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Air Force Life Cycle Management Center



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Lessons Learned: Stress Ratio Influence on da/dN when using the Generalized Willenborg Model

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Outline



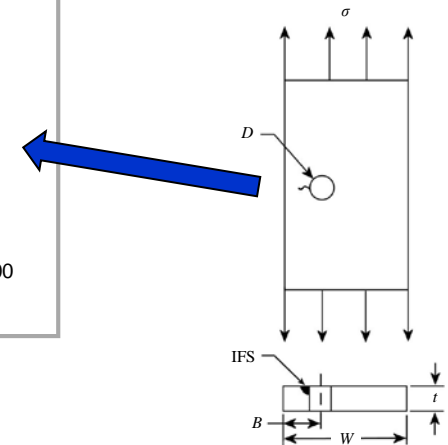
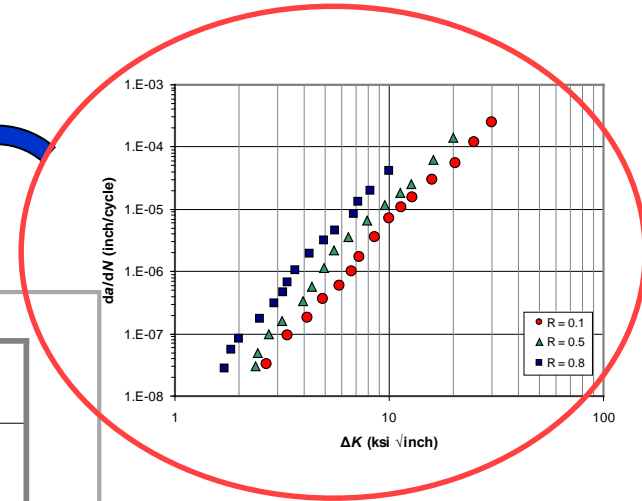
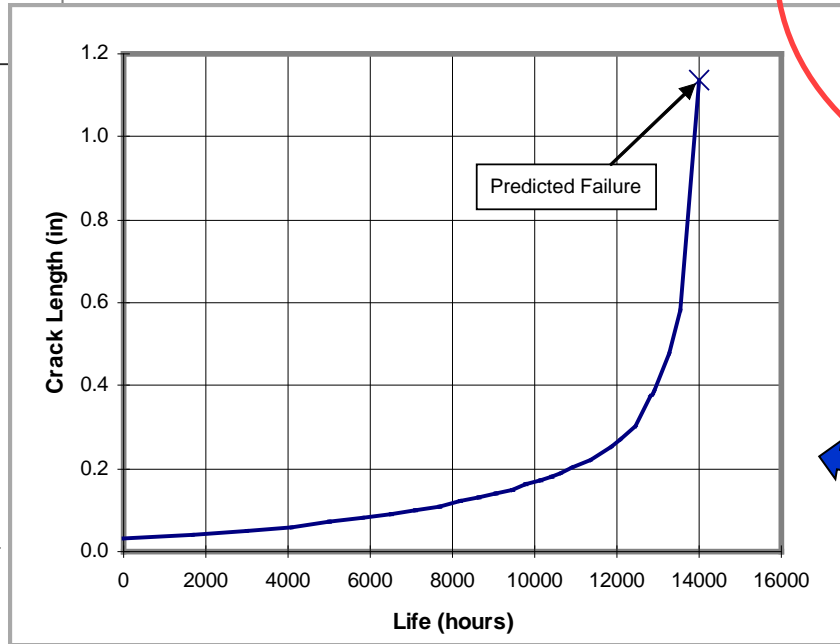
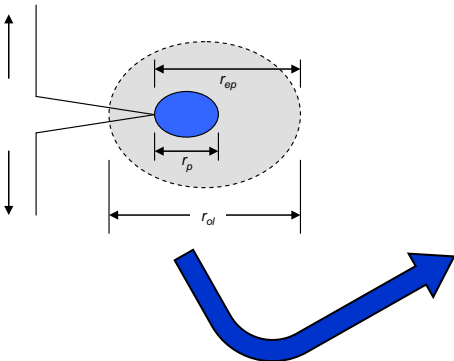
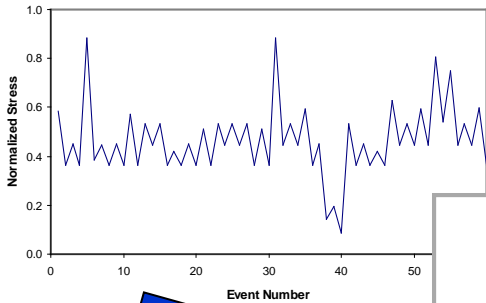
- **Background**
- **Issue**
- **Initial Thoughts**
- **Generalized Willenborg Model**
- **R vs R_{eff}**
- **Summary**



Background

■ Damage Tolerance Analysis

$$a_n = a_i + \sum_{j=1}^n da_j$$





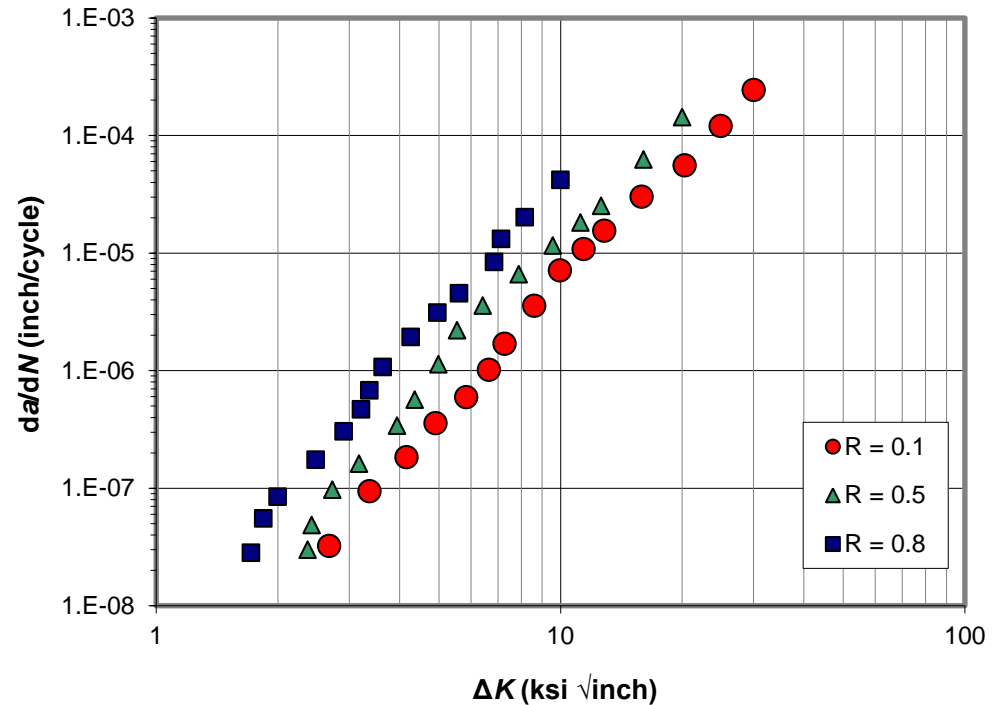
Background (cont.)

