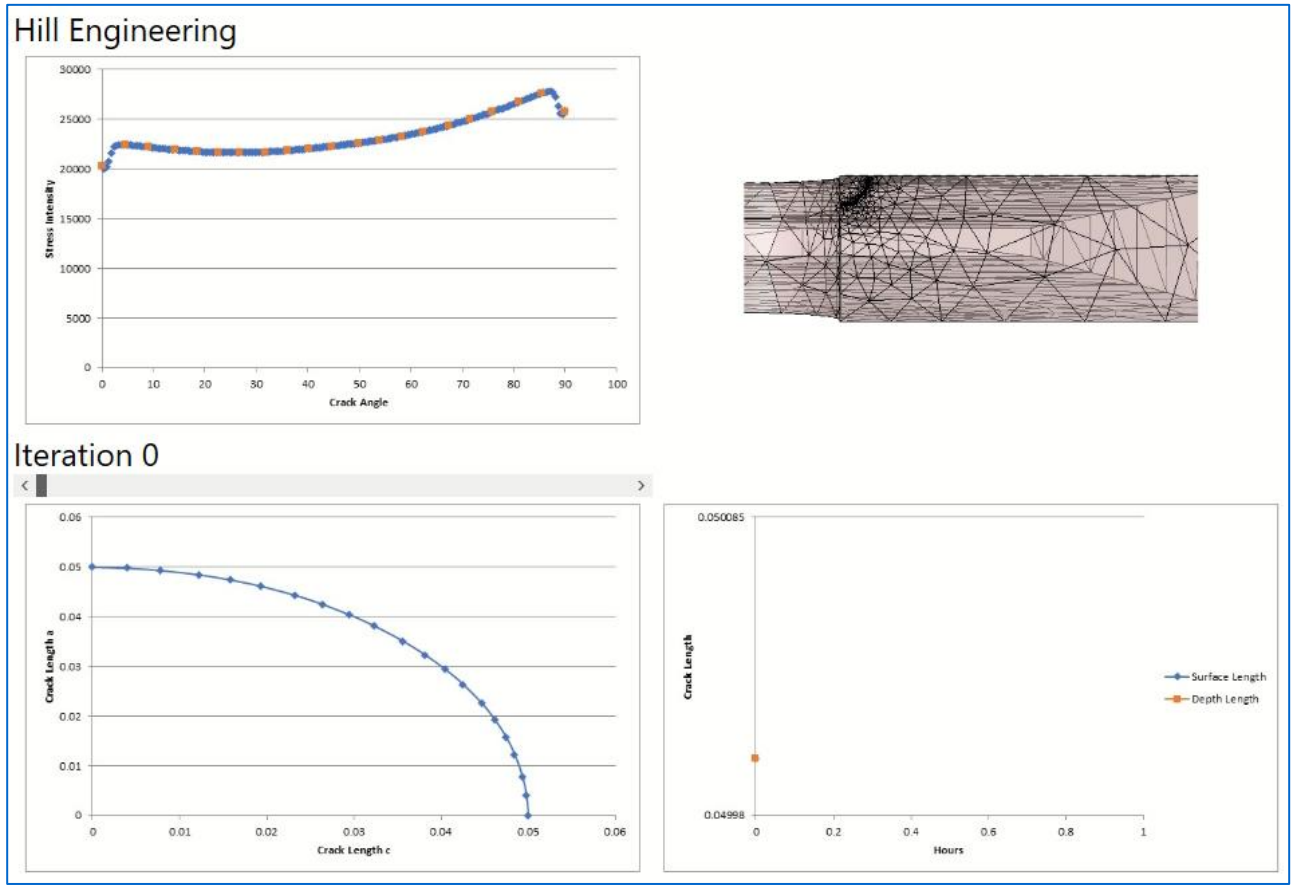
https://www.psychologicalscience.org/news/releases/helping-others-dampens-the-effects-of-everyday-stress.html

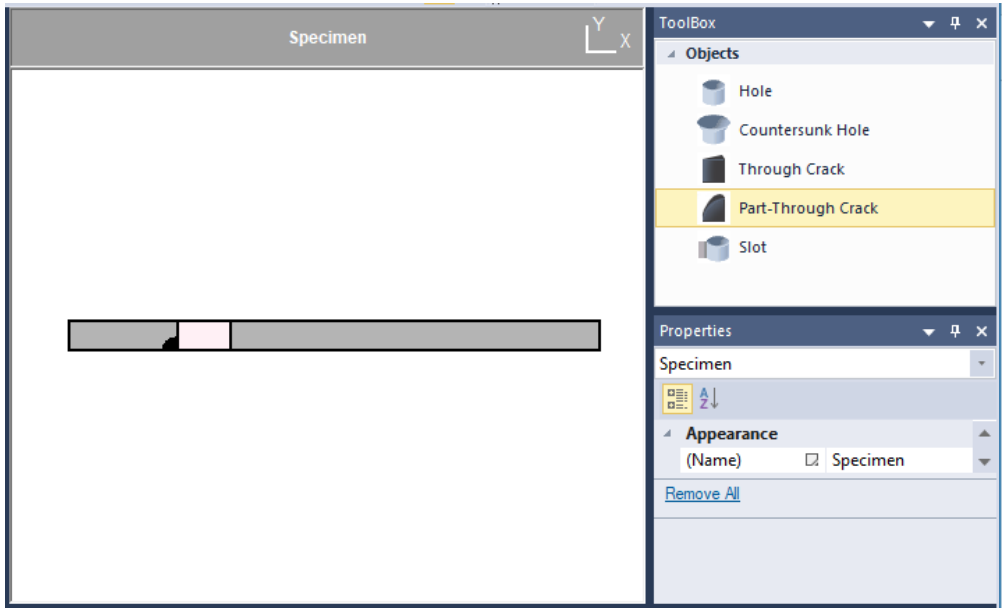
Outline

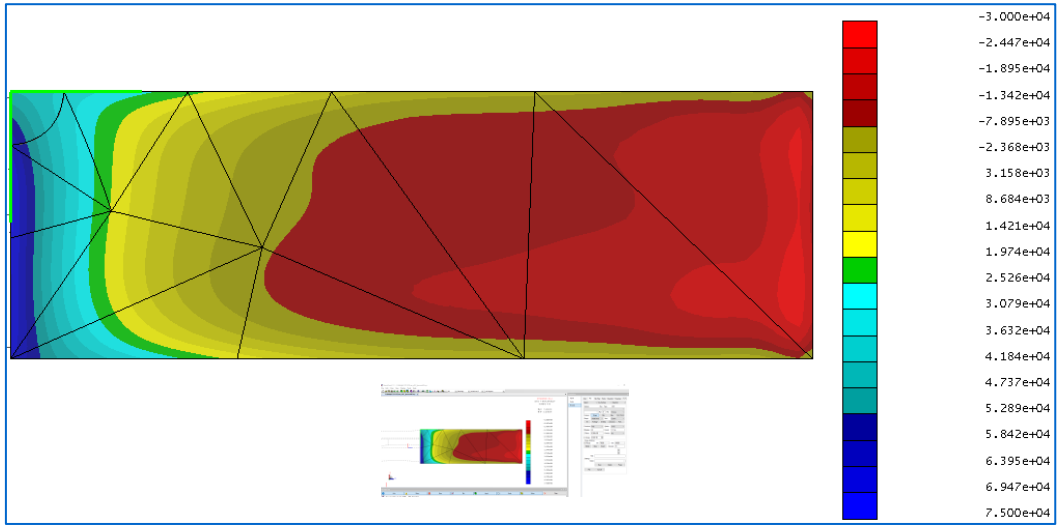
- Background
  - DTA report update
- BAMpF Ground Rules
  - Stress Equations
  - Model Validation
- RS Ground Rules
  - RS sources
  - Cautions on manipulating RS fields

A-10 DTA Report Update

- **Advanced models**
- **Multi-point analysis for select locations**
- **Residual stresses for CX holes**

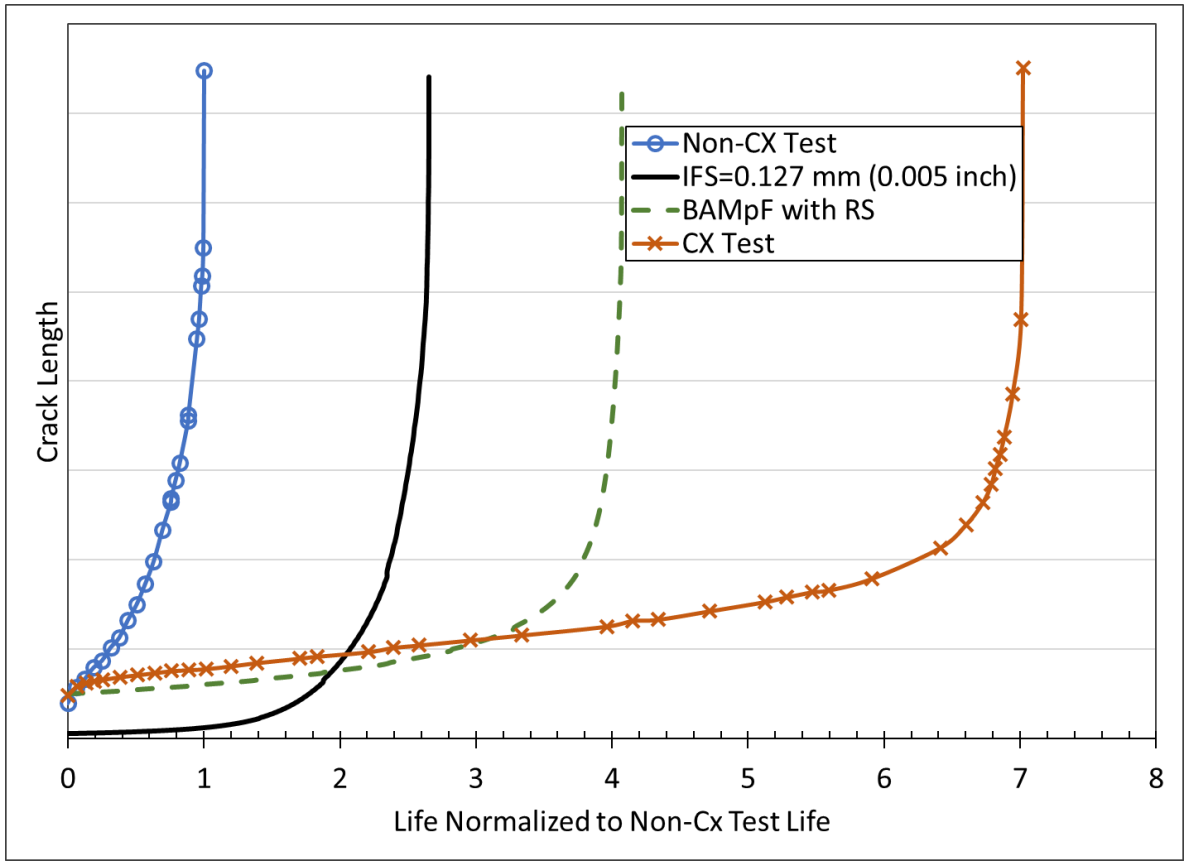


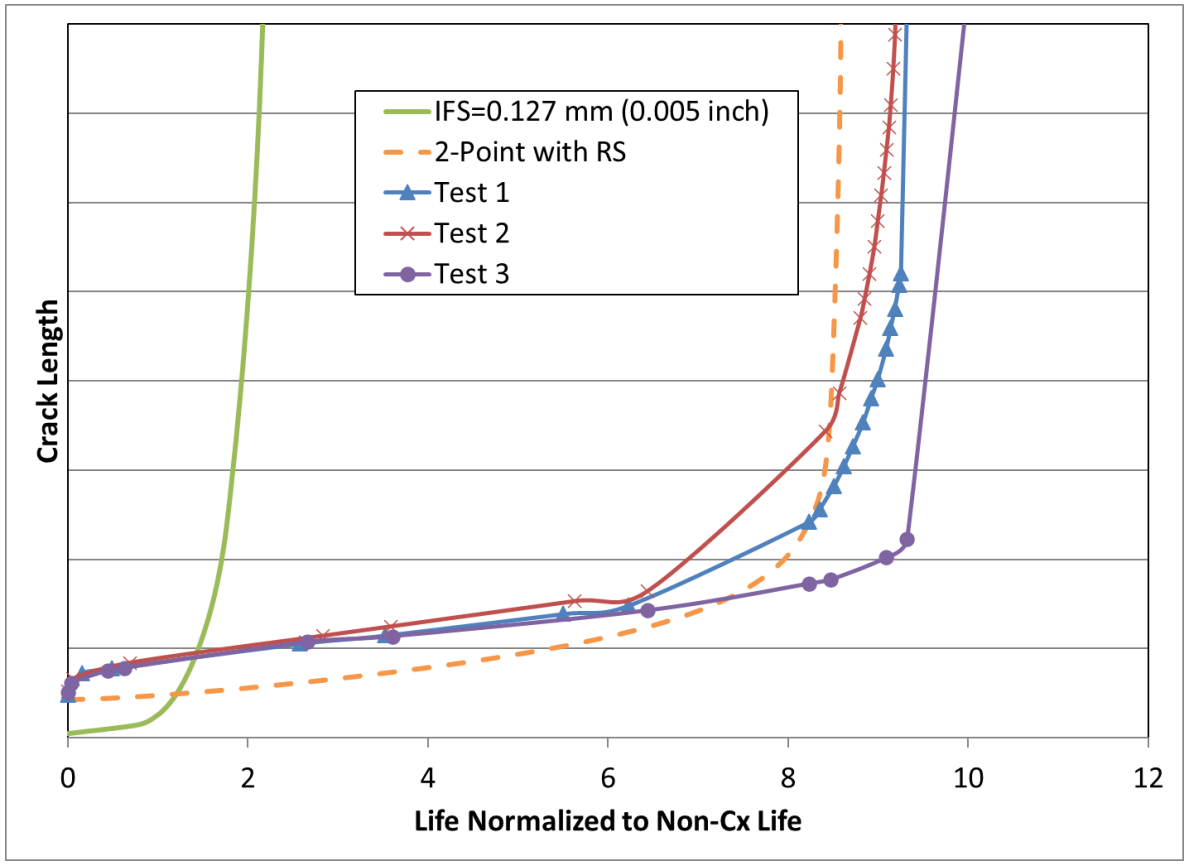




“Fiducia non Superbia” (Confidence not Arrogance)

