

Air Force Life Cycle Management Center



U.S. AIR FORCE

A-10 Retardation Parameter (SOLR) Correlation

13 Sept 2022

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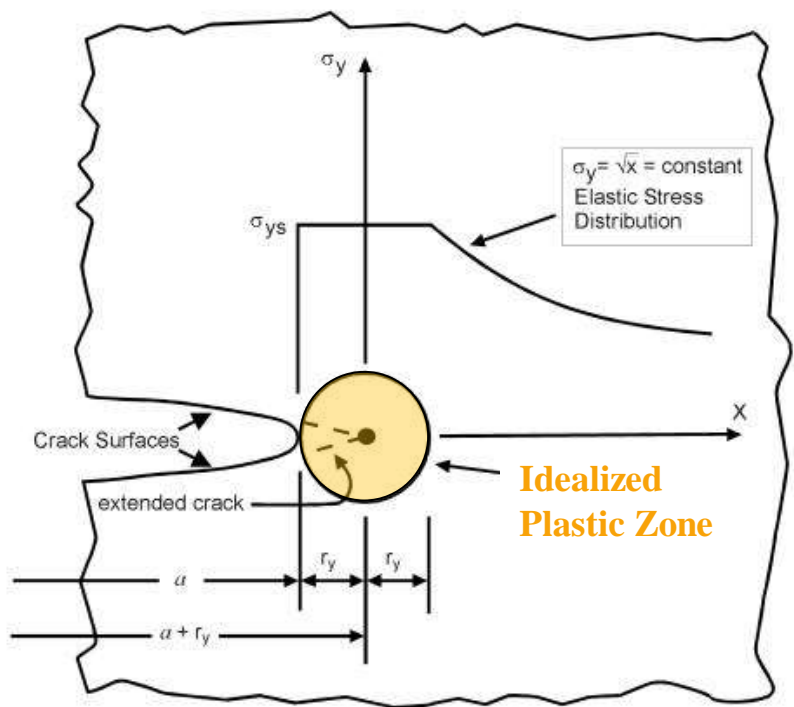
Overview



- **Retardation Background**
- **SOLR Derivation and Testing**
- **Previous Correlation Procedure**
- **Correlation Procedure Study and Results**
- **Application of SOLR to non-tested geometry, spectra and stress levels**

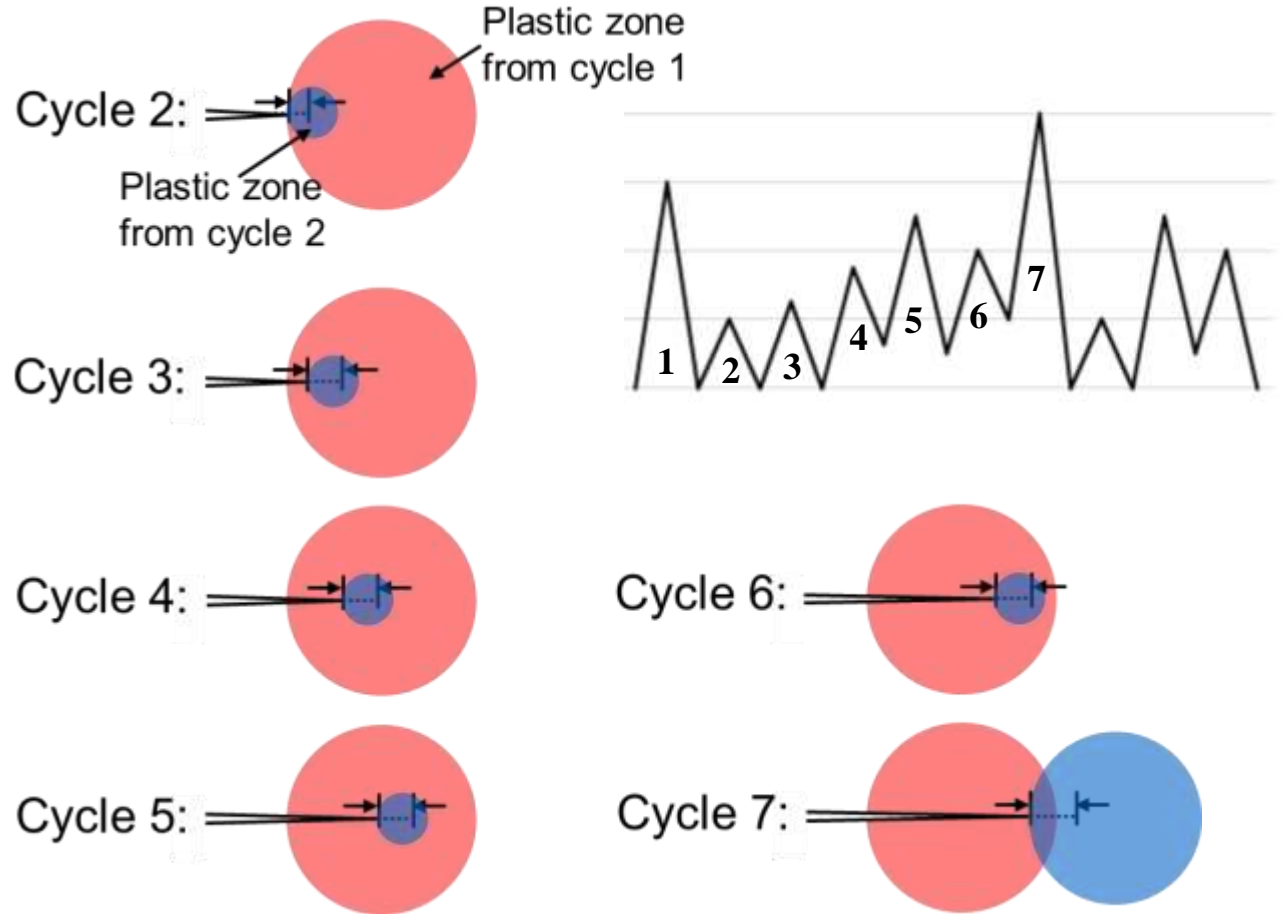


Retardation (Load History influence)



https://www.afgrow.net/applications/dtdhandbook/sections/page2_2_4.aspx

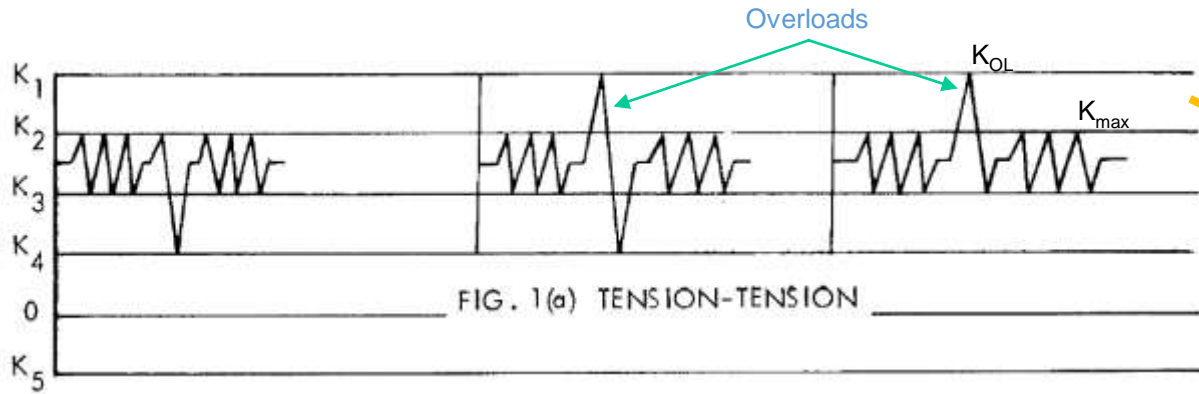
$$r_y = \frac{1}{2\pi} \left(\frac{K_I}{\sigma_{ys}} \right)^2$$



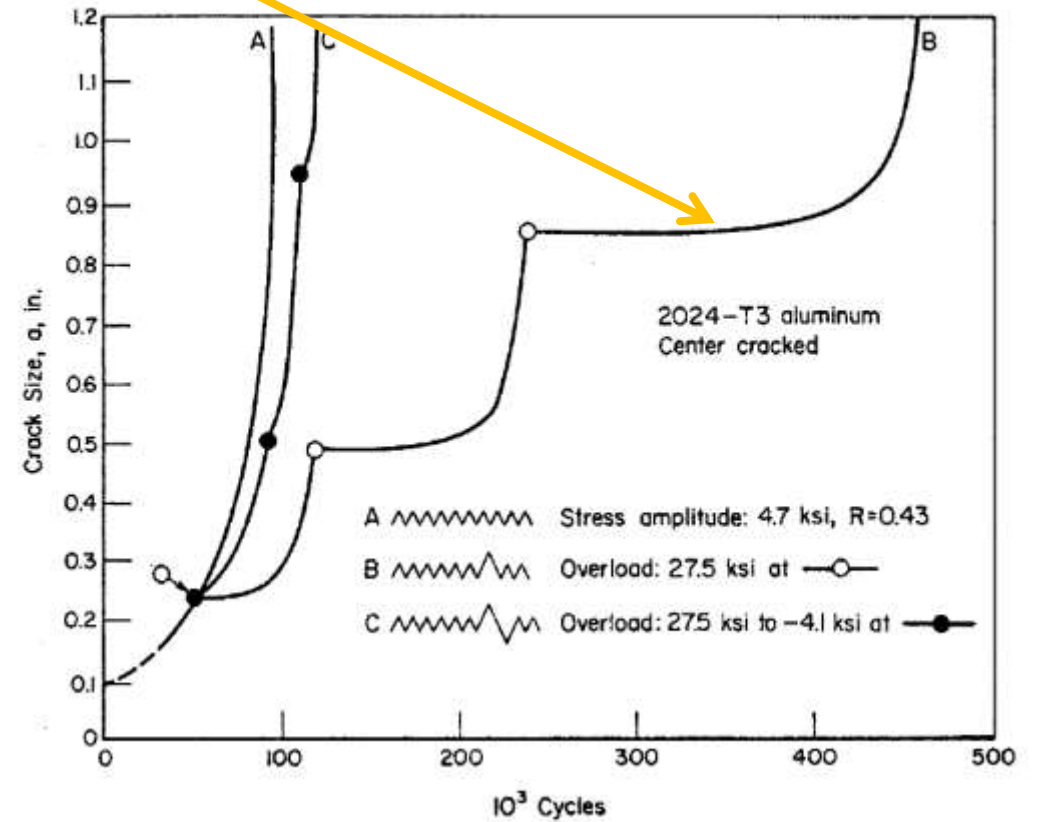
Warner, Damage Tolerance Analysis Course (Plastic Zone and Load History)



Overload Connection to Retardation

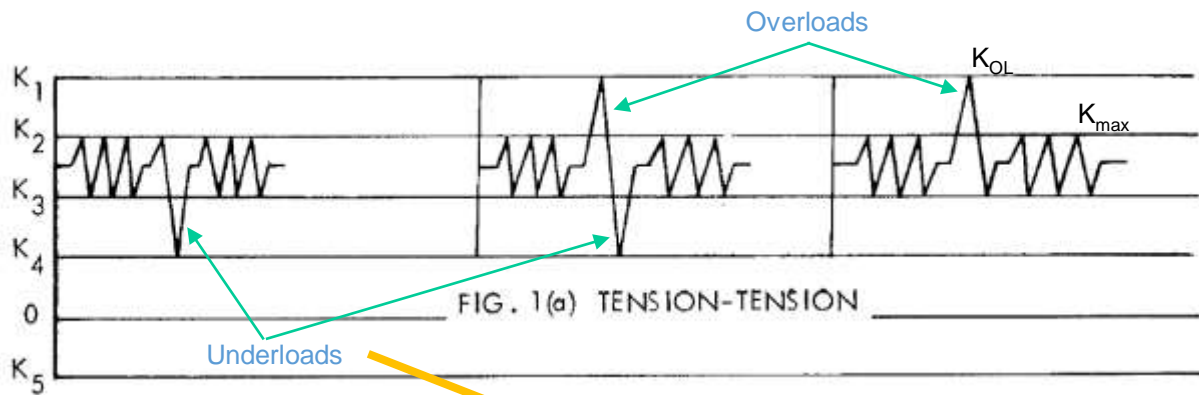


Overloads slows crack growth

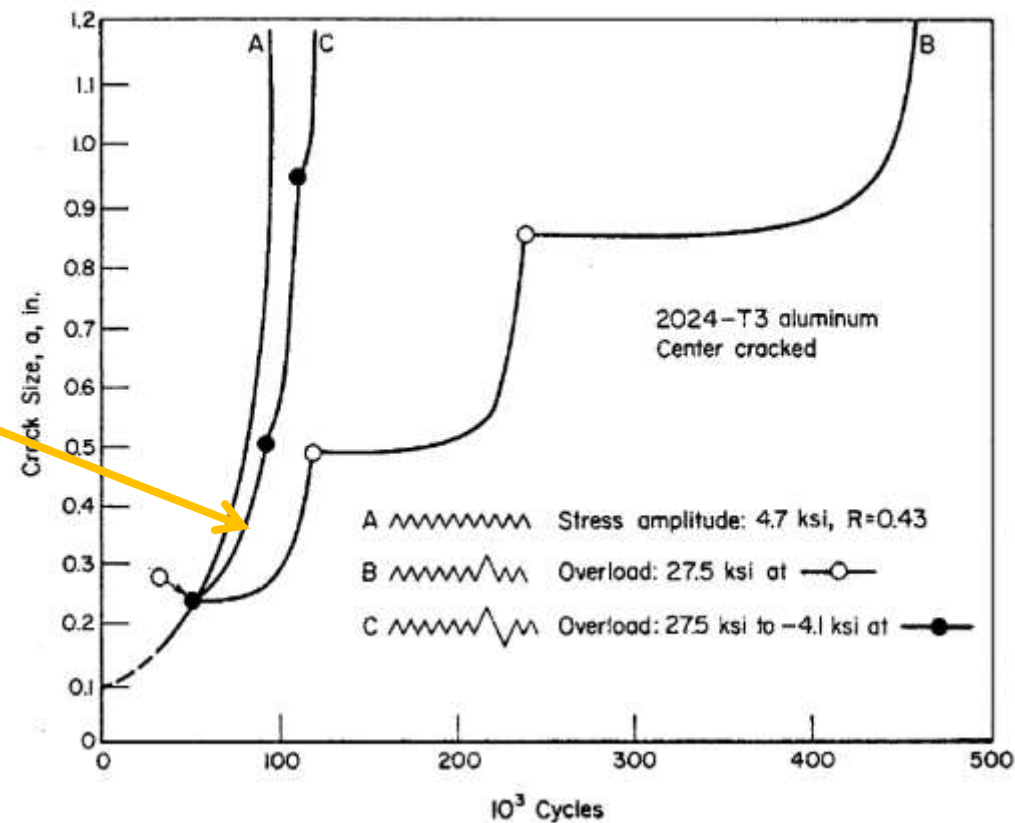




Overload vs Underload

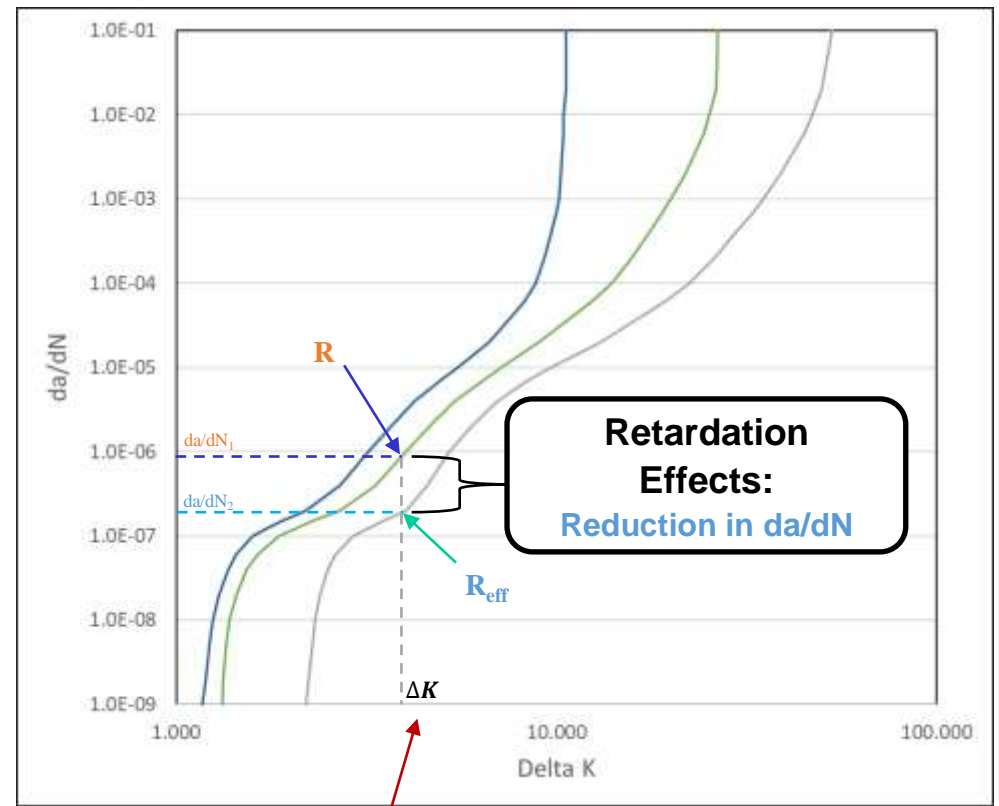


Underloads after overloads reduce effects of retardation



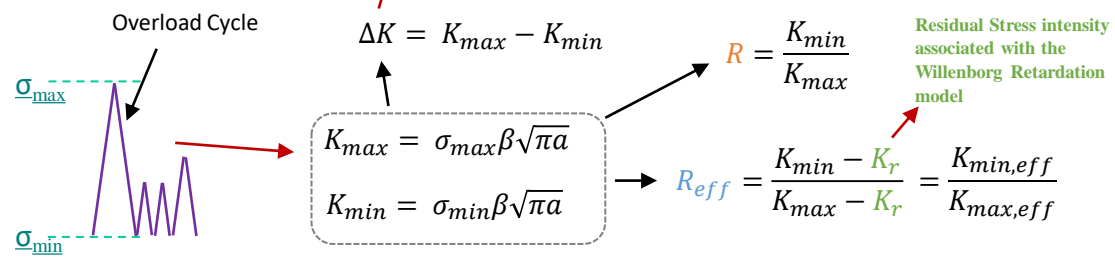


Willenborg Retardation Affects



K_r is applied to K_{min} and K_{max} as a reduction

$$\Delta K = (K_{max} - K_r) - (K_{min} - K_r) = \Delta K_{eff}$$

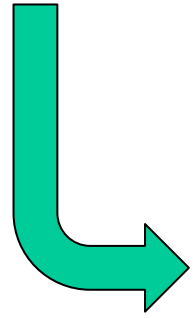




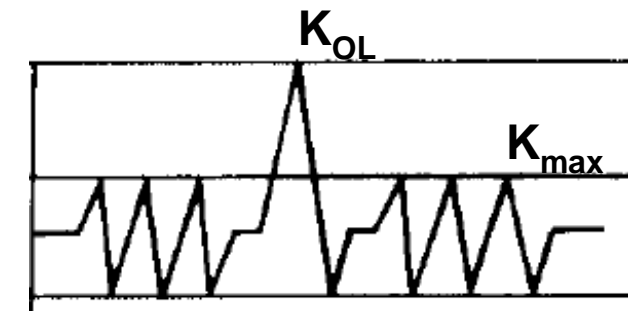
Generalized Willenborg Retardation Parameter (SOLR)



$$K_r = \frac{1 - \frac{\Delta K_{th}}{K_{max}}}{(SOLR - 1)} \left[K_{OL} \sqrt{1 - \frac{x - x_{OL}}{r_{OL}^y}} - K_{max} \right]$$



$$SOLR = \frac{K_{OL}}{K_{max}}$$

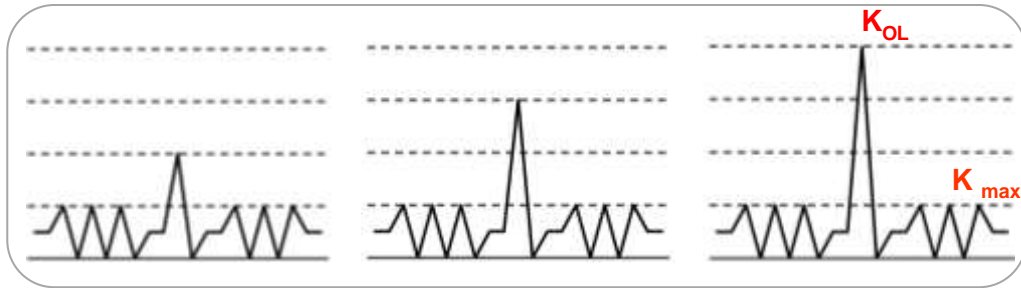


SOLR is derived as the maximum overload stress intensity factor (K_{OL}) to the maximum stress intensity factor (K_{max}) ratio that produces no crack growth.



