

# Ogden Air Logistics Center



## Investigating Spectrum Crack Growth Retardation Methods and Models for the A-10

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**U.S. AIR FORCE**



# Purpose

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***A-10 Generalized Willenborg retardation values (SOLR) have received criticism for being un-conservative. Therefore, material lookup file development was re-evaluated to assess the impact on SOLR and crack growth life.***



# Overview



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- **SOLR & Lookup File Project Summary**
- **Development of Material Look-up Files**
- **SOLR Development**
- **Effect on Life Predictions**
- **Results and Conclusions**

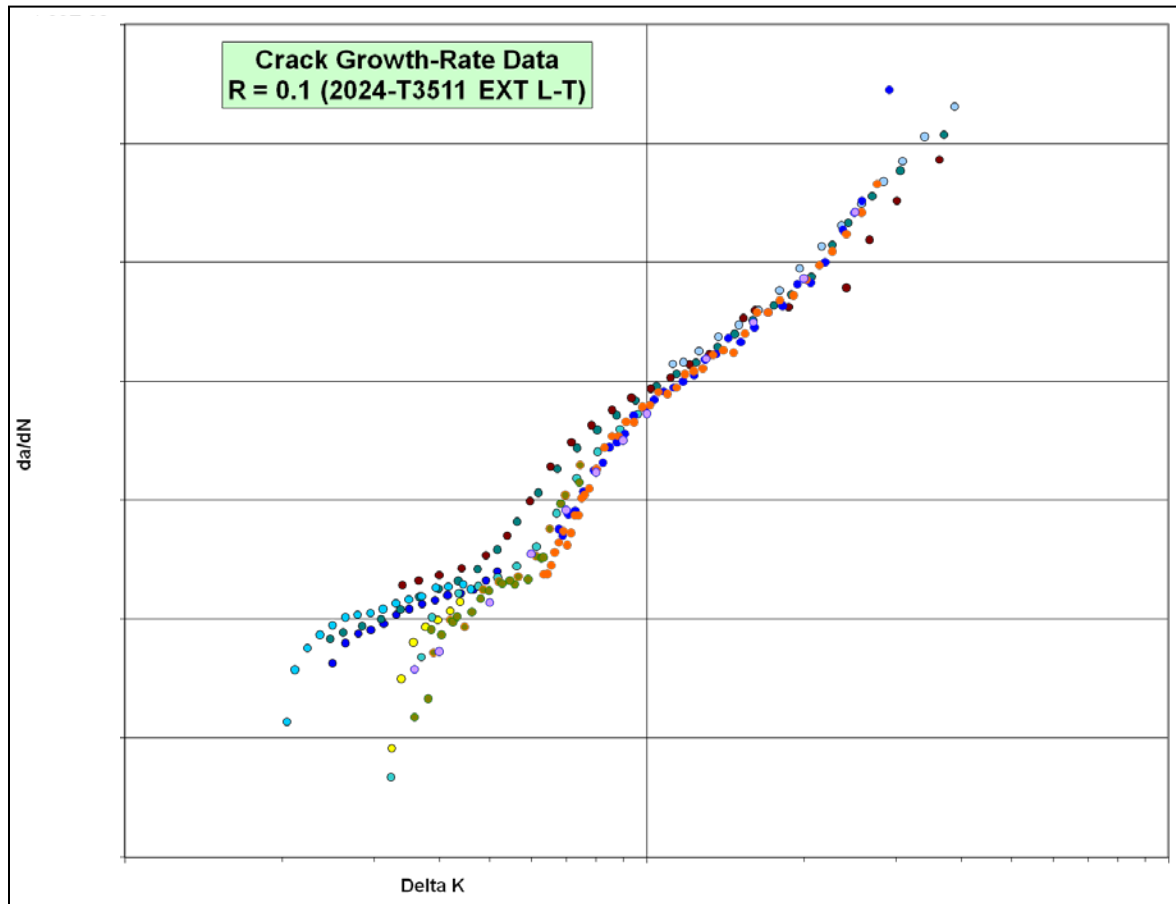


# SOLR & Material Lookup File Project



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- Crack growth rate ( $da/dN$ ) vs. stress intensity ( $\Delta K$ ) for a given material at different stress ratios ( $R$ ).



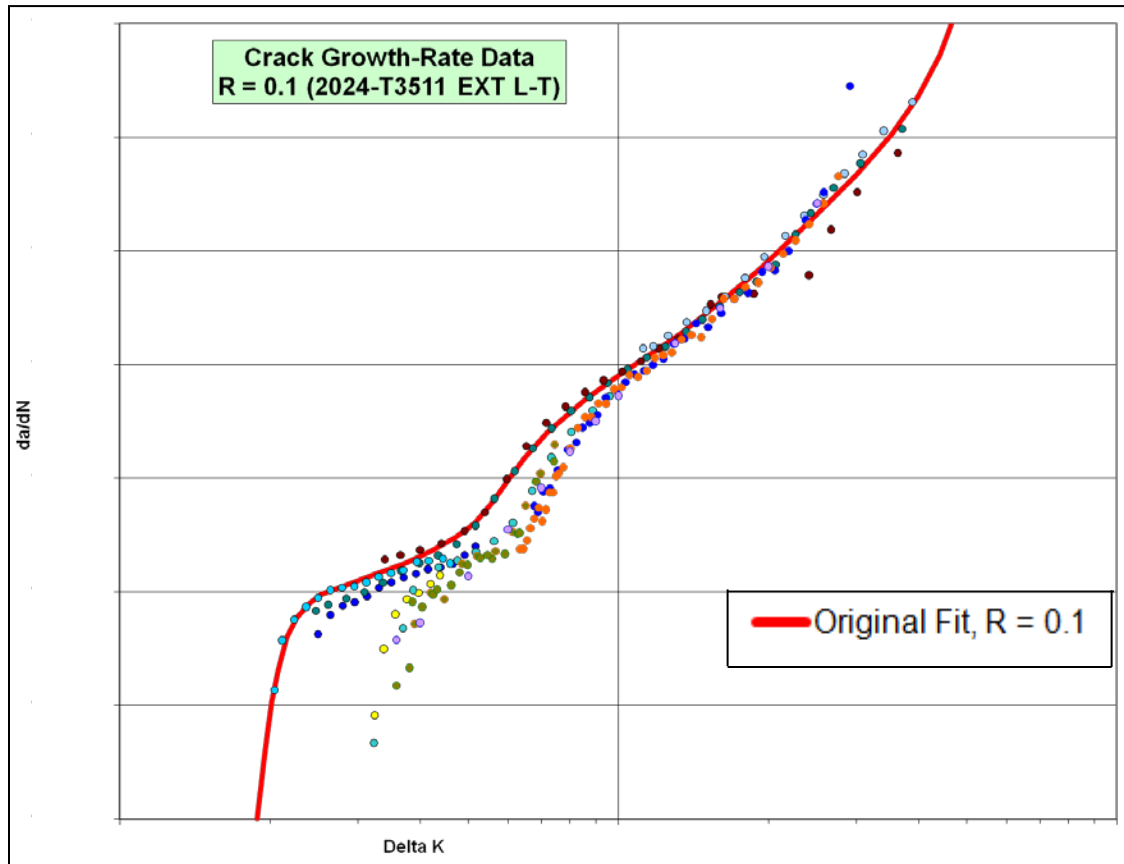


# SOLR & Material Lookup File Project



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- Initially, an assumption was made that fitting a curve slightly above the data points would be a more conservative approach (current data in 0207 report).