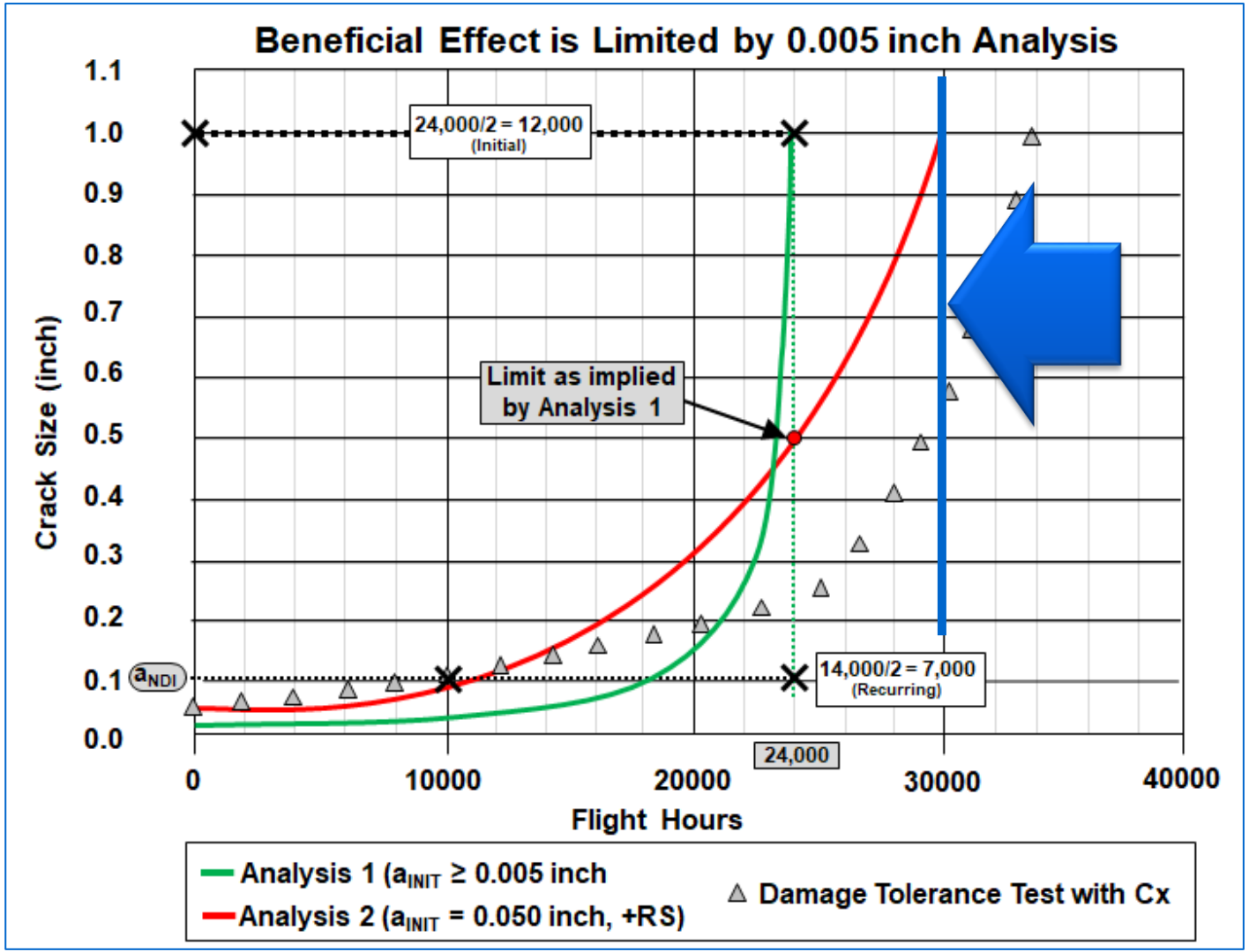
- Validate predictions with test data
- When limited test data is available lean on conservative inputs while test validation is performed





Conservative Limit to RS Benefit

- From USAF Structures Bulletin EZ-SB-17-001 Rev A:



BAMpF Ground Rules

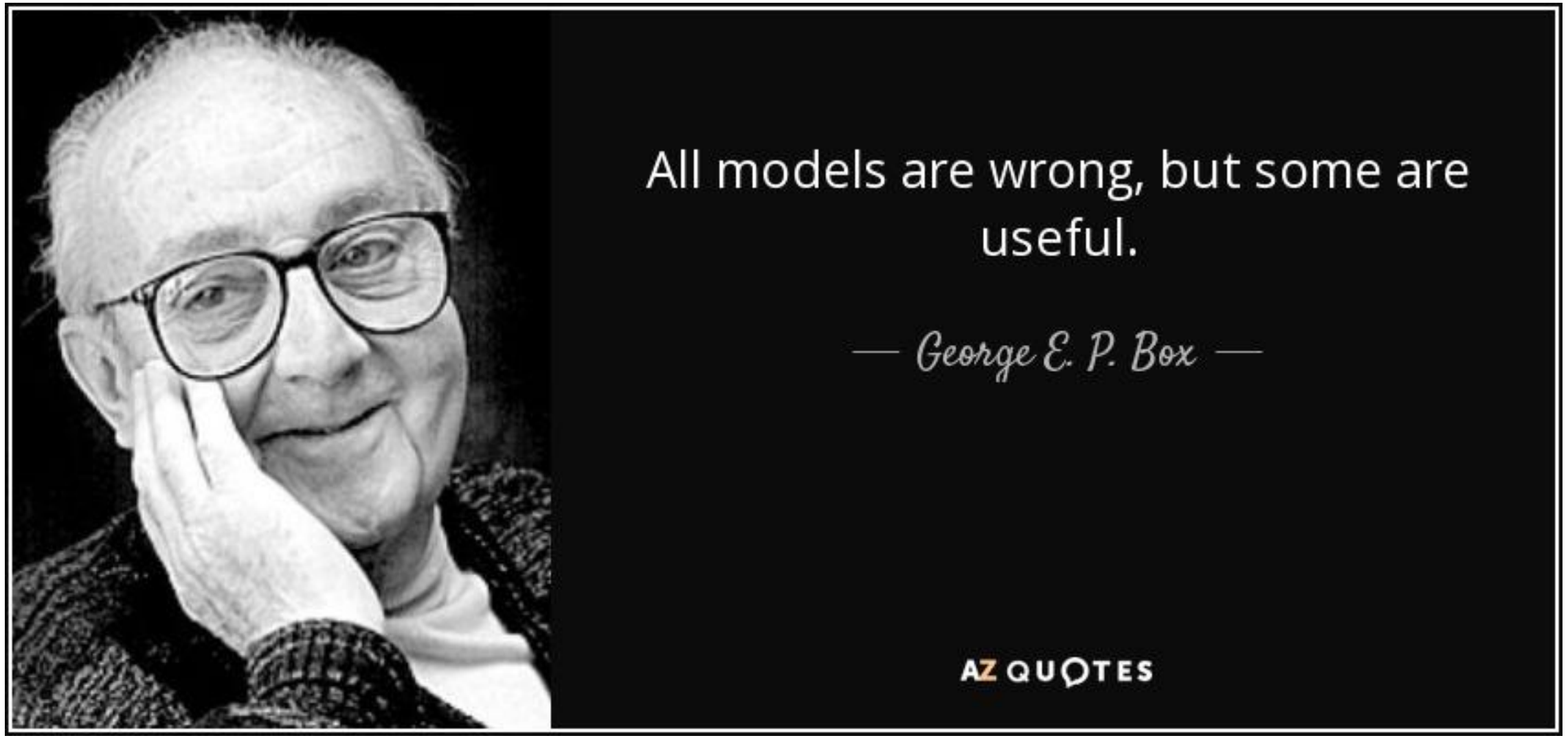
- **A-10 guidance for multi-point analysis**

	PREPARED BY:	DATE:	CHECKED BY:	DATE:	REV.	PAGE:
SwRI	Jacob Warner	9/19/2022	Brian Boeke		F	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

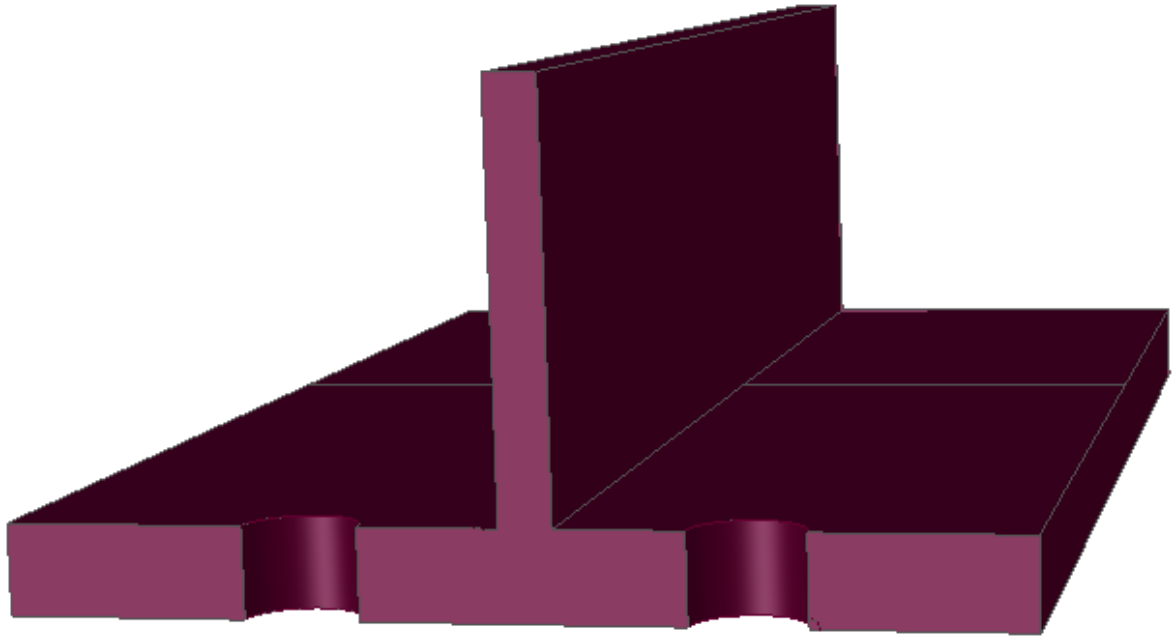
The following guidelines describe A-10 best practices for conducting multi-point fracture mechanics analysis using the Broad Application for Multi-point Fatigue (BAMpF) software. Beginning with SA220R0207 Revision F the A-10 uses BAMpF for Damage Tolerance Analysis (DTA) on a number of Control Point (CP) locations which include CPs that previously used the StressCheck COM to define beta corrections and CPs that utilize residual stresses from cold expansion.

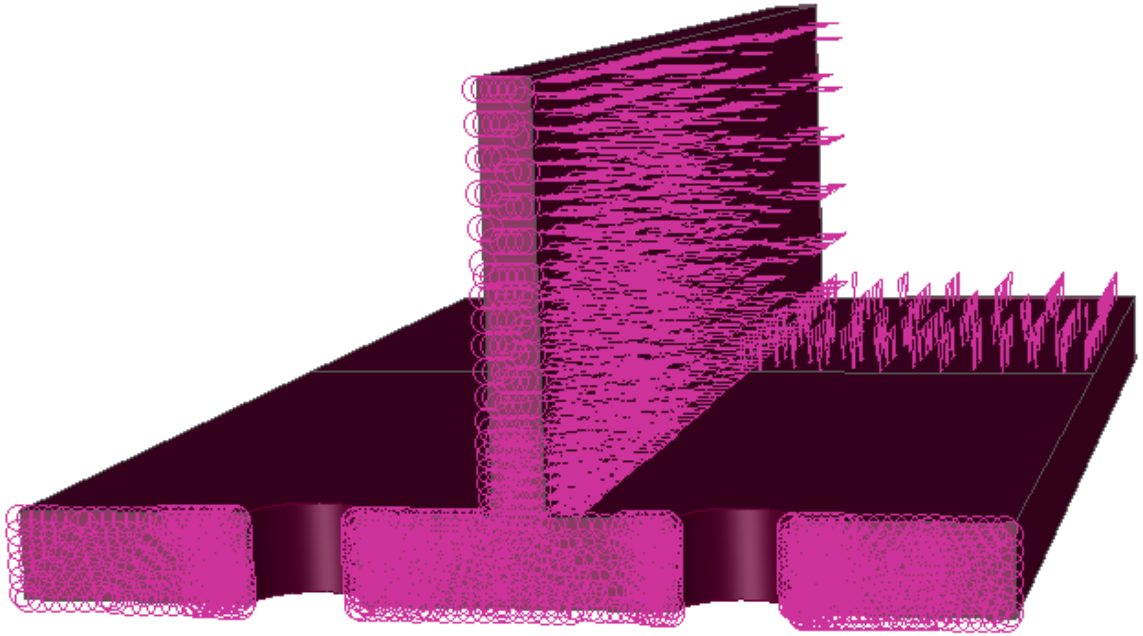
Building the BAMpF Model



Multi-Point Model Development

- **Follow all relevant finite element modeling best practices**
  - **Verify constraint behavior produces reasonable deformation**
  - **Verify analytical convergence**
  - **Verify modeling assumptions are sufficiently accurate and applicable**
  - **Etc.**