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1970s SOLR testing (Probst & Hillberry Testing - 1974)



- Testing performed for different K_{max} levels to determine the shut-off overload ratio for 2024-T3.
- Stress ratio remained constant at 0.30 for each test.
- $SOLR = K_0 / K_{max} = \sim 2.3 = 1.0/0.435$

Independent of K_{max} (K₂)
Did not test different stress ratios

Spectra w/ Only Overloads

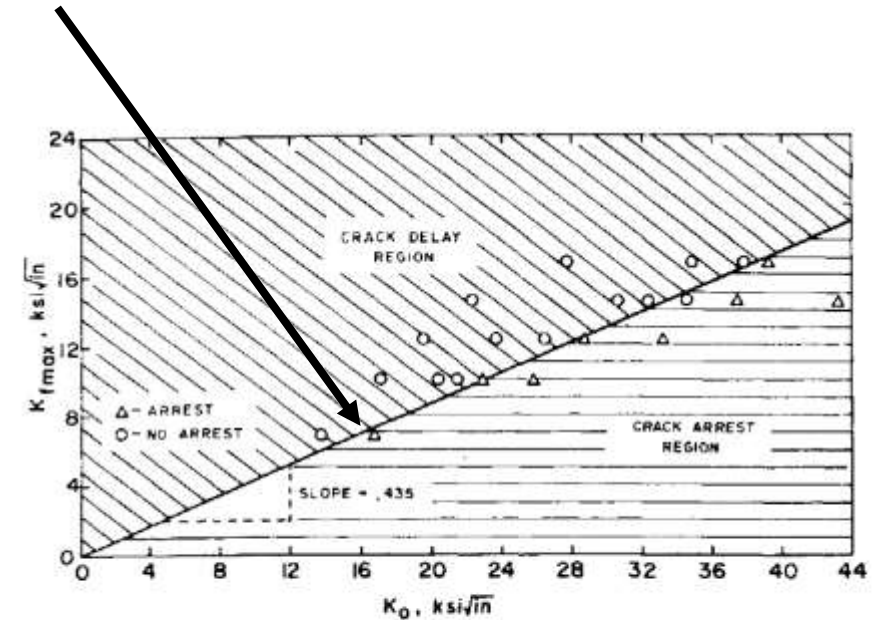
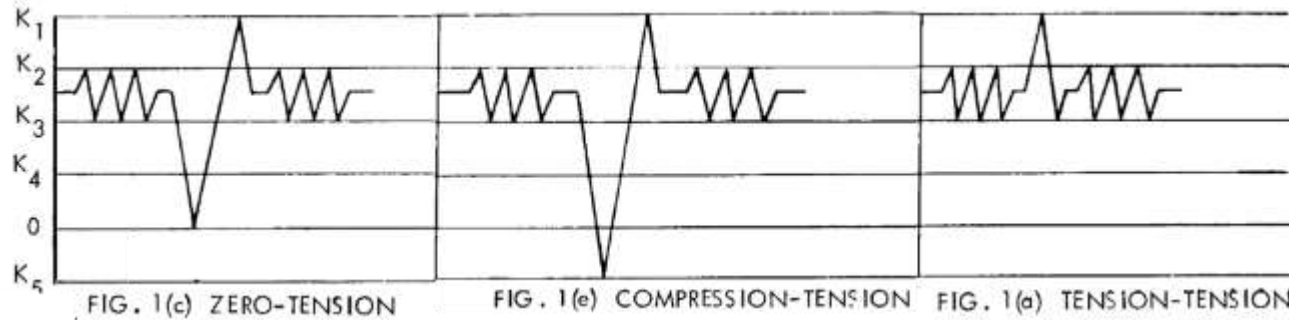


Fig. 5 Division between overloads that produced crack arrest vs crack delay.



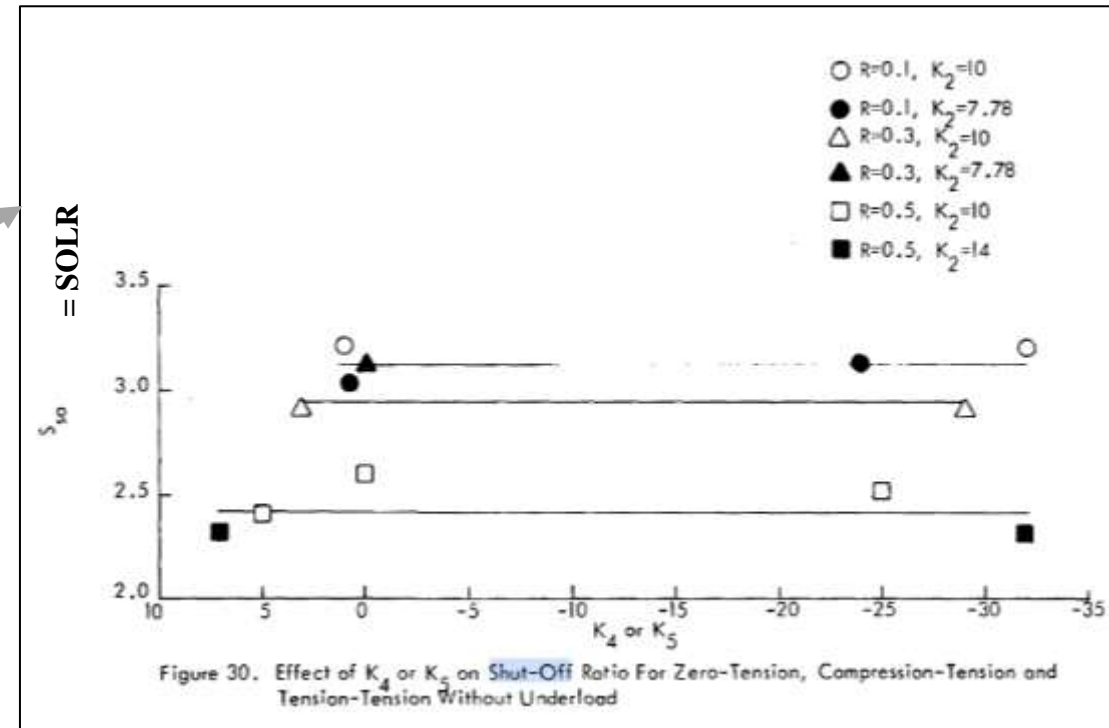
1970s SOLR testing (McGee & Hsu Testing - 1977)



- Testing performed for different K_{max} levels and stress ratios to determine the shut-off overload ratio for 2219-T851.

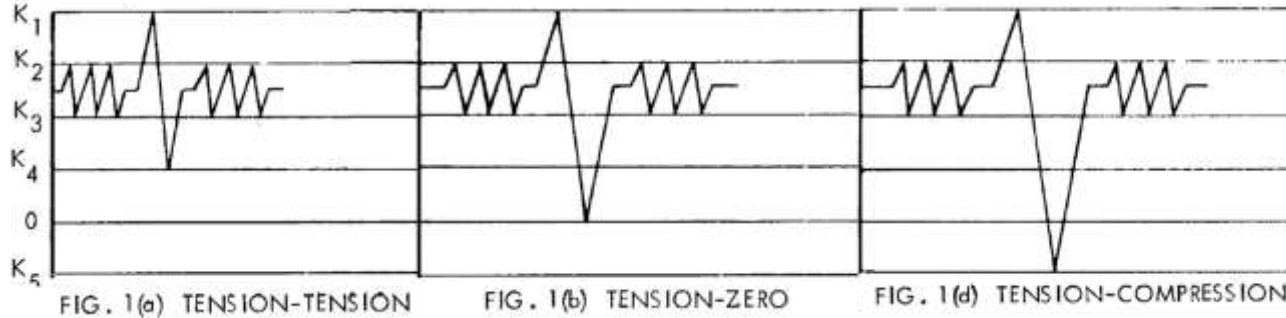
**Independent of K_{max} (K_2)
Dependence on Stress Ratio**

*Spectra w/ Underloads before Overloads or
with only Overloads*



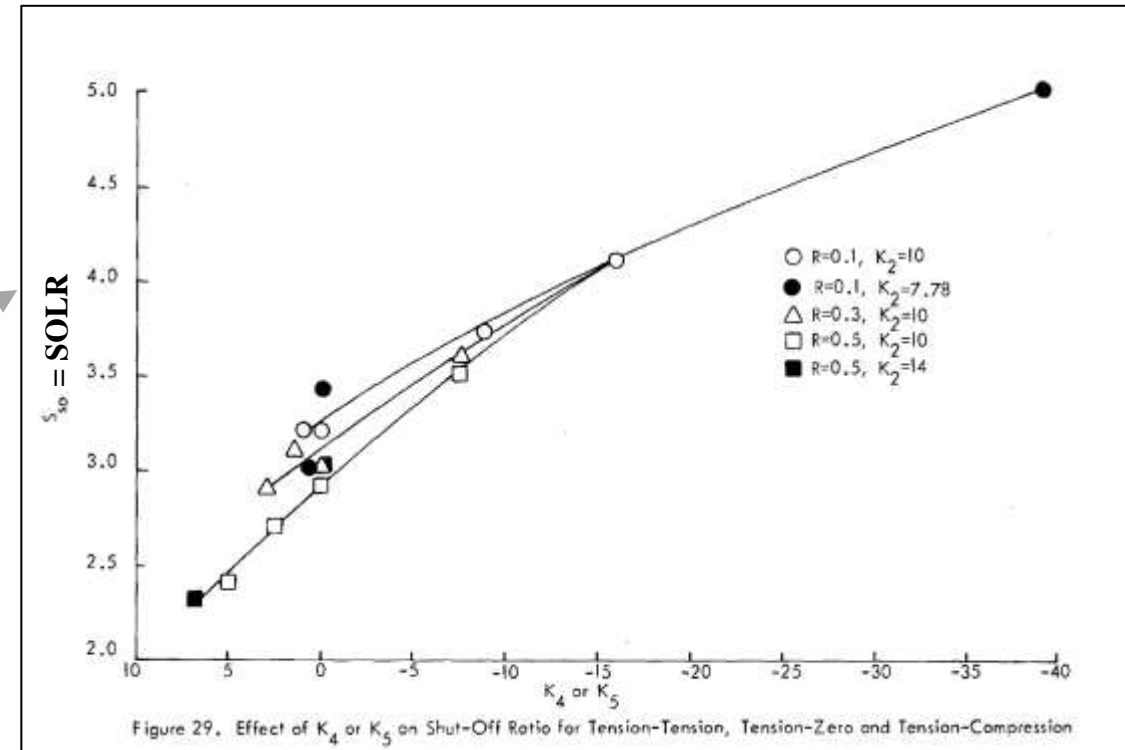


1970s SOLR testing (McGee & Hsu Testing - 1977)



- Testing performed for different K_{max} levels and stress ratios to determine the shut-off overload ratio for 2219-T851.

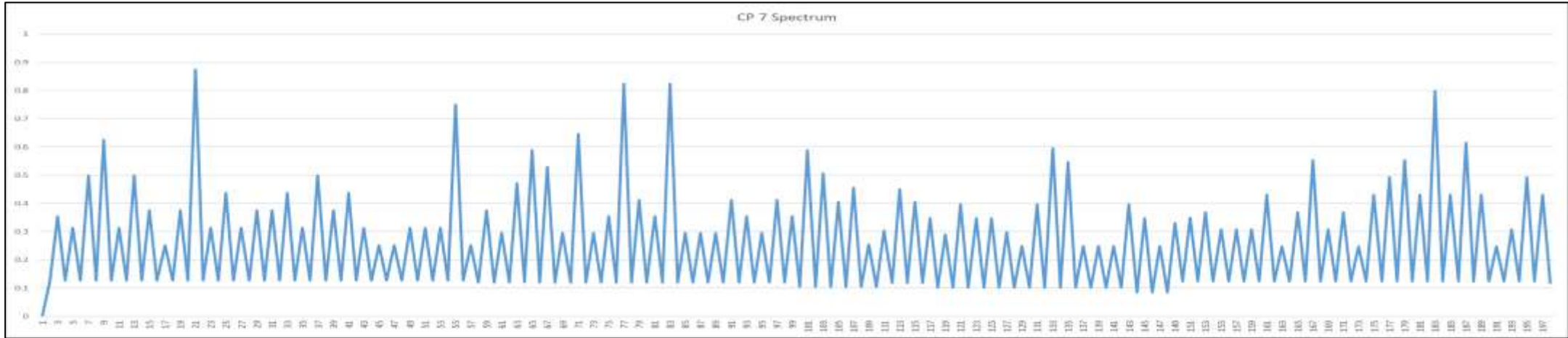
Independent of K_{max} (K_2)
Dependence on Stress Ratio
Dependence on Underload Magnitude