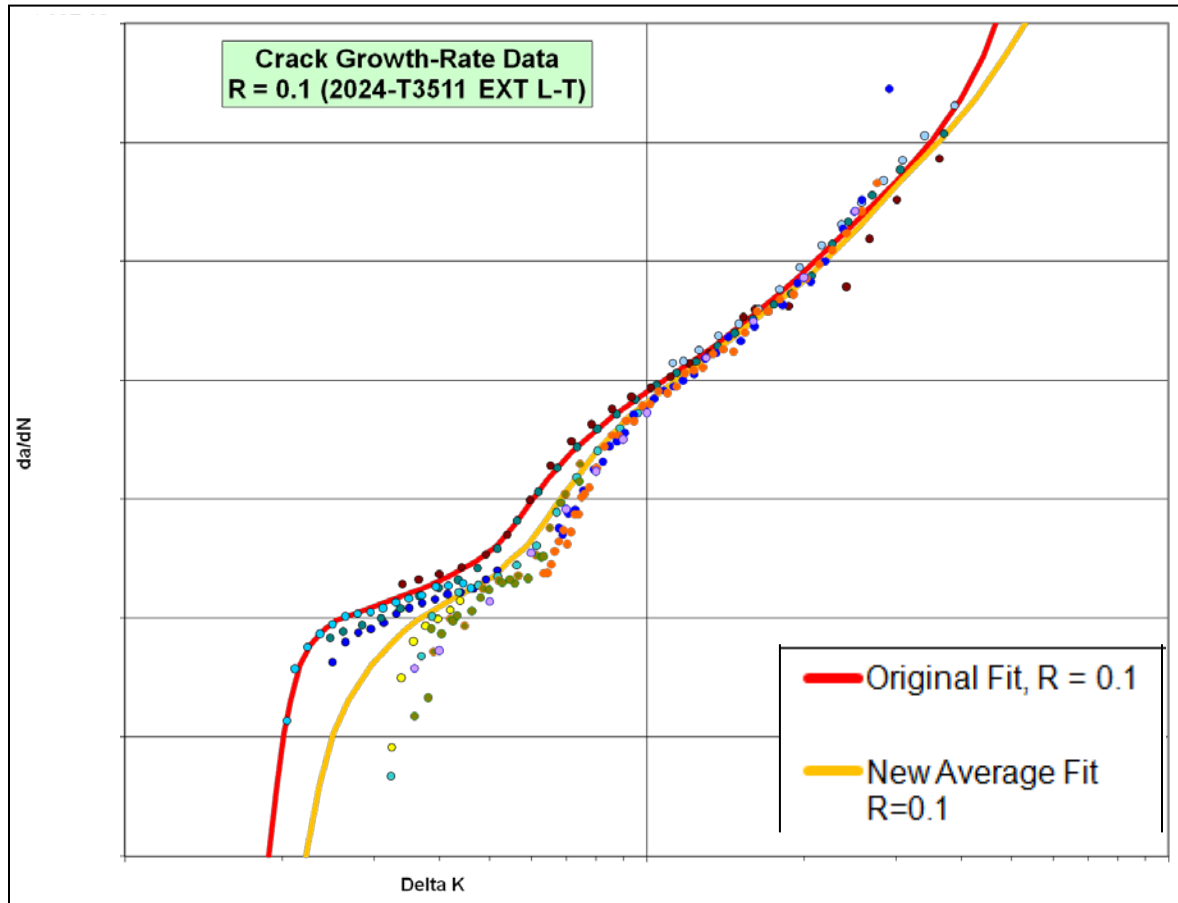


# SOLR & Material Lookup File Project



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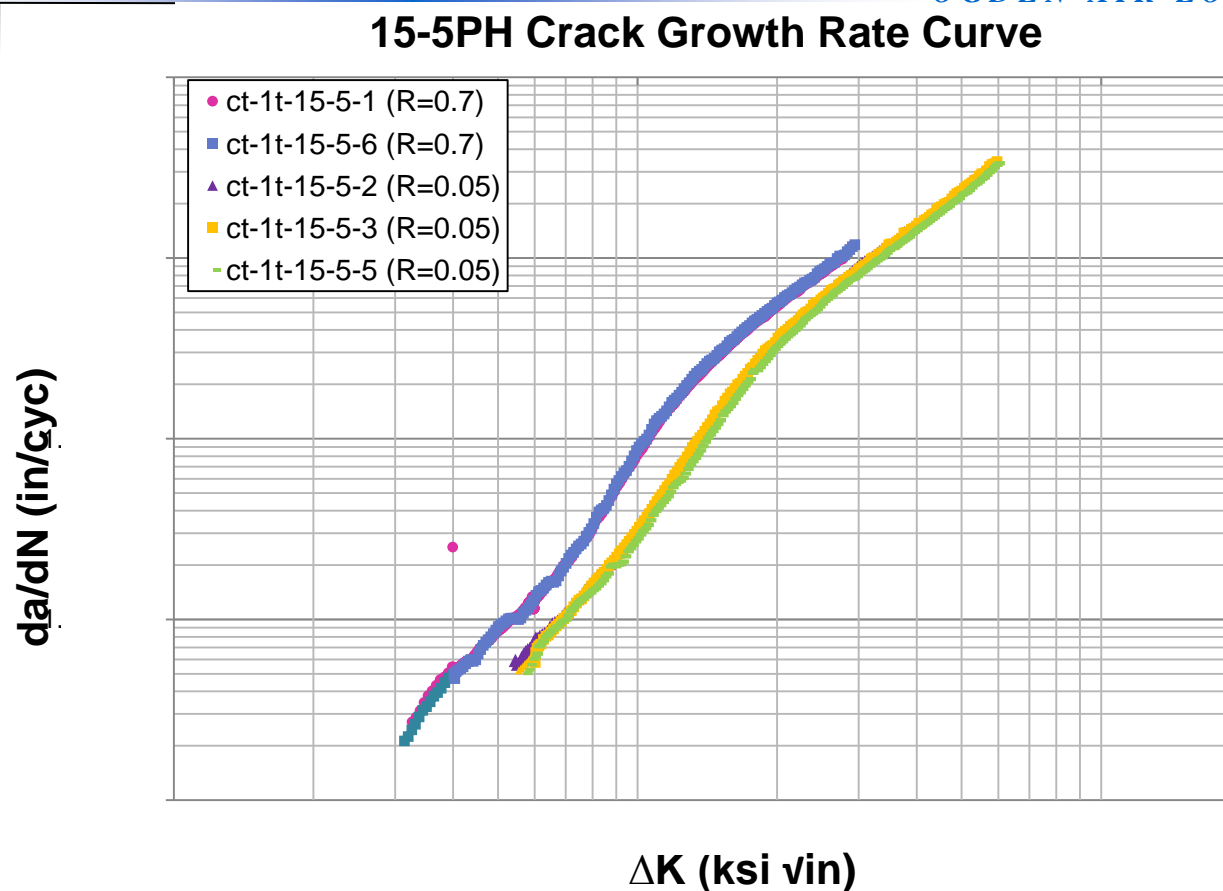
- By fitting the curve more exactly along the test data, i.e. more averaged values, we may achieve more 'typical' SOLR values.





# da/dN vs $\Delta K$ Curve

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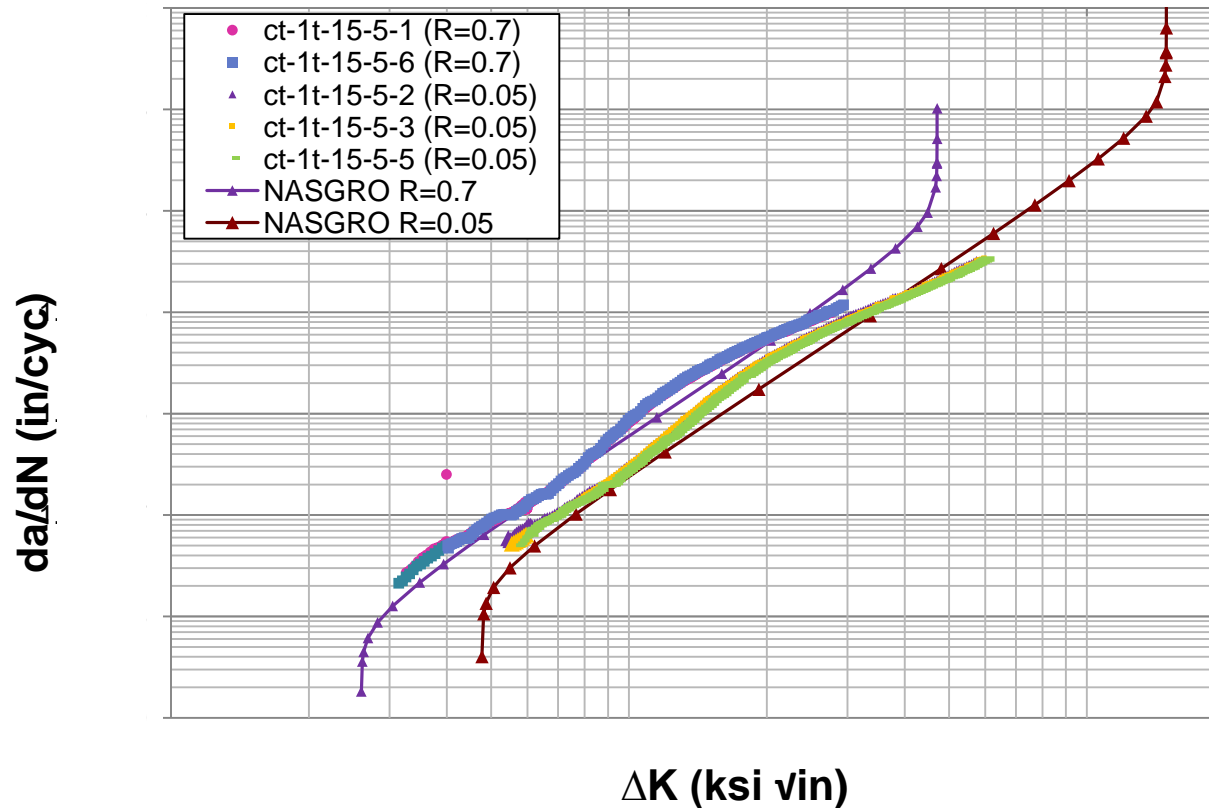
- Begin with crack growth rate data
  - Plot the test points as da/dN vs  $\Delta K$



# da/dN vs $\Delta K$ Curve

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## 15-5PH Crack Growth Rate Curve