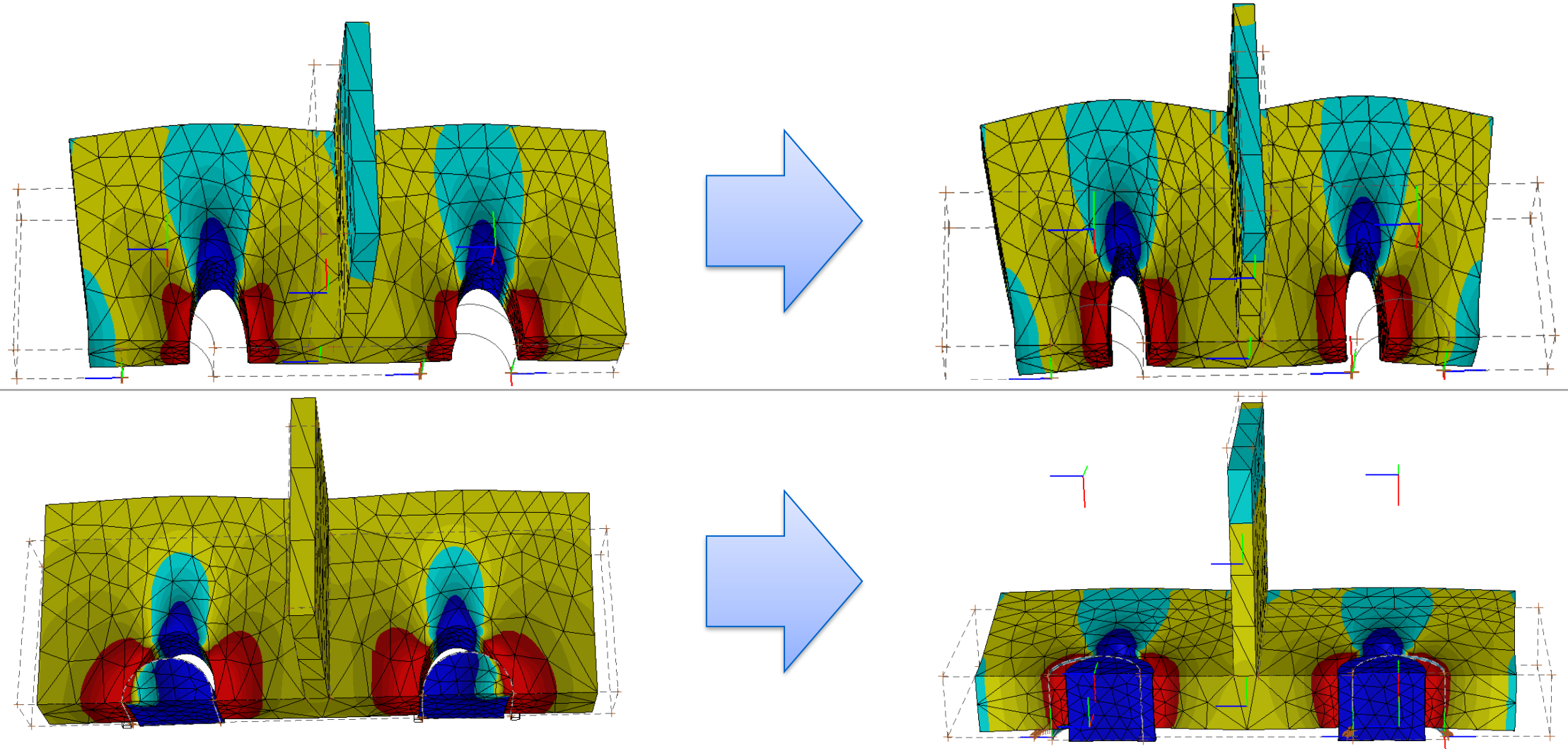




Sensitivity to Modeling Constraints

BAD CONSTRAINTS

GOOD CONSTRAINTS



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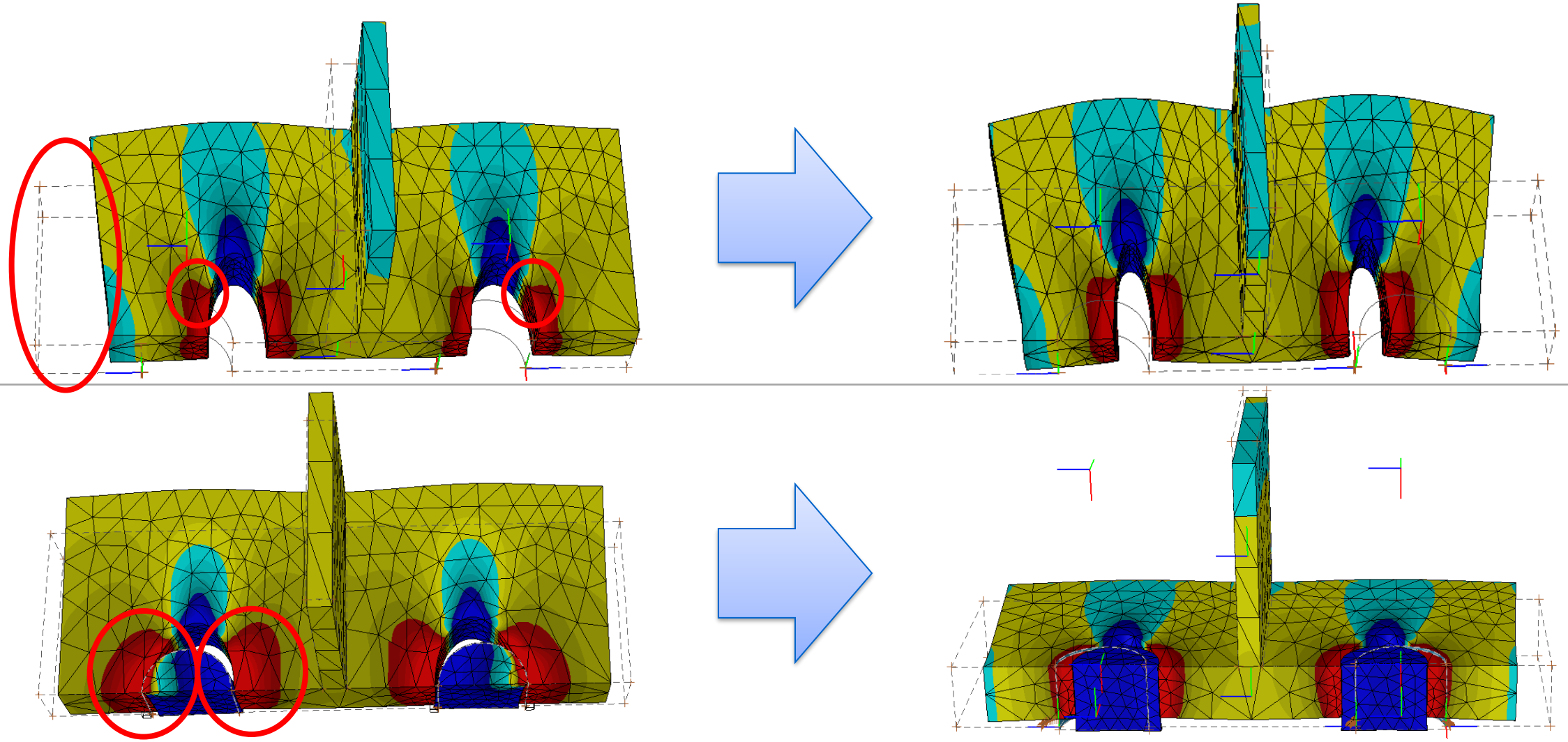
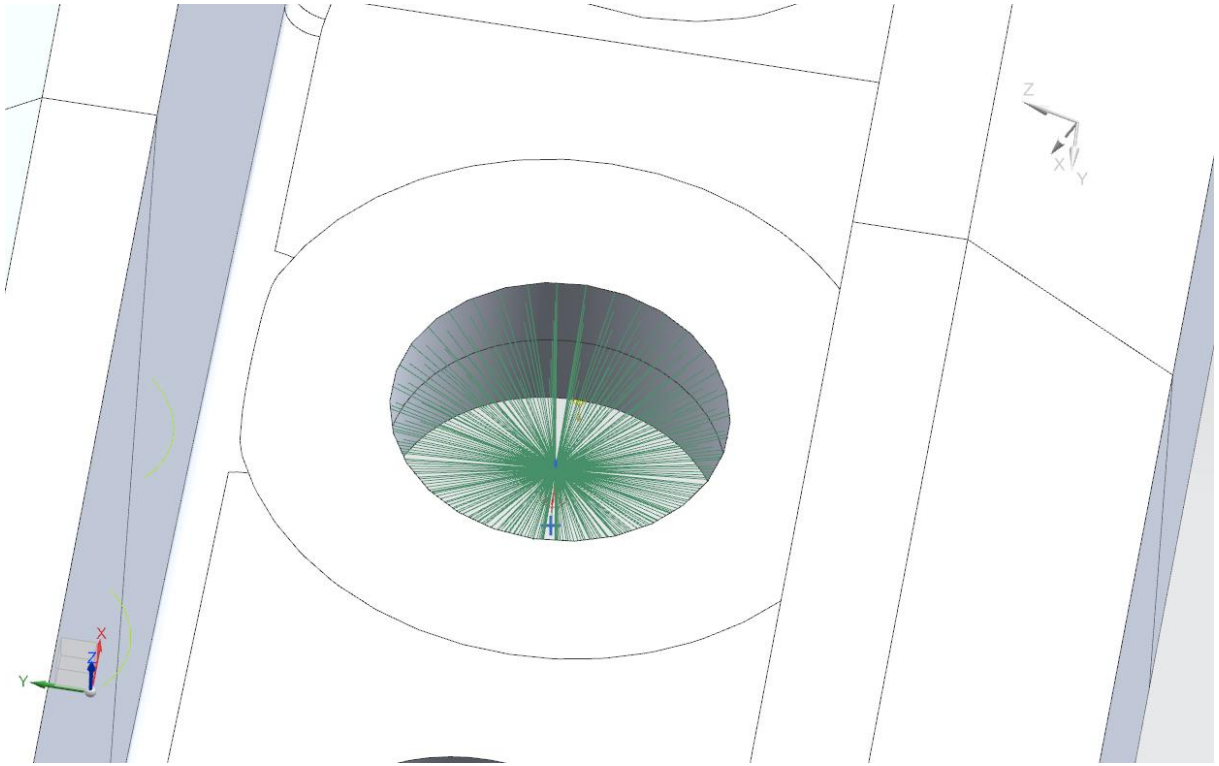


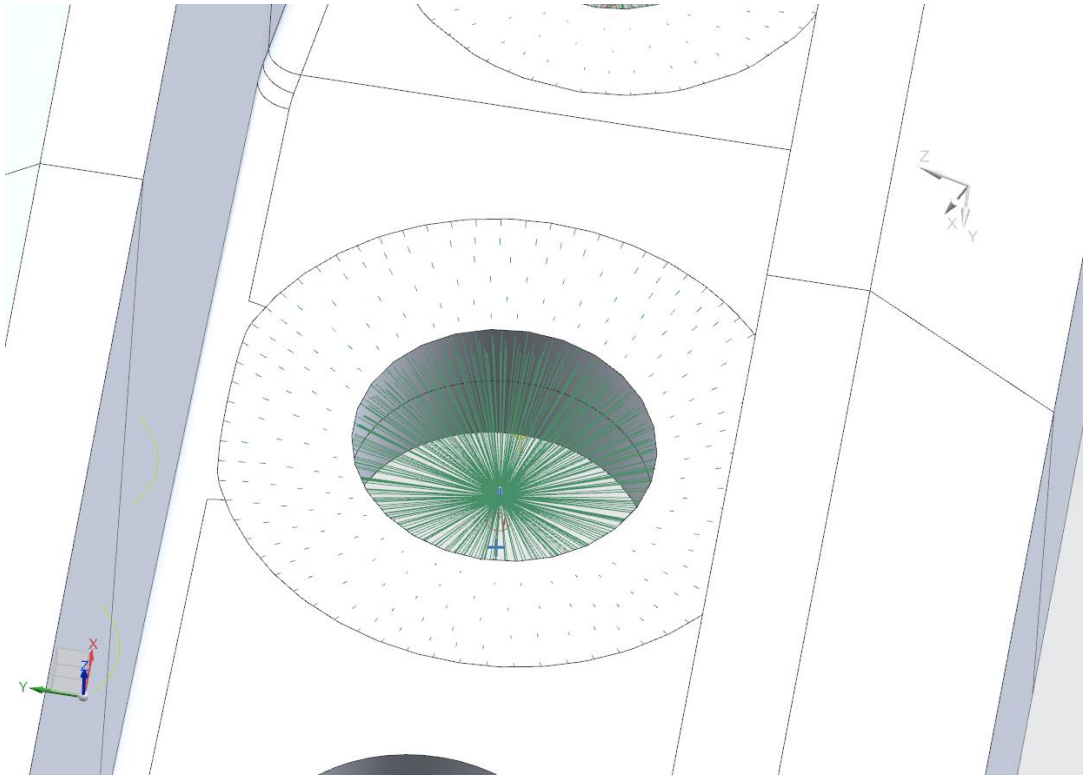
Model BC's are important

- **Two different fastener approximations evaluated**

CELAS to hole shank with RBE3s (model 1)

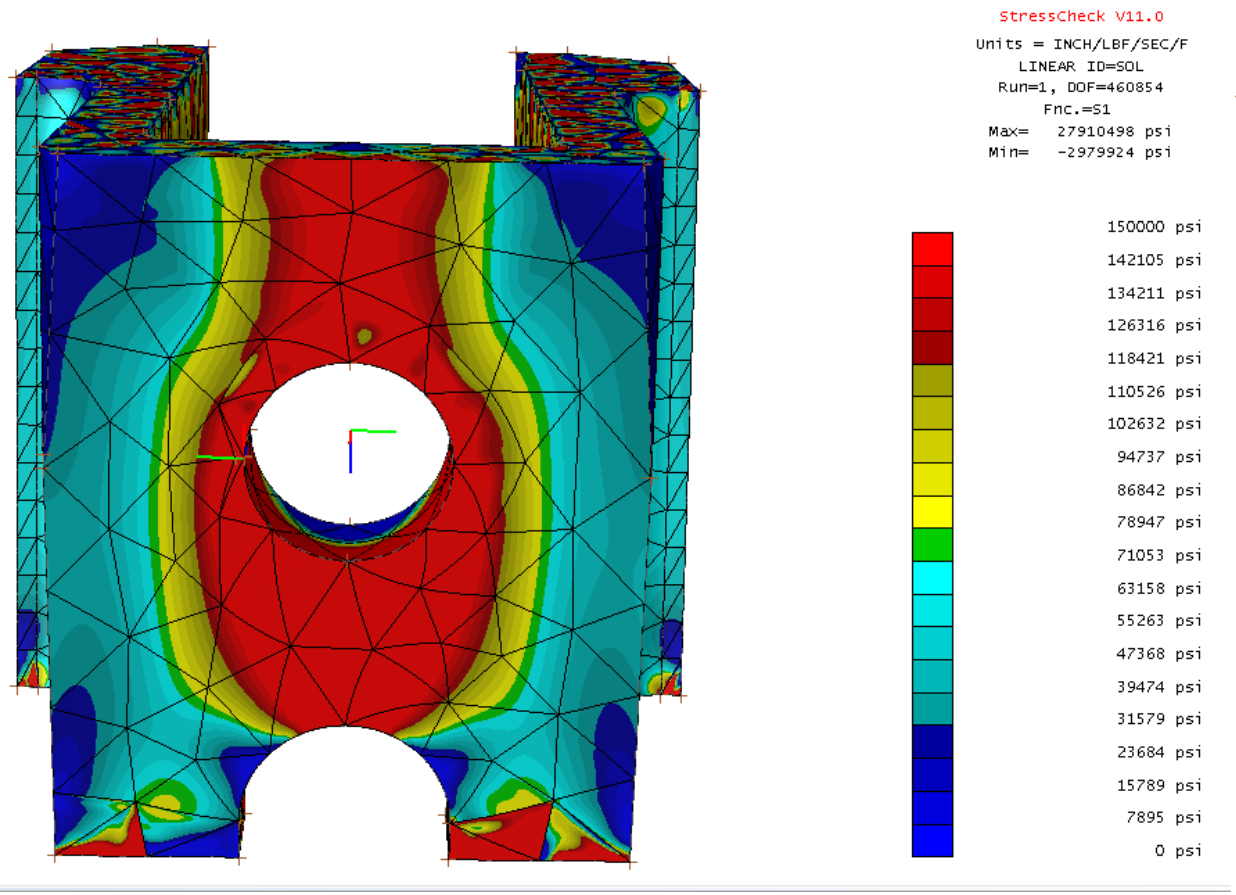


Beam to fastener head area with RBE2s (model 2)

