



**U.S. AIR FORCE**

# T-38 Integrity and Analysis Section



**U.S. AIR FORCE**

## 2019 DADTA Report Update, -29 Wing Correlation

11 September 2019

Michael Wilcox (USAF)



# Overview



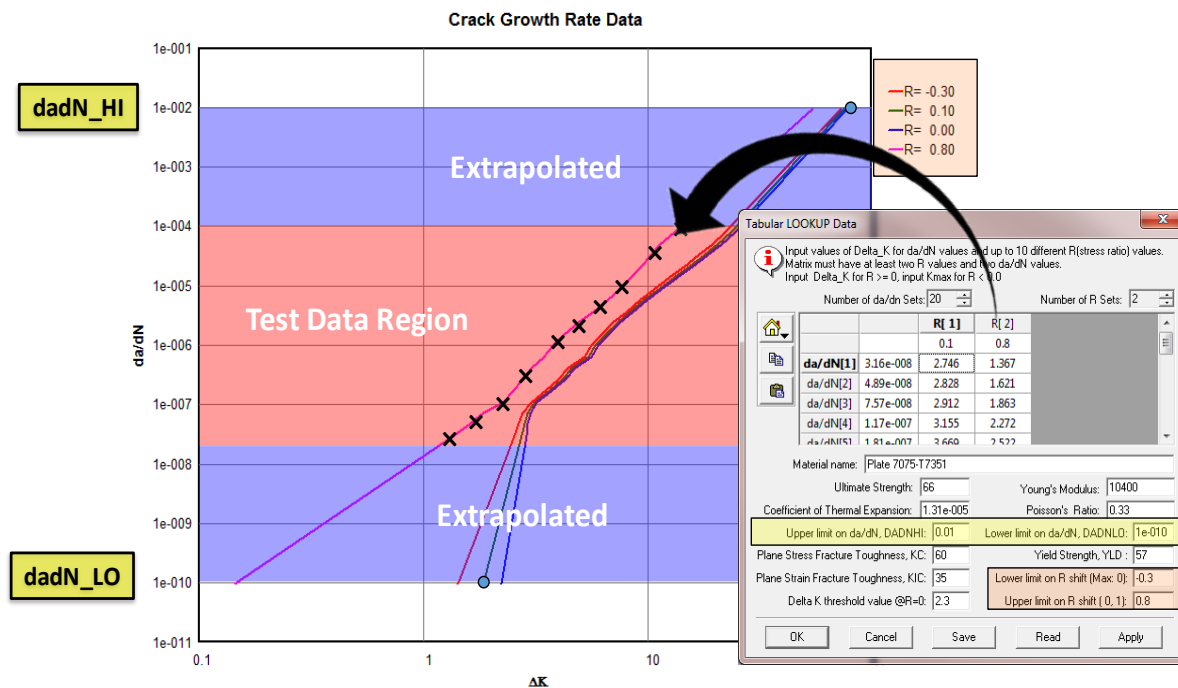
- **Background**
- **Correlation Approach**
- **Correlation Examples**
- **SOLR Selection**
- **DADTA Update Results**
- **Summary and Future Work**



# Background

- Crack growth analyses extensively used regions of the  $da/dN$  vs.  $\Delta K$  space that current material models didn't describe

### Tabular Lookup Material Model in AFGROW



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



# Background (cont.)



- **Material testing and model creation followed**
- **Updated material models used in 2018 DADTA update**
  - **Results were drastically different from the 2017 DADTA Report results**
    - **Generally longer life predictions (Unconservative?)**
    - **2018 DADTA Results have been viewed as “For Reference Only”**
  - **Identified the need for the Generalized Willenborg retardation parameter (SOLR) to be re-correlated for all test specimens and new SOLR values for each FCL selected**
- **2017 DADTA report has been authoritative in the interim**