- Develop curve fit for the data
  - Self Generate or Plot NASGRO or FORMAN line

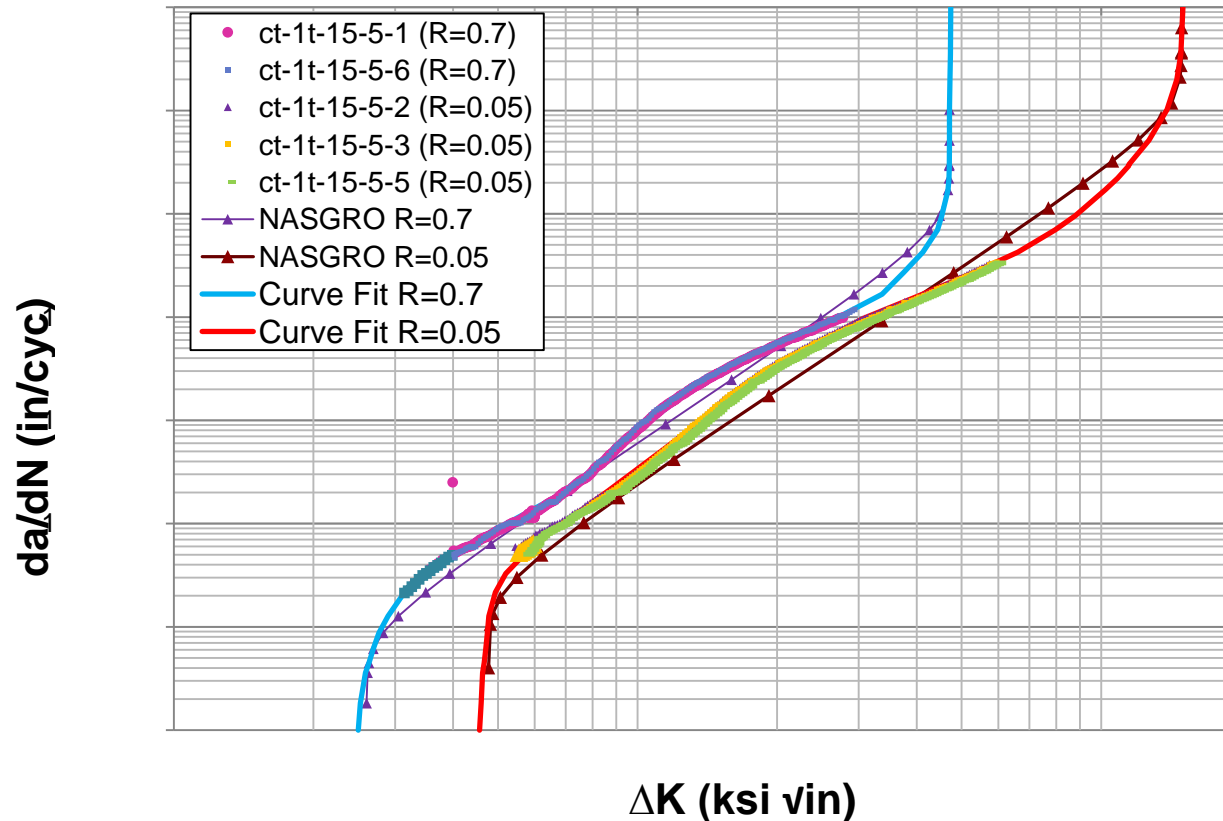




# da/dN vs $\Delta K$ Curve

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## 15-5PH Crack Growth Rate Curve



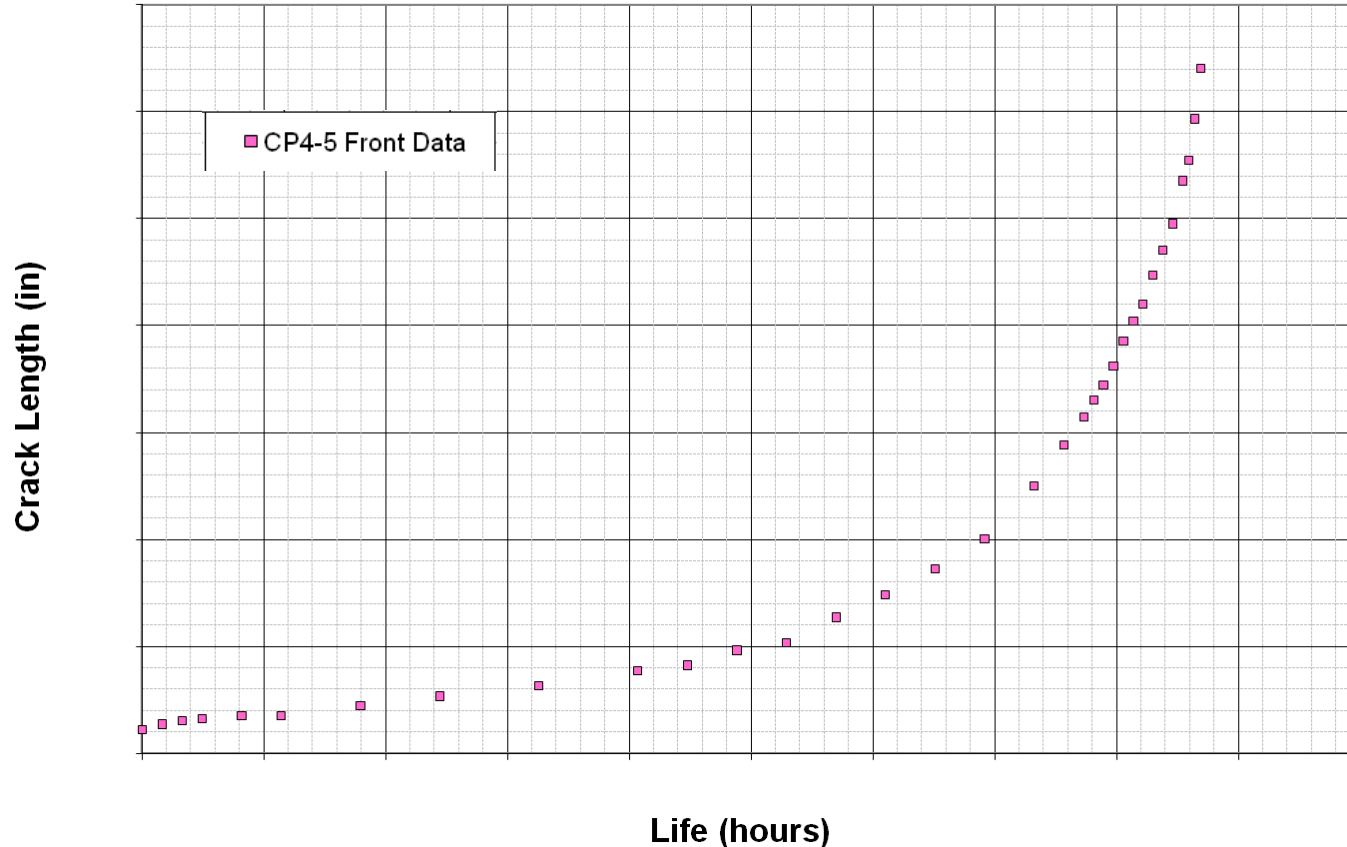
- Create lookup file from curve fit data points



# Crack Growth Curve

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CP4-5 Test Data with SOLR Curve Fits



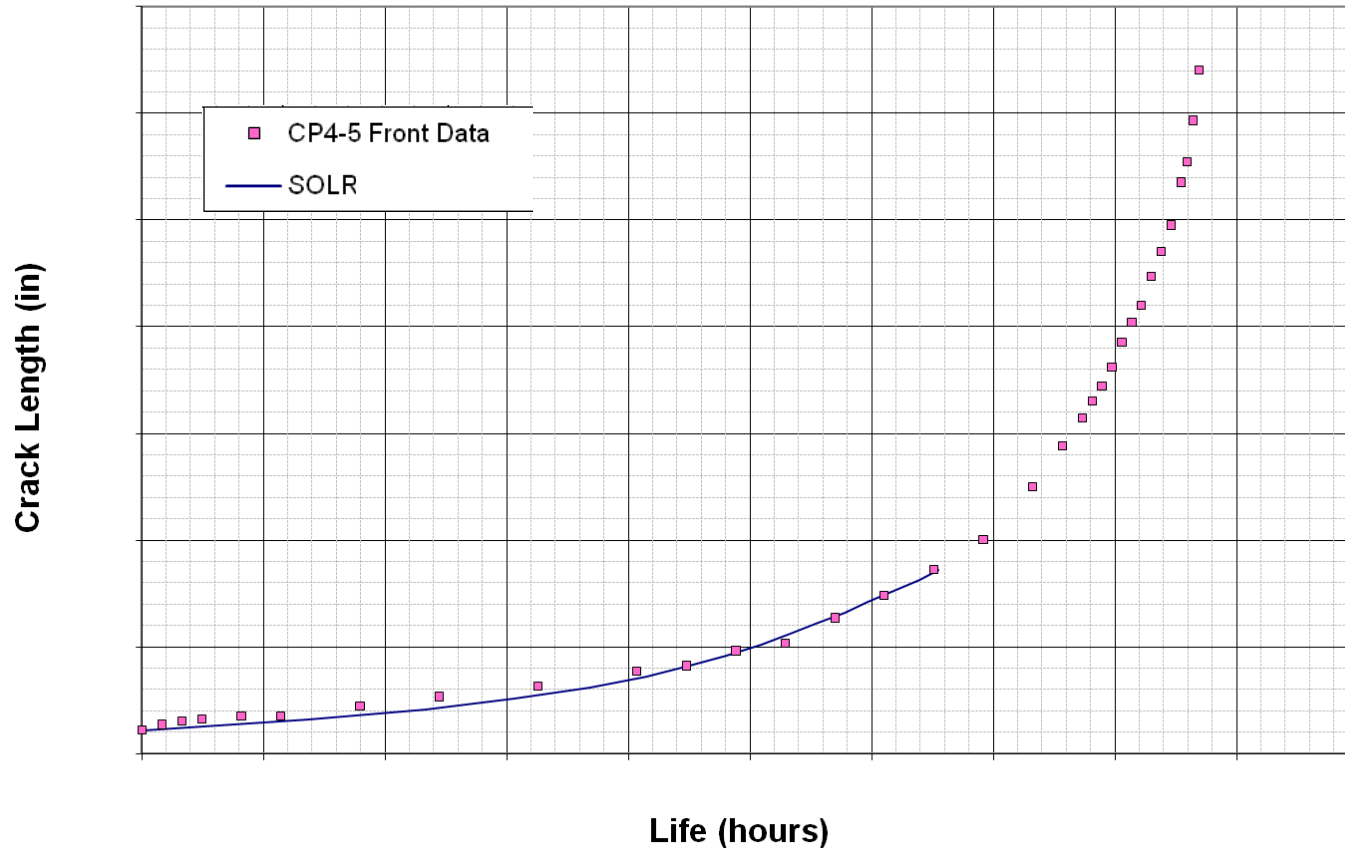
- Begin with test crack growth data
- Plot the test points as crack length vs. life



# Crack Growth Curve

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CP4-5 Test Data with SOLR Curve Fits