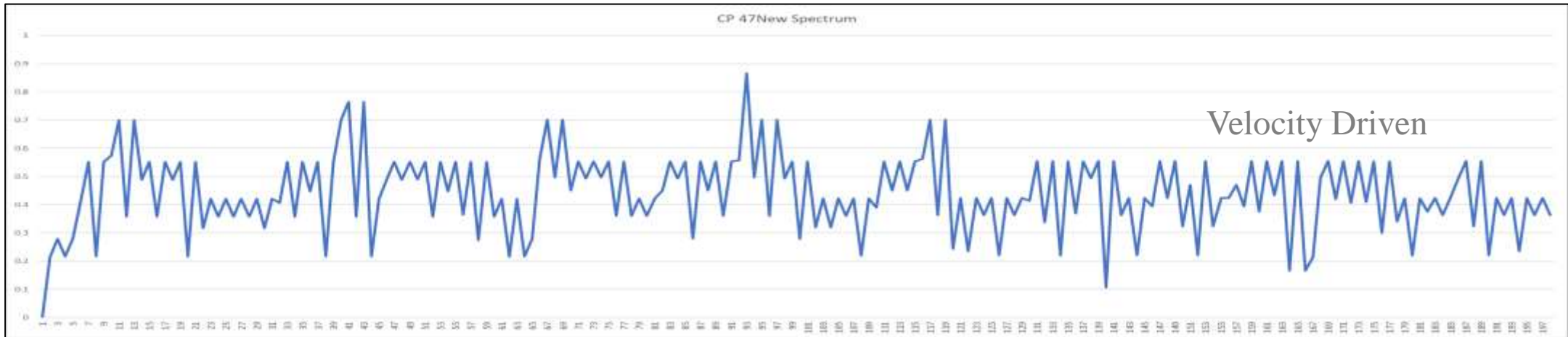
Spectra w/ Underloads After Overloads



A-10 has Spectra with and without Underloads



Overload Dominated Spectrum



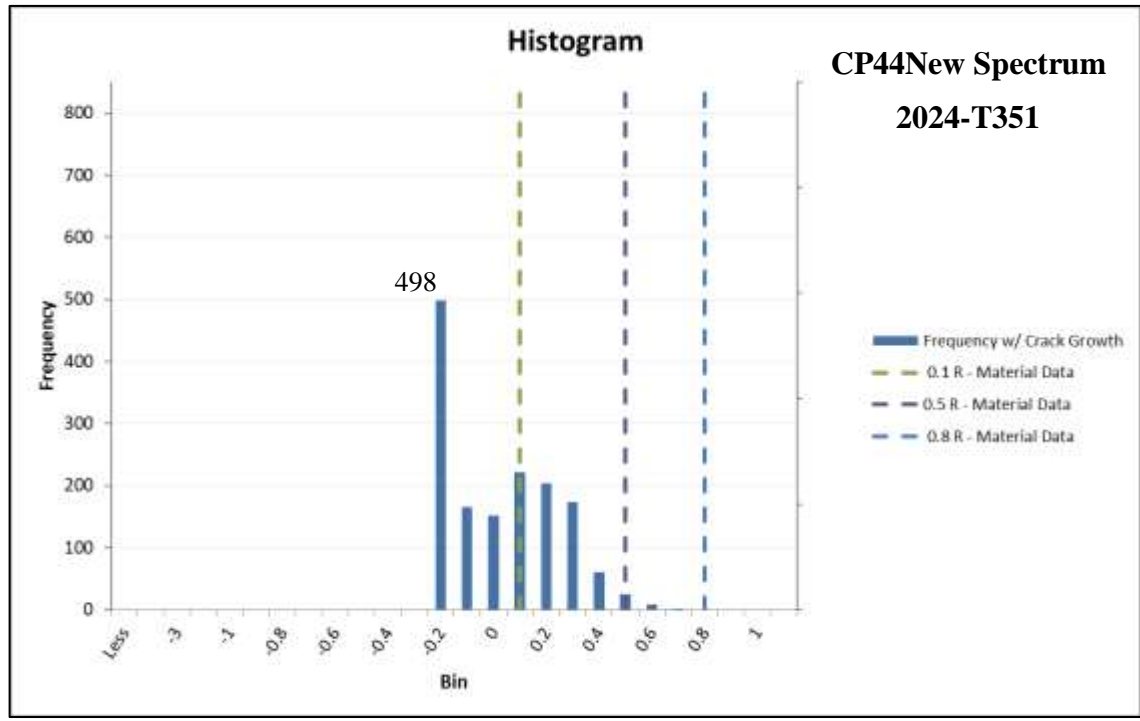
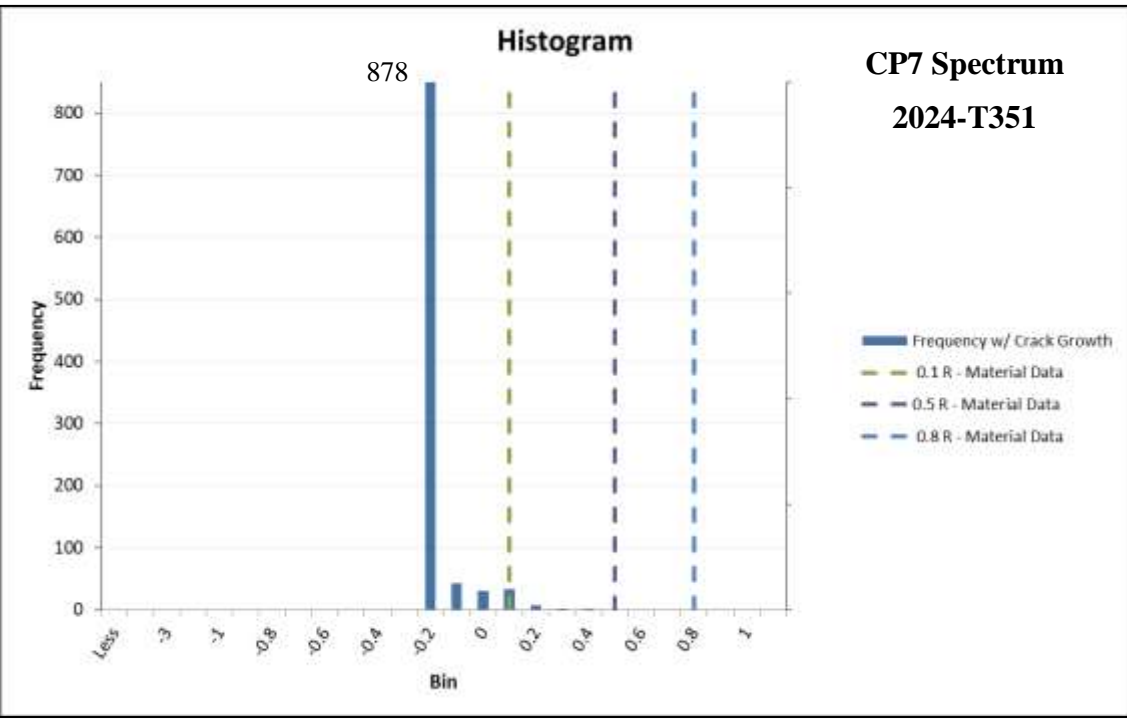
Overload & Underload Spectrum



A-10 has Spectra with and without Underloads

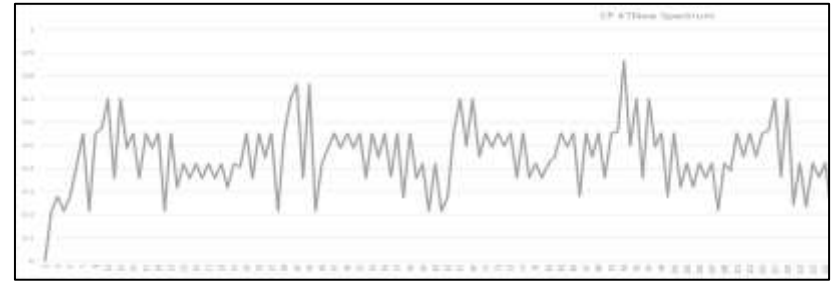
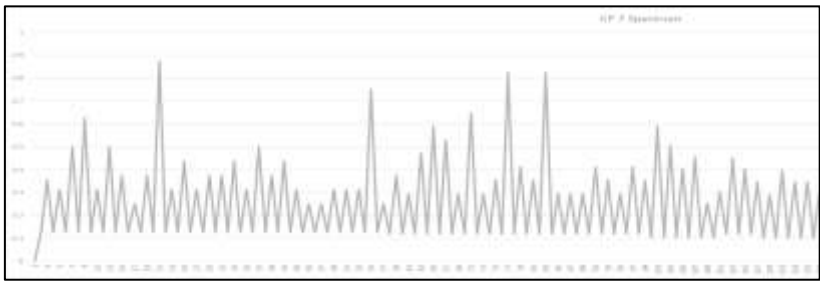


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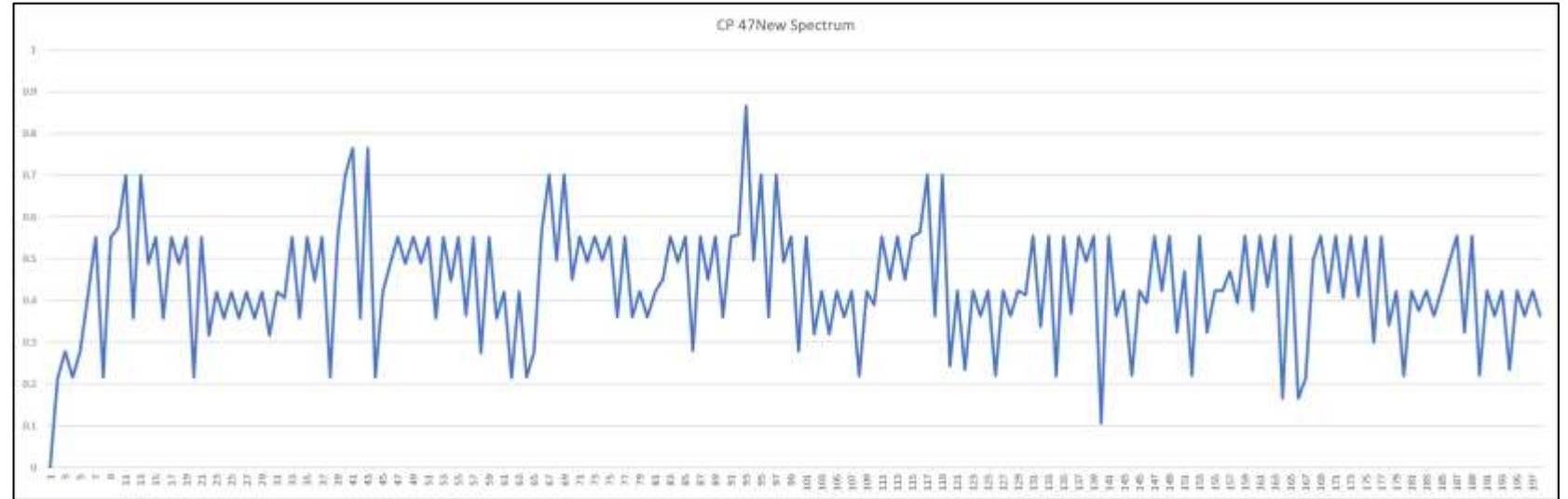
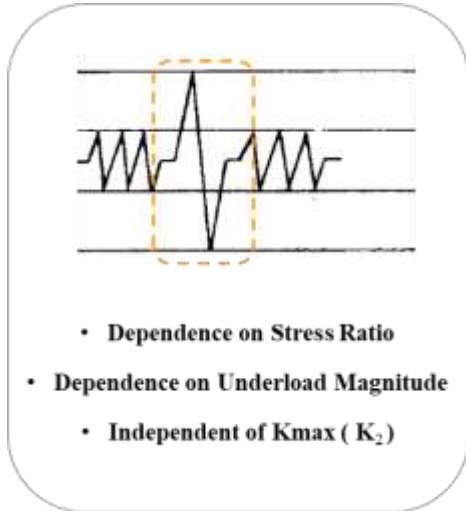


Stress Ratio count
1 pass
SOLR included

Note: 7075-T6 & 2024-T3511 behave similarly



SOLR and Variable Amplitude Load Spectrum Testing



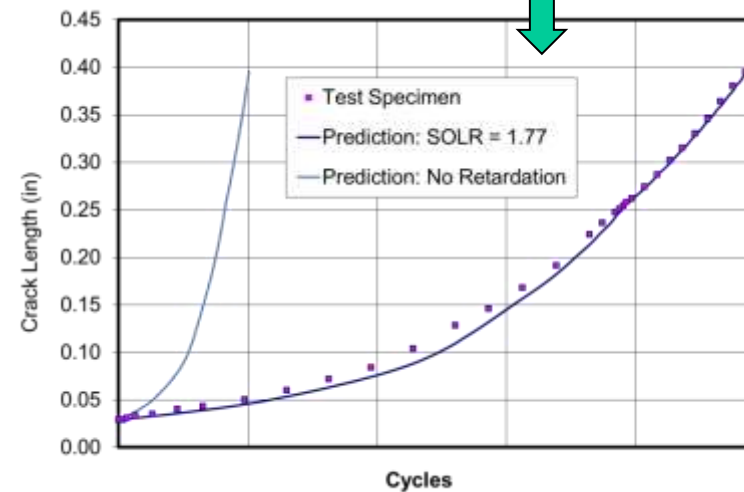
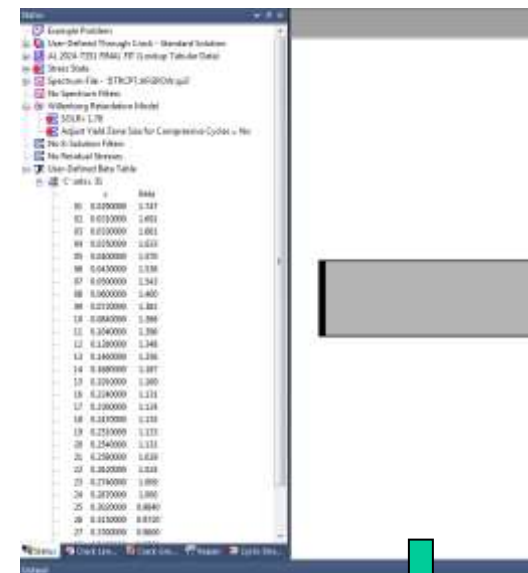
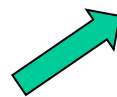
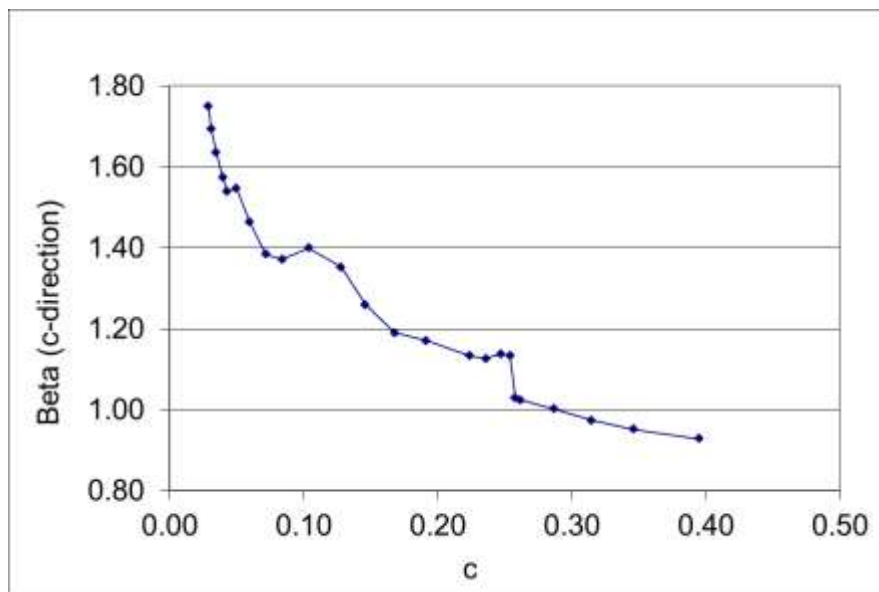
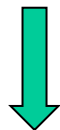
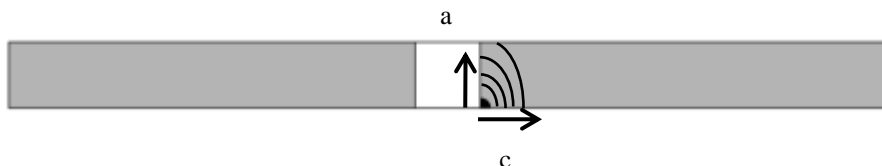
So, How is SOLR Derived for Variable Amplitude Loading?



Previous Correlation Procedure

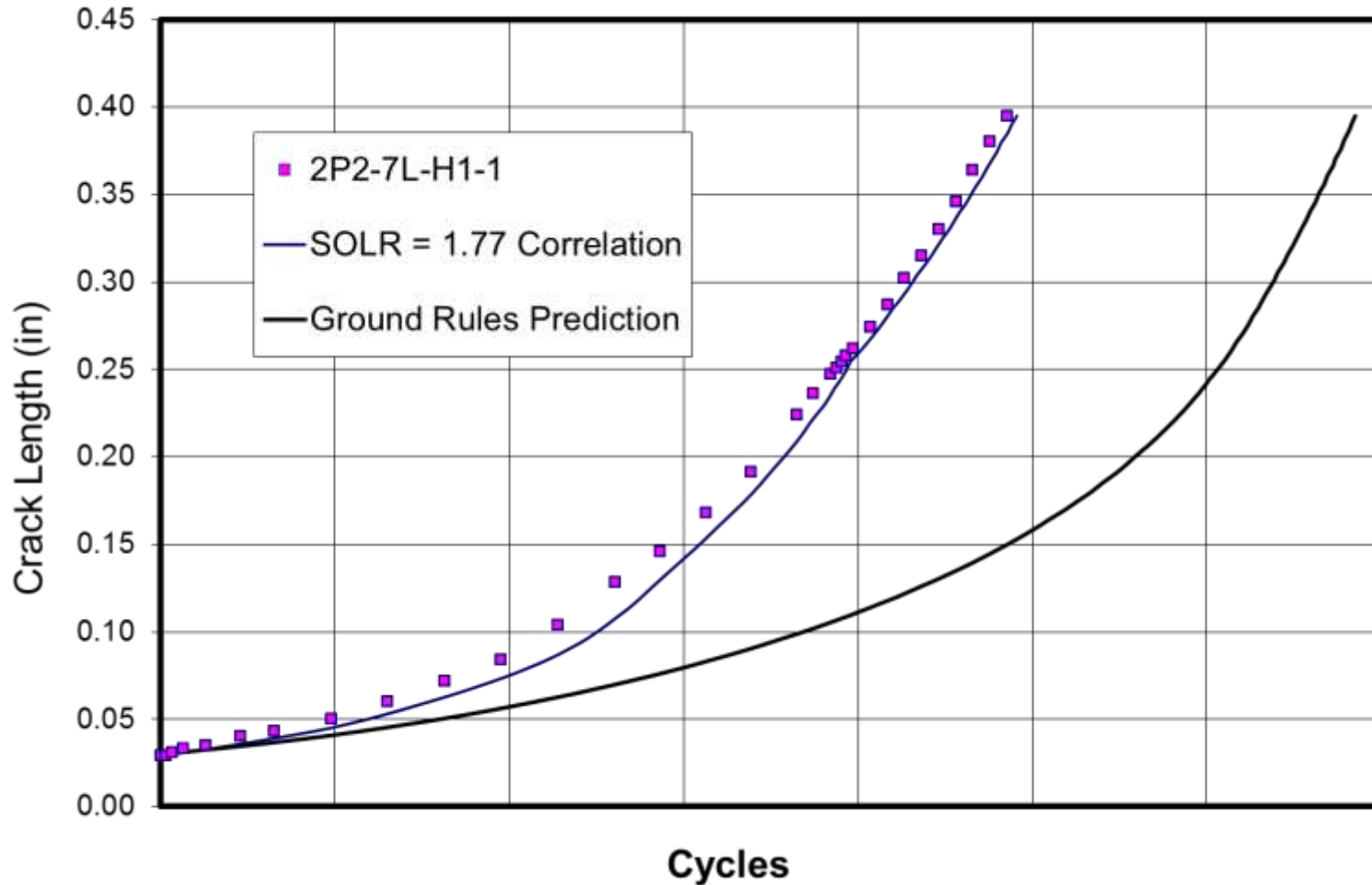


Previous Correlation Procedure



Previous Correlation Procedure (Results)

2024-T351 Low Peak Stress (Thick Skin)



Ground Rules Model:

- 1) $A/C = 1$
- 2) AFGROW Classic corner crack at a hole model.
- 3) Coupon Geometry and Stress used
- 4) $SOLR = 1.77$

Correlation Model:

