

Effects of Full Countersink Holes in Metallic Structure

Lawrence "Charlie" Stoker

September 2020

- Background
- Model Setup
- Convergence Study
- SIF Results
- AFGROW Results
- Conclusion

Background

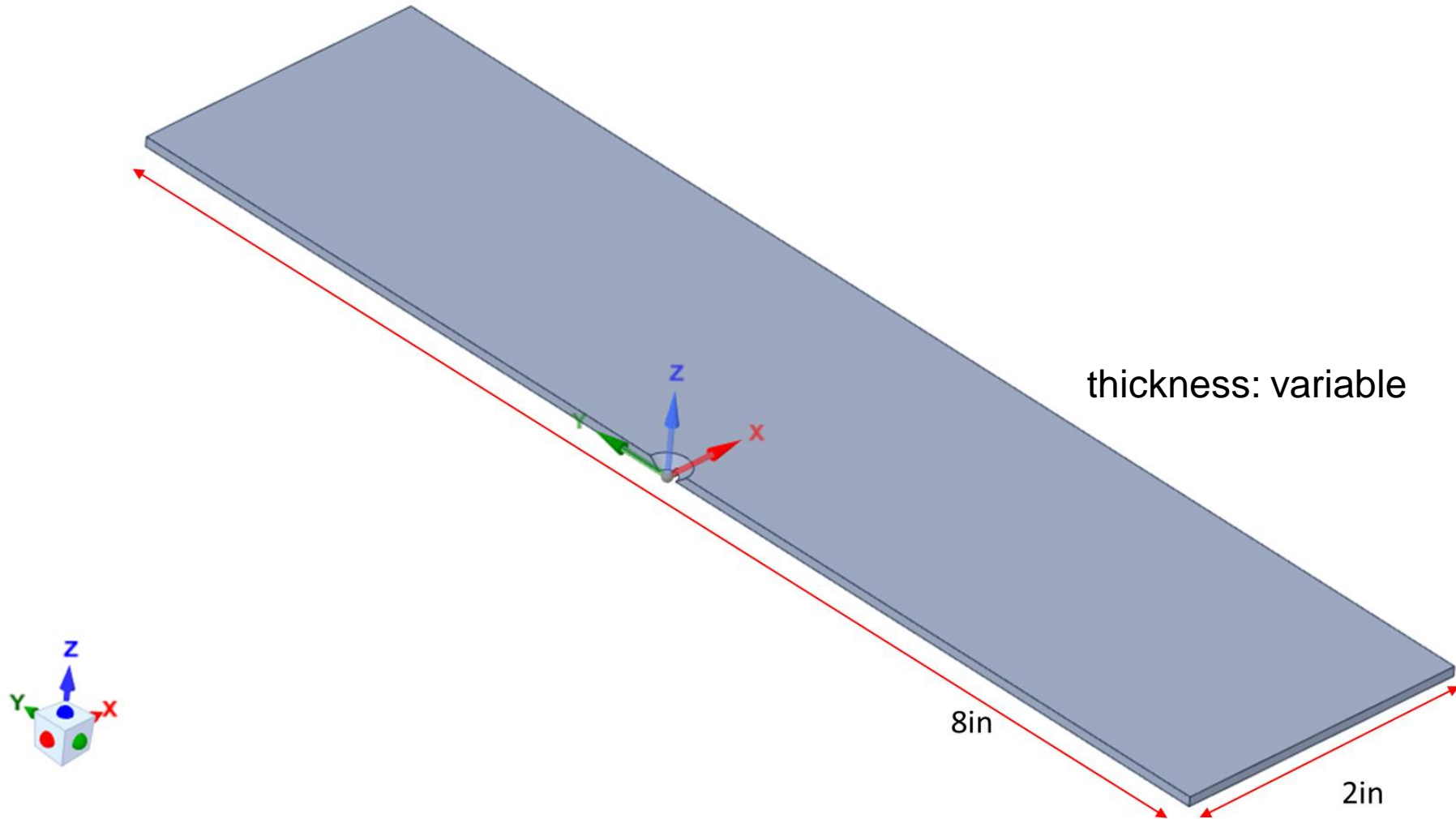
- Knife-edge holes (countersink depth $> 2/3$ material thickness) are avoided as a poor engineering practice
- Effect on stress concentrations is relatively well-known
- Effect on life not well documented
- Situations may arise where a full countersink is needed from:
 - ▶ An unusual requirement
 - ▶ Poor repair choice implemented in the field – “It came in that way!”
 - ▶ Field repair is impractical
 - ▶ Desired service life is short
 - ▶ Asset is due to be retired

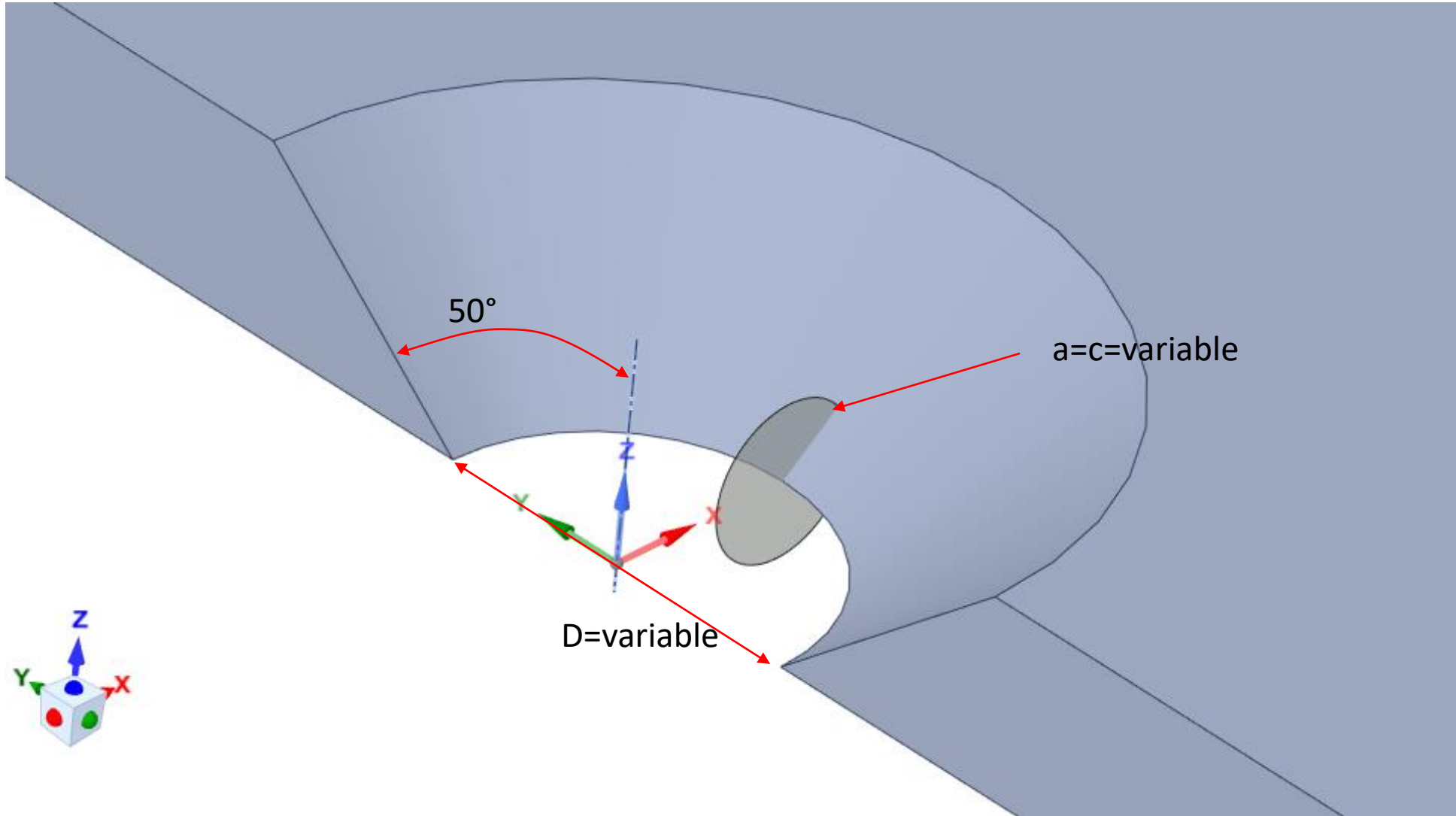
Underlying Question: Can we characterize full countersink effect on SIFs and make life predictions?