- Fatigue Crack Growth Rate (aka da/dN)
- $da/dN = f(\Delta K, R)$

$$\Delta K = \Delta\sigma \sqrt{\pi a} \beta$$

$$\Delta\sigma = \sigma_{\max} - \sigma_{\min}$$

$$R = \frac{\sigma_{\min}}{\sigma_{\max}}$$

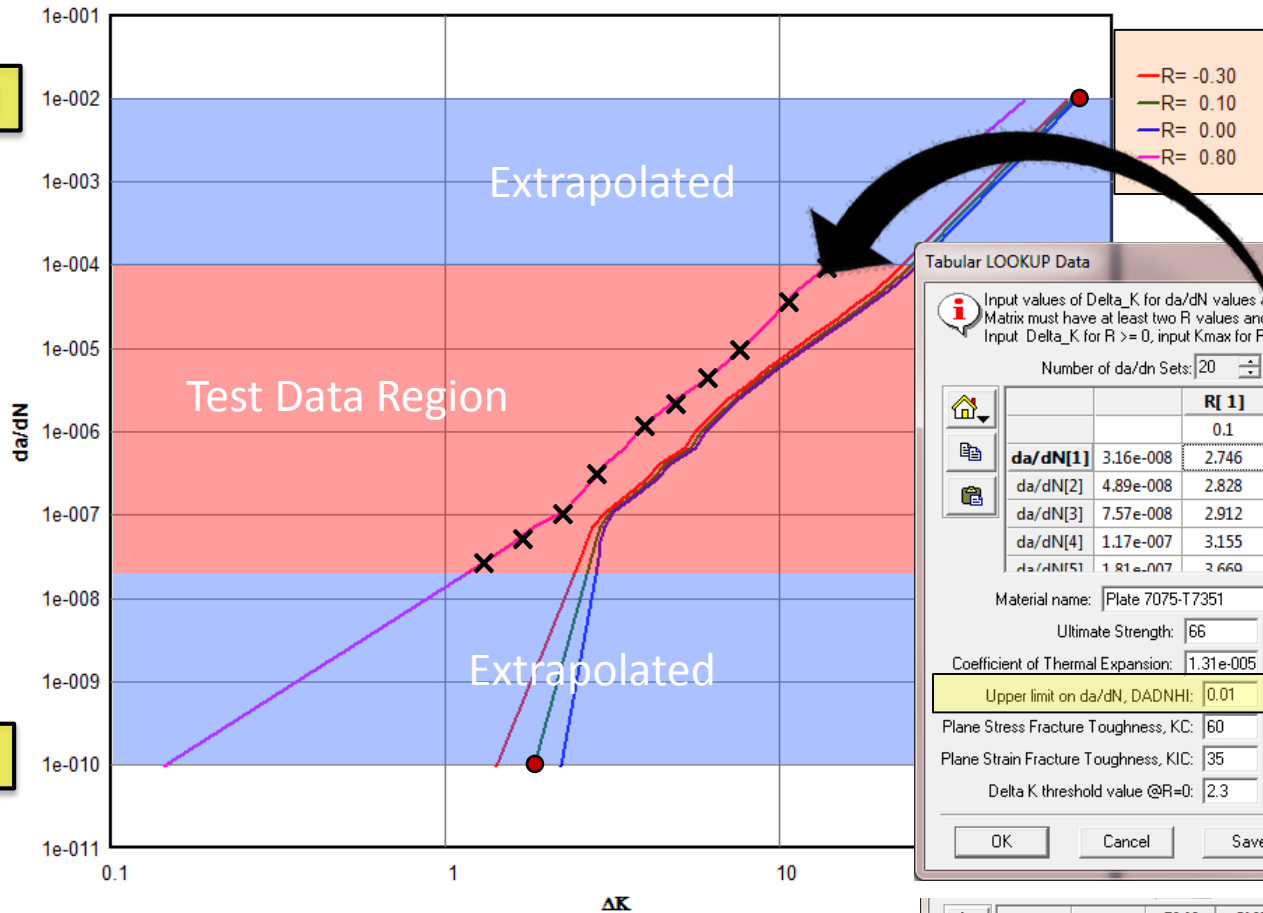




Background (cont.)

Crack Growth Rate Data

dadN_HI



dadN_LO

Tabular LOOKUP Data

Input values of Delta_K for da/dN values and up to 10 different R(stress ratio) values. Matrix must have at least two R values and two da/dN values. Input: Delta_K for R >= 0, input Kmax for R < 0.0

Number of da/dn Sets: 20 Number of R Sets: 2

	R[1]	R[2]
da/dN[1]	3.16e-008	2.746
da/dN[2]	4.89e-008	2.828
da/dN[3]	7.57e-008	2.912
da/dN[4]	1.17e-007	3.155
da/dN[5]	1.81e-007	3.660

Material name: Plate 7075-T7351

Ultimate Strength: 66 Young's Modulus: 10400

Coefficient of Thermal Expansion: 1.31e-005 Poisson's Ratio: 0.33

Upper limit on da/dN, DADNHI: 0.01 Lower limit on da/dN, DADNLD: 1e-010

Plane Stress Fracture Toughness, KIC: 60 Yield Strength, YLD: 57

Plane Strain Fracture Toughness, KIC: 35 Lower limit on R shift (Max: 0): -0.3

Delta K threshold value @R=0: 2.3 Upper limit on R shift (0, 1): 0.8

OK Cancel Save Read Apply

	R[1]	R[2]
da/dN[17]	3.40e-005	17.9038
da/dN[18]	5.26e-005	20.6614
da/dN[19]	8.14e-005	23.4389
da/dN[20]	1.26e-004	26.0663

Note: For R < 0.0, Kmax is used instead of Delta K



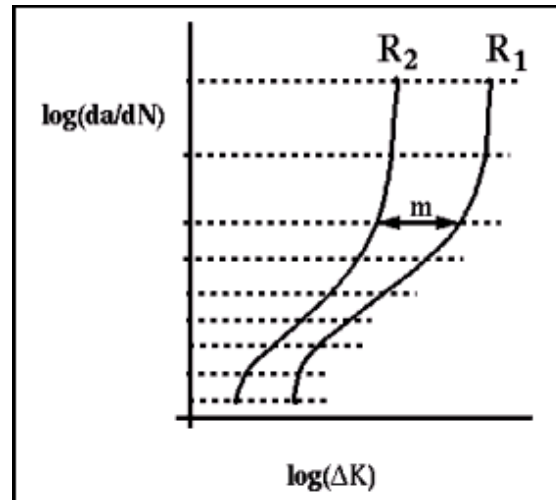
Background (cont.)

