

# Harter Finite Width Correction Evaluation



**U.S. AIR FORCE**



**Jake Warner  
A-10**

**A-10**



# Acknowledgements

- Kaylon Anderson
- Austin Ekenstam
- God and Family
- Jim Harter
- Josh Hodges
- Jim Newman
- Mike Worley



“Alone we can do so **LITTLE**;  
**Together** we can do so **much**.”  
- Helen Keller



# Background

## “We have a problem”

- 2021, Jim Harter AFGROW presentation, “Finite Width Correction for Part-Through Cracked Holes
- [https://afgrow.net/workshop/documents/2021/James\\_Harter\\_Finite\\_Width\\_Correction\\_for\\_Part-Through\\_Cracked\\_Holes\\_Workshop-2021.pdf](https://afgrow.net/workshop/documents/2021/James_Harter_Finite_Width_Correction_for_Part-Through_Cracked_Holes_Workshop-2021.pdf)



### Finite Width Correction



## What Do We Know?

The 1986 Newman Fw correction is low when  $a/t < 0.6$

The 1986 Newman Fw correction is high when  $a/t > 0.6$

The actual Fw is not the same for each crack dimension

Fw is a function of  $W/D$ ,  $r/t$ ,  $a/c$ , and  $a/t$

We have a problem



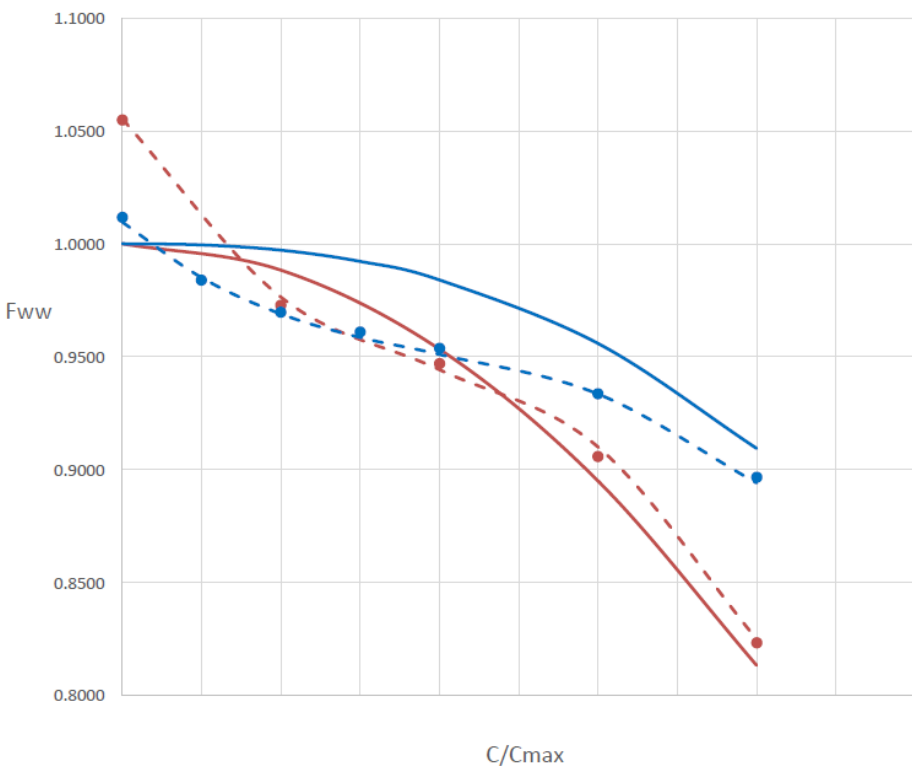
# Background

## Update Through Crack Solution Comparison

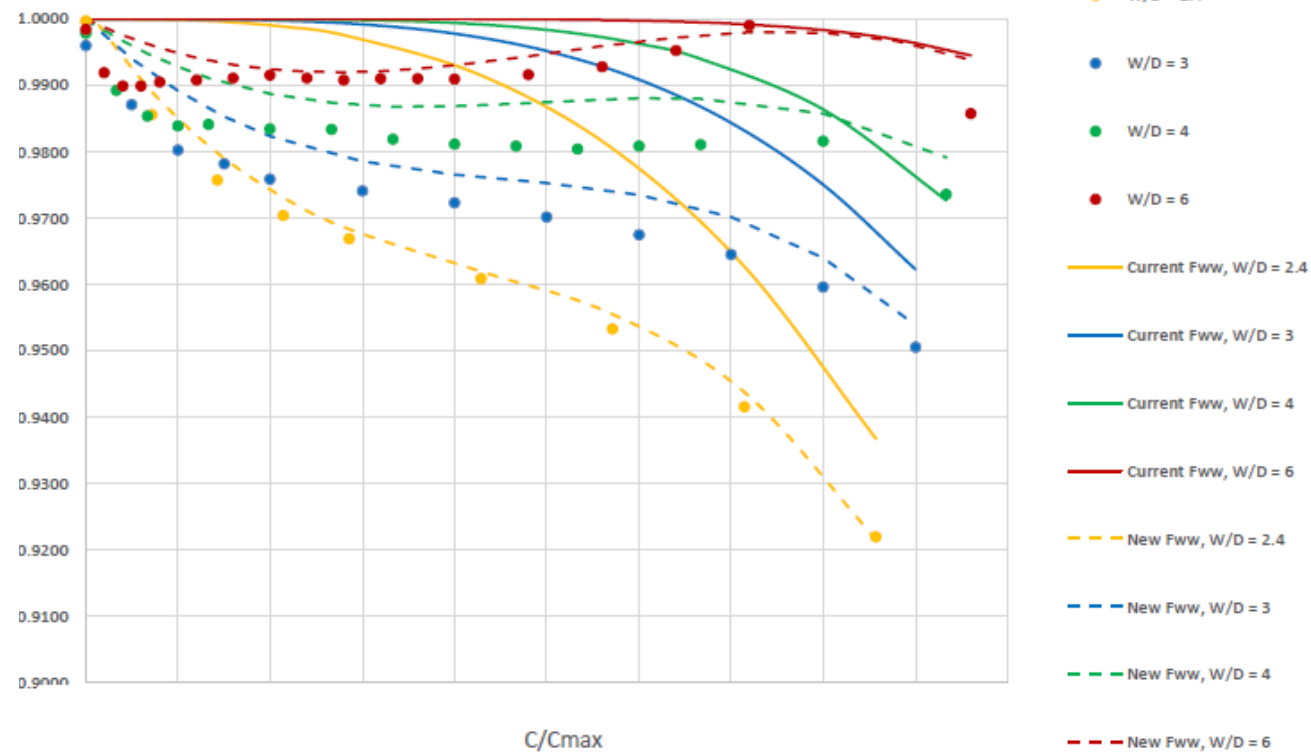


### Through Cracked Hole Finite Width Correction

Fww for W/D = 1.5 & 2.0



Fww for W/D = 2.4, 3, 4, & 6



C/Cmax



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## COM Comparisons





# A-10 AFGROW COM

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1	Project Information Here			Material Information:			Model Information:														Spectrum:			Retardation Model:				
2	CP #	Title	Comments	Method	Material Code	Kc	Crack Geometry	Width (W)	Thickness (T)	Hole Diameter (D)	W/D	Is the Hole Offset?	Hole Offset (B) or fastener spacing	Crack Length - 'C' Direction	Crack Length - 'A' Direction	Keep 'A/C' Constant	Oblique Through Crack	Tension Stress Ratio	Bending Stress Ratio	Bearing Stress Ratio	Filled Unloaded Hole	Stress Multiplication Factor (SMF)	Residual Strength Requirements (Pxx)	Open Spectrum File (*.sp3)	Type of Retardation	Retardation Parameter	Adtional Retardation Parameters	Open Load Ratio
3	1T	Fuel pump holes in forward lower wing skin, W.S. 23	Aircraft 582 and up	99	2024-T3511		1001	13.700	0.520	0.250	54.800	1	1.700	0.05	0.05	0	0	1	0.0	0	0	30.51	30.51	DTRCP7.AFGR Dw	1	1.70		
4	2T	Front Spar Cap, W.S.23	Aircraft 582 and up	99	2024-T3511		1001	4.860	0.384	0.562	8.648	1	1.121	0.005	0.005	0	0	0.94	0.0	0.239	0	23.992	23.992	DTRCP7.AFGR Dw	1	1.70		
5	3T	Front Spar Web, W.S.23	Aircraft 582 and up	99	7075-T76		1001	14.570	0.190	0.438	33.265	1	1.000	0.005	0.005	0	0	0.89	0.0	0.593	0	22.382	22.382	DTRCP7.AFGR Dw	1	2.05		
6	4T	Lower FwD Skin, W.S.23	Aircraft 582 and up	99	2024-T3511		1001	26.940	0.420	0.562	47.936	1	1.410	0.005	0.005	0	0	0.8	0.0	0.758	0	23.992	23.992	DTRCP7.AFGR Dw	1	1.70		
7	5T	Rear Spar Cap, W.S. 23	Aircraft 582 and up	99	2024-T3511		1001	5.480	0.394	0.500	10.960	1	1.040	0.005	0.005	0	0	0.94	0.0	0.346	0	29.78	29.78	DTRCP7.AFGR Dw	1	1.70		
8	6T	Rear Spar Web, W.S. 23	Aircraft 582 and up	99	7075-T7351		1001	13.420	0.245	0.438	30.639	1	1.050	0.005	0.005	0	0	0.89	0.0	0.593	0	23.432	23.432	DTRCP7.AFGR Dw	1	2.05		
9	7T	Lower Cover at Rear Spar, W.S. 23 (IATP 1)	Aircraft 582 and up	99	2024-T351		1001	26.940	0.410	0.500	53.880	1	1.690	0.005	0.005	0	0	0.8	0.0	0.851	0	30.315	30.315	DTRCP7.AFGR Dw	1	1.76		
10	8T	Rear Spar Wing/Fuselage Fitting, W.S. 23	Aircraft 582 and up	99	AMS_6526		1001	4.500	0.190	0.438	10.274	1	0.830	0.005	0.005	0	0	0.366	0.0	2.403	0	50.143		DTRCP8.AFGR Dw	1	1.98		



# AFGROW COM Inputs

- All inputs followed A-10 DTA ground rules
- Advanced model
- Variable aspect ratio
- 1% growth increment

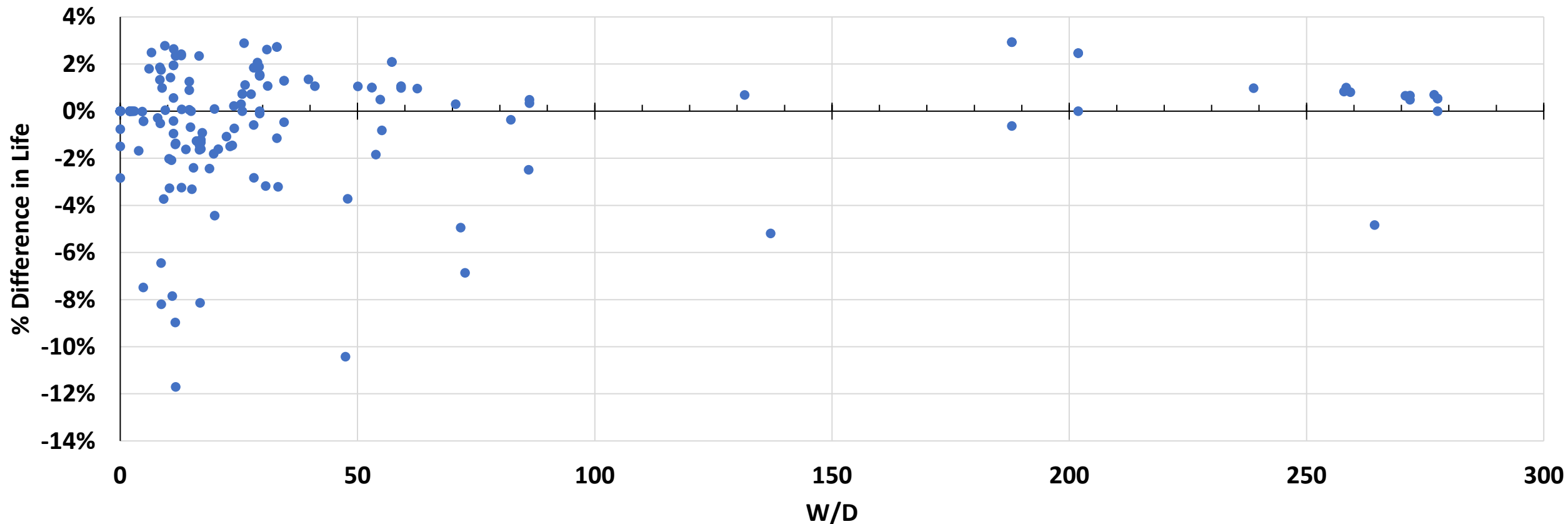


```
Willenborg Retardation Model
├── SOLR= 1.86
├── Adjust Yield Zone Size for Compressive Cycles = No
├── No K-Solution Filters
└── Specimen
    ├── Load
    │   ├── Axial Stress Fraction= 1
    │   ├── Bending Stress Fraction= 0
    │   └── Bearing Stress Fraction= 0
    ├── Width (W)=4
    ├── Thickness (T)=0.1
    ├── No In-Plane Bending
    ├── Crack #1 (Corner Crack at Hole)
    │   ├── C Length = 0.05
    │   ├── A Length = 0.05
    │   └── Position: Left At Hole
    └── Hole #1 (Hole)
        ├── Diameter = 0.343
        └── Offset = 0.5
```



# A-10 COM Finite Width Comparisons

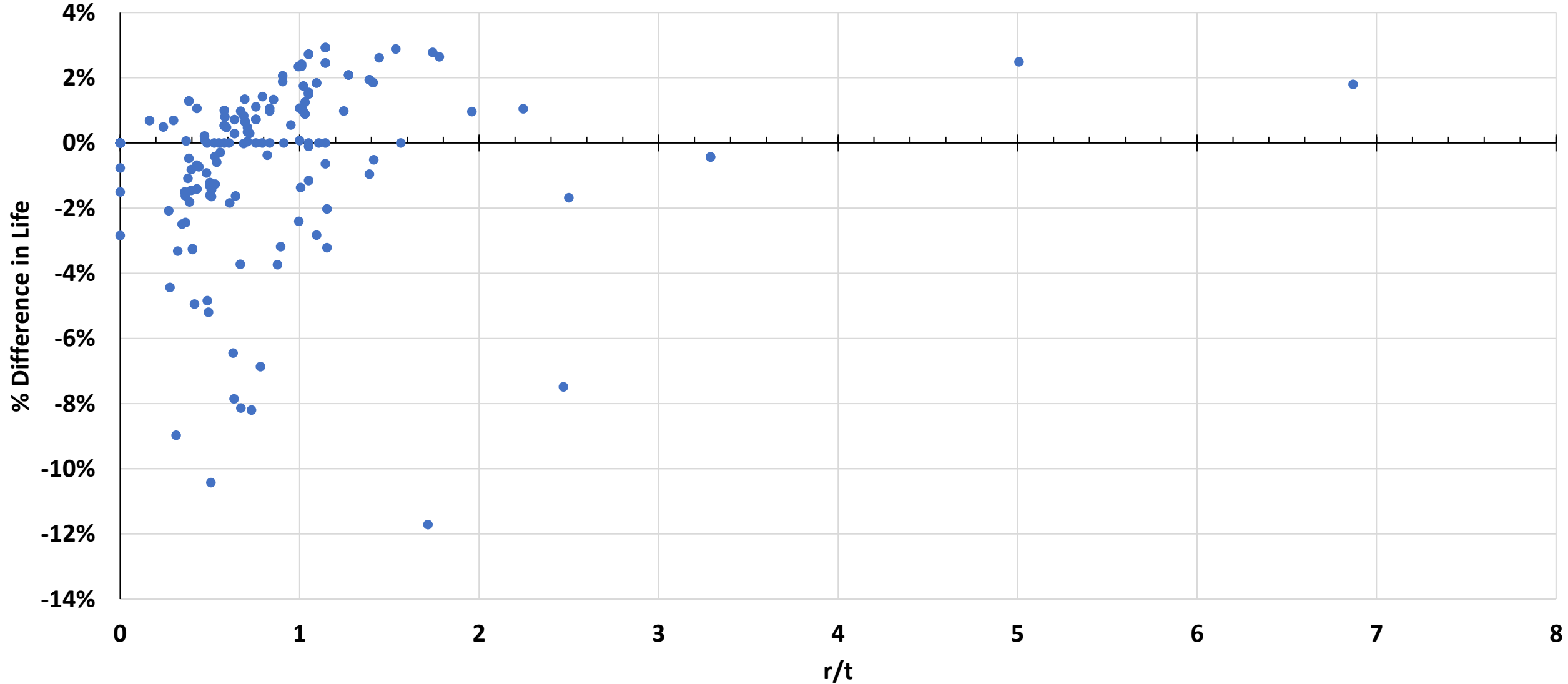
- A-10 COM output for all CPs using both finite width corrections
- Positive difference = longer life using Harter correction
- Negative difference = shorter life using Harter correction







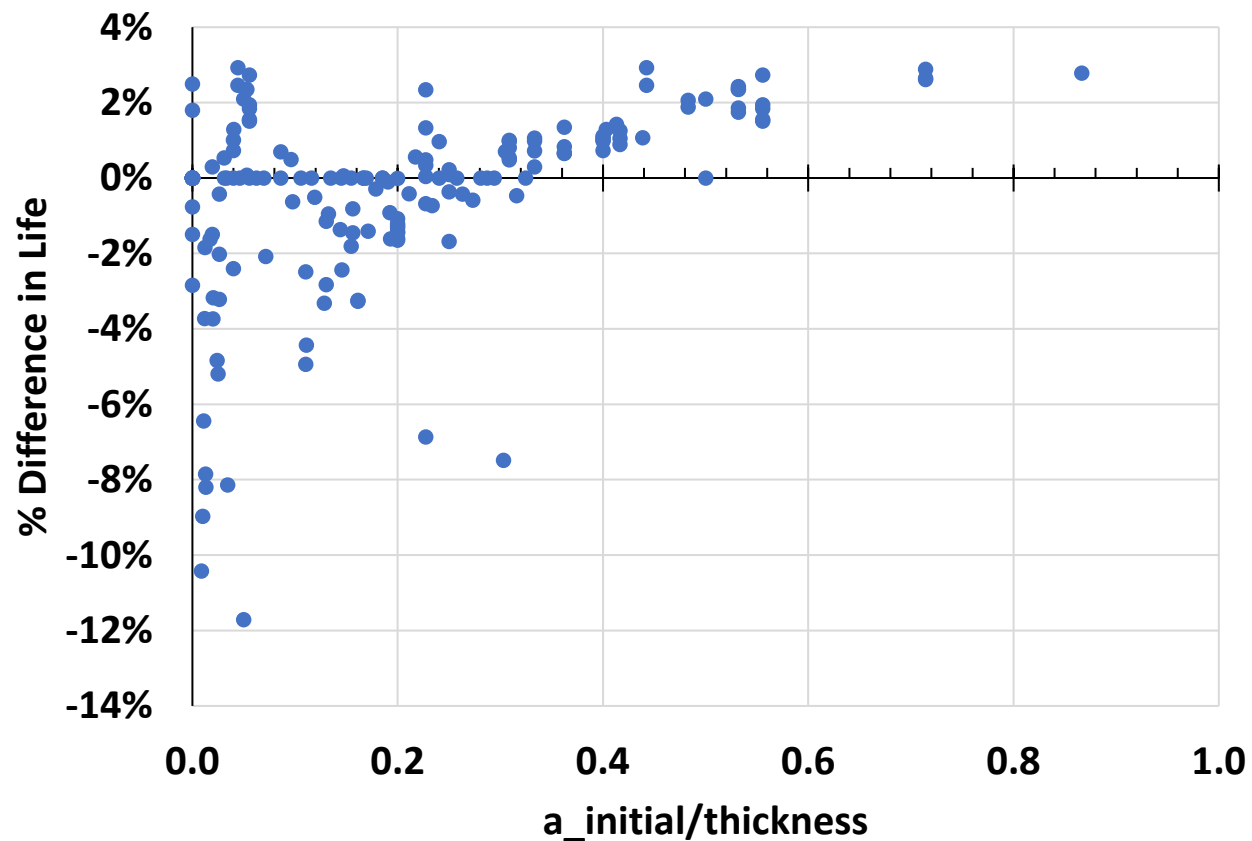
# A-10 COM Finite Width Comparisons (r/t)



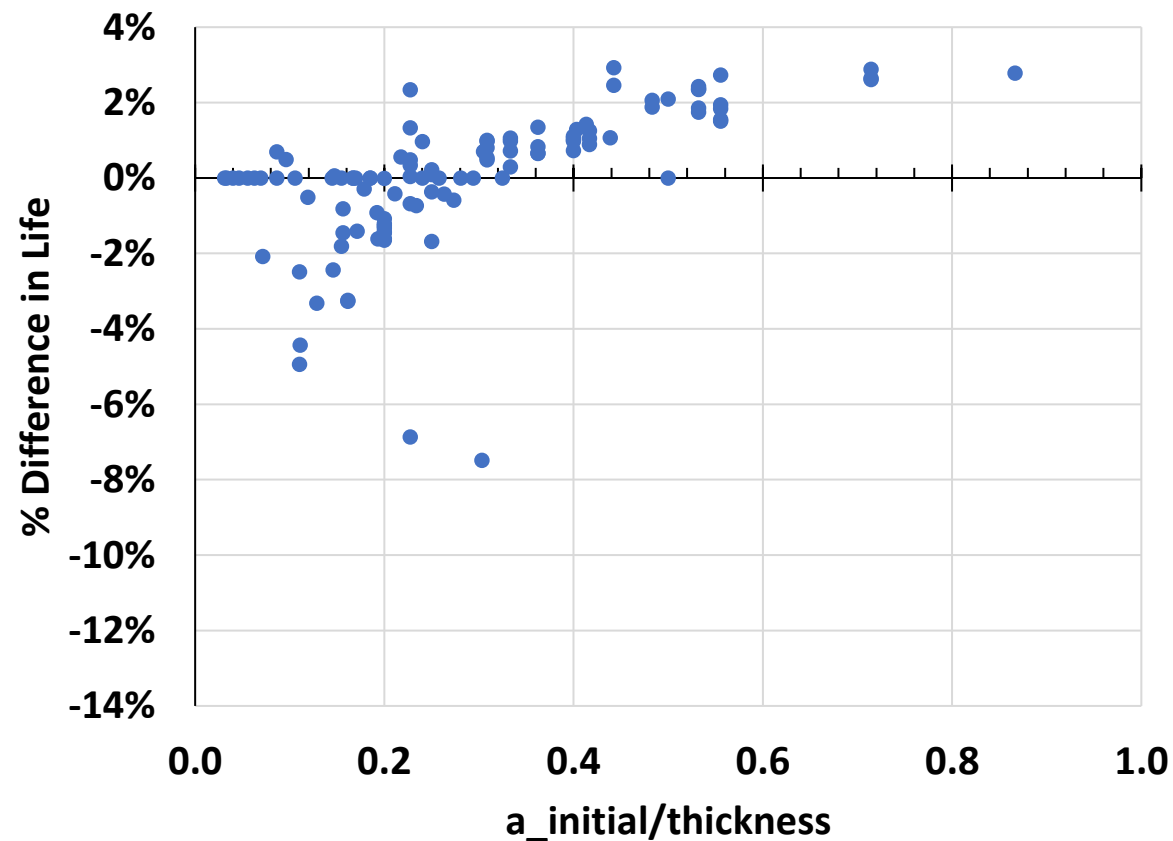


# COM Comparisons ( $a_{\text{initial}}/t$ )

All A-10 Analyses



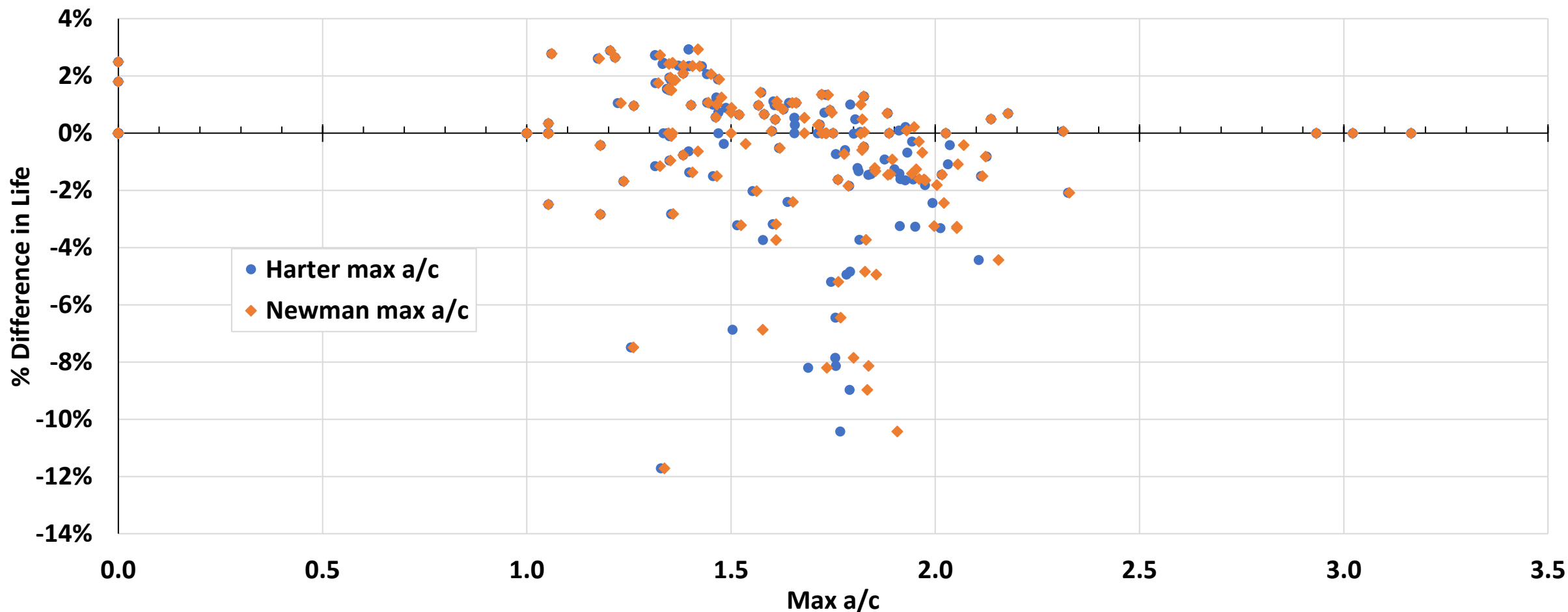
Starting Crack  $\geq 0.05$ " Only





# COM Comparisons (max a/c)

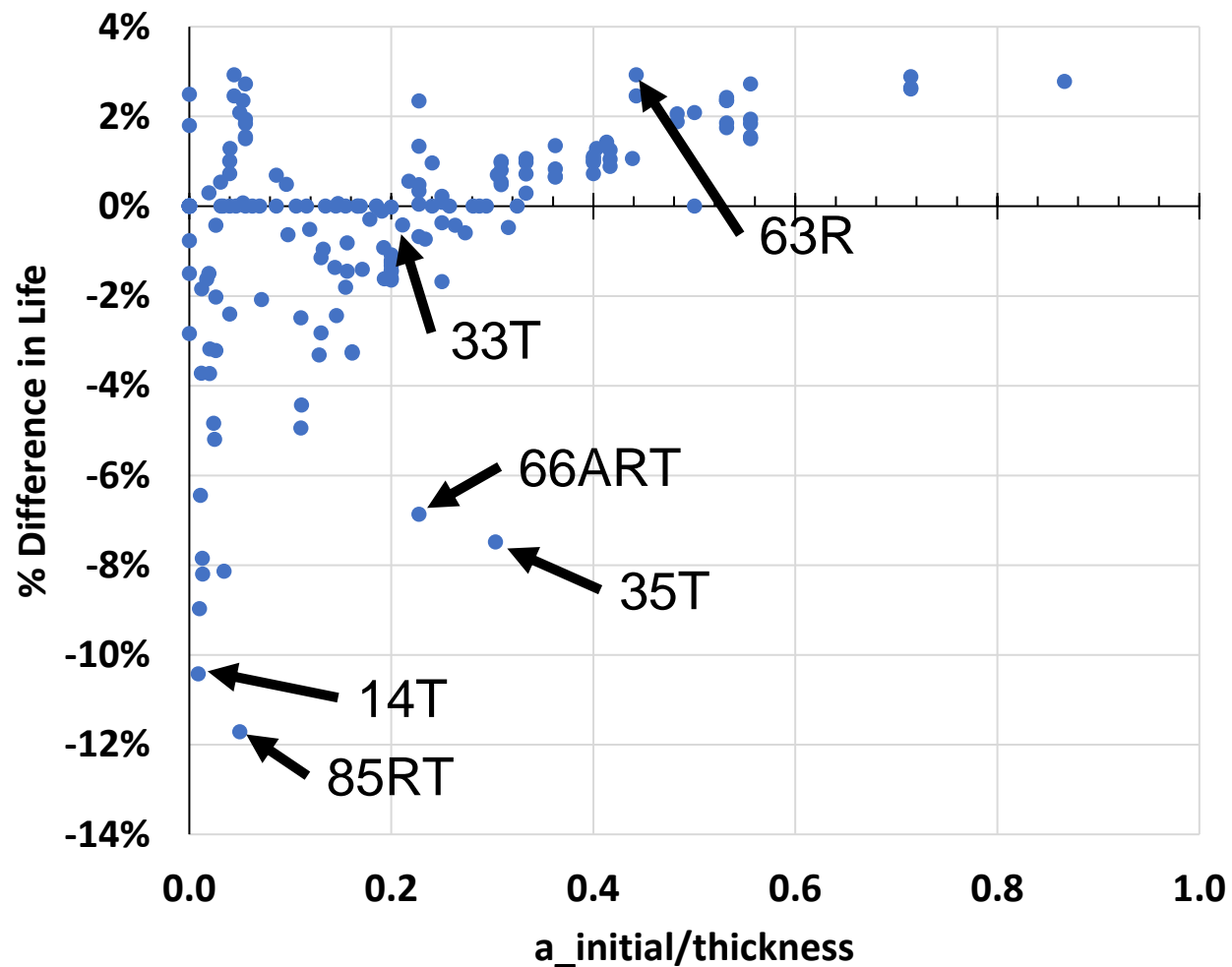
- All analyses start with  $a/c=1$
- Max aspect ratio is typically just before transition to thru thickness