- Scope: holes in tension only

Model Setup

- Geometry
 - ▶ Solid model
 - ▶▶ Solidworks
 - ▶ Crack shape
 - ▶▶ ANSYS Spaceclaim
- Solver
 - ▶ ANSYS 2020 R1
- Material Analyzed
 - ▶ 2024-T3
 - ▶▶ Static properties from MMPDS-06
 - ▶▶ Fracture properties from AFGROW's AFMAT

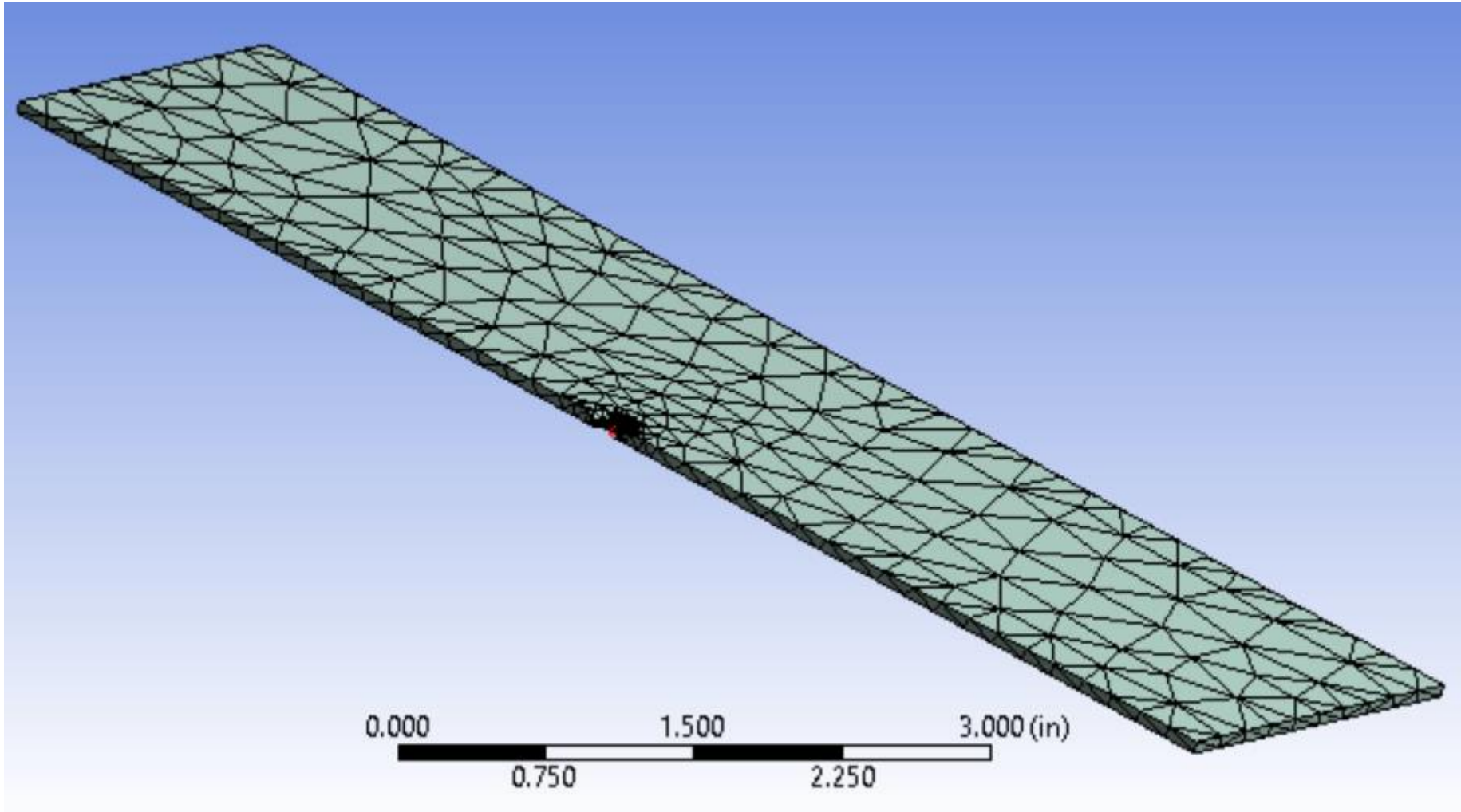


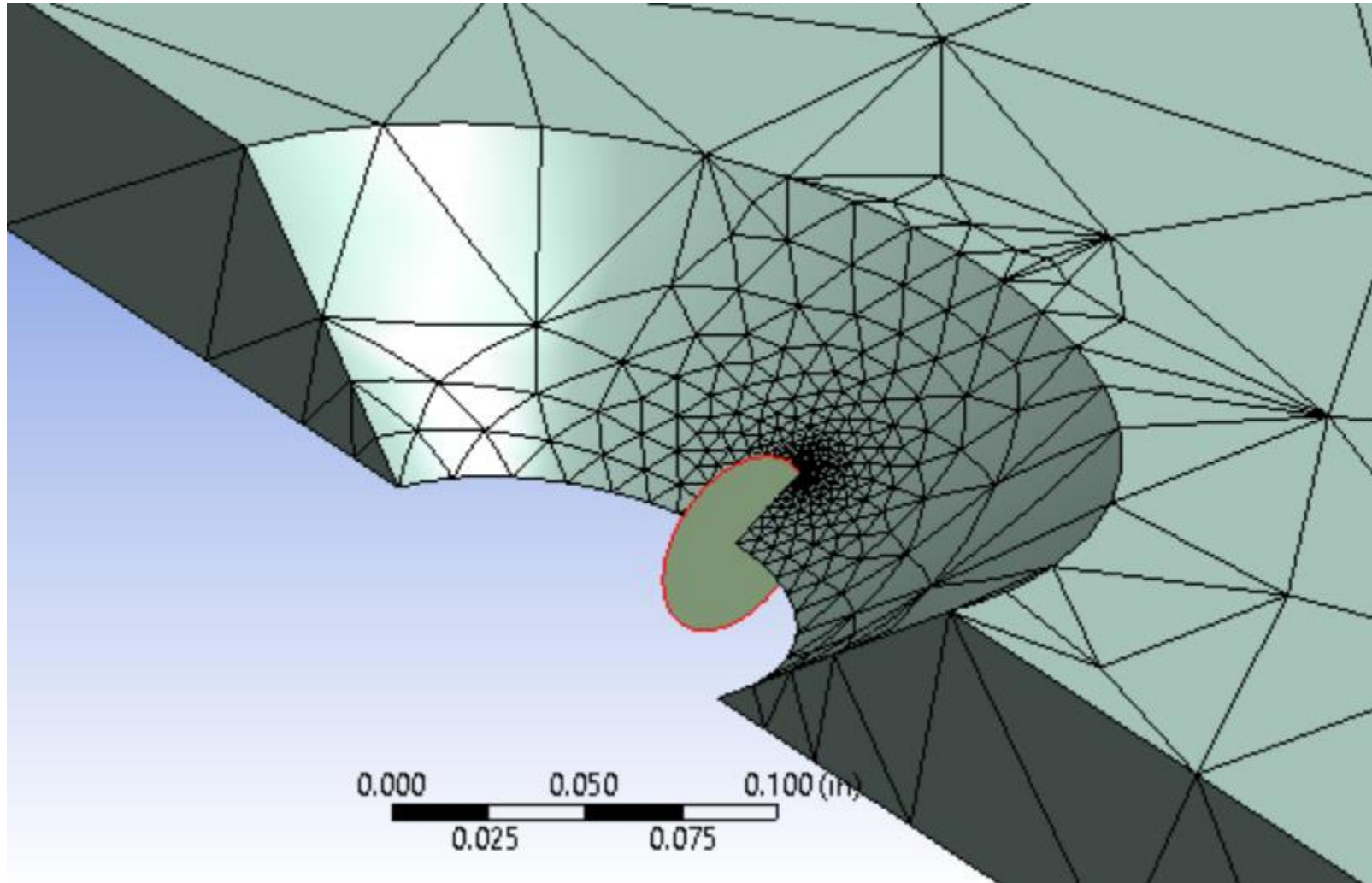


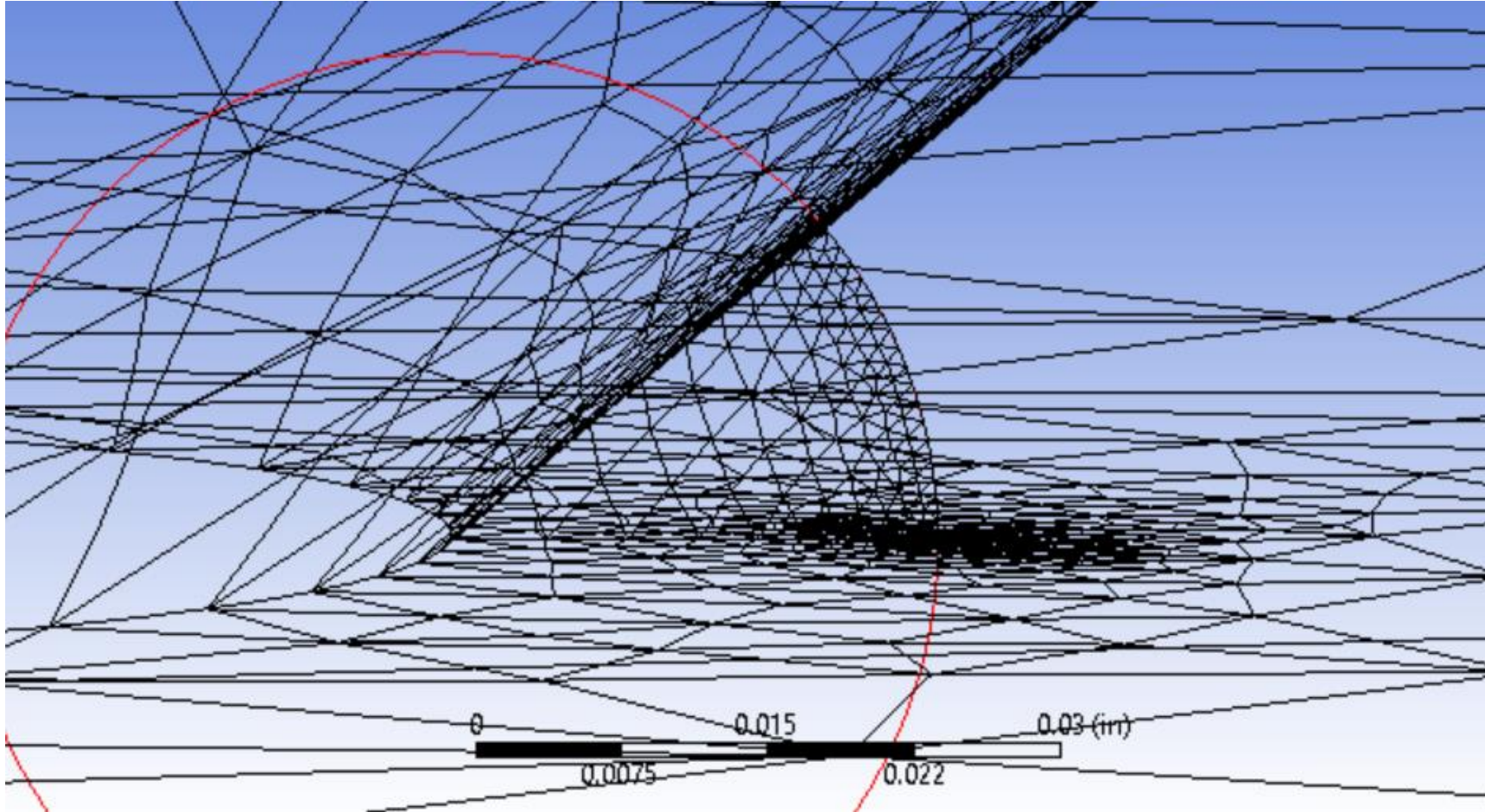
- Test Matrix

- ▶ **RED**: Geometry violation
- ▶ **YELLOW**: Crack tip refinement not possible
- ▶ **GRAY**: Skipped

Model #	D	t	w	D/t	D/w	Crack size (c, in)							
						0.025	0.05	0.075	0.1	0.15	0.2	0.25	0.4
1	0.125	0.063	4	1.984127	0.03125	x	x	YELLOW	RED	RED	RED	RED	RED
2	0.125	0.08	4	1.5625	0.03125	x	x	x	YELLOW	RED	RED	RED	RED
3	0.125	0.1	4	1.25	0.03125	x	x	x	x	YELLOW	RED	RED	RED
4	0.125	0.15	4	0.833333	0.03125								
5	0.125	0.25	4	0.5	0.03125		x	x	x		x		
6	0.125	0.5	4	0.25	0.03125								
7	0.1875	0.063	4	2.97619	0.046875	x	x	YELLOW	RED	RED	RED	RED	RED