■ Harter-T Method

- Shifts da/dN curves for any R
- Applies Walker Equation (point-by-point basis)

For a given crack growth rate:

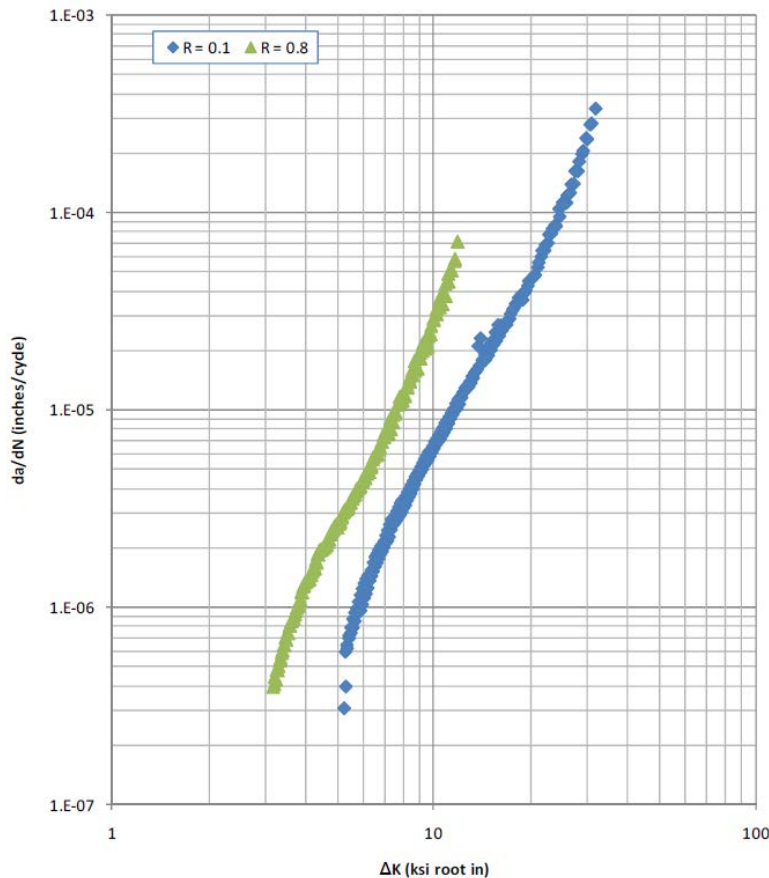
$$\Delta K_1 (1 - R_1)^{(m-1)} = \Delta K_2 (1 - R_2)^{(m-1)} \quad (\text{When, } R_1 \text{ \& } R_2 > 0)$$





Issue

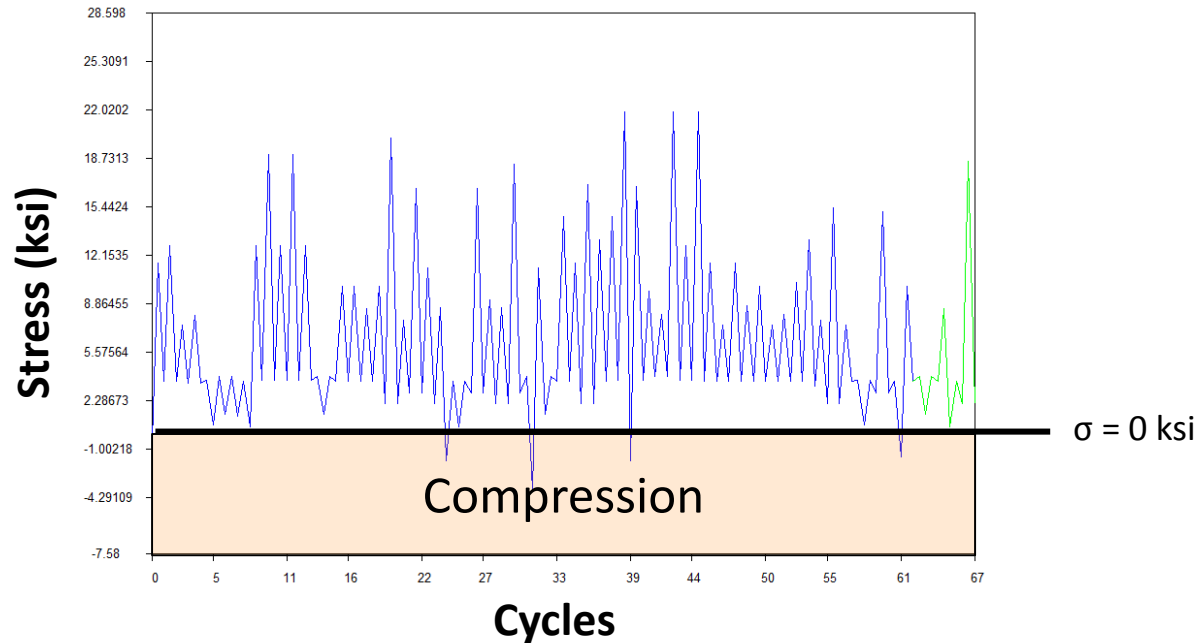
- What stress ratios would be most beneficial for future da/dN testing of 7075-T7351?