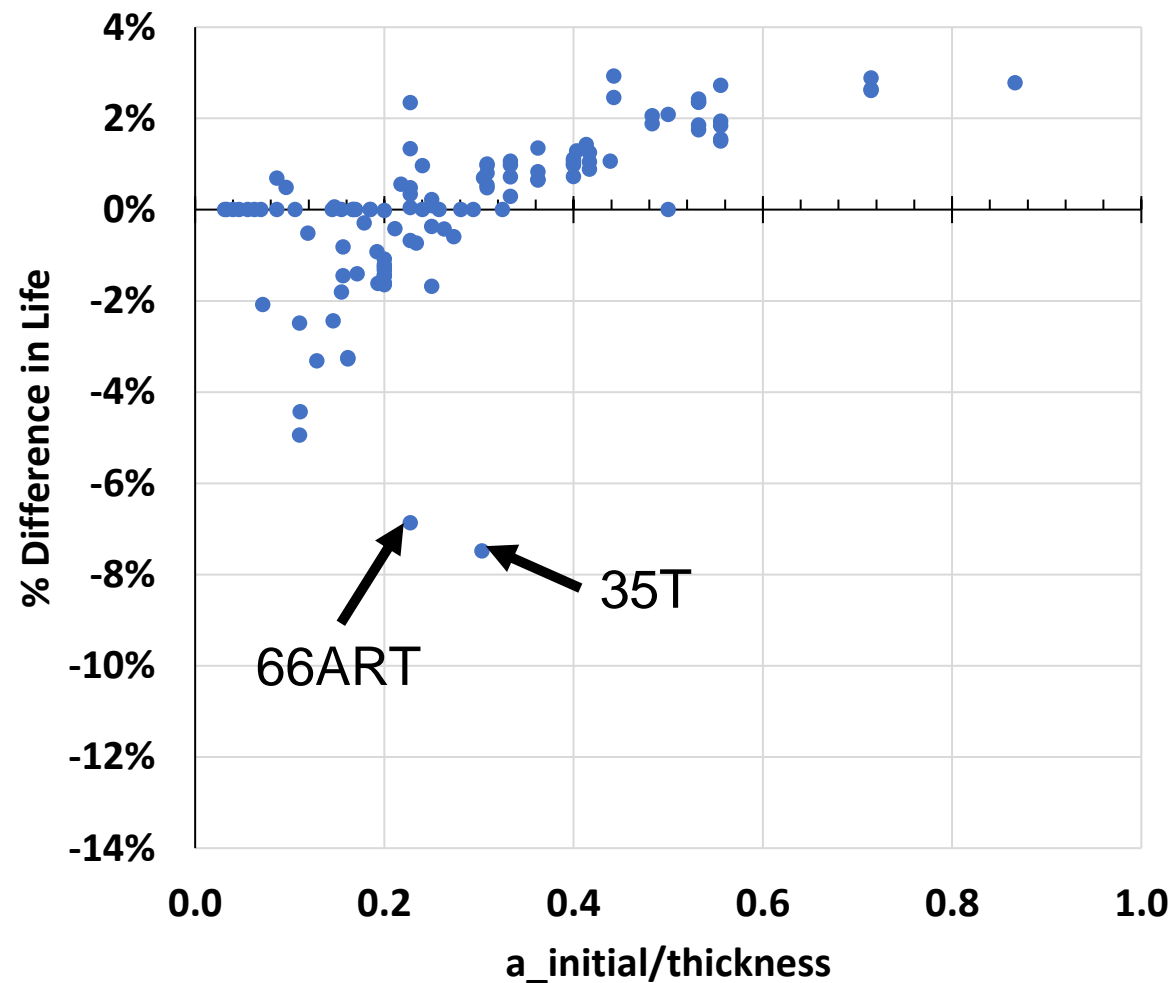


# COM Comparisons ( $a_{\text{initial}}/t$ )

All A-10 Analyses



Starting Crack  $\geq 0.05$ " Only





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## Spar Cap Pylon Stud Hole



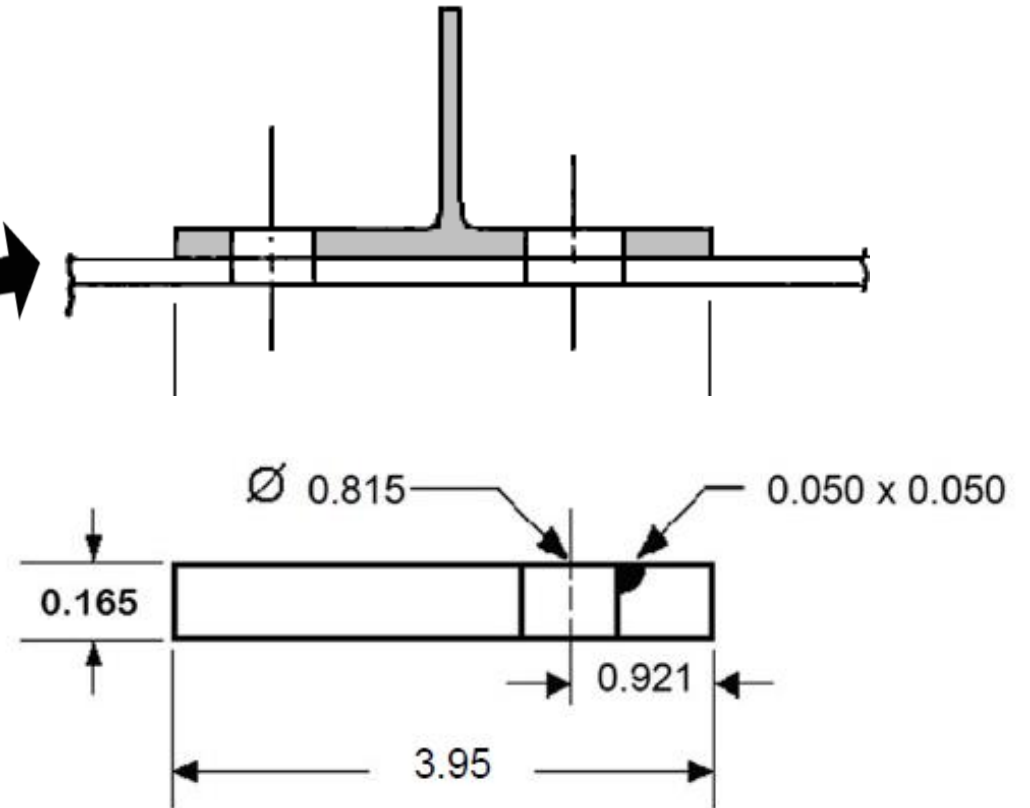
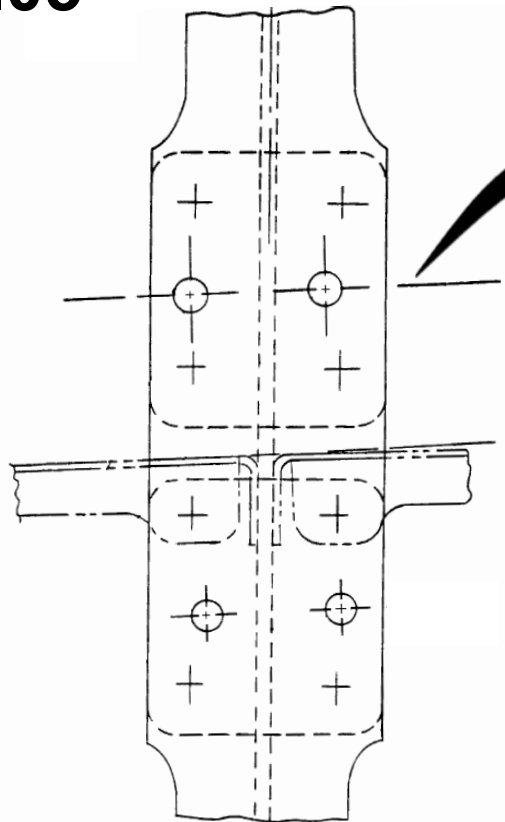
**Greatest Life Difference From 0.05" Example**

**A-10**



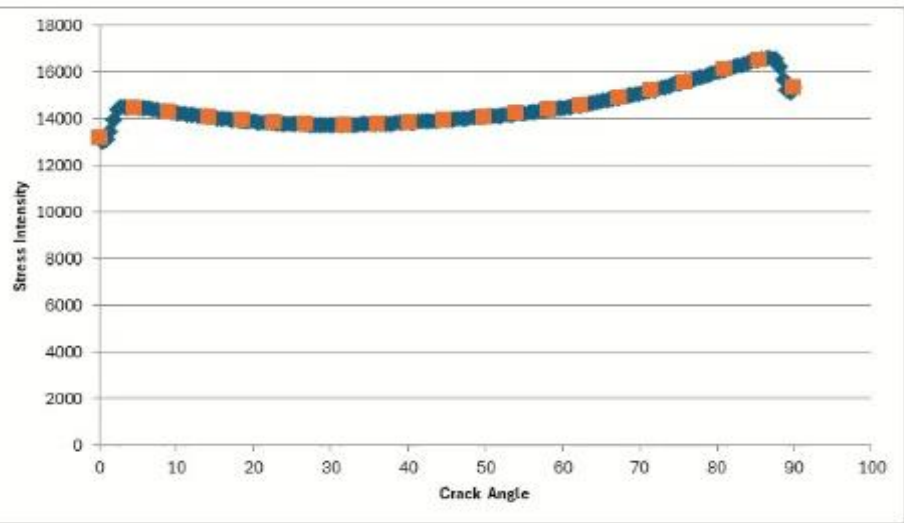
# Spar Cap Pylon Stud Hole (35T)

- -7.5% difference in life between finite width corrections
  - Greatest % difference from a 0.05" starting crack
- Max  $\sigma$ , SMF = 16.03 ksi (axial load only)
- Starting crack size: 0.05"
- 2024-T3511



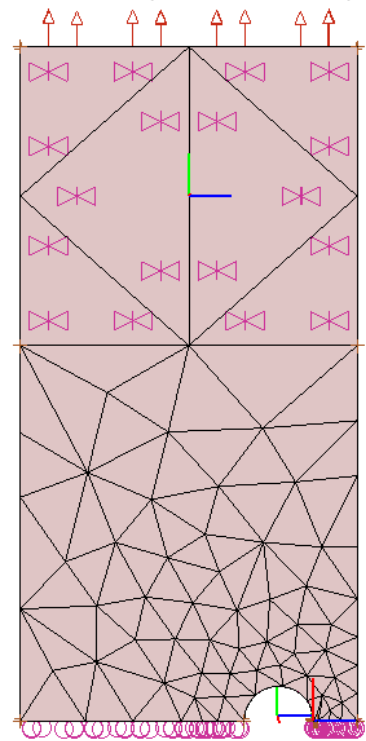
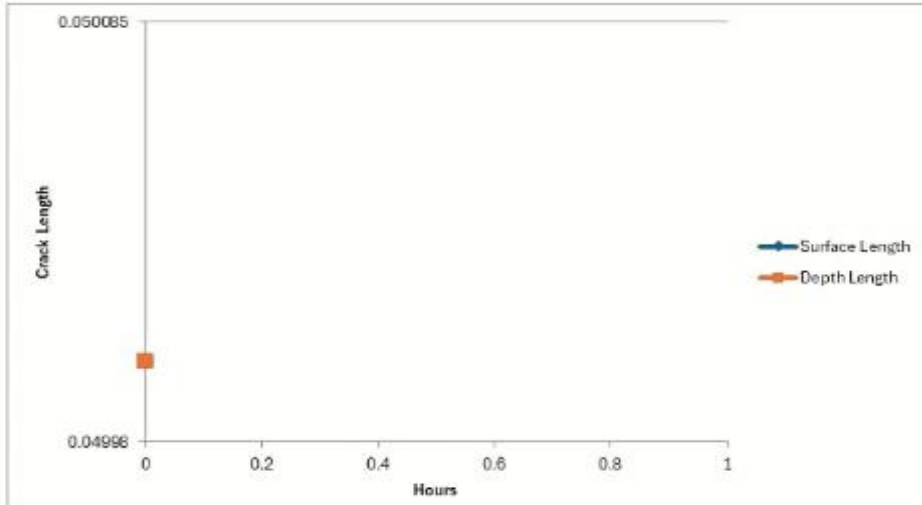
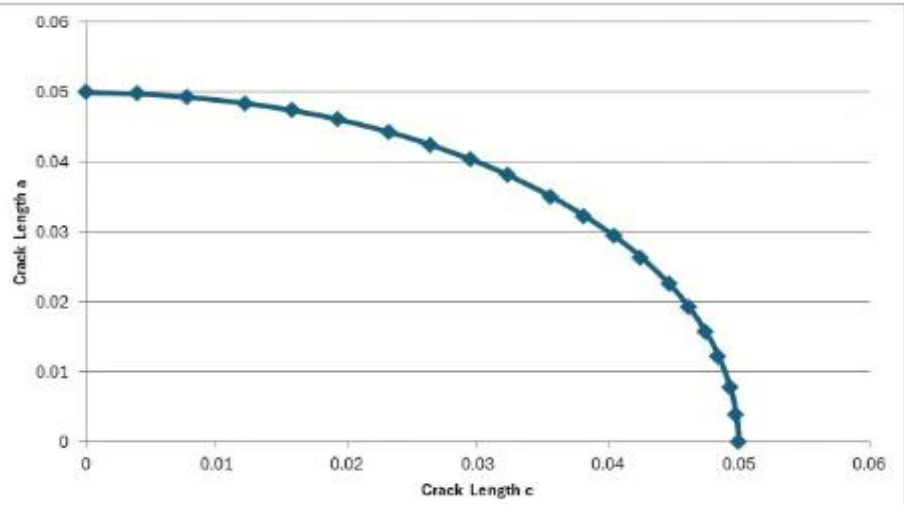


# 35T BAMpF Results



Diam			8.1500e-01
EdgeDist			9.2100e-01
Em			1.0300e+07
GripHeight	Height of hy...		3.5000e+00
Height		W..	7.9000e+00
PointsCrack1			2.1000e+01
Stress			1.6030e+04
Thickness			1.6500e-01
v			3.3000e-01
Width			3.9500e+00

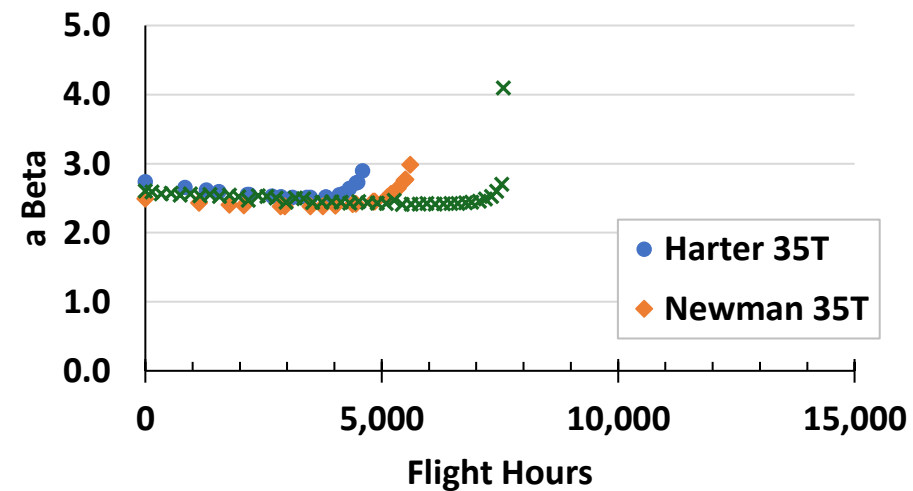
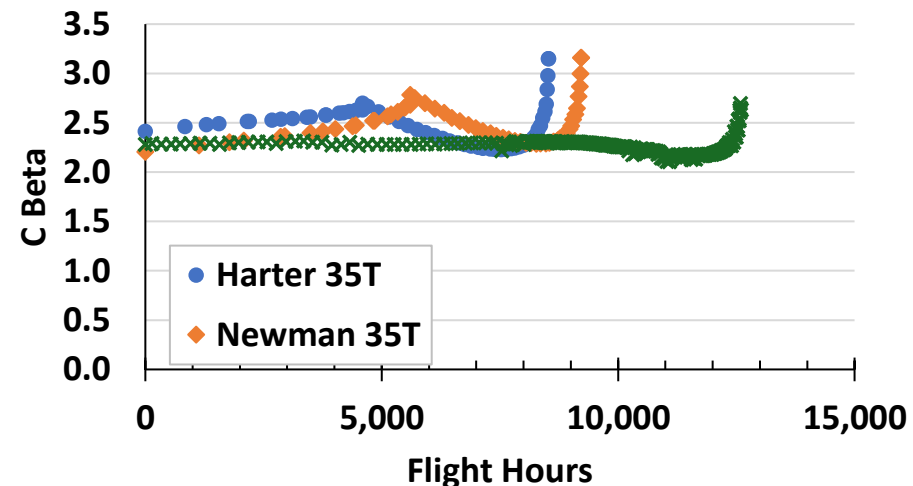
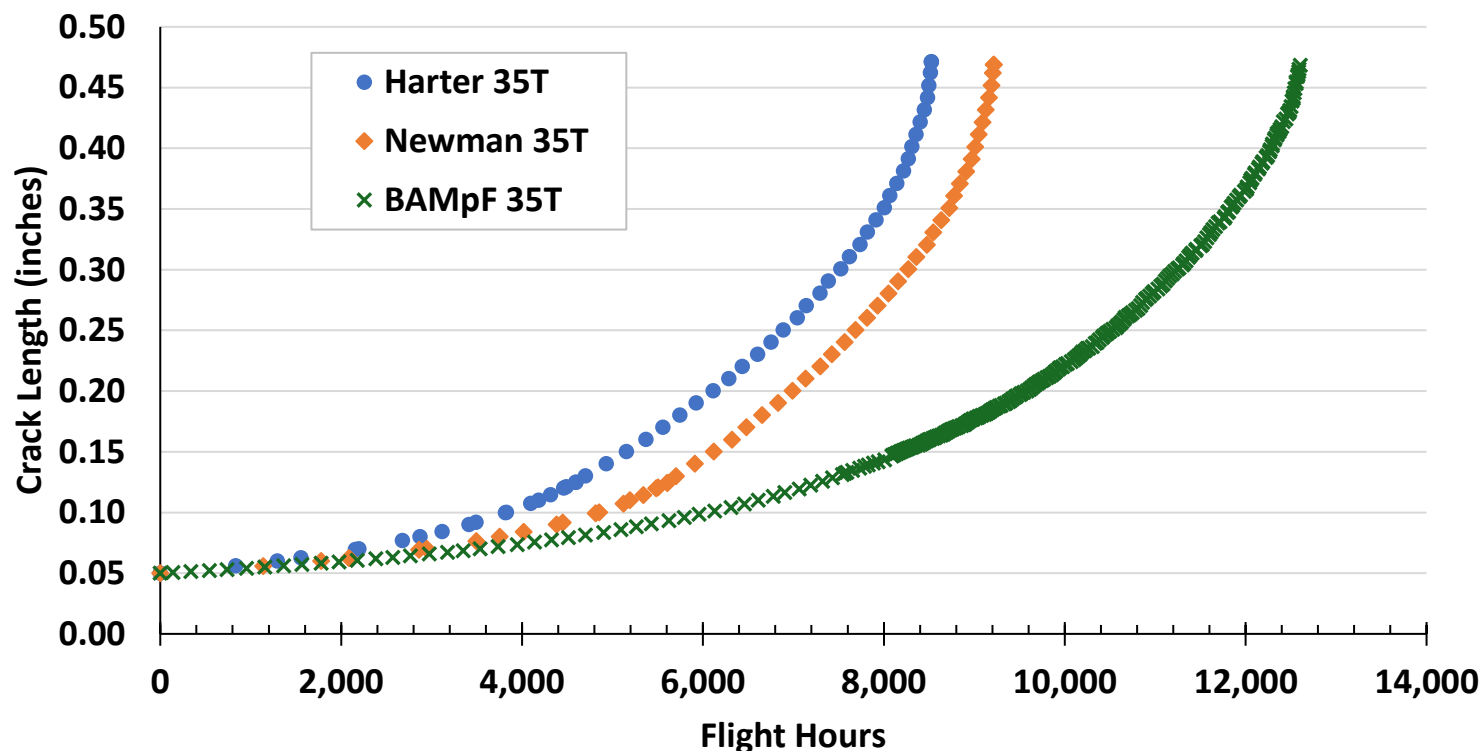
## Iteration 0





# Spar Cap Pylon Stud Hole (35T)

- -7.5% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 16.03 ksi (axial load only)
- Starting crack size: 0.05"
- $W=3.95''$ ,  $t=0.165''$ ,  $D=0.815''$ ,  $e/D=1.13$

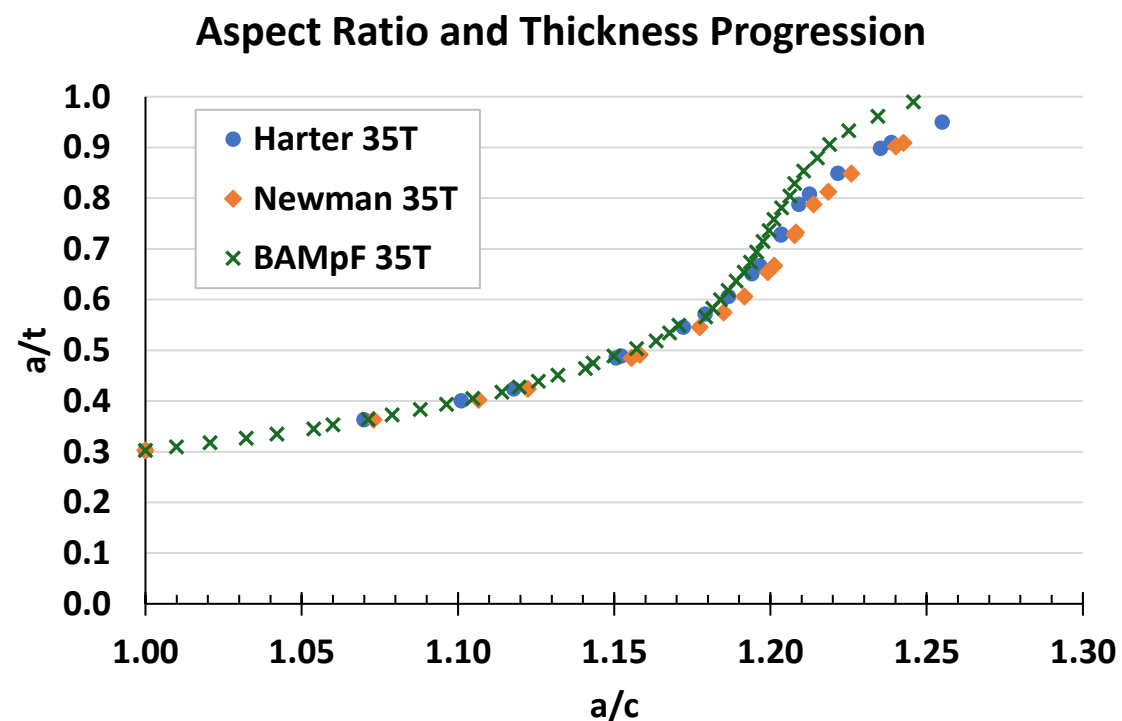
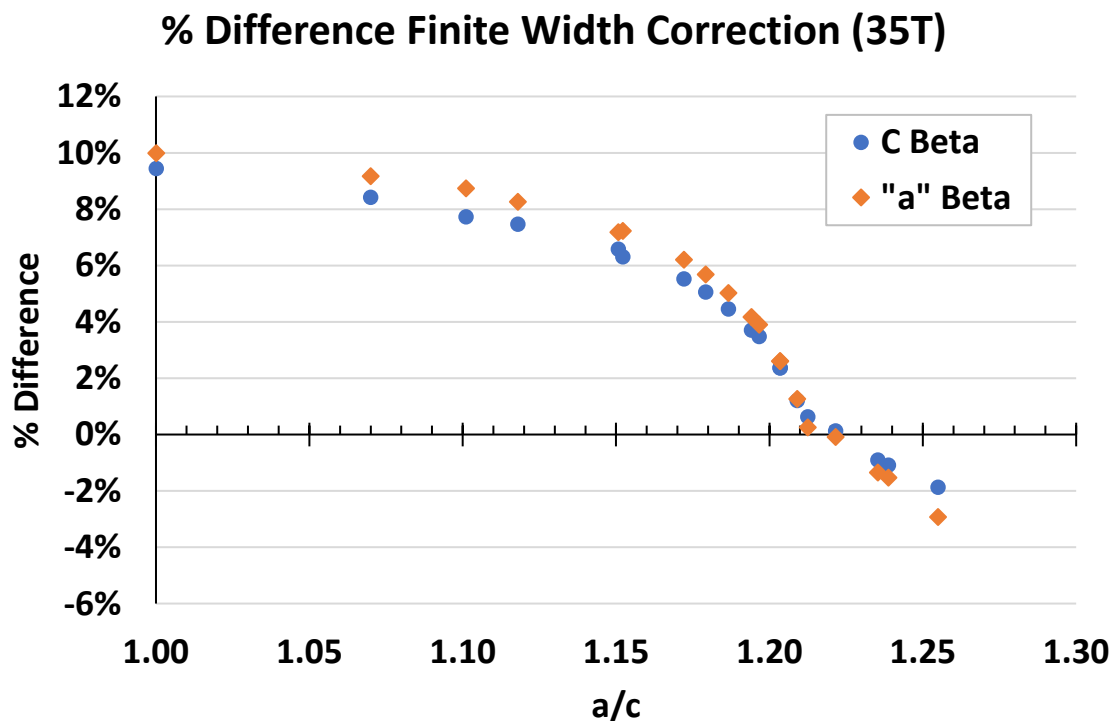