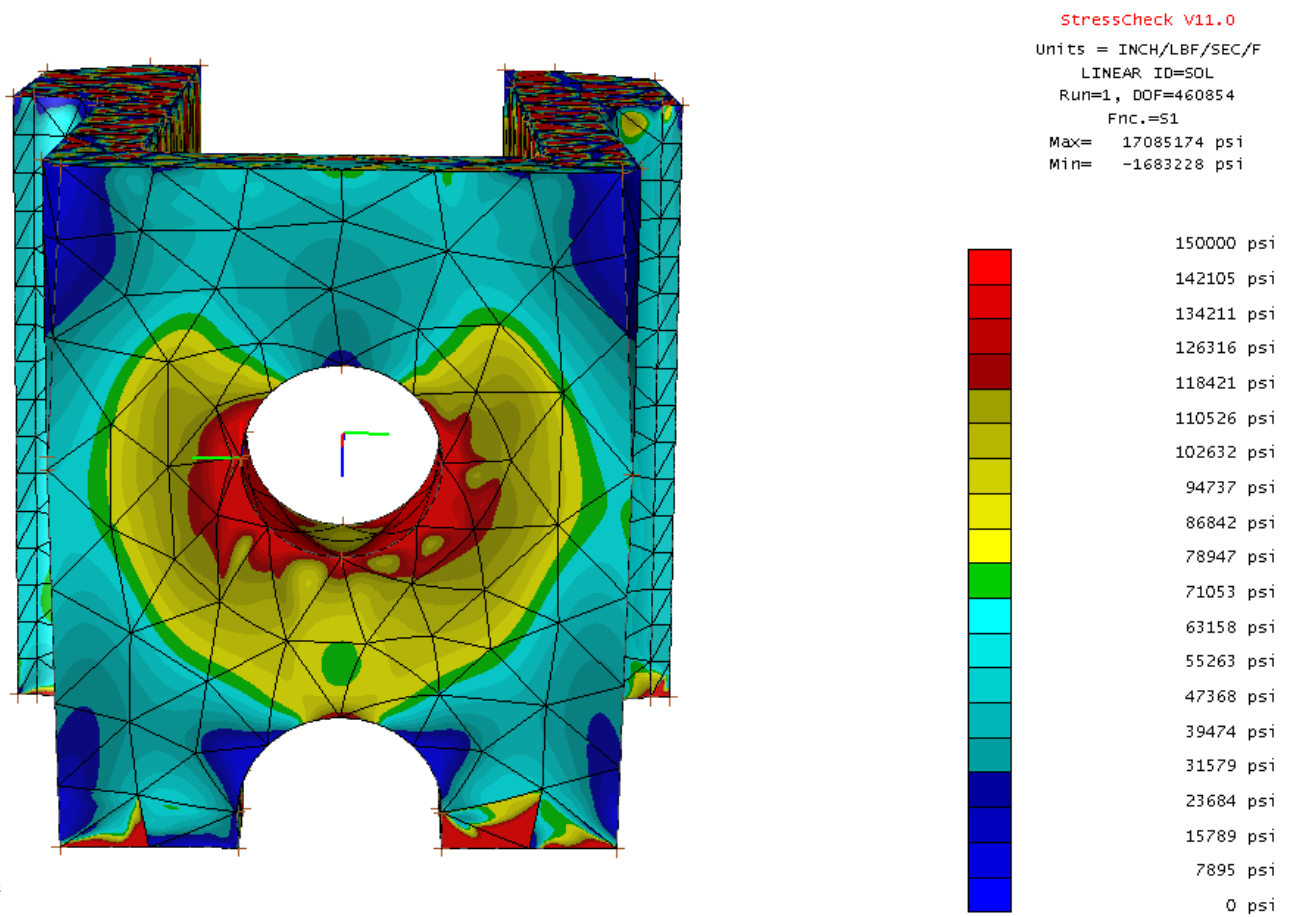


Stress Contour Differences

Model 1



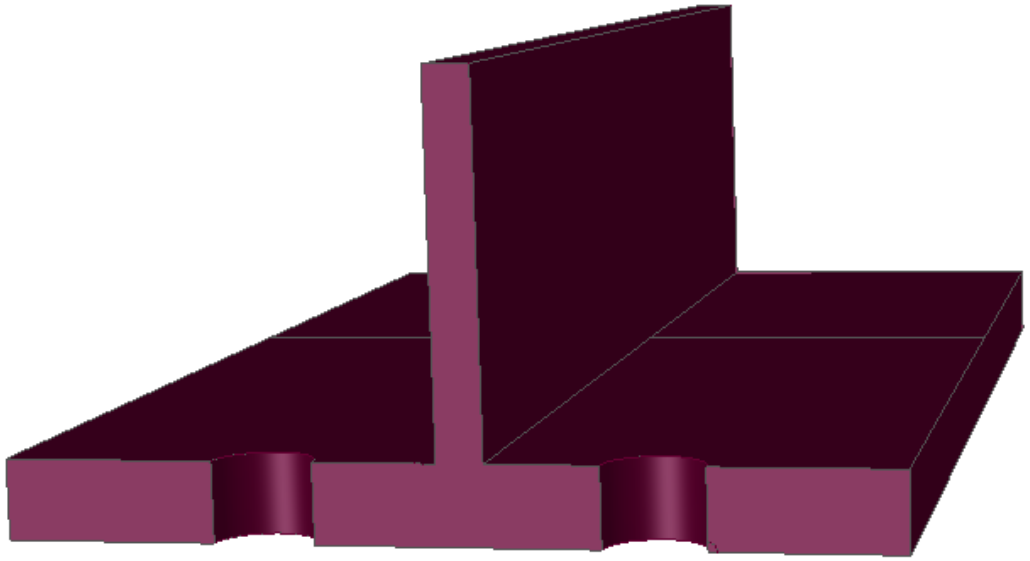
Model 2



Multi-Point Model Stresses

- **2-point stress is not necessarily applicable to multi-point model**

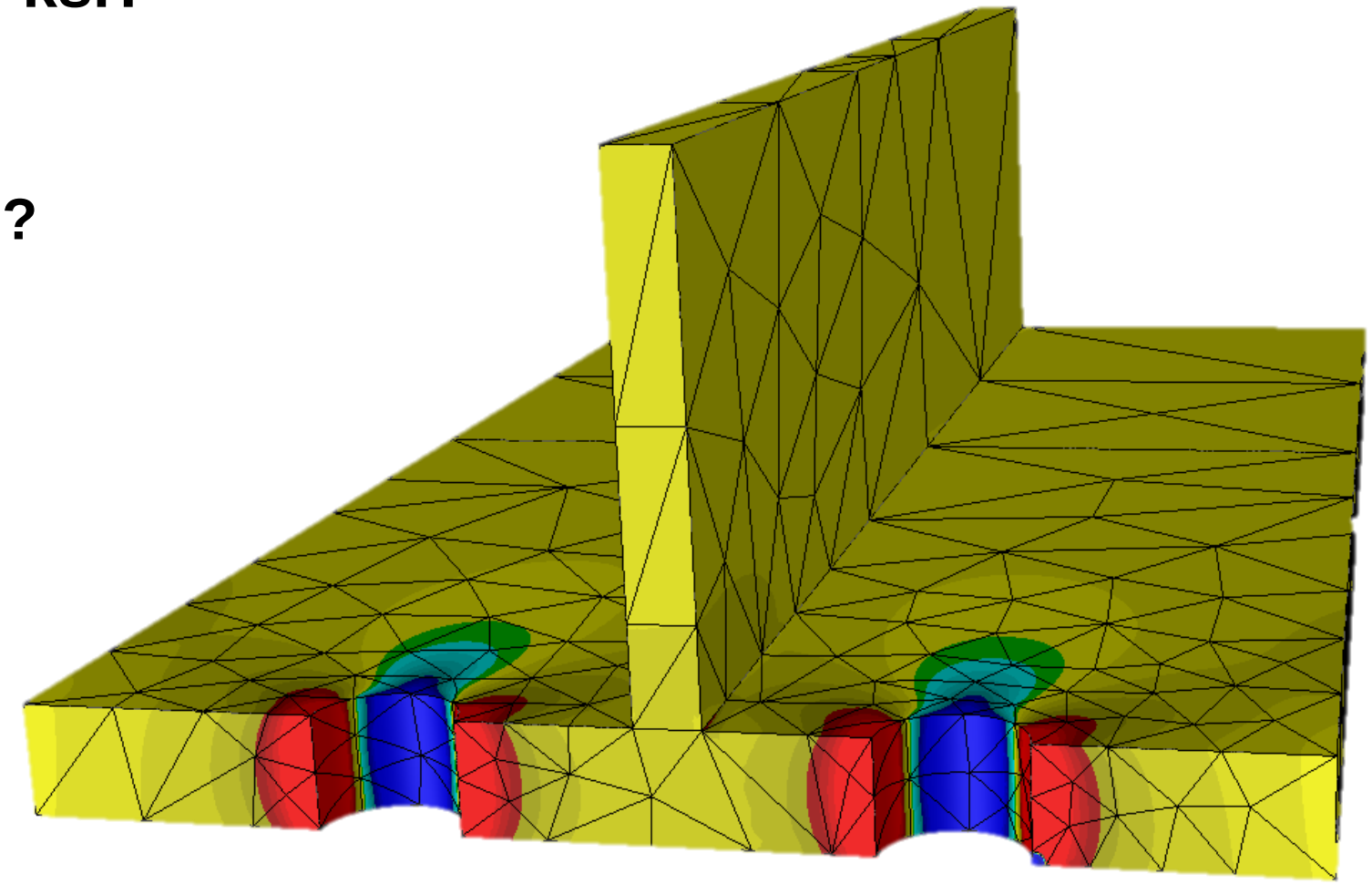
$\neq$



$$\sigma_{Two\ point} \neq \sigma_{Multi\ point}$$

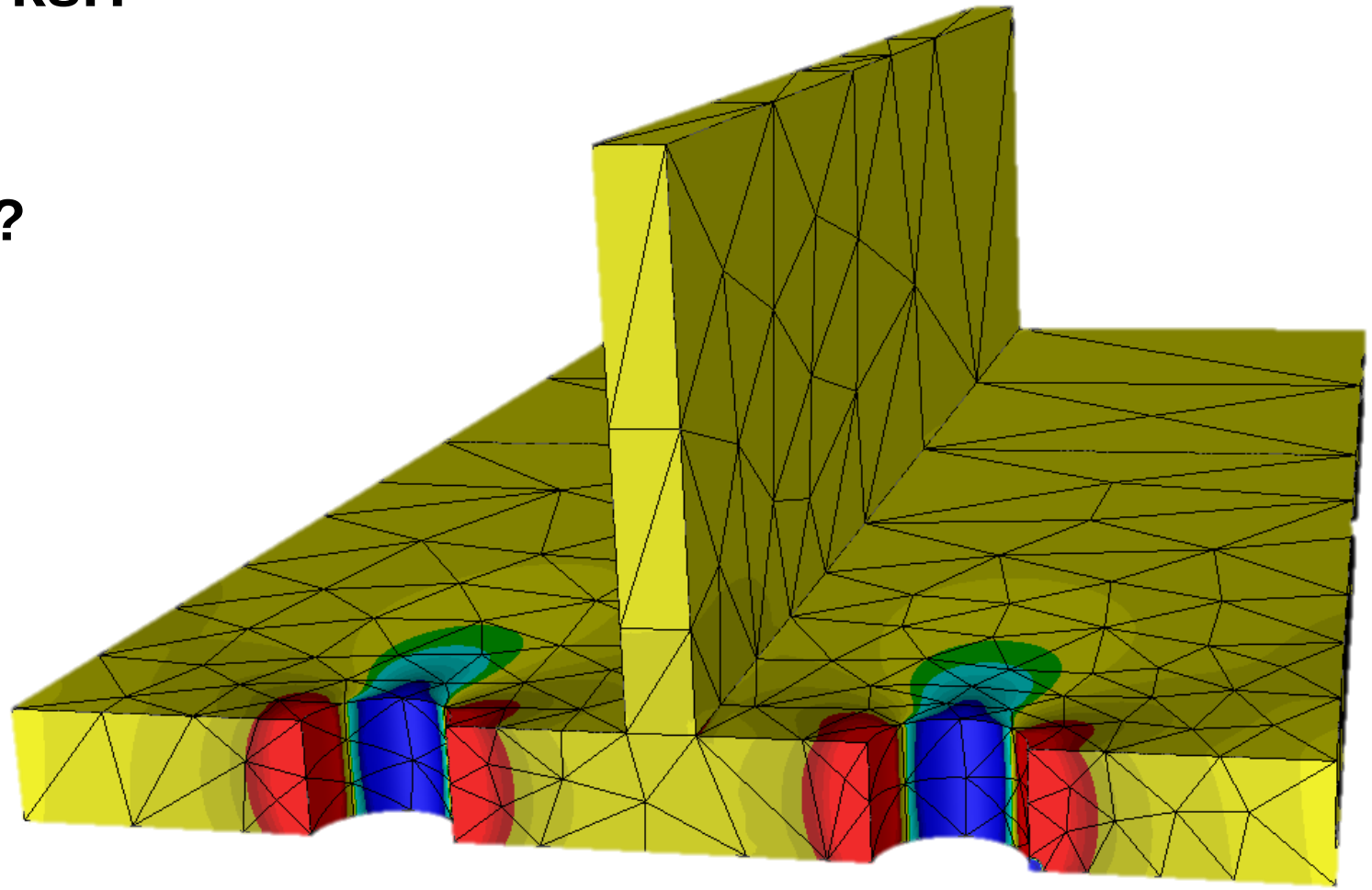
Model Stress

- What stress should be 29.714 ksi?
  - At the crack front?
  - The max stress?
  - Average of the cross section?
  - Applied stress?
  - Something else?



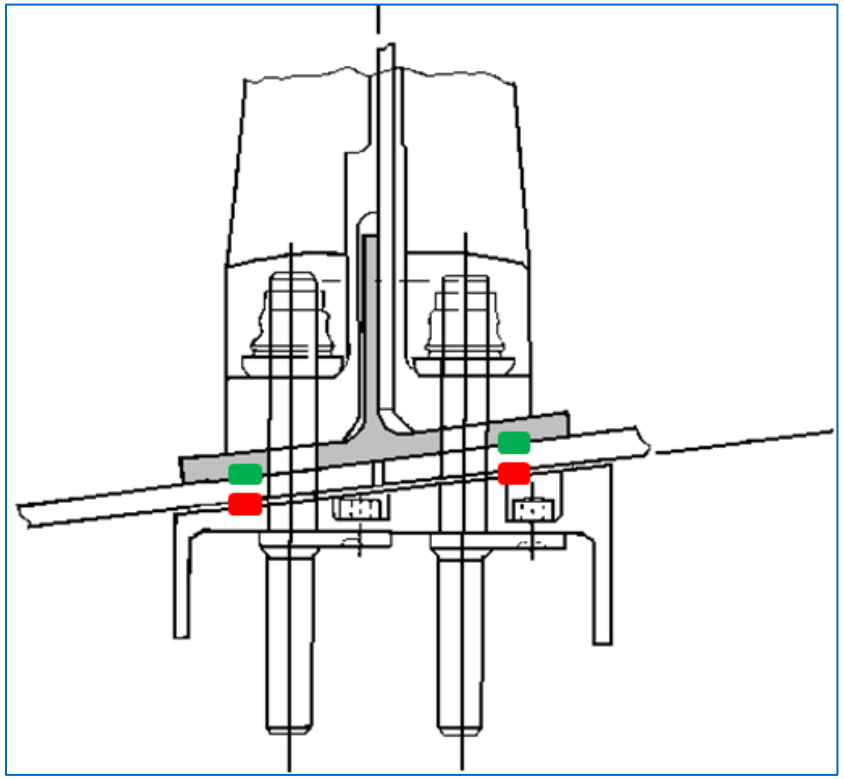
Model Stress

- What stress should be 29.714 ksi?
  - At the crack front?
  - The max stress?
  - Average of the cross section?
  - Applied stress?
  - **Something else!**
- The right question is:
  - What stress does the loading spectrum represent?
  - What far field stress mimics spectrum loading?