Initial Thoughts

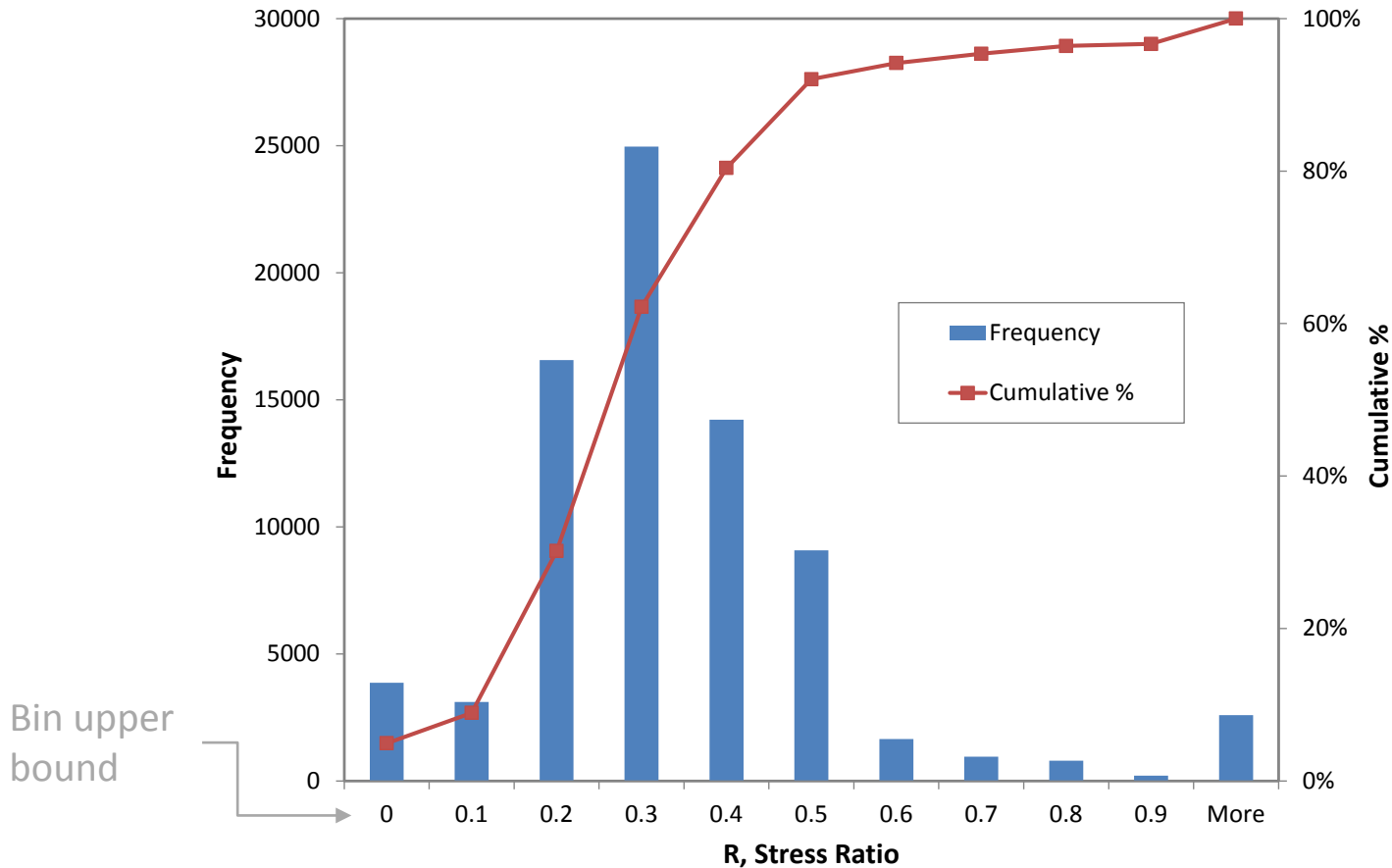
- Consider Current Data
 - Tested stress ratios
 - $R = 0.1, 0.8$ are most common; some $R = 0.5$
 - Wing stress spectra





Stress Ratio (R) Histogram

Wing Spectrum



When using the Generalized Willenborg Model, this is NOT the R that is used to determine da/dN



Generalized Willenborg Model



- Adjusts da/dN by reducing R to R_{eff}

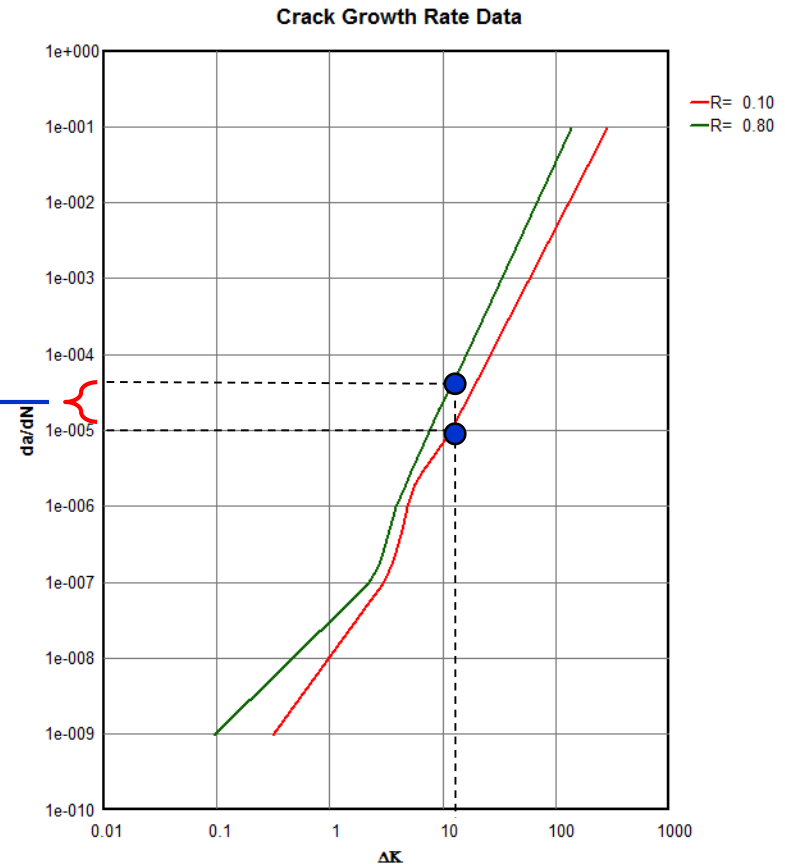
$$K_r = \frac{1 - \frac{\Delta K_{th}}{K_{max}}}{(SOLR - 1)} \left[K_{OL} \sqrt{1 - \frac{x - x_{OL}}{r_{OL}}} - K_{max} \right]$$

