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Air Force Life Cycle Management Center



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Relationship of Tension (axial) and Bearing Beta Solutions for Pin Loaded Fastener Holes

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Overview

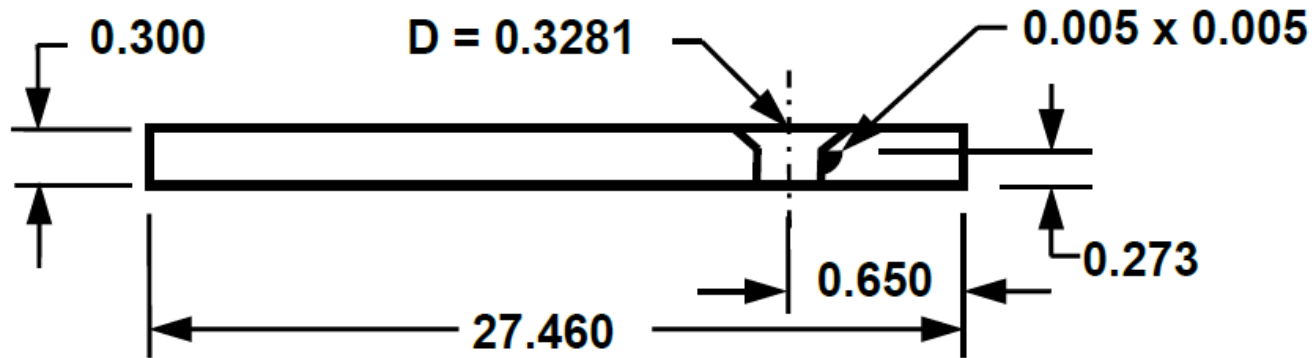


- **Original Study**
- **A Discussion on TSF, BSF and Effective Width**
- **Comparison of Betas from AFGROW and StressCheck**
- **Conclusion/Recommendations**



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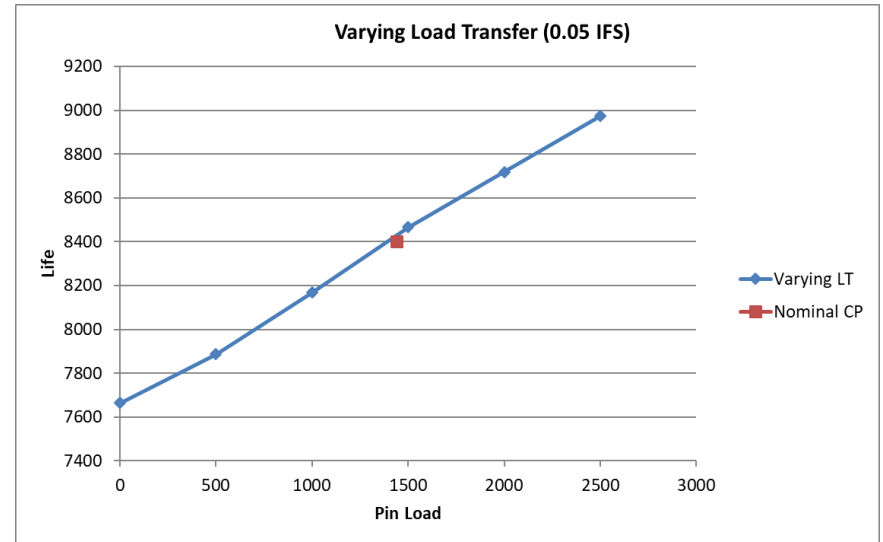
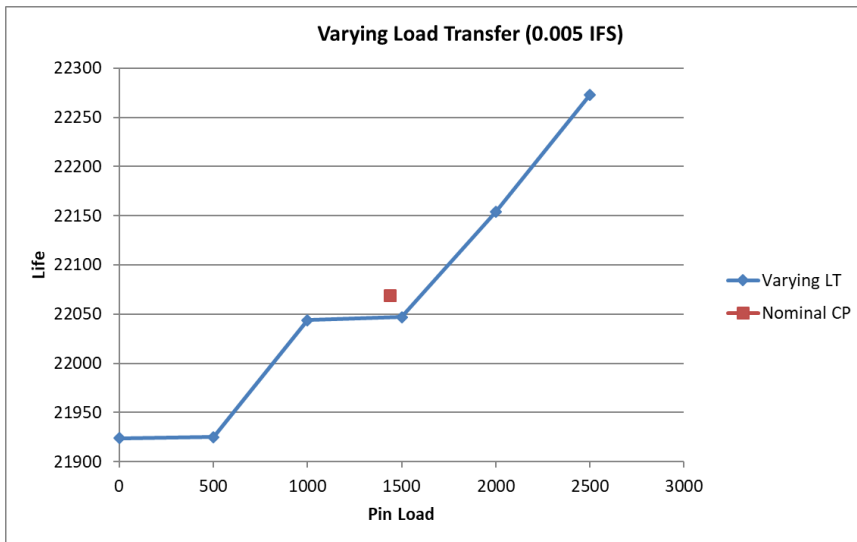
Original Study Configuration 01 Geometry





Original Study Fastener Load vs Life Configuration 01

	Width	Thickness	Diameter	Offset	IFS	Pin Load	Weff	TSF	BrSF	Stress	Life	IFS 0.05
	27.46	0.273	0.3281	0.65	0.005		1.219					
Varying LT		0.273	0.3281			0	1.219	1.000	0.000	42.396	21924	7664
		0.273	0.3281			500	1.219	0.965	0.132	42.396	21925	7887
		0.273	0.3281			1000	1.219	0.929	0.263	42.396	22044	8168
		0.273	0.3281			1500	1.219	0.894	0.395	42.396	22047	8467
		0.273	0.3281			2000	1.219	0.858	0.527	42.396	22154	8718
		0.273	0.3281			2500	1.219	0.823	0.658	42.396	22273	8974

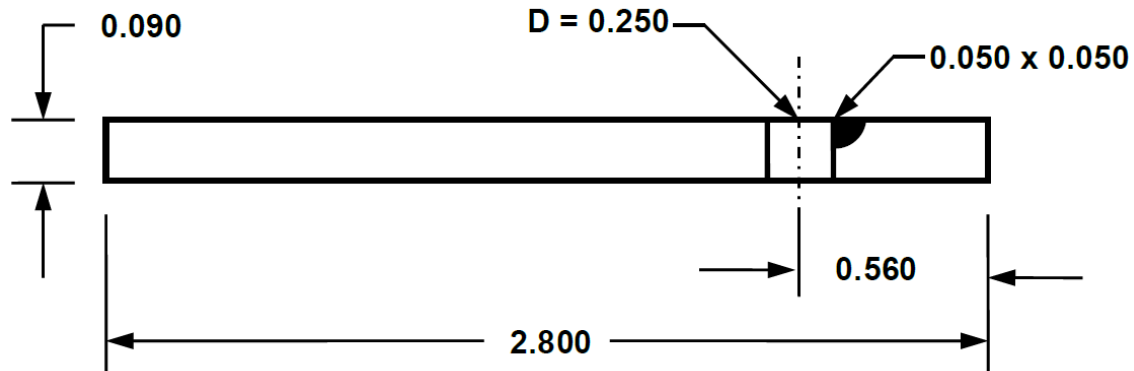


As the Pin Load Increases the Life Decreases
This Trend is counter Intuitive



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Original Study Configuration 02 Geometry



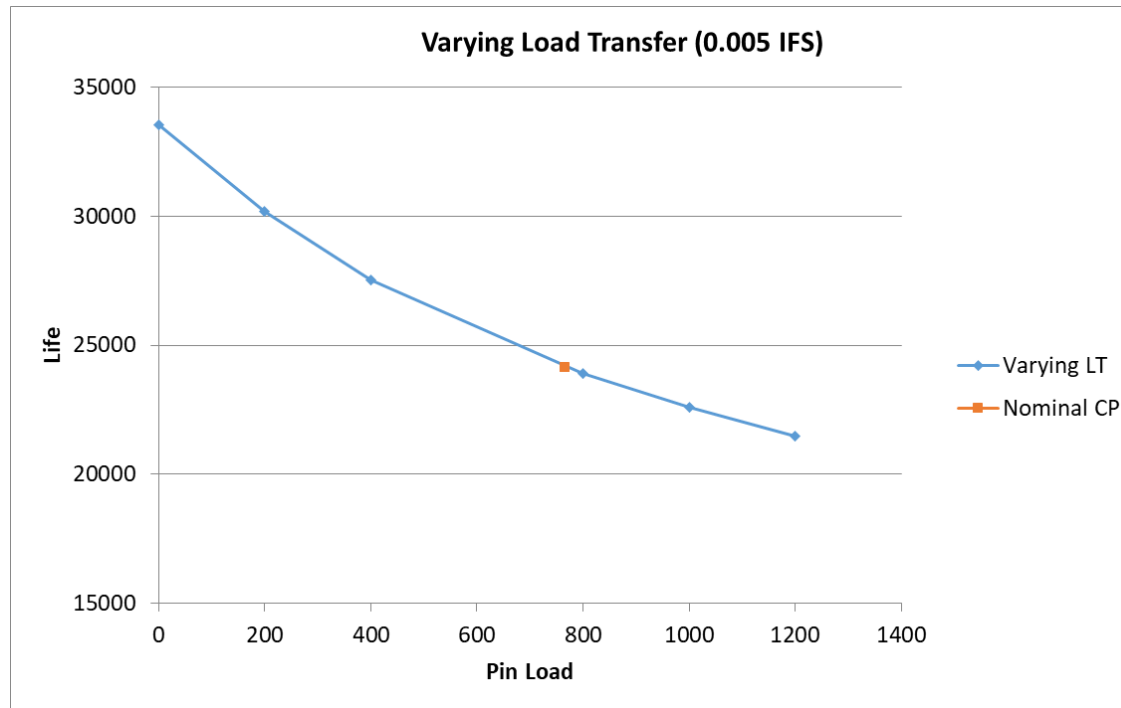


Original Study

Fastener Load vs Life Configuration 02



										Weff_bearing
Method: Vary Pin Load and calculate TSF and BrSF using Weff and run prediction										
Width	Thickness	Diameter	Offset	IFS	Pin Load	Weff	TSF	BrSF	Stress	Life
2.8	0.09	0.25	0.56	0.005		1.494			17.662	
Varying LT		0.09	0.25		0	1.494	1.000	0.000	17.662	33547
		0.09	0.25		200	1.494	0.916	0.503	17.662	30187
		0.09	0.25		400	1.494	0.832	1.007	17.662	27535
		0.09	0.25		800	1.494	0.663	2.013	17.662	23918
		0.09	0.25		1000	1.494	0.579	2.516	17.662	22595
		0.09	0.25		1200	1.494	0.495	3.020	17.662	21484

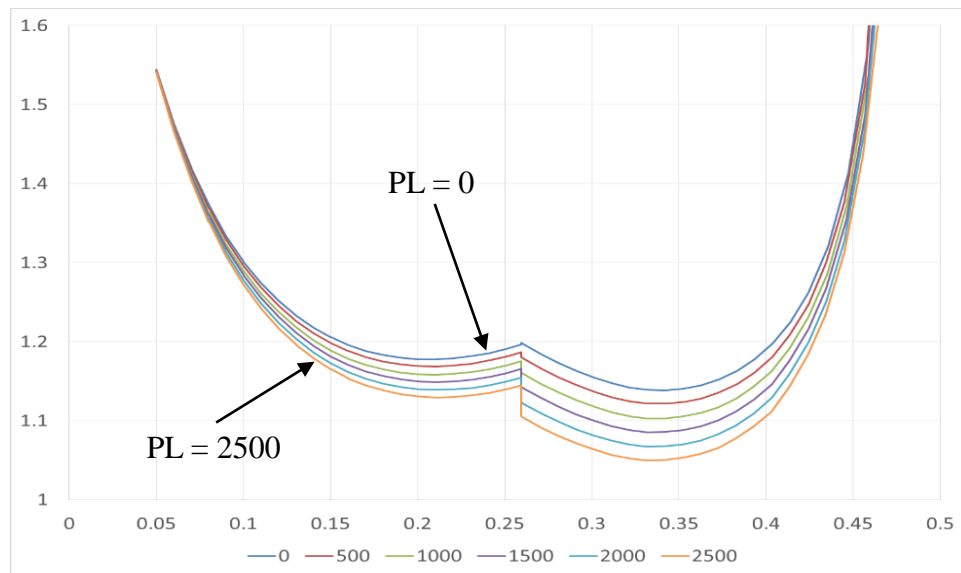




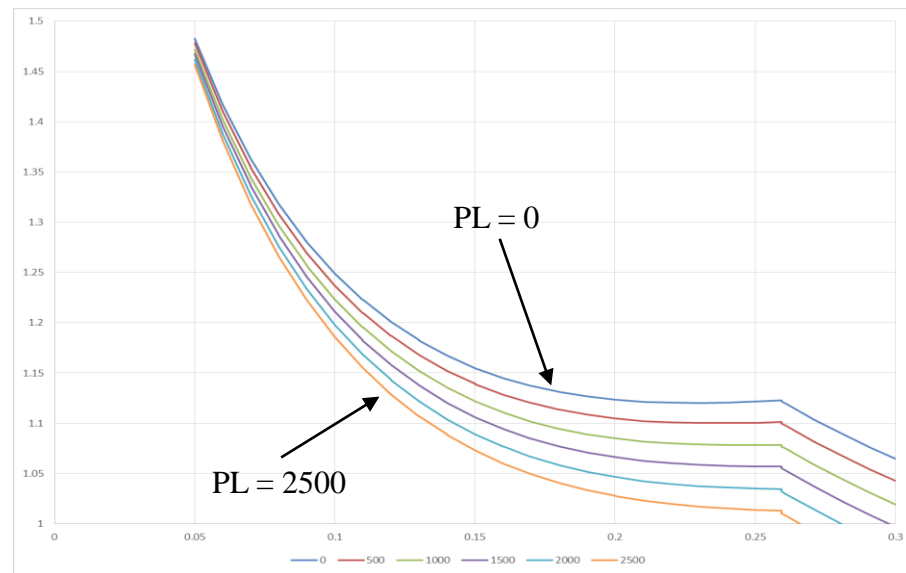
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SwRI Study: AFGROW Solution

Beta Curve as a Function of Pin Load (Config. 01)



Config. 01 Offset Hole
Beta Curve with Varying Load Transfer



Config. 01 Centered Hole
Beta Curve with Varying Load Transfer

Note: Centered Hole Model Removes the Hole Offset Effect and Finite Width Effect

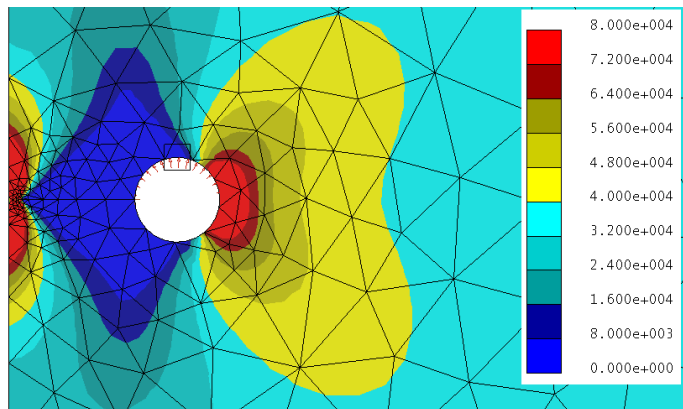
IFS = 0.05'' – both Offset Hole and Centered Hole