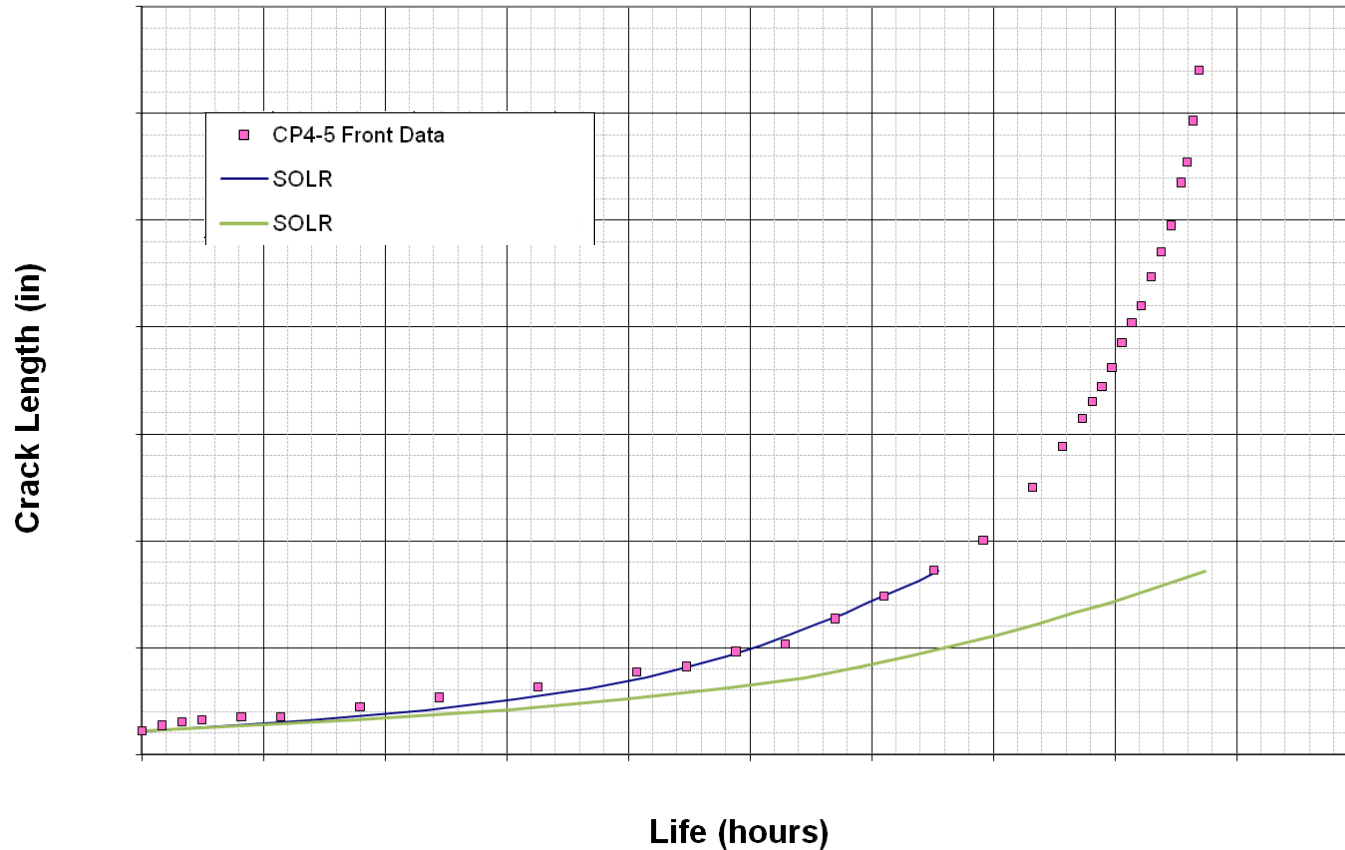
- Create AFGROW model of test coupon
  - Modify SOLR until AFGROW curve matches test data



# Crack Growth Curve

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CP4-5 Test Data with SOLR Curve Fits



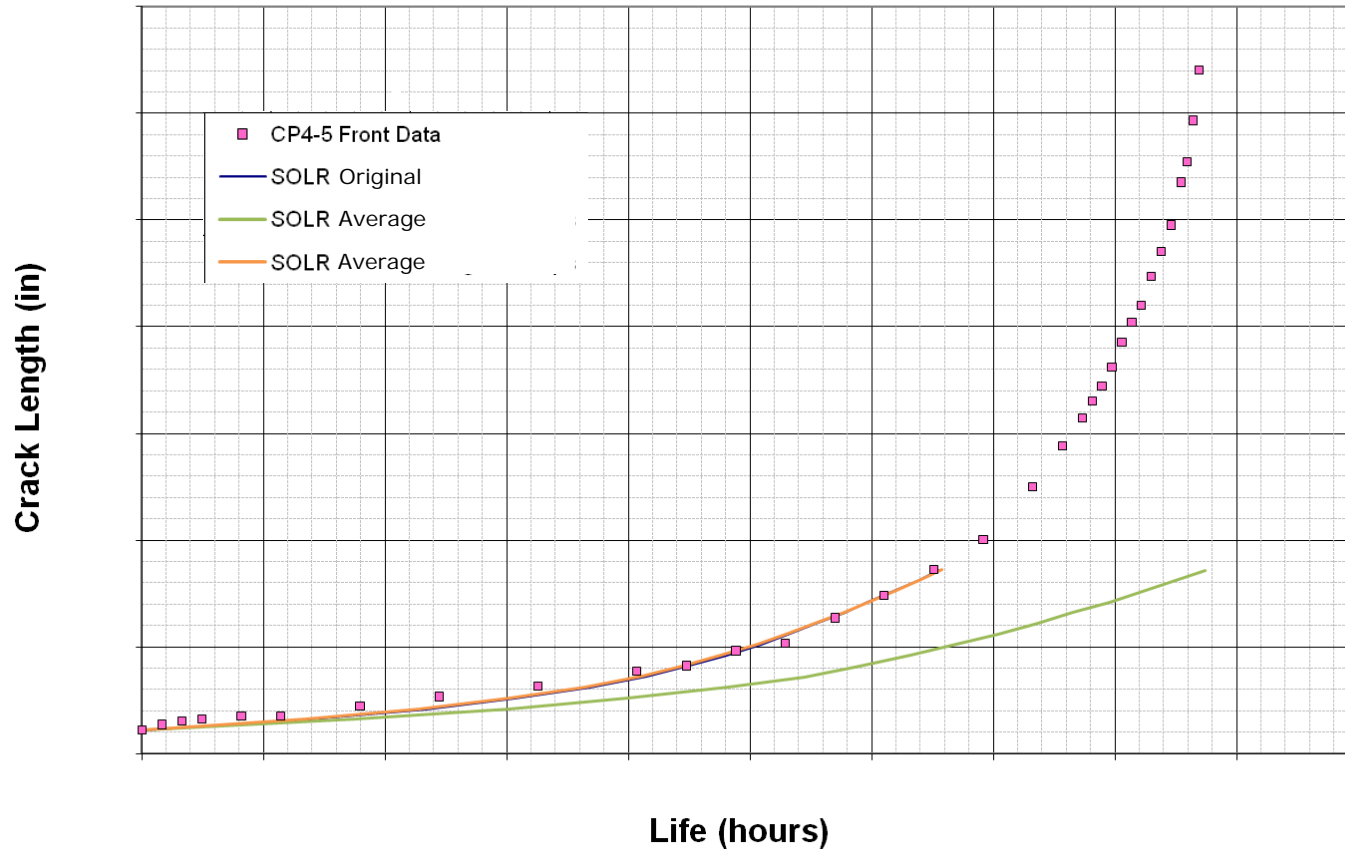
■ Insert new lookup files into AFGROW



# Crack Growth Curve

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CP4-5 Test Data with SOLR Curve Fits



■ **Modify SOLR until AFGROW model matches test data**



# SOLR vs. Peak Stress

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- New SOLRs are generated for each test - High and Low stress tests with similar thicknesses are selected and the SOLRs are averaged.

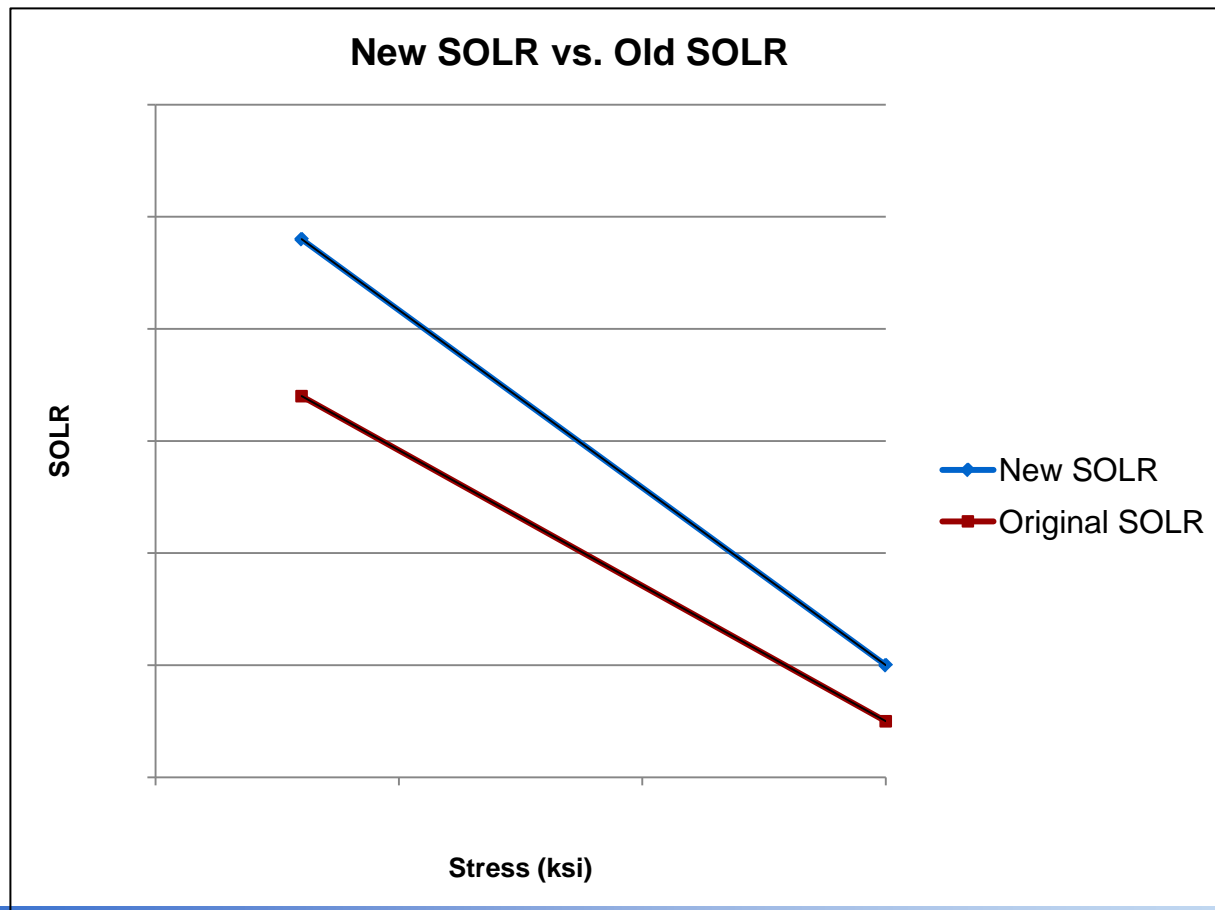
Material	Thickness (in)	Peak Stress (ksi)	Correlated SOLR
2024-T3511	0.320	HIGH ↑ ↓ LOW	1.41
2024-T3511	0.320		1.37
2024-T3511	0.320		1.51
2024-T3511	0.320		1.39
2024-T3511	0.320		1.40
2024-T3511	0.320		1.51
2024-T3511	0.250		1.62
2024-T3511	0.250		1.59
2024-T3511	0.250		1.51
2024-T3511	0.250		1.50
2024-T3511	0.250		2.10
2024-T3511	0.250		1.91
2024-T3511	0.250		2.02