$$K_{min,eff} = K_{min} - K_r$$

$$K_{max,eff} = K_{max} - K_r$$

$$R_{eff} = \frac{K_{min,eff}}{K_{max,eff}}$$

Retardation Effect:
Reduction in da/dN

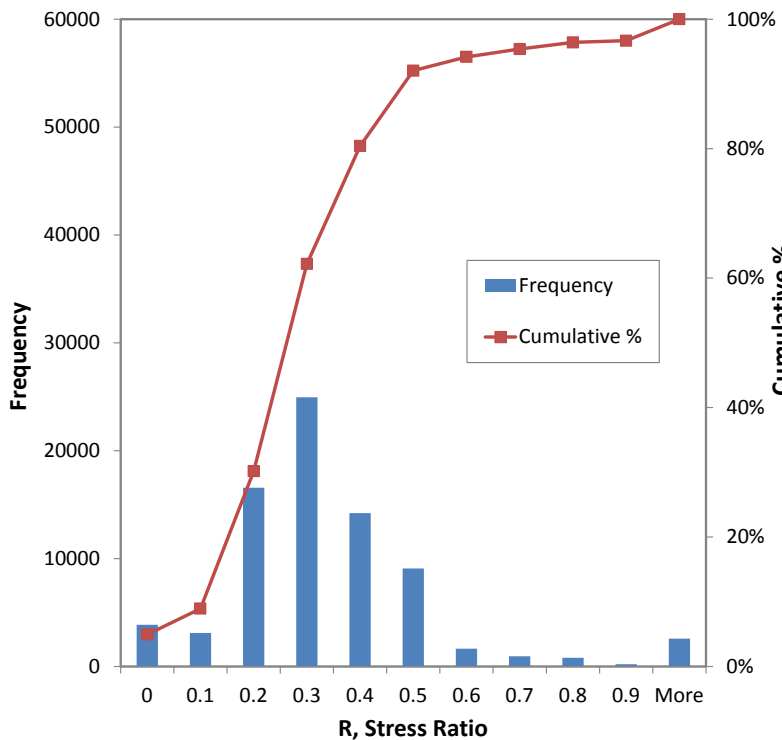


Note: For $R < 0.0$, K_{max} is used instead of Delta K

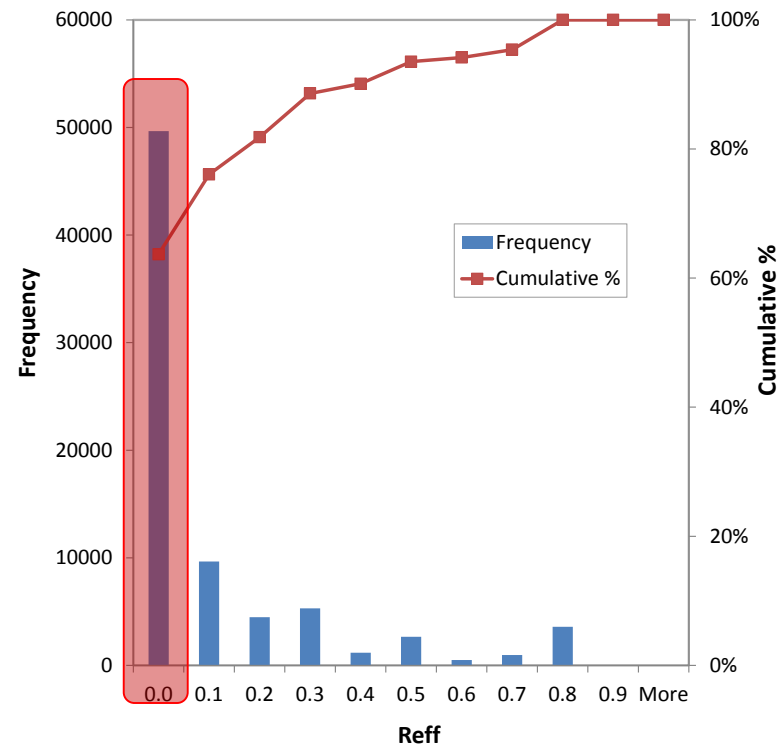


R vs R_{eff}

Wing Spectrum



R, Stress Ratio



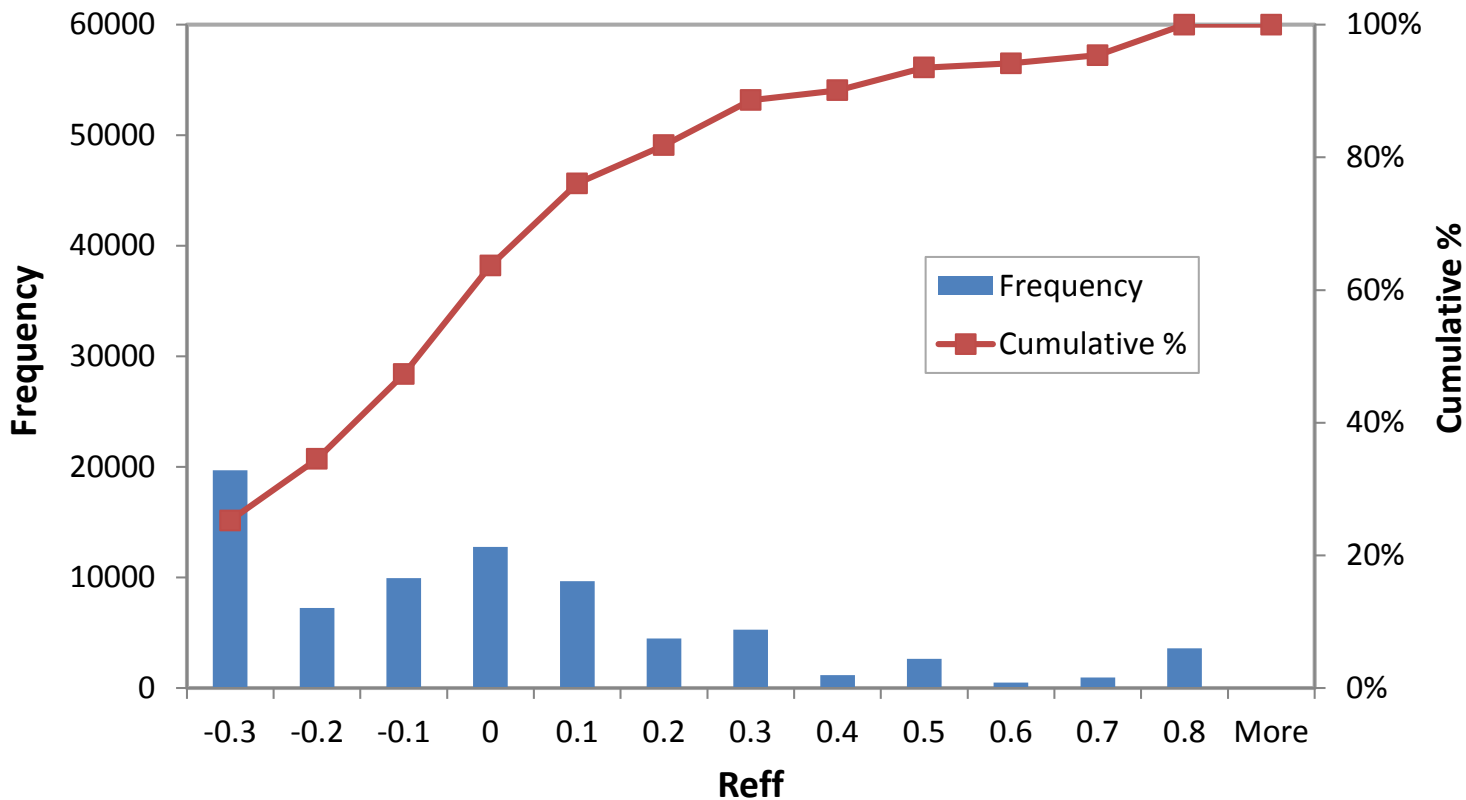
R_{eff}, Effective Stress Ratio

1st 1000 hours



1st 1000 hours

Wing Spectrum

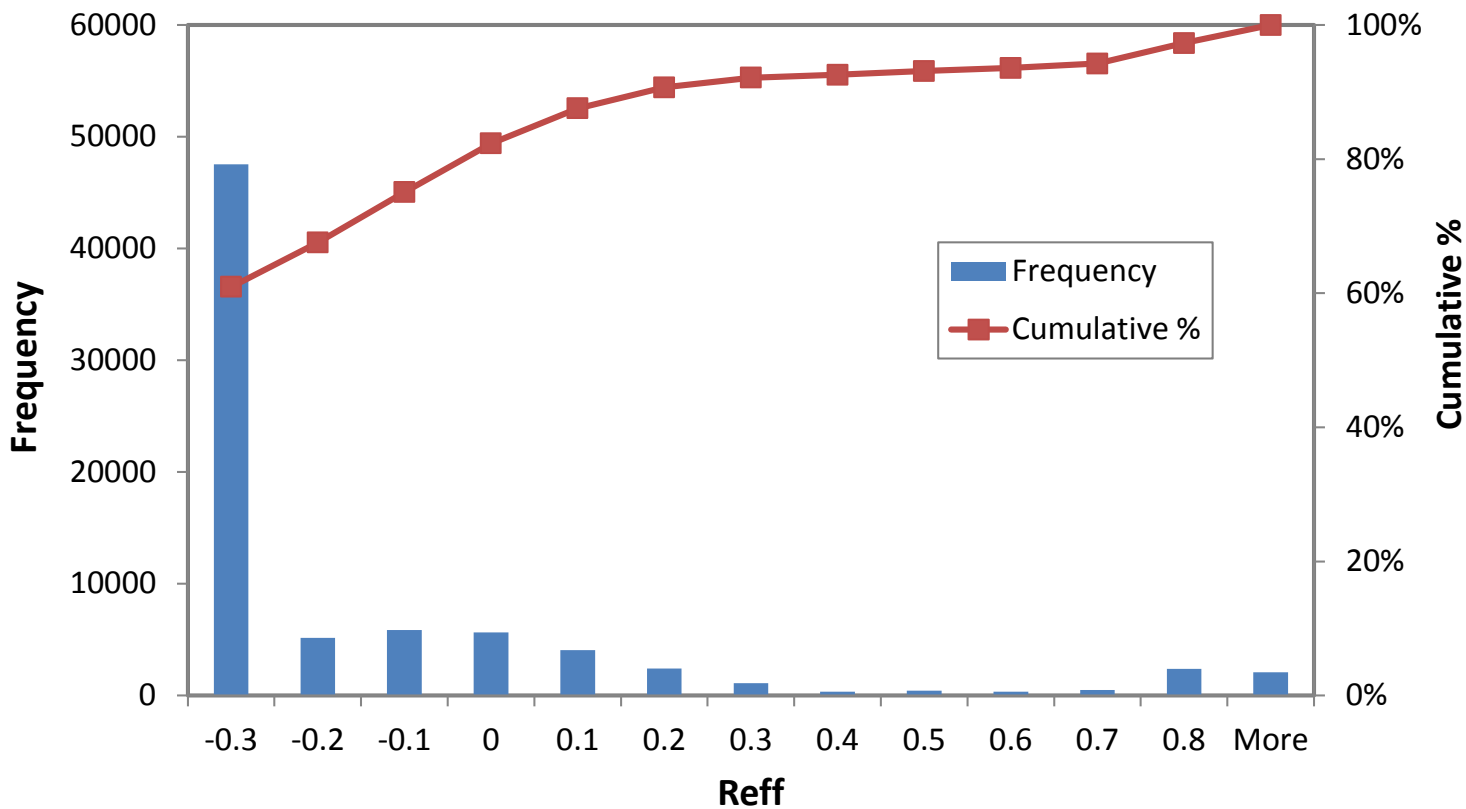


R_{eff} Effective Stress Ratio



2nd 1000 hours

Wing Spectrum



R_{eff} Effective Stress Ratio

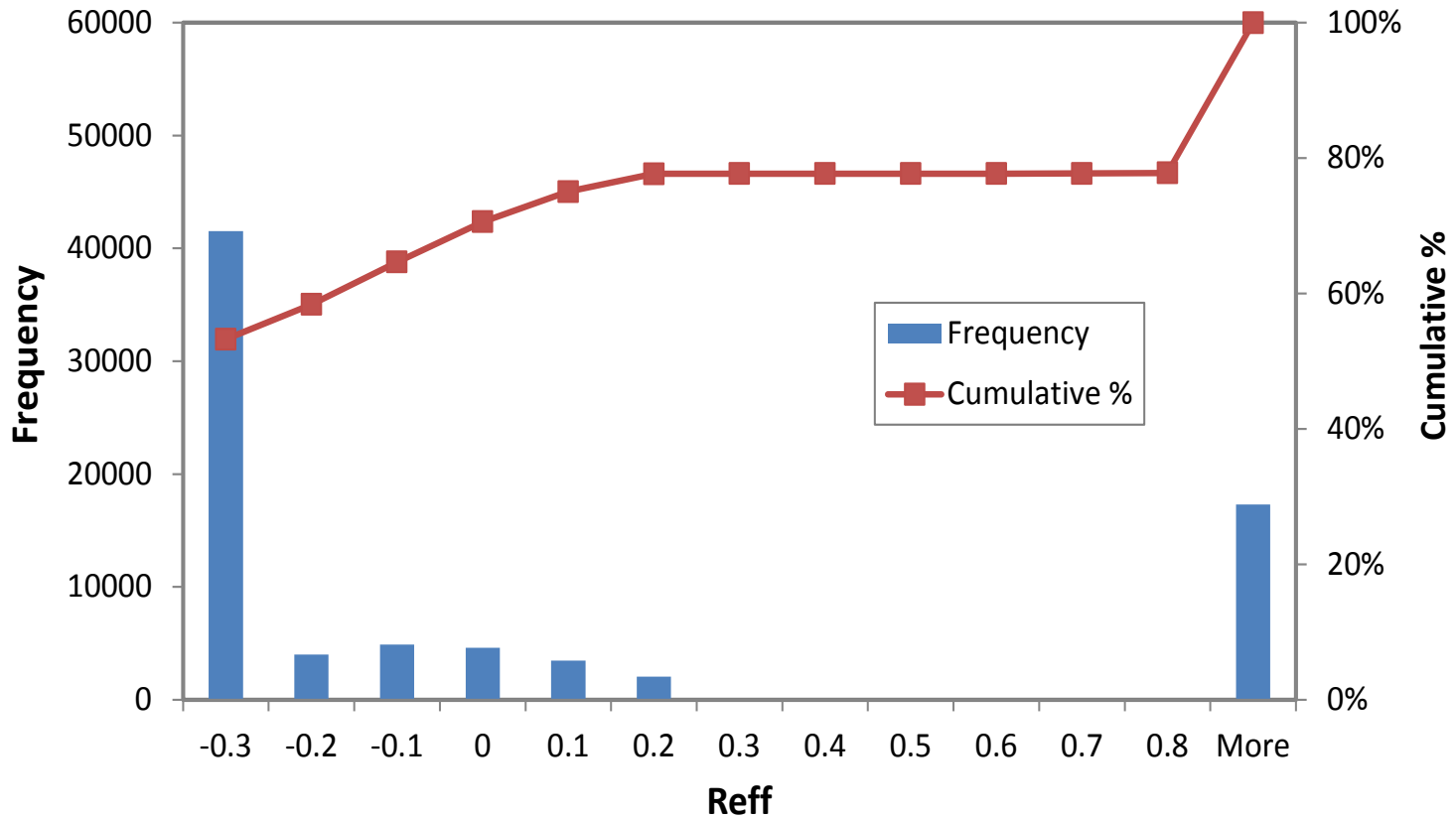


R_{eff}



3rd 1000 hours

Wing Spectrum



R_{eff} Effective Stress Ratio



AFGROW .pl2



- $K_{min,eff}$ and $K_{max,eff}$ are negative
- $da/dN = 0$

$$R_{eff} = \frac{K_{min,eff}}{K_{max,eff}}$$

C Length	Cycles	Pass	DeltaK C	dC/DN	Max Stress	R(final) C	R
0.43085	233958	4	6.566	1.95E-06	12.22	-0.300	0.33
0.43085	233959	4	9.098	5.60E-06	13.39	-0.300	0.30
0.43086	233960	4	0.000	0.00E+00	7.93	3.786	0.49
0.43086	233961	4	0.000	0.00E+00	8.62	10.175	0.45
0.43086	233962	4	0.000	0.00E+00	4.14	1.661	0.25
0.43086	233963	4	0.000	0.00E+00	4.39	1.559	0.41
0.43086	233964	4	0.000	0.00E+00	4.39	1.586	0.38
0.43086	233965	4	0.000	0.00E+00	4.04	1.680	0.22
0.43086	233966	4	9.103	5.61E-06	13.39	-0.300	0.31