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# Front Spar Web Access Panel Doubler



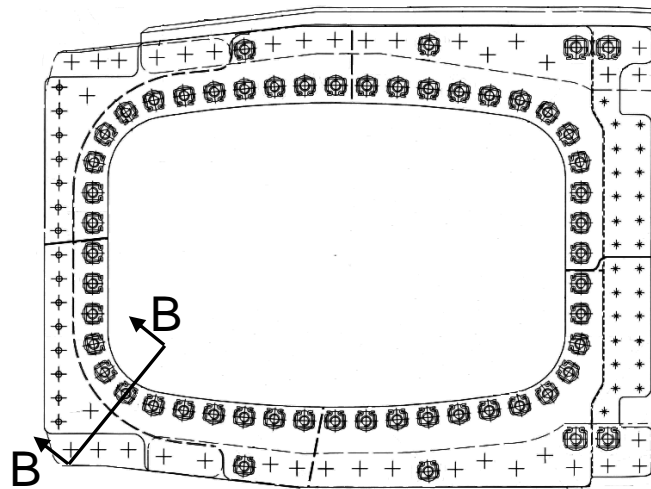
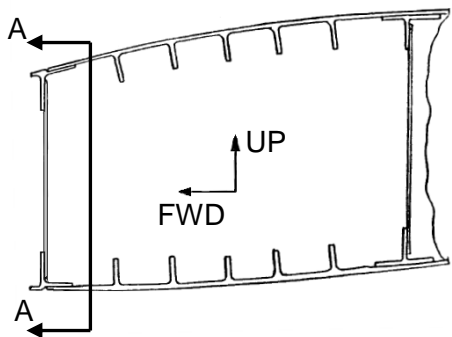
**Greatest Life Difference Example (0.005" Starting Crack)**

**A-10**

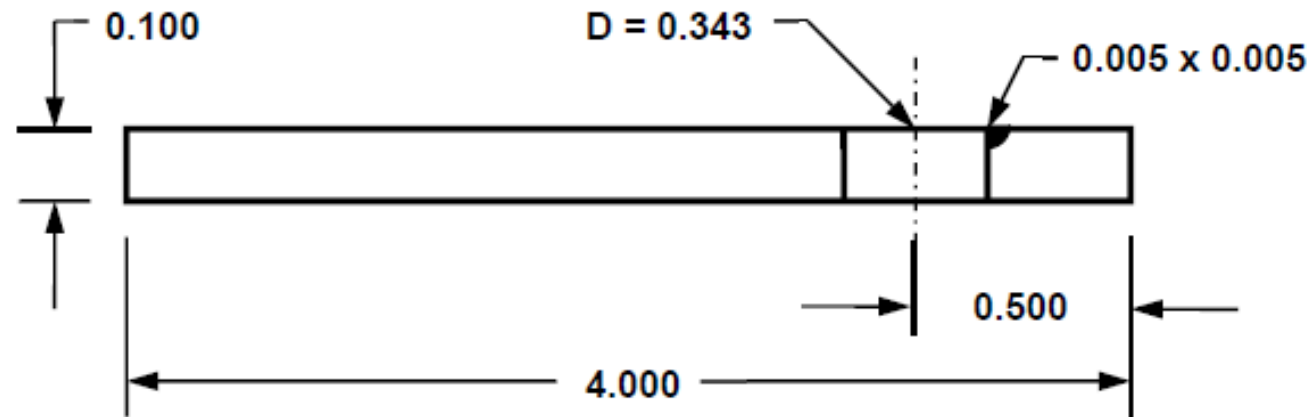


# Front Spar Web Access Panel Doubler (85RT)

- -11.71% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 32.057 ksi (Nutplate hole, i.e. no load transfer)
- IFS = 0.005"
- 2024-T3



SECTION A-A  
(LOOKING FWD)



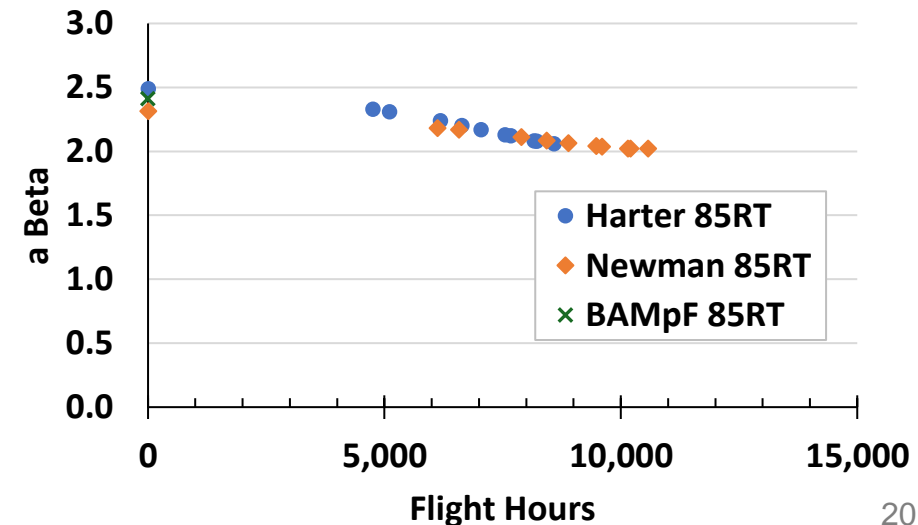
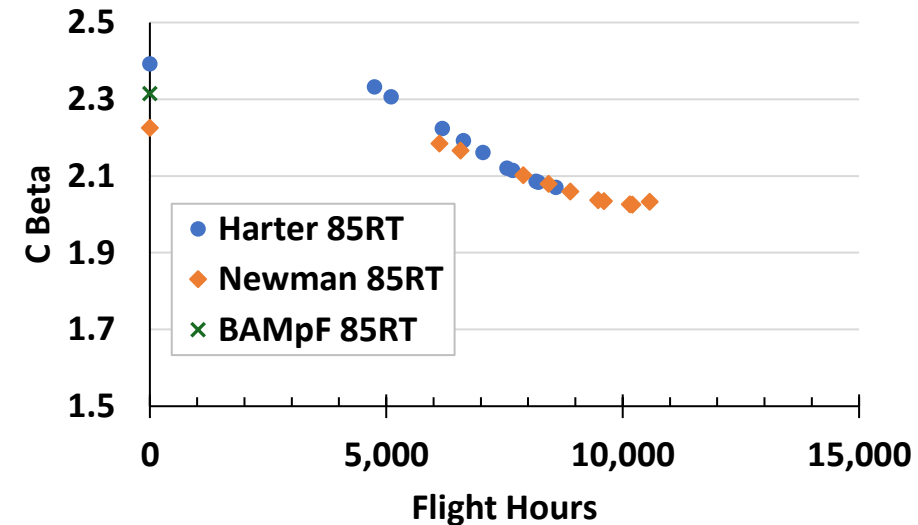
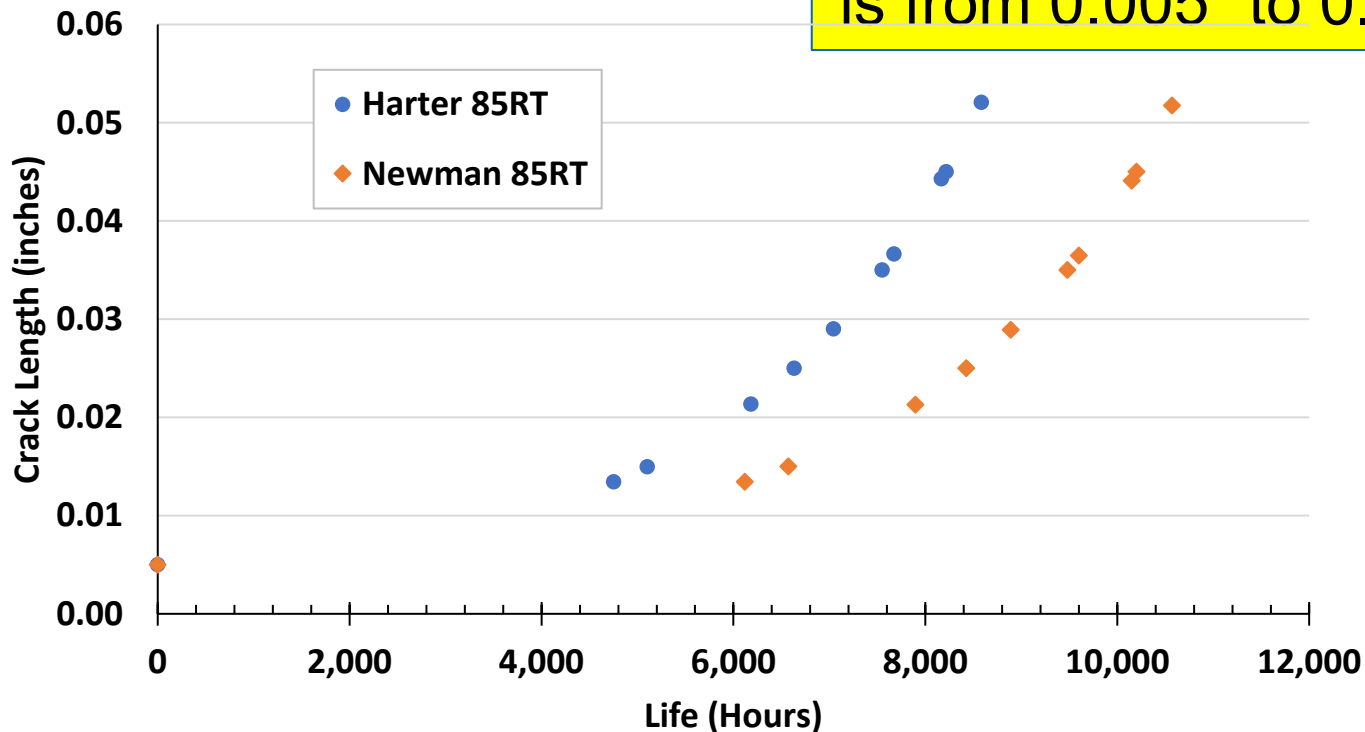
SECTION B-B



# Front Spar Web Access Panel Doubler (85RT)

- -11.71% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 32.057 ksi (TSF = 1)
- $W=4''$ ,  $t=0.1''$ ,  $D=0.343''$ ,  $e/D=1.46$
- IFS = **0.005''**

95% of life difference is from 0.005'' to 0.05''

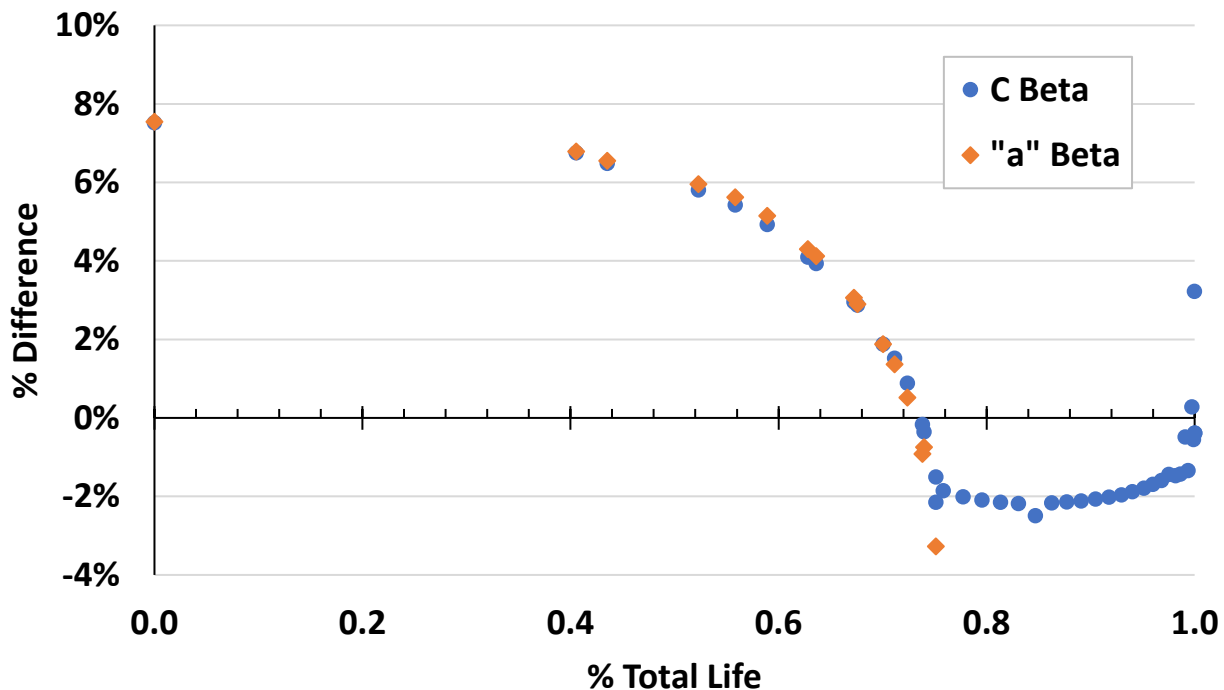




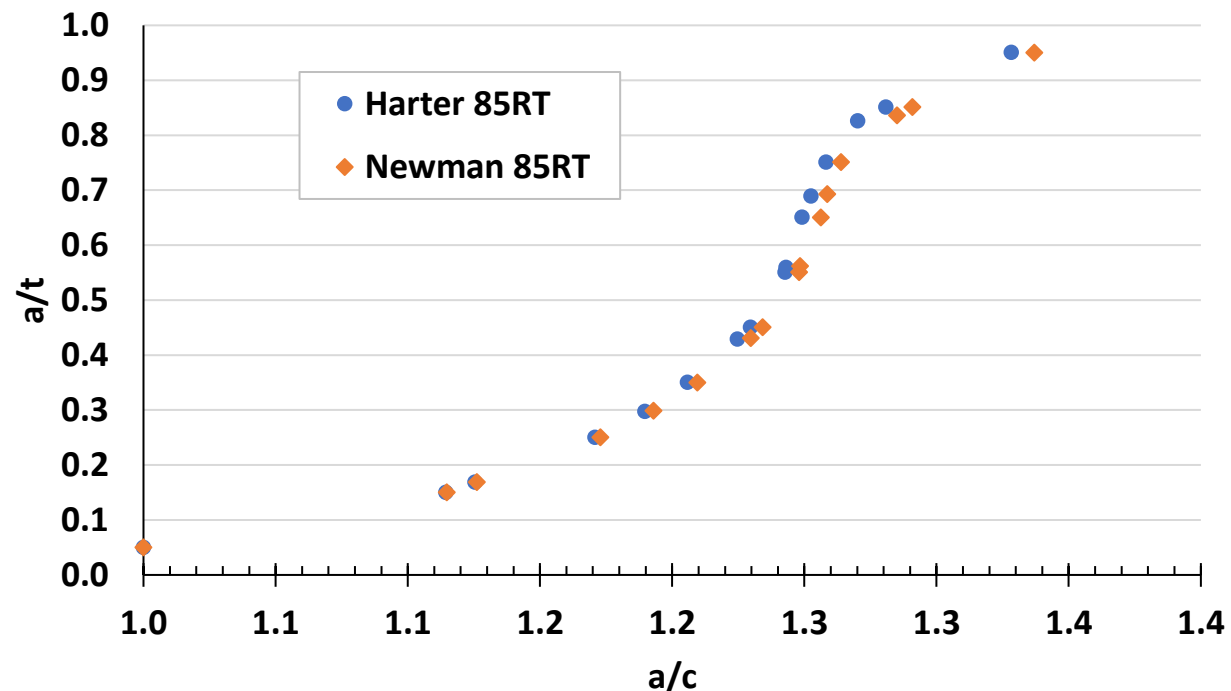
# Front Spar Web Access Panel Doubler (85RT)

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- Max  $\sigma$ , SMF = 32.057 ksi (TSF = 1)
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- IFS = **0.005''**

% Diff. Width Correction Betas (85RT)

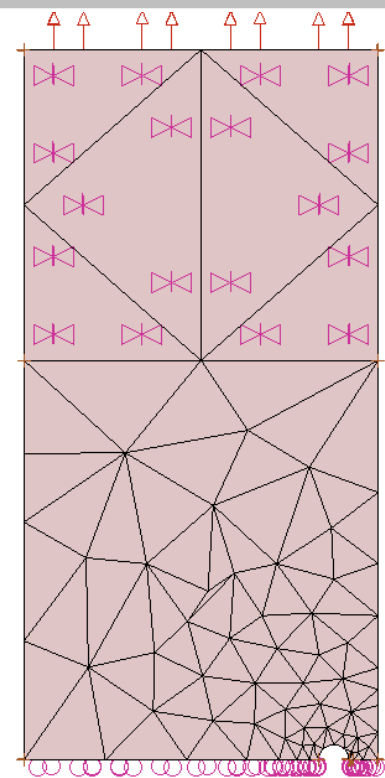
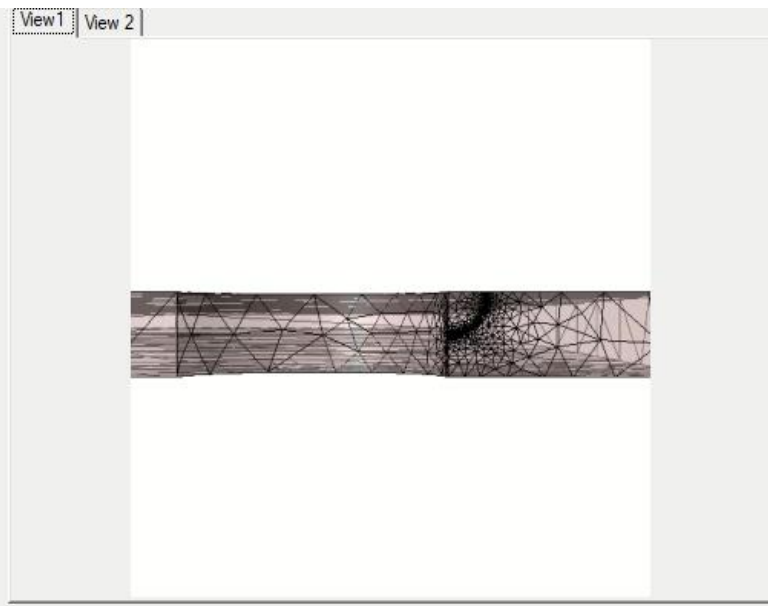
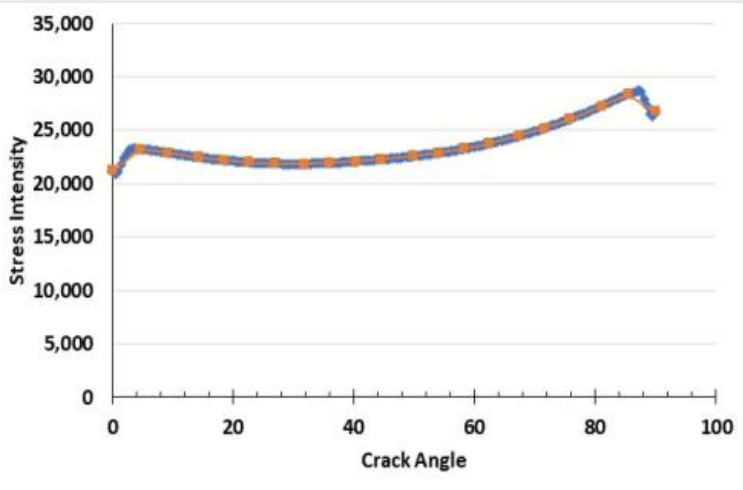


Aspect Ratio and Thickness Progression

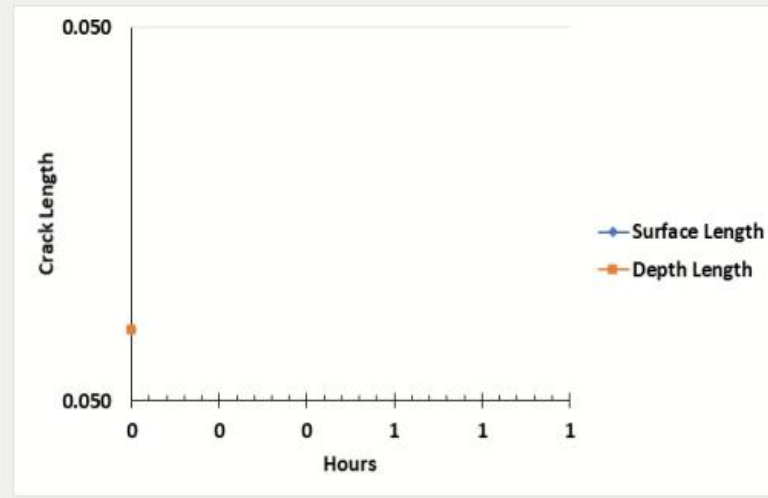
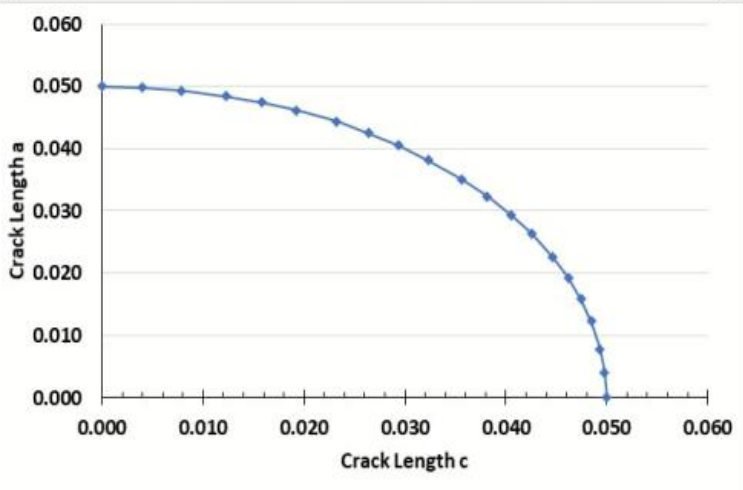




# 85RT BAMpF Results (from 0.05")



BAMpF: Viewing Iteration 1



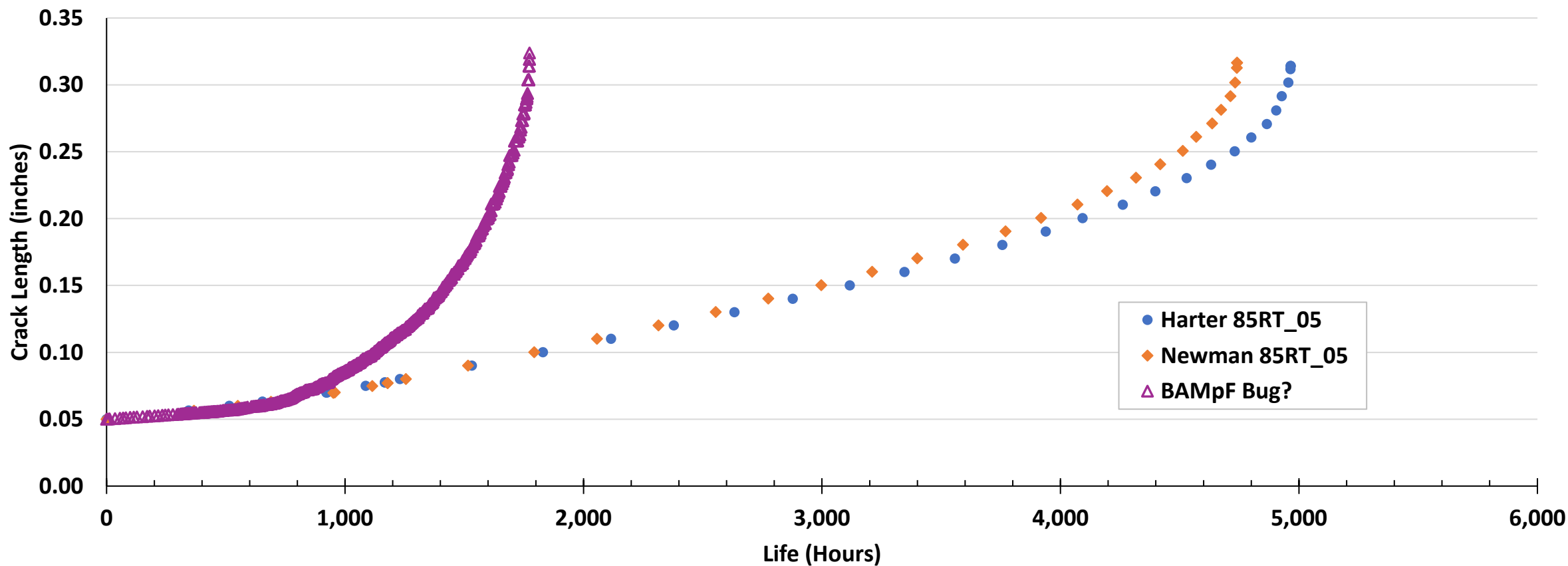
Diam		3.4300e-01
EdgeDist		5.0000e-01
Em		1.0300e+07
GripHeight	Height ...	3.5000e+00
Height		8.0000e+00
PointsCrack1		2.1000e+01
Stress		3.2057e+04
Thickness		1.0000e-01
v		3.3000e-01
Width		4.0000e+00