8	0.1875	0.08	4	2.34375	0.046875	x	x	x	YELLOW	RED	RED	RED	RED
9	0.1875	0.1	4	1.875	0.046875	x	x	x	x	YELLOW	RED	RED	RED
10	0.1875	0.15	4	1.25	0.046875								
11	0.1875	0.25	4	0.75	0.046875								
12	0.1875	0.5	4	0.375	0.046875	x	x	x	x	x	x	x	x
13	0.25	0.063	4	3.968254	0.0625	x	x	YELLOW	RED	RED	RED	RED	RED
14	0.25	0.08	4	3.125	0.0625								
15	0.25	0.1	4	2.5	0.0625	x	x	x		YELLOW	RED	RED	RED
16	0.25	0.15	4	1.666667	0.0625								
17	0.25	0.25	4	1	0.0625								
18	0.25	0.5	4	0.5	0.0625						x	x	x







- Crack front refinement using ANSYS

- ▶ Number of Contour Radii

- ▶▶ 6

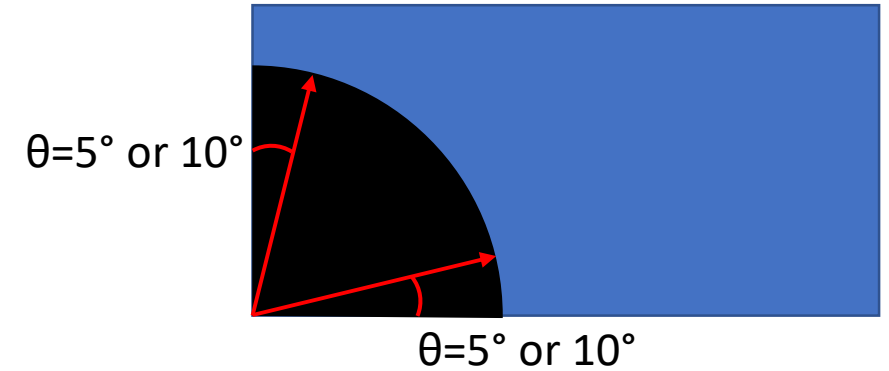
- ▶ Largest Contour Radius

- ▶▶ 0.4*c

- ▶ Growth Rate

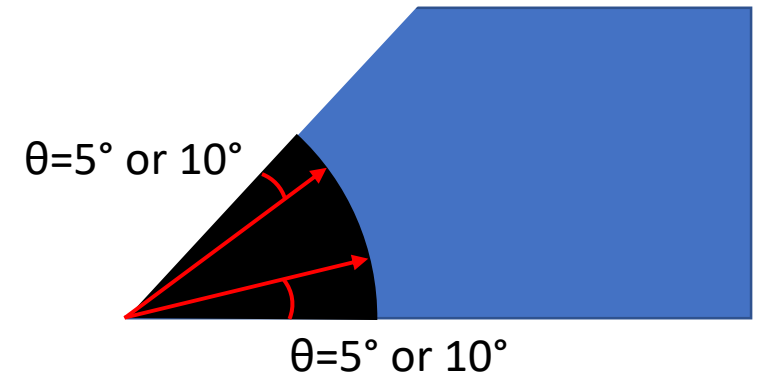
- ▶▶ 1.2 (default)

- ❖ Used 1.3 for uncooperative meshes



- SIF Extraction

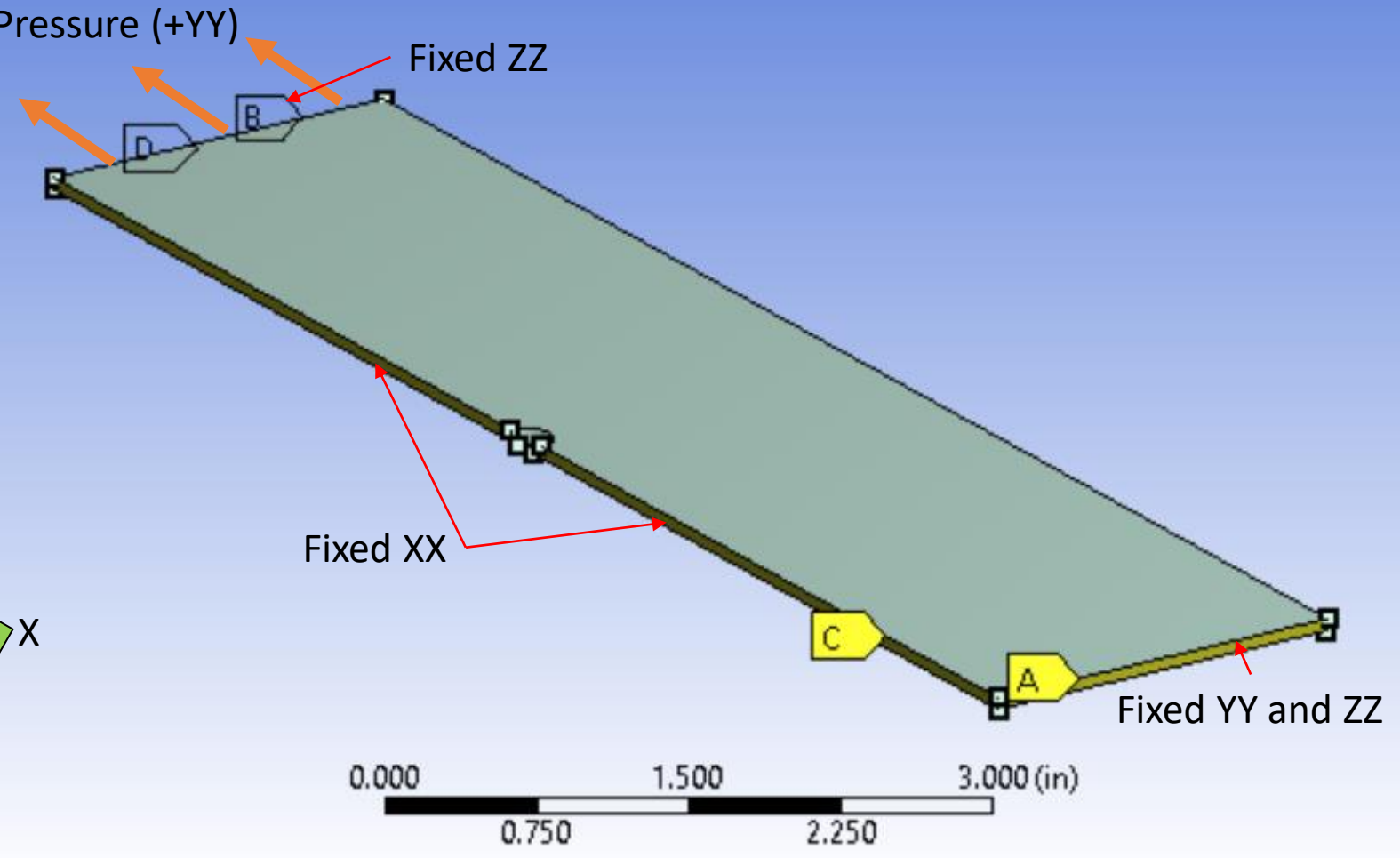
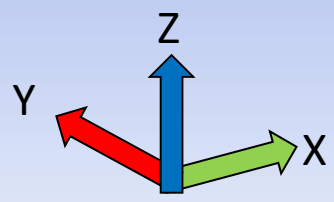
- ▶ Used 10 degrees from free surfaces