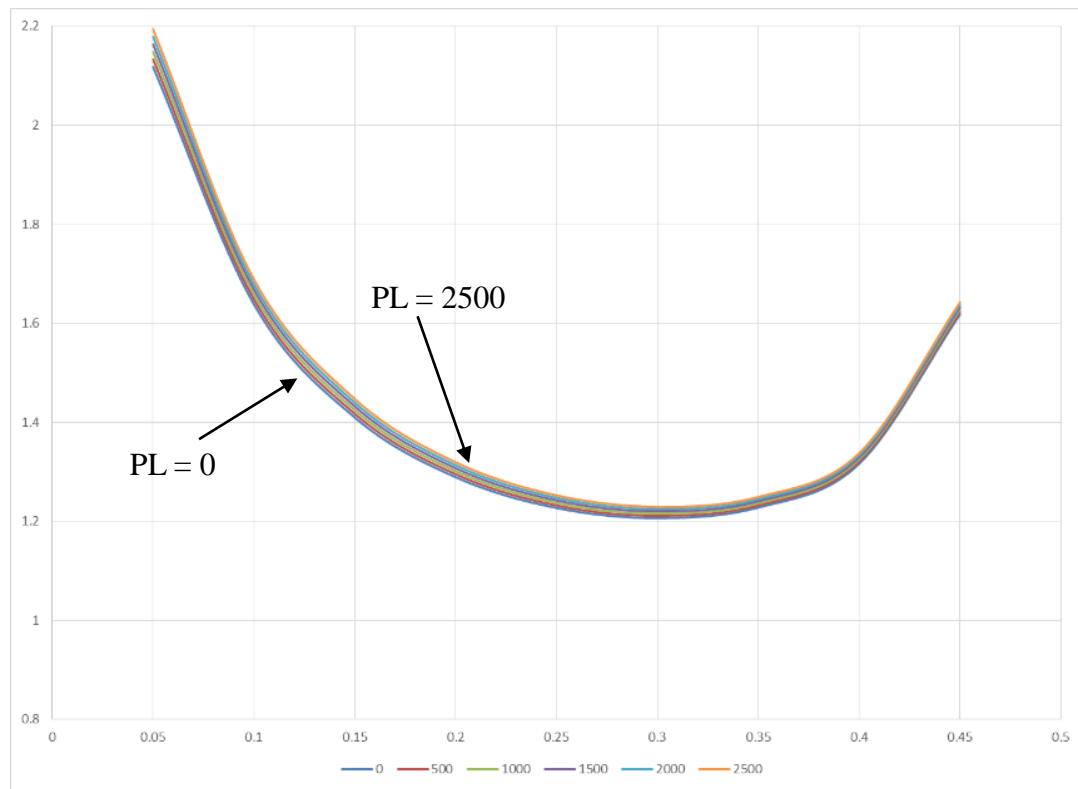
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SwRI Study: StressCheck Solution

Beta Curve as a Function of Pin Load Wide Plate



Config. 01 Two-Dimensional StressCheck Model



Conf. 01 Two-Dimensional StressCheck Model Beta Curve

The Finite Element Model shows the opposite trend from AFGROW??



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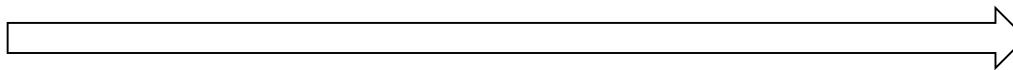
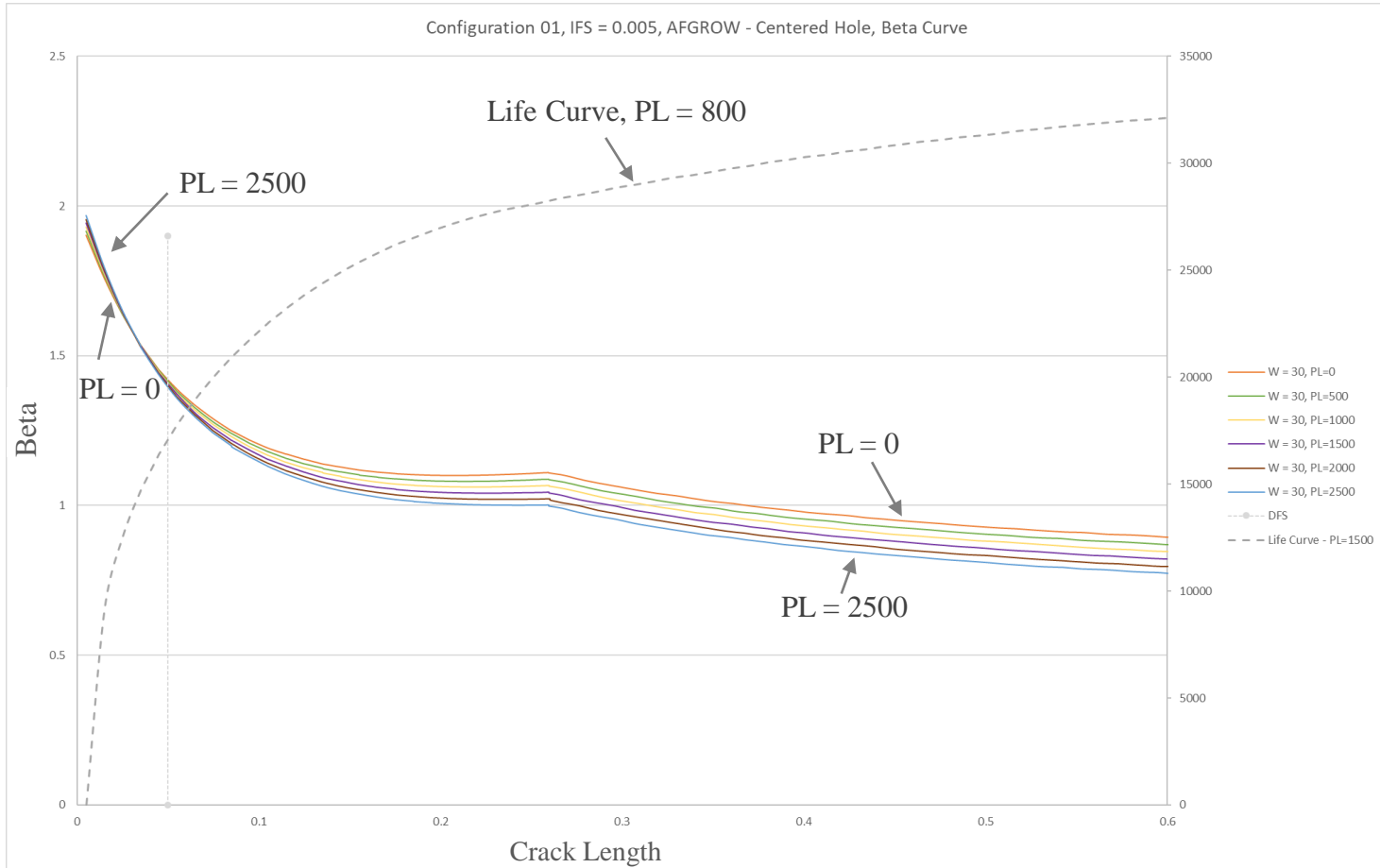


USAF Study: AFGROW Solution (Config. 01)



USAF Study: AFGROW Solution

Beta Curve as a Function of Pin Load (Config. 01)

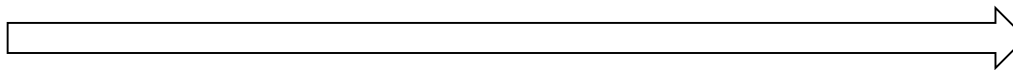
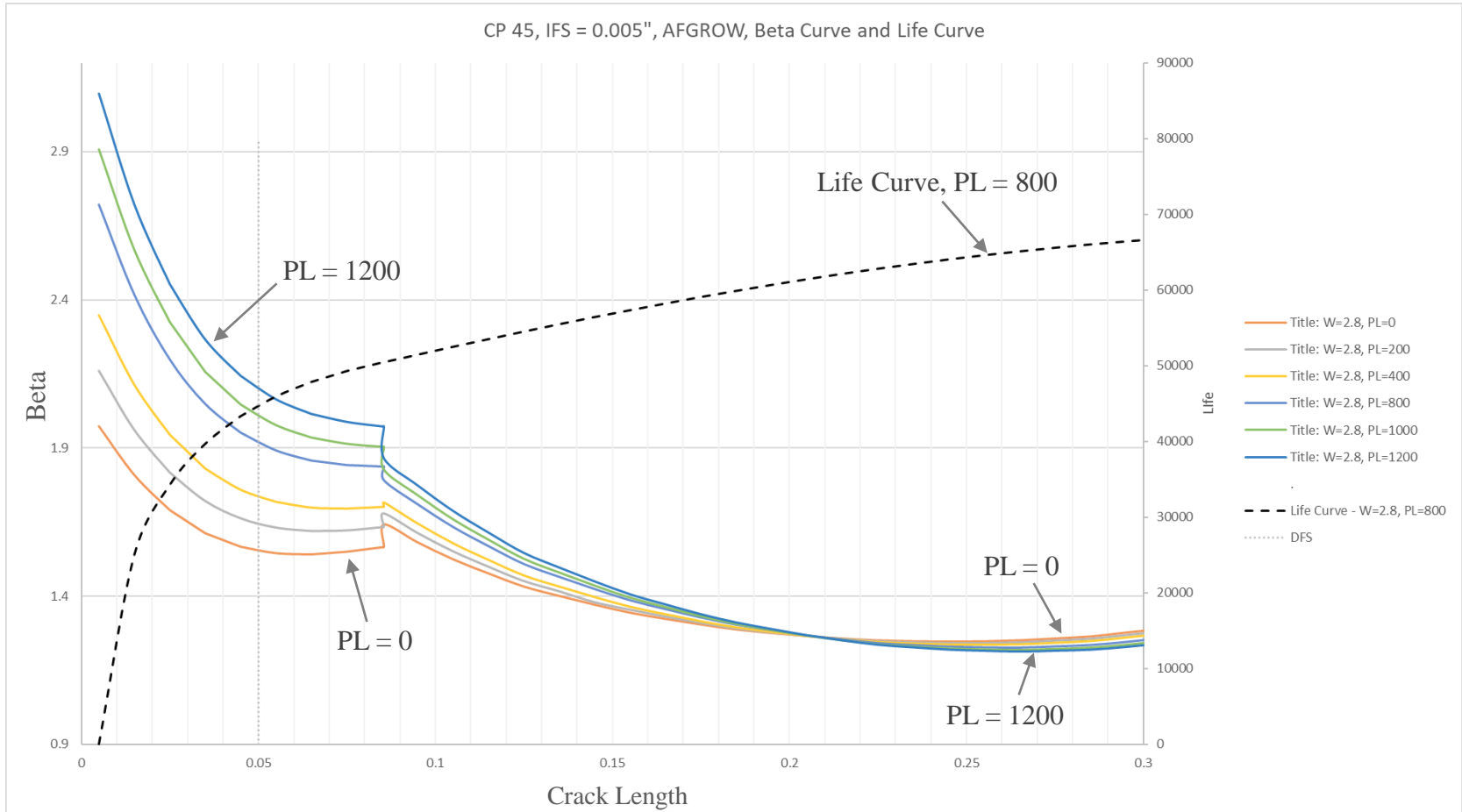


Bearing influence reduces as the distance from the hole increases



USAF Study: AFGROW Solution

Beta Curve as a Function of Pin Load (Config. 02)



Bearing influence reduces as the distance from the hole increases



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USAF Study: Stress Check Load Transfer Model Comparison With AFGROW Solution (Config. 01)



USAF Study: StressCheck vs AFGROW

StressCheck Load Transfer Model



Solution Space:

Model Count = 55

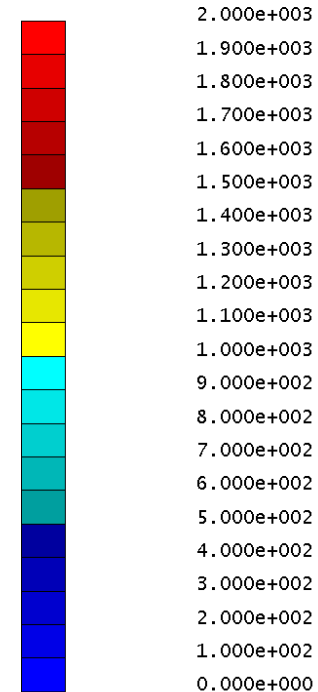
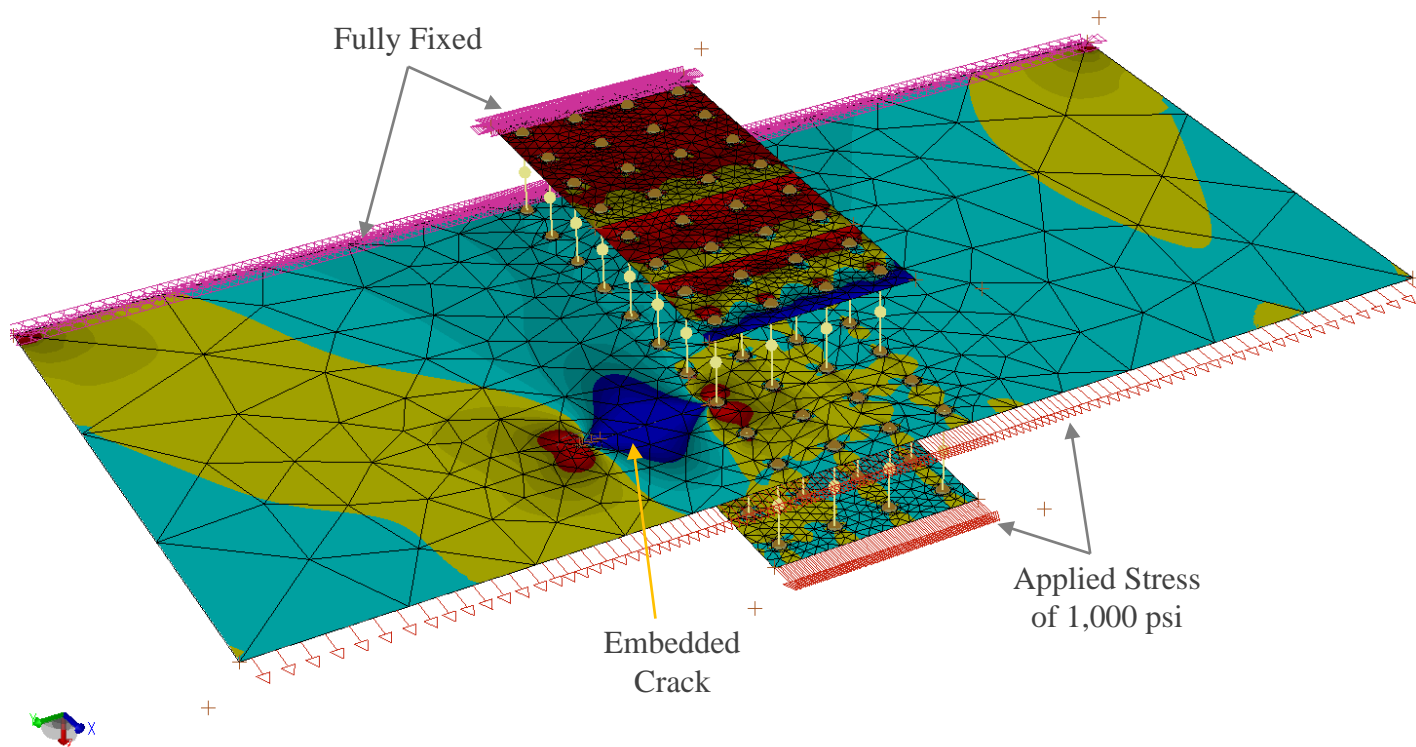
Diameter – 0.1875, 0.3281

Repair Thickness – 0.1, 0.2, 0.4

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0

StressCheck v10.4

Units = INCH/LBF/SEC/F
 LINEAR ID=LSOL
 Run=1, DOF=345624
 Fnc.=S1
 Max= 4.369e+004
 Min=-2.380e+002