# Front Spar Web Access Panel Doubler (85RT)

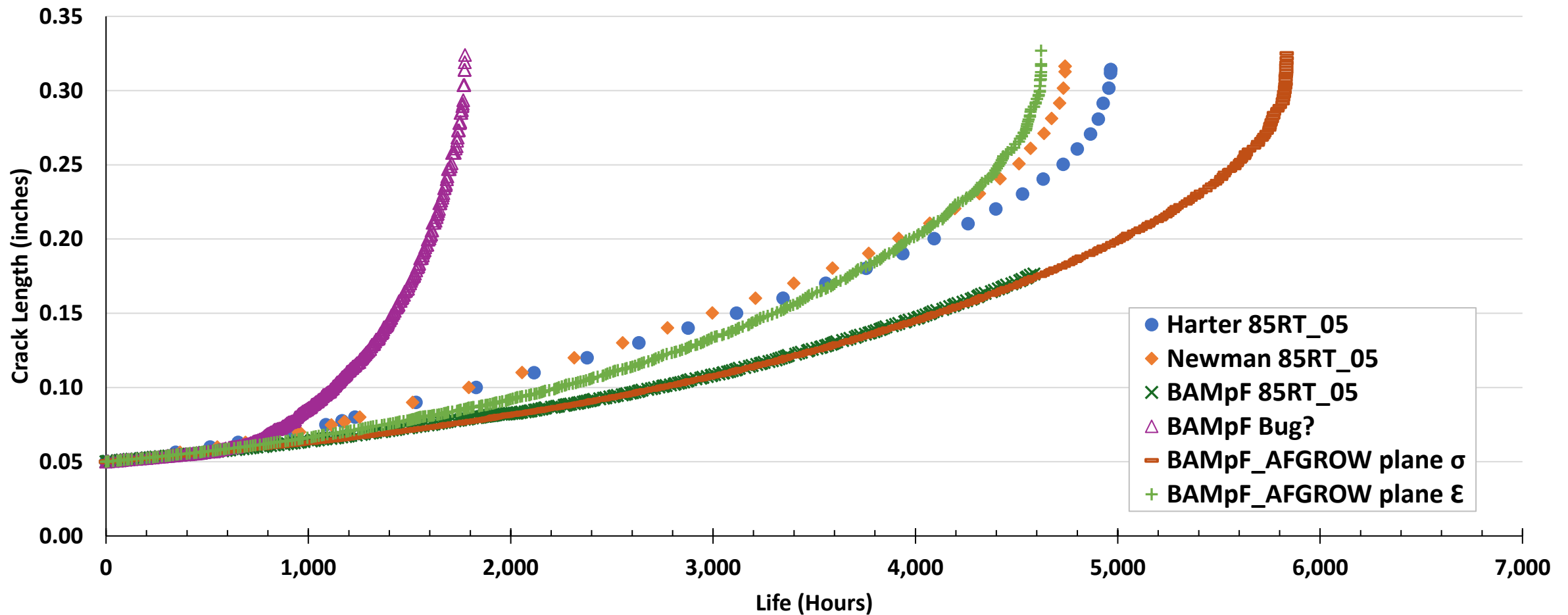
- -11.71% difference in life between finite width corrections
- SMF = 32.057 ksi (TSF = 1),  $W=4''$ ,  $t=0.1''$ ,  $D=0.343''$ ,  $e/D=1.46$
- IFS = **0.05''**





# AFGROW Stress State

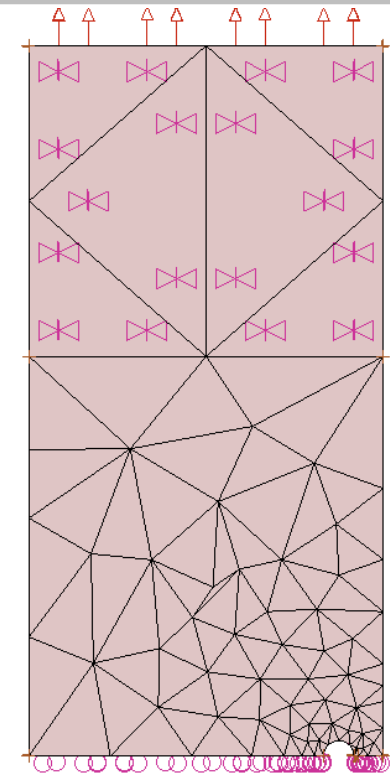
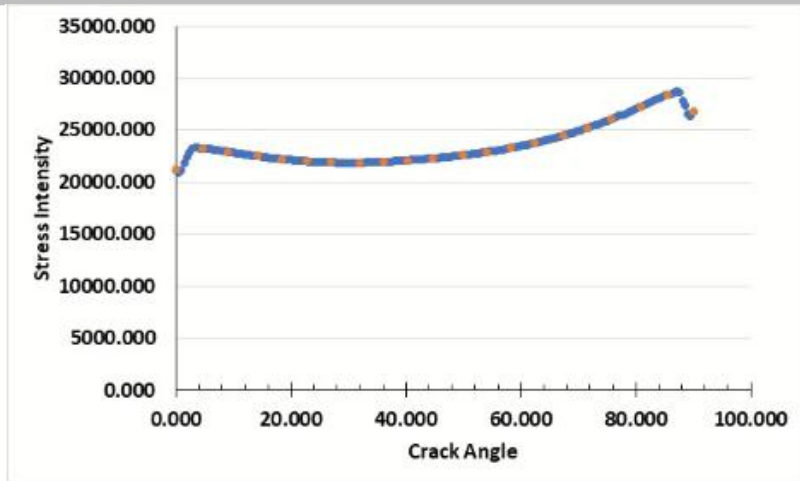
- Repeated analysis with AFGROW stress state set to 2 and 6 (plane stress and plane strain, respectively)



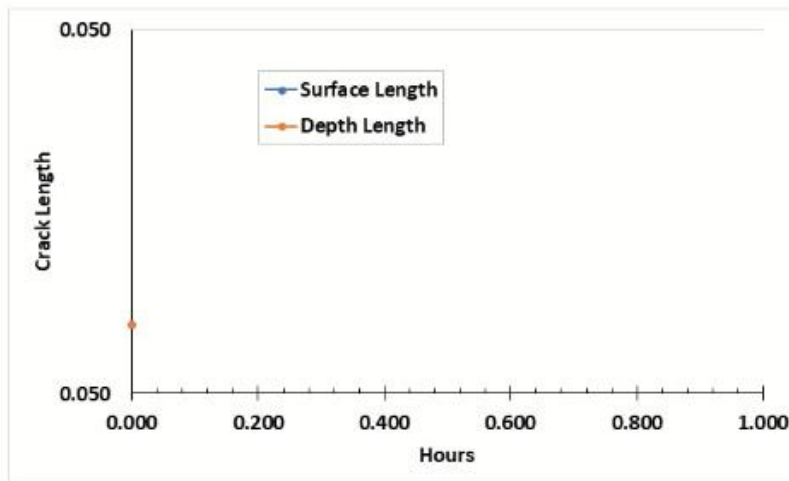
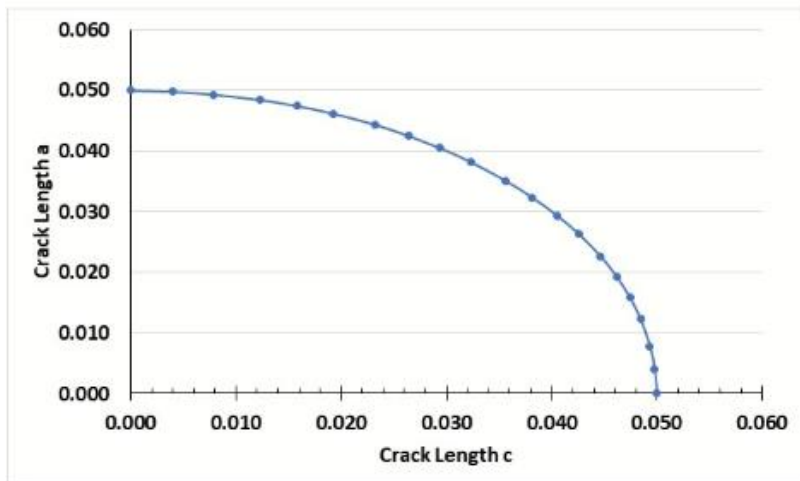




# BAMpF Results (Different BAMpF Version)



Iteration 0

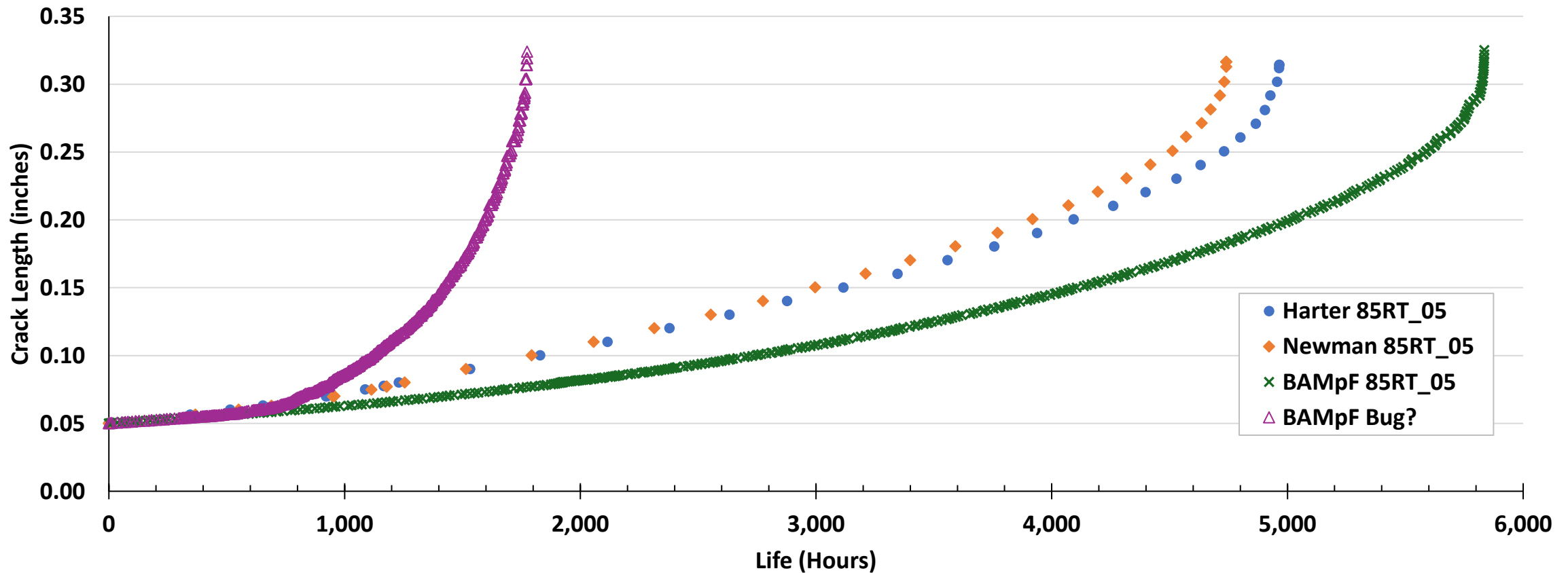


Diam		3.4300e-01
EdgeDist		5.0000e-01
Em		1.0300e+07
GripHeight	Height ...	3.5000e+00
Height		8.0000e+00
PointsCrack1		2.1000e+01
Stress		3.2057e+04
Thickness		1.0000e-01
v		3.3000e-01
Width		4.0000e+00



# Front Spar Web Access Panel Doubler (85RT)

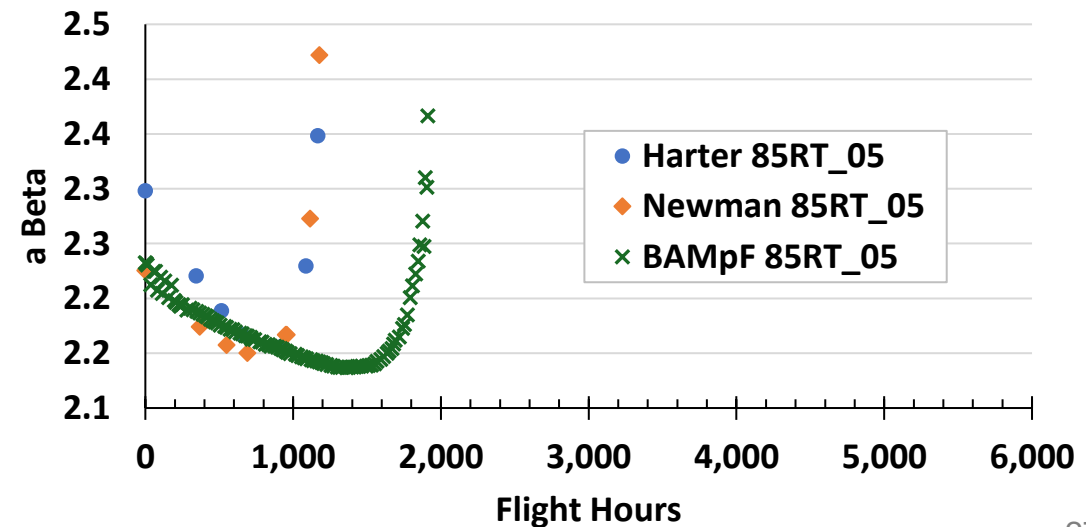
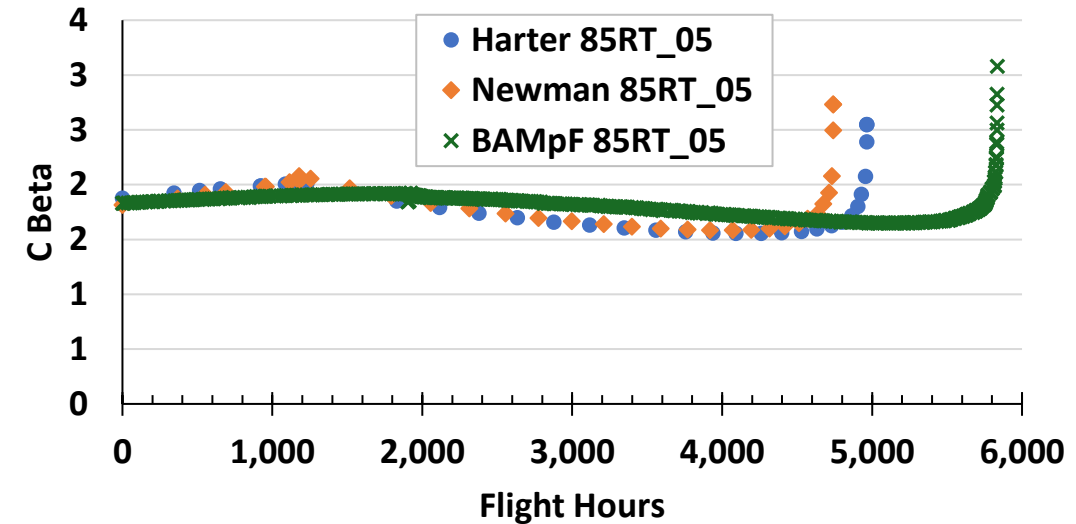
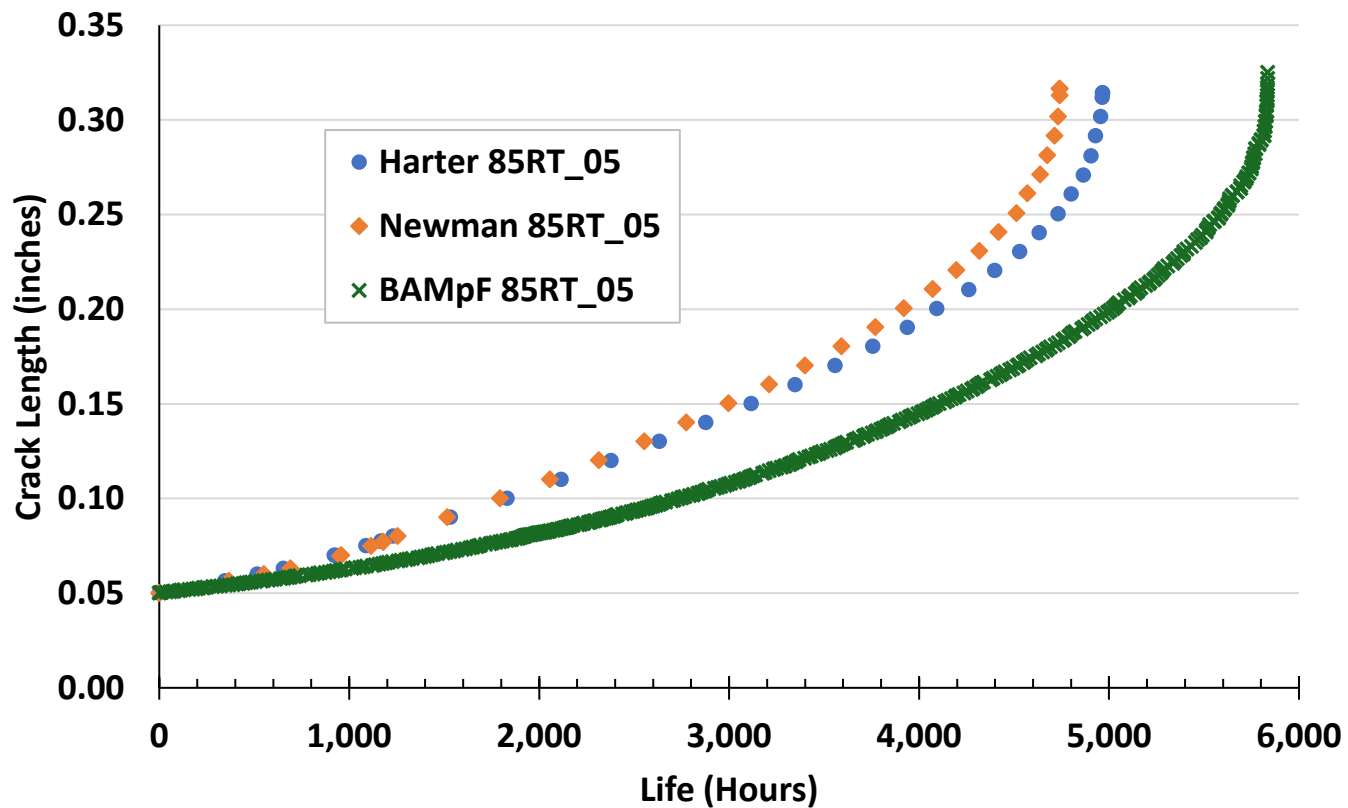
- -11.71% difference in life between finite width corrections
- SMF = 32.057 ksi (TSF = 1),  $W=4''$ ,  $t=0.1''$ ,  $D=0.343''$ ,  $e/D=1.46$
- IFS = **0.05''**





# Front Spar Web Access Panel Doubler (85RT)

- $W=4''$ ,  $t=0.1''$ ,  $D=0.343''$ ,  $e/D=1.46$
- Max  $\sigma$ , SMF = 32.057 ksi (TSF = 1)
- IFS = 0.05''

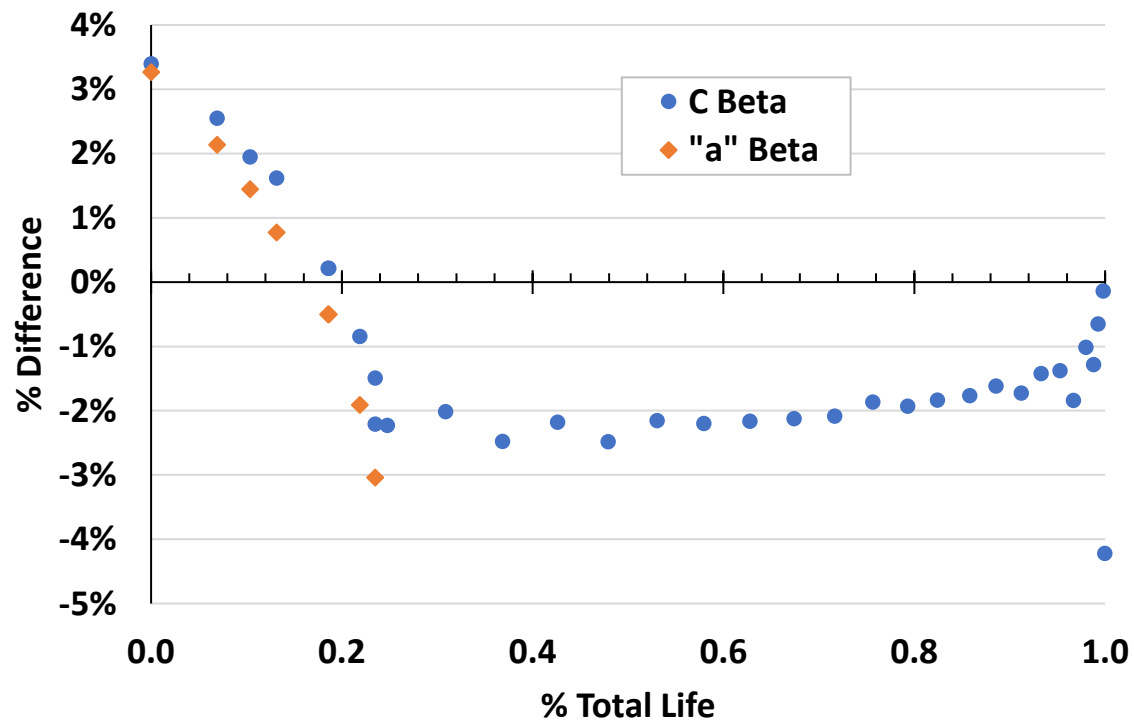




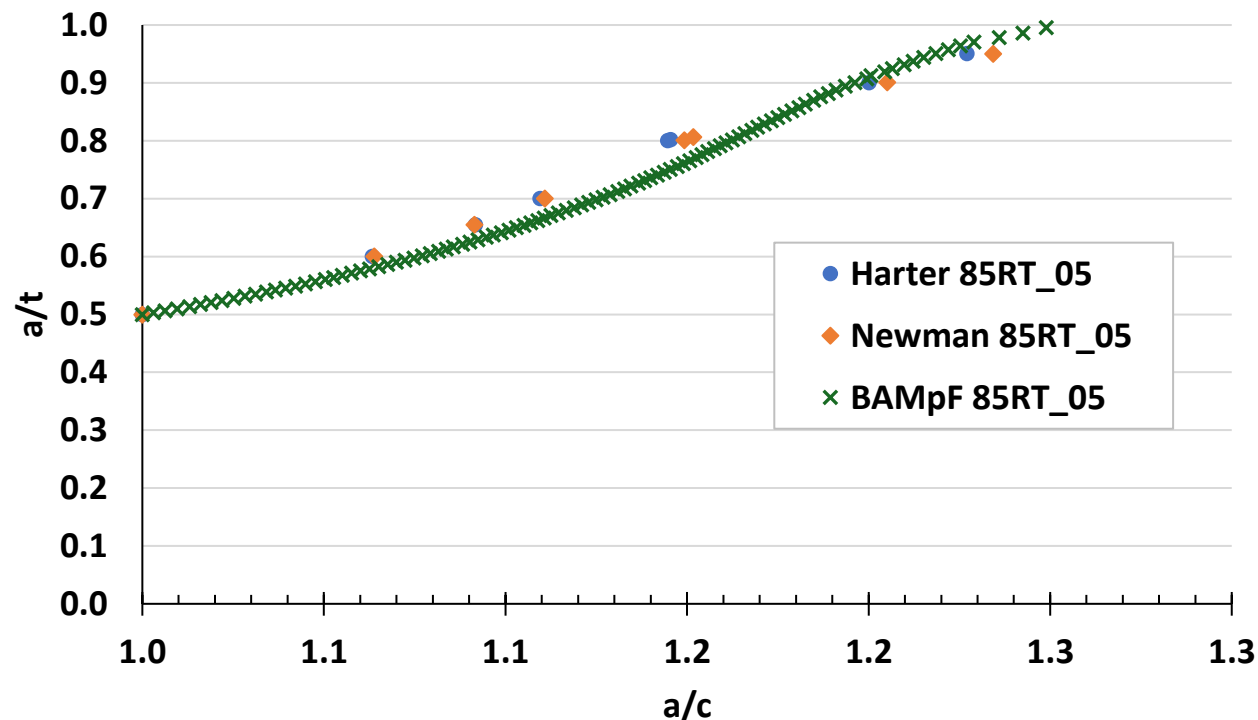
# Front Spar Web Access Panel Doubler (85RT)

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- IFS = **0.05''**

% Difference Finite Width Correction (85RT)



Aspect Ratio and Thickness Progression





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## Pylon Stud Hole



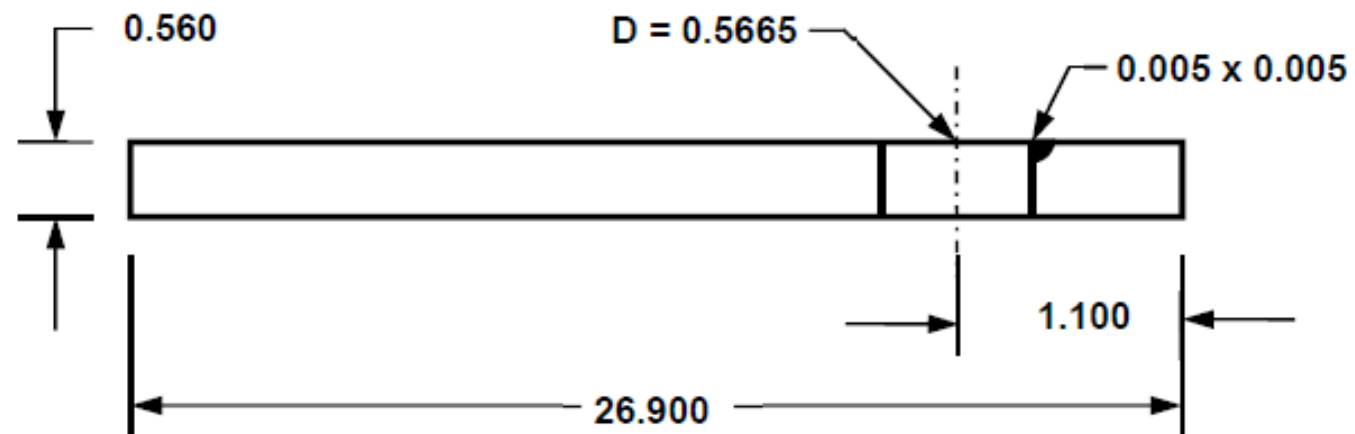
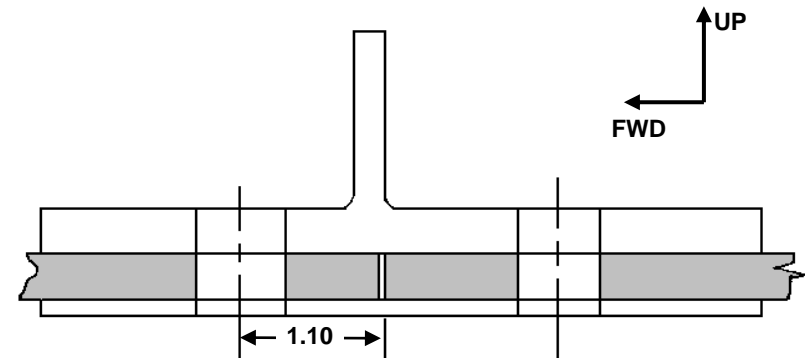
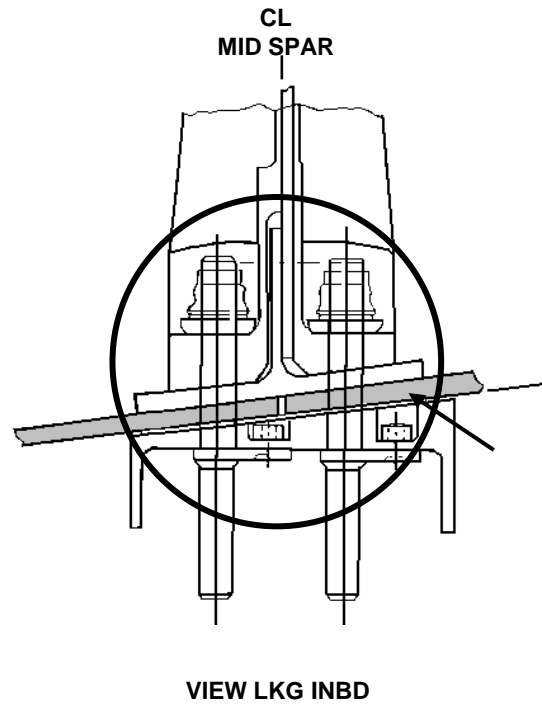
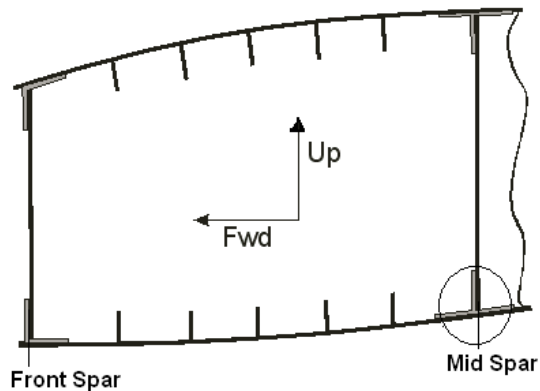
**Second Largest Difference in Life**