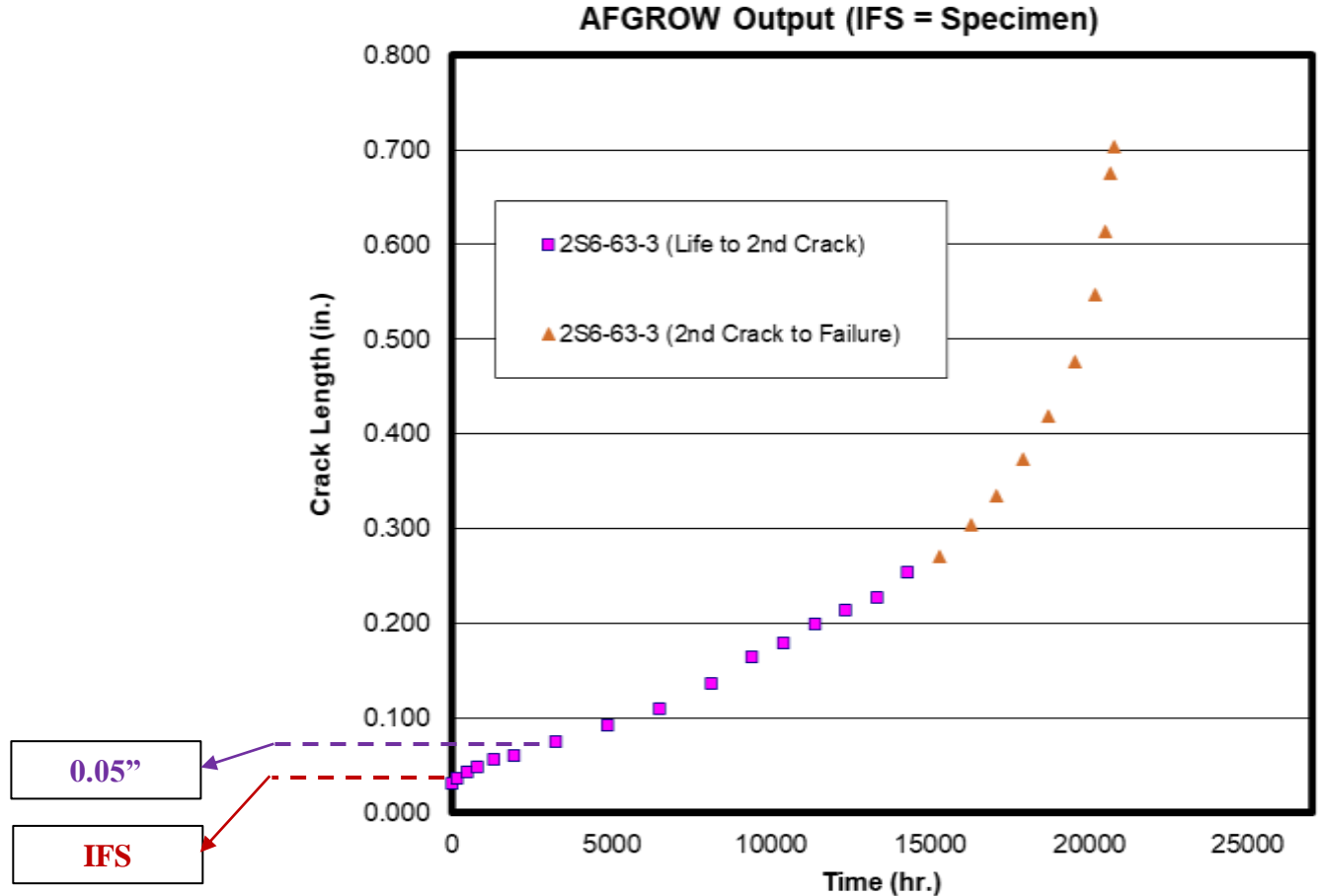
- 1) $A/C = \text{Variable}$
- 2) User Defined Betas from StressCheck
- 3) Coupon Geometry and Stress used
- 4) $SOLR = 1.77$



Correlation Procedure Study

Spectrum Test Correlation Study (Where to Start?)

Cycles	Flight Hrs	Flight Hours from 0.05 IFS	Crack Length					
			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
0				0.020				0.018
60,000				0.030				0.031
0	0			0.030				0.031
5,000	163			0.035				0.037
15,000	489			0.042				0.042
25,000	815			0.048				0.050
40,000	1303	349		0.055				0.055
60,000	1955	1001		0.060				0.062
100,000	3258	2304		0.074				0.074
150,000	4887	3933		0.091				0.095
200,000	6516	5562		0.109		0.037		
250,000	8146	7191		0.135		0.083		
290,000	9449	8495		0.163		0.130		
320,000	10426	9472		0.178		0.140		
350,000	11404	10450		0.198		0.158		
380,000	12381	11427		0.213		0.202		
410,000	13359	12404		0.227		0.218		
440,000	14336	13382		0.253		0.247		
470,000	15314	14359	0.061	0.271	0.057	0.253		
500,000	16291	15337	0.107	0.304	0.093	0.279		
525,000	17106	16151	0.141	0.335	0.124	0.309		
550,000	17920	16966	0.172	0.374	0.163	0.351		
575,000	18735	17781	0.219	0.419	0.212	0.397		
600,000	19549	18595	0.285	0.476	0.269	0.460		
620,000	20201	19247	0.351	0.547	0.348	0.543		
630,000	20527	19573	0.414	0.614	0.412	0.599		
635,000	20690	19735	0.470	0.676	0.471	0.676		
638,000	20787	19833	0.496	0.703	0.502	0.697		
640,715	20876		Specimen Failed					



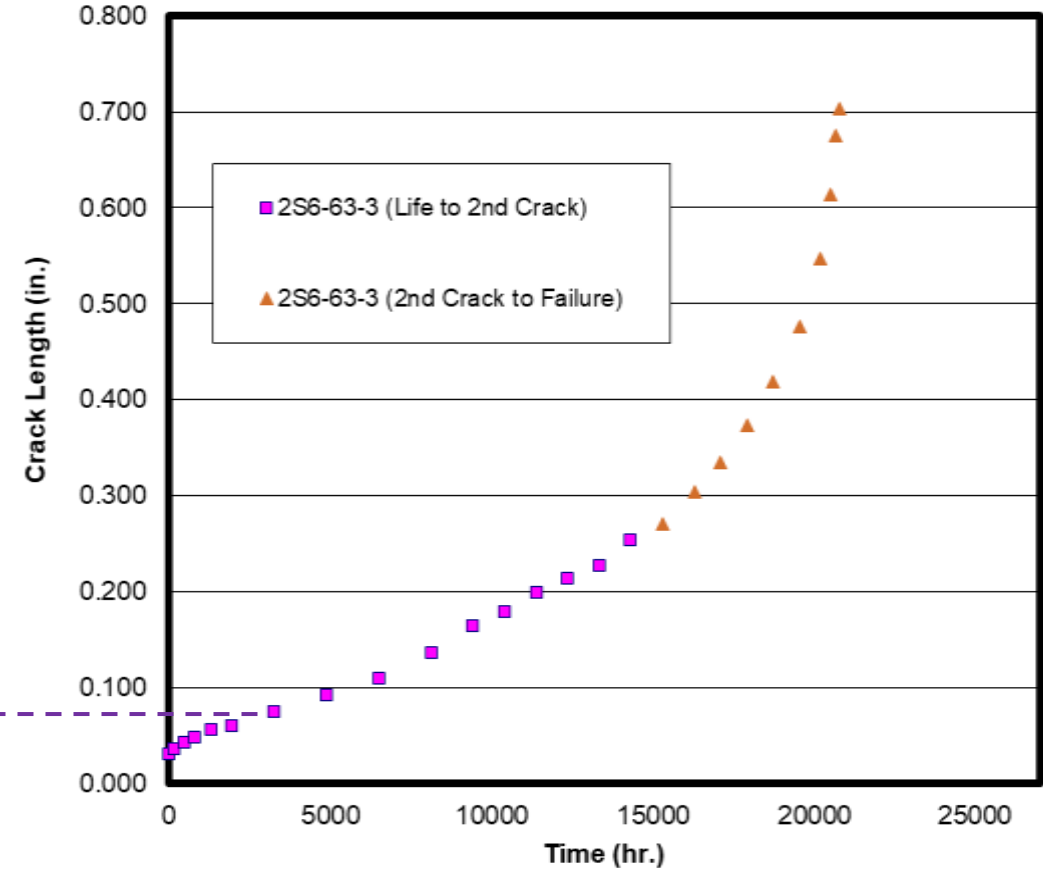


Spectrum Test Correlation Study (Where to End?)



Cycles	Flight Hrs	Flight Hours from 0.05 IFS	Crack Length					
			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
0				0.020				0.018
60,000				0.030				0.031
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640,715	20876		Specimen Failed					

AFGROW Output (IFS = Specimen)



Half Life to Thru Crack

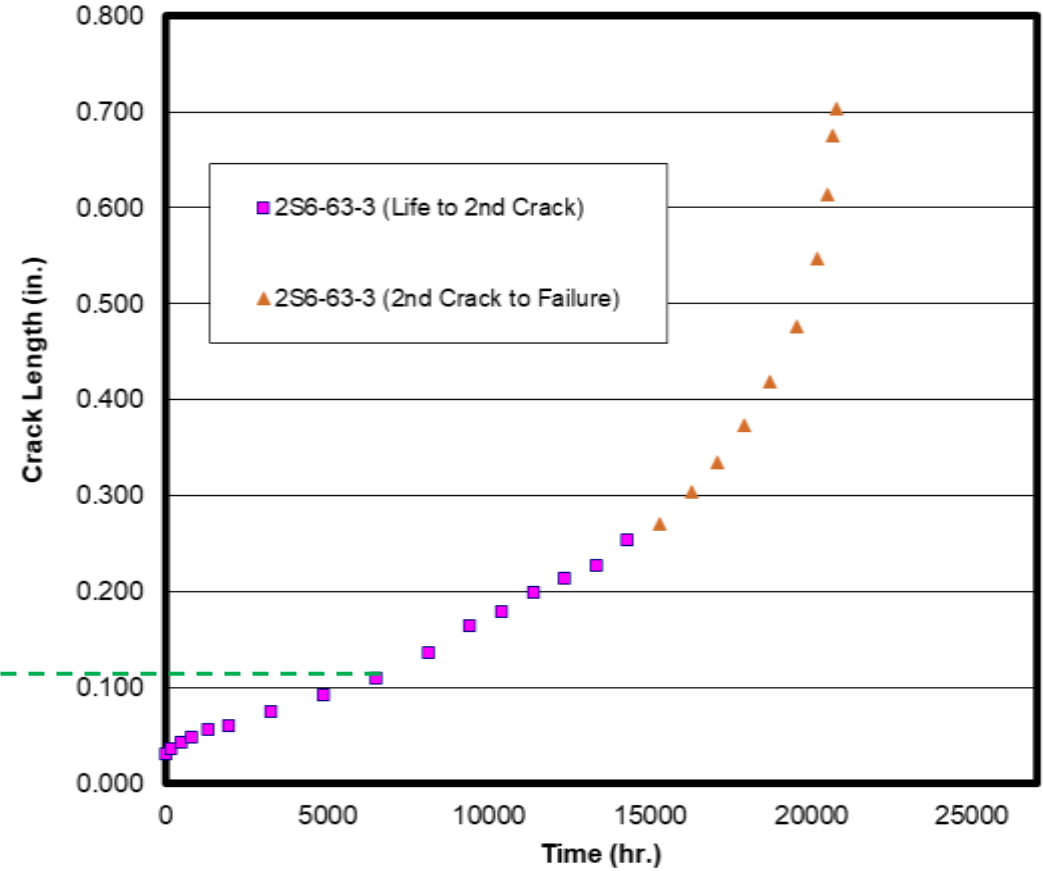
Spectrum Test Correlation Study

(Where to End?)

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640,715	20876		Specimen Failed					

Thru thickness transition

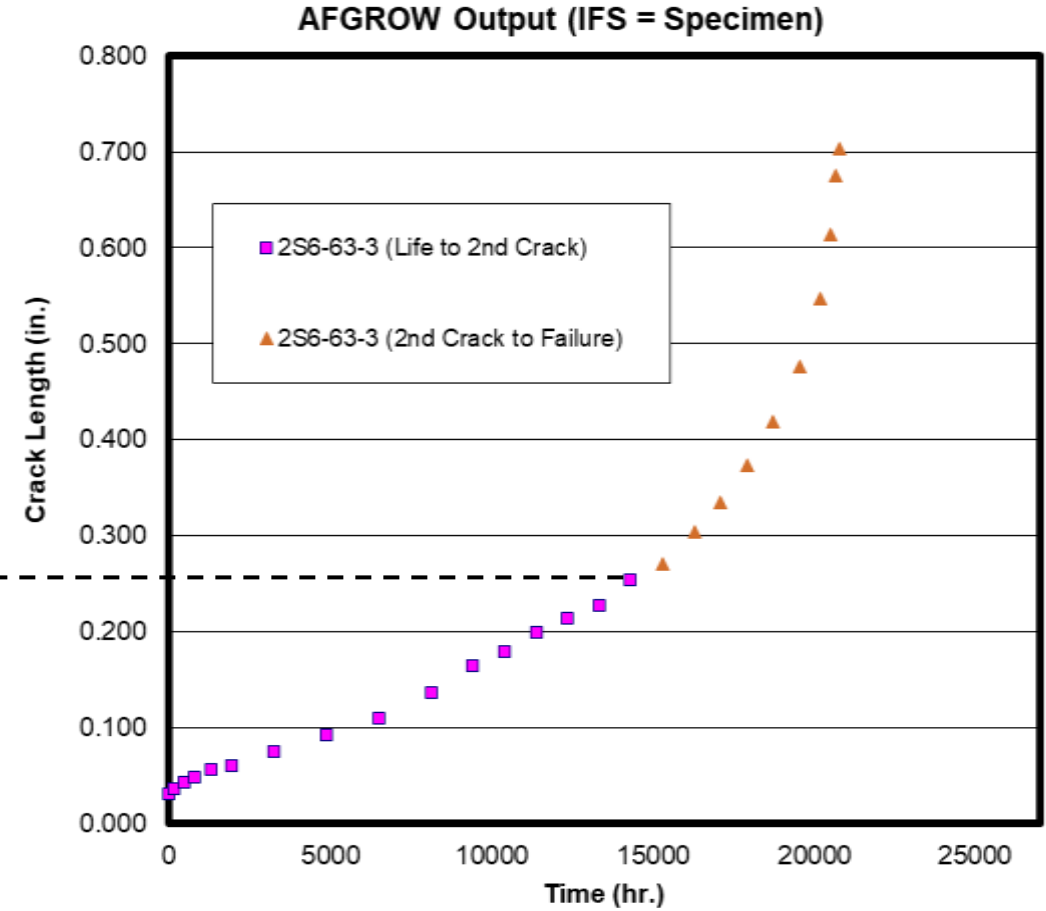
AFGROW Output (IFS = Specimen)



Spectrum Test Correlation Study (Where to End?)

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			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
0				0.020			0.018	
60,000				0.030			0.031	
0	0			0.030			0.031	
5,000	163			0.035			0.037	
15,000	489			0.042			0.042	
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40,000	1303	349		0.055			0.055	
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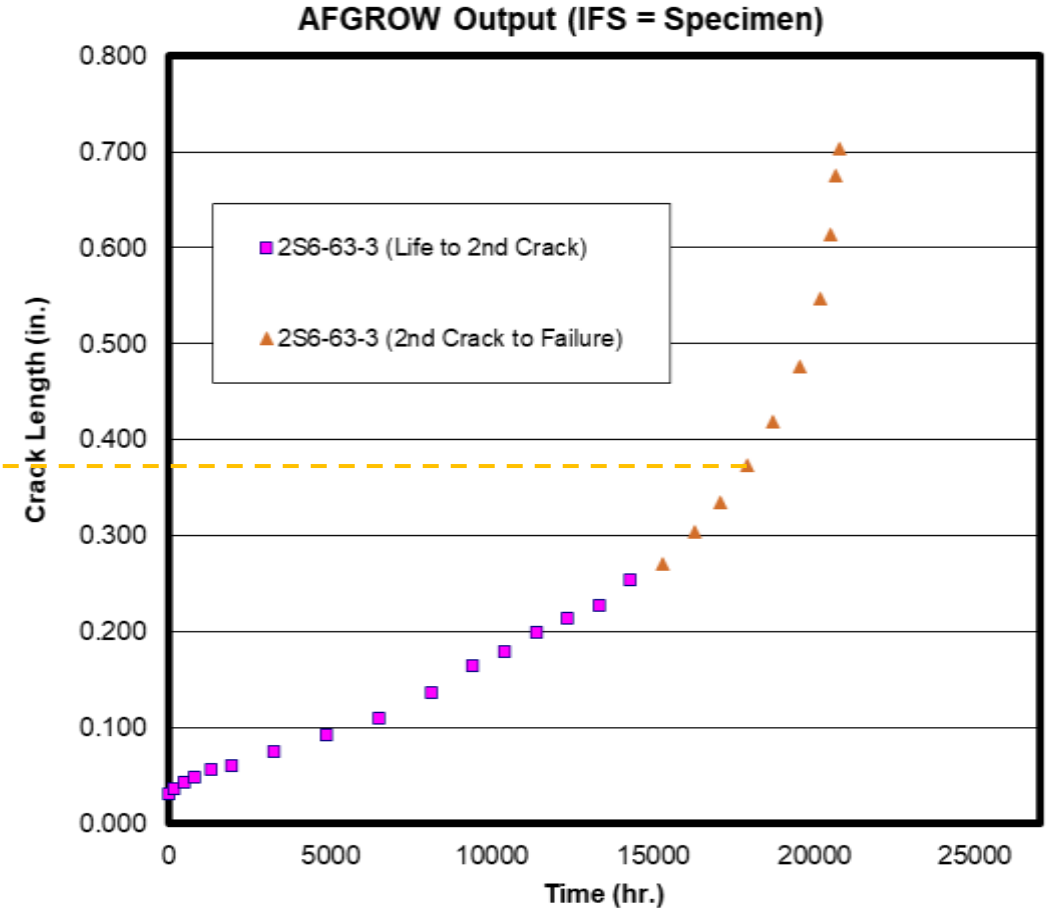
Life to Secondary Crack



Spectrum Test Correlation Study (Where to End?)