Additional FCLs Investigated



- Two Wing
- Two Fuselage
 - Aluminum and steel
- Multiple Usages
- Same Trends Seen
 - Significant shift in R vs R_{eff}
 - Continues to shift with subsequent passes



Question

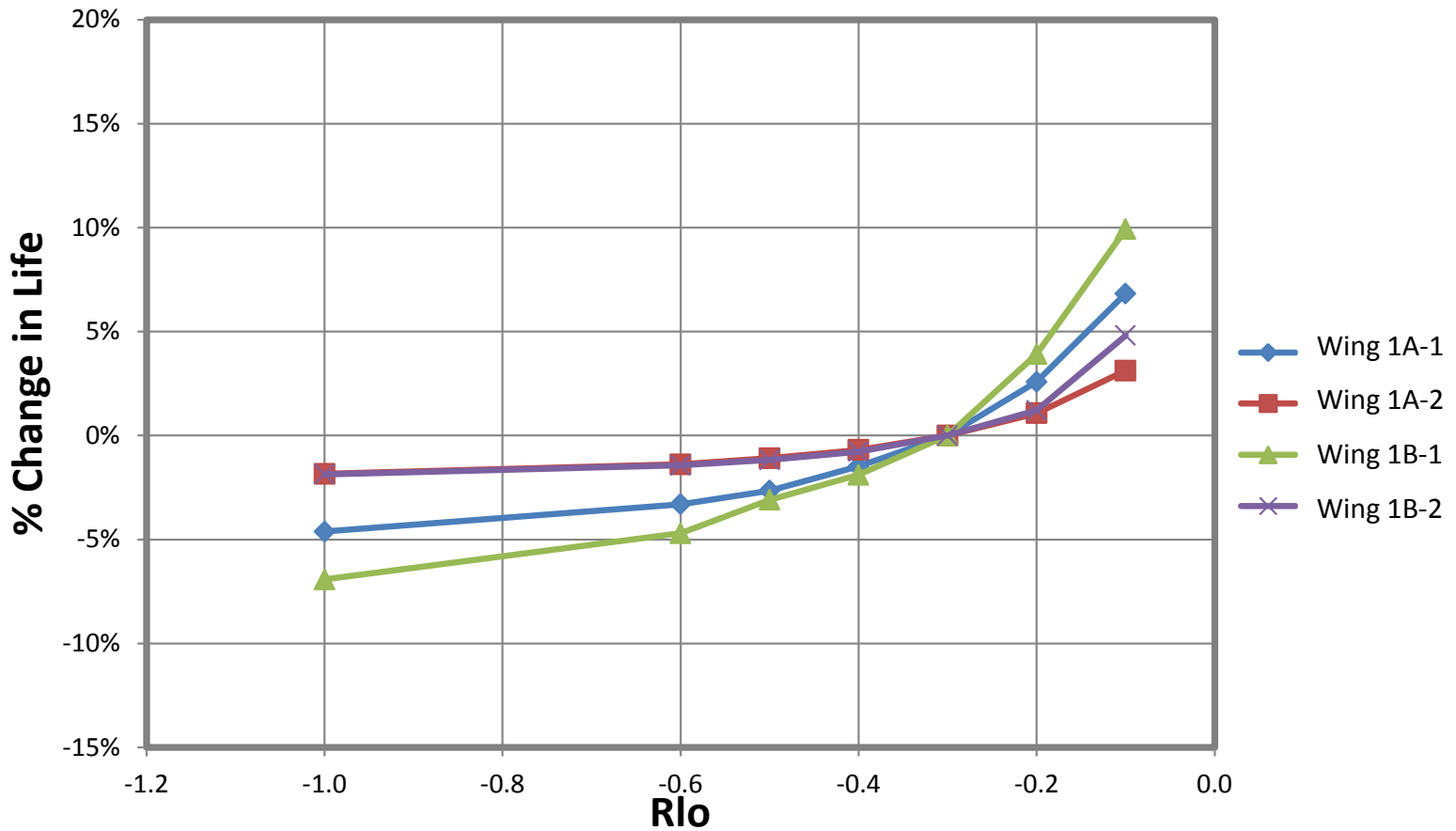
- What percentage of the crack growth is due to cycles with $R_{eff} < 0$?

Location	Usage	% of Growth at $R_{eff} < 0$	% of Growth at $R_{eff} = -0.3 (R_{LO})$	Material
Wing 1A	1	55%	11%	7075-T7351
Wing 1A	2	61%	19%	7075-T7351
Wing 2A	1	66%	19%	7475-T7351
Wing 1B	1	56%	12%	7075-T7351
Fuselage 1	1	20%	5%	7075-T73511
Fuselage 2	1	22%	2%	4130
Fuselage 2	2	45%	9%	4130