**A-10**



# Pylon Stud Hole (14T)

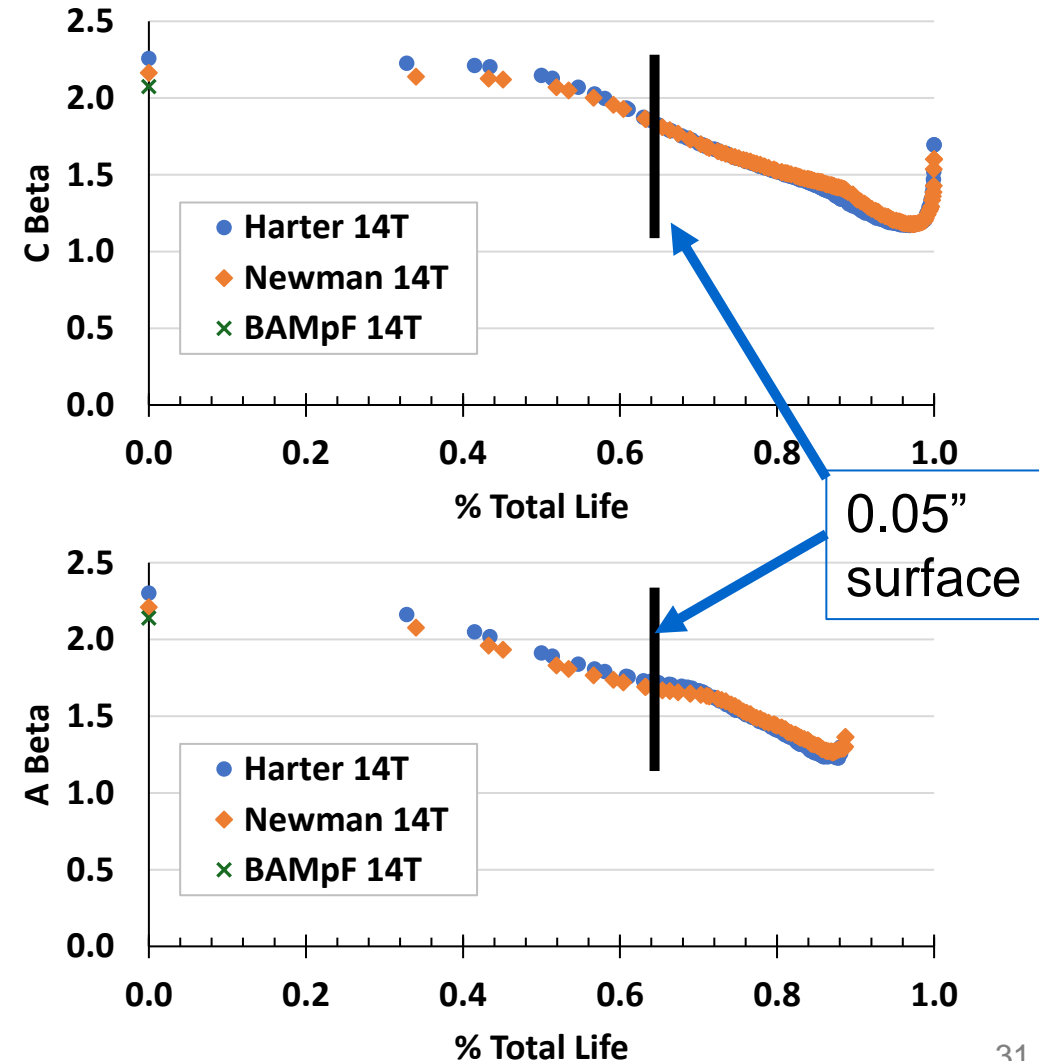
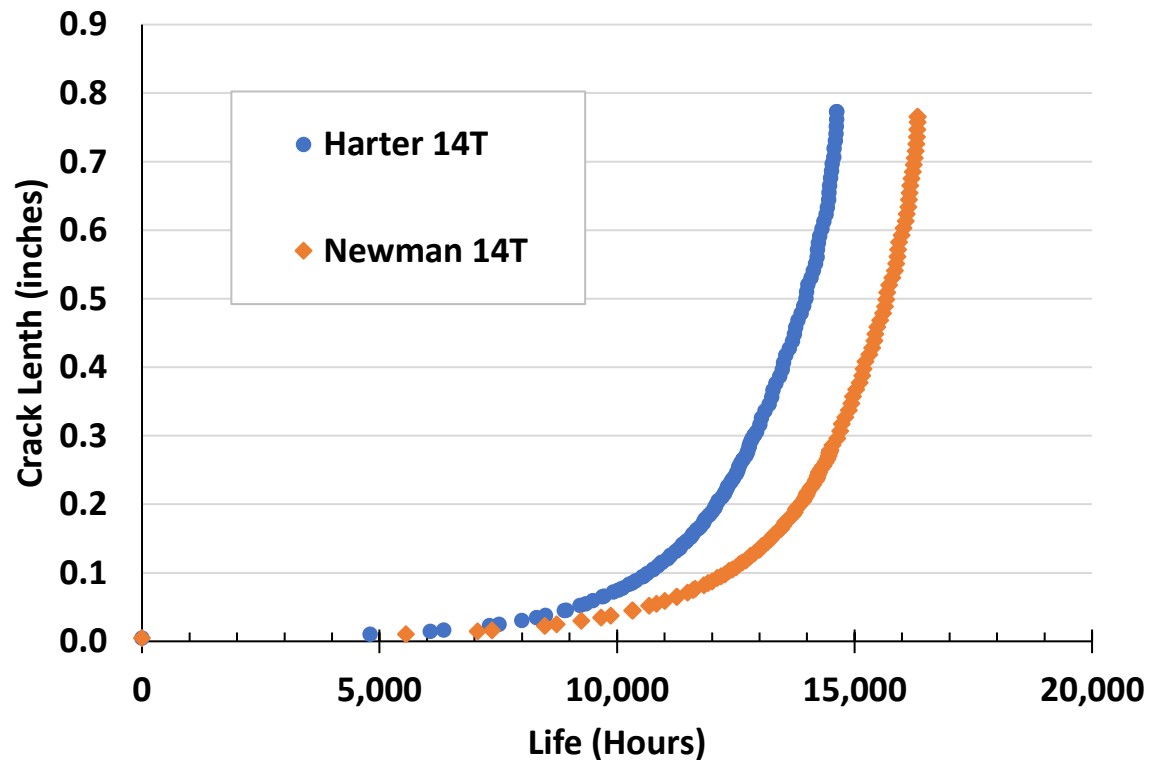
- -10.42% difference in life between finite width corrections
- SMF = 33.445 (Stud hole, i.e. no load transfer)
- IFS = 0.005"
- 2024-T3511





# Pylon Stud Hole (14T)

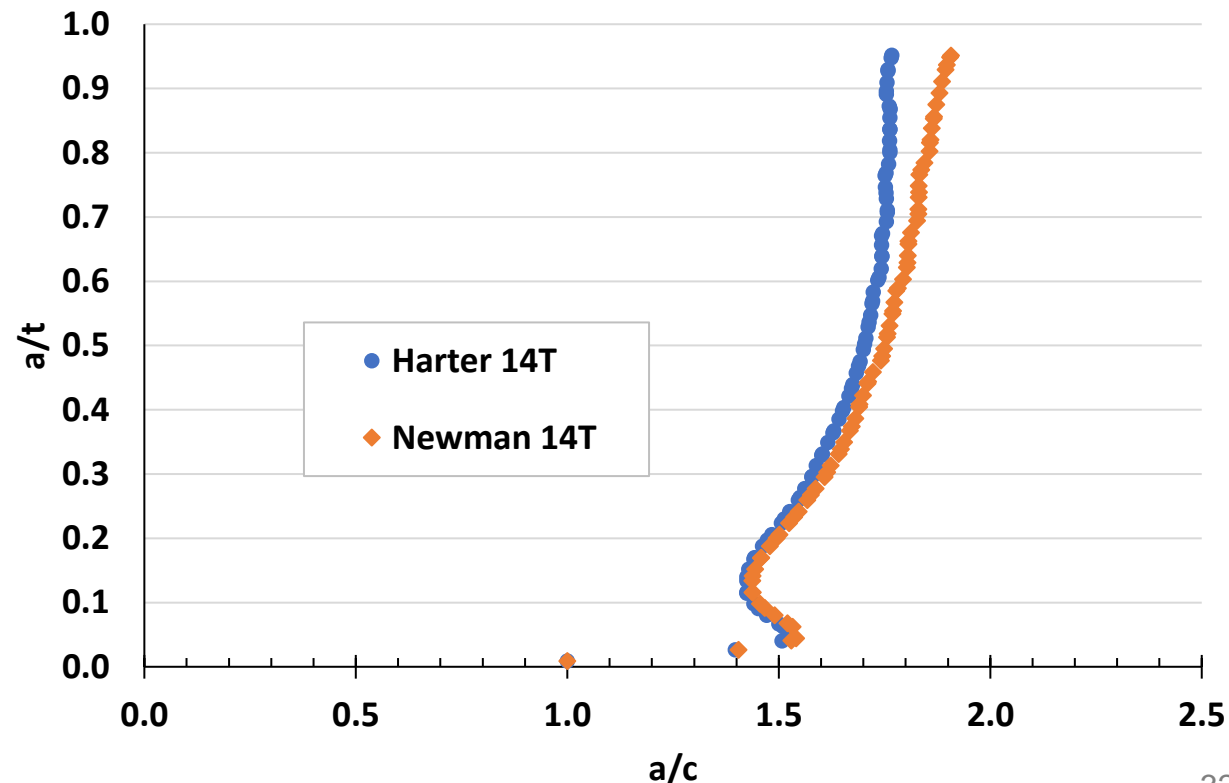
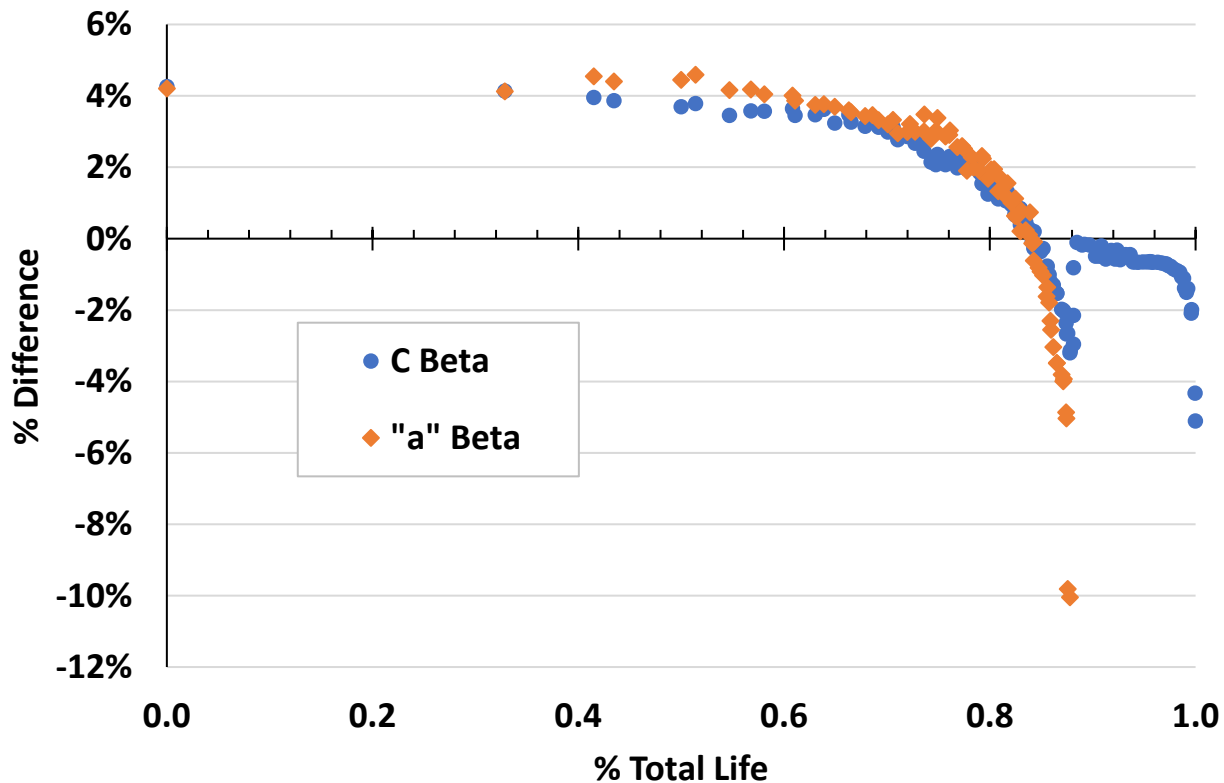
- -10.42% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 33.445 (TSF = 1)
- IFS = **0.005"**, 95% of life difference < 0.05"
- W=26.9", t=0.56", D=0.5665", e/D=1.94





# Pylon Stud Hole (14T)

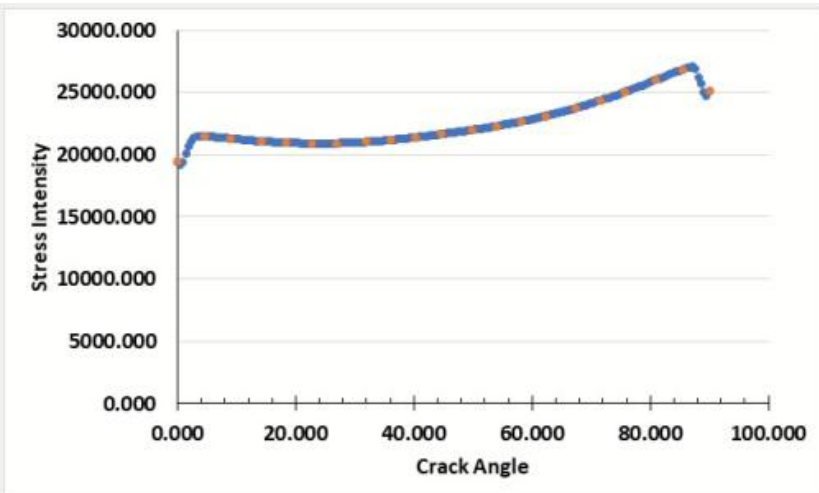
- -10.42% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 33.445 (TSF = 1)
- IFS = 0.005", 95% of life difference < 0.05"
- W=26.9", t=0.56", D=0.5665", e/D=1.94



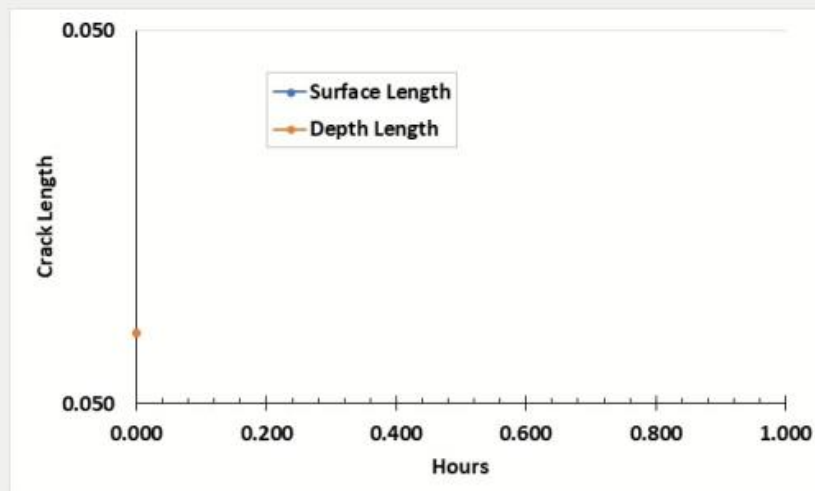
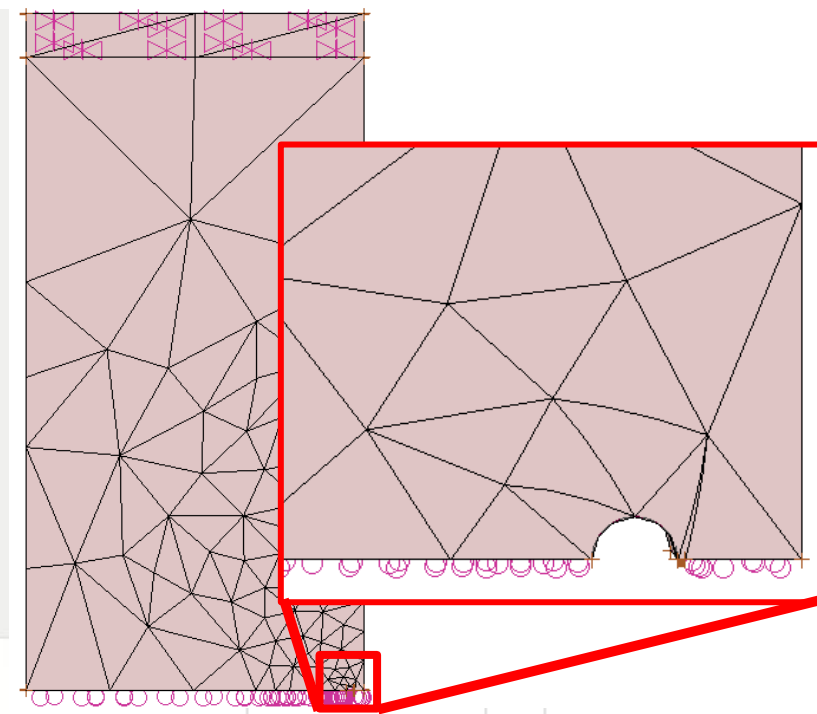
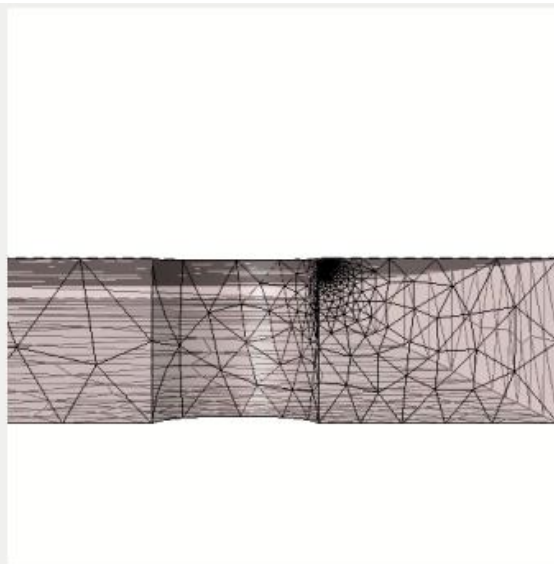
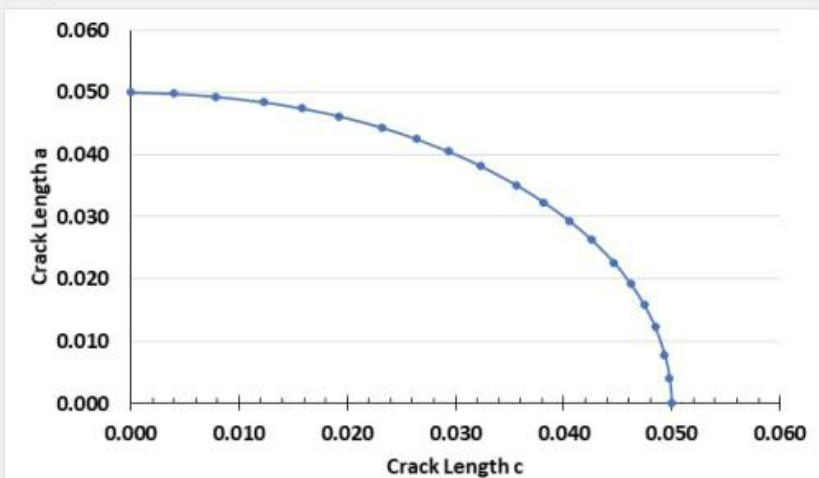
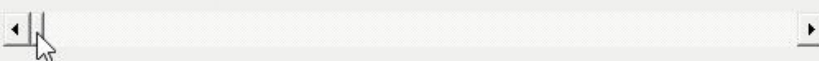




# 14T BAMpF Results



BAMpF: Viewing Iteration 1

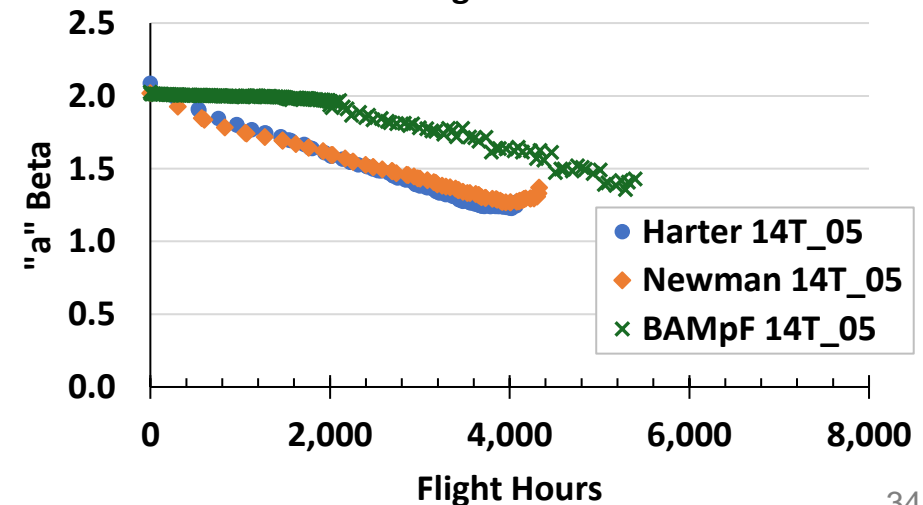
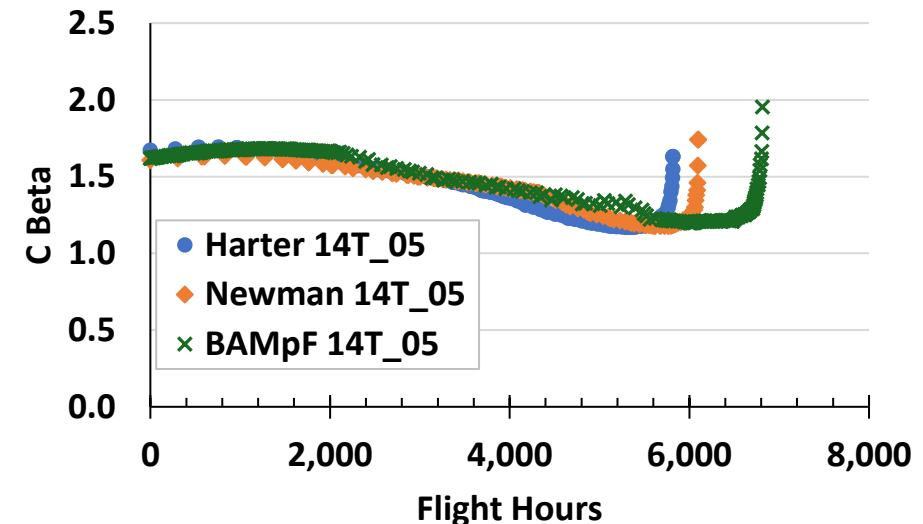
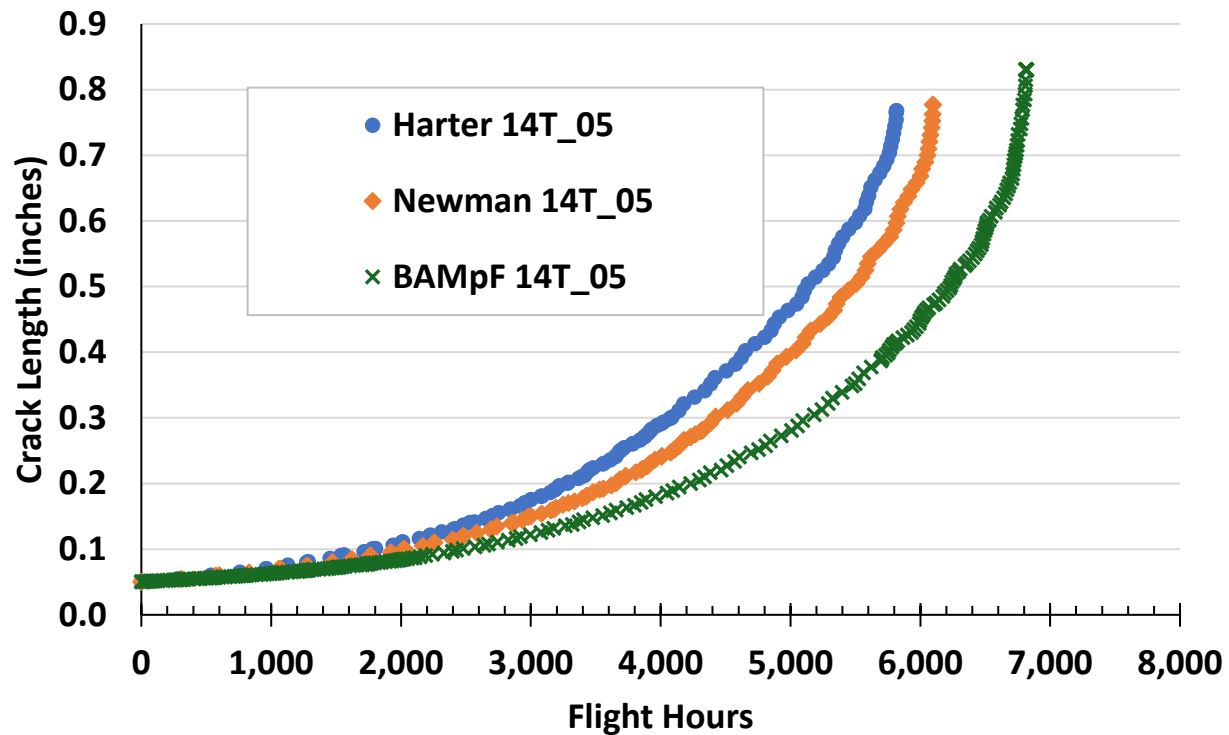


Diam		5.6650e-01
EdgeDist		1.1000e+00
Em		1.0300e+07
GripHeight	Height of hydr...	3.5000e+00
Height	W	5.3800e+01
PointsCrack1		2.1000e+01
Stress		3.3445e+04
Thickness		5.6000e-01
v		3.3000e-01
Width		2.6900e+01



# Pylon Stud Hole (14T)

- -10.42% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 33.445 (TSF = 1)
- $W=26.9''$ ,  $t=0.56''$ ,  $D=0.5665''$ ,  $e/D=1.94$
- IFS = **0.05''**