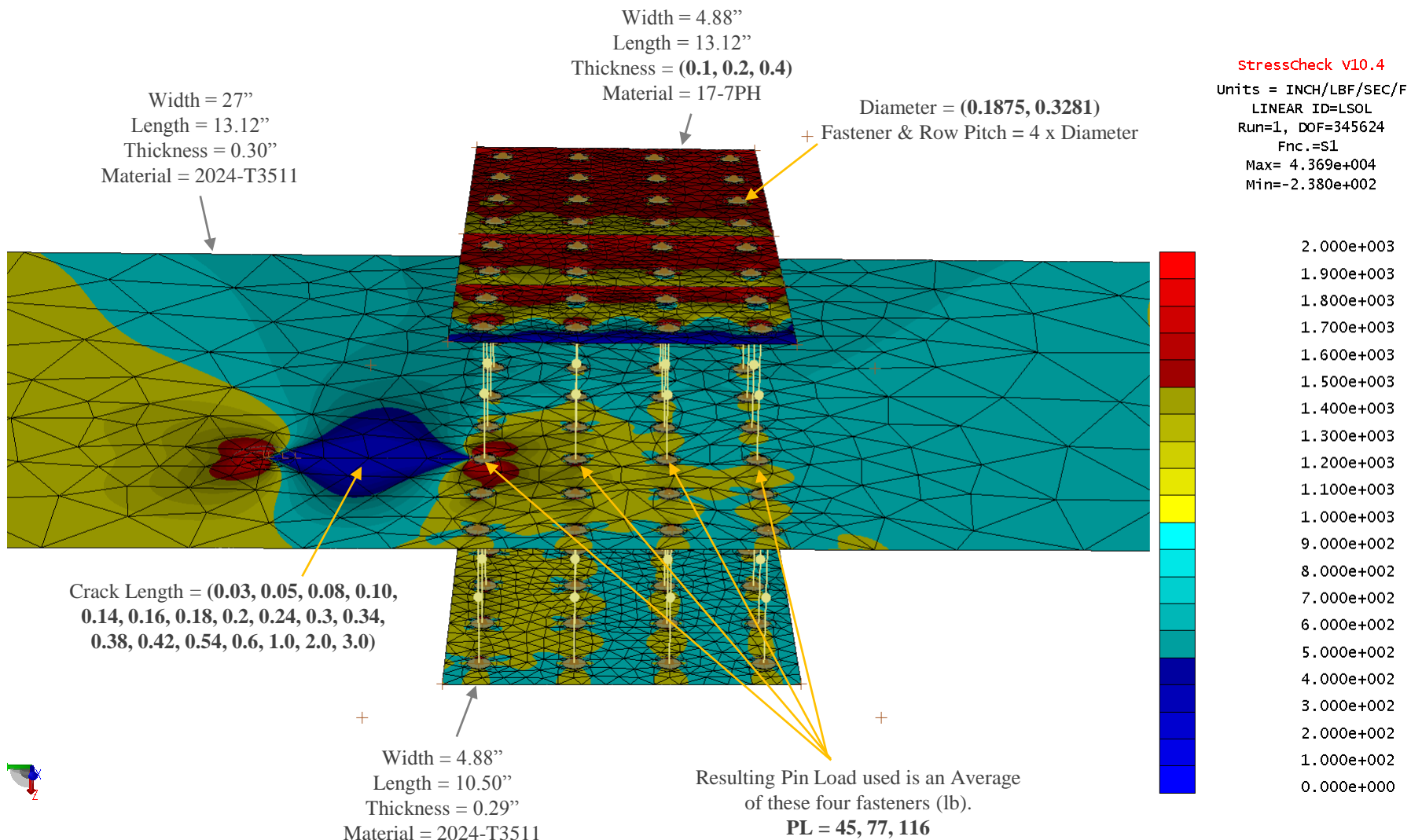




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USAF Study: StressCheck vs AFGROW

StressCheck Load Transfer Model

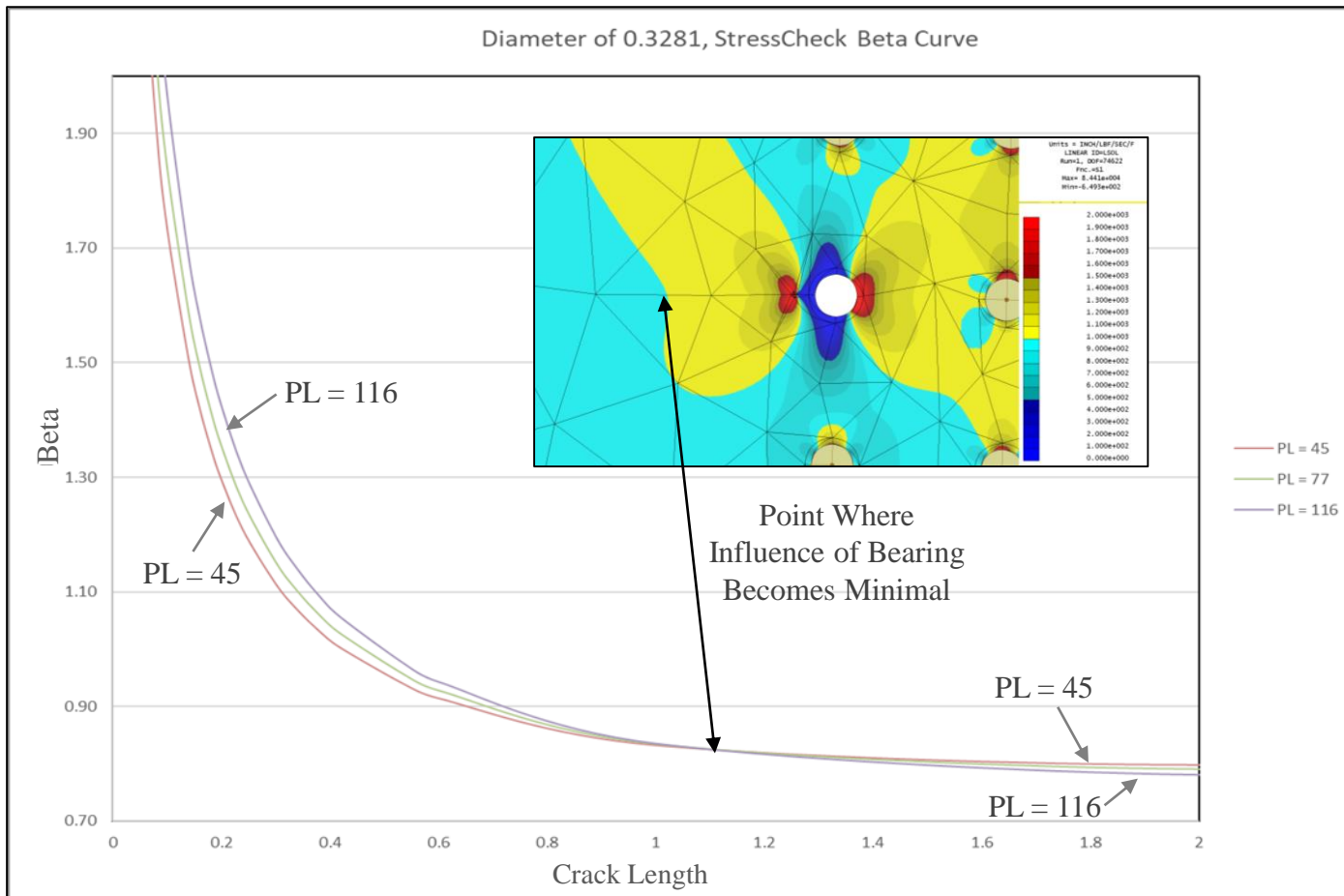




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USAF Study: StressCheck vs AFGROW

StressCheck Beta Curve (0.3281" Diameter_Centered Hole)





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TSF, BSF and Effective Width



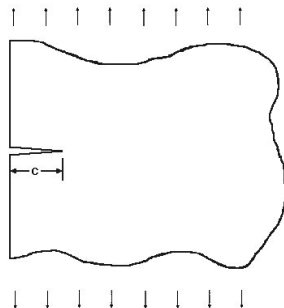
Beta factor is used to calculate the stress intensity factor

$$K = \sigma_{Ref} \sqrt{\pi x} \beta$$

β is beta

x is the crack length

Example of Beta for an edge crack in a semi infinite plate



$$\beta = 1.122$$



Combined Beta Solutions (Tension and Bearing Only)



Loading is combined using Superposition

$$K_{\text{Total}} = K_{\text{Tension}} + K_{\text{Bearing}}$$

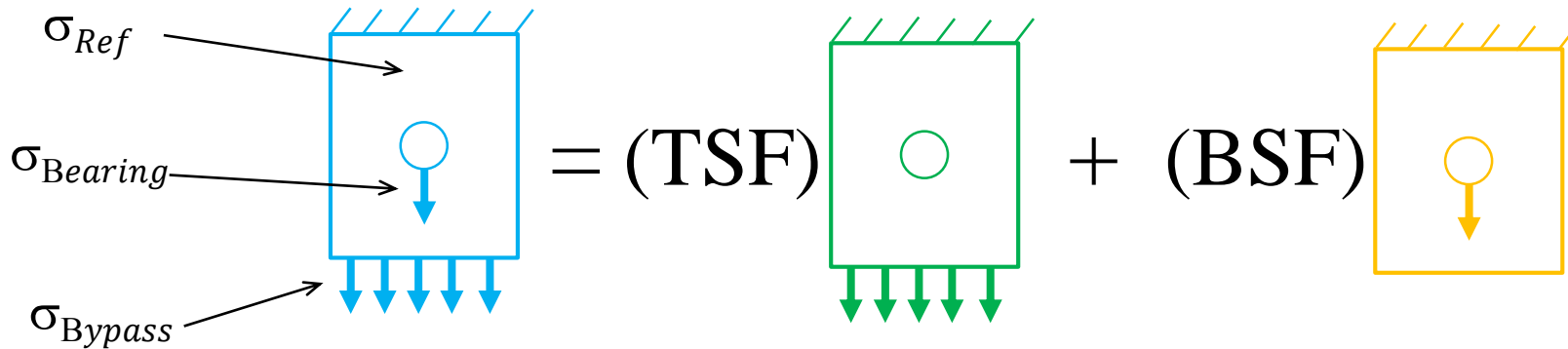
$$\beta_{\text{Total}} = (\text{TSF}) \beta_{\text{Tension}} + (\text{BSF}) \beta_{\text{Bearing}}$$

$$\text{TSF} = \frac{\sigma_{\text{Bypass}}}{\sigma_{\text{Ref (Far field)}}} = 1 - \left(\text{BSF} \frac{D}{W_{\text{eff}}} \right)$$

$$\text{BSF} = \frac{\sigma_{\text{Bearing}}}{\sigma_{\text{Ref (Far field)}}} = (1 - \text{TSF}) \frac{W_{\text{eff}}}{D}$$



Combined Beta Solutions (Pictorially)



$$\beta_{Total} = (TSF) \beta_{Tension} + (BSF) \beta_{Bearing}$$



Represents the amount of tension stress compared to the reference stress



Represents the amount of Bearing stress compared to the reference stress

$$K = \sigma_{Ref} \sqrt{\pi x} \beta$$

$$\beta_{Total} = \left(\frac{\sigma_{Bypass}}{\sigma_{Ref}}\right) \beta_{Tension} + \left(\frac{\sigma_{Bearing}}{\sigma_{Ref}}\right) \beta_{Bearing}$$



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StressCheck Betas vs AFGROW Betas

(Centered Hole, Wide Plate, Single Fastener)

Note: Removes finite width & hole offset assumptions



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StressCheck Load Transfer Model (Centered Hole, Wide Plate, Single Fastener)



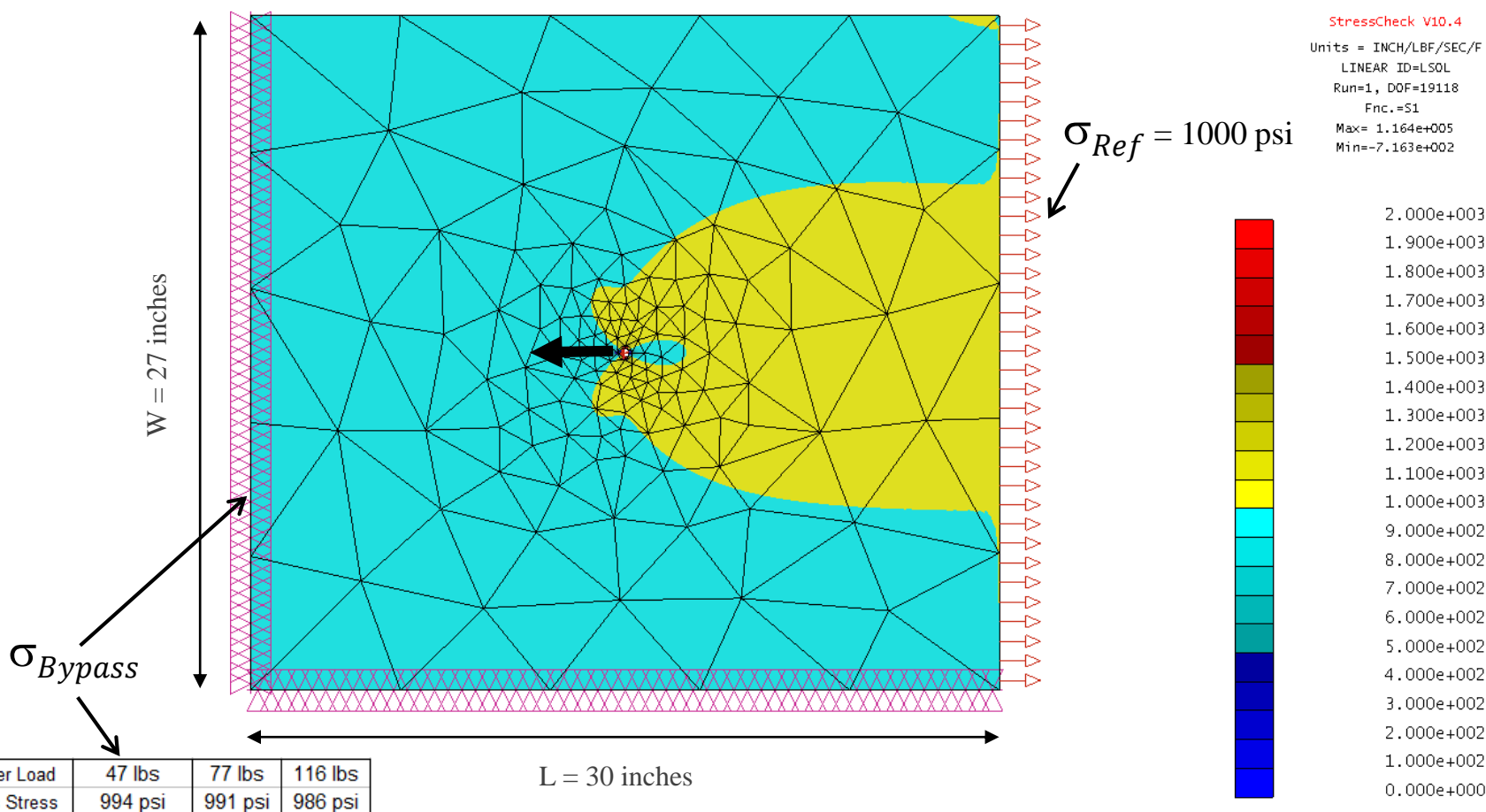
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0



Note: Bypass stress is calculated as an average over the width of 27 inches.