# Background (cont.)



## ■ Generalized Willenborg Model

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

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

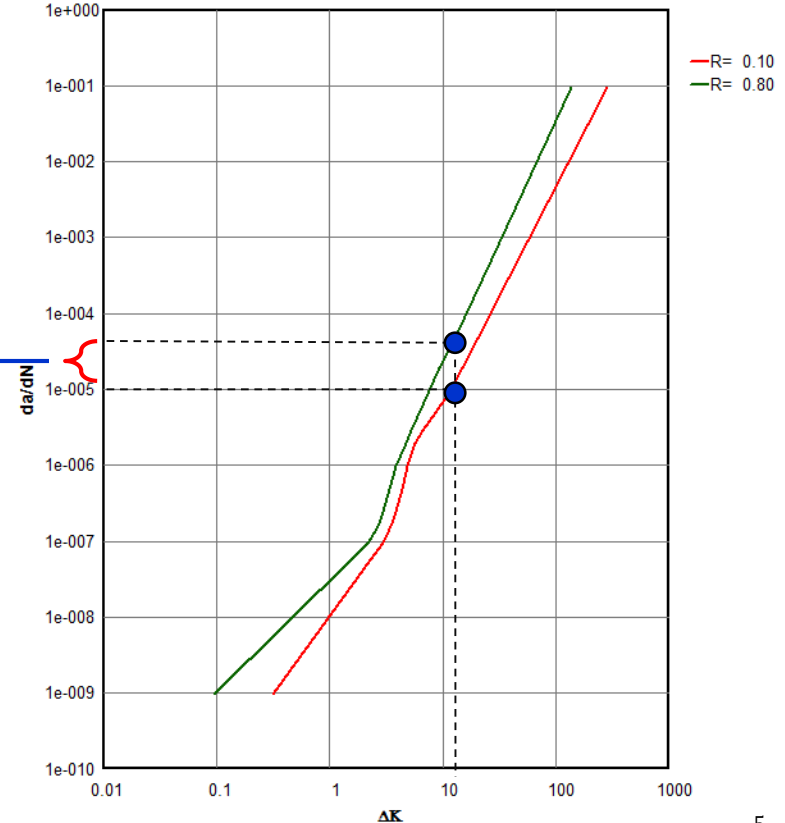
$$K_{min,eff} = K_{min} - K_r$$

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

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

Retardation Effect:  
Reduction in  $da/dN$

Crack Growth Rate Data



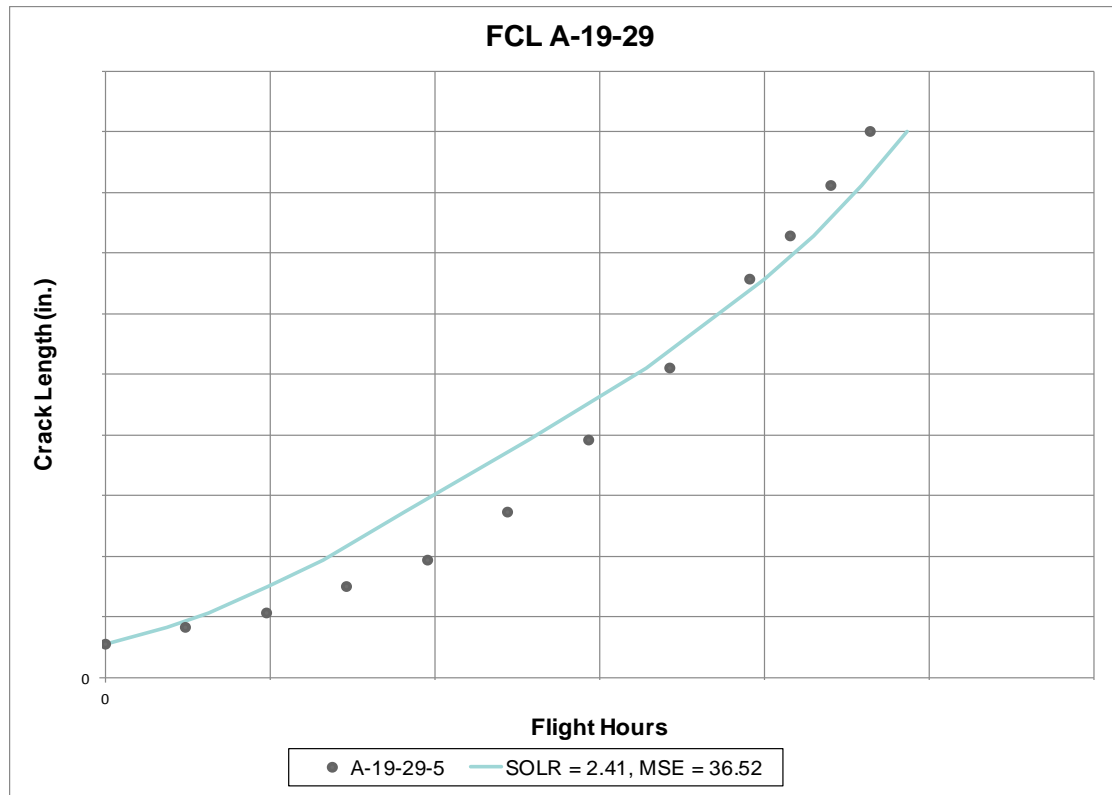
Note: For  $R < 0.0$ ,  $K_{max}$  is used instead of Delta K