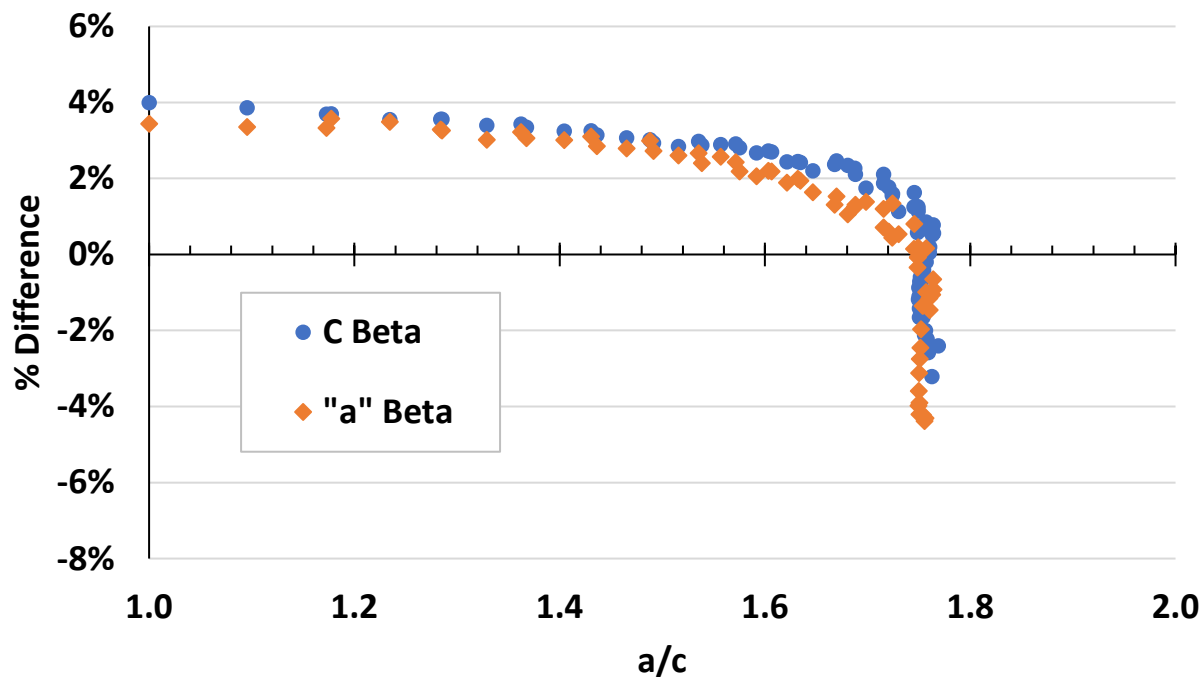




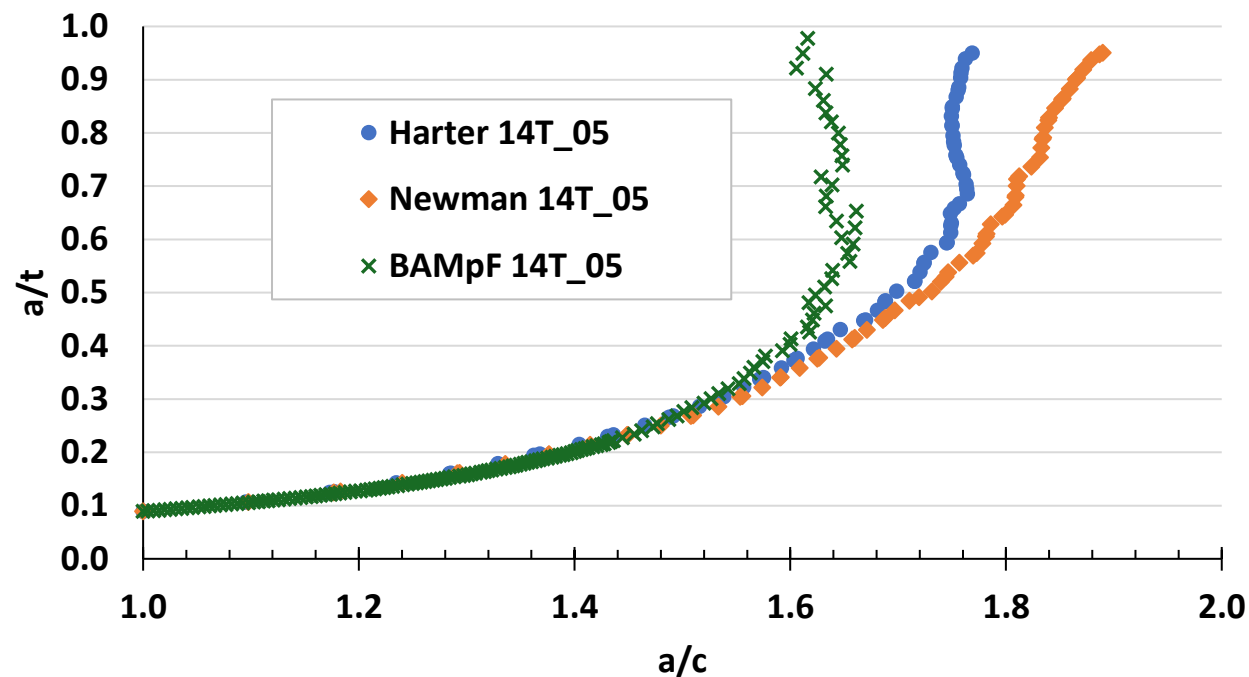
# Pylon Stud Hole (14T)

- -10.42% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 33.445 (TSF = 1)
- $W=26.9''$ ,  $t=0.56''$ ,  $D=0.5665''$ ,  $e/D=1.94$
- IFS = **0.05''**

% Difference Finite Width Correction (14T\_05)



% Diff. Harter - Newman (14T\_05)





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## Outer Wing, Lower Skin



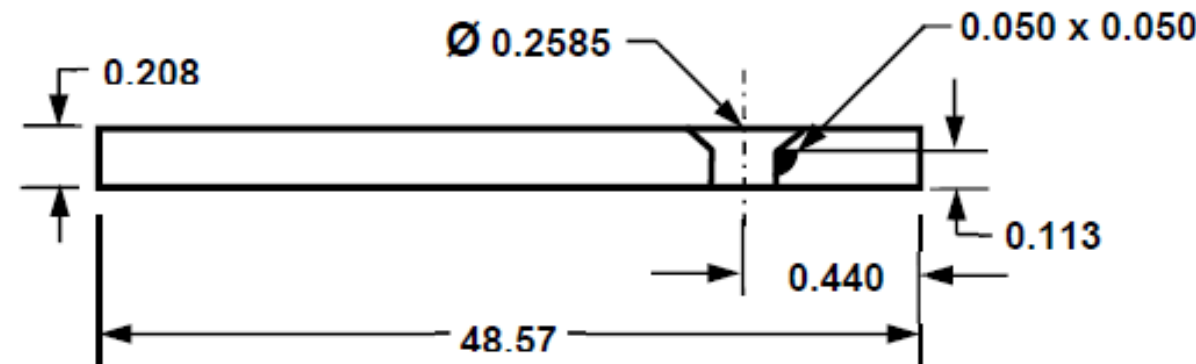
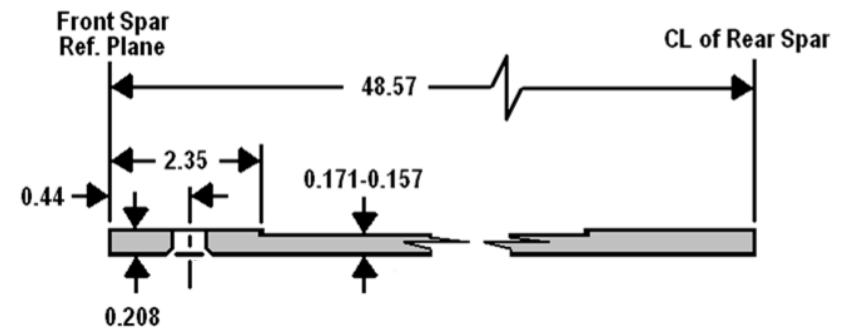
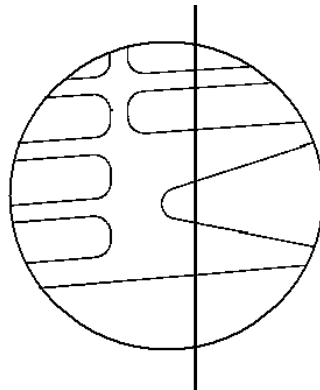
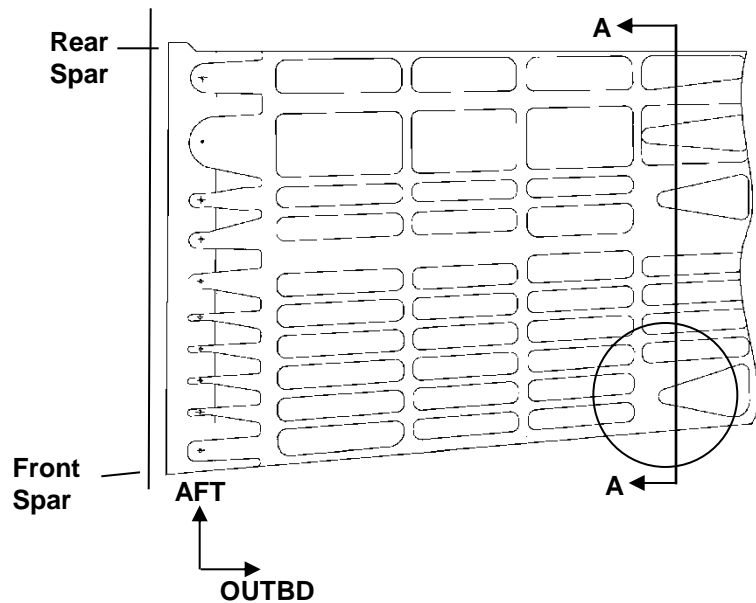
**Greatest Life Increase With Harter Correction**

**A-10**



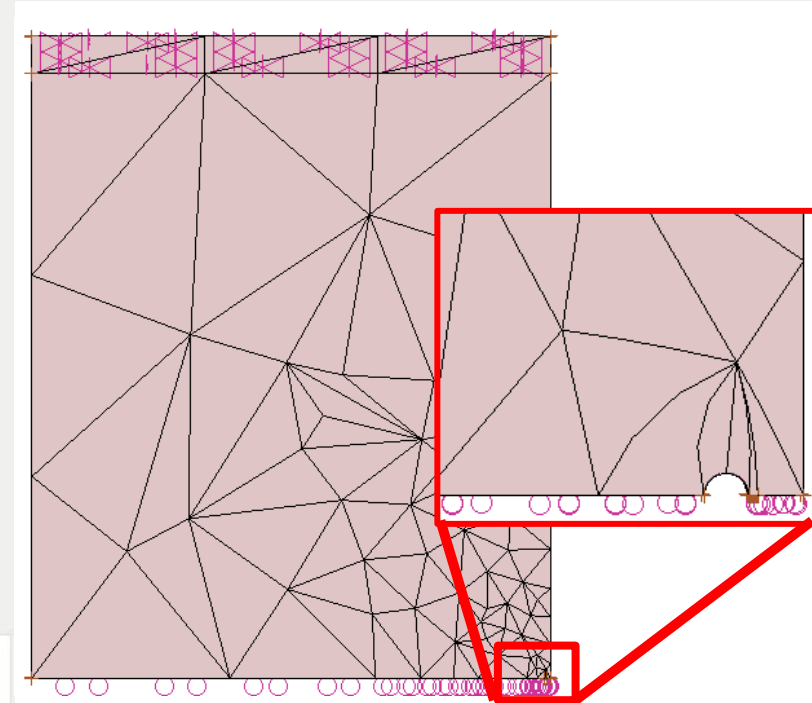
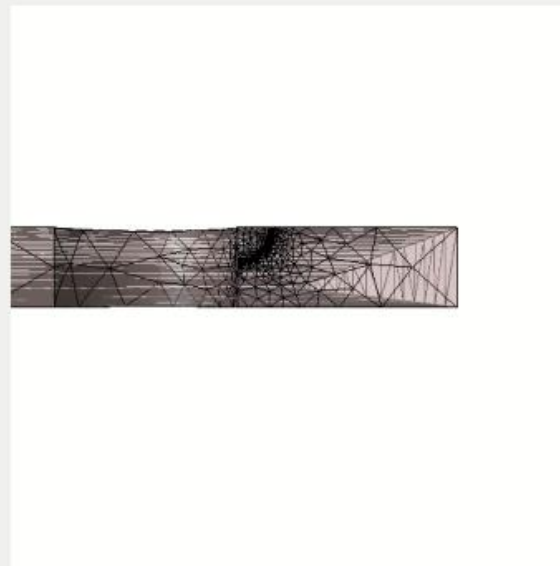
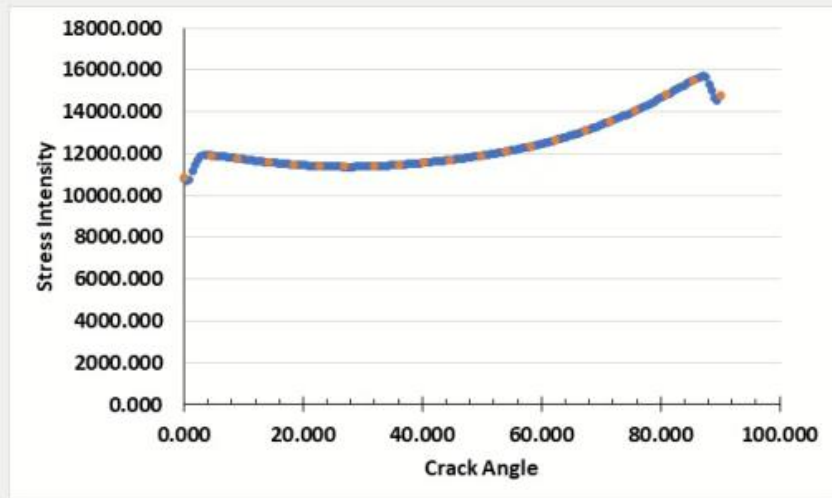
# Outer Wing, Lower Skin (63R)

- 2.93% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 19.142 ksi (TSF = 1)
- $W=48.57''$ ,  $t=0.208''$ ,  $D=0.2585''$ ,  $e/D=1.7$
- IFS = 0.05'''
- 2024-T351

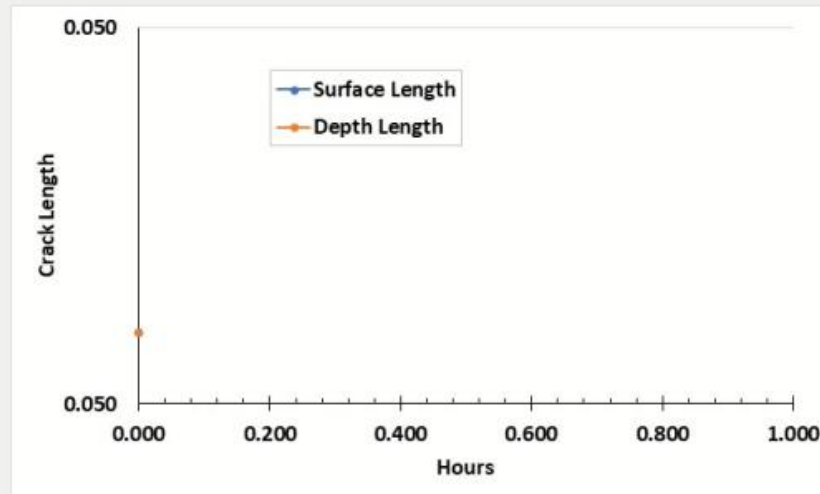
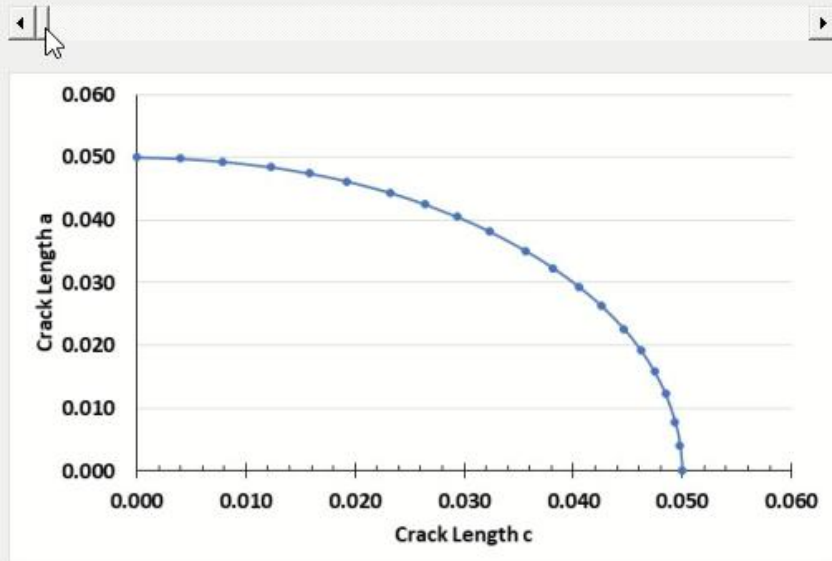




# 63R BAMpF Results



BAMpF: Viewing Iteration 1

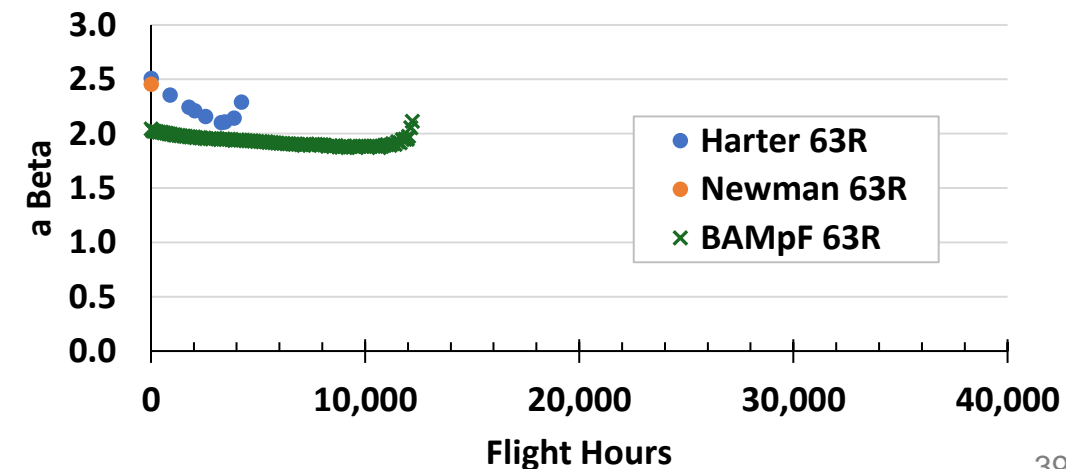
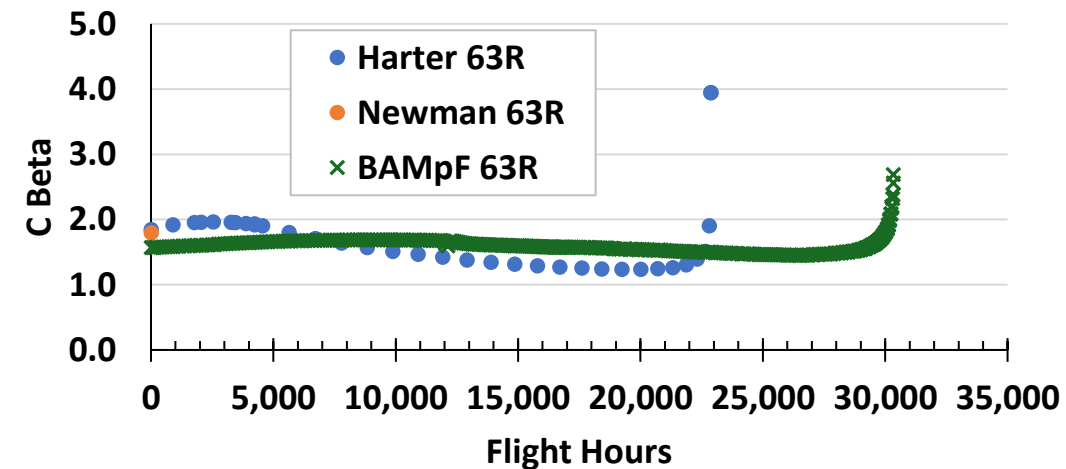
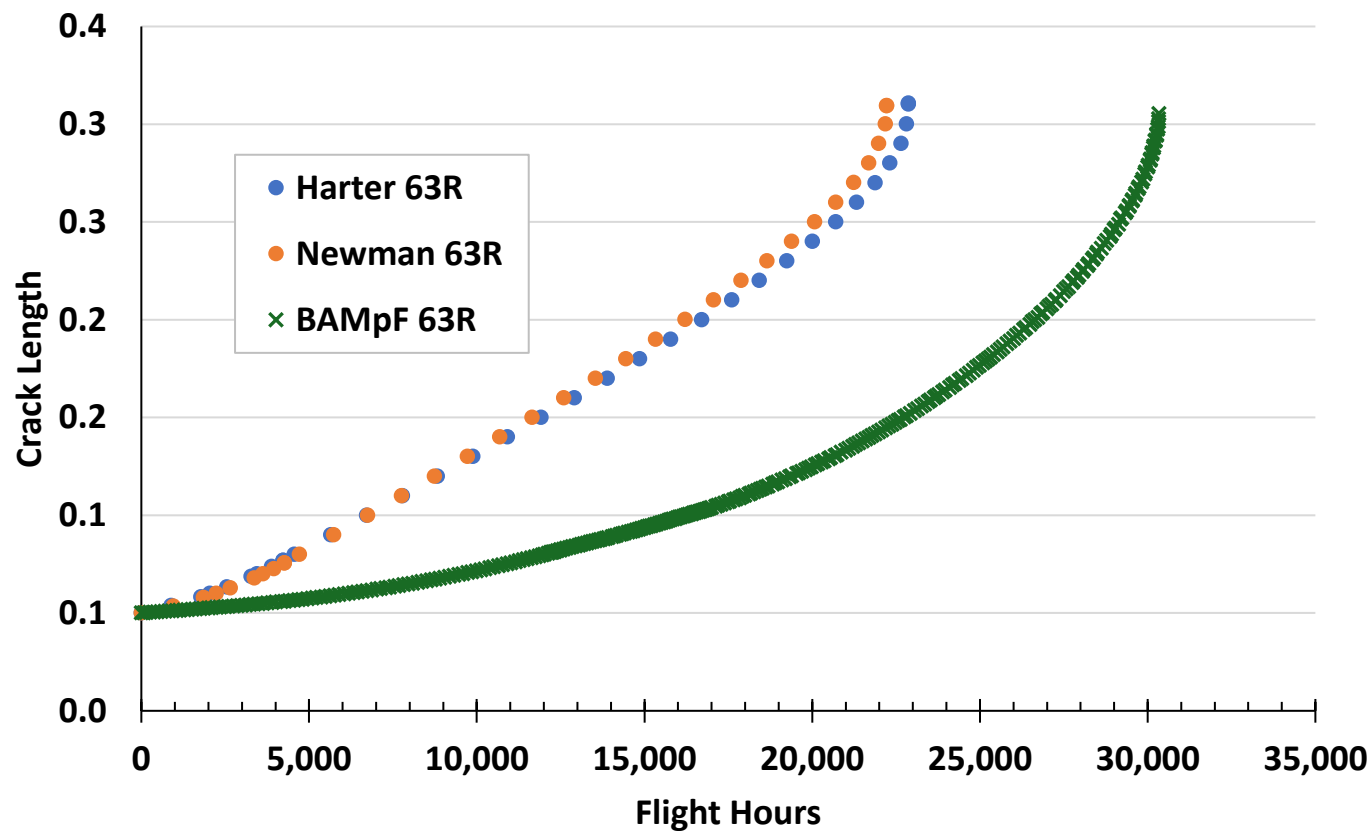


Diam		2.5900e-01
EdgeDist		4.4000e-01
Em		1.0300e+07
GripHeight	Height of h...	3.5000e+00
Height		6.0000e+01
PointsCrack1		2.1000e+01
Stress		1.9142e+04
Thickness		1.1300e-01
v		3.3000e-01
Width		4.8570e+01



# Outer Wing, Lower Skin (63R)

- 2.93% difference in life between finite width corrections
- SMF = 19.142 ksi (TSF = 1),  $W=48.57''$ ,  $t=0.208''$ ,  $D=0.2585''$ ,  $e/D=1.7$
- IFS = 0.05''

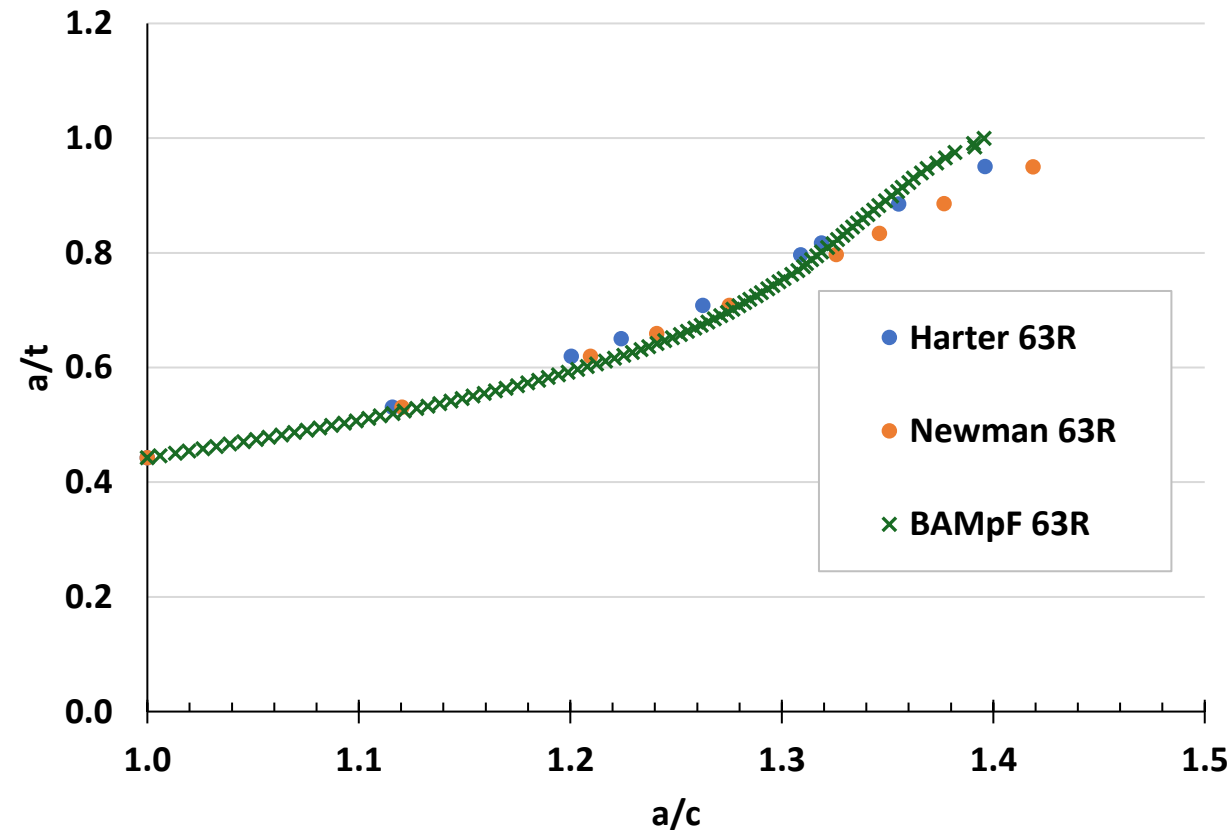
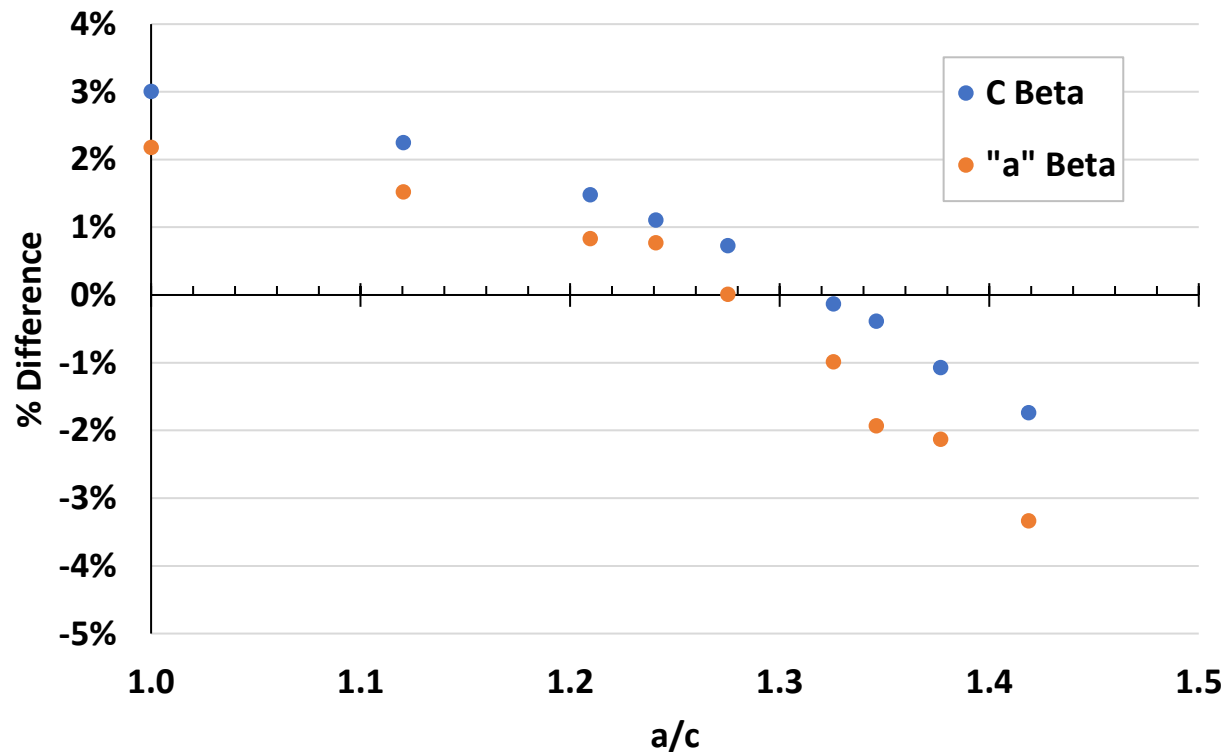