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Tension & Bearing Beta Curve (Separated)

(SC & AFGROW - Centered Hole, Wide Plate, Single Fastener)

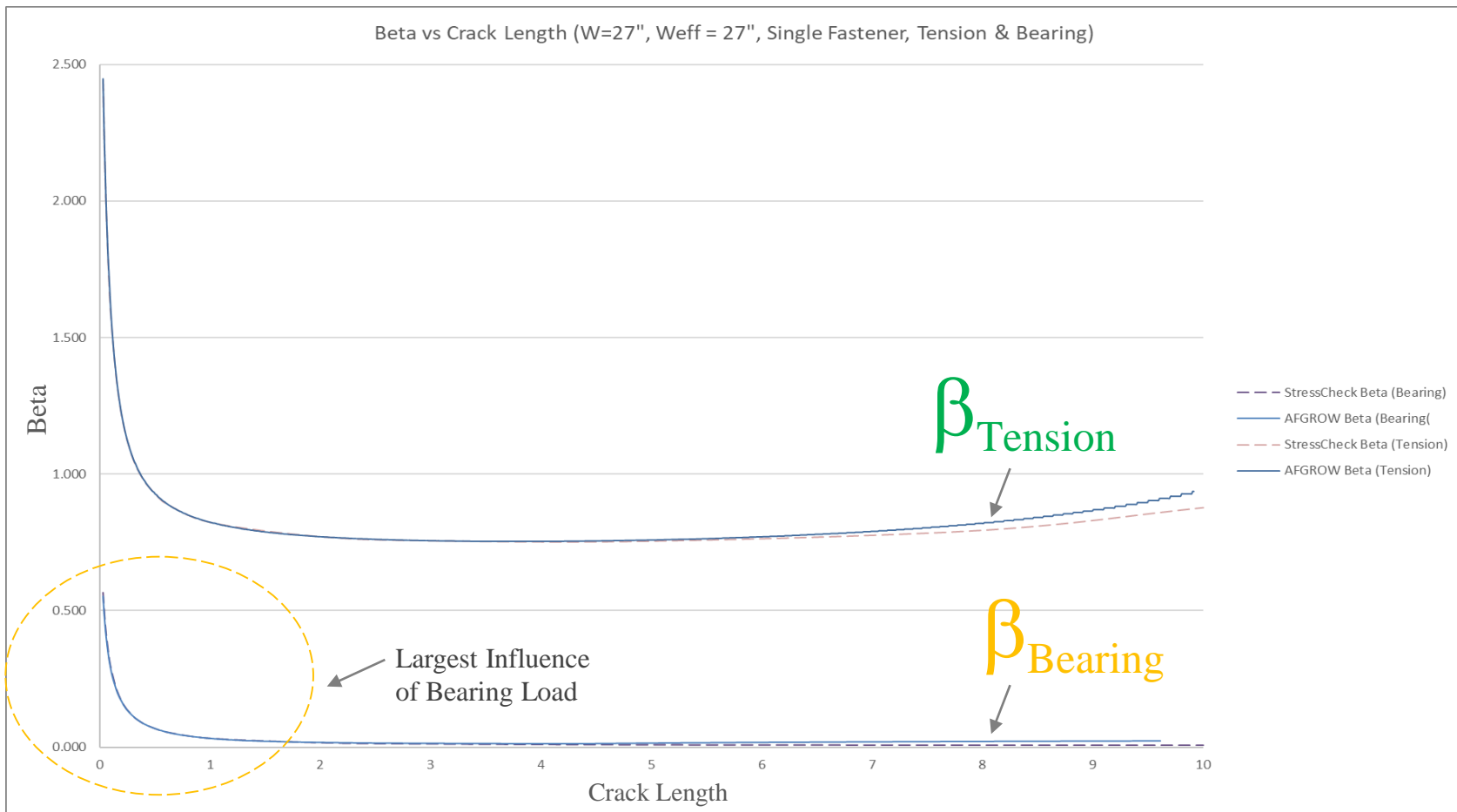
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0





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Combining the Tension & Bearing Beta Curve

(Centered Hole, Wide Plate, Single Fastener)



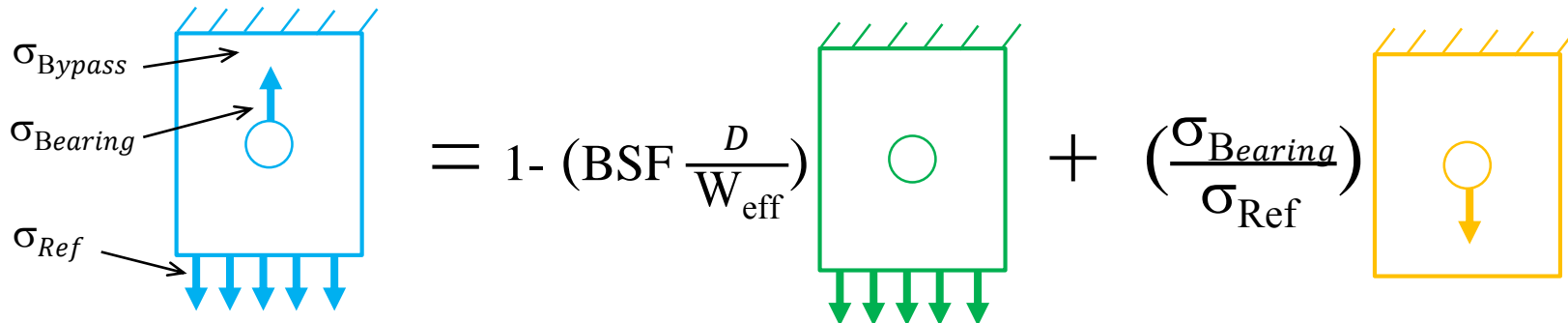
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0



$$\beta_{Total} = 1 - (0.477 \frac{0.3281}{?}) \beta_{Tension} + (\frac{477.50}{1,000}) \beta_{Bearing}$$

If $W_{eff} = 27.0$, then

$$\beta_{Total} = (0.994) \beta_{Tension} + (0.477) \beta_{Bearing}$$



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Tension & Bearing Beta Curve (Separated)

(SC & AFGROW - Centered Hole, Wide Plate, Single Fastener)

Solution Space:

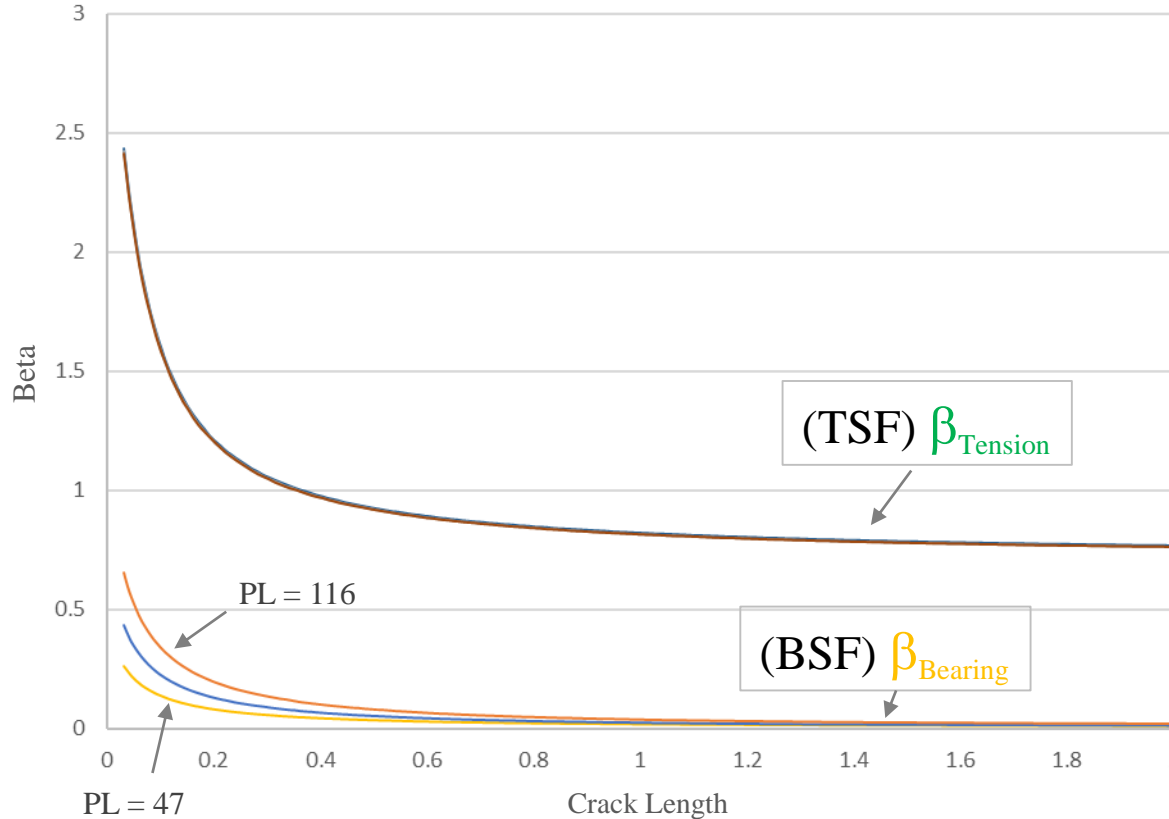
Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0

Beta vs Crack Length (W=27", Weff=27", Single Fastener, Tension & Bearing)



	TSF	BSF
47 lbs	0.994	0.477
77 lbs	0.990	0.782
116 lbs	0.986	1.179

- AFGROW Beta - PL=47 lbs (Bearing)
- AFGROW Beta - PL=77 lbs (Bearing)
- AFGROW Beta - PL=116 lbs (Bearing)
- AFGROW Beta - PL=47 lbs (Tension)
- AFGROW Beta - PL=77 lbs (Tension)
- AFGROW Beta - PL=116 lbs (Tension)



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Tension & Bearing Beta Curve (Combined)

(SC & AFGROW - Centered Hole, Wide Plate, Single Fastener)

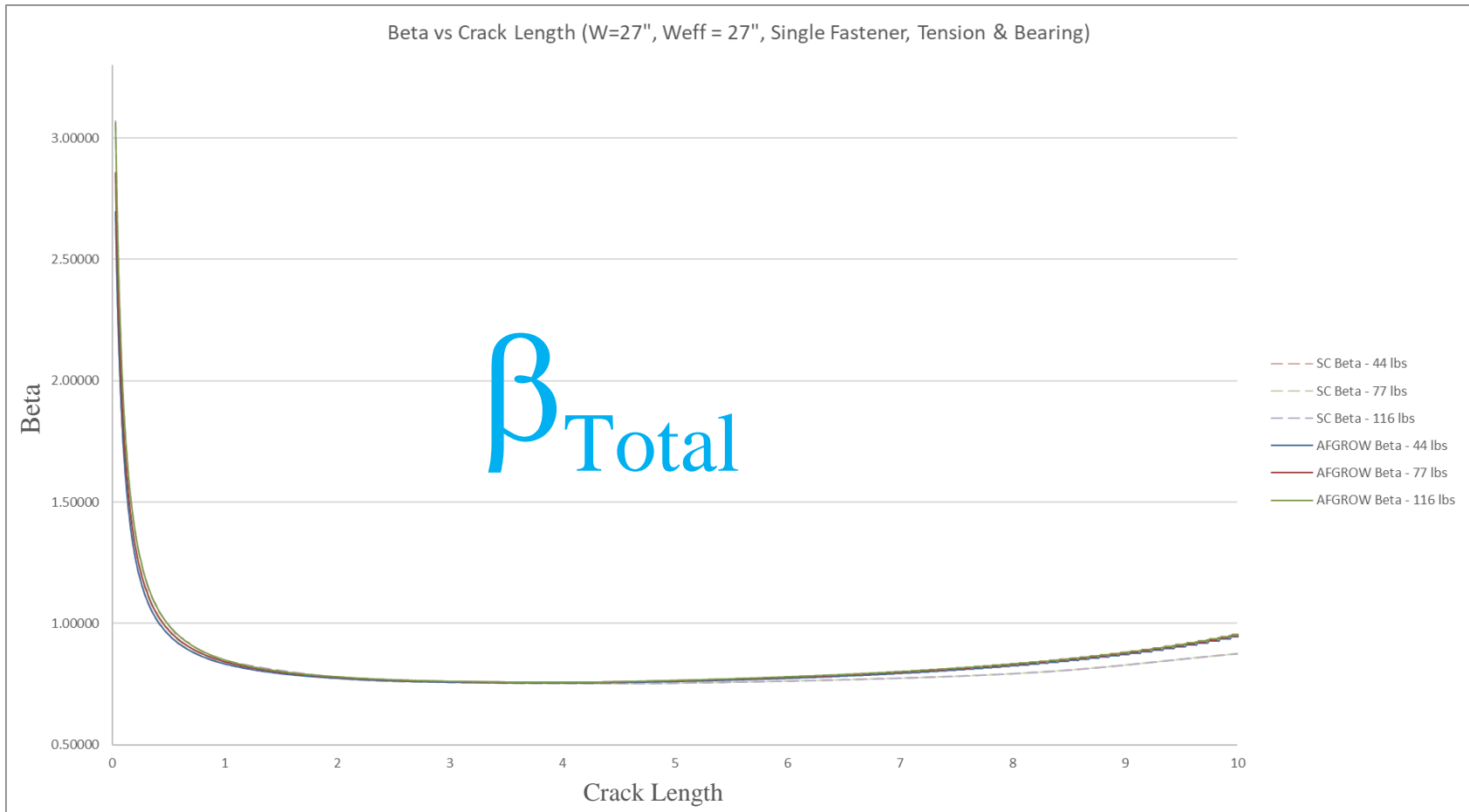
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 44, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0





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Tension & Bearing Beta Curve (Combined)

(SC & AFGROW - Centered Hole, Wide Plate, Single Fastener)

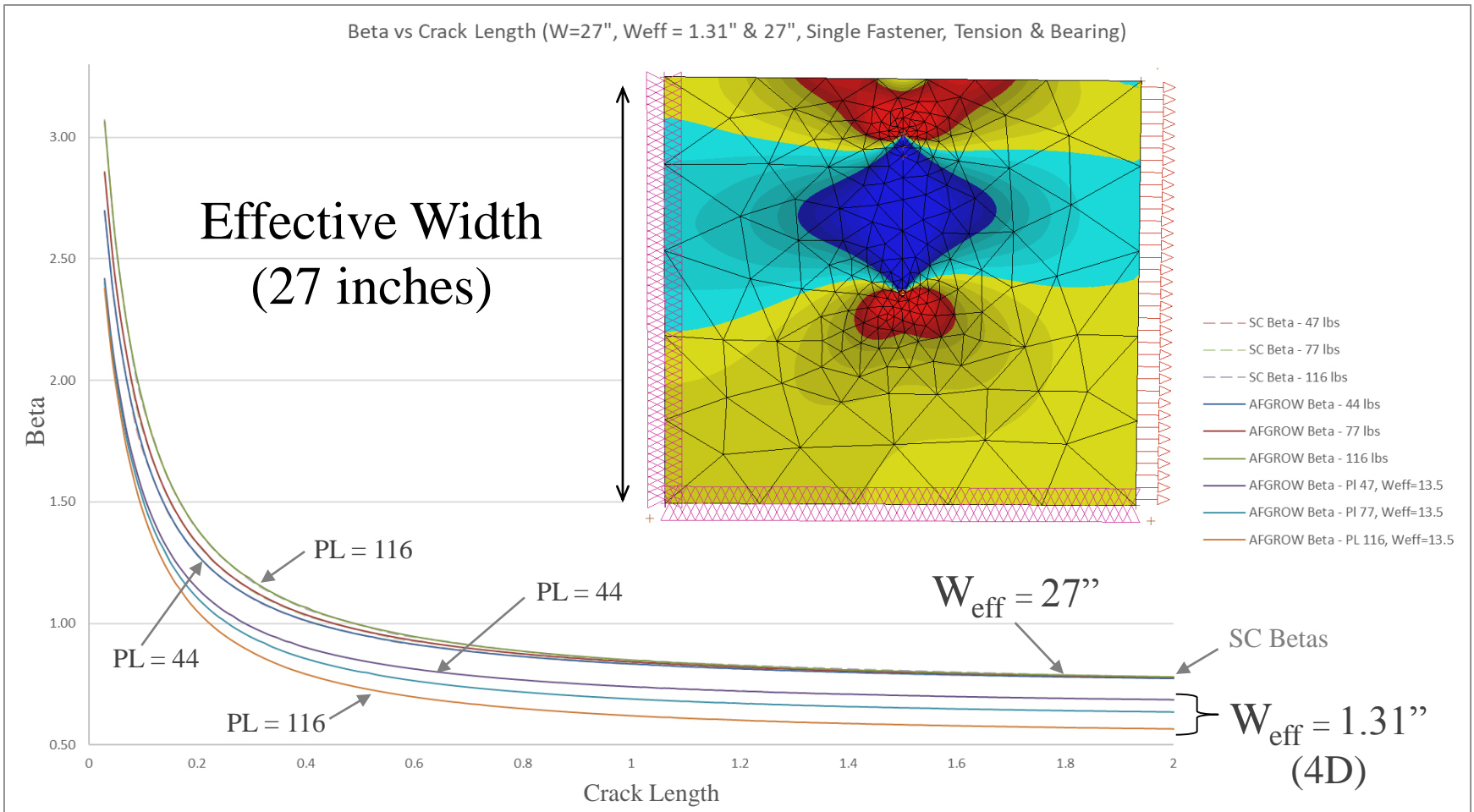
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0