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			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
0				0.020				0.018
60,000				0.030				0.031
0	0			0.030				0.031
5,000	163			0.035				0.037
15,000	489			0.042				0.042
25,000	815			0.048				0.050
40,000	1303	349		0.055				0.055
60,000	1955	1001		0.060				0.062
100,000	3258	2304		0.074				0.074
150,000	4887	3933		0.091				0.095
200,000	6516	5562		0.109		0.037		
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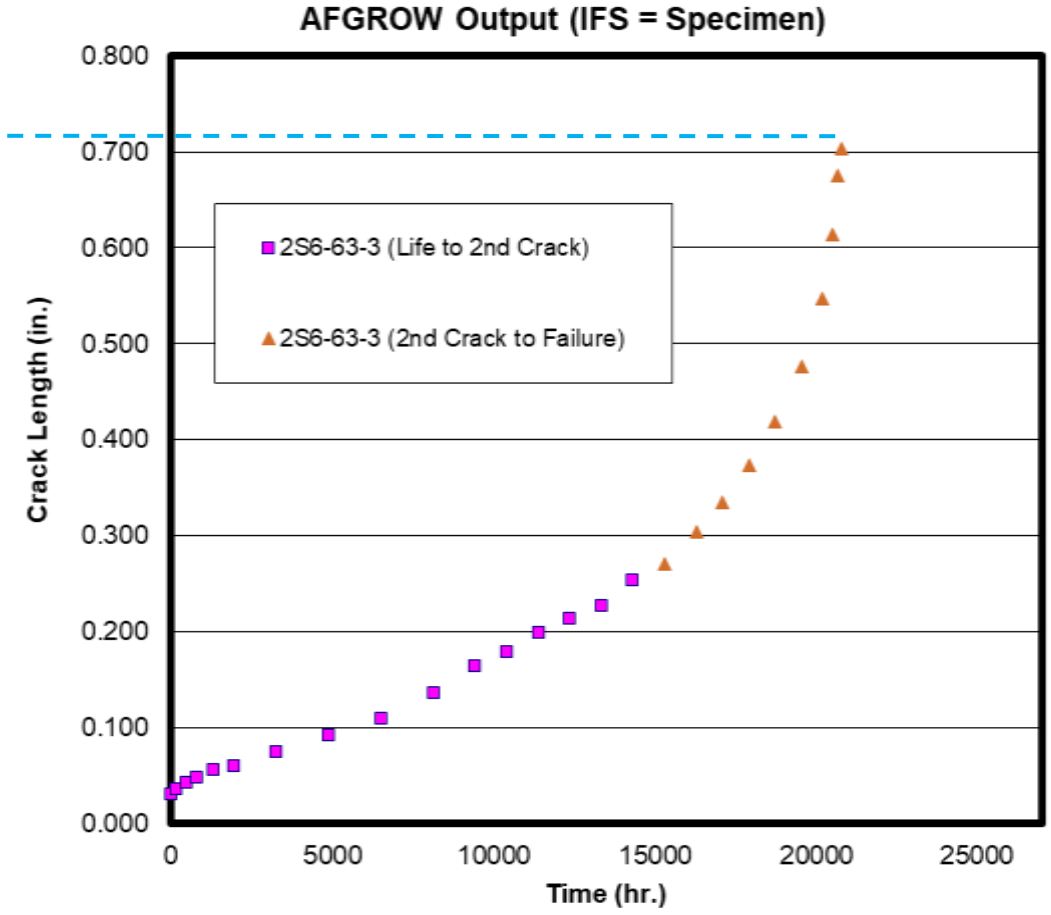
Half Life to Failure



Spectrum Test Correlation Study (Where to End?)

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			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
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60,000				0.030			0.031	
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250,000	8146	7191		0.135		0.083		
290,000	9449	8495		0.163		0.130		
320,000	10426	9472		0.178		0.140		
350,000	11404	10450		0.198		0.158		
380,000	12381	11427		0.213		0.202		
410,000	13359	12404		0.227		0.218		
440,000	14336	13382		0.253		0.247		
470,000	15314	14359	0.061	0.271	0.057	0.253		
500,000	16291	15337	0.107	0.304	0.093	0.279		
525,000	17106	16151	0.141	0.335	0.124	0.309		
550,000	17920	16966	0.172	0.374	0.163	0.351		
575,000	18735	17781	0.219	0.419	0.212	0.397		
600,000	19549	18595	0.285	0.476	0.269	0.460		
620,000	20201	19247	0.351	0.547	0.348	0.543		
630,000	20527	19573	0.414	0.614	0.412	0.599		
635,000	20690	19735	0.470	0.676	0.471	0.676		
638,000	20787	19833	0.496	0.703	0.502	0.697		
640,715	20876							Specimen Failed

Total Life to Failure

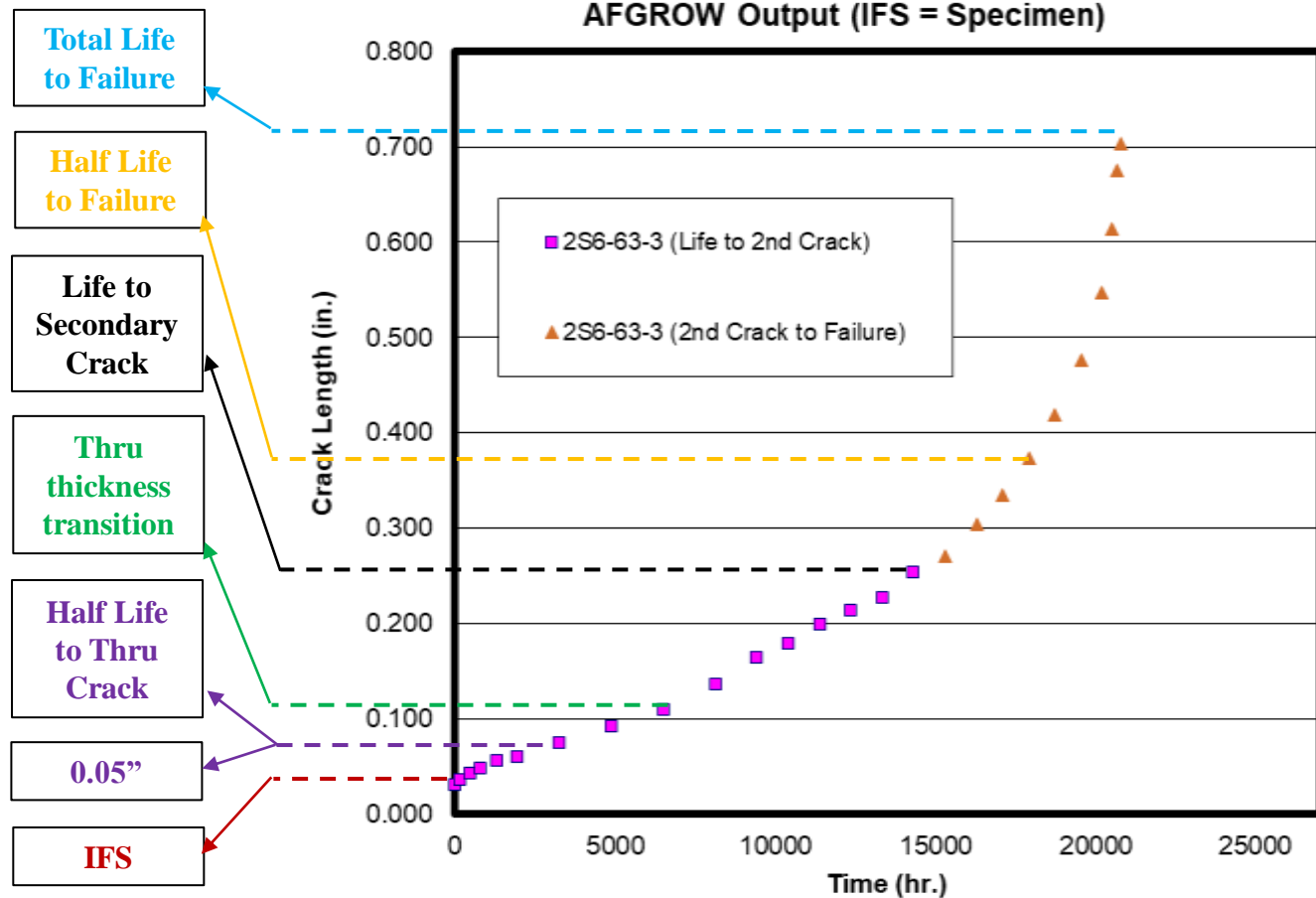




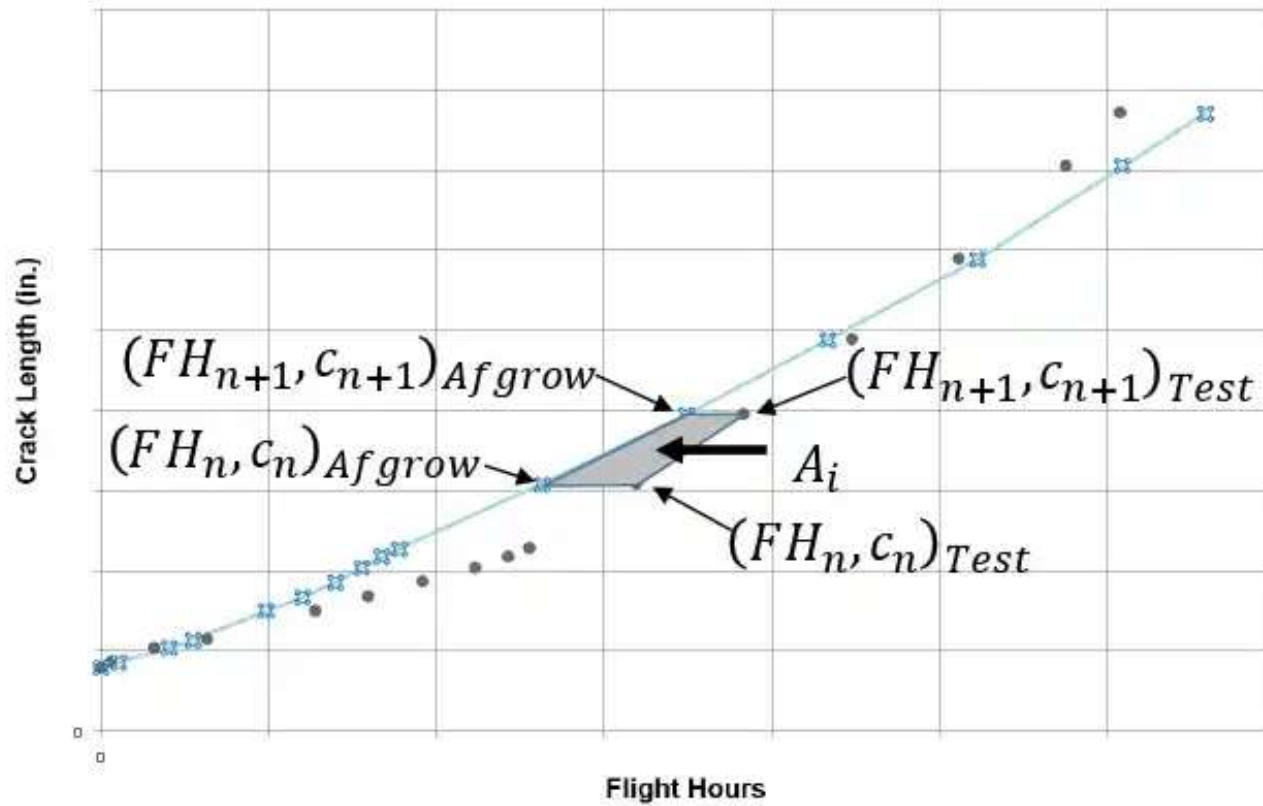
Spectrum Test Correlation Study (Where to End?)



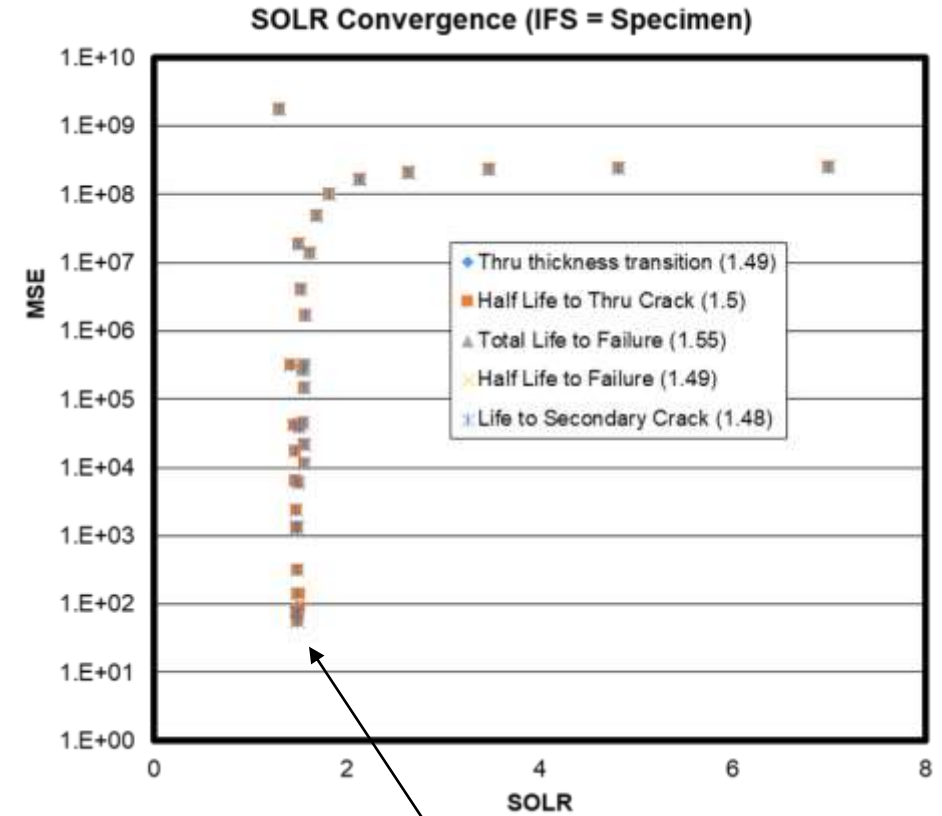
Cycles	Flight Hrs	Flight Hours from 0.05 IFS	Crack Length					
			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
0				0.020				0.018
60,000				0.030				0.031
0	0			0.030				0.031
5,000	163			0.035				0.037
15,000	489			0.042				0.042
25,000	815			0.048				0.050
40,000	1303	349		0.055				0.055
60,000	1955	1001		0.060				0.062
100,000	3258	2304		0.074				0.074
150,000	4887	3933		0.091				0.095
200,000	6516	5562		0.109		0.037		
250,000	8146	7191		0.135		0.083		
290,000	9449	8495		0.163		0.130		
320,000	10426	9472		0.178		0.140		
350,000	11404	10450		0.198		0.158		
380,000	12381	11427		0.213		0.202		
410,000	13359	12404		0.227		0.218		
440,000	14336	13382		0.253		0.247		
470,000	15314	14359	0.061	0.271	0.057	0.253		
500,000	16291	15337	0.107	0.304	0.093	0.279		
525,000	17106	16151	0.141	0.335	0.124	0.309		
550,000	17920	16966	0.172	0.374	0.163	0.351		
575,000	18735	17781	0.219	0.419	0.212	0.397		
600,000	19549	18595	0.285	0.476	0.269	0.460		
620,000	20201	19247	0.351	0.547	0.348	0.543		
630,000	20527	19573	0.414	0.614	0.412	0.599		
635,000	20690	19735	0.470	0.676	0.471	0.676		
638,000	20787	19833	0.496	0.703	0.502	0.697		
640,715	20876							Specimen Failed



Correlation Targets (Mean Square Error)



Michael Wilcox, "T-38 Durability and Damage Tolerance Analysis Update", AFGROW Conference 2019



Iterated until Difference in SOLR was less than 0.01

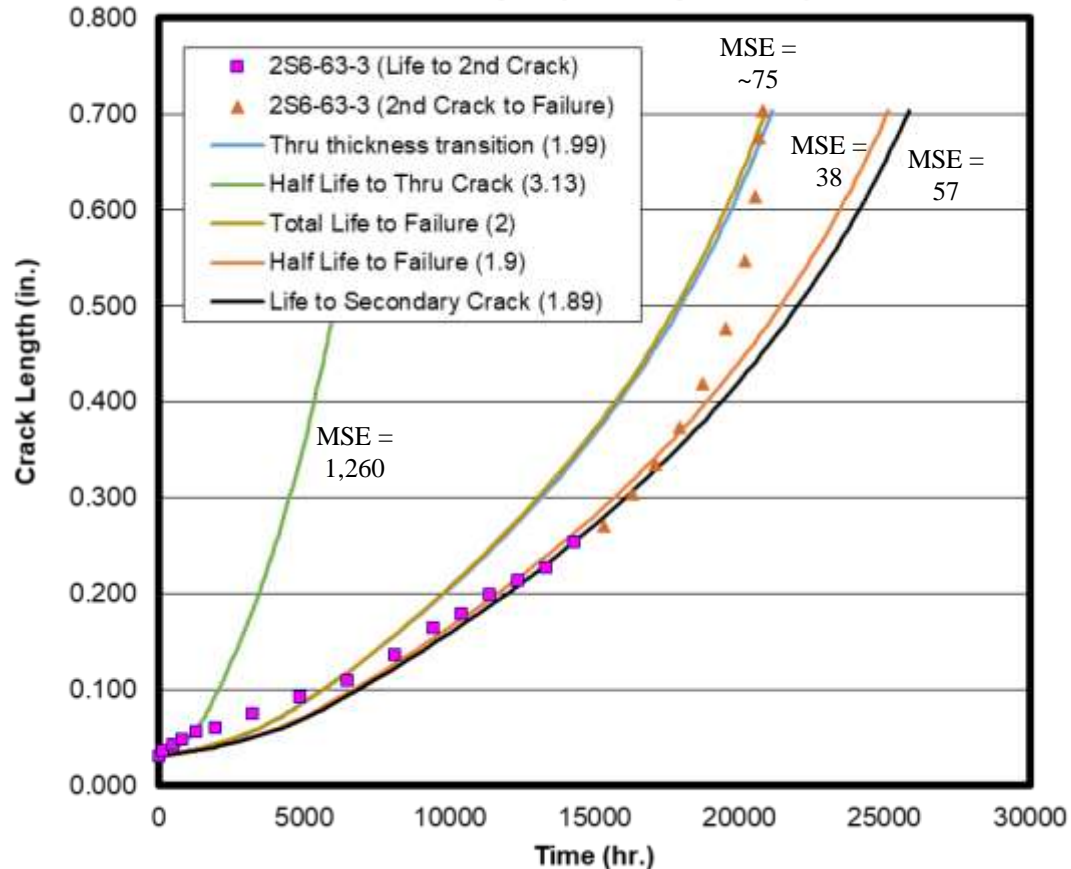


Correlation Study (Results)



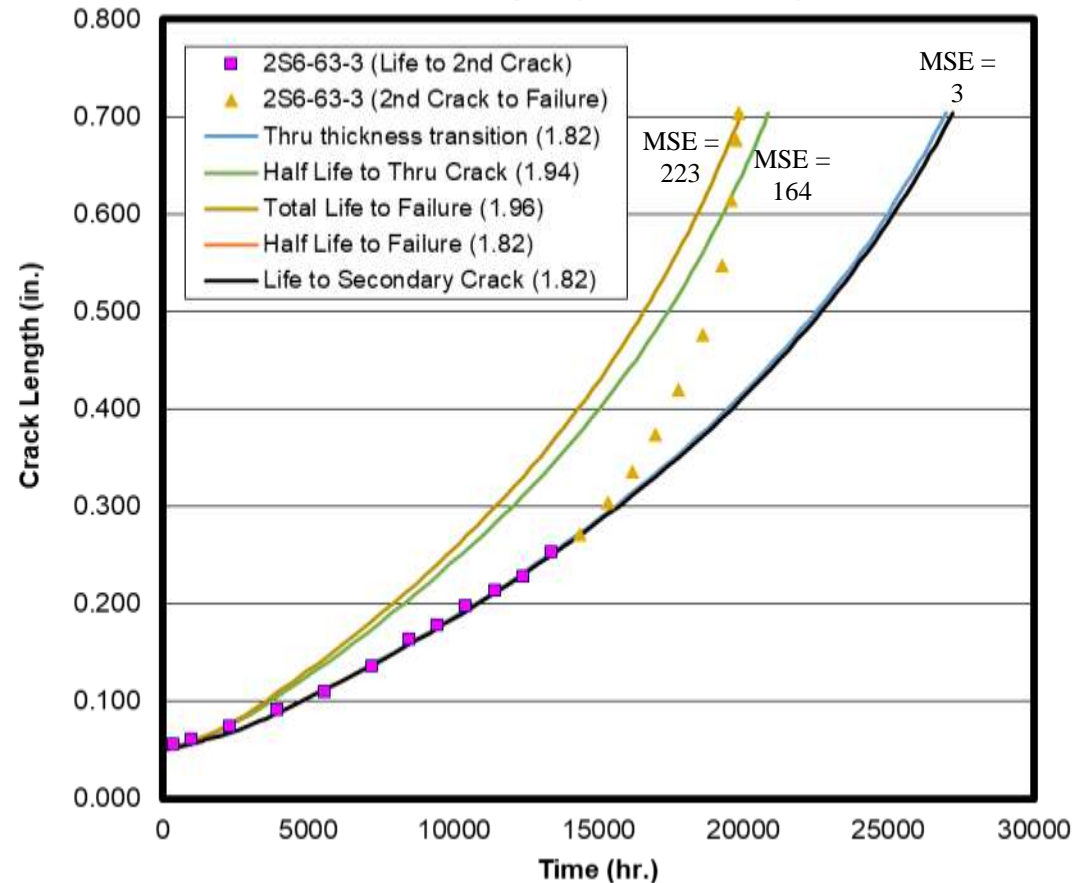
Note: In all cases, the MSE value compares the portion of the crack growth curve from 0.05 / IFS to the secondary flaw.