Model Stress

- Stress equation for this scenario is based on a strain gage on the lower wing skin, between fastener rows, minimizing any stress concentration (far field stress)
- Stress transfer function was used to convert to spar cap stresses from lower wing skin stresses
- FEM loading should reflect the loading for the max stress condition from the loading spectrum
  - Loading, deflections and stresses should be evaluated for linearity
  - If non-linear effects are present, then multiple loading scenarios must be included in BAMpF using the K-array functionality



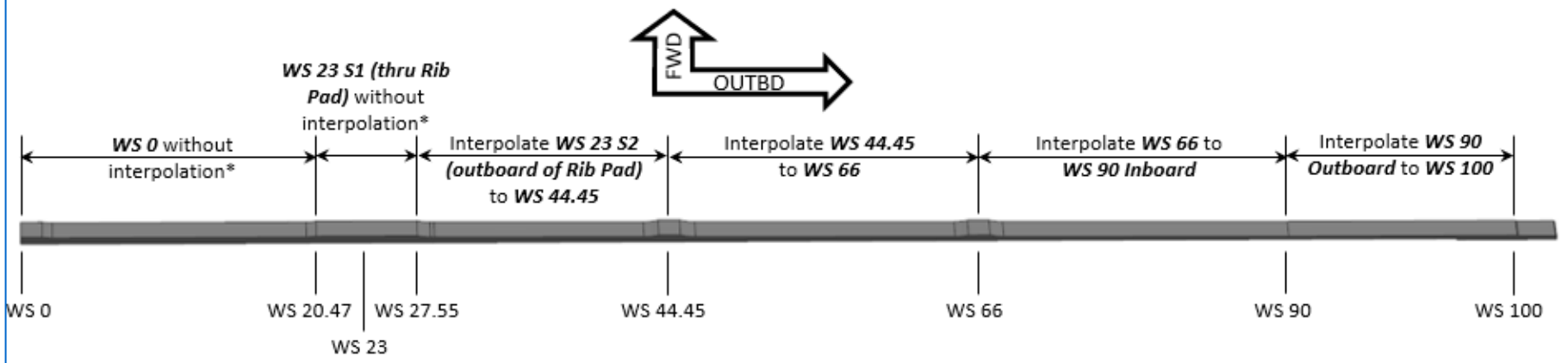
Verify Stress Transfer Function

- **Compare stress function to complex bending solution**

DTR CONTROL POINT 13

Stress Equation: (Aircraft Effectivity – Retrofit 7 – 151, Production 152 – 581)

$$\sigma_{\text{CP 13 THIN SKIN}} = 0.98021 * \sigma_{\text{CP 7 THIN SKIN}}$$



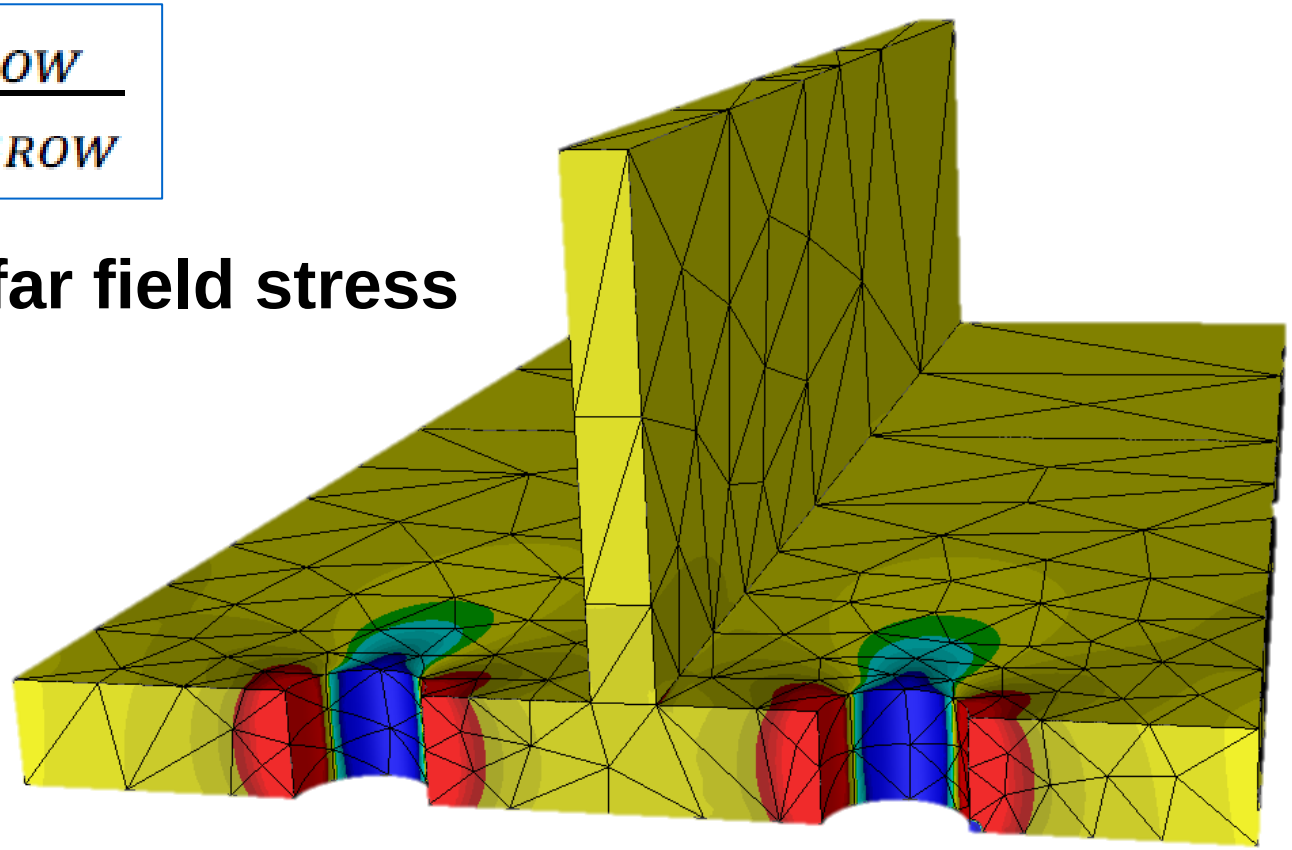
RPDS SAT Cond 35											
WS Section Selection		Location in Aircraft Coordinates		Location in Wing Coords Rel. to Wing CG		Ix (in^4)	Iz (in^4)	Ixz (in^4)	Mx (in-lb)	Mz (in-lb)	Bending Stress (psi)
		x	z	x	z						
Inboard	0	462.50	73.80	-27.48	-3.24	3626	16213	-1659	14800000	0	25896
Outboard	23 S2 (Outboard of Rib Pad)	462.50	73.80	-27.66	-3.00	3718	16632	-1779	14800000	0	24980
Desired Location	23.00	462.50	73.80	-27.48	-3.24	3626	16213	-1659	14800000	0	**25896**

BAMpF Stress Parameter

- **“Stress” is required BAMpF parameter**
- **Stress parameter is passed to AFGROW with the stress intensity**

$$\alpha = \frac{K_{StressCheck}}{stress_{StressCheck}} = \frac{K_{AFGROW}}{SMF_{AFGROW}}$$

- **Stress parameter should represent far field stress**

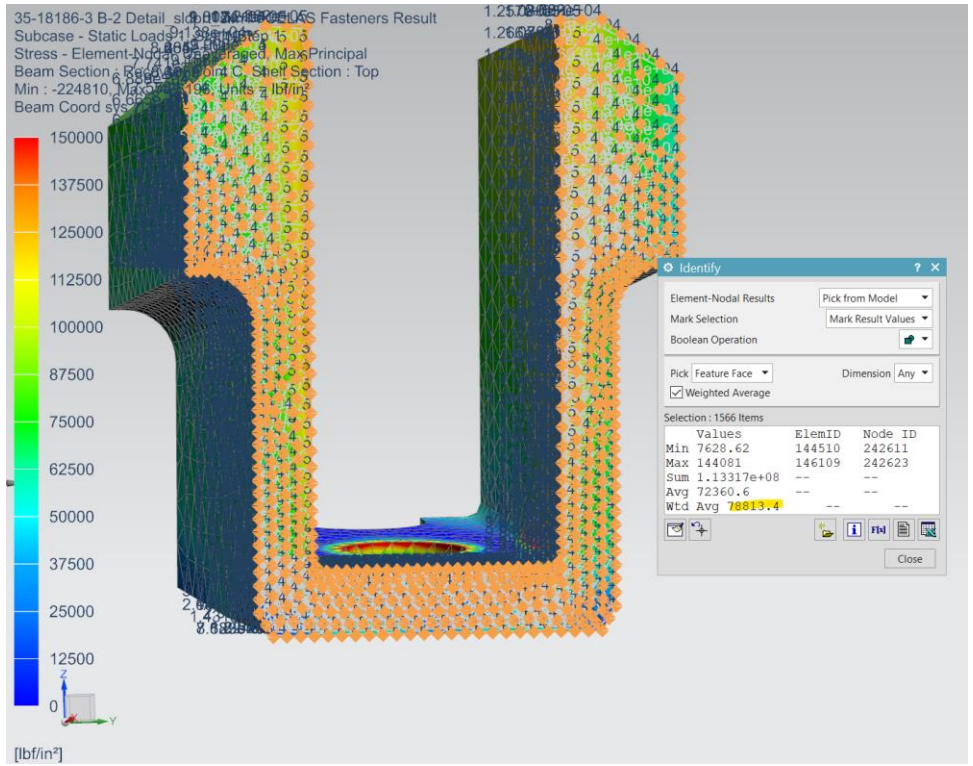


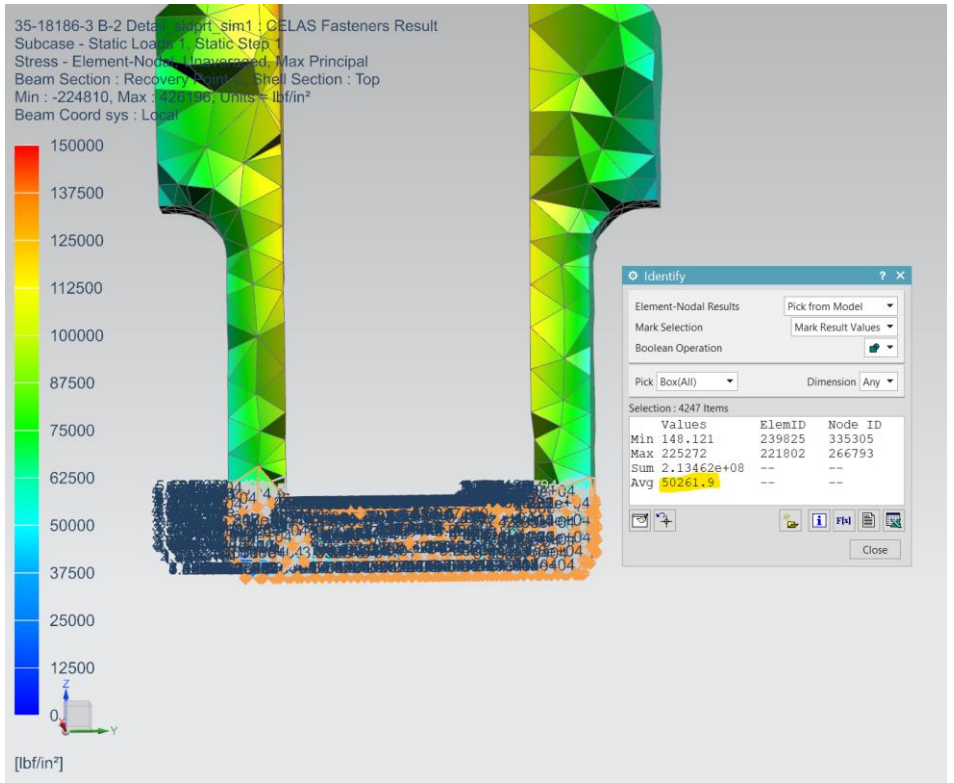
BAMpF Stress Parameter

- **Entering the appropriate stress parameter in BAMpF is very important**
  - **K/σ, where σ is a user defined parameter in StressCheck**

For defined load set:

Boeing Solution	63.9 ksi
FEM avg on x-section	78.8 ksi
FEM avg where crack is growing	50.3 ksi

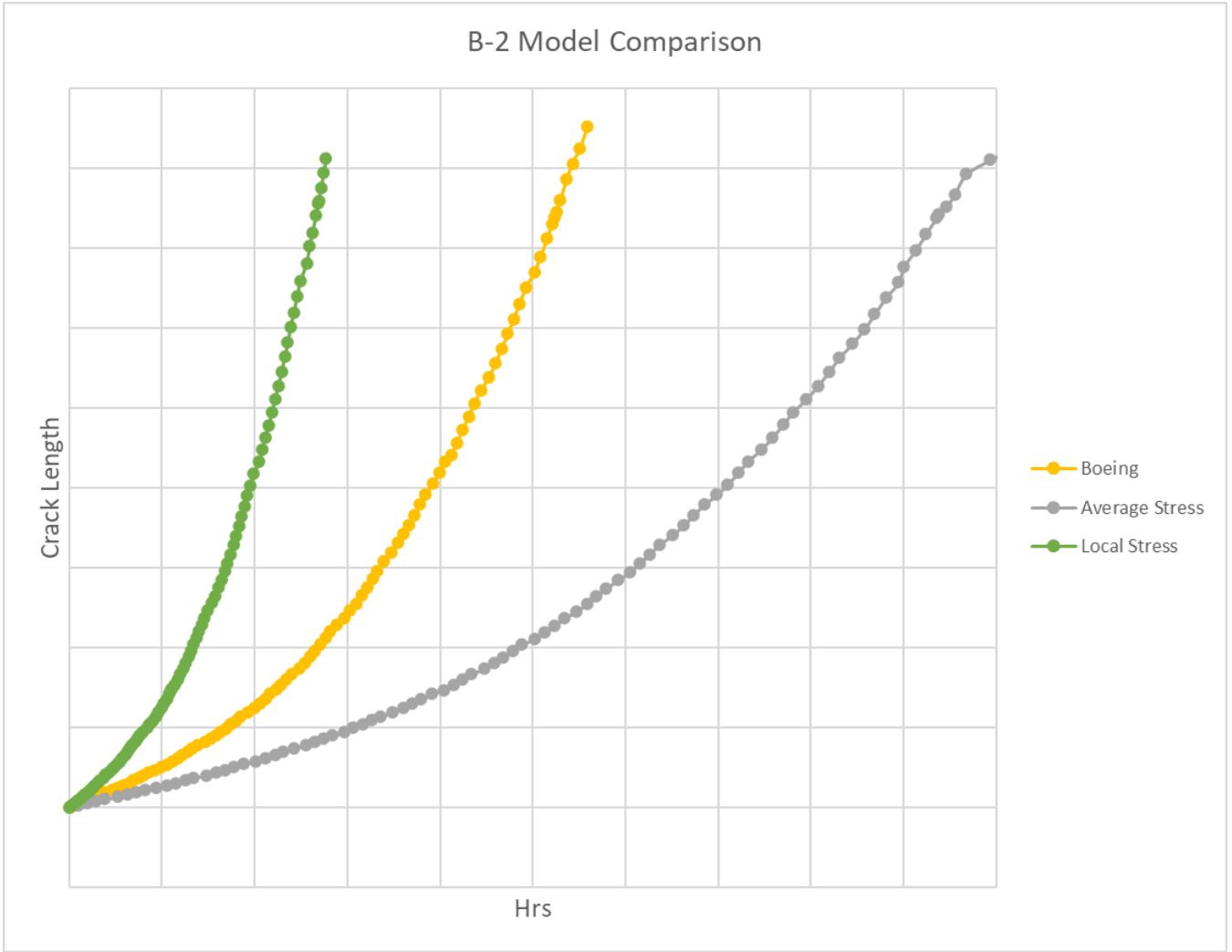




Andrew, D., et. al., "Working Together to Help Modernize the B-52 ASIP", ASIP Conference 2022