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StressCheck Betas vs AFGROW Betas

(Centered Hole, Wide Plate, Three Fasteners)



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StressCheck Load Transfer Model

(Centered Hole, Wide Plate, Three Even Spaced Fasteners)

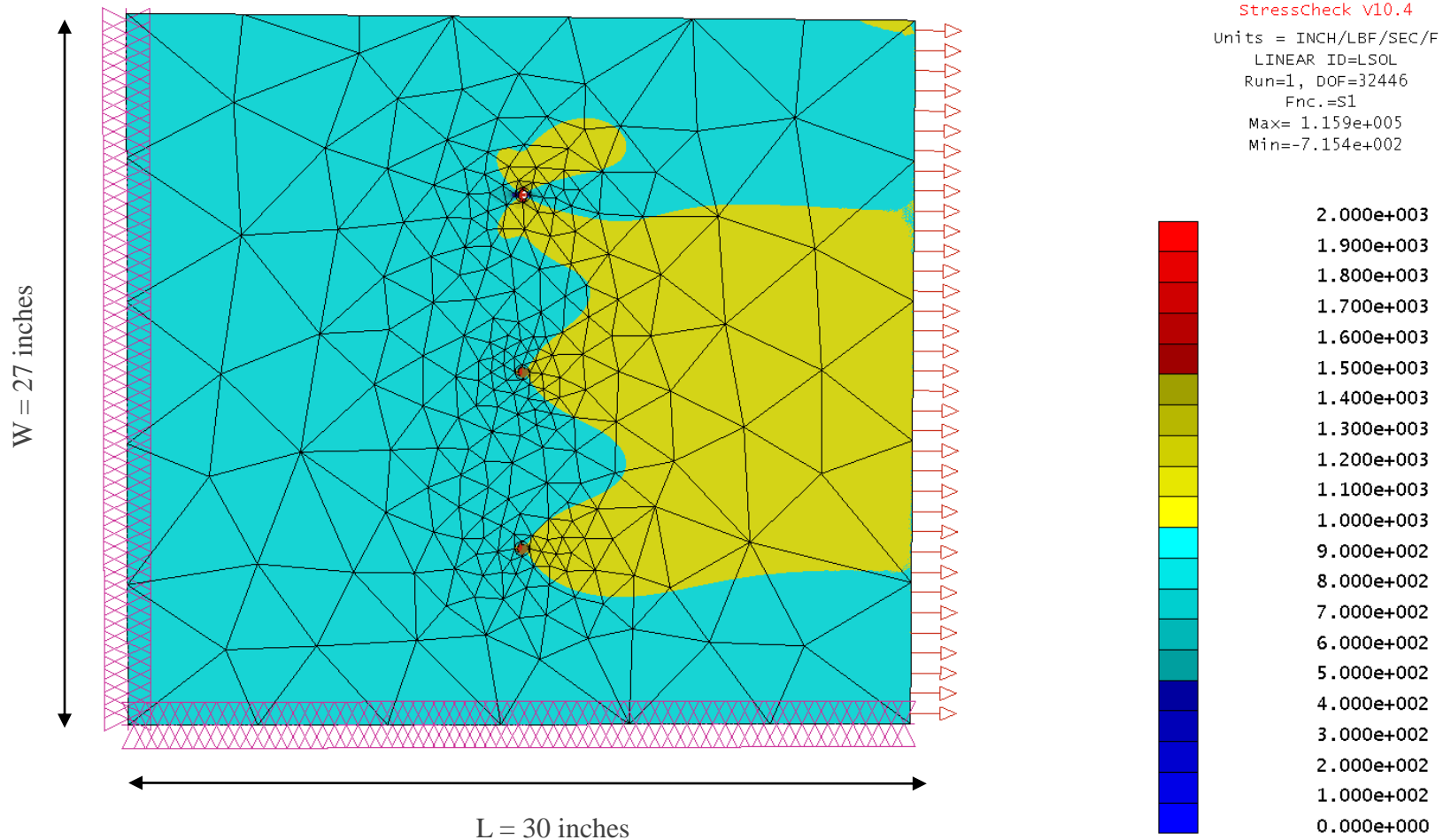
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0





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SC & AFGROW Tension & Bearing Beta Curve (Centered Hole, Narrow Plate, Three Even Spaced Fasteners)



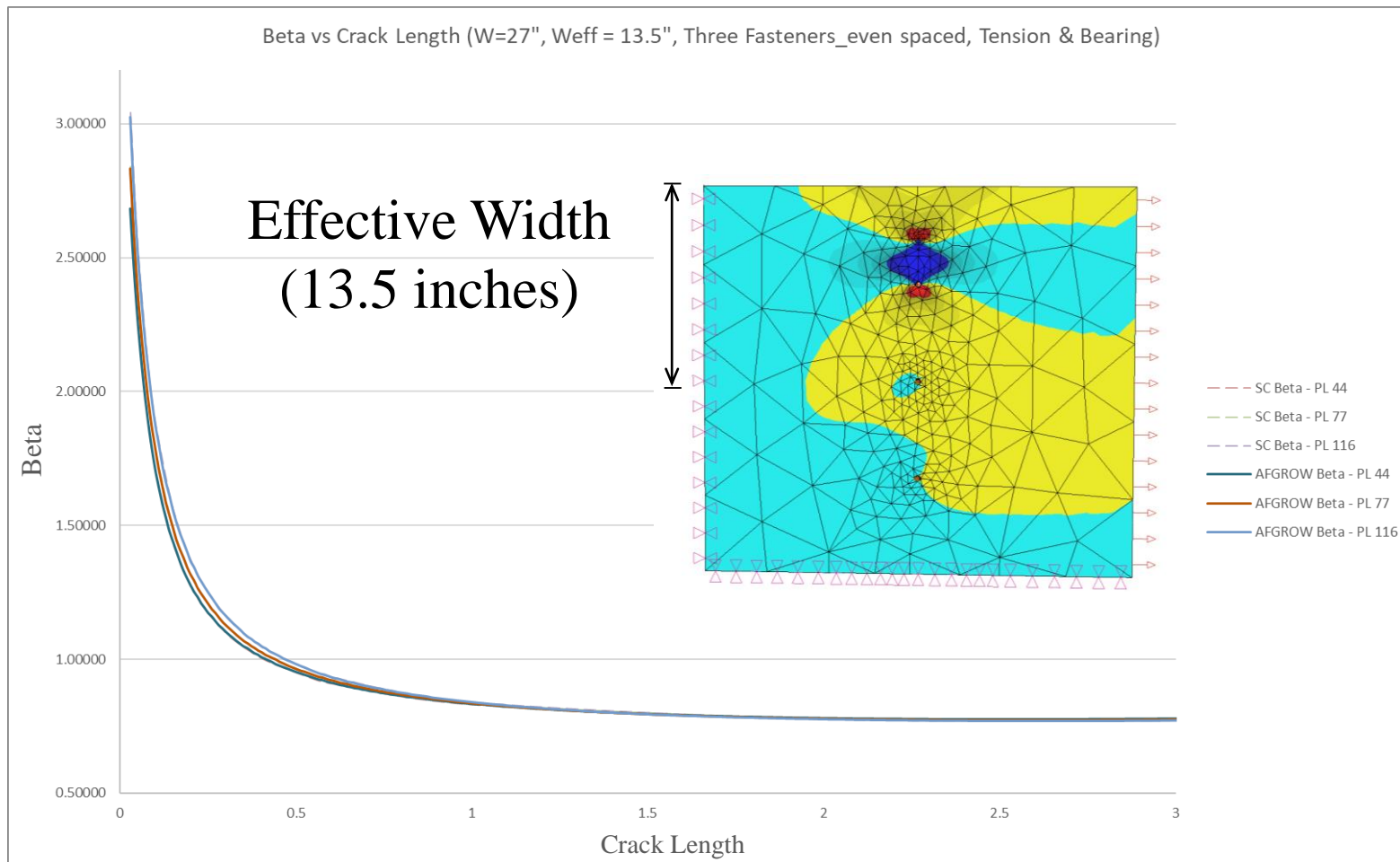
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0





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StressCheck Load Transfer Model

(Centered Hole, Wide Plate, Three Uneven Spaced Fasteners)



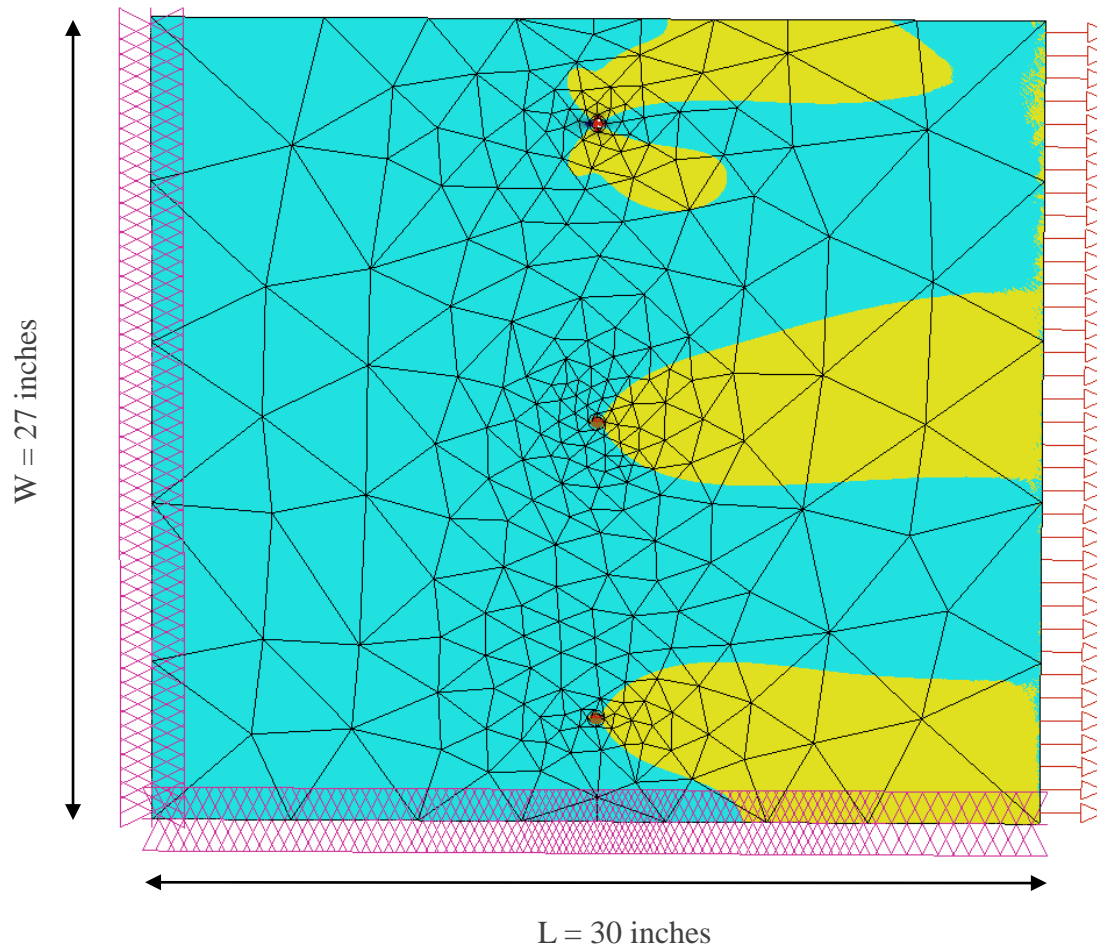
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 2.8



StressCheck v10.4

Units = INCH/LBF/SEC/F
 LINEAR ID=LSOL
 Run=1, DOF=33742
 Fnc.=S1
 Max= 1.159e+005
 Min=-7.154e+002



- 2.000e+003
- 1.900e+003
- 1.800e+003
- 1.700e+003
- 1.600e+003
- 1.500e+003
- 1.400e+003
- 1.300e+003
- 1.200e+003
- 1.100e+003
- 1.000e+003
- 9.000e+002
- 8.000e+002
- 7.000e+002
- 6.000e+002
- 5.000e+002
- 4.000e+002
- 3.000e+002
- 2.000e+002
- 1.000e+002
- 0.000e+000



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SC & AFGROW Tension & Bearing Beta Curve (Centered Hole, Narrow Plate, Three Uneven Spaced Fasteners)



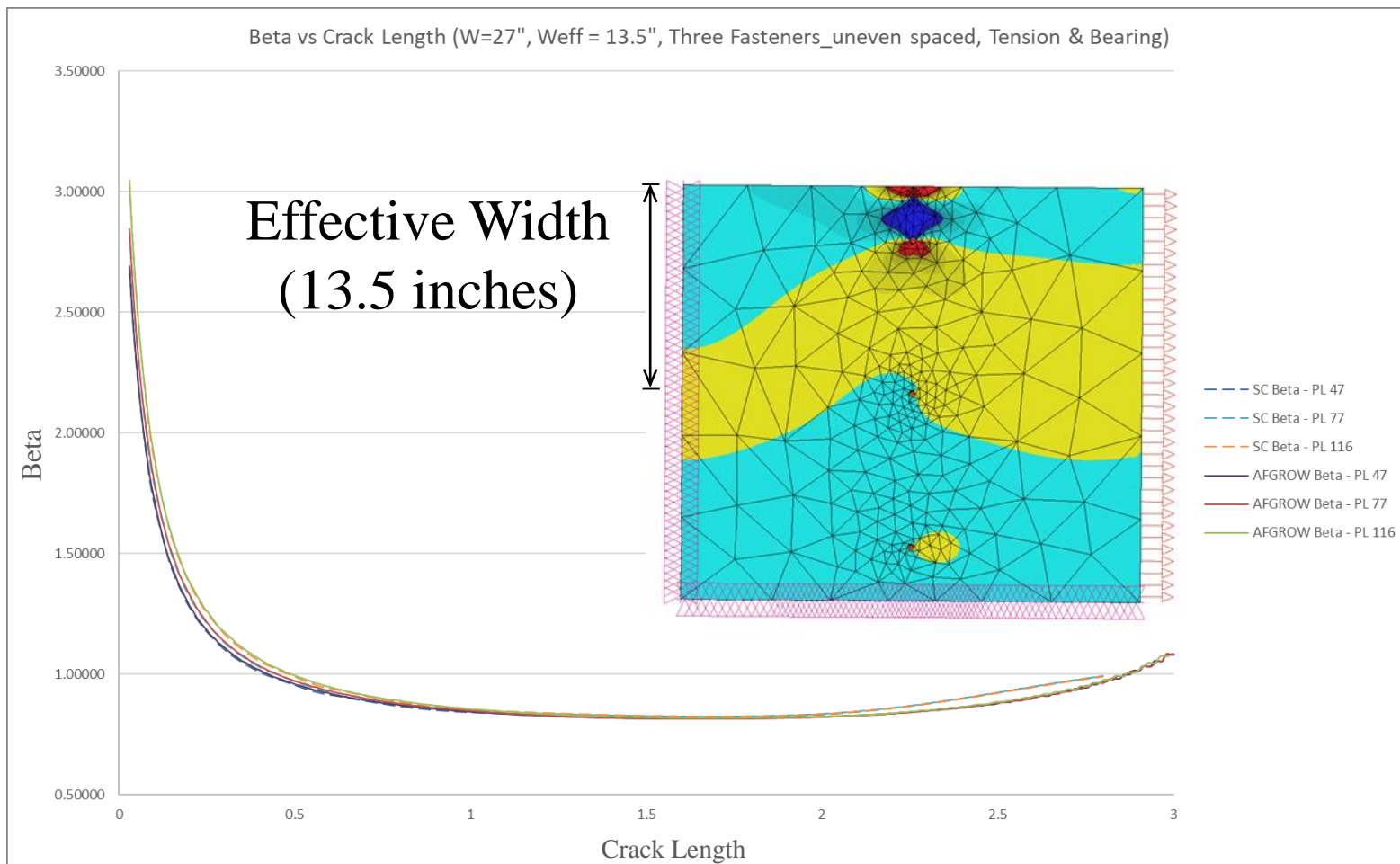
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 2.8