# Outer Wing, Lower Skin (63R)

- 2.93% difference in life between finite width corrections
- SMF = 19.142 ksi (TSF = 1),  $W=48.57''$ ,  $t=0.208''$ ,  $D=0.2585''$ ,  $e/D=1.7$
- IFS = 0.05''

% Diff. Width Correction Betas (63R)





# SOLR Impact



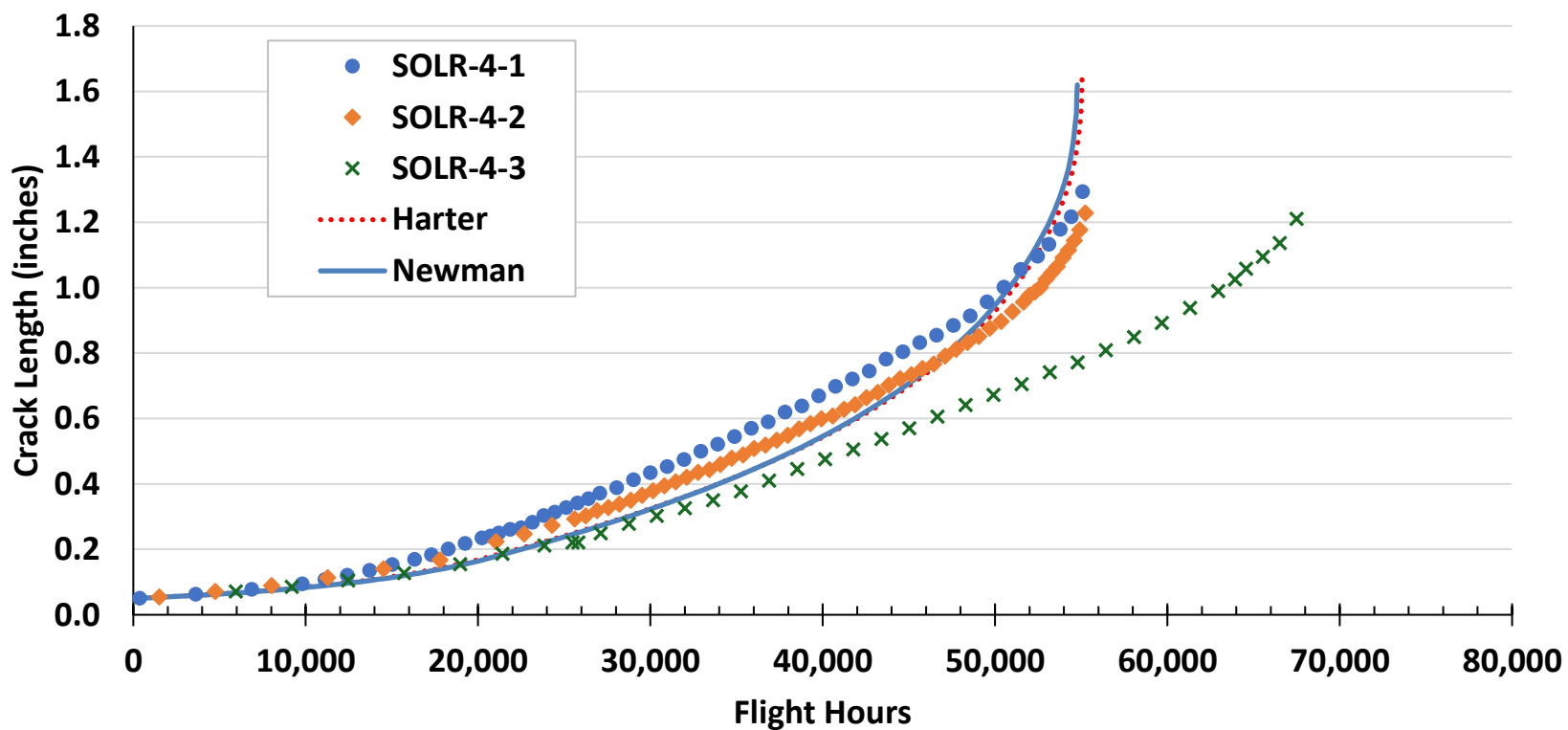
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# SOLR Correlation

- SOLR correlated with both width corrections for one test group
- SOLR = 1.67 used for both analyses shown
- Finite width correction doesn't appear to have a significant influence on SOLR correlation





# Finite Width Impact on SOLR

- **SOLR adjusted to get equivalent life using Harter width correction**
  - **85RT – From 1.86 to 1.81**
  - **14T – From 1.7 to 1.66**
  - **35T – From 2.06 to 2.02**
  - **66ART – From 2.06 to 2.02**



# Summary

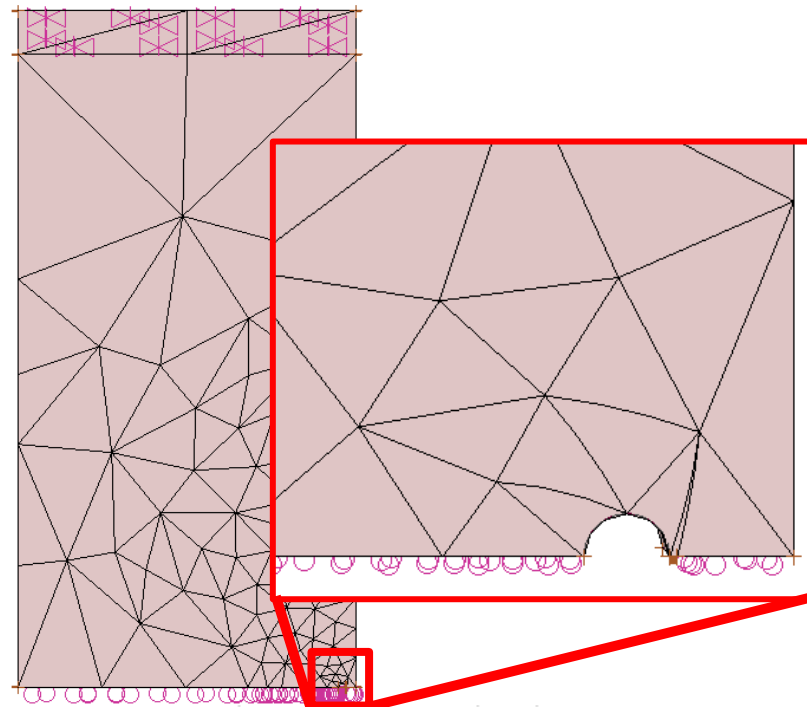
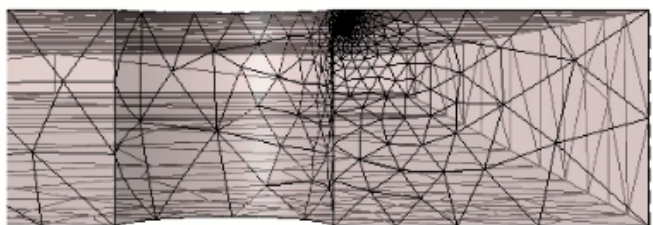
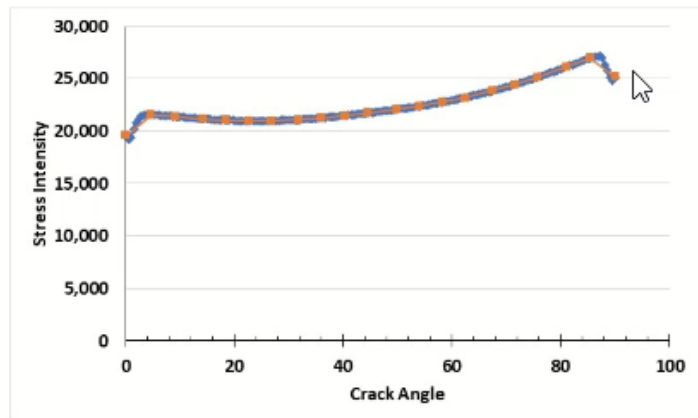
- **The Harter finite width correction is generally more conservative, producing slightly higher betas, therefore shorter lives**
  - **However, the Harter correction did result in slightly longer lives in two scenarios where BAMpF also produced longer lives**
- **Aspect ratios often stay smaller (closer to one) with the Harter correction**
- **Influence of finite width corrections have relatively low impact for most A-10 locations**
- **Finite width correction has a limited influence on SOLR correlation**





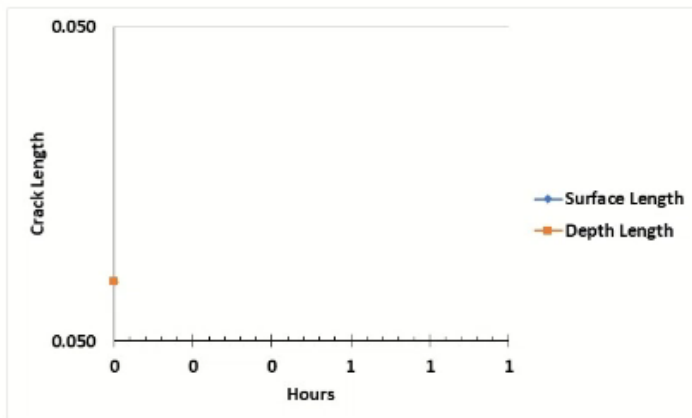
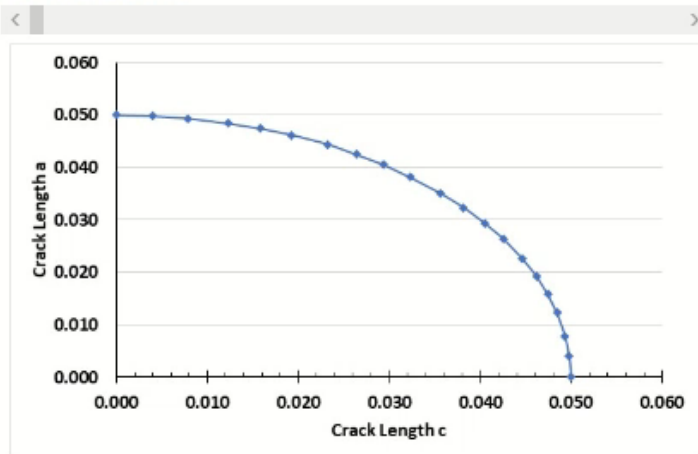
# 14T Buggy BAMpF Results

1



Diam		5.6650e-01
EdgeDist		1.1000e+00
Em		1.0300e+07
GripHeight	Height of hydr...	3.5000e+00
Height	W	5.3800e+01
PointsCrack1		2.1000e+01
Stress		3.3445e+04
Thickness		5.6000e-01
v		3.3000e-01
Width		2.6900e+01

Iteration 0





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## Lower Rear Spar Cap, Outer Wing



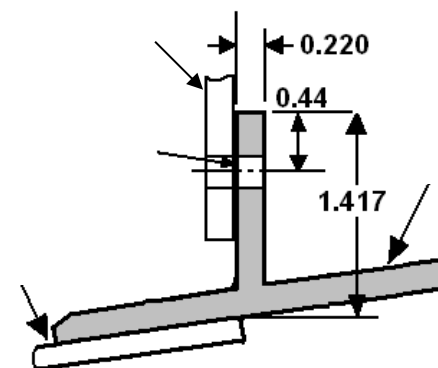
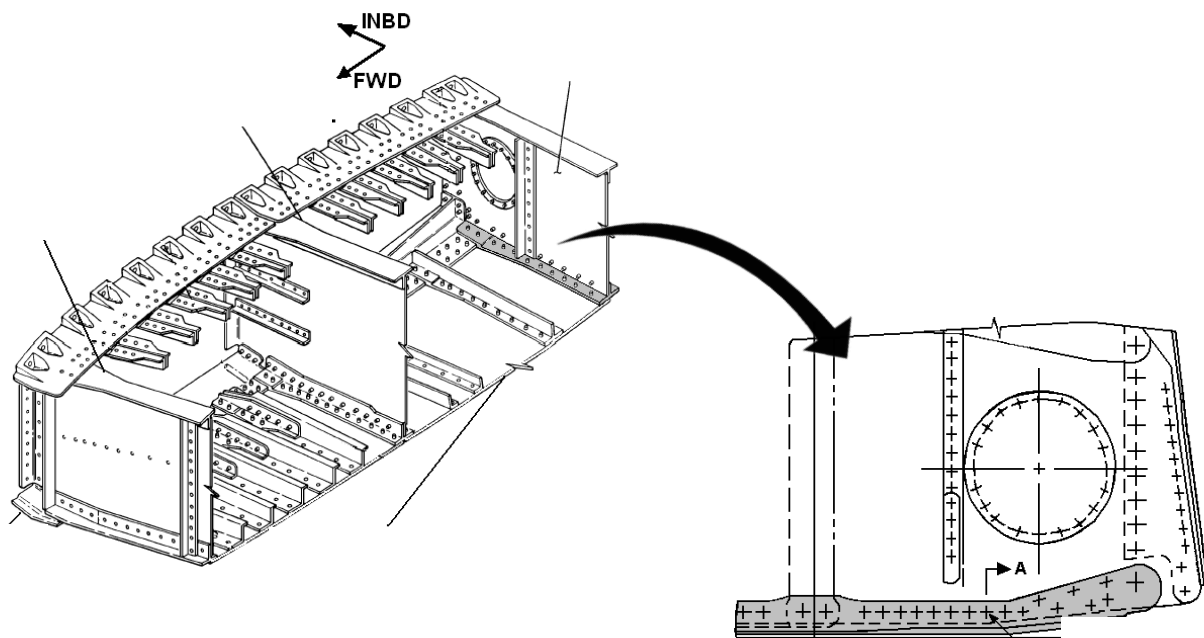
**Average Life Difference Example**

**A-10**

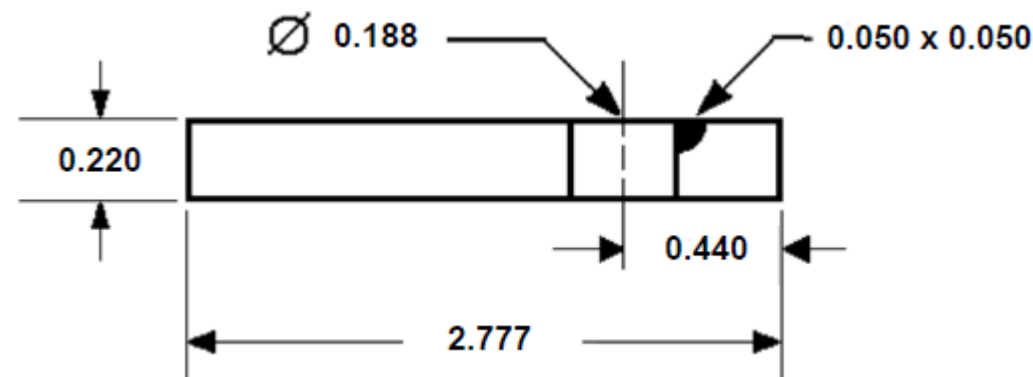


# Lower Rear Spar Cap, Outer Wing (33T)

- -0.68% difference in life between finite width corrections
  - Average % difference
- SMF = 25.7 ksi (TSF = 0.795, BSF = 0.955)
- Starting crack size: 0.05"
- 2024-T3511



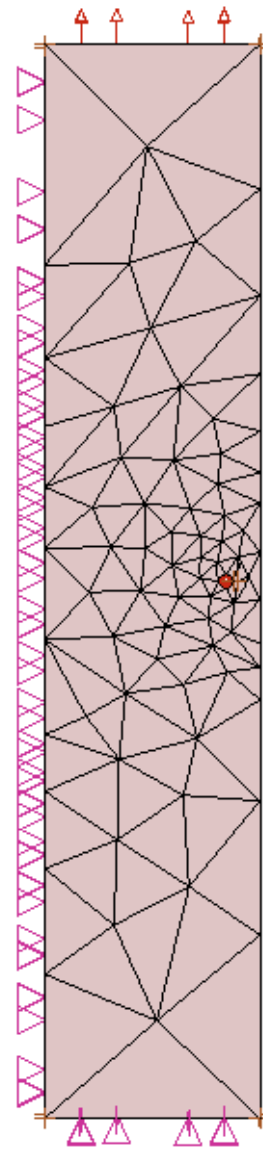
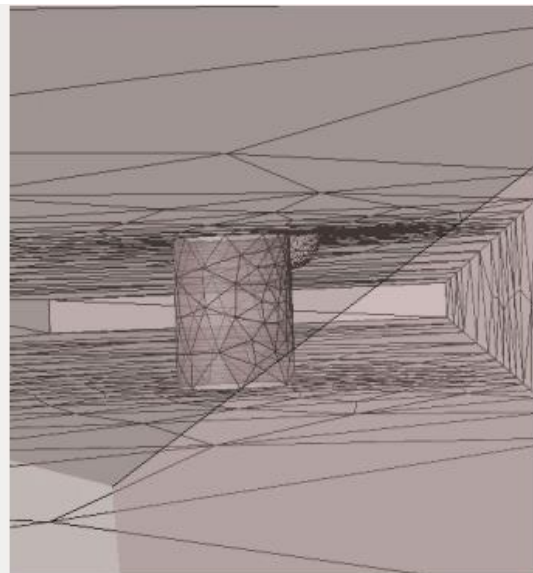
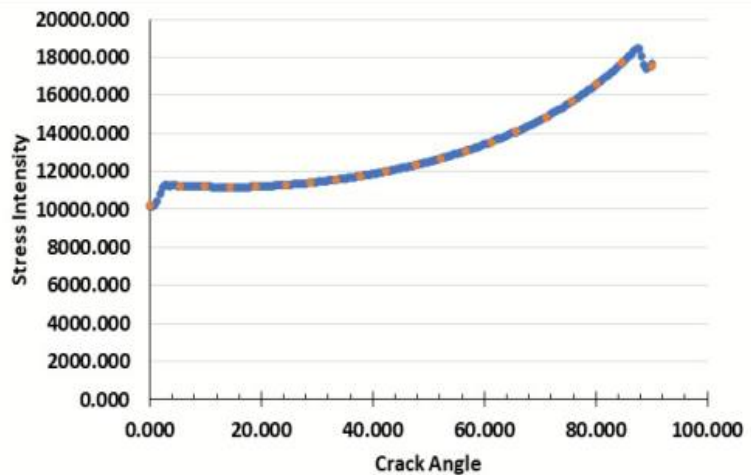
SECTION A-A  
(WS 118)





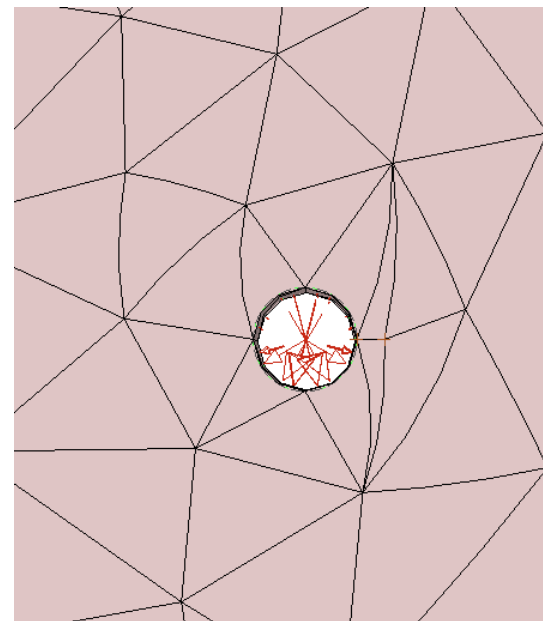
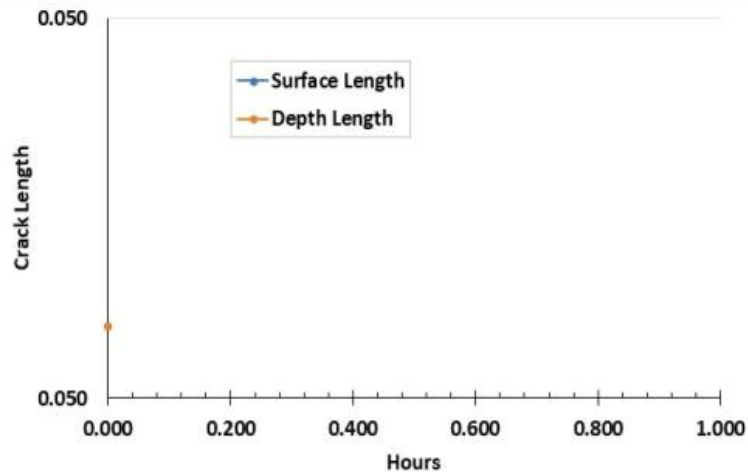
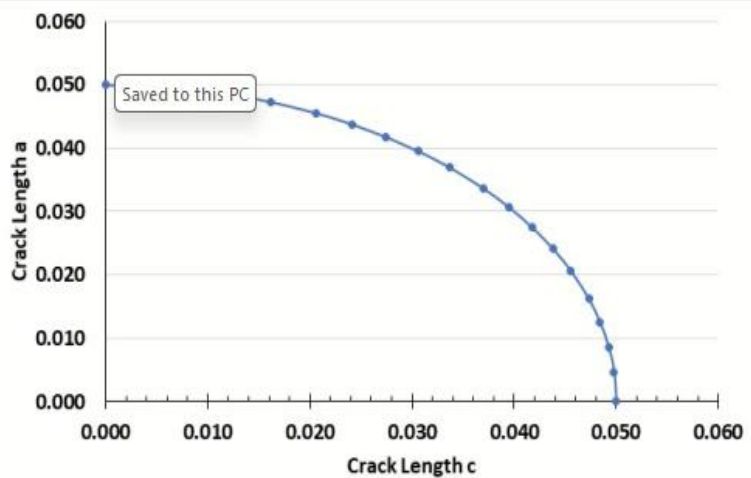


# 33T BAMPf Results



Em		10300000.000000
FarFieldStr...	Stress	20431.500000
Height	5*W	13.885000
HoleOffset		0.440000
PinLoad		1015.000000
PointsCrack1		20.000000
Stress	25700*.795	20431.500000
SurfaceLen...		0.050000
thickness	t...	0.220000
v		0.330000
VerticalHol...	Height/2	6.942500
W	w.	2.777000