Difference in CGC

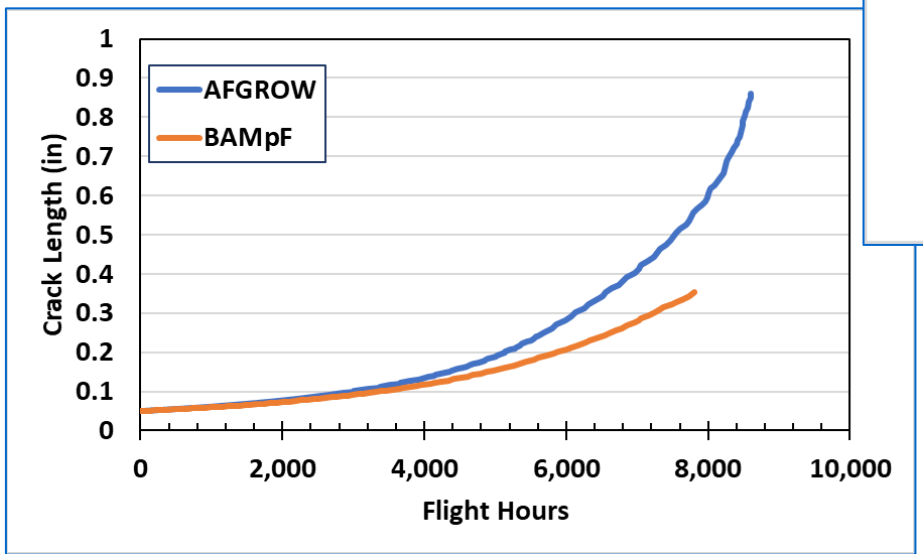
- **Stress local to crack: baseline**
- **Boeing stress: ~2x baseline**
- **Average stress over section: ~3.5x baseline**
- **Very important to understand how your load condition relates to the peak stress in the spectrum and how the spectrum was created.**

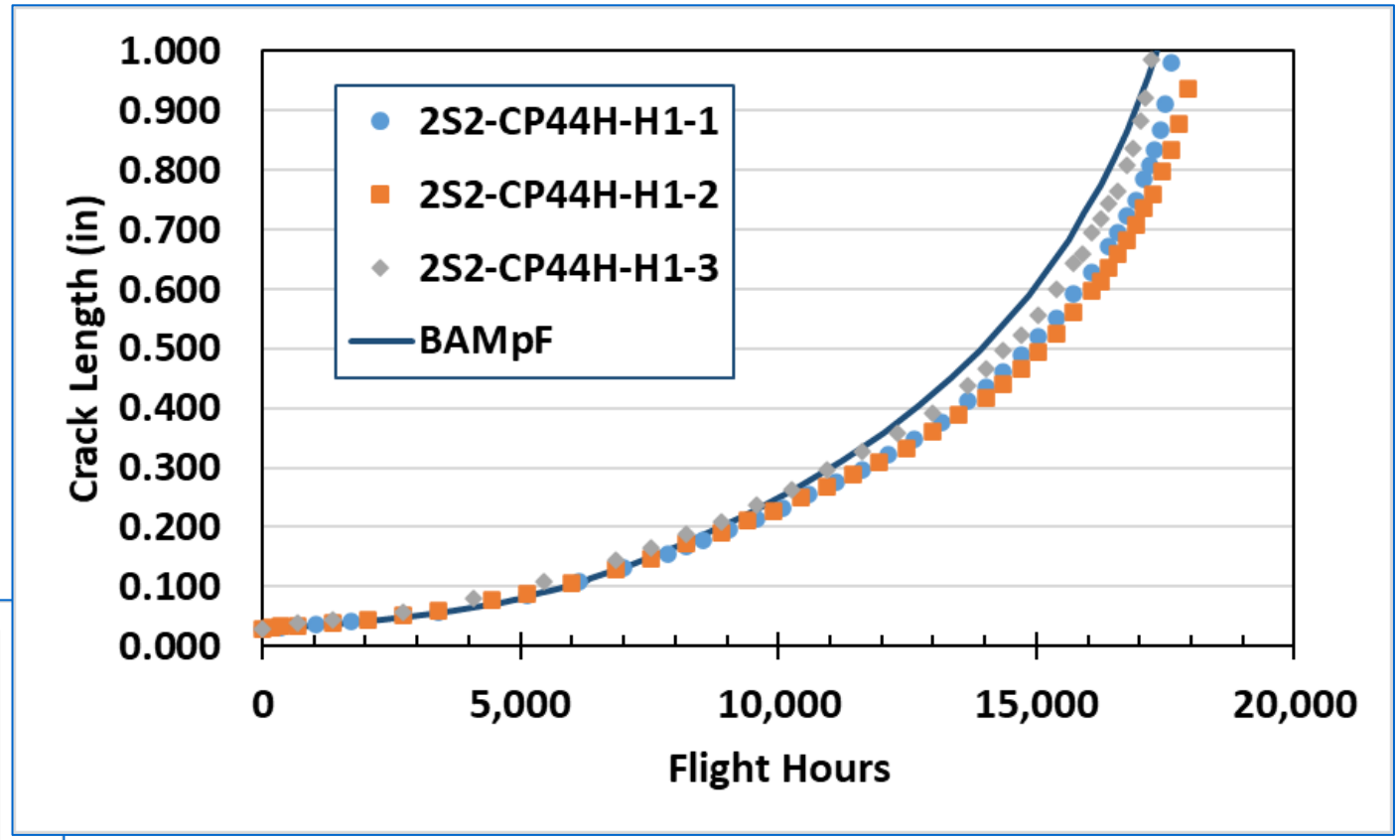


Andrew, D., et. al., "Working Together to Help Modernize the B-52 ASIP", ASIP Conference 2022

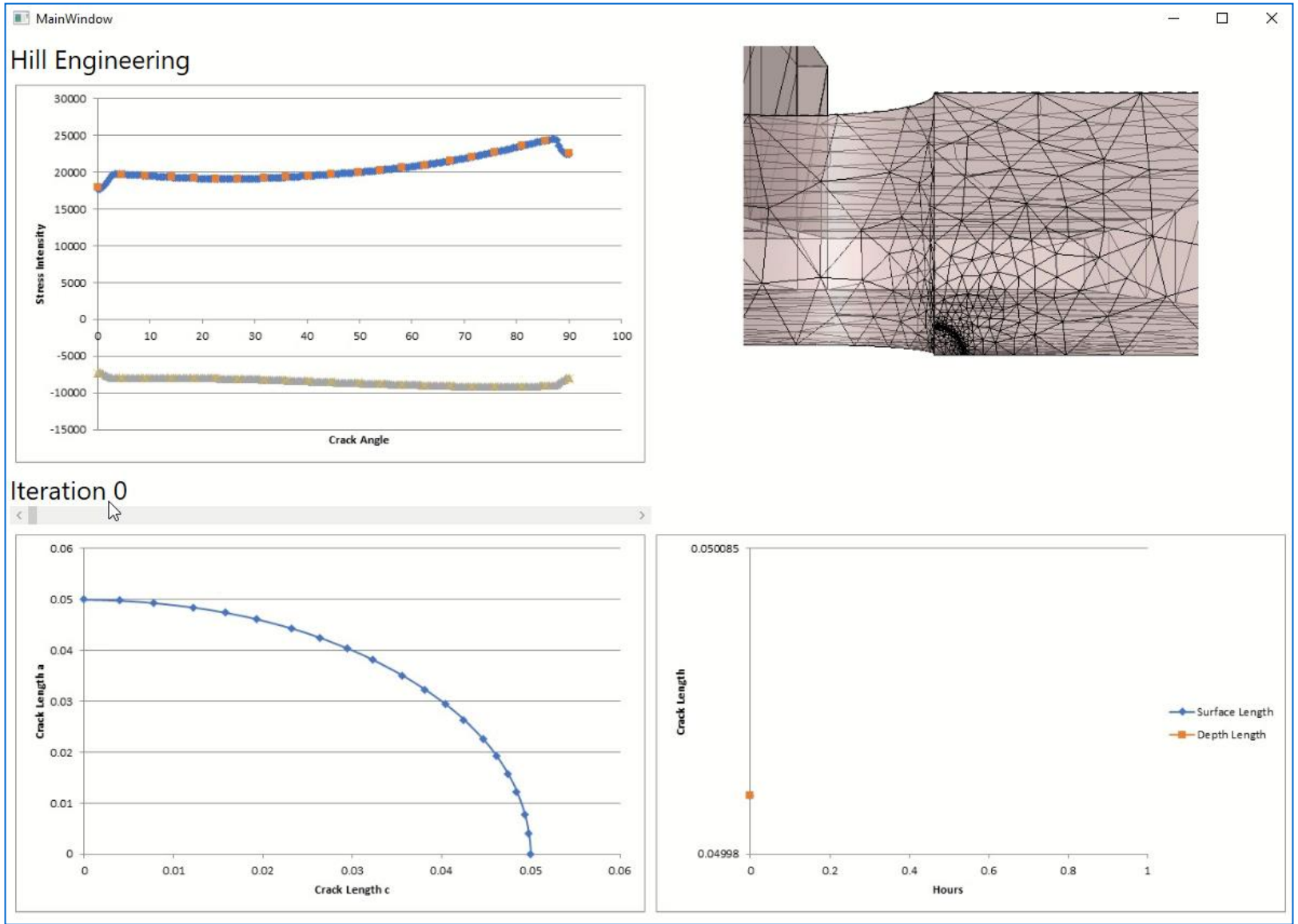
BAMpF Validation

- **Validate BAMpF model *without RS***
  - **Verify model is behaving as expected for baseline (no RS) condition**
- **If tests are not available, compare to traditional AFGROW model**



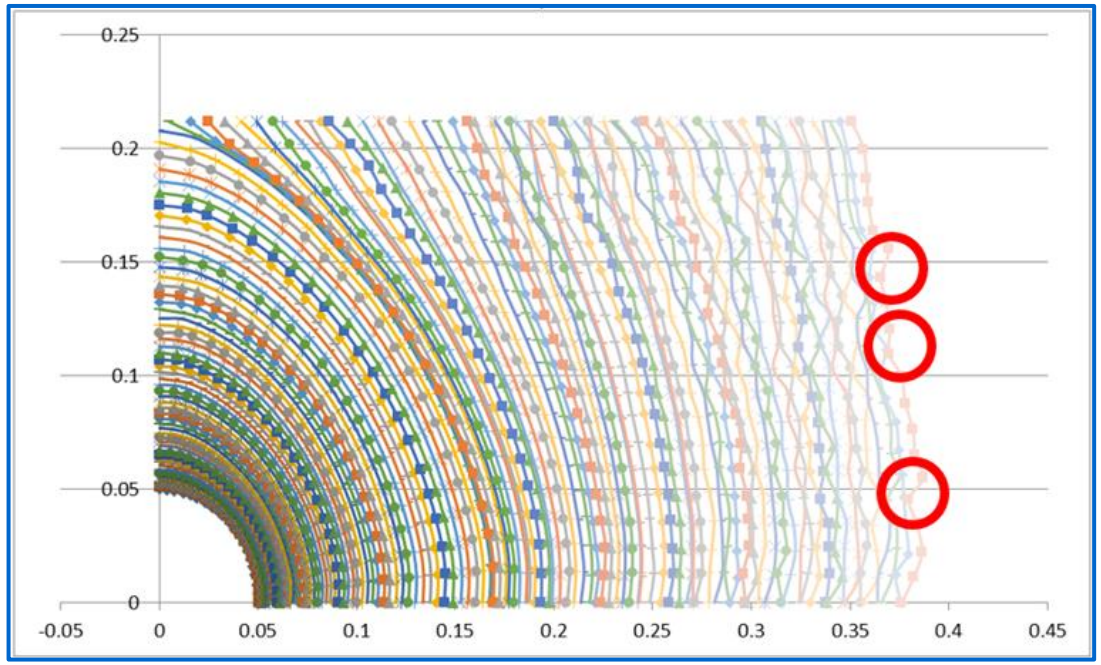


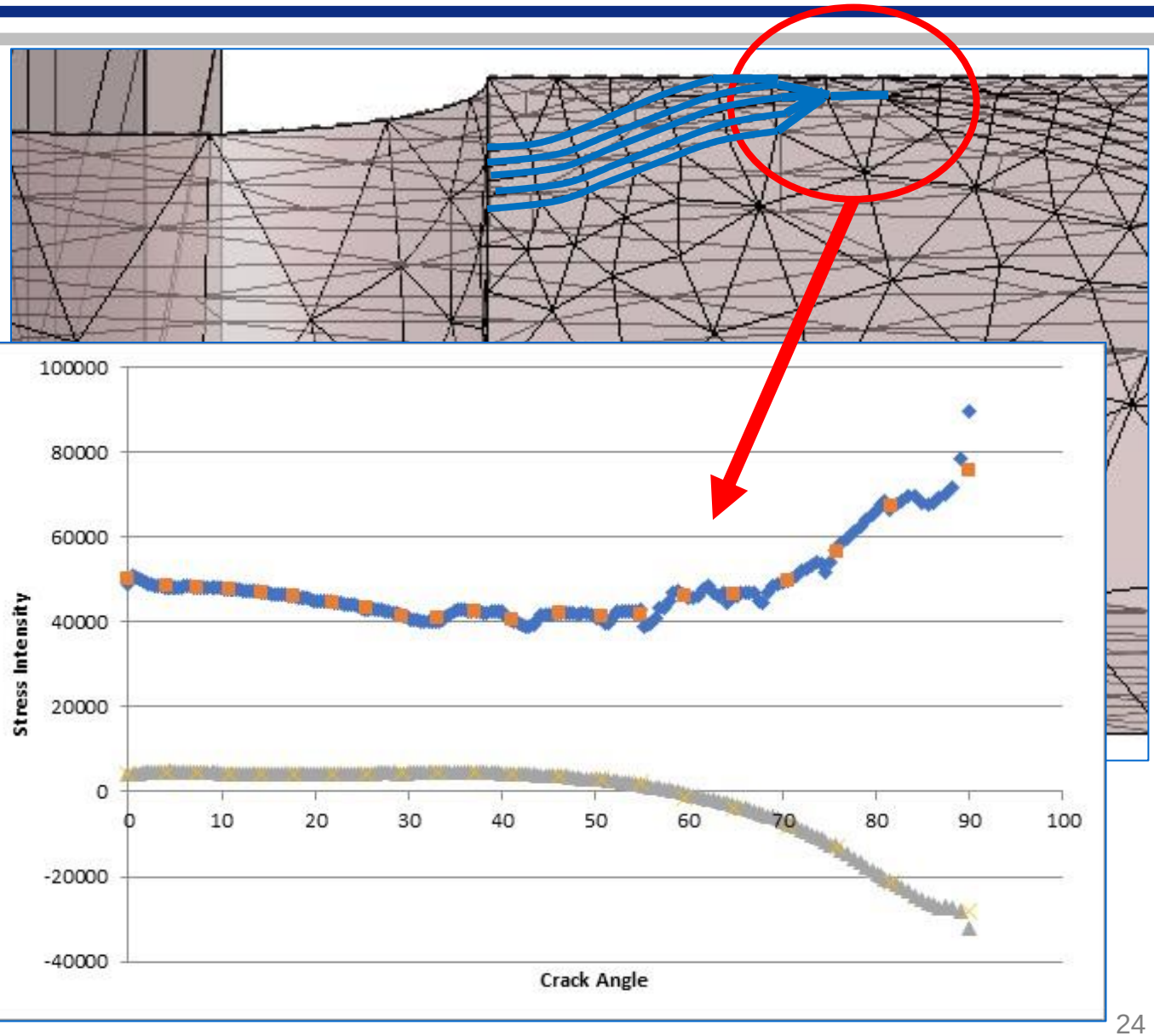
Determining the Last Useful BAMpF Iteration