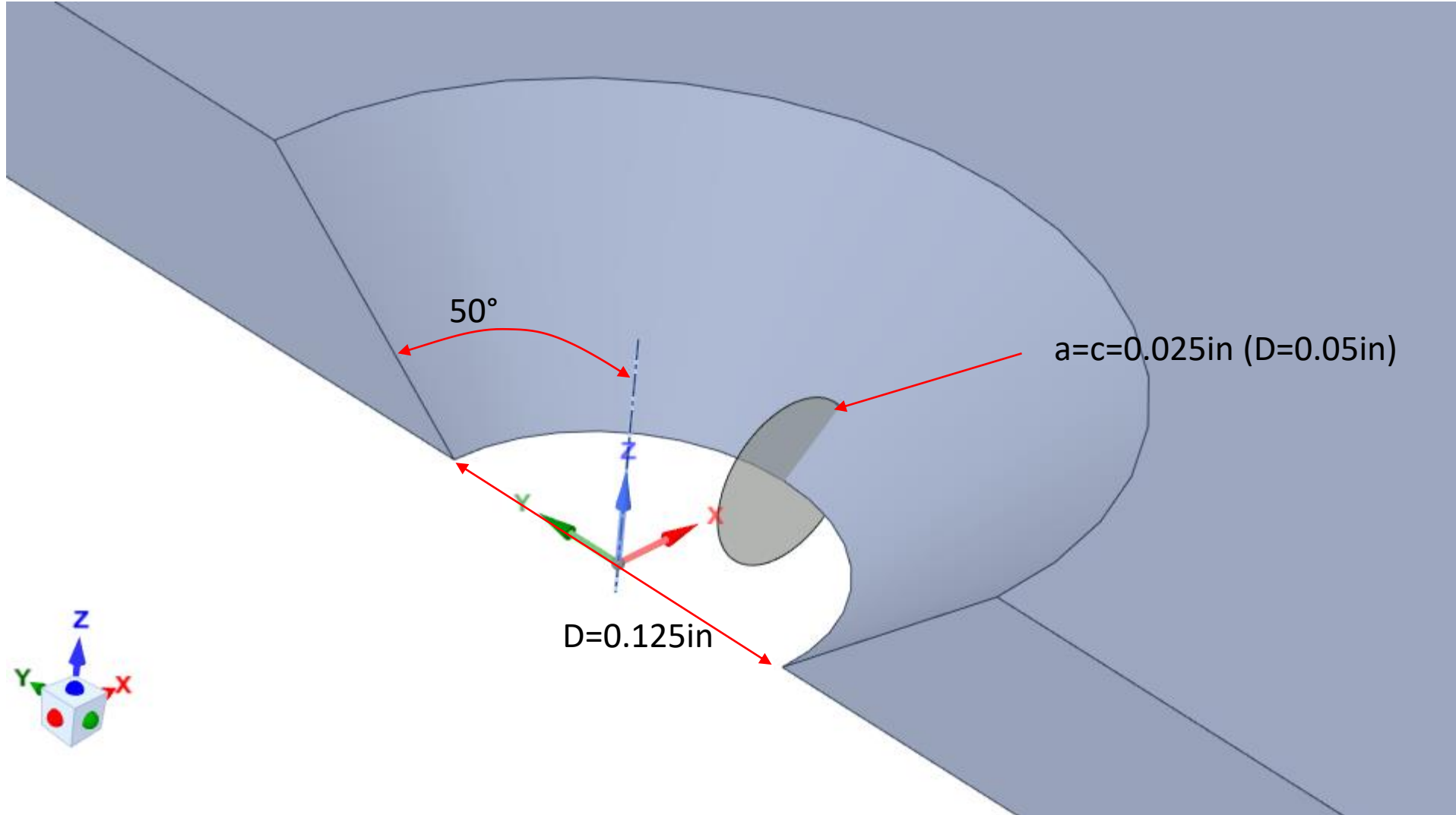
10° used for this analysis

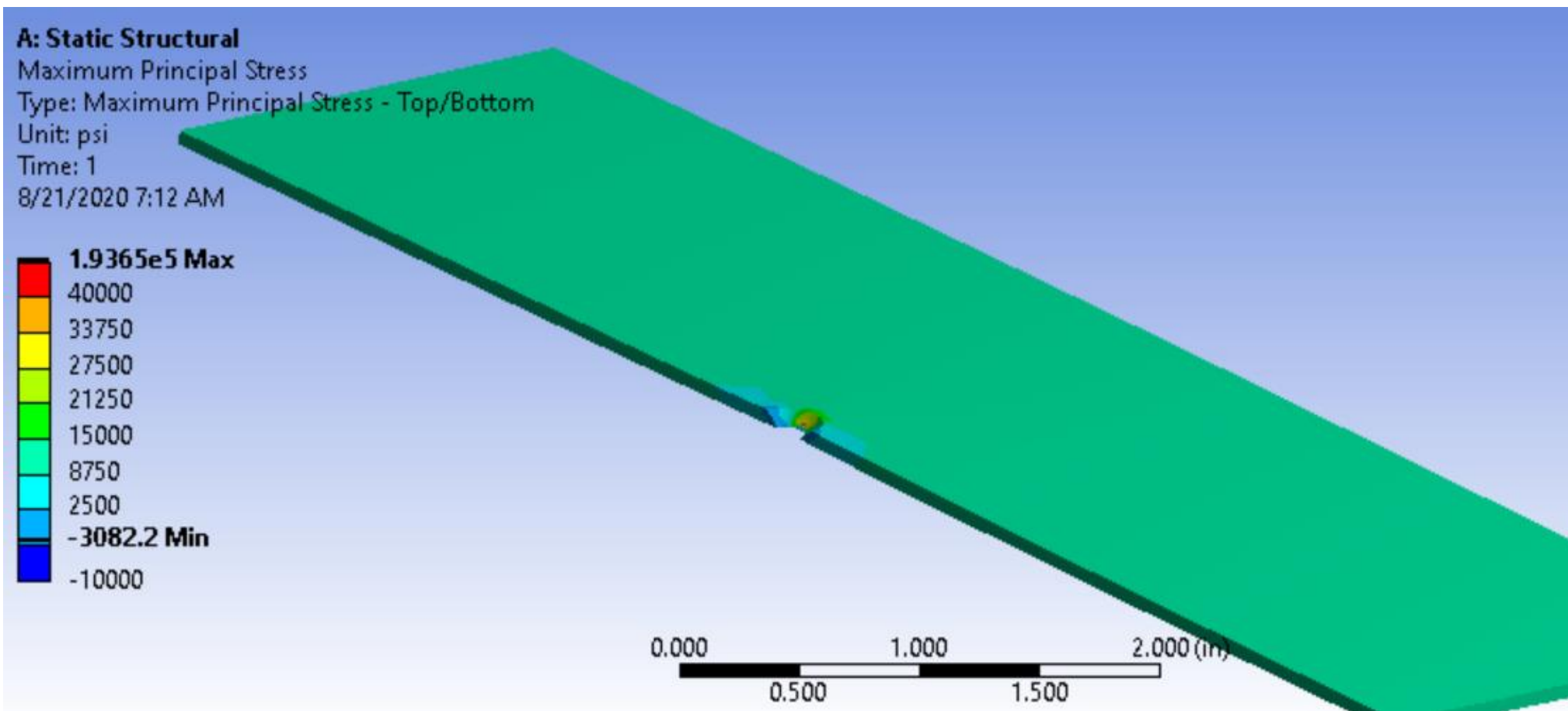
A: Static Structural
Static Structural
Time: 1. s
8/21/2020 7:13 AM