AFGROW Output (IFS = Specimen)



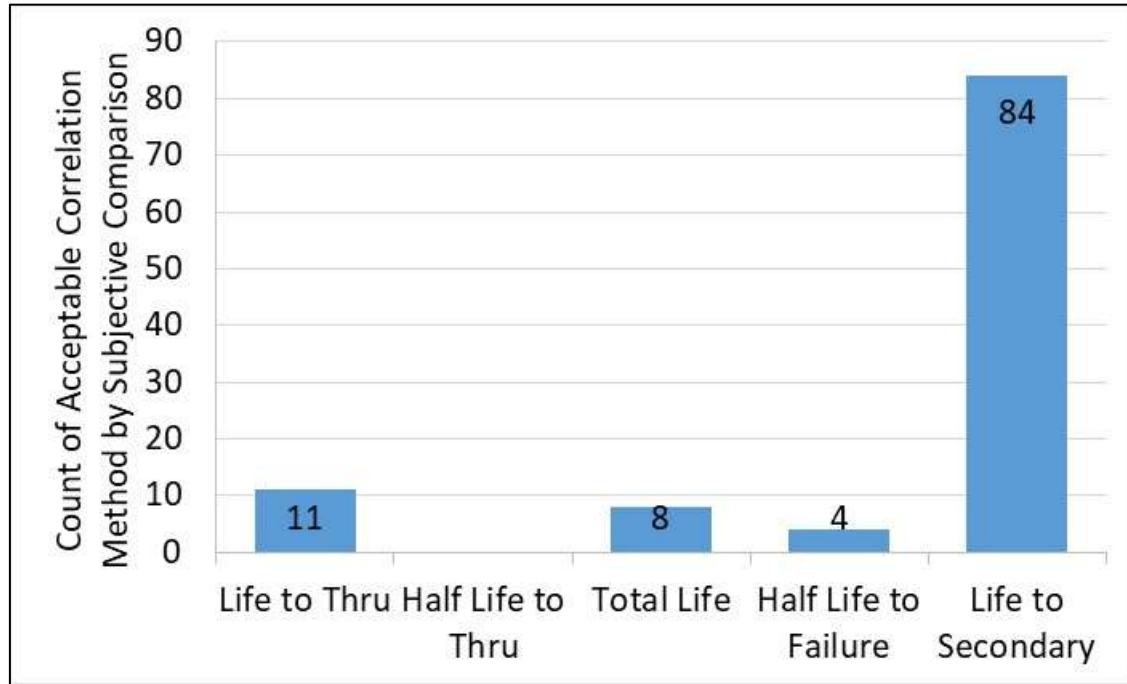
Starting from the IFS

AFGROW Output (IFS = 0.050 in.)



Starting from the 0.05"

Correlation Study (Results)



	Life to Thru	Half Life to Thru	Total Life	Half Life	Life to Secondary
Max MSE	279.22	572.02	824.06	114.67	107.55
Average MSE	48.01	144.27	118.21	21.59	15.43



General Patterns Noticed and SOLR Correlation Results

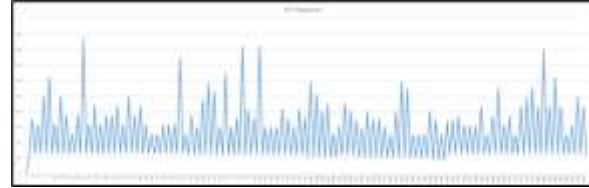


Determine SOLR for Non-Tested Geometry (Overload Dominated Spectra – Spectra Comparisons)



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Material	Spectrum	Coupon Type	Thickness	Stress	Test ID	SOLR (new)	SOLR (Highest SOLR)	SOLR (Average SOLR)
7075-T6	DTRCP69.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-1	1.57	1.57	1.55
7075-T6	DTRCP69.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-2	1.53	1.57	1.55
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-3	1.54	1.59	1.56
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-4	1.59	1.59	1.56
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-5	1.54	1.59	1.56
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	25	NCX 2024-5	1.73	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	25	NCX 2024-6	1.76	1.78	1.75
2024-T351	DTRCP34.AFGROW	Corner Crack at Centered Hole	0.21	22.594	B-CP-34T-1	1.74	1.78	1.75
2024-T351	DTRCP34.AFGROW	Corner Crack at Centered Hole	0.21	22.337	B-CP-34T-2	1.75	1.78	1.75
2024-T351	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.128	28.558	A10-CP42A-3	1.7	1.77	1.74
2024-T351	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.128	28.558	A10-CP42A-1	1.77	1.77	1.74
2024-T3511	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.252	20.977	CP-42B-2	1.7	1.7	1.70
2024-T3511	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.252	20.961	CP-42B-1	1.69	1.7	1.70
2024-T3511	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	20	SOLR-4-1	1.71	1.71	1.68
2024-T3511	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	20	SOLR-4-2	1.69	1.71	1.68
2024-T3511	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	20	SOLR-4-3	1.64	1.71	1.68
2224-T3511	DTRCP27.AFGROW	Corner Crack at Centered Hole	0.22	24.31	E-CP-30T-1	2.08	2.08	1.96
2224-T3511	DTRCP27.AFGROW	Corner Crack at Centered Hole	0.22	24.31	E-CP-30T-2	1.93	2.08	1.96
2224-T3511	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.4	23.992	E-CP4T-2	1.91	2.08	1.96
2224-T3511	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.4	23.992	E-CP4T-3	1.93	2.08	1.96
7075-T76	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.165	36.675	CP6-1	1.96	2.13	2.05
7075-T76	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.165	36.675	CP6-5	2.01	2.13	2.05
7075-T76	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.165	33.425	CP6-2	2.08	2.13	2.05
7075-T76	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.165	33.425	CP6-3	2.13	2.13	2.05
7075-T76	DTRCP15.AFGROW	Corner Crack at Centered Hole	0.19	18.714	CP15T-1	2	2	1.97
7075-T76	DTRCP15.AFGROW	Corner Crack at Centered Hole	0.19	18.714	CP15T-2	1.94	2	1.97
7075-T76	DTRCP15.AFGROW	Corner Crack at Centered Hole	0.19	18.714	CP15T-4	1.96	2	1.97
7175-T74	DTRCP27.AFGROW	Corner Crack at Centered Hole	0.18	19.79	7FA-CP27L-1	2.1	2.15	2.13
7175-T74	DTRCP27.AFGROW	Corner Crack at Centered Hole	0.18	19.79	7FA-CP27L-2	2.15	2.15	2.13
7175-T74	DTRCP51L.AFGROW	Corner Crack at Centered Hole	0.5	22.121	CP51-A	1.98	1.98	1.96
7175-T74	DTRCP51L.AFGROW	Corner Crack at Centered Hole	0.5	22.121	CP51-C	1.94	1.98	1.96



~1.55

~1.75

~1.70

~1.96

~2.00

~2.00



Determine SOLR for Non-Tested Geometry

(Spectra with overload/underloads – Spectra Comparisons)



Material	Spectrum	Coupon Type	Thickness	Stress	Test ID	SOLR (new)	SOLR (Highest SOLR)	SOLR (Average SOLR)
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	28.106	CP44-3H	1.59	1.6	1.60
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	28.106	CP44-6H	1.6	1.6	1.60
2024-T3511	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.25	28.106	2E6-44B-1	1.54	1.6	1.53
2024-T3511	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.25	28.106	2E6-44B-2	1.52	1.6	1.53
7075-T76511	DTRCP47.AFGROW	Corner Crack at Centered Hole	0.125	29.044	7E2-CP47-A1	1.85	2.1	1.97
7075-T76511	DTRCP47.AFGROW	Corner Crack at Centered Hole	0.125	29.044	7E2-CP47-A2	1.89	2.1	1.97
7075-T76511	DTRCP47.AFGROW	Corner Crack at Centered Hole	0.125	29.044	7E2-CP47-A3	2.1	2.1	1.97
7075-T76511	DTRCP47new.AFGROW	Corner Crack at Centered Hole	0.125	29.044	7E6-47-A1	2.02	2.1	1.97
7075-T76511	DTRCP47new.AFGROW	Corner Crack at Centered Hole	0.125	29.044	7E6-47-A3	1.99	2.1	1.97
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2S2-CP44H-H1-1	1.88	1.88	1.88
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2S2-CP44H-H1-2	1.88	1.88	1.88
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2S2-CP44H-H1-3	1.88	1.88	1.88
2024-T3	DTRCP451.AFGROW	Corner Crack at Centered Hole	0.183	25.133	2S2-CP45-H1-1	2.34	2.26	2.33
2024-T3	DTRCP451.AFGROW	Corner Crack at Centered Hole	0.183	25.133	2S2-CP45-H1-2	2.32	2.26	2.33
2024-T351	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2P6-44A-1	1.65	1.69	1.67
2024-T351	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2P6-44A-4	1.69	1.69	1.67
2024-T351	DTRCP451.AFGROW	Corner Crack at Centered Hole	0.183	25.133	2P2-CP45-H1-2	2.11	2.26	2.08
2024-T351	DTRCP451.AFGROW	Corner Crack at Centered Hole	0.183	25.133	2P2-CP45-H1-1	2.05	2.26	2.08



Determine SOLR for Non-Tested Geometry (Overload Dominated Spectra – Stress Level Comparisons)



Stresses
between 70%
Fty and 20 ksi

For overload dominated spectra there does not appear to be a dependence on stress level when the stresses are between 20 ksi and 70% Fty for all the material we have data for, with the exception of 7075-T6.

7075-T6 Does not follow same pattern as remaining material

Material	Spectrum	Coupon Type	Thickness	Stress	Test ID	SOLR (new)	SOLR (Highest SOLR)	SOLR (Average SOLR)
7075-T6	DTRCP69.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-1	1.57	1.57	1.55
7075-T6	DTRCP69.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-2	1.53	1.57	1.55
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-3	1.54	1.59	1.56
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-4	1.59	1.59	1.56
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.063	40.611	CP69-H-5	1.54	1.59	1.56
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.105	36.675	CP3-H-1	1.66	1.66	1.65
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.105	36.675	CP3-H-2	1.63	1.66	1.65
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.105	33.425	CP3-H-3	1.69	1.72	1.69
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.105	33.425	CP3-H-5	1.67	1.72	1.69
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.105	33.425	CP3-H-4	1.72	1.72	1.69
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.108	22.588	752-CP7-1-1	1.89	1.89	1.85
7075-T6	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.108	22.588	752-CP7-1-3	1.81	1.89	1.85
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	35	2P2-7M-H1-1	1.74	1.88	1.76
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	35	2P2-7M-H1-2	1.77	1.88	1.76
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	33	NCX 2024-1	1.73	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	33	NCX 2024-2	1.77	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	33	NCX 2024-3	1.69	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.2)	0.25	33	OFF-NCX2024-5	1.80	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.3)	0.25	33	NCX130ED-1	1.83	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.3)	0.25	33	NCX130ED-2	1.73	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.4)	0.25	33	NCX140ED-1	1.77	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.4)	0.25	33	NCX140ED-2	1.76	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.5)	0.25	33	NCX150ED-1	1.76	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 1.5)	0.25	33	NCX150ED-2	1.75	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 2.0)	0.25	33	NCX200ED-1	1.69	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at offset Hole (ED = 2.0)	0.25	33	NCX200ED-2	1.73	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	27.909	2P2-7L-H1-2	1.78	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.3	27.909	2P2-7L-H1-1	1.78	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	25	NCX 2024-4	1.72	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	25	NCX 2024-5	1.73	1.78	1.75
2024-T351	DTRCP7.AFGROW	Corner Crack at Centered Hole	0.25	25	NCX 2024-6	1.76	1.78	1.75
2024-T351	DTRCP34.AFGROW	Corner Crack at Centered Hole	0.21	22.594	B-CP-34T-1	1.74	1.78	1.75
2024-T351	DTRCP34.AFGROW	Corner Crack at Centered Hole	0.21	22.337	B-CP-34T-2	1.75	1.78	1.75





Determine SOLR for Non-Tested Geometry (Both Spectra Types – Low Stress Level)



Material	Spectrum	Coupon Type	Thickness	Stress	Test ID	SOLR (new)	SOLR (Highest SOLR)	SOLR (Average SOLR)
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2S2-CP44H-H1-1	1.88	1.88	1.88
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2S2-CP44H-H1-2	1.88	1.88	1.88
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	28.106	2S2-CP44H-H1-3	1.88	1.88	1.88
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	18.45	2S2-CP44L-H1-1	3.35	3.82	3.59
2024-T3	DTRCP44NEW.AFGROW	Corner Crack at Centered Hole	0.183	18.45	2S2-CP44L-H1-2	3.82	3.82	3.59
2024-T351	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.128	28.558	A10-CP42A-3	1.7	1.77	1.74
2024-T351	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.128	28.558	A10-CP42A-1	1.77	1.77	1.74
2024-T351	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.183	18.833	2P6-42A-3	2.05	2.05	2.06
2024-T351	DTRCP42.AFGROW	Corner Crack at Centered Hole	0.183	18.833	2P6-42A-2	2.06	2.05	2.06
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	28.106	CP44-3H	1.59	1.6	1.60
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	28.106	CP44-6H	1.6	1.6	1.60
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	18.45	CP44-1L	2.67	2.67	2.57
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	18.45	CP44-2L	2.59	2.67	2.57
2024-T3511	DTRCP44.AFGROW	Corner Crack at Centered Hole	0.25	18.45	CP44-5L	2.44	2.67	2.57

There are not many tests that have stress levels lower than 20 ksi. Where there were tests with the stress below 20 ksi and above 20 ksi, it was found that there was a large difference in SOLR.

Low Stress magnitudes for both spectra types have a large impact on the resulting SOLR. Why?