Determining the Last Useful BAMpF Iteration

- As failure is approached mesh fidelity, stress intensity, etc. can be compromised
- Interrogate BAMpF output to verify last meaningful iteration to use for results





RS Ground Rules

- **A-10 Guidance for including RS in analysis**

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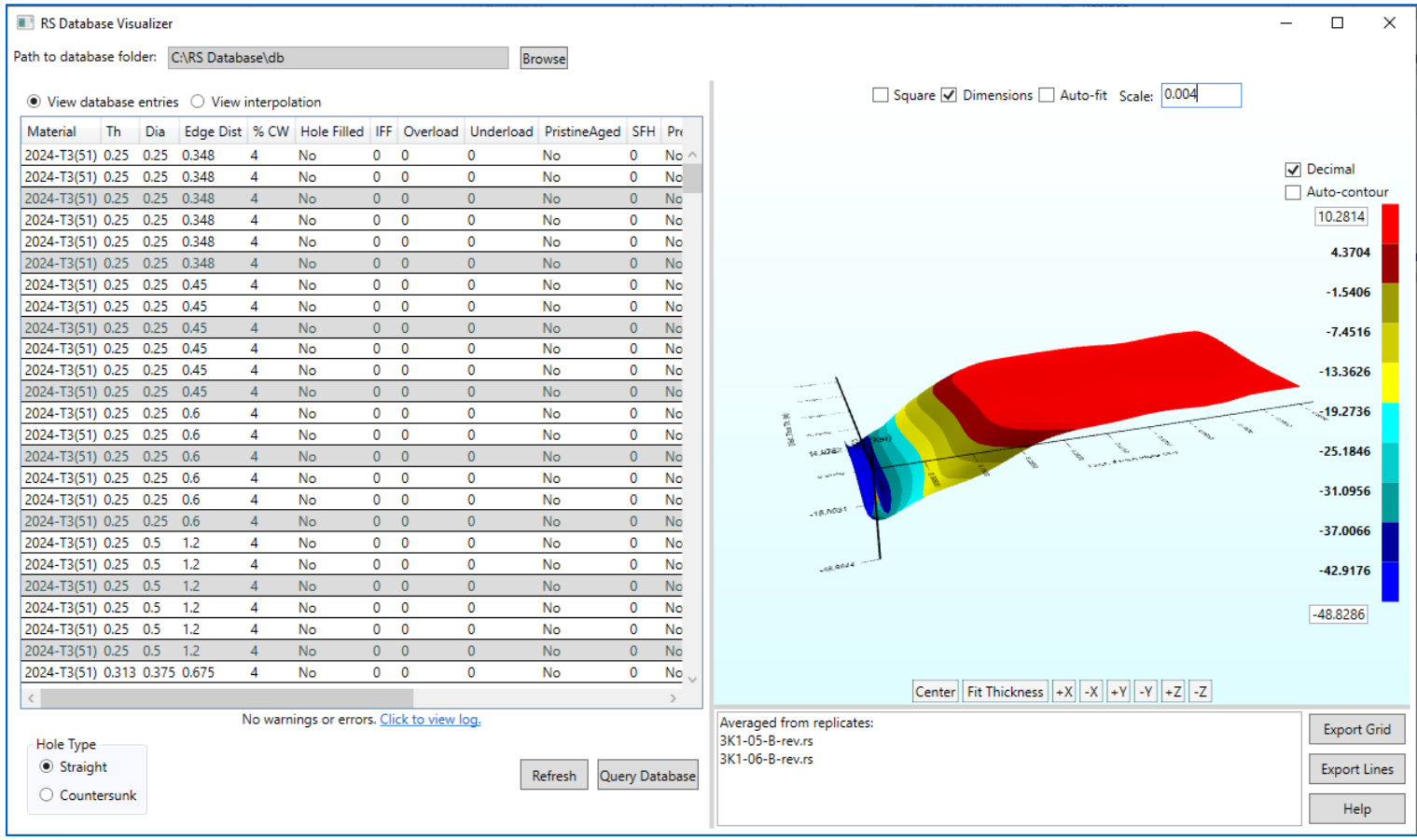
A-10 DTA RPDS Severe	Jacob Warner	9/19/2022	Kaylon Anderson		F	C-1
	Appendix C: Ground Rules for Including Residual Stresses from Cold Expansion in DTAs		CHECKED BY: Luciano Smith (SwRI)	DATE:	REPORT NO: SA220R0207 1 April 2023	

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

The following guidelines describe A-10 best practices for including Residual Stress (RS) in Damage Tolerance Analyses (DTAs). Beginning with SA220R0207 Revision F residual stresses were used in DTAs for cold expanded hole locations. Structures Bulletin EZ-SB-17-001, Revision A (Reference 8.a) provides some basic guidance for including residual stresses in analysis. Primarily, the structures bulletin permits the use of residual stresses in analysis as long as the life benefit is clipped to the analytical life of a 0.005" corner crack.

RS Field

- **Sources:**
  - **RS Database (Contour)**
  - **FEA simulations**
  - **MMM**
- **Closest match and interpolation limits/requirements**
  - **Same material**
  - **D match within ¼” (if D<3/4”)**
  - **Thickness matches within MMPDS thickness range**
  - **e/D > validation case**
  - **Avoid max % expansion**