# SOLR vs. Peak Stress

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- Generate linear equation between high and low stress points
  - Used to select SOLR for stresses





# RESULTS

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Material	Fatigue Critical Location	Change (% SOLR)	Change (% Life)
7075-T6 Sheet	1	10	11
	2	10	26
	3	10	13
	4	9	13
	5	9	-17
	6	9	-13
	7	9	4
2024-T3511	1	6	11
	2	7	15
	3	6	8
	4	7	20
	5	6	-7
	6	9	-12
	7	6	-14
	8	7	-13
2024-T351	1	9	2
	2	9	0
	3	9	-4
	4	10	5
	5	10	3
7175-T76	1	5	3
	2	17	13
	3	14	0
	4	18	1
	5	18	3
	6	18	0





# Conclusion

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- **Generating less conservative material Look-up Files results in an increase in SOLR vales**
- **±10% change in life predications at critical locations**
- **Continue with original Look-up Files and SOLRs**



# Purpose

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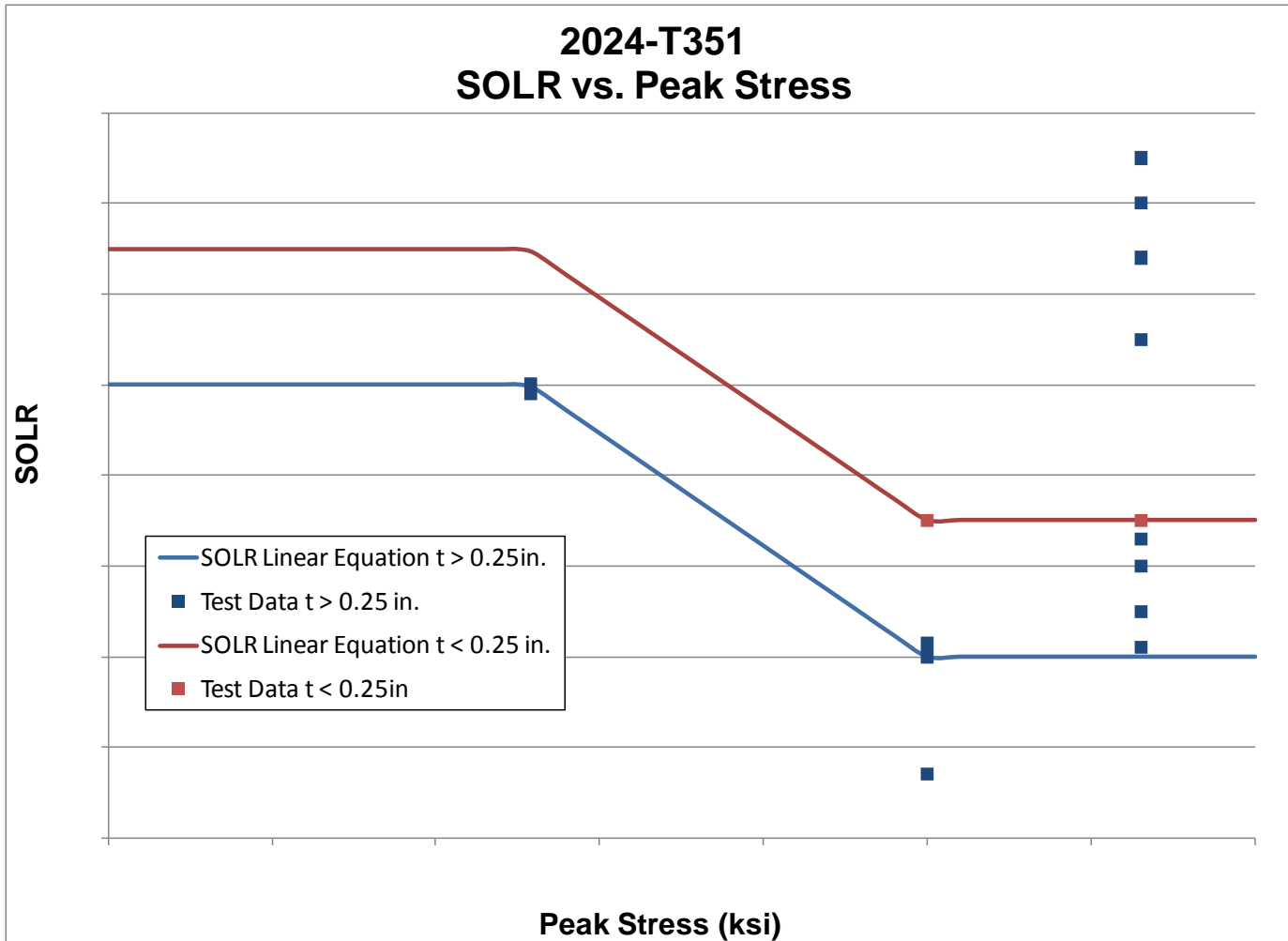
***To investigate the different crack growth retardation model options in AFGROW to ensure the best model is being used for the A-10 ASIP team.***

- 1. Familiarization technique**
- 2. Verification**
- 3. Input from technical experts**
- 4. Criticism of low SOLR values**
- 5. SOLR value dependencies**



# SOLR vs. Peak Stress

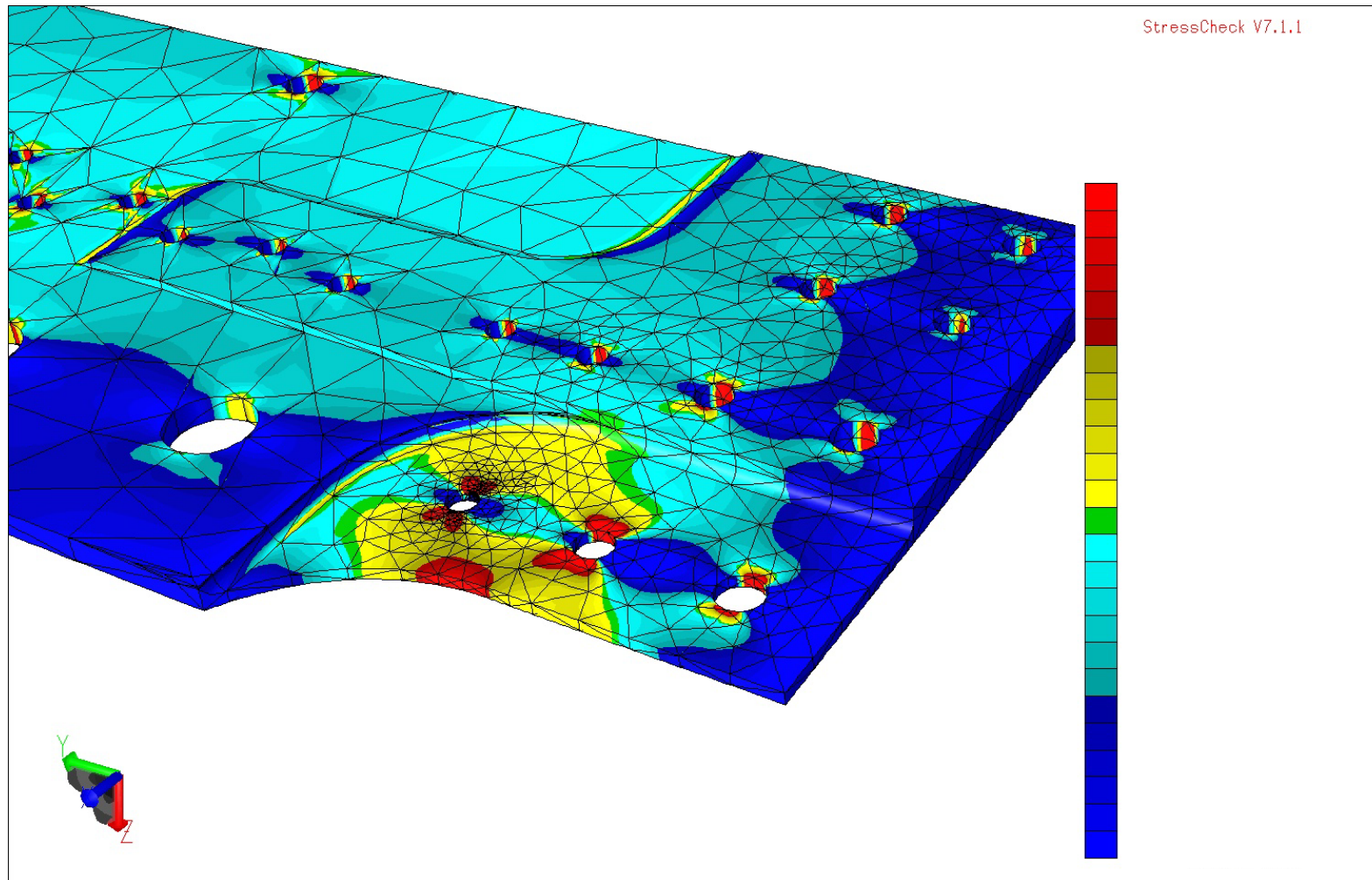
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# Far Field Stress?