R_{LO} Sensitivity

Wing 1 Spectrum

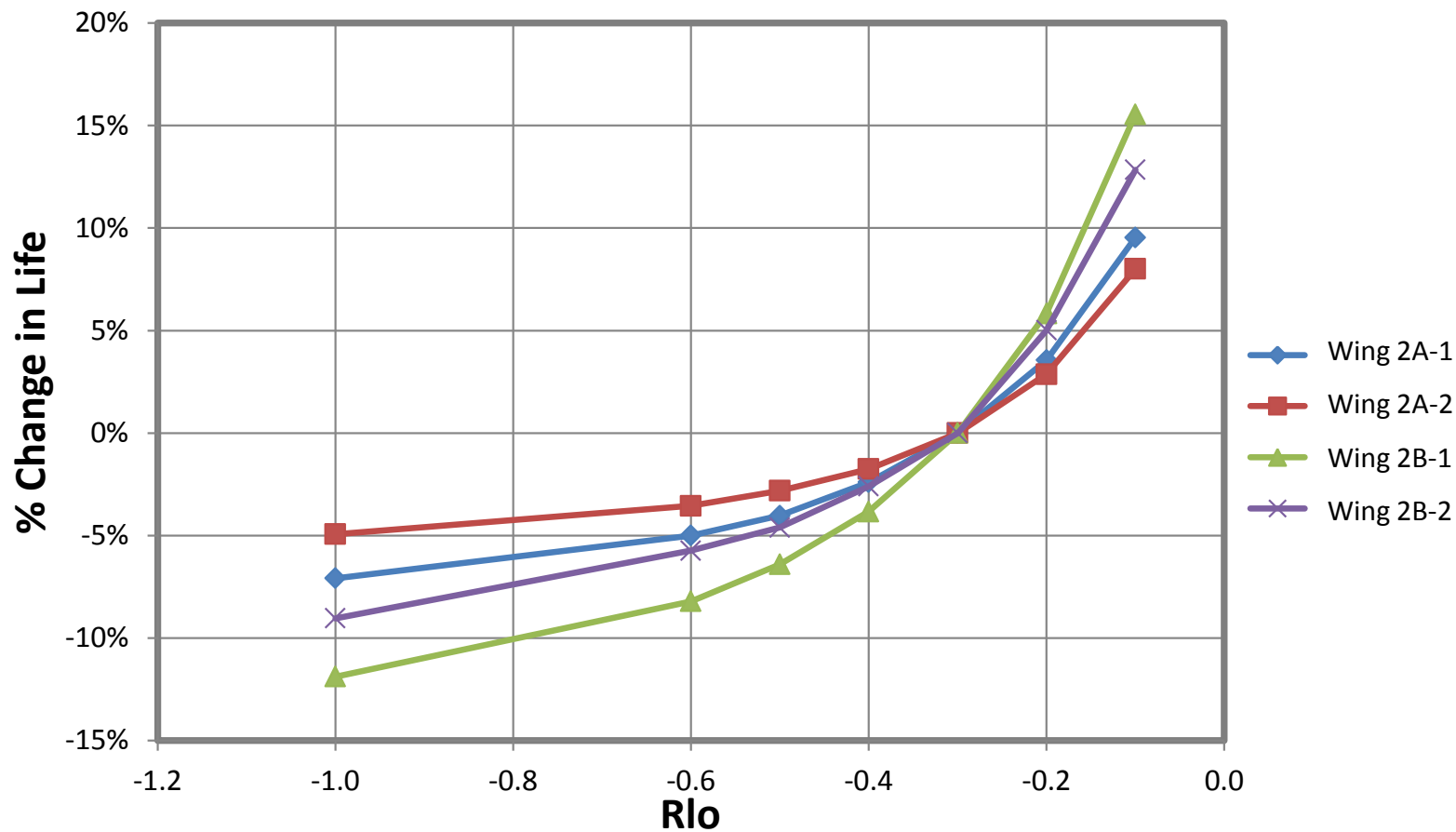


2 Locations, 2 Usages



R_{LO} Sensitivity

Wing 2 Spectrum

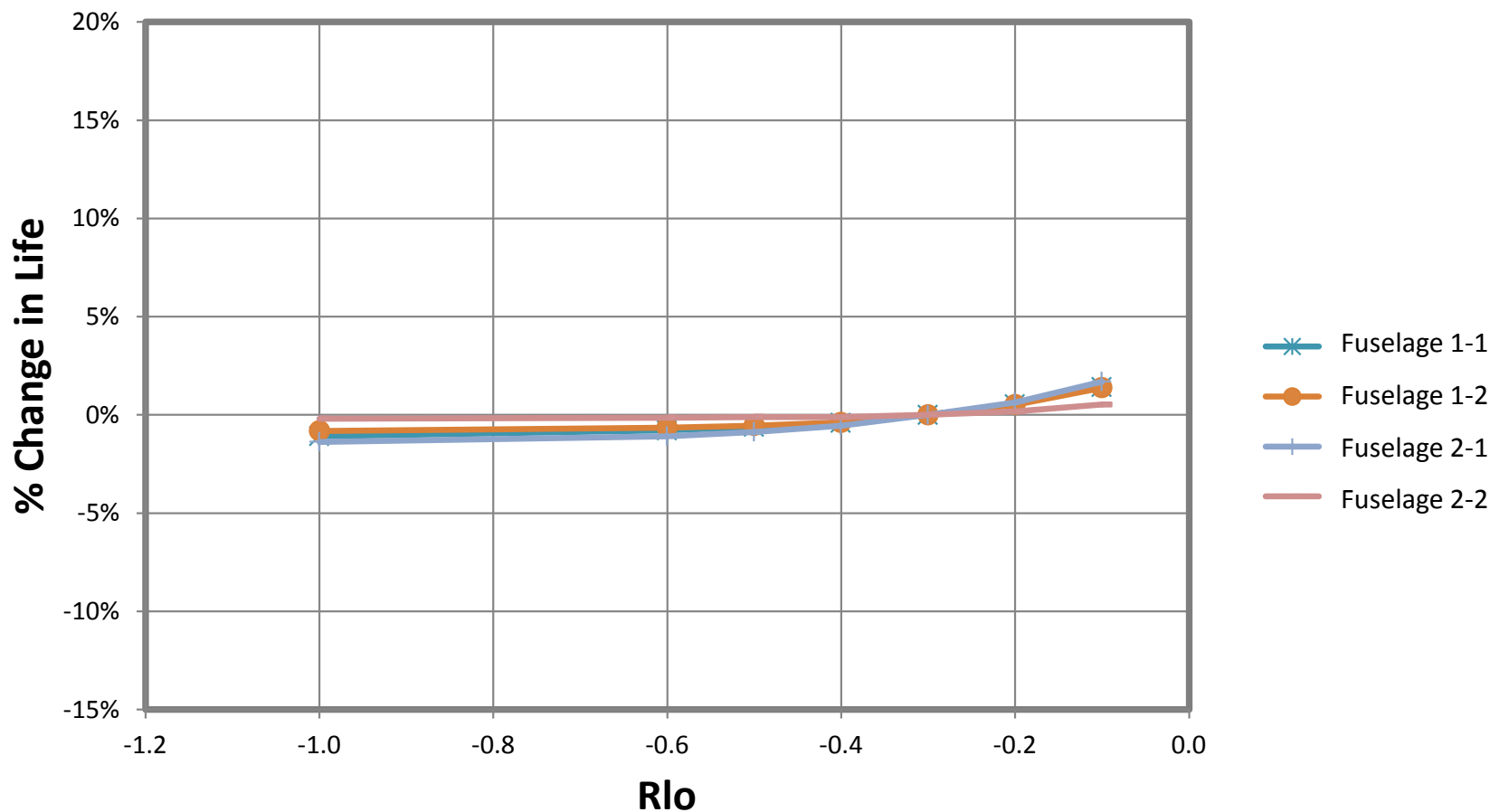


2 Locations, 2 Usages



R_{LO} Sensitivity

Fuselage Spectrum



2 Locations, 2 Usages



Summary



- **Test Program at $R < 0$**
 - $R = -1.0, -0.5, -0.3$
 - Compare test data to extrapolation at $R < 0$
 - Determine R_{LO}
- **Lessons Learned**
 - Generalized Willenborg: think R_{eff}
 - da/dN : extrapolation vs interpolation



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Questions?