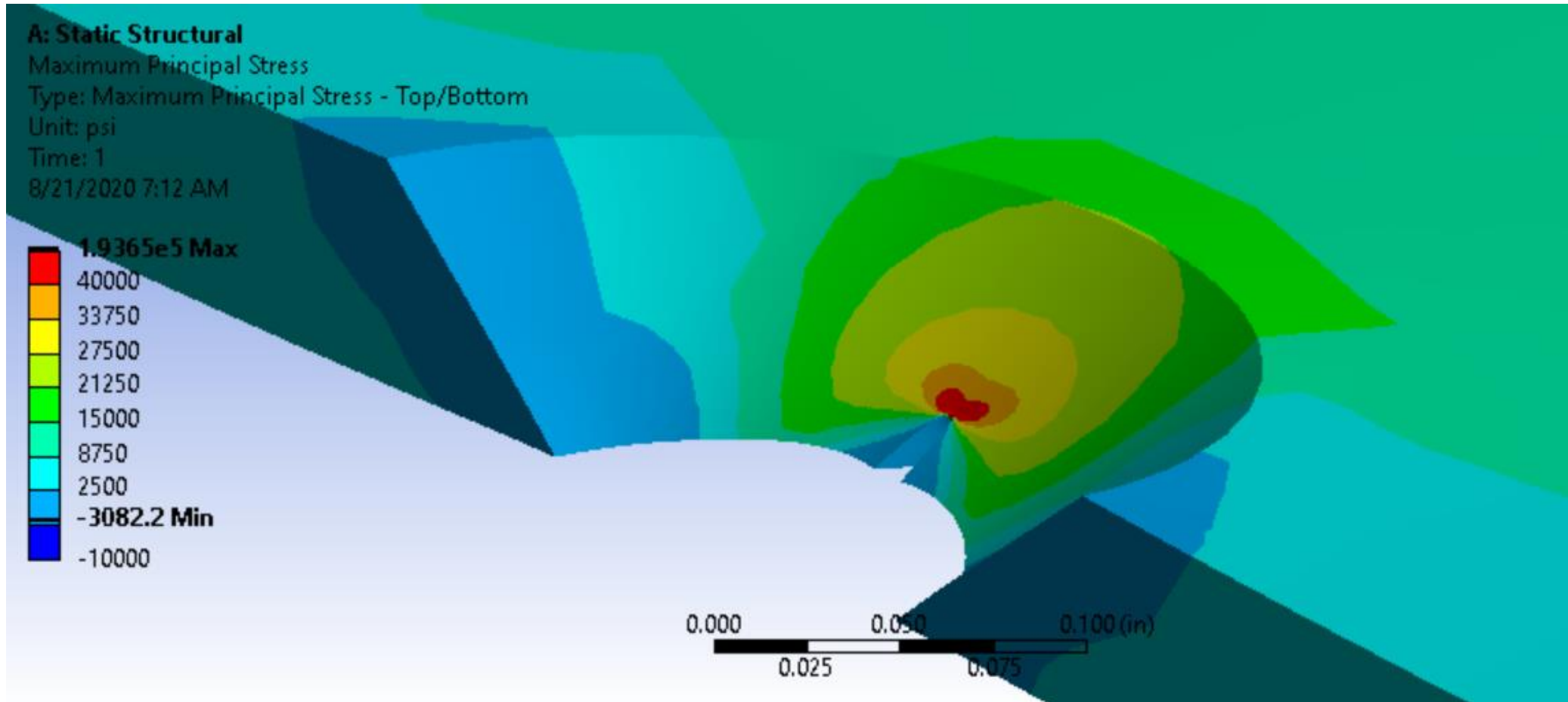
- A** Displacement 2
- B** Displacement 3
- C** Displacement
- D** Pressure: -10000 psi