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StressCheck Betas vs AFGROW Betas

(Centered Hole, Wide Plate, Four Fasteners)



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StressCheck Load Transfer Model

(Centered Hole, Wide Plate, Four Even Spaced Fasteners)

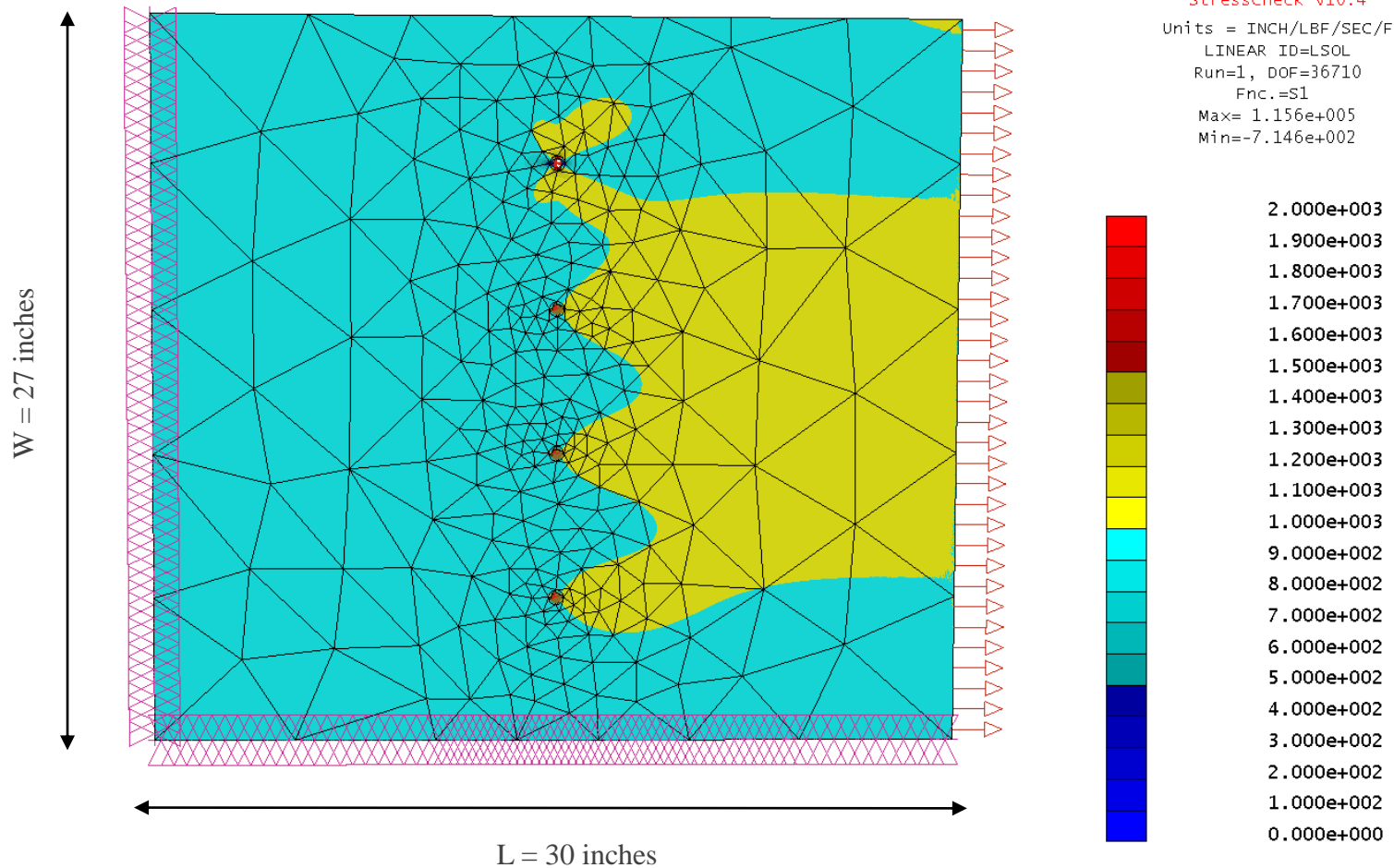
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0





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SC & AFGROW Tension & Bearing Beta Curve

(Centered Hole, Narrow Plate, Four Even Spaced Fasteners)



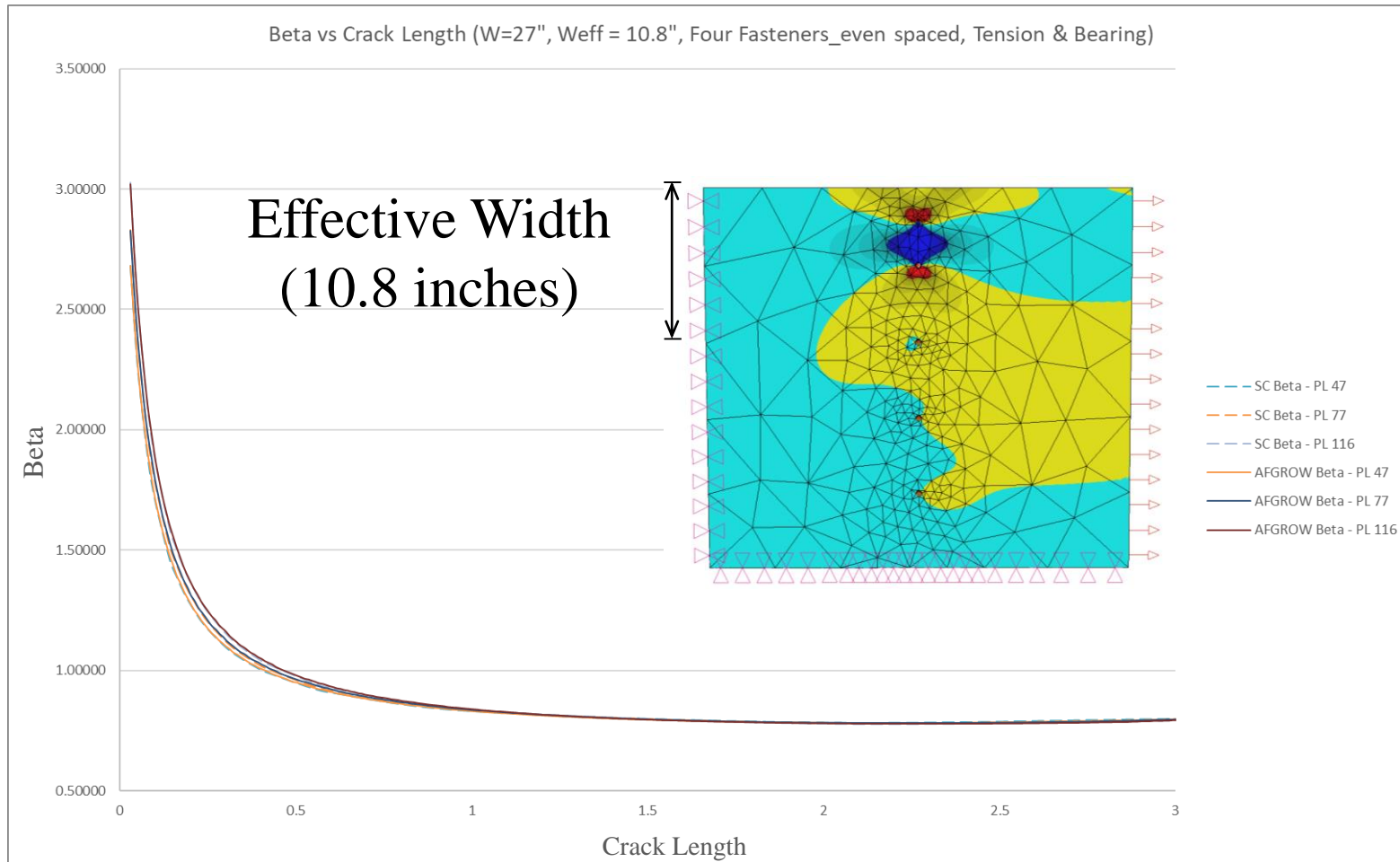
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0





StressCheck Betas vs AFGROW Betas

(Centered Hole, Narrow Plate, Single Fastener)

Note: Removes hole offset assumptions



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USAF Study: StressCheck vs AFGROW

StressCheck Load Transfer Model (Single Fastener)



Solution Space:

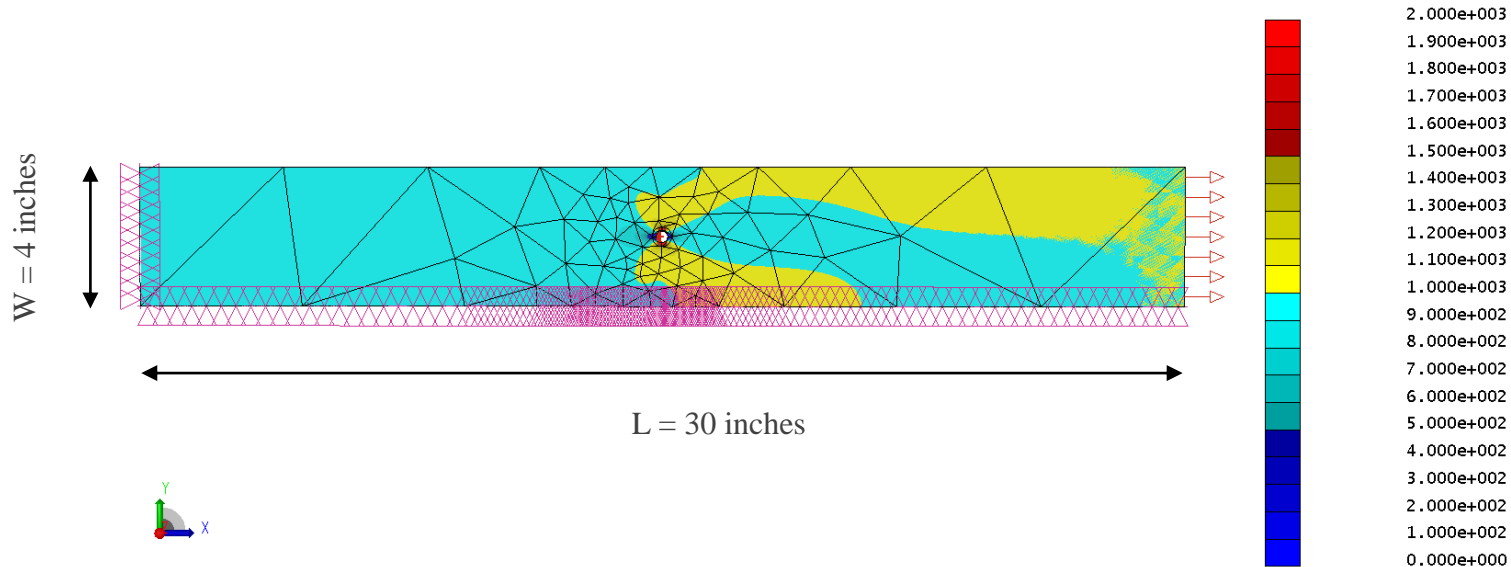
Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 1.25, 1.2, 1.3, 1.4, 1.5

StressCheck v10.4
Units = INCH/LBF/SEC/F
LINEAR ID=LSOL
Run=1, DOF=10166
Fnc.=S1
Max= 1.153e+005
Min=-7.141e+002





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StressCheck & AFGROW Tension Beta Curve

(Centered Hole, Narrow Plate, Single Fastener)



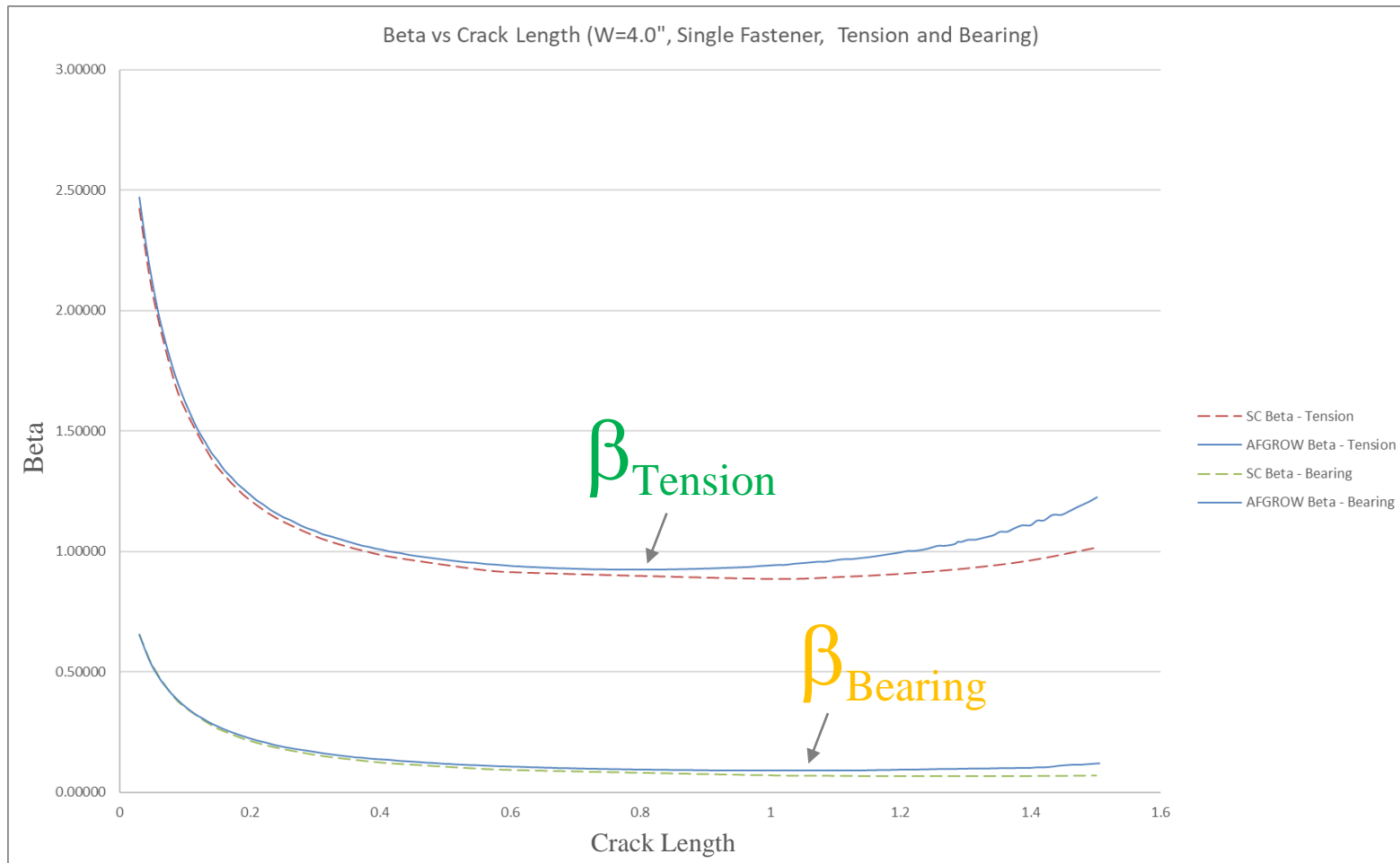
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 1.25, 1.2, 1.3, 1.4, 1.5