Conclusion



- **Consistent Material Fits combined with consistent correlation approaches provide more consistent behavior with respect to SOLR.**



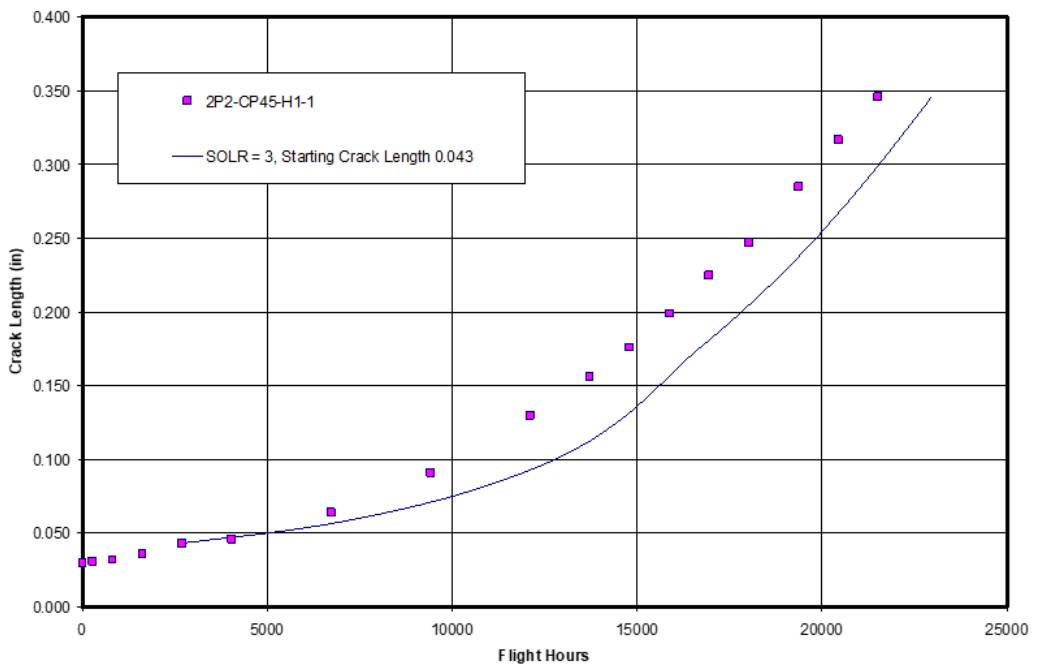
Back Up Slides



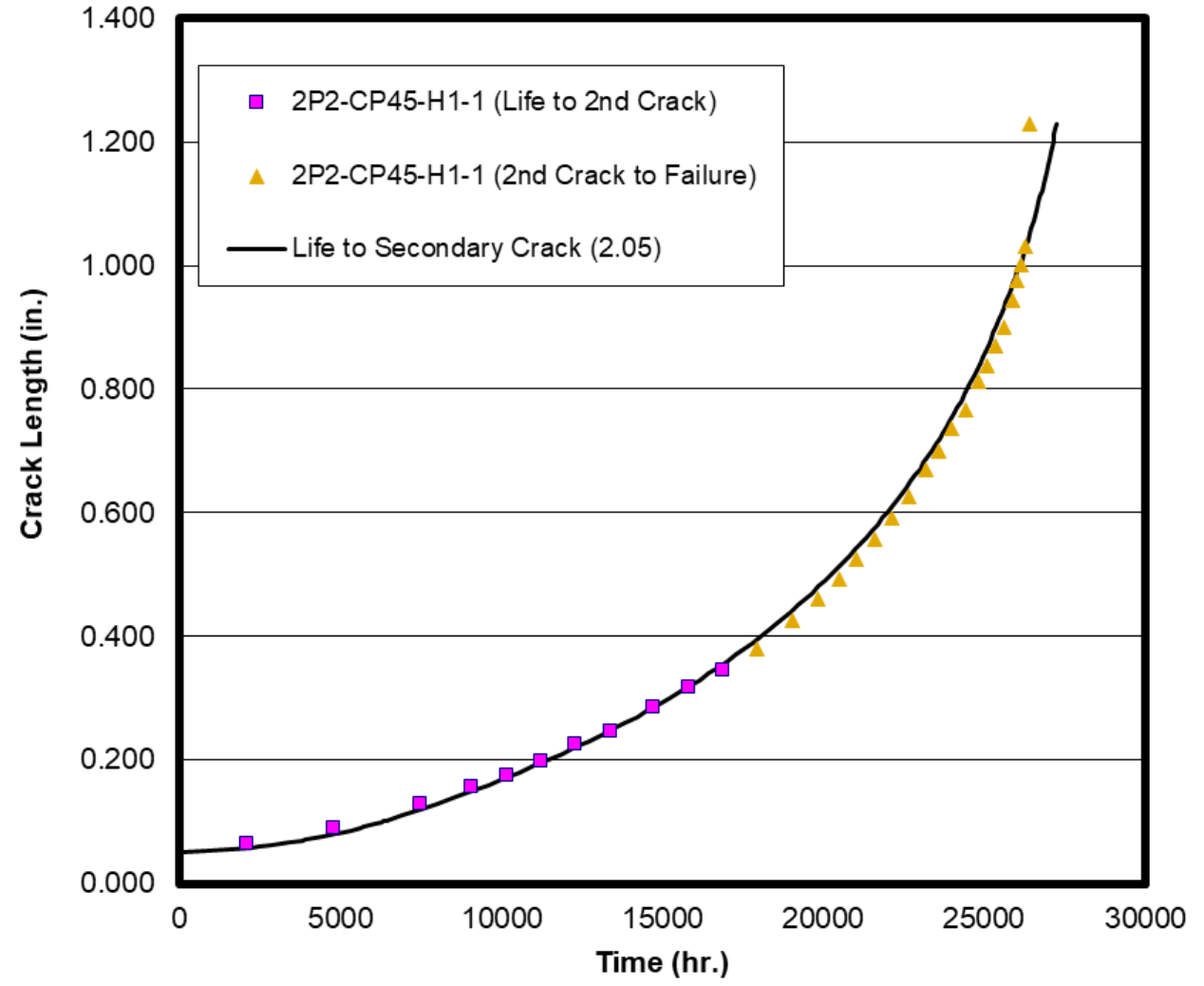
2024-T351 – Comparison with Old fits to New



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AFGROW Output (IFS = 0.050 in.)

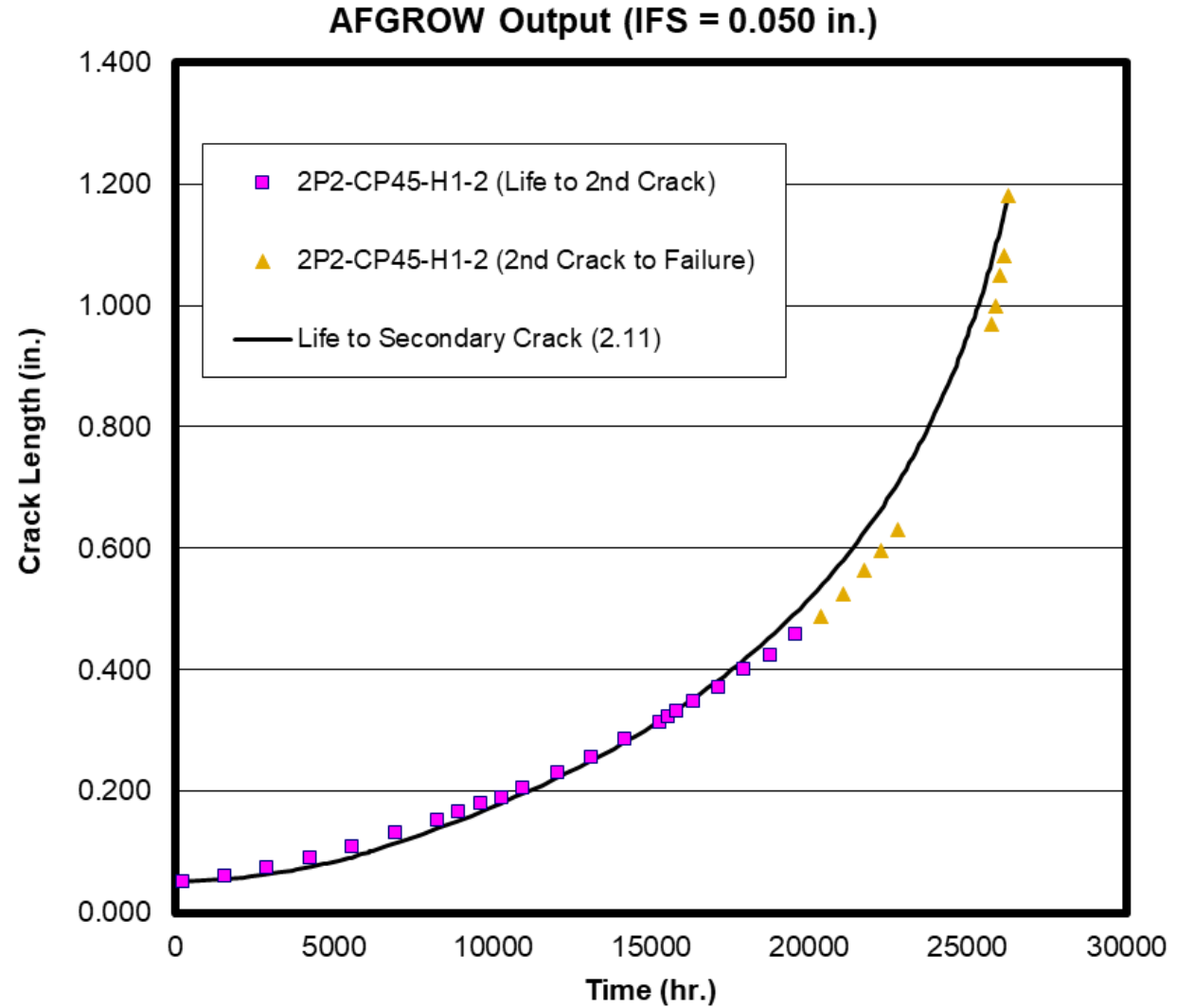
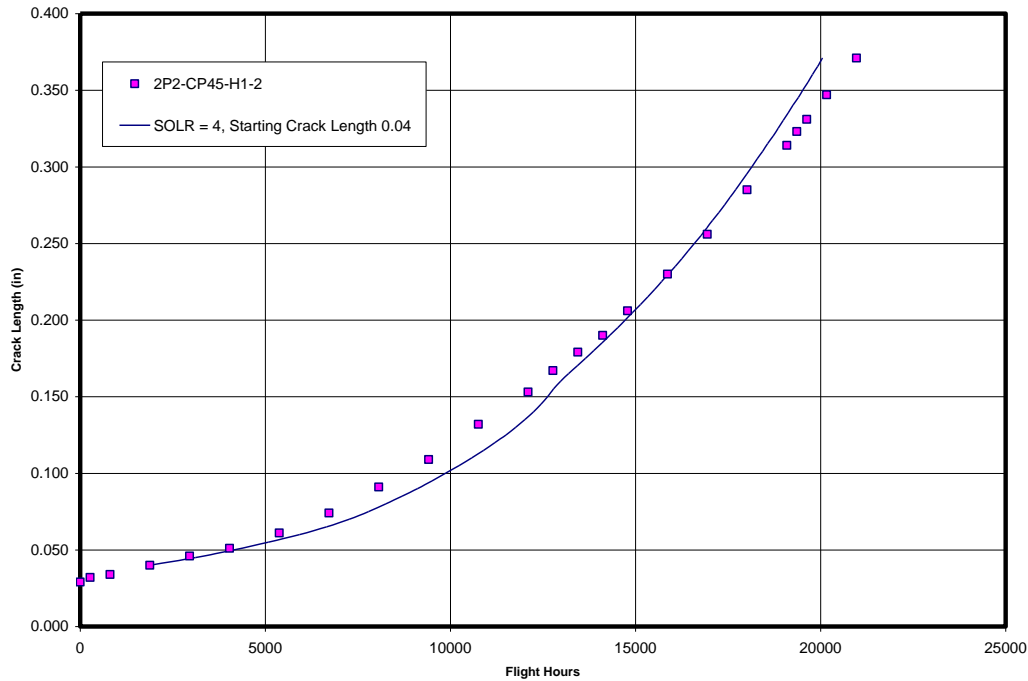




2024-T351 – Comparison with Old fits to New

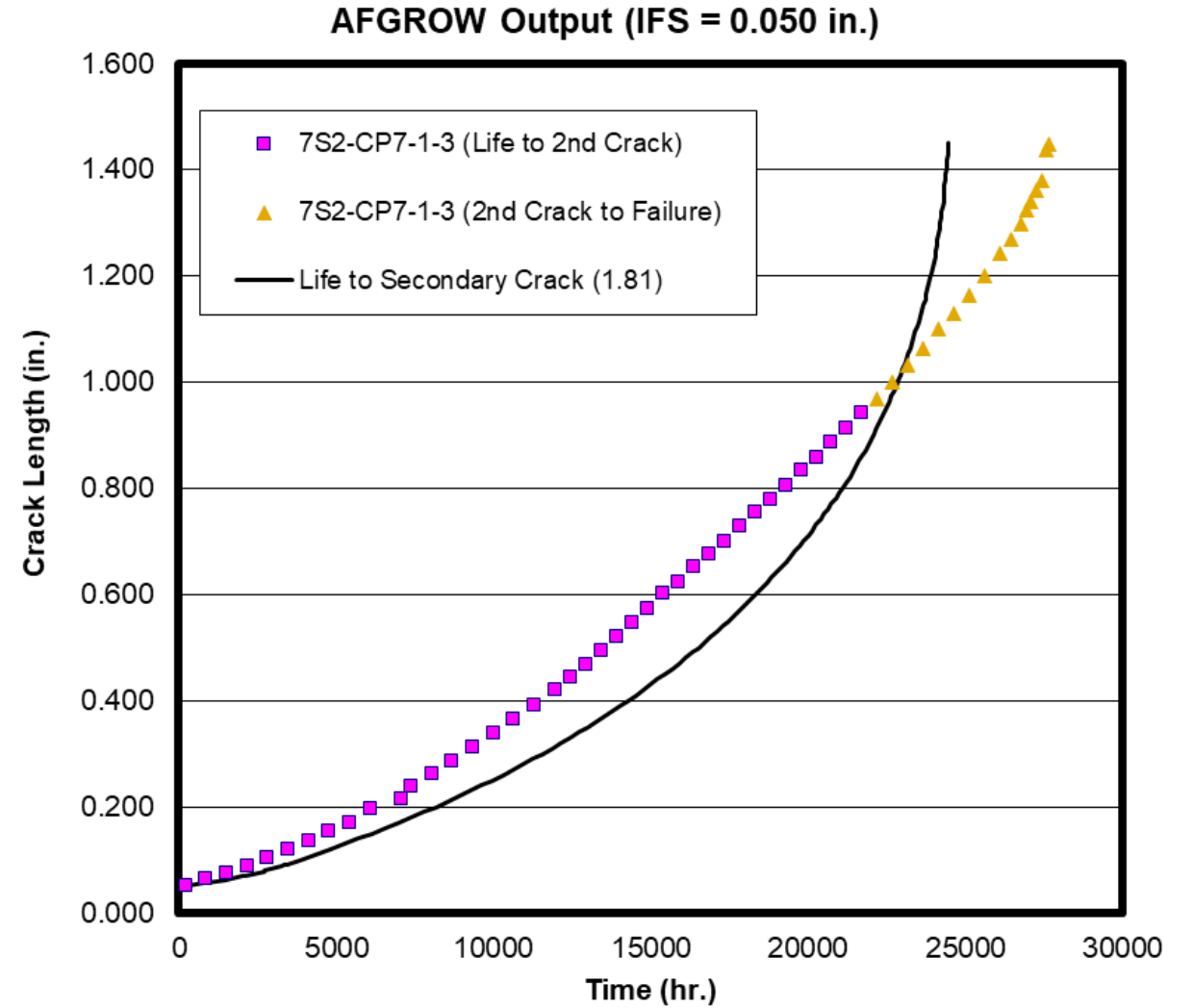
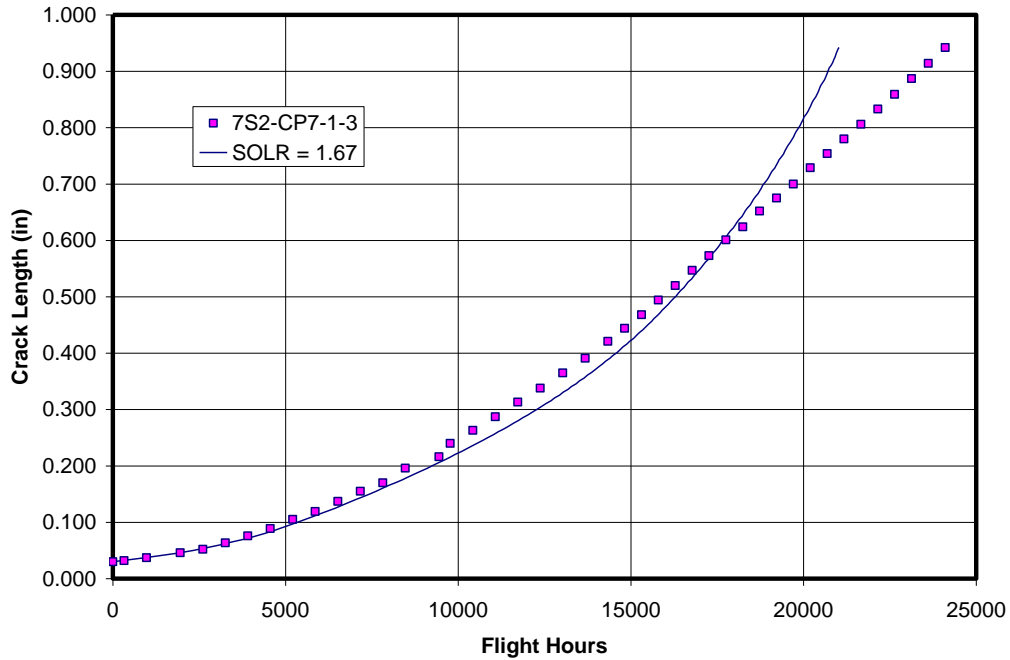


U.S. AIR FORCE



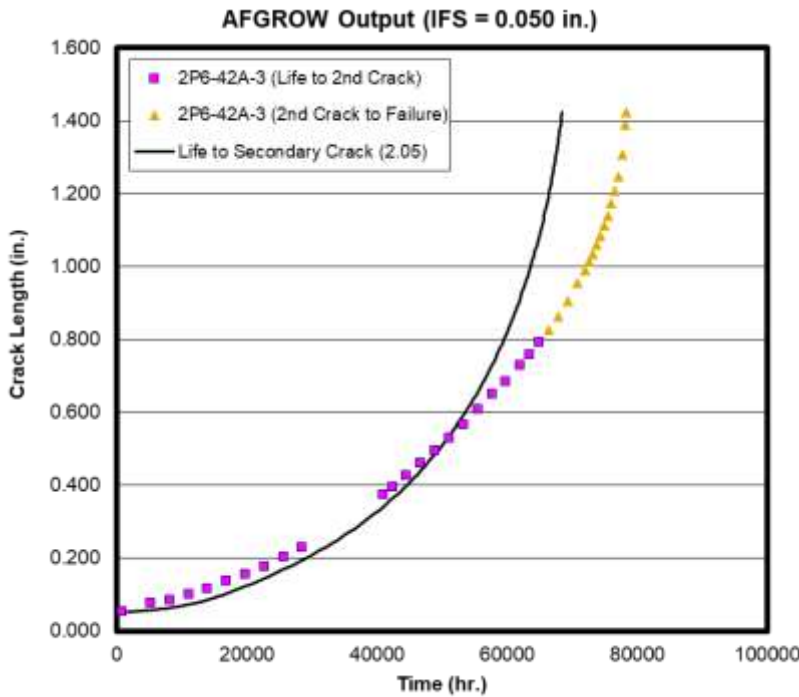


7075-T6 – Comparison with Old fits to New



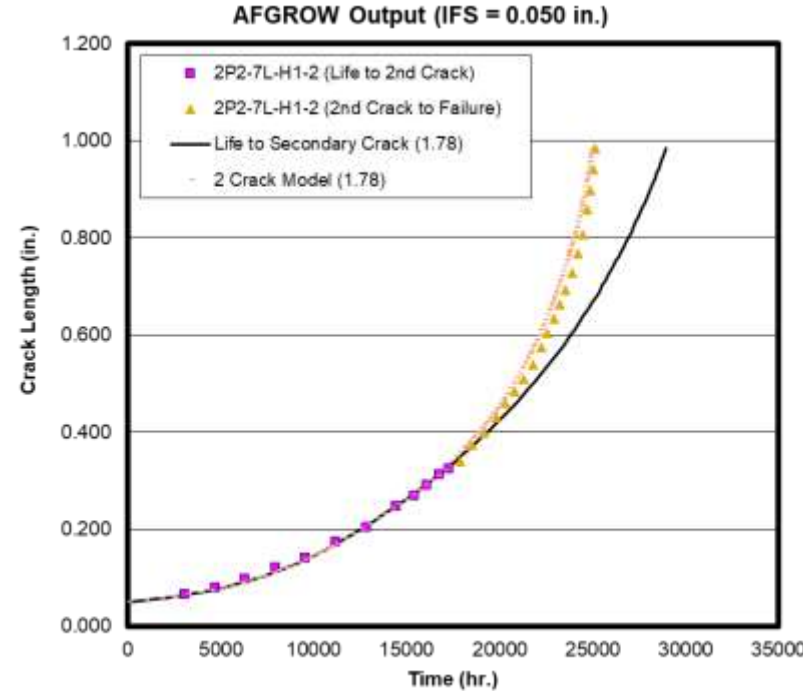


SOLR Correlations (3 Patterns Noticed with Fits)



26% of test data fit in this manner. Analytical curve does not fit life to secondary flaw and is conservative compared to test data.