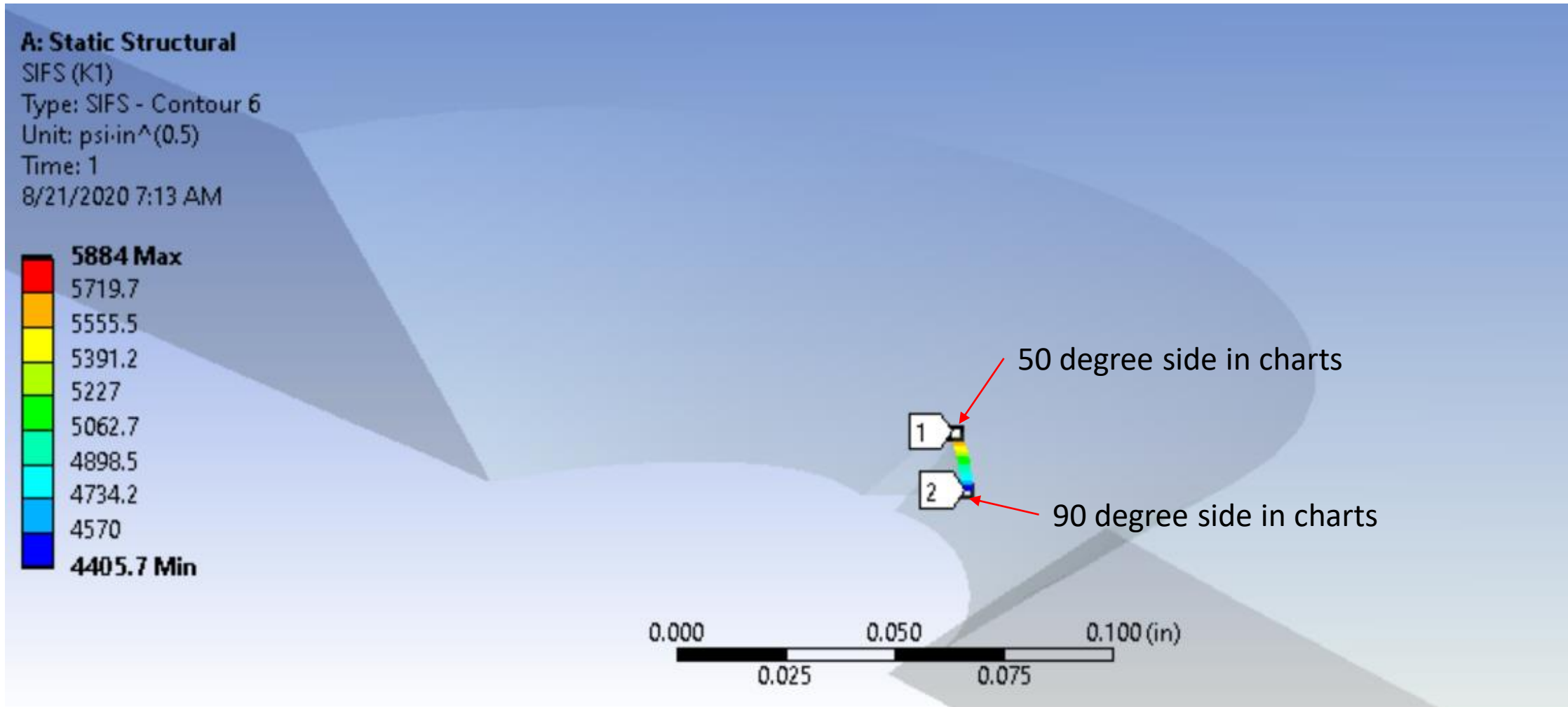


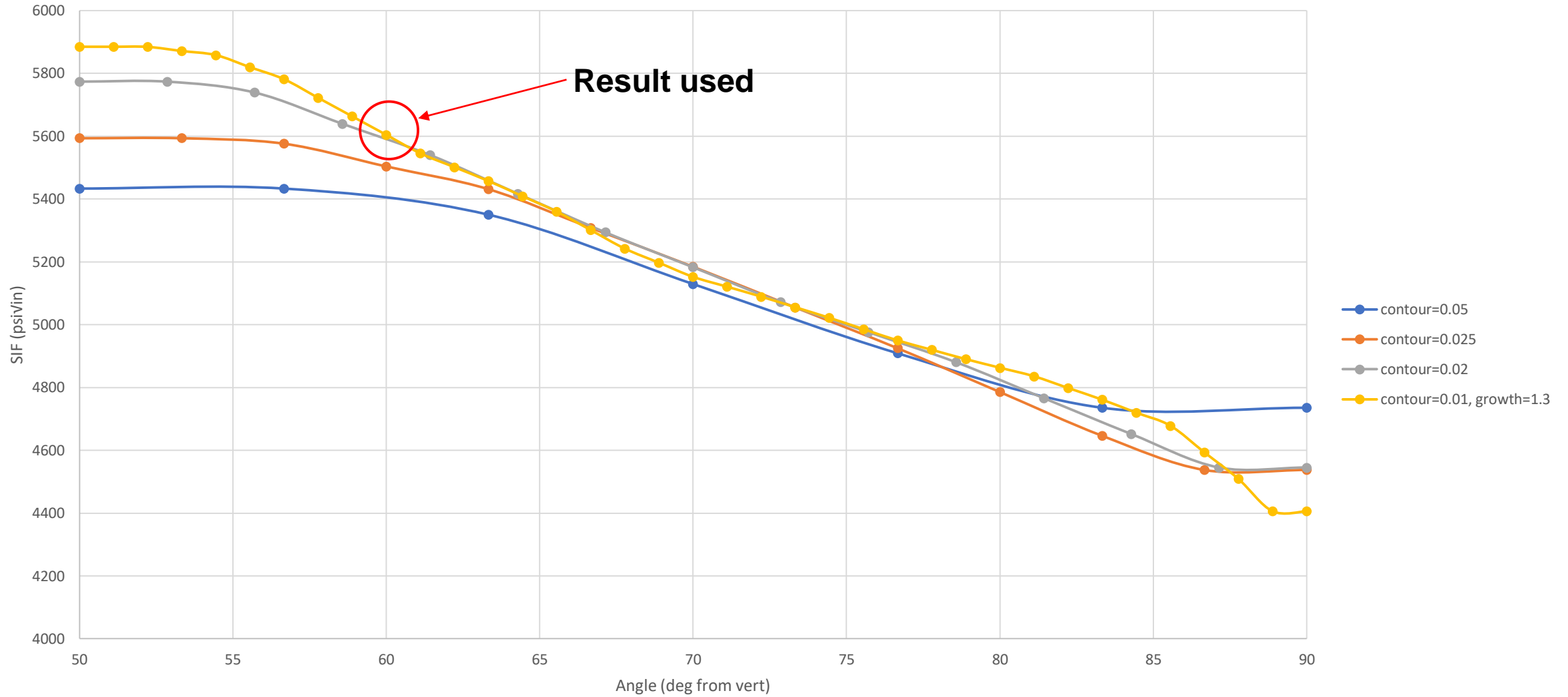
Convergence Study

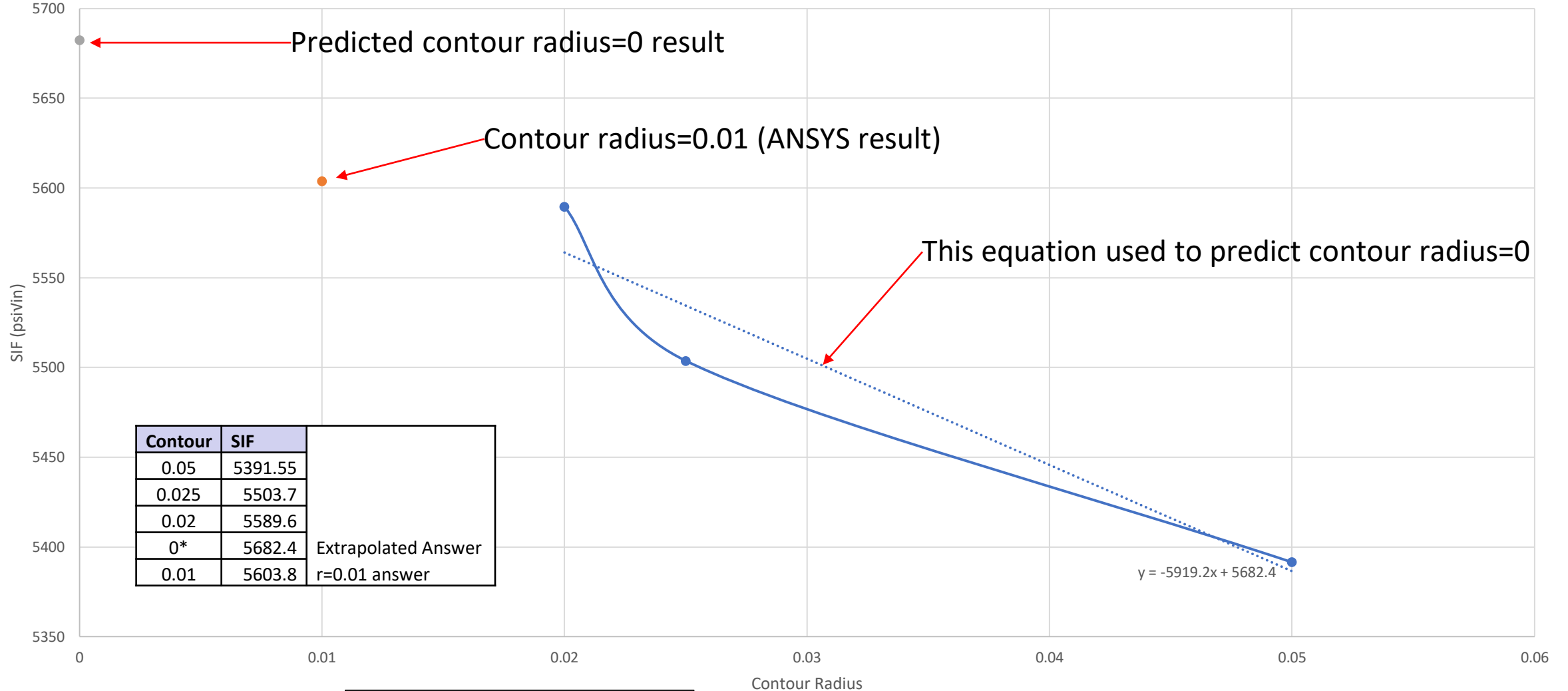








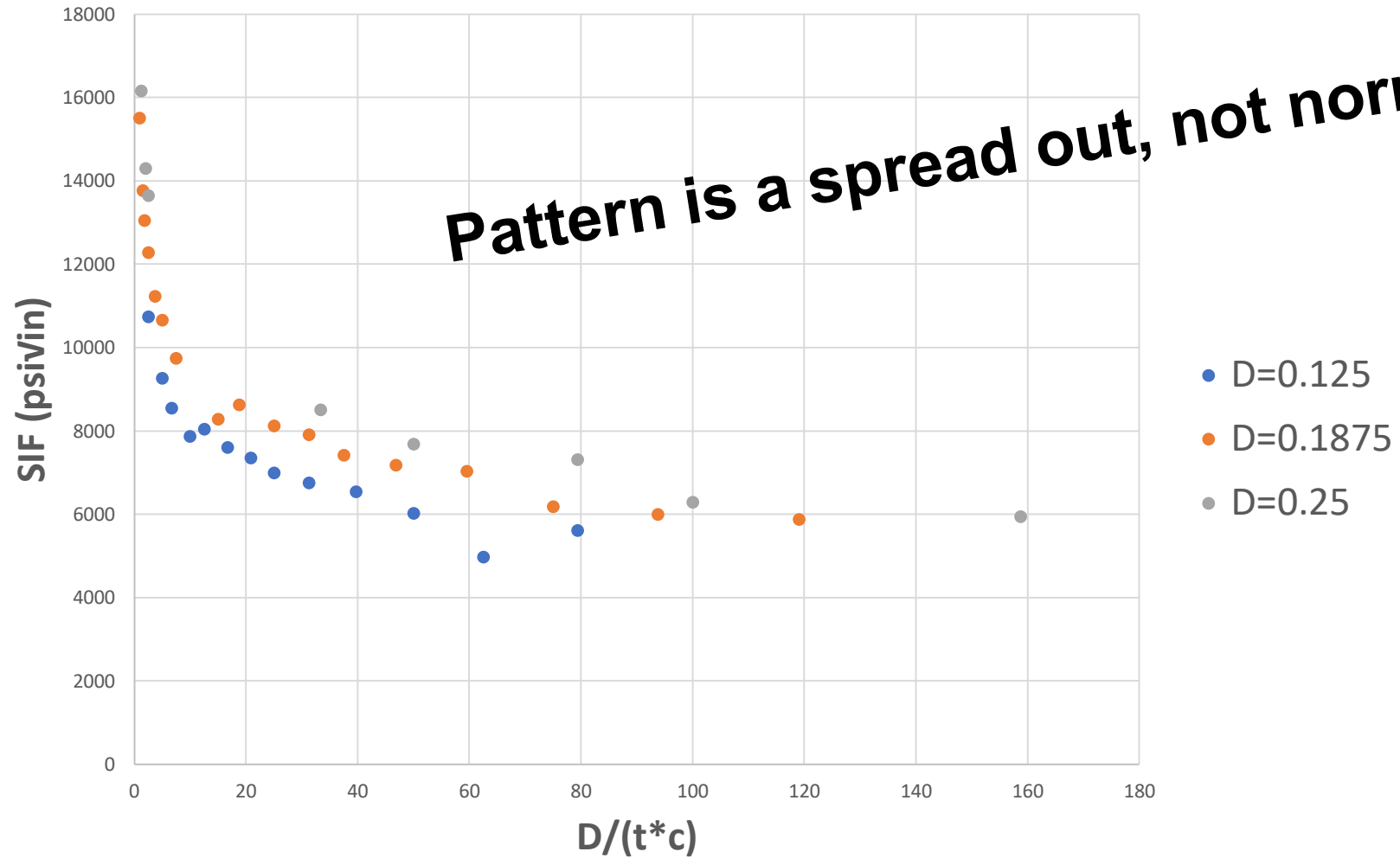


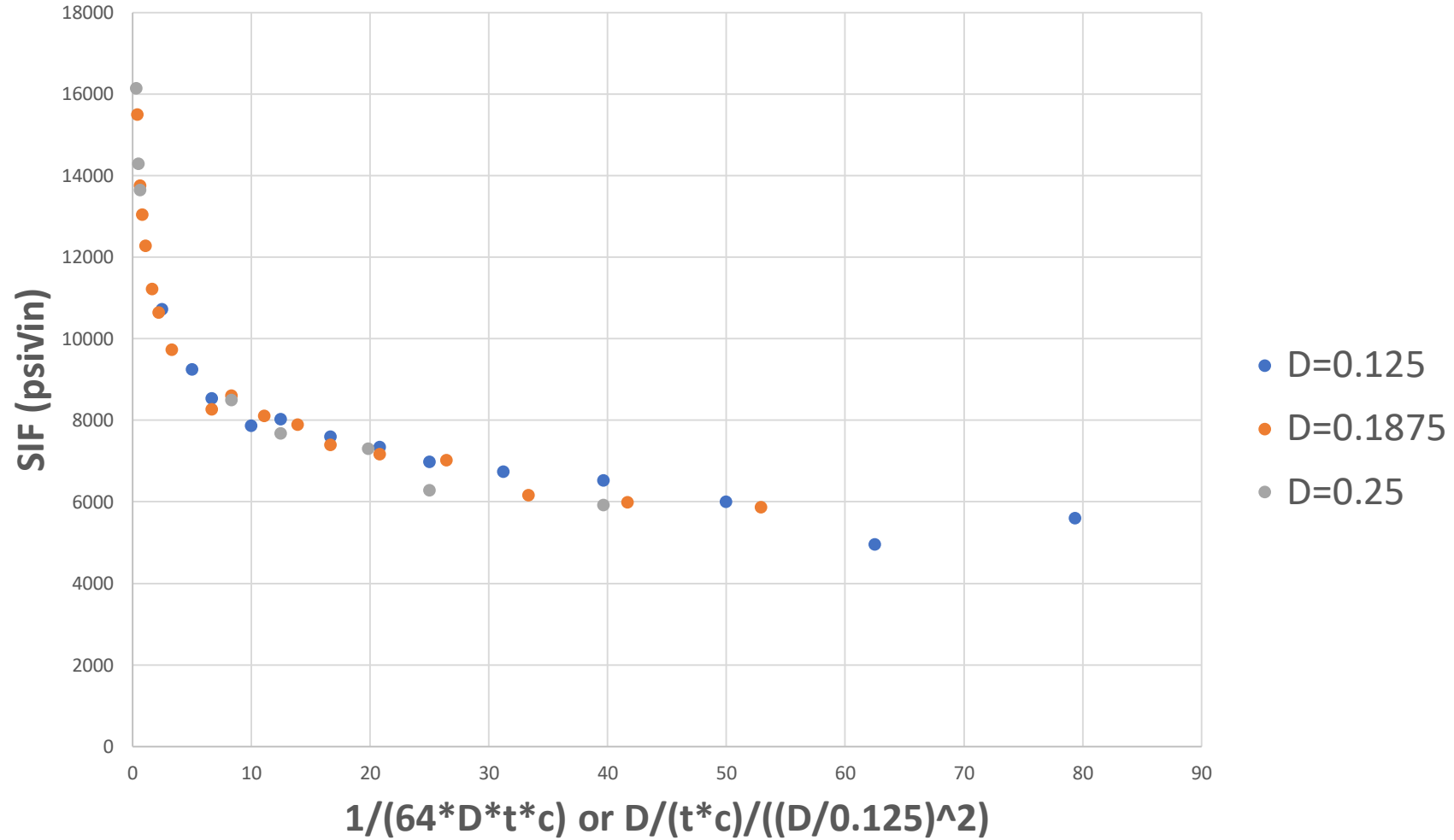


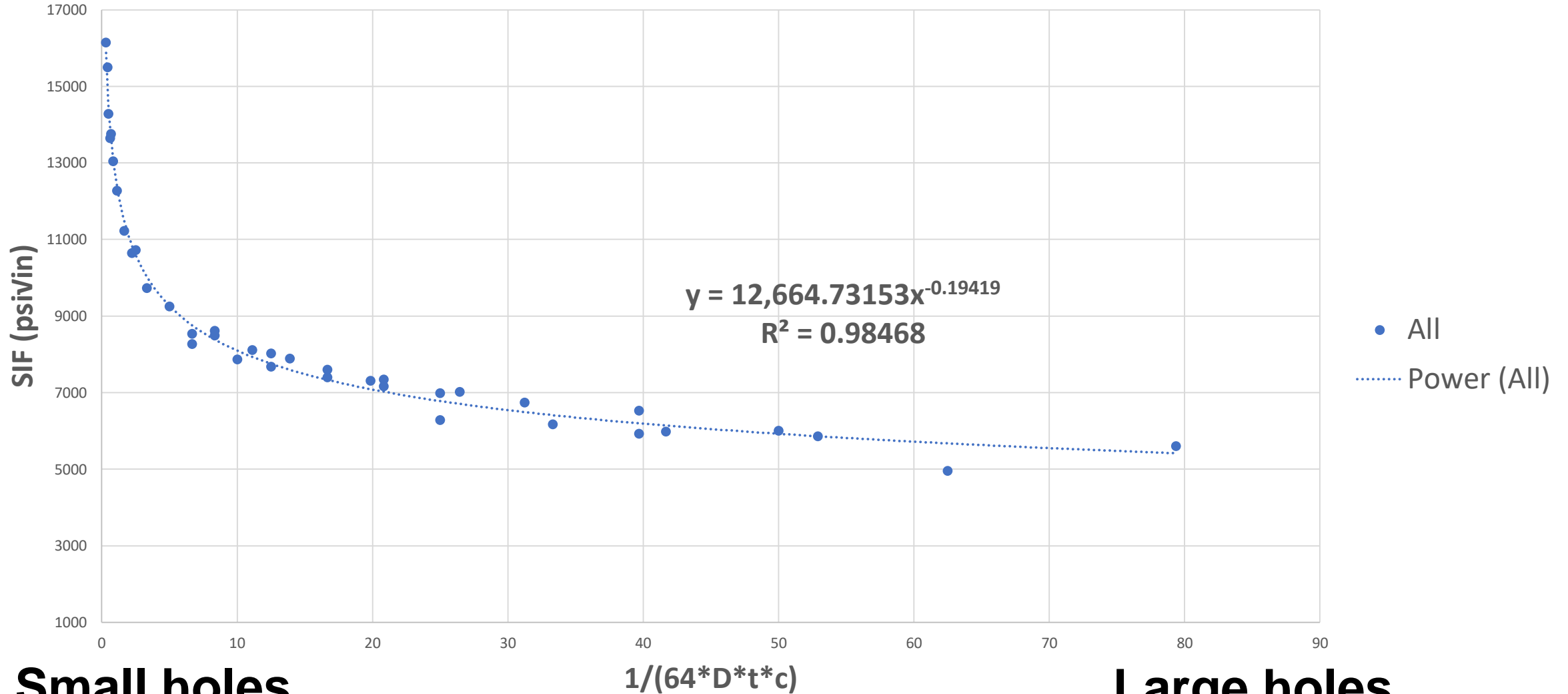
$$\frac{rad_c}{c} = \frac{0.01}{0.025} = 0.4$$

$$rad_c = 0.4c$$

SIF Results







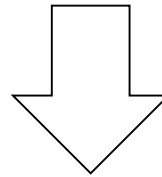
**Small holes,
Large cracks**



**Large holes,
Small cracks**

- Characteristic Equation

$$SIF = 12664.73 \left(\frac{1}{64D \cdot t \cdot c} \right)^{-0.19419} \cdot \frac{\sigma_{app}(ksi)}{10ksi}$$



$$SIF = 2840.11 \left(\frac{1}{D \cdot t \cdot c} \right)^{-0.19419} \cdot \frac{\sigma_{app}(ksi)}{1ksi}$$