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SC & AFGROW Tension & Bearing Beta Curve

(Centered Hole, Narrow Plate, Single Fastener)

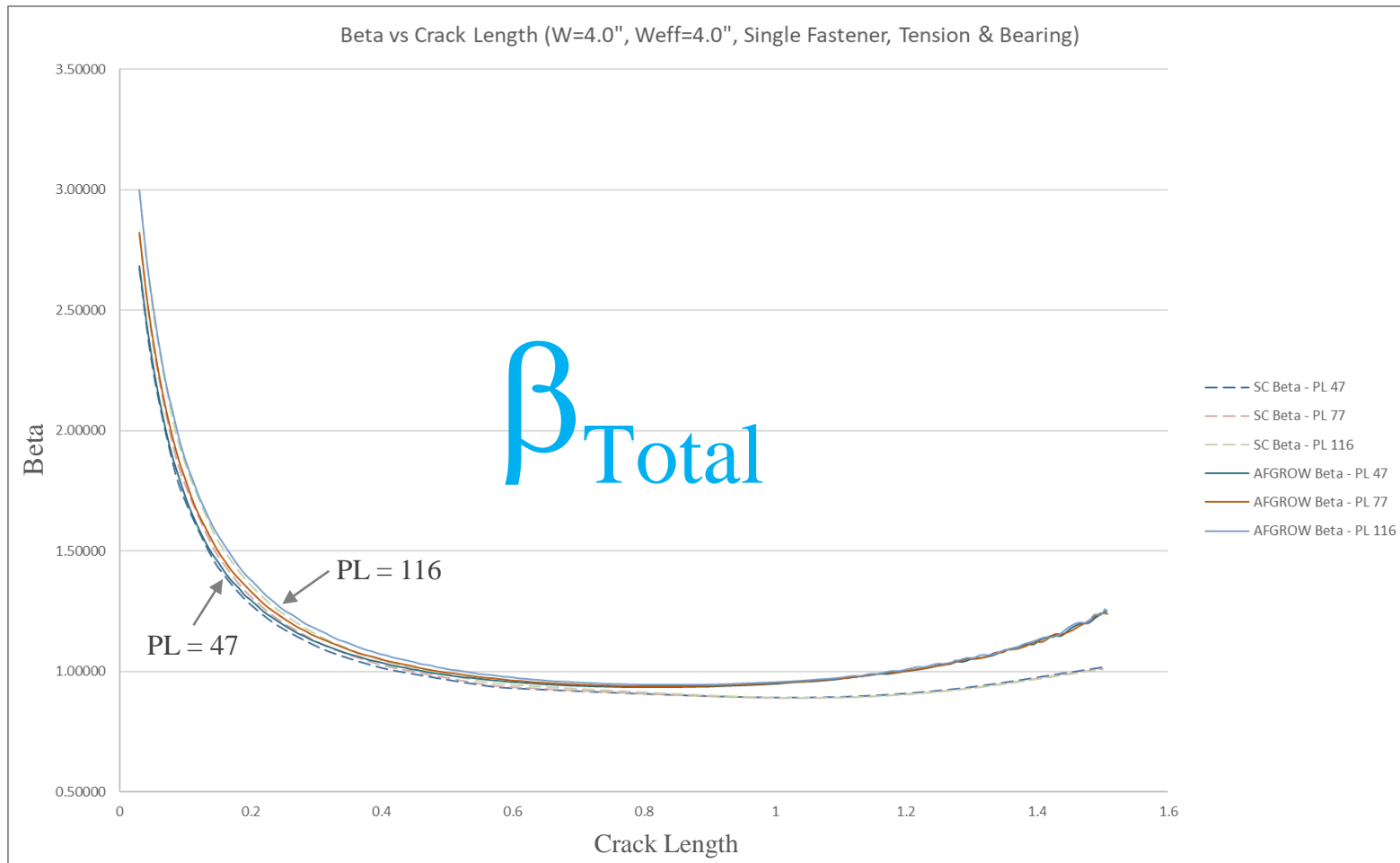


Solution Space:

Diameter – 0.3281

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 1.25, 1.2, 1.3, 1.4, 1.5





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SC & AFGROW Tension & Bearing Beta Curve

(Centered Hole, Narrow Plate, Single Fastener)

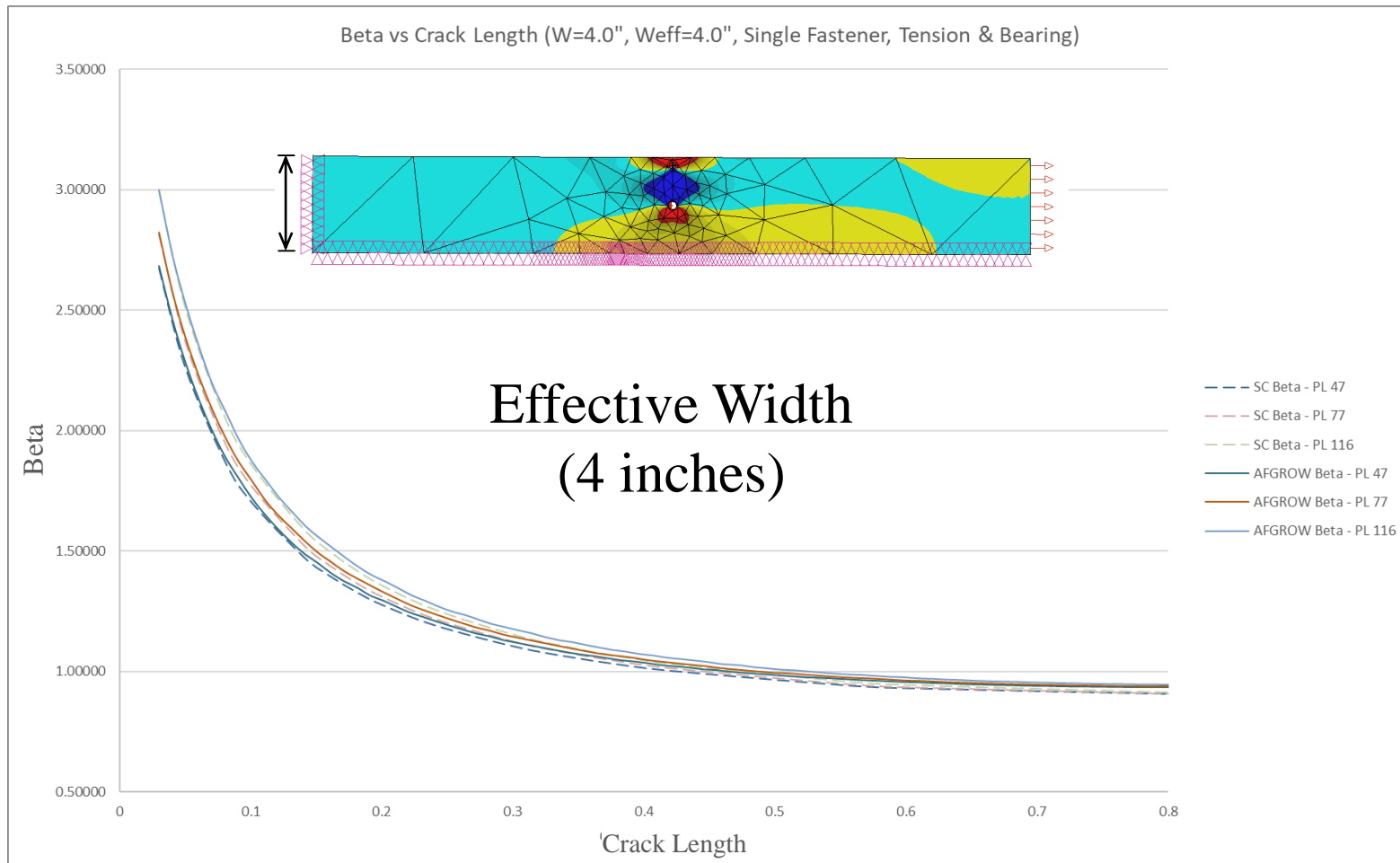


Solution Space:

Diameter – 0.3281

Pin Load – 44, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 1.25, 1.2, 1.3, 1.4, 1.5





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StressCheck Betas vs AFGROW Betas

Summary



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StressCheck vs AFGROW

(Summary)



The anomaly of increasing fastener load and increasing life is correct based on how the study was conducted.

- As the pin load increases the BSF increases and the TSF decreases. In the case of Config 01. The decreasing TSF is over the crack growth curve from the IFS to the critical crack length. Therefore, it would naturally show an increase in life as the pin load decreases.

Bearing and Tension Beta Solutions:

- Line up well for Wide Centered Hole Models
- Line up well for Wide Offset Hole Models
- Have differences for Narrow Centered Hole Models

The Effective width assumption that A-10 currently uses appears to be small compared to what values are necessary to allow StressCheck and AFGROW to match up.

- Appears that it should be from the edge of the part to the adjacent fastener.

In all cases ran, the betas as the crack nears the edge of the part do not line up.



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StressCheck vs AFGROW

(Recommendation)



- Run Series of Models with larger Fastener Load to ensure that trend is still valid with smaller TSF values, i.e. a larger range of TSF.
- Run Config. 01 with the larger effective width to determine the resulting life trends with increase pin load.
- Run model with crack growing from fastener to fastener.
- Run a sensitivity study to determine how much the change in effective width effects the resulting life.



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Backup Slides



Combining the Tension & Bearing Beta Curve

(Centered Hole, Wide Plate, Single Fastener)

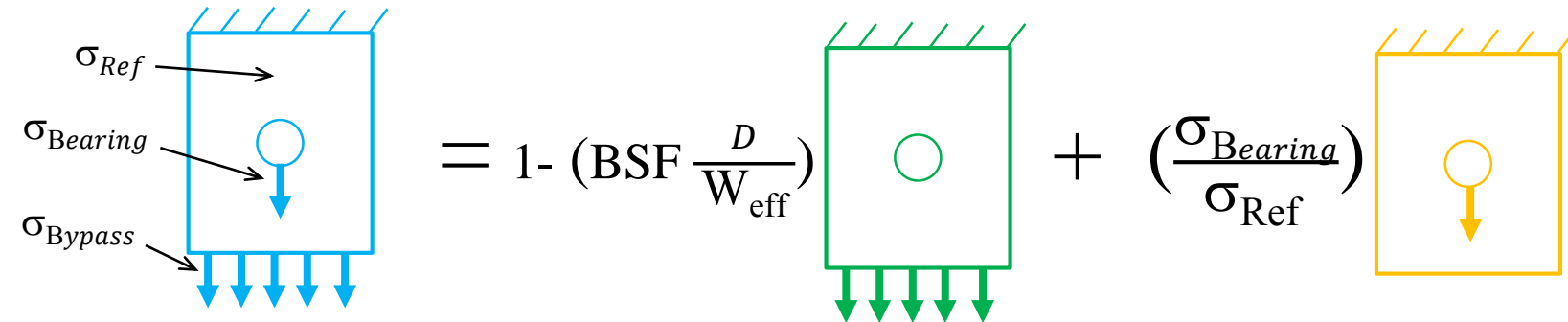
Solution Space:

Diameter – 0.3281

Thickness – 0.30

Pin Load – 47, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0



$$= 1 - \left(BSF \frac{D}{W_{eff}} \right) + \left(\frac{\sigma_{Bearing}}{\sigma_{Ref}} \right)$$

$$\beta_{Total} = 1 - \left(0.475 \frac{0.3281}{?} \right) \beta_{Tension} + \left(\frac{477.50}{1,006} \right) \beta_{Bearing}$$

If $W_{eff} = 27.0$, then

$$\beta_{Total} = (0.994) \beta_{Tension} + (0.475) \beta_{Bearing}$$



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StressCheck & AFGROW Tension Beta Curve (Centered Hole, Wide Plate, Single Fastener)

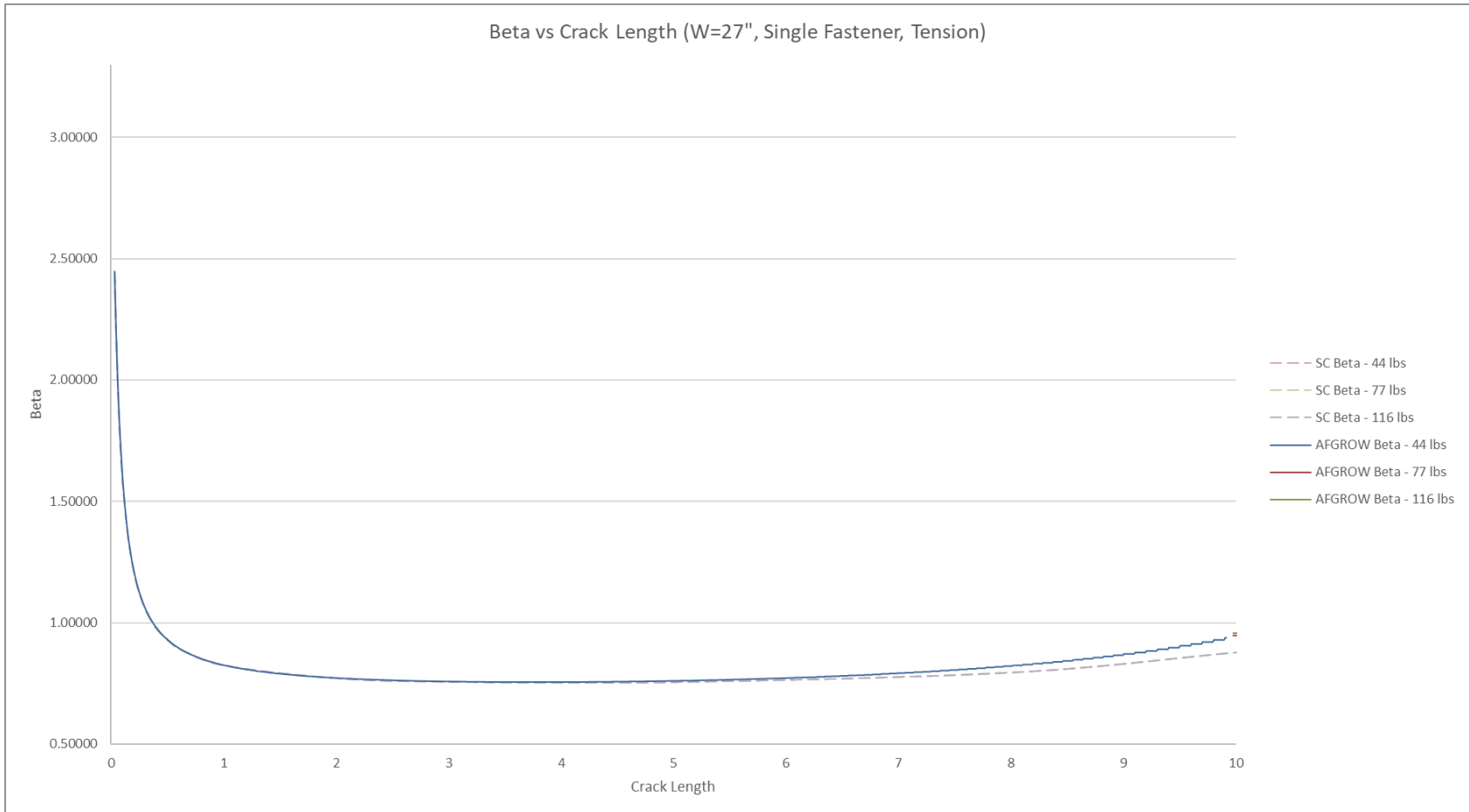


Solution Space:

Diameter – 0.3281

Load – 44, 77, 116

Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0





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StressCheck & AFGROW Bearing Beta Curve

(Centered Hole, Wide Plate, Single Fastener)