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# Overview



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- **Technical Approach**
- **FASTRAN Model**
- **Hsu Model**
- **Closure Model**
- **Summary**



# Technical Approach

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- **Retardation Model comparisons were done for three materials**
  - **2024-T3511**
  - **2024-T351**
  - **7075-T6**
  
- **Using test specimen input file:**
  - **Varied retardation models & parameters**
  - **Correlated the different crack growth curves to fit test data**



# FASTRAN Model

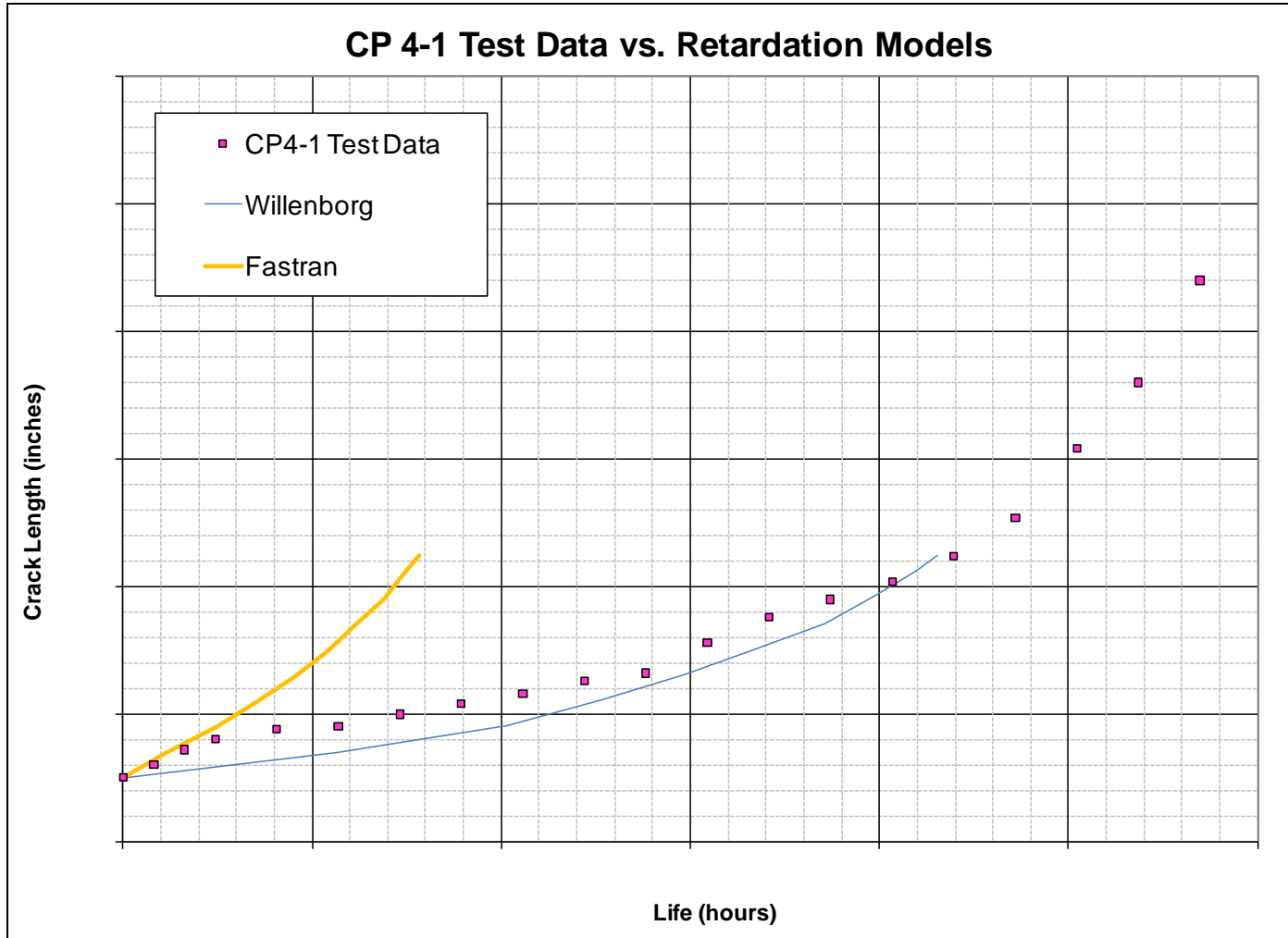
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- Uses an effective  $\Delta K$  ( $\Delta K_{\text{eff}}$ ) concept to determine crack growth rate.
- Comprised of 10 different inputs
  - Notch option
  - Effective stress intensity factors
  - Crack growth equation options
  - Threshold & fracture constants
  - Variable or Constant Constraint option
  - Constraint factors



# FASTRAN Model

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# FASTRAN Model



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- **Not a viable alternative**
  - **Must convert to single da/dN vs.  $\Delta K$  curve**
  - **Allows only tabular lookup files**
  - **Little variation in curve**



# Hsu Model

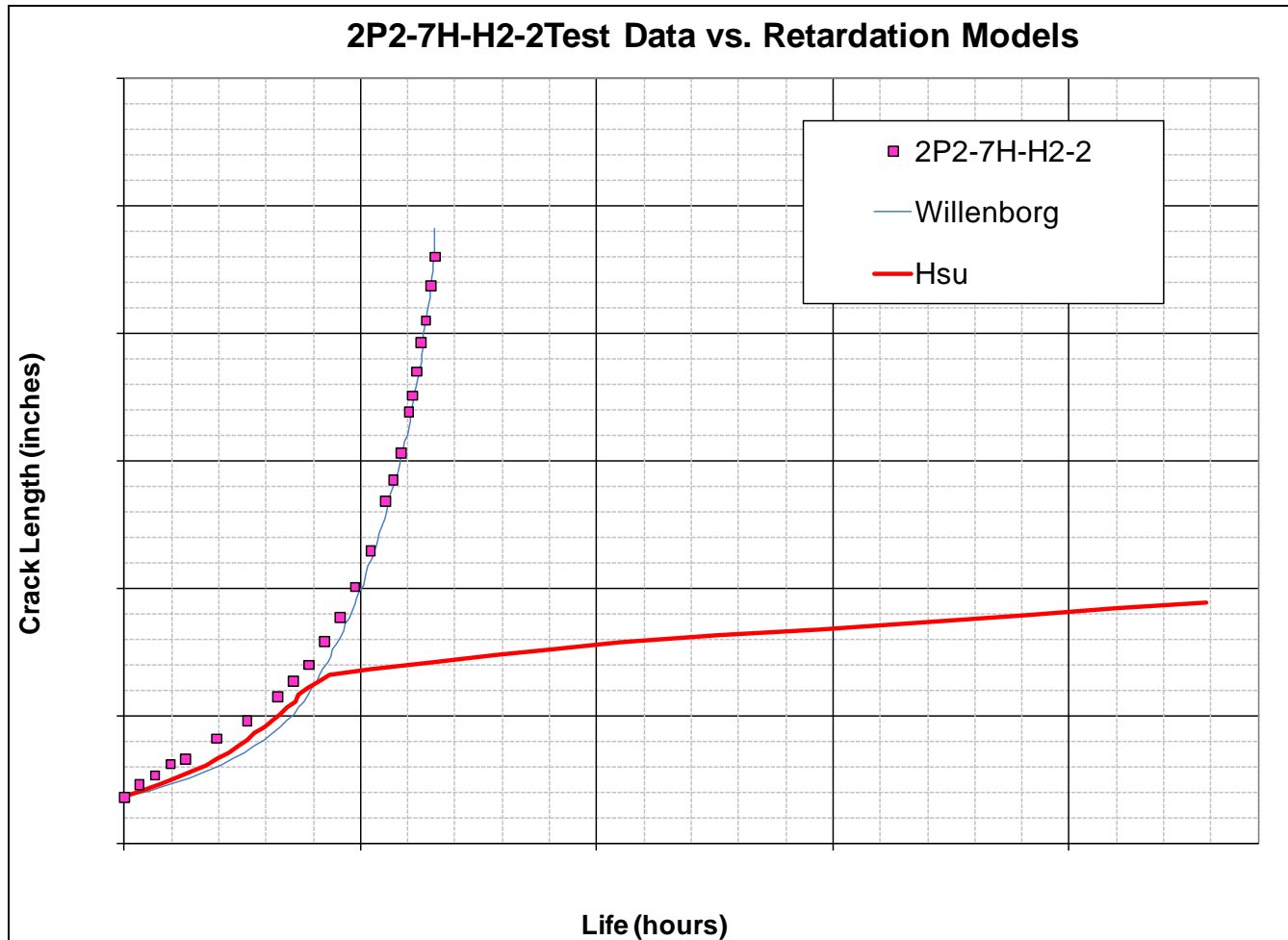
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- Uses an effective stress and closure concept
- Two inputs
  - $M_0$  – limiting value where the effect of retardation starts being reduced
  - $R_{cut}$  – upper limit of applied stress ratio
- Values must range between 0 and 1