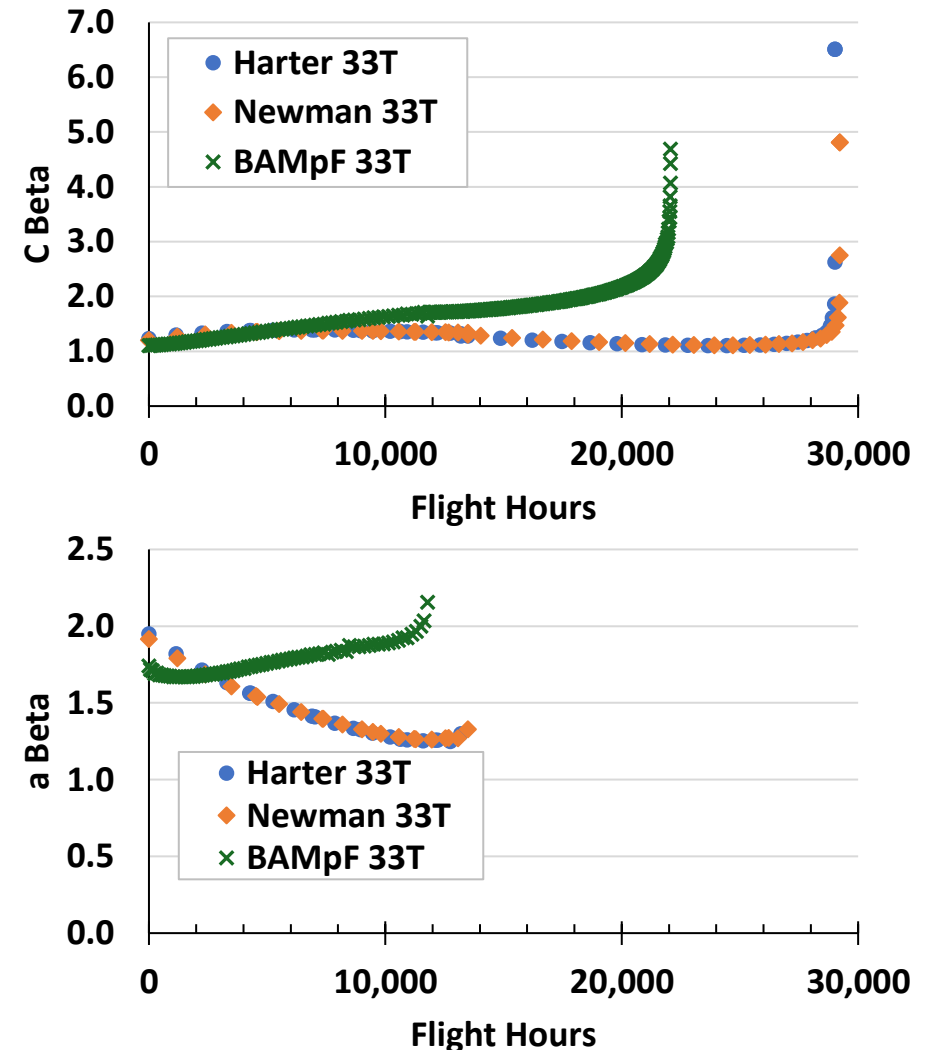
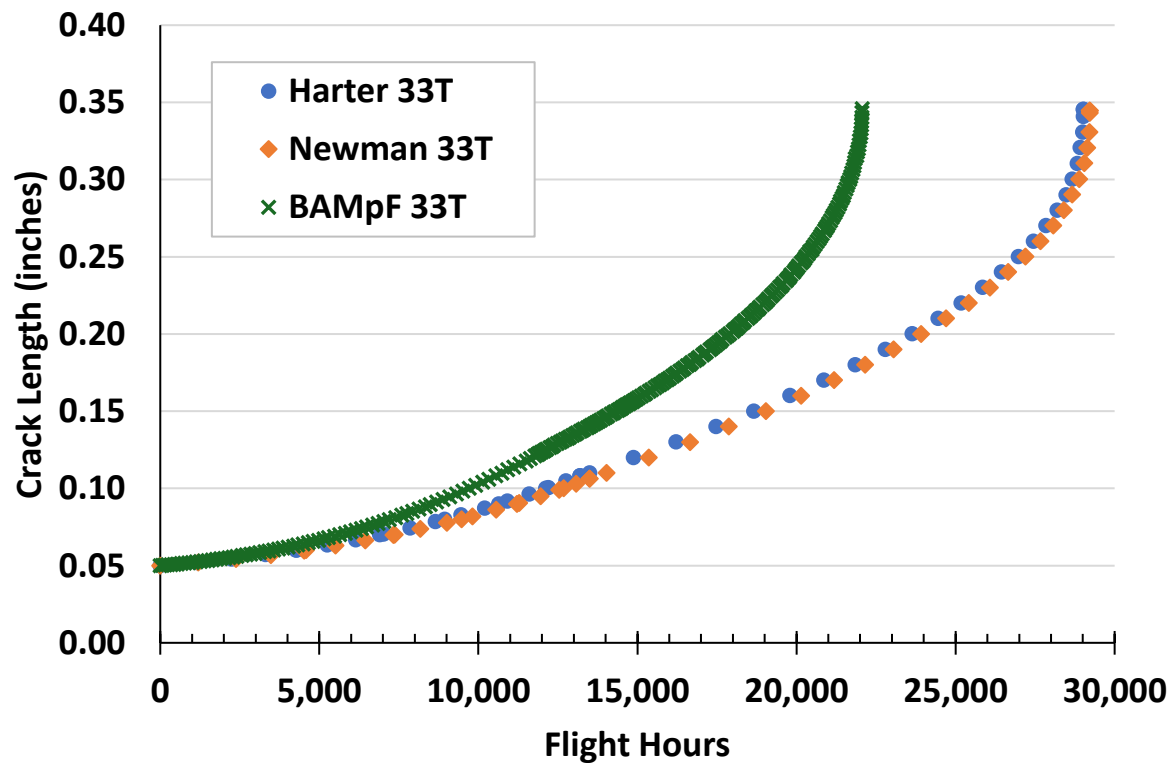
BAMPf: Viewing Iteration 1





# Lower Rear Spar Cap, Outer Wing (33T)

- **-0.68% difference in life between finite width corrections**
- **SMF = 25.7 ksi (TSF= 0.795, BSF= 0.955)**
- **Starting crack size: 0.05"**
- **$W=2.77''$ ,  $t=0.22''$ ,  $D=0.188''$ ,  $e/D=2.34$**

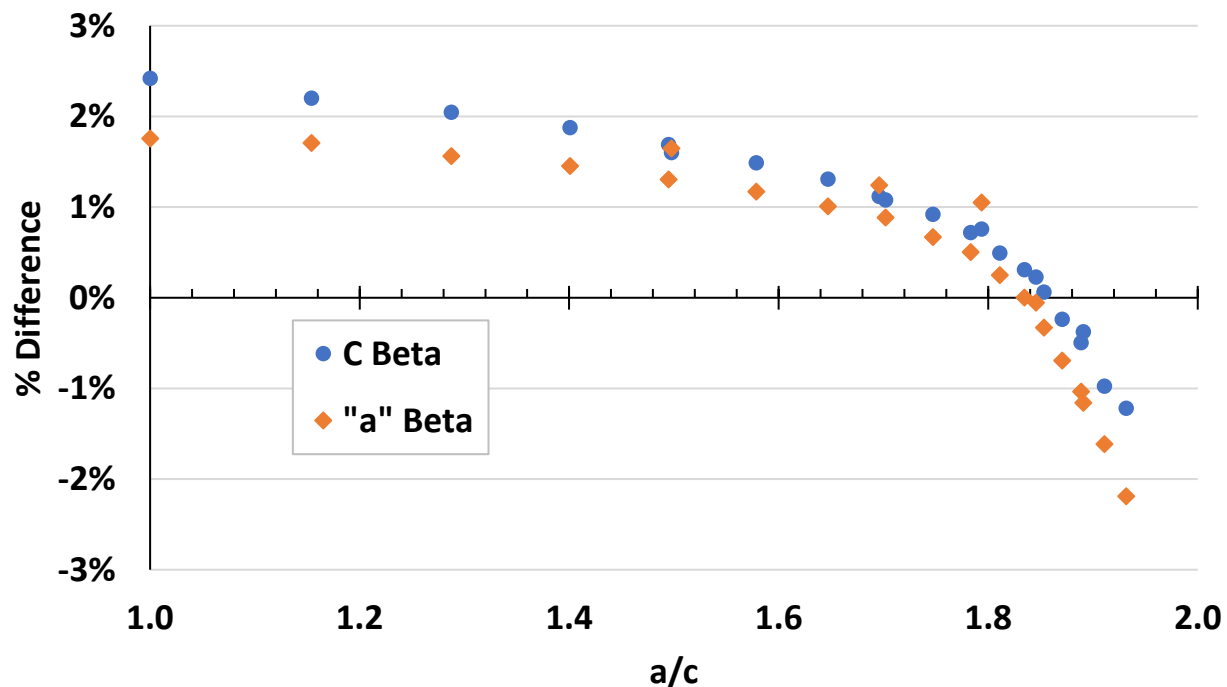




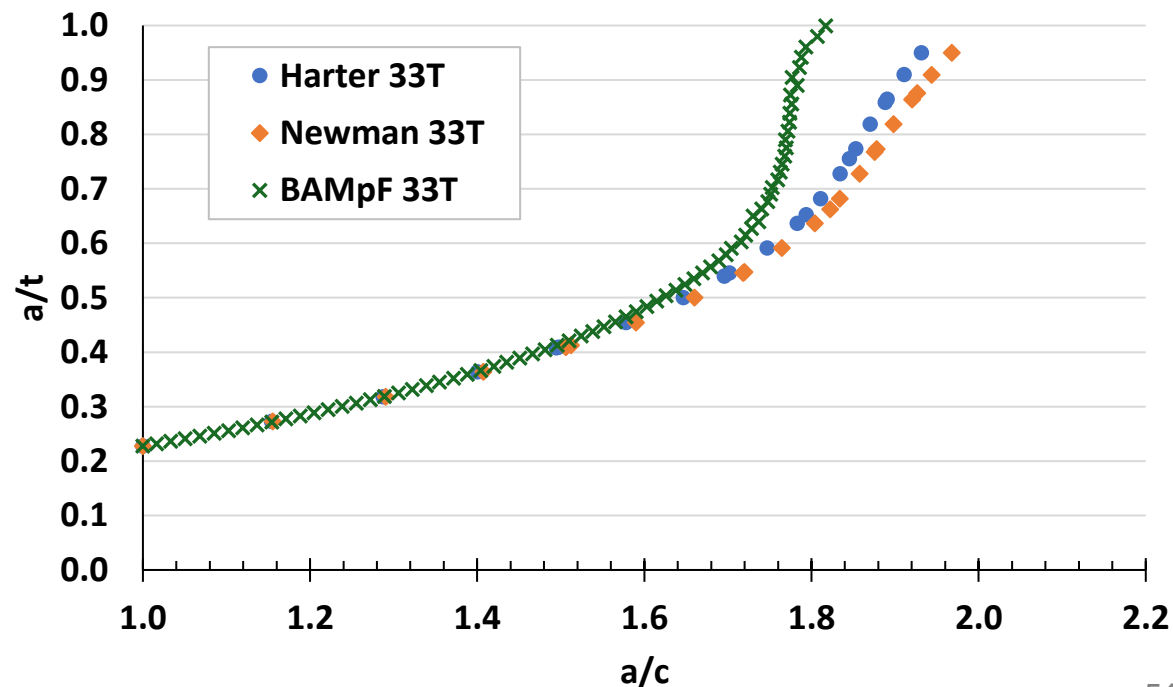
# Lower Rear Spar Cap, Outer Wing (33T)

- **-0.68%** difference in life between finite width corrections
- **SMF = 25.7 ksi (TSF = 0.795, BSF = 0.955)**
- **Starting crack size: 0.05"**
- **$W=2.77"$ ,  $t=0.22"$ ,  $D=0.188"$ ,  $e/D=2.34$**

% Difference Finite Width Correction (33T)



Aspect Ratio and Thickness Progression





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## Lower Skin, Near LG Trunnion



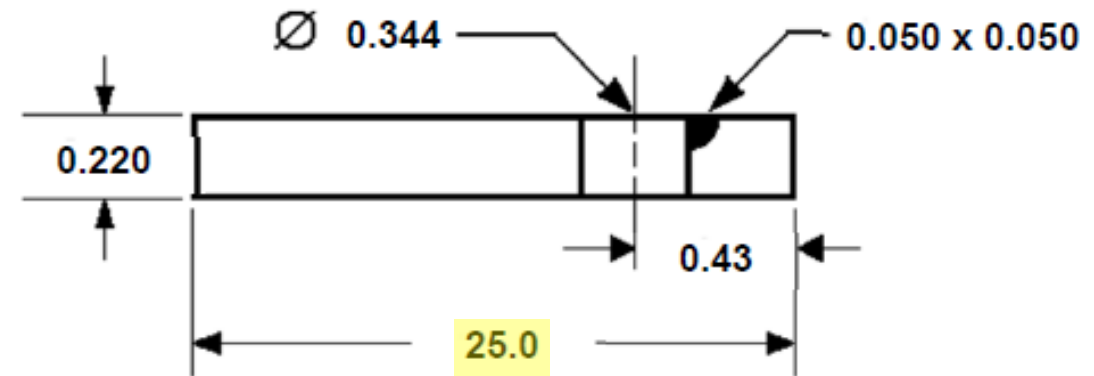
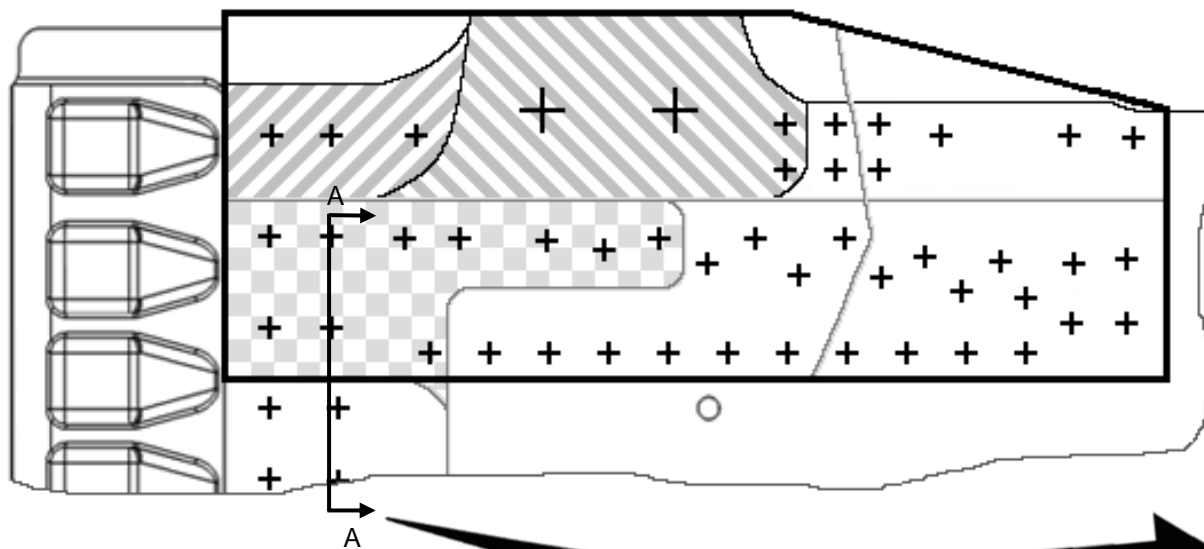
**Greatest Life Difference From 0.05" with Bearing Example**

**A-10**



# Lower Skin, Near LG Trunnion (66ART)

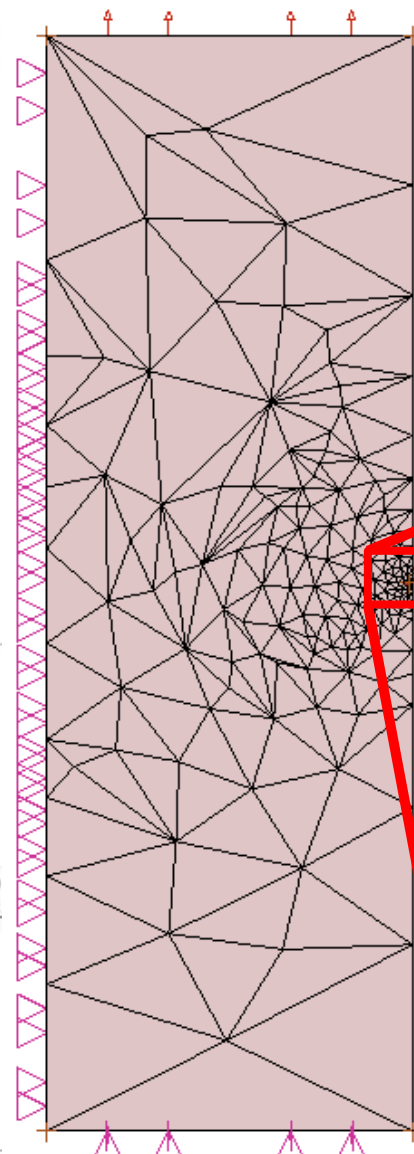
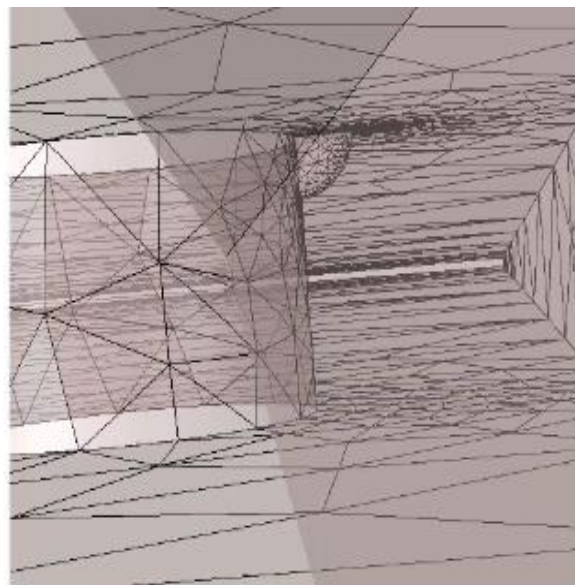
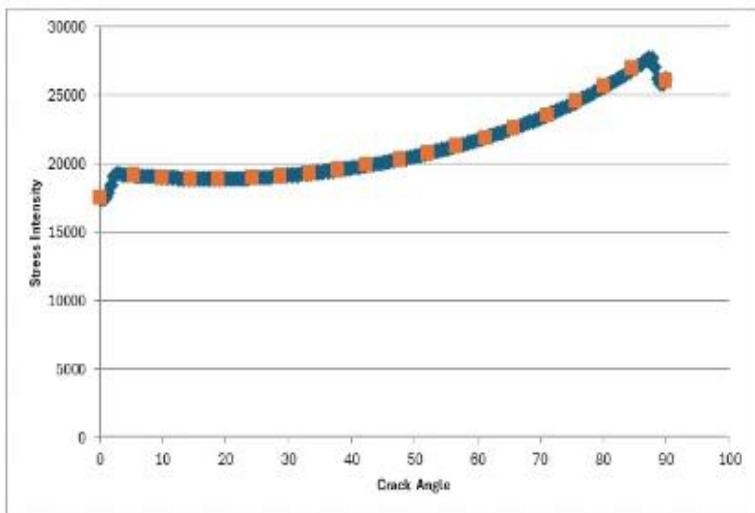
- -6.8% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 21.5 ksi (TSF = 0.536, BSF = 1.9)
- Starting Crack size: 0.05"
- 2024-T351



Section A-A

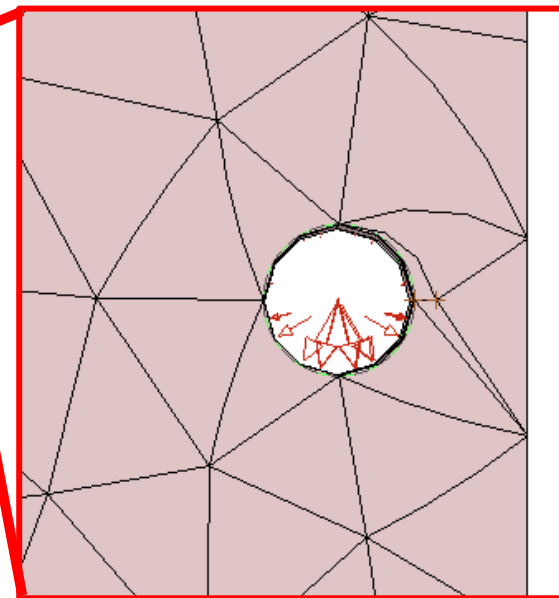
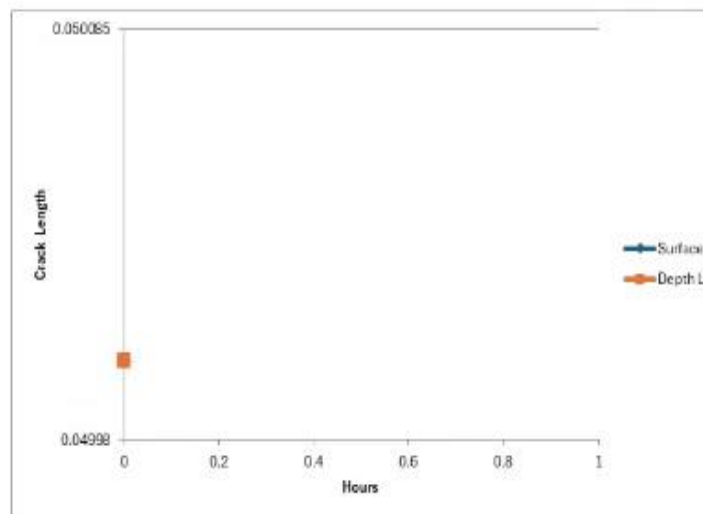
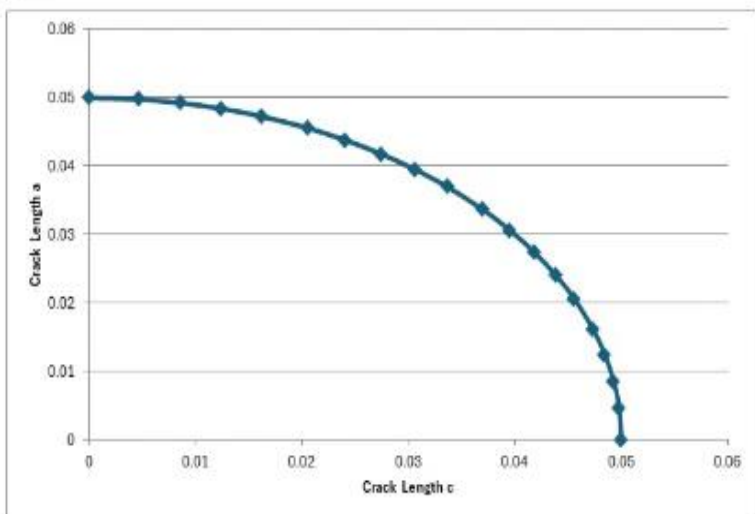


# 66ART BAMpF Results



Dia			0.344000
Em			103000000...
FarFieldStress	Stress		21500.00...
Height	3*W		75.000000
HoleOffset			0.430000
PinLoad			3094.800...
PointsCrack1			20.000000
Stress			21500.00...
SurfaceLength			0.050000
thickness	thickn...		0.220000
v			0.330000
VerticalHoleOffset	Height/2		37.500000
W	width		25.000000

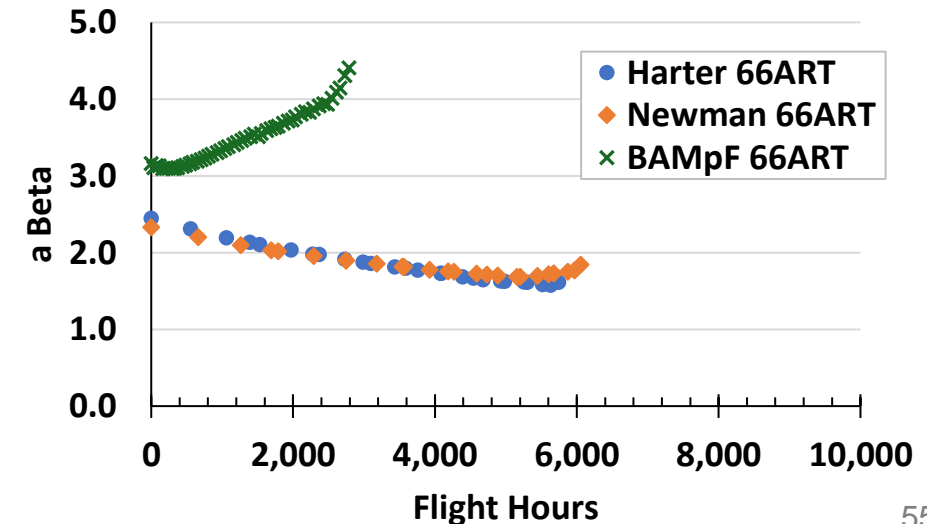
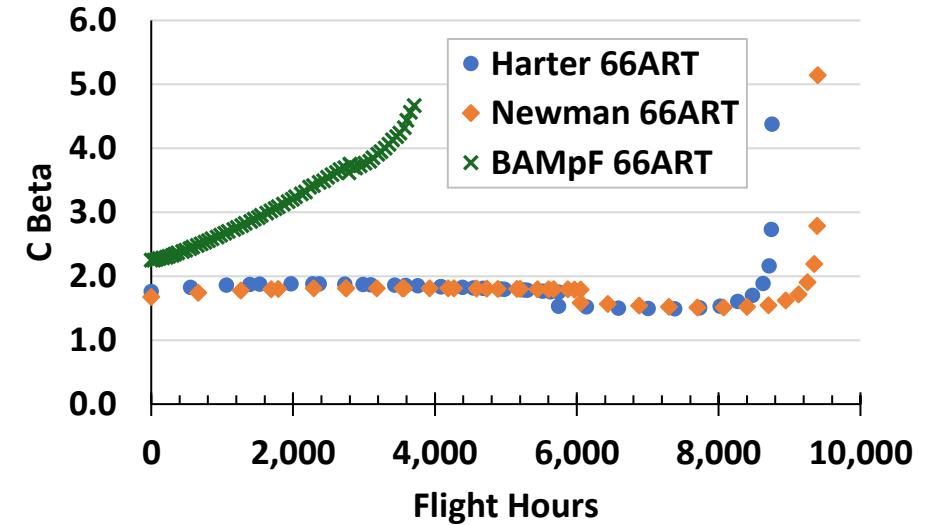
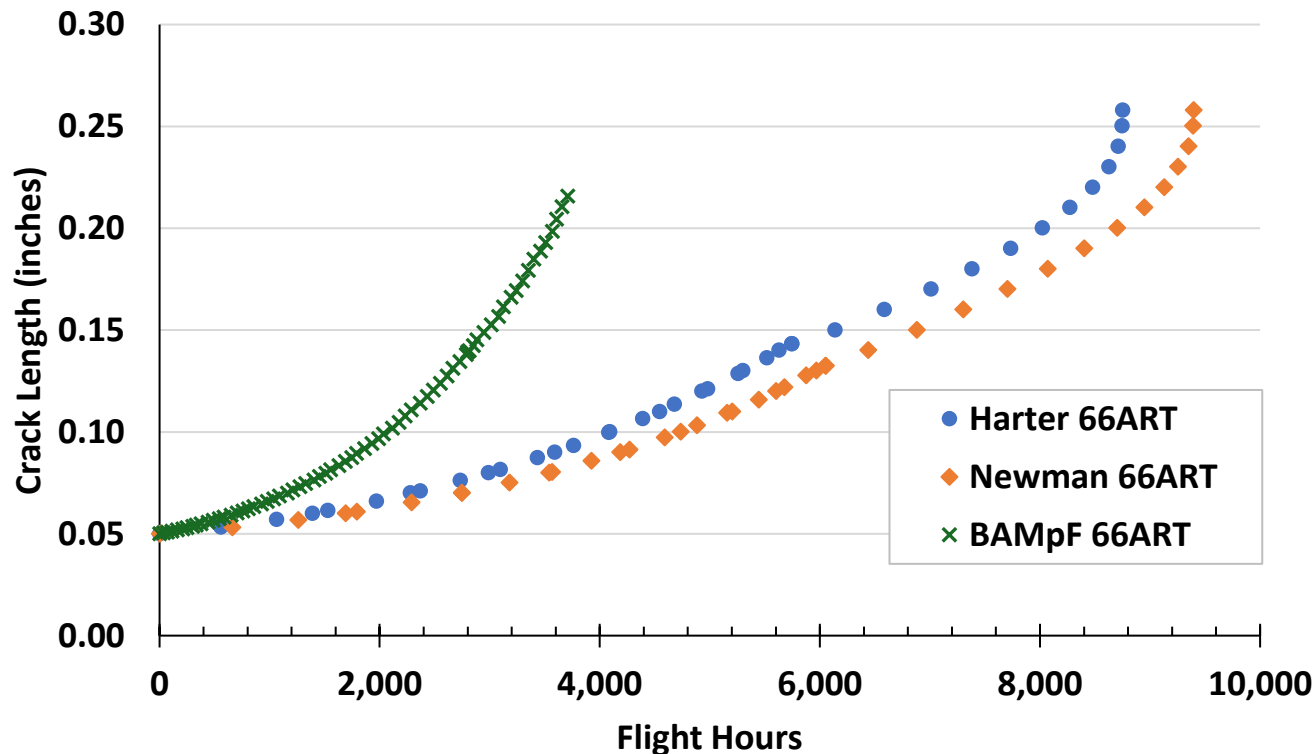
Iteration 0





# Lower Skin, Near LG Trunnion (66ART)

- -6.8% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 21.5 ksi (TSF = 0.536, BSF = 1.9)
- Starting Crack size: 0.05"
- $W=25''$ ,  $t=0.22''$ ,  $D=0.344''$ ,  $e/D=1.25$





# Lower Skin, Near LG Trunnion (66ART)

- -6.8% difference in life between finite width corrections
- Max  $\sigma$ , SMF = 21.5 ksi (TSF = 0.536, BSF = 1.9)
- Starting Crack size: 0.05"
- $W=25''$ ,  $t=0.22''$ ,  $D=0.344''$ ,  $e/D=1.25$