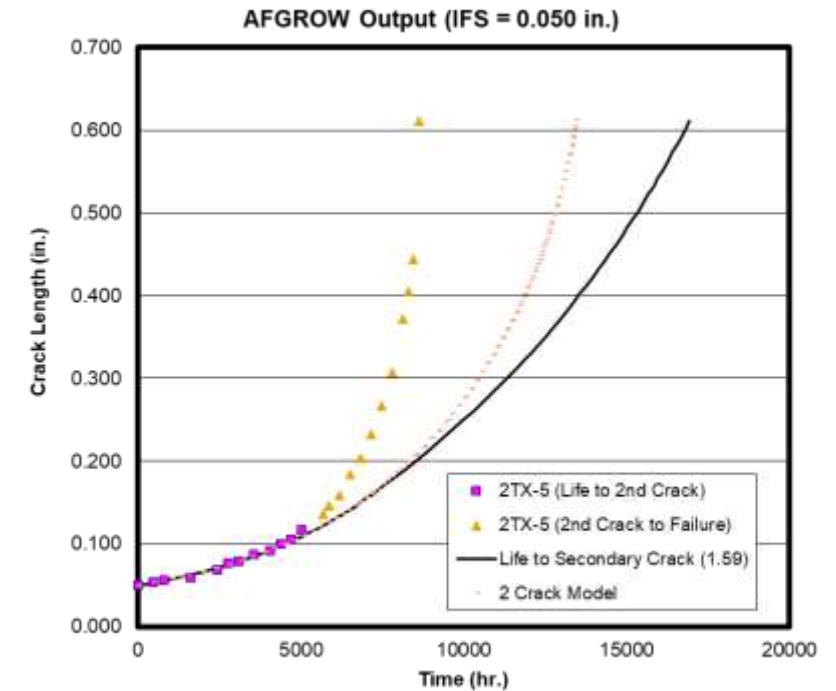
SOLR correlated using 0.05" to secondary flaw matching.



The rest fit in this manner. Either test curve fit the analysis curve with a single crack or by using a secondary flaw model.

The yellow dot line is the secondary flaw model, the black solid line is a single crack model.

All SOLRs were correlated with single crack model using the 0.05" to secondary flaw matching.



16% of test data fit in this manner. All had stress levels that were 70% Fty and above.

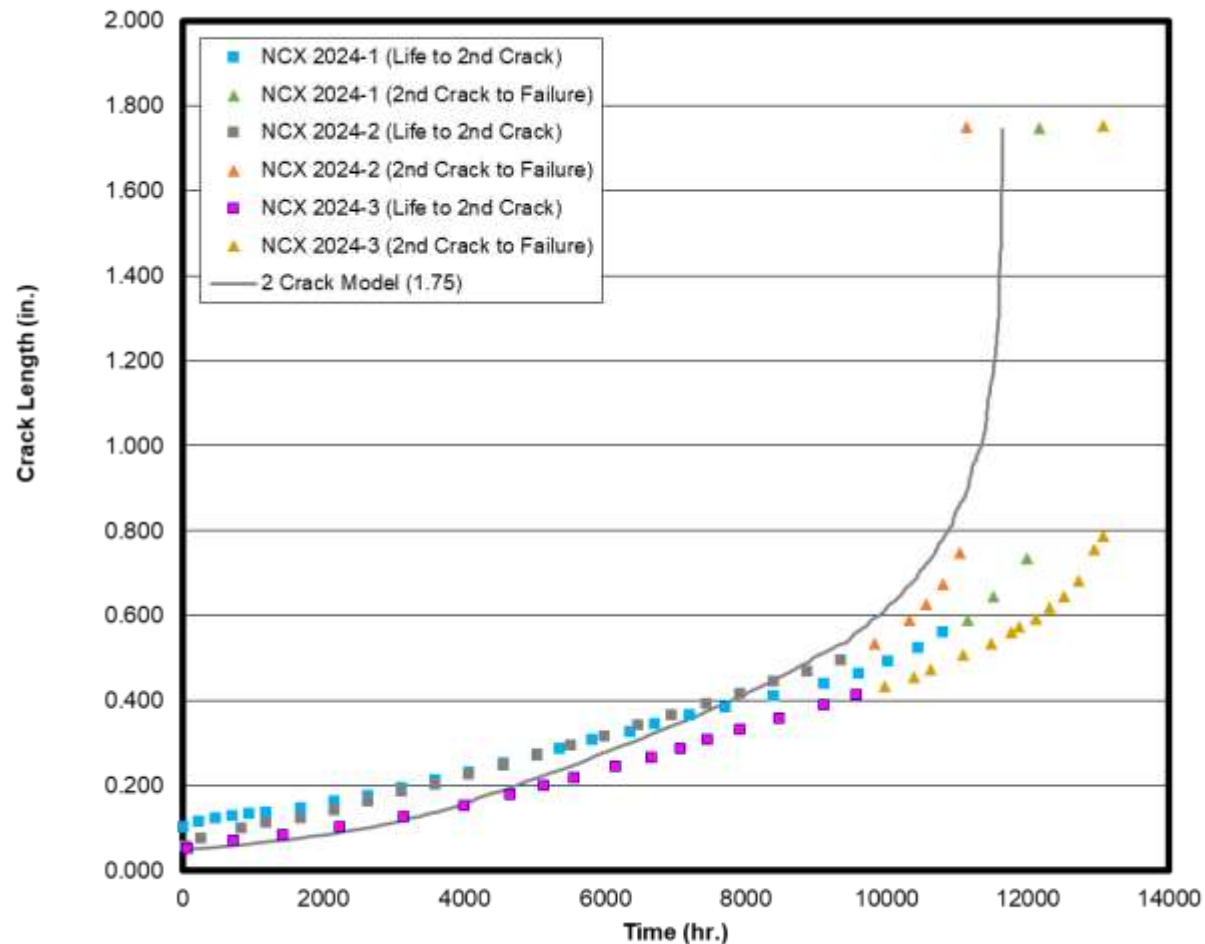
Due to this, forced the correlation to be end life matching instead of 0.05" to secondary flaw matching.



SOLR Correlations (Average SOLR)

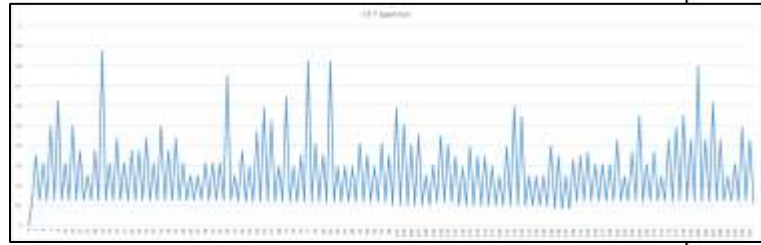


AFGROW Output (IFS = 0.050 in.)



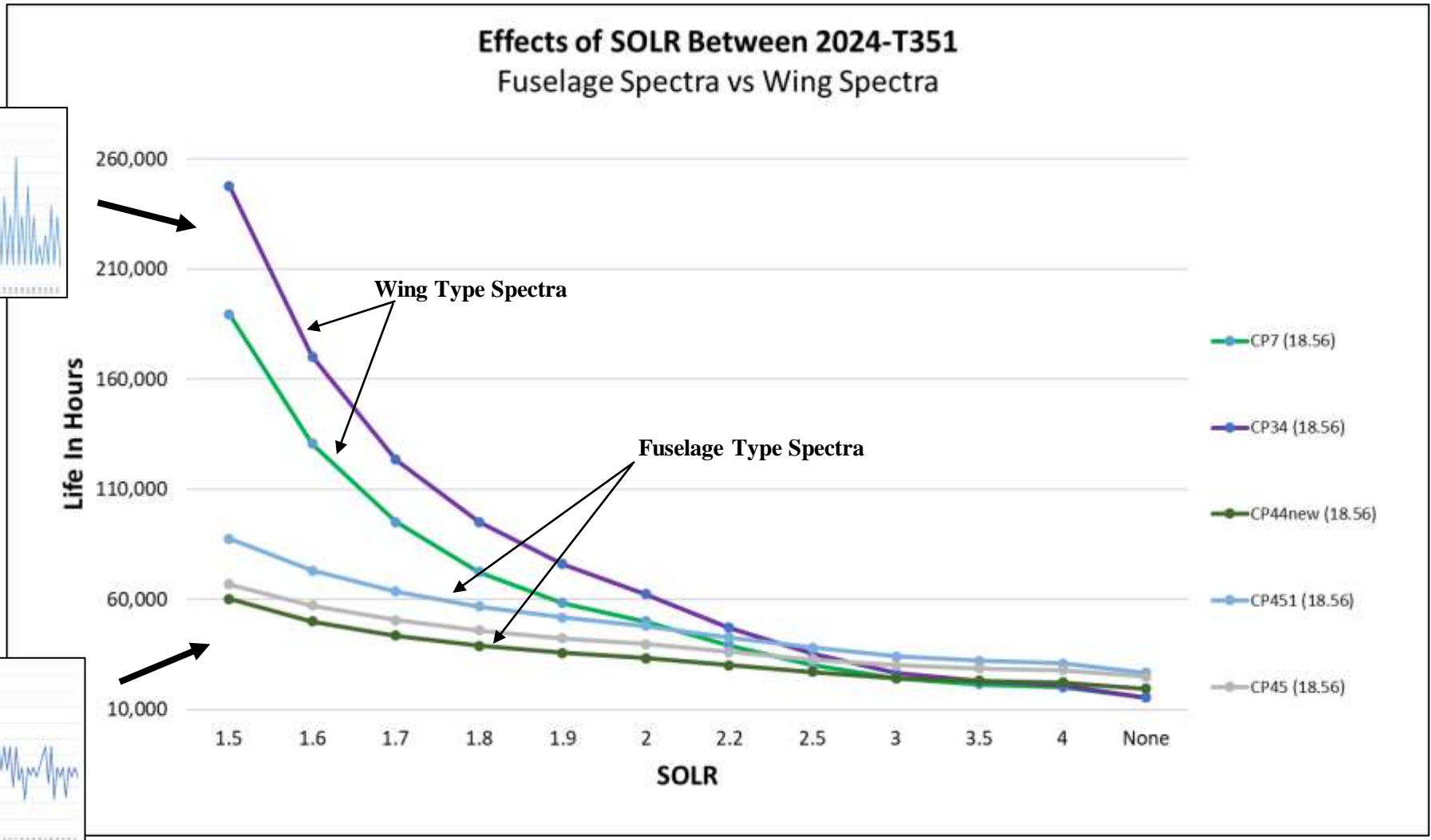


Determine SOLR for Non-Tested Geometry (SOLR vs Life Curves comparisons)



Comparison of Wing Type Spectra with Fuselage Type Spectra

This comparison provides the bases for many of the assumptions made

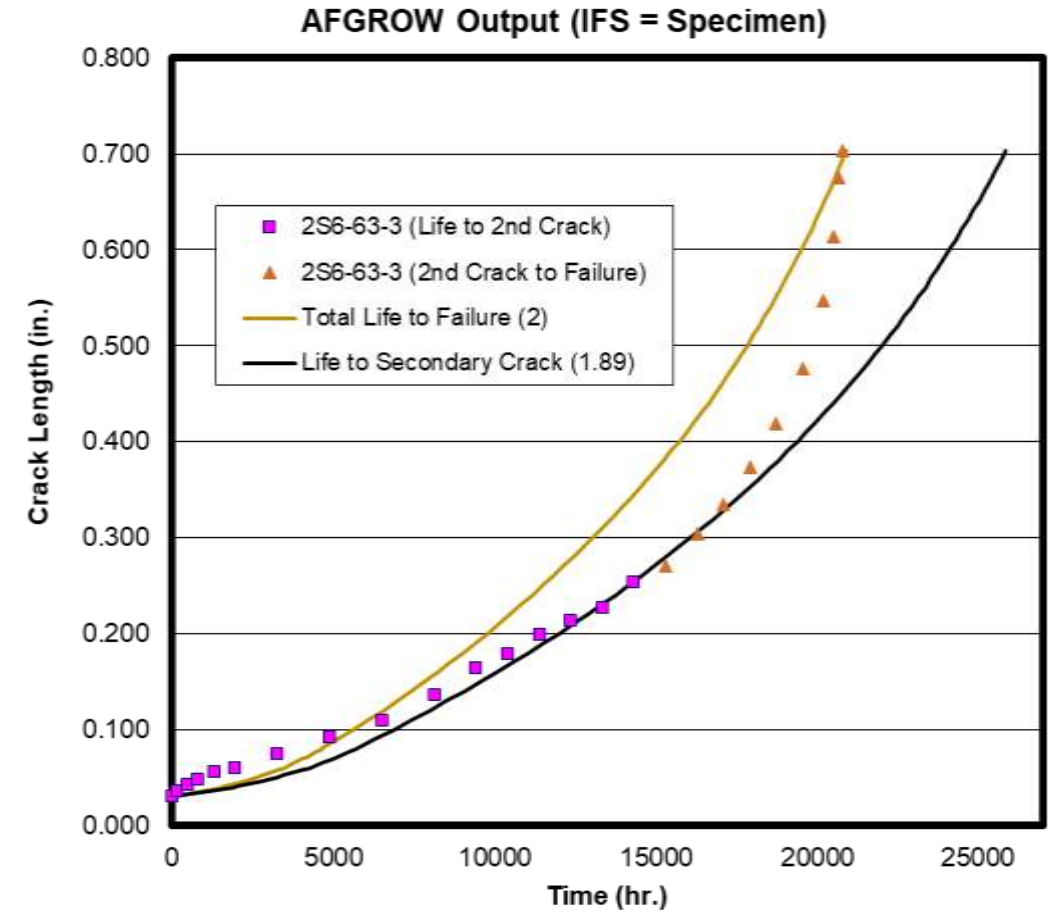


Spectrum Test Correlation

(How SOLR is developed for Variable Amplitude Spectra)

Cycles	Flight Hrs	Flight Hours from 0.05 IFS	Crack Length					
			Front		Rear		Bore	
			Left	Right	Left	Right	Left	Right
0				0.020			0.018	
60,000				0.030			0.031	
0	0			0.030			0.031	
5,000	163			0.035			0.037	
15,000	489			0.042			0.042	
25,000	815			0.048			0.050	
40,000	1303	349		0.055			0.055	
60,000	1955	1001		0.060			0.062	
100,000	3258	2304		0.074			0.074	
150,000	4887	3933		0.091			0.095	
200,000	6516	5562		0.109		0.037		
250,000	8146	7191		0.135		0.083		
290,000	9449	8495		0.163		0.130		
320,000	10426	9472		0.178		0.140		
350,000	11404	10450		0.198		0.158		
380,000	12381	11427		0.213		0.202		
410,000	13359	12404		0.227		0.218		
440,000	14336	13382		0.253		0.247		
470,000	15314	14359	0.061	0.271	0.057	0.253		
500,000	16291	15337	0.107	0.304	0.093	0.279		
525,000	17106	16151	0.141	0.335	0.124	0.309		
550,000	17920	16966	0.172	0.374	0.163	0.351		
575,000	18735	17781	0.219	0.419	0.212	0.397		
600,000	19549	18595	0.285	0.476	0.269	0.460		
620,000	20201	19247	0.351	0.547	0.348	0.543		
630,000	20527	19573	0.414	0.614	0.412	0.599		
635,000	20690	19735	0.470	0.676	0.471	0.676		
638,000	20787	19833	0.496	0.703	0.502	0.697		
640,715	20876		Specimen Failed					

Spectrum Testing then helps to provide a somewhat Average SOLR



What Part of the test curve do we try to match?

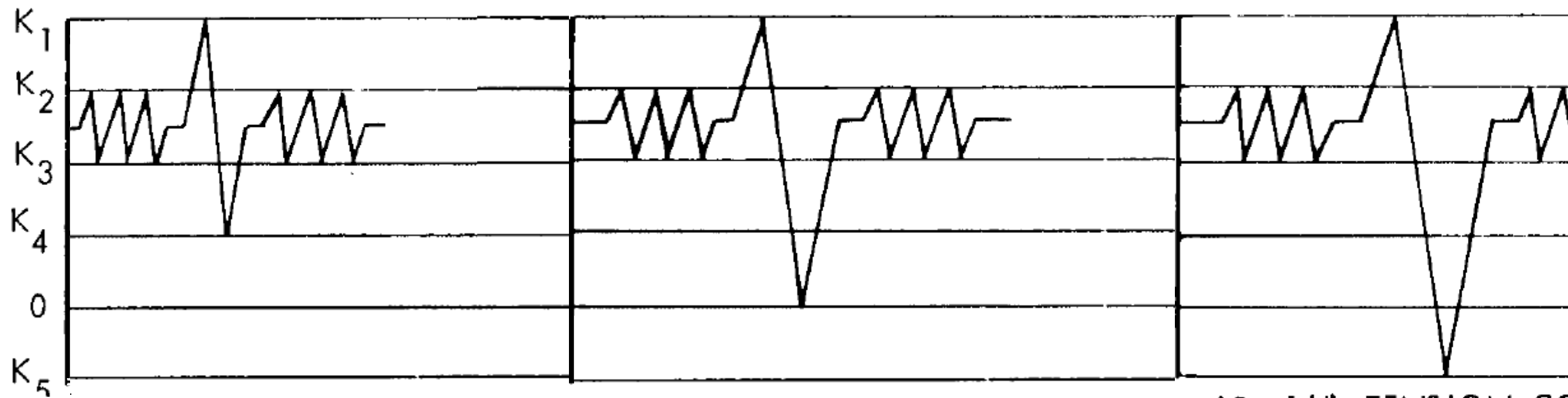


FIG. 1(a) TENSION-TENSION

FIG. 1(b) TENSION-ZERO

FIG. 1(d) TENSION-CO