# Hsu Model

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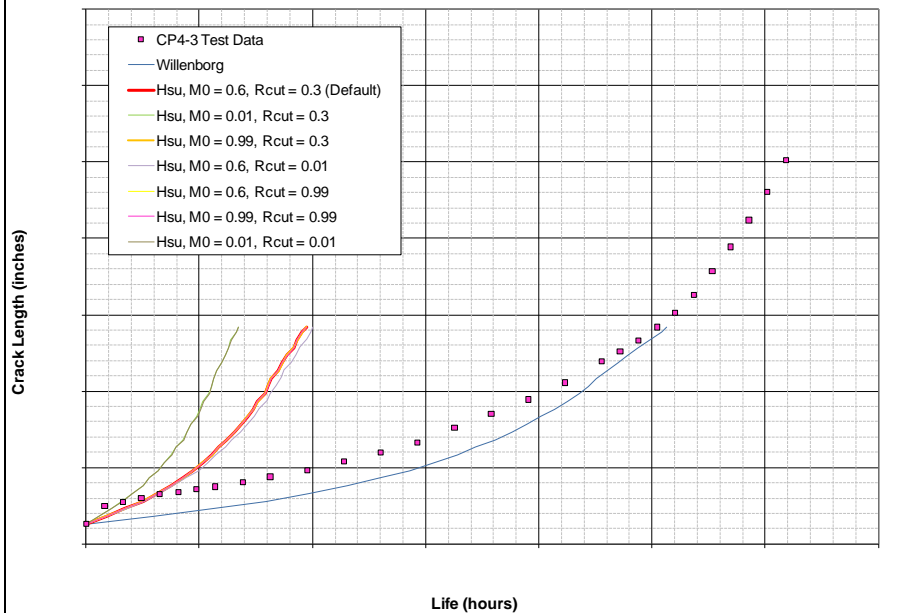


# Hsu Model

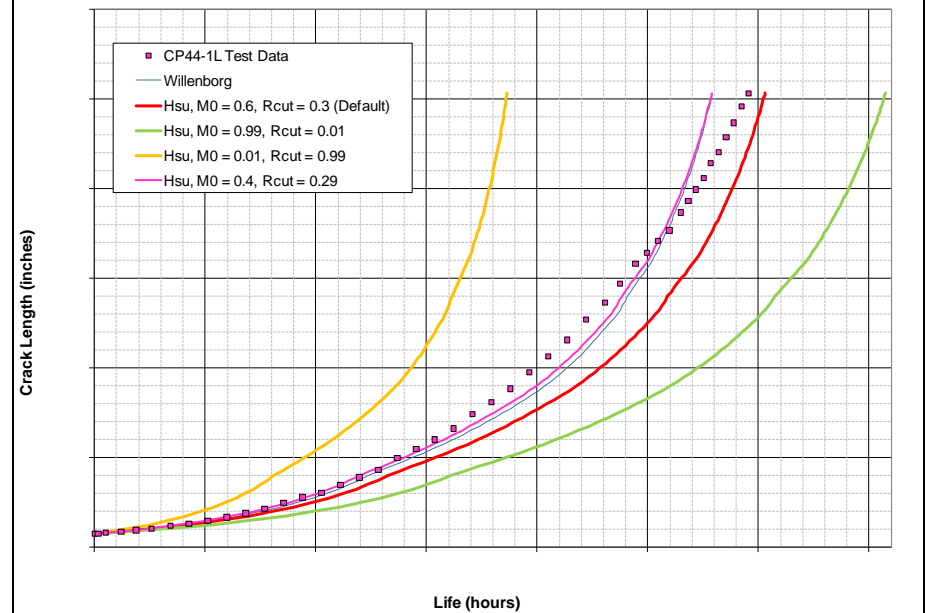
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- Little variation in most crack growth curves with max variation in parameters

CP 4-3 Test Data vs. Retardation Models



CP 44-1L Test Data vs. Retardation Models



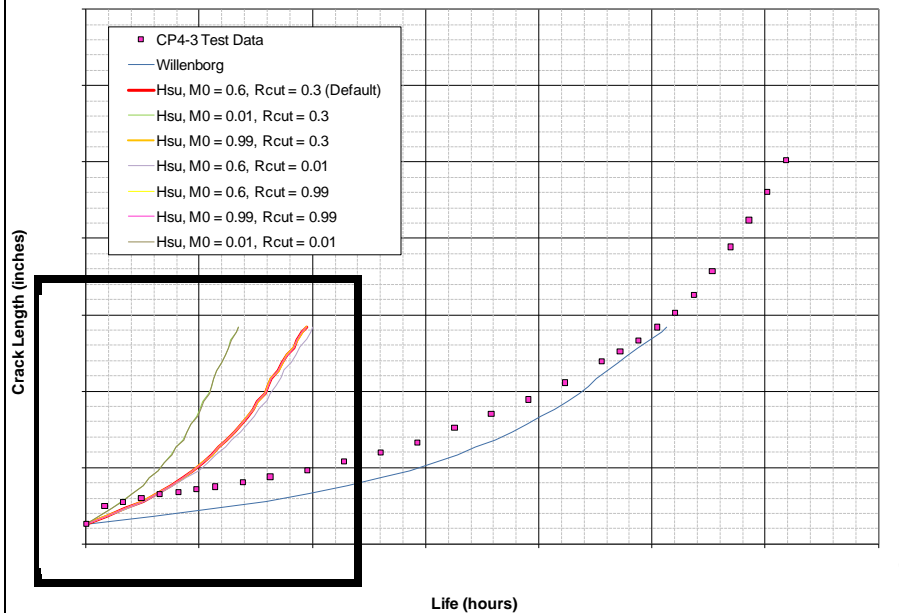


# Hsu Model

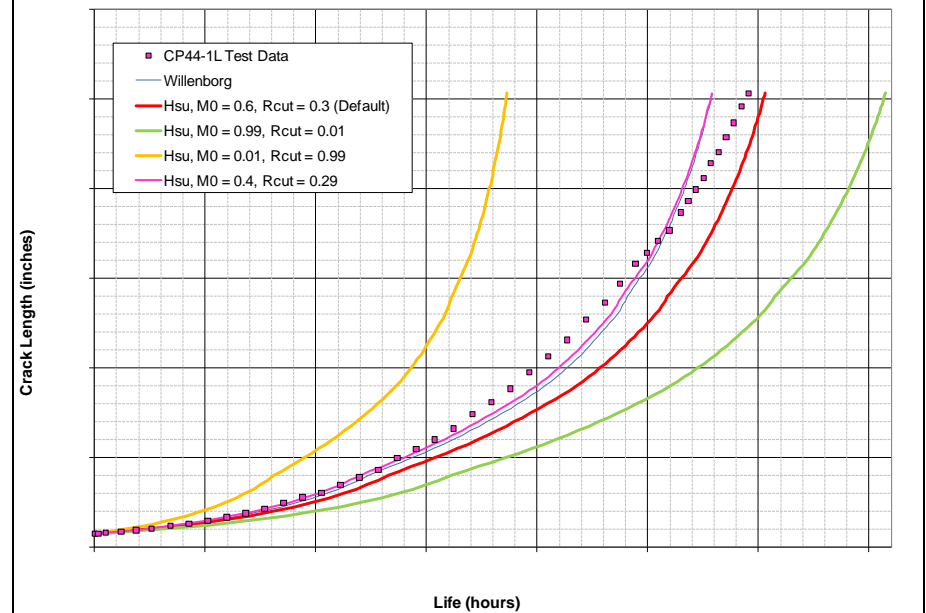
OGDEN AIR LOGISTICS CENTER

- Little variation in most crack growth curves with max variation in parameters

CP 4-3 Test Data vs. Retardation Models



CP 44-1L Test Data vs. Retardation Models

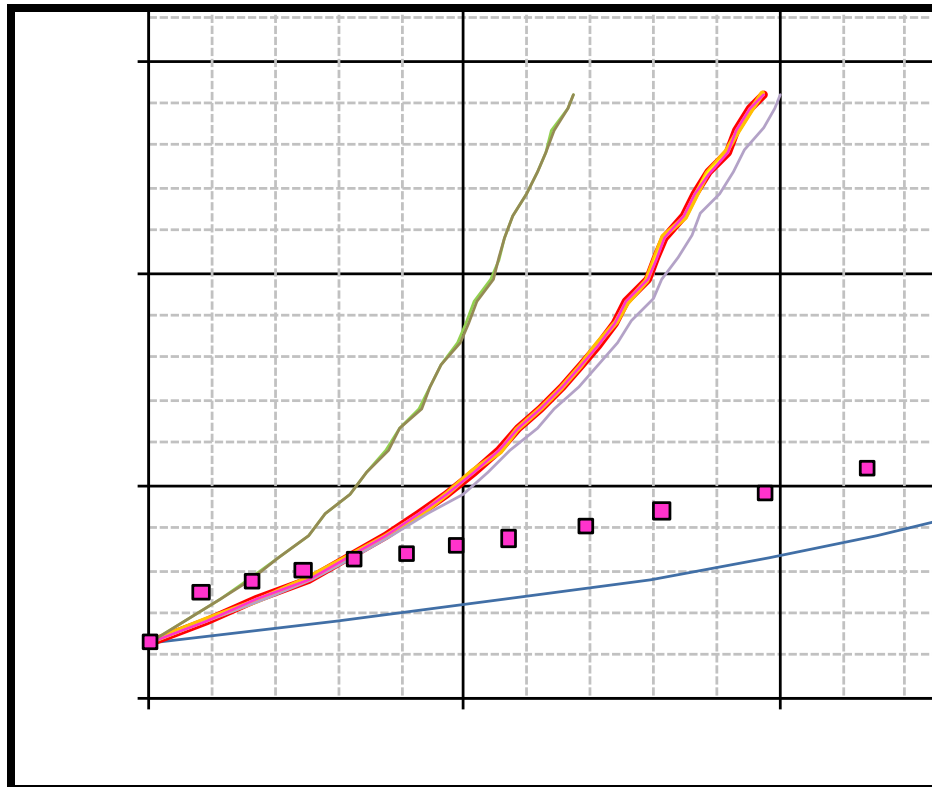




# Hsu Model

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- Other issues - Hsu input parameters,  $M_0$  and  $R_{cut}$ 
  - Little variation in most crack growth curves with max variation in parameters