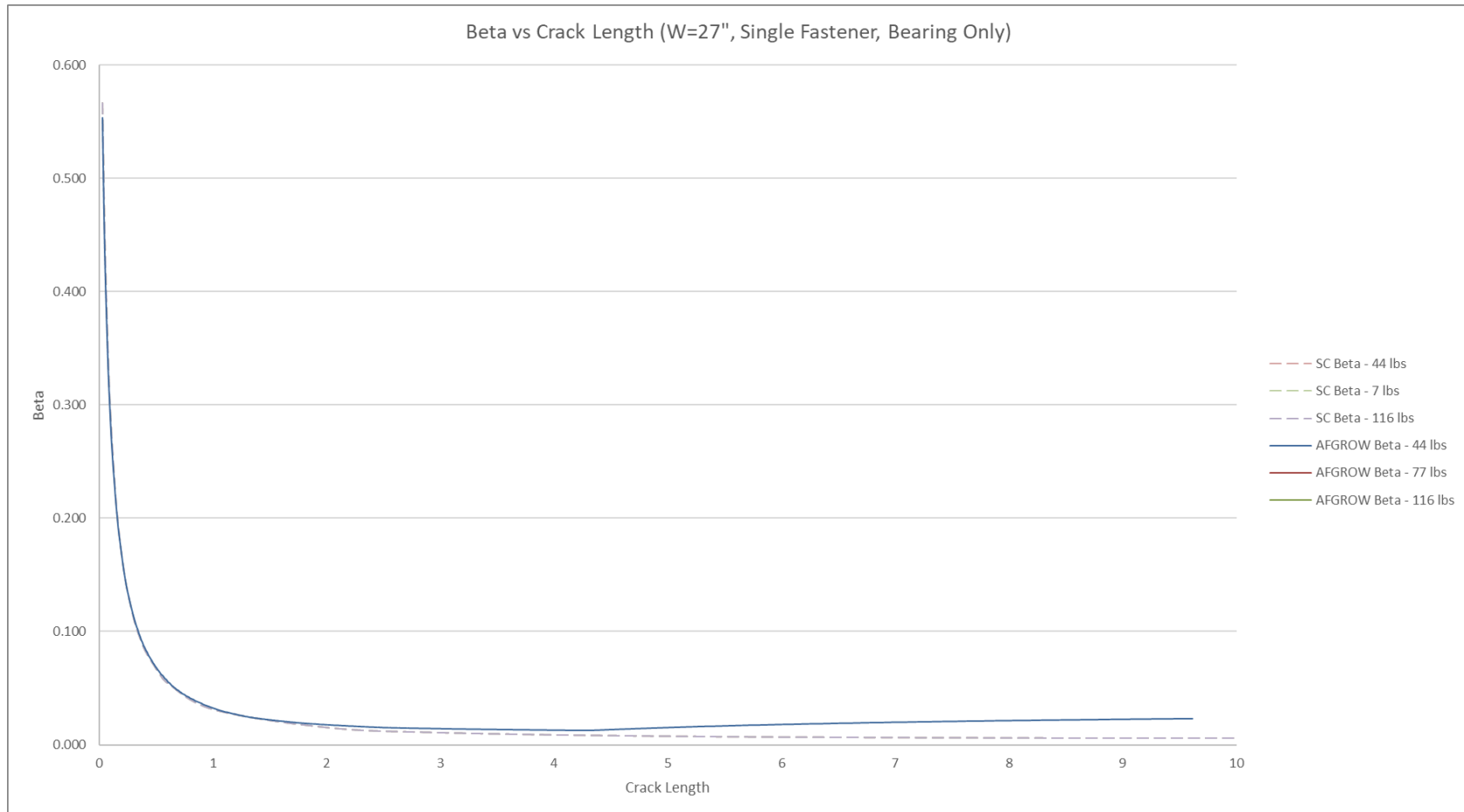


Solution Space:

Diameter – 0.3281

Load – 44, 77, 116

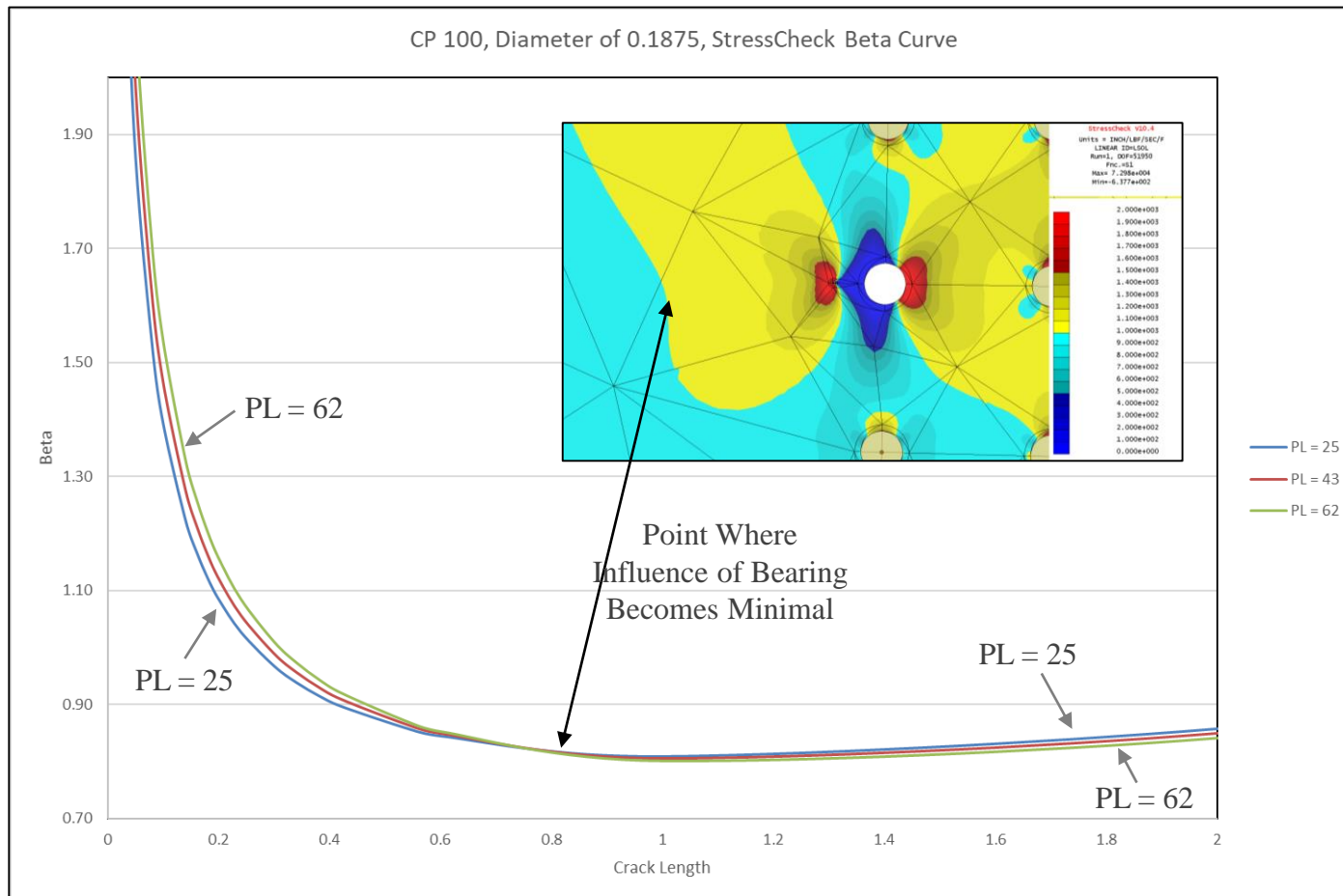
Crack Length – 0.03, 0.05, 0.08, 0.1, 0.14, 0.16, 0.18, 0.2, 0.24, 0.3, 0.34, 0.38, 0.42, 0.54, 0.6, 1.0, 2.0, 3.0, 5.0, 8.0, 10.0





USAF Study: StressCheck vs AFGROW

StressCheck Beta Curve (0.1875" Diameter_Centered Hole)

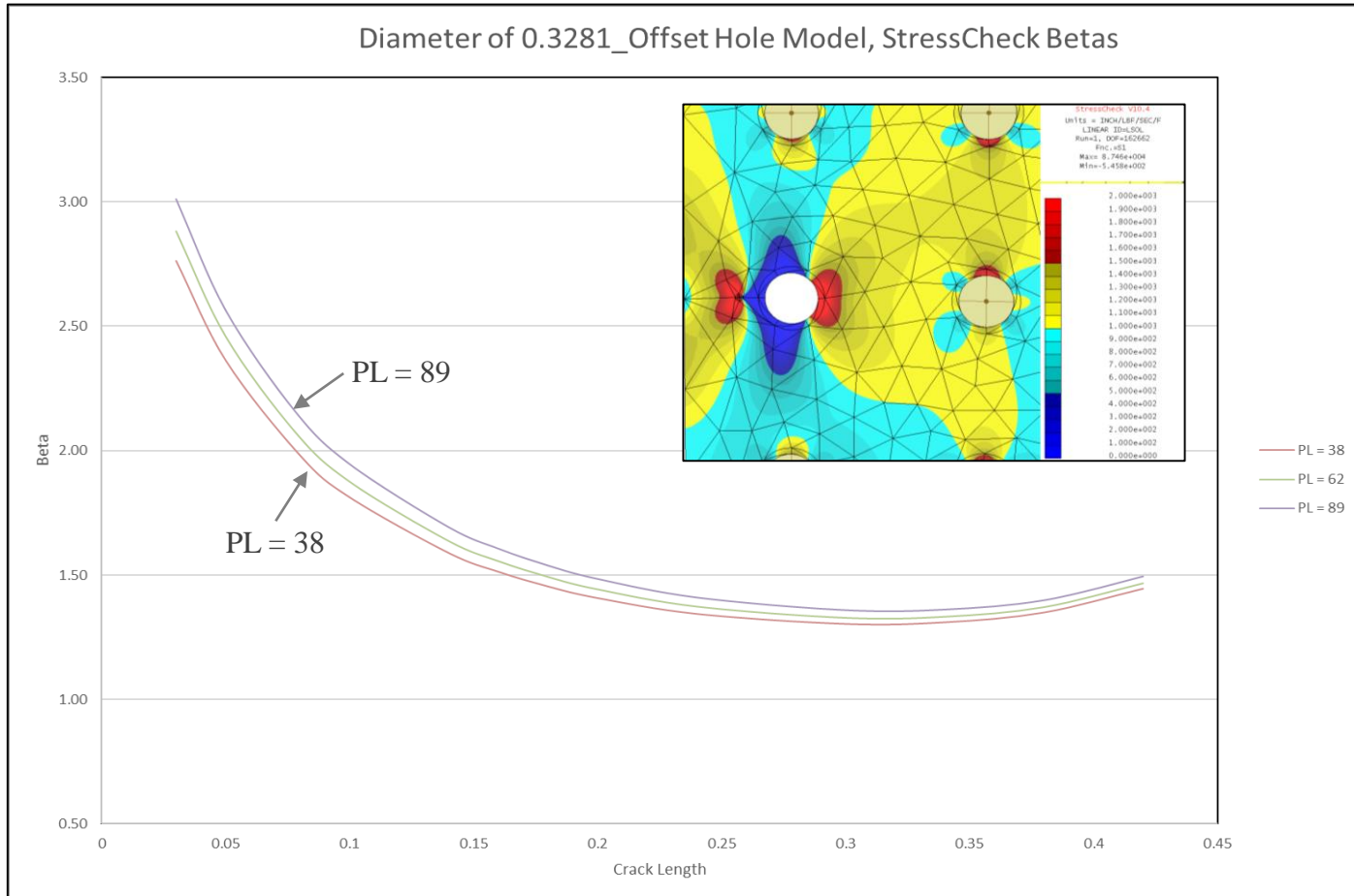




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USAF Study: StressCheck vs AFGROW

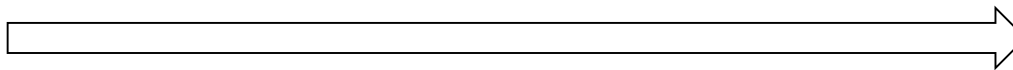
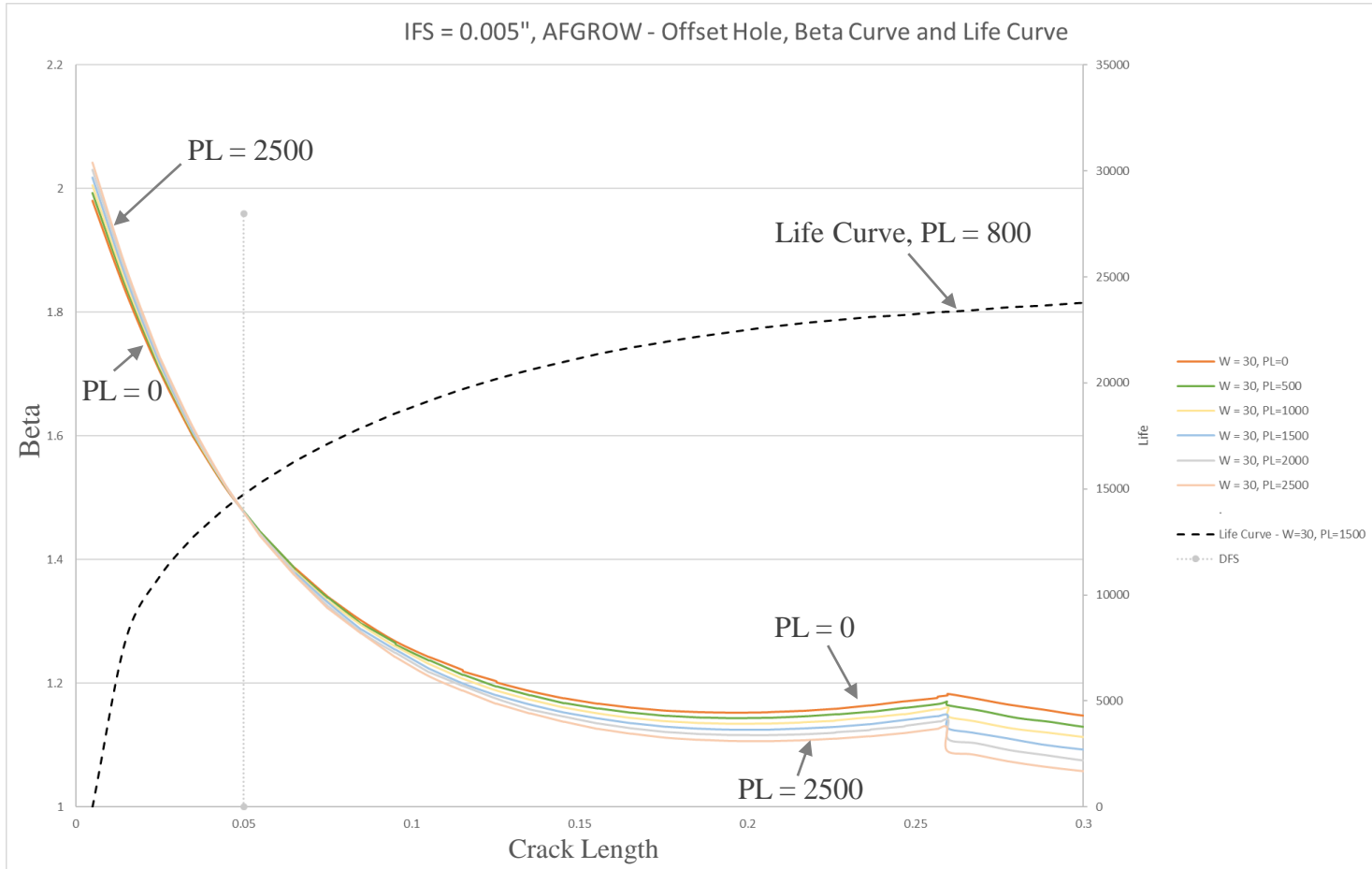
StressCheck Beta Curve (0.3281" Diameter_Offset Hole)





USAF Study: AFGROW Solution

Beta Curve as a Function of Pin Load (Config. 01)



Bearing influence reduces as the distance from the hole increases