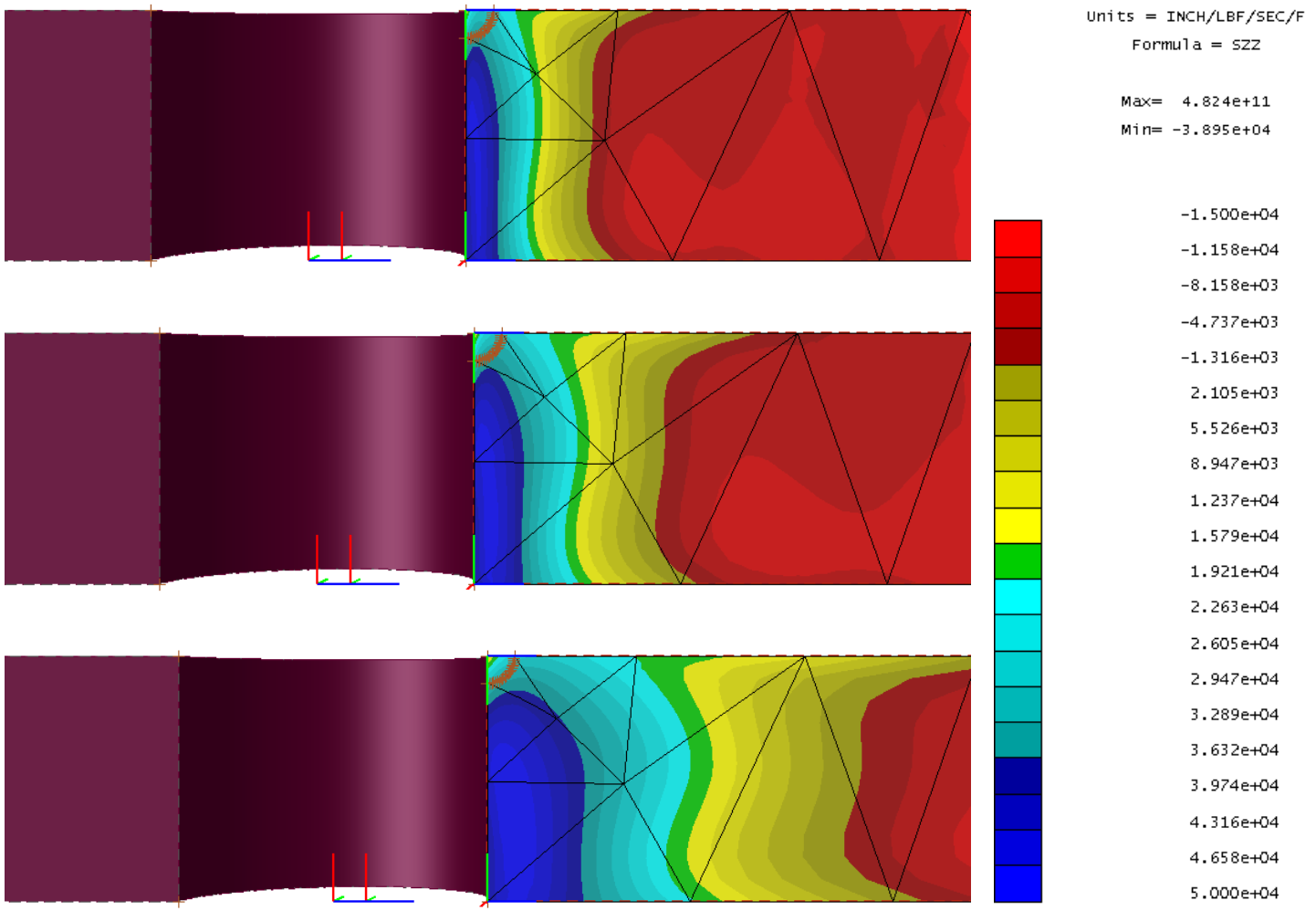
Problems Stretching the RS Field

- **Stretching RS field introduces fictitiously deep compressive stresses**

Original RS for 0.95” ligament

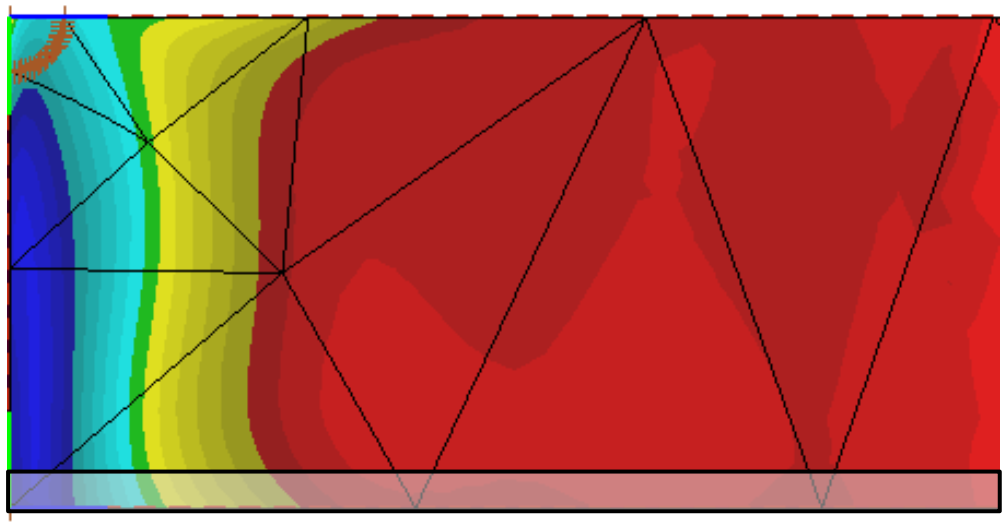
RS stretched to fill 1.425” ligament

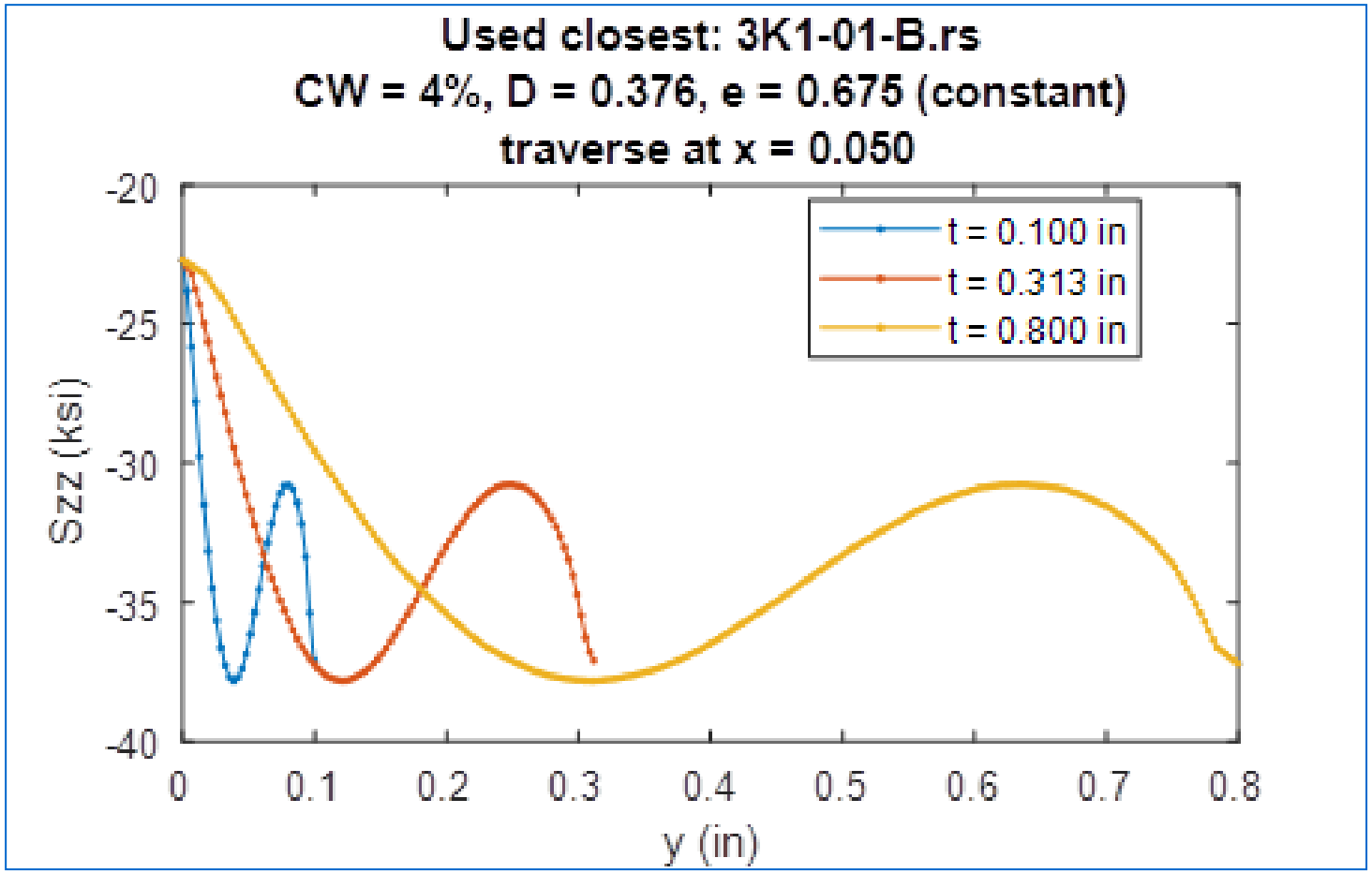
RS stretched to fill 2.85” ligament



Problems Stretching the RS Field

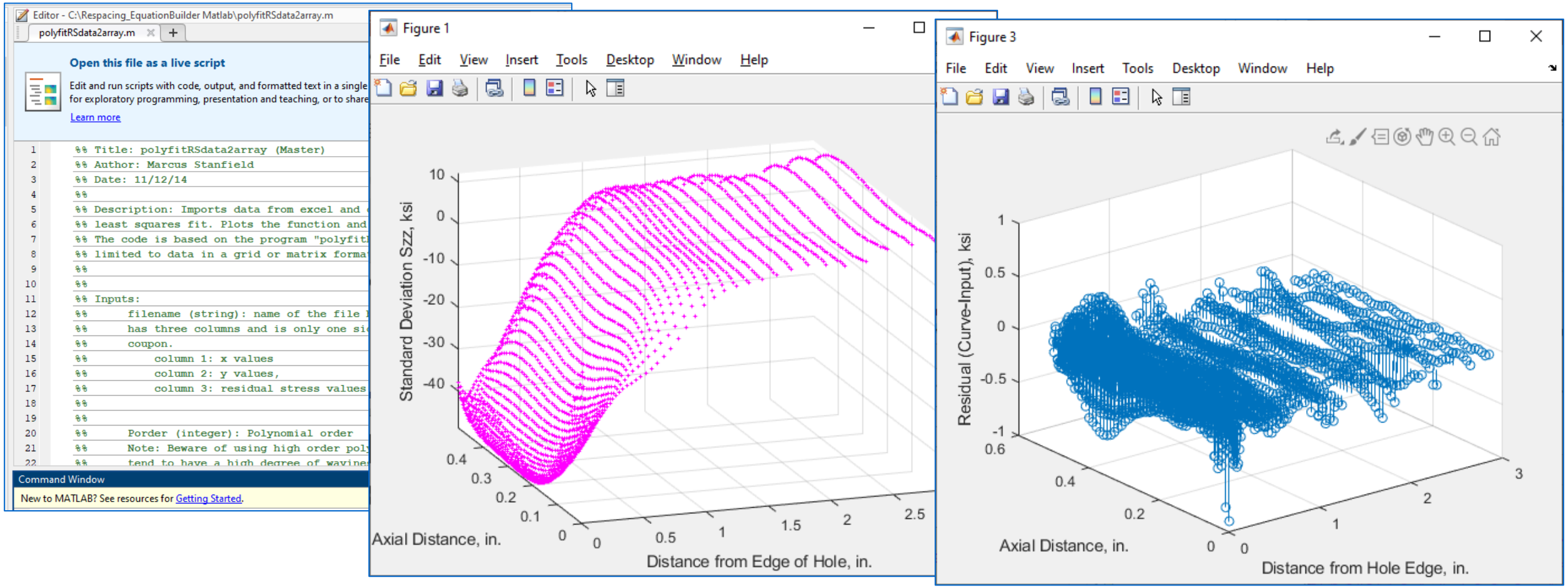
- Stretching in the thickness direction skews RS distribution through thickness
- If a thinner section is needed, clip the mandrel exit face





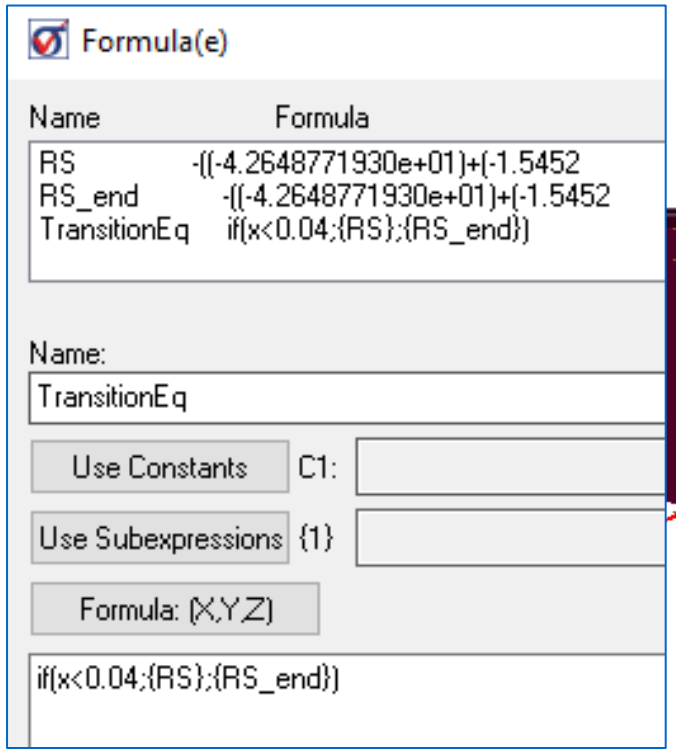
RS Polynomial

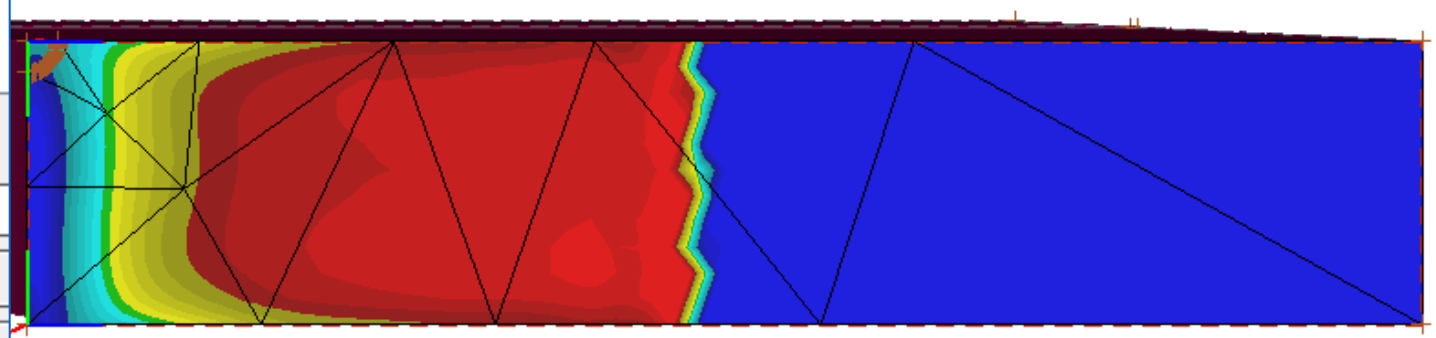
- RS field applied in StressCheck as a formula
- Create a polynomial approximation of the RS field in Matlab

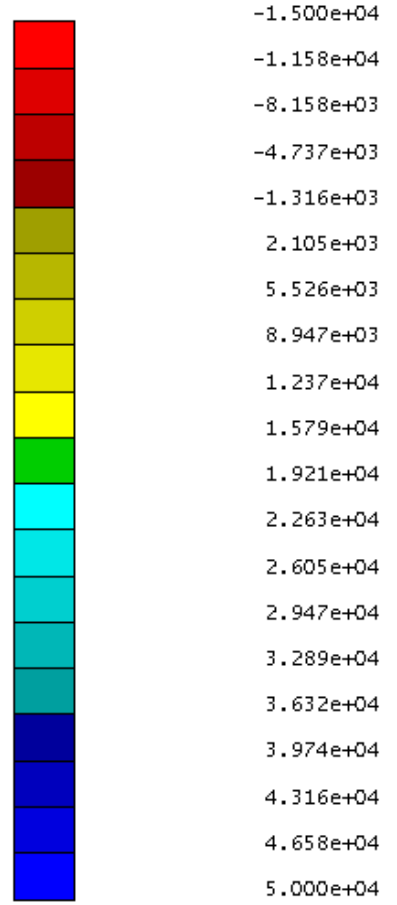


Ensuring Valid Polynomial Domain

- **Applying a RS field developed for a shorter edge distance to a larger edge distance scenario can provide irrational results beyond the domain of the polynomial derivation**

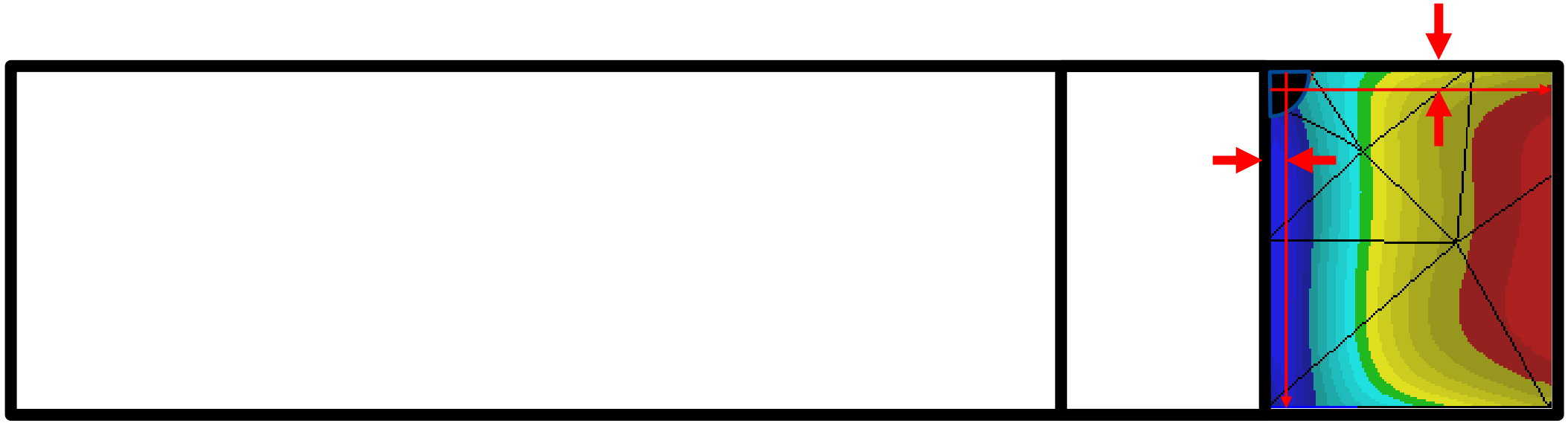






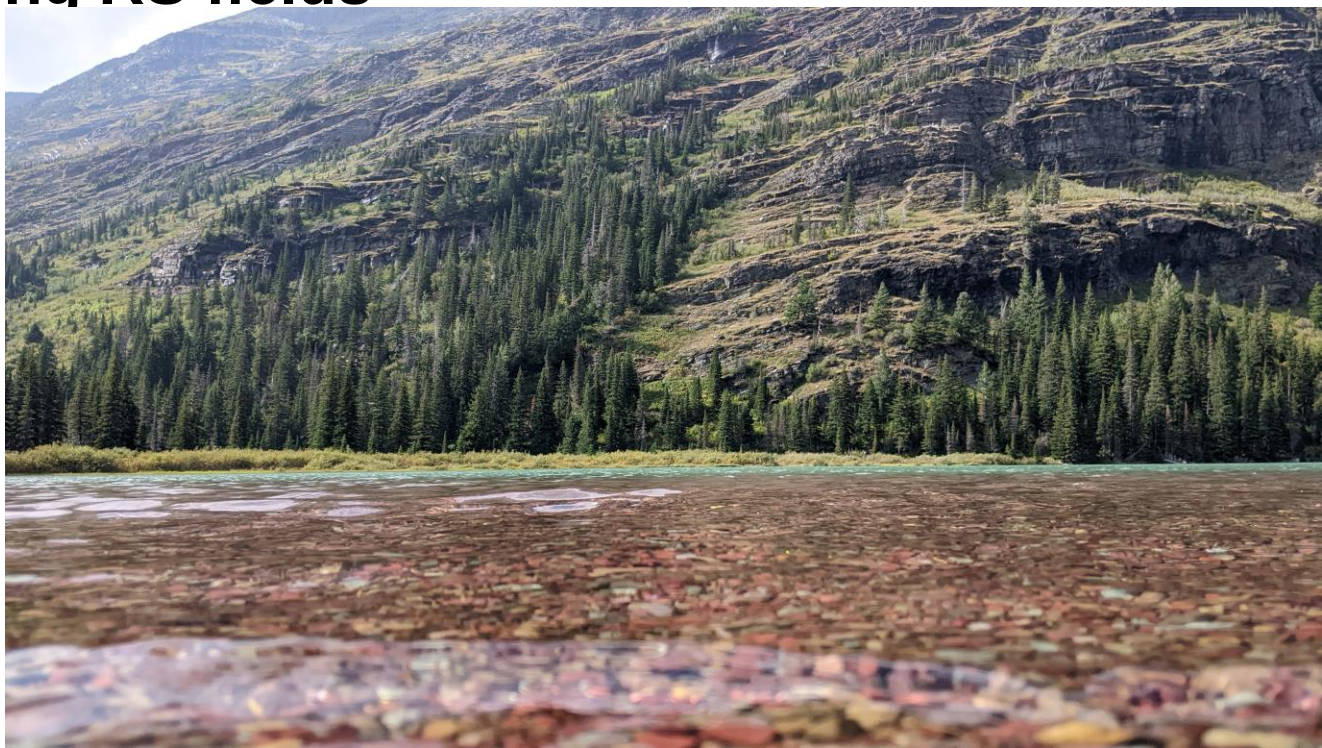
2-point RS

- Validate to test or BAMpF
- Vectors
  - Recommend 0.02” offset
  - See AFGROW 2021 presentation “Rapid 2 Point RS Predictions”



Summary

- Validate with test data
- Follow modeling best practices
- Leverage BAMpF and RS ground rules to help guide successful analysis
  - Attention to details required for defining loading scenarios and constraints
  - Caution must be used in manipulating RS fields
- We can move mountains together!

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