- CP4-3 Test Data
- Willenborg
- Hsu,  $M_0 = 0.6$ ,  $R_{cut} = 0.3$  (Default)
- Hsu,  $M_0 = 0.01$ ,  $R_{cut} = 0.3$
- Hsu,  $M_0 = 0.99$ ,  $R_{cut} = 0.3$
- Hsu,  $M_0 = 0.6$ ,  $R_{cut} = 0.01$
- Hsu,  $M_0 = 0.6$ ,  $R_{cut} = 0.99$
- Hsu,  $M_0 = 0.99$ ,  $R_{cut} = 0.99$
- Hsu,  $M_0 = 0.01$ ,  $R_{cut} = 0.01$

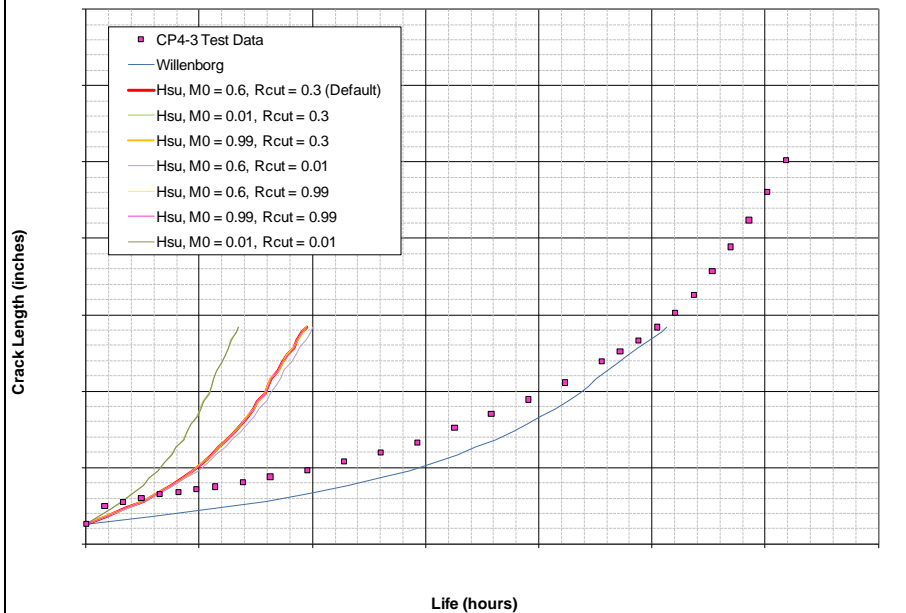


# Hsu Model

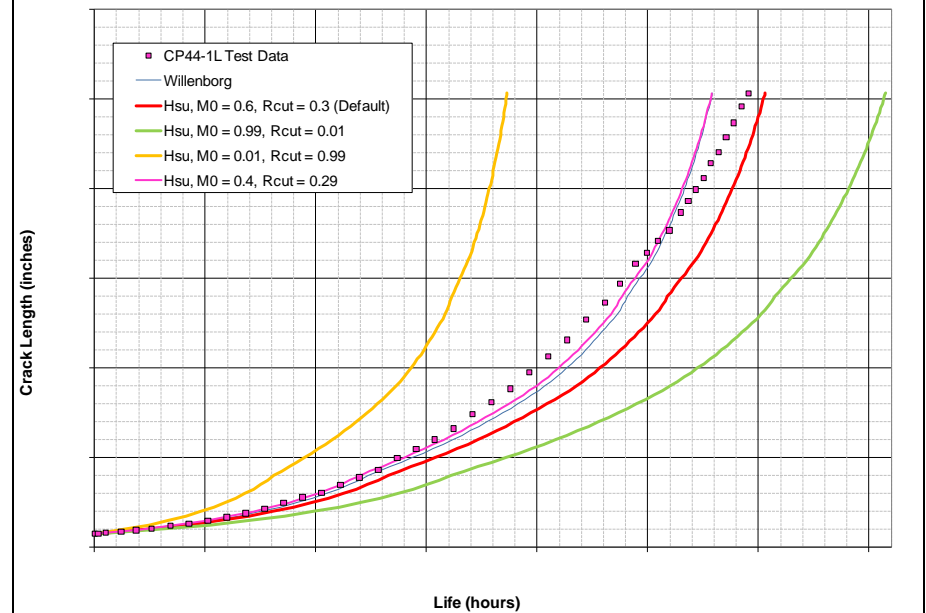
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- Little variation in most crack growth curves with max variation in parameters

CP 4-3 Test Data vs. Retardation Models



CP 44-1L Test Data vs. Retardation Models





# Closure Model

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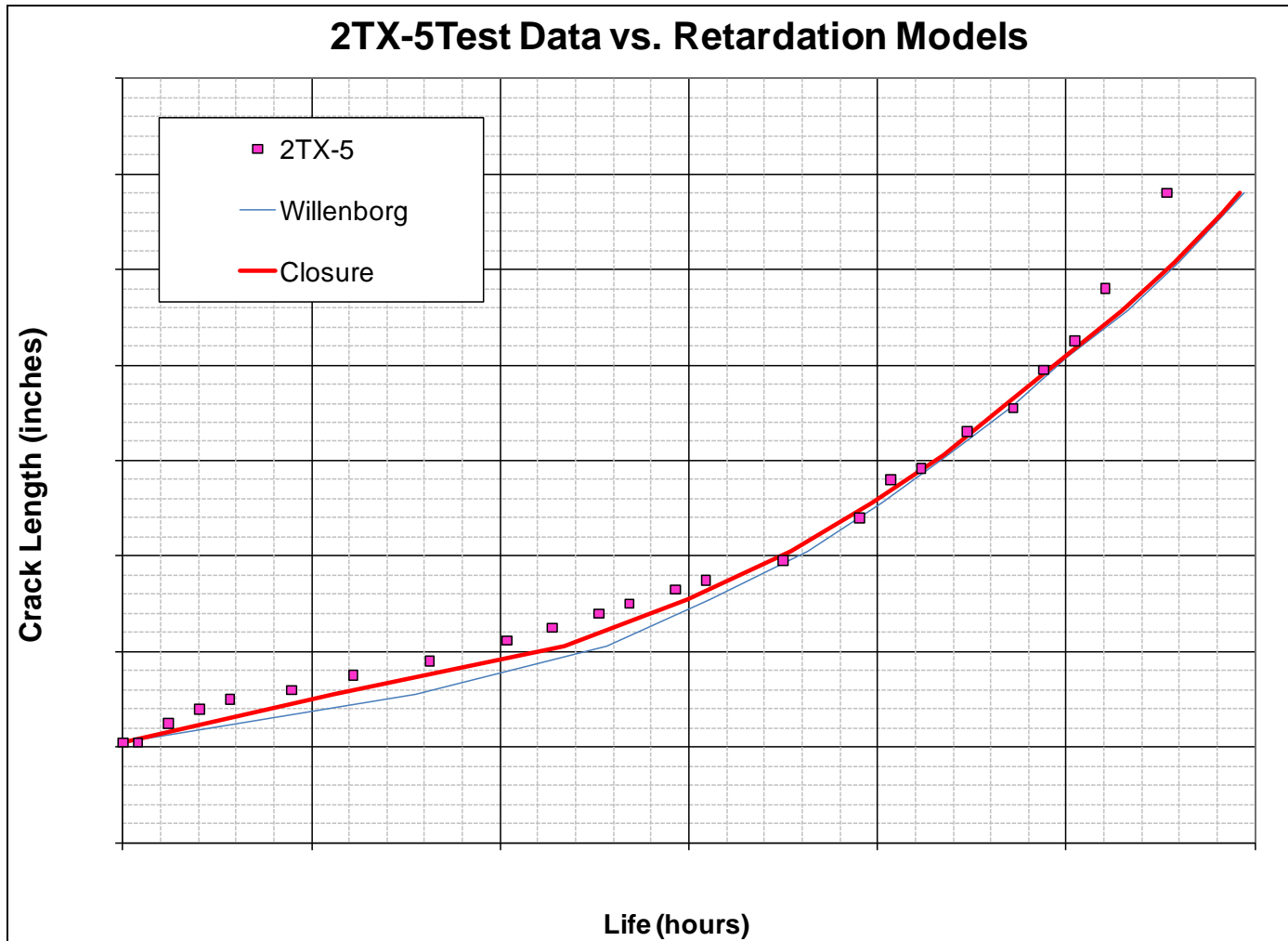
- A single parameter plasticity model
  - Cf, Closure Factor at  $R=0.0$
- Based on the idea that the crack is 'closed' when no load is applied and a certain load must be applied to 'open' the crack tip.
- Matched Willenborg curve almost exactly
- As SOLR values went up, Cf values went down





# Closure Model

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# Closure Model

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- Provides an alternative to using Generalized Willenborg model
- Would require changing existing work without any apparent benefit



# Summary



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- **Generalized Willenborg remains best fit for A-10 ASIP**
- **Further study of SOLR parameters beneficial**
- **Follow-up on purposes:**
  1. **Familiarization technique**
  2. **Verification**
  3. **Input from technical experts**
  4. **Criticism of low SOLR values**
  5. **SOLR value dependencies**



# Acknowledgements



*OGDEN AIR LOGISTICS CENTER*

- **Lucky Smith**
- **Jim Harter**
- **USAF A-10 ASIP Team**