Scaling factor

for lbs/in/s

- The equation is only valid for values of “c” where the crack tip is in the countersink face. Once the crack breaks into the top surface, the equation is no longer valid
- **Only performed with 2024-T3, need to validate for 7000-series aluminum and recreate for steels**

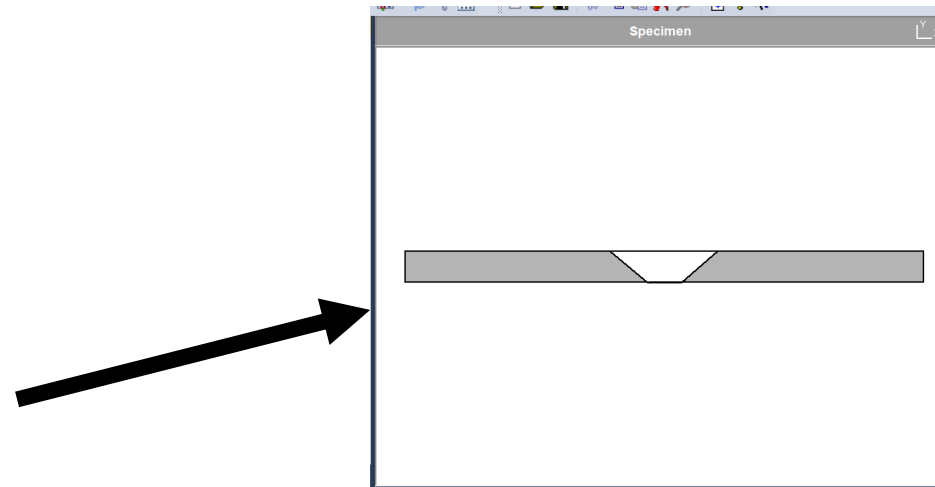
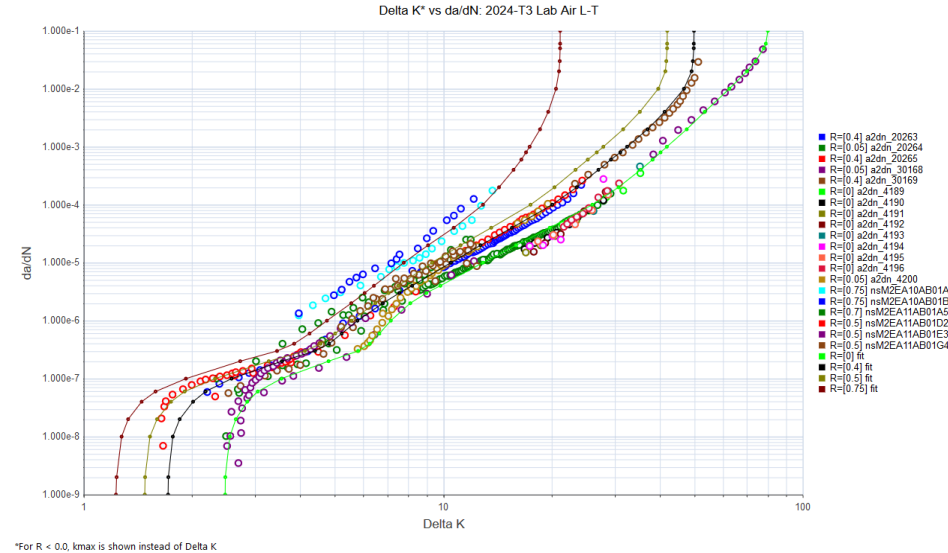
- FYI, for 4" wide, 0.25" diameter hole, 0.25" thick plate:
 - ▶ AFGROW standard solution, corner crack at a hole
 - ▶ SIF=5729 psi $\sqrt{\text{in}}$
 - ▶ ANSYS full countersink
 - ▶ SIF=6351 psi $\sqrt{\text{in}}$
- 10.8% increase in SIF

AFGROW Results

- 10ksi, fully reversed (R=-1), cyclic loading
- Material file from AFMAT database
- Four AFGROW Models run:
 - ▶ 1. AFGROW standard solution
 - ▶ 2. User-defined β

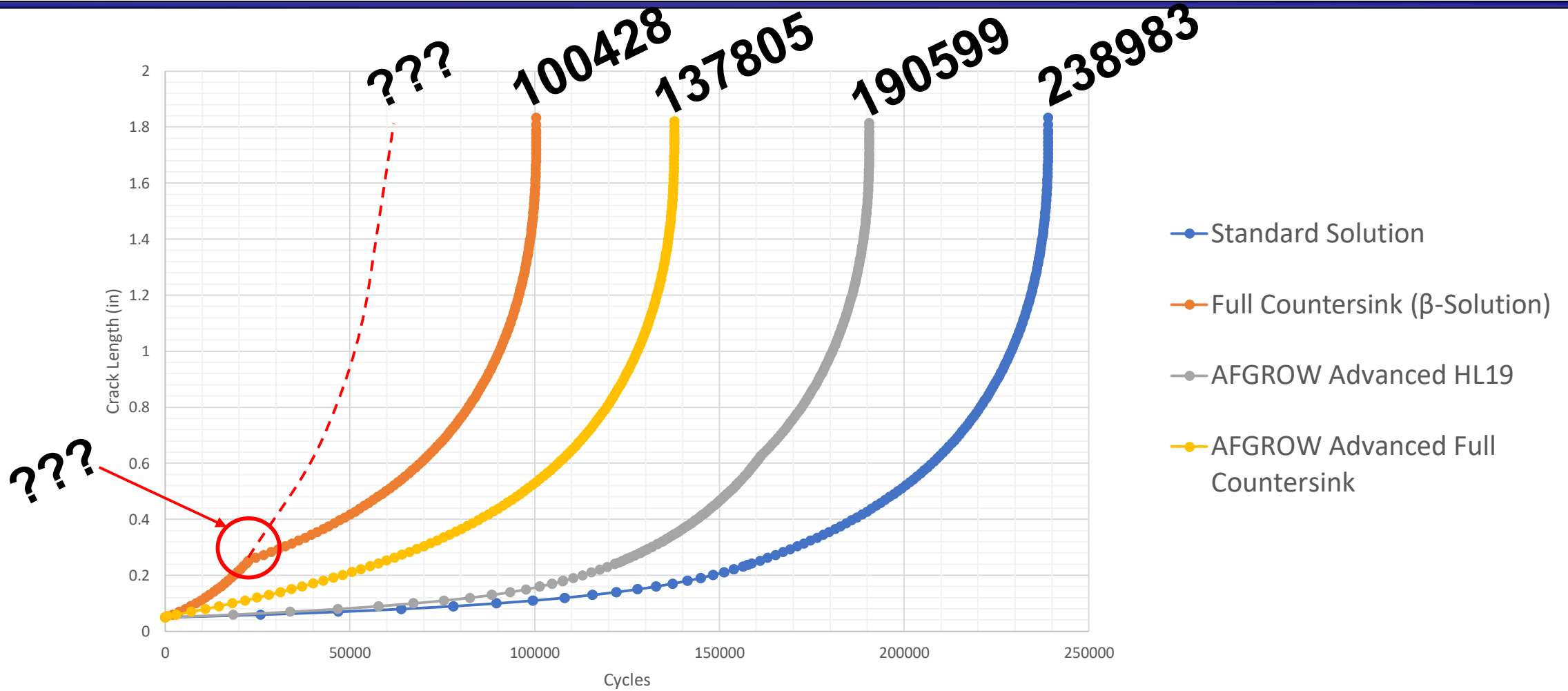
Crack	$1/(64 \cdot D \cdot t \cdot c)$	SIF	β
0.05	5	9265.37	2.3378
0.06	4.166667	9599.29	2.2110
0.075	3.333333	10024.39	2.0652
0.1	2.5	10600.34	1.8912
0.125	2	11069.78	1.7665
0.15	1.666667	11468.72	1.6707
0.175	1.428571	11817.23	1.5938
0.2	1.25	12127.66	1.5300
0.225	1.111111	12408.24	1.4759
0.25	1	12664.73	1.4291

- ▶ 3. AFGROW advanced solution using HL19 geometry
- ▶ 4. AFGROW advanced solution using near full countersink geometry
 - ▶▶ An obvious invalid use but an educational datapoint



- Note:

- ▶ User-defined β used only up to $c=0.25$ ". Switched to the remainder of the corner crack simulation (a thru-crack at this point) for rest of life.



Lose 58% of life from straight bore, 47% of life from HL19 countersink

Conclusion

- Knife-edge holes are “as bad as they say” and should be avoided excepting the most extreme circumstances
- 10% in SIF results in 50% loss of life
- ANSYS can provide SIFs for general geometry
- Further work:
 - ▶ Refine transition region from bore-to-surface of crack growth
 - ▶ Generalize for materials of differing E and ν (if required)
 - ▶ Verify SIF solutions in ANSYS against benchmark cases
 - ▶ Lab test to validate results