# Correlation Approach



- Goal: Iterate on SOLR values until the analytical crack growth resembles the tested growth as closely as possible

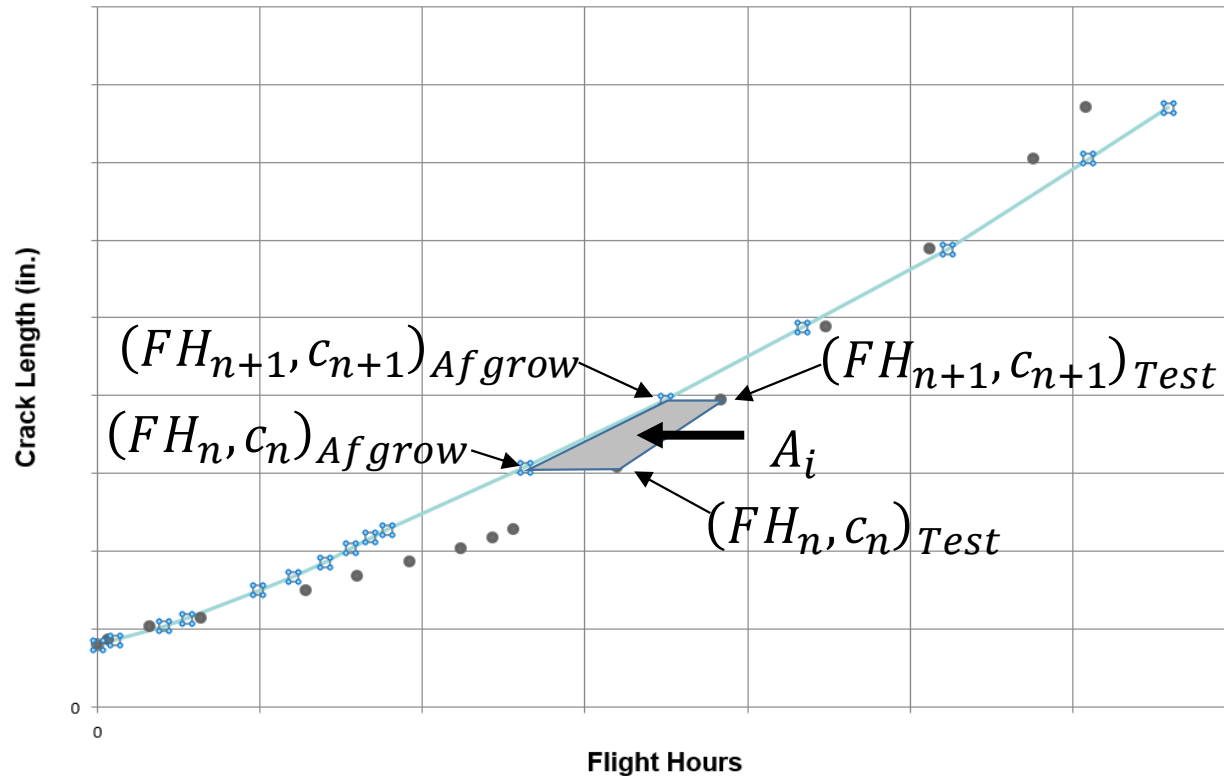




# Correlation Approach



- Strategy: Minimize the difference between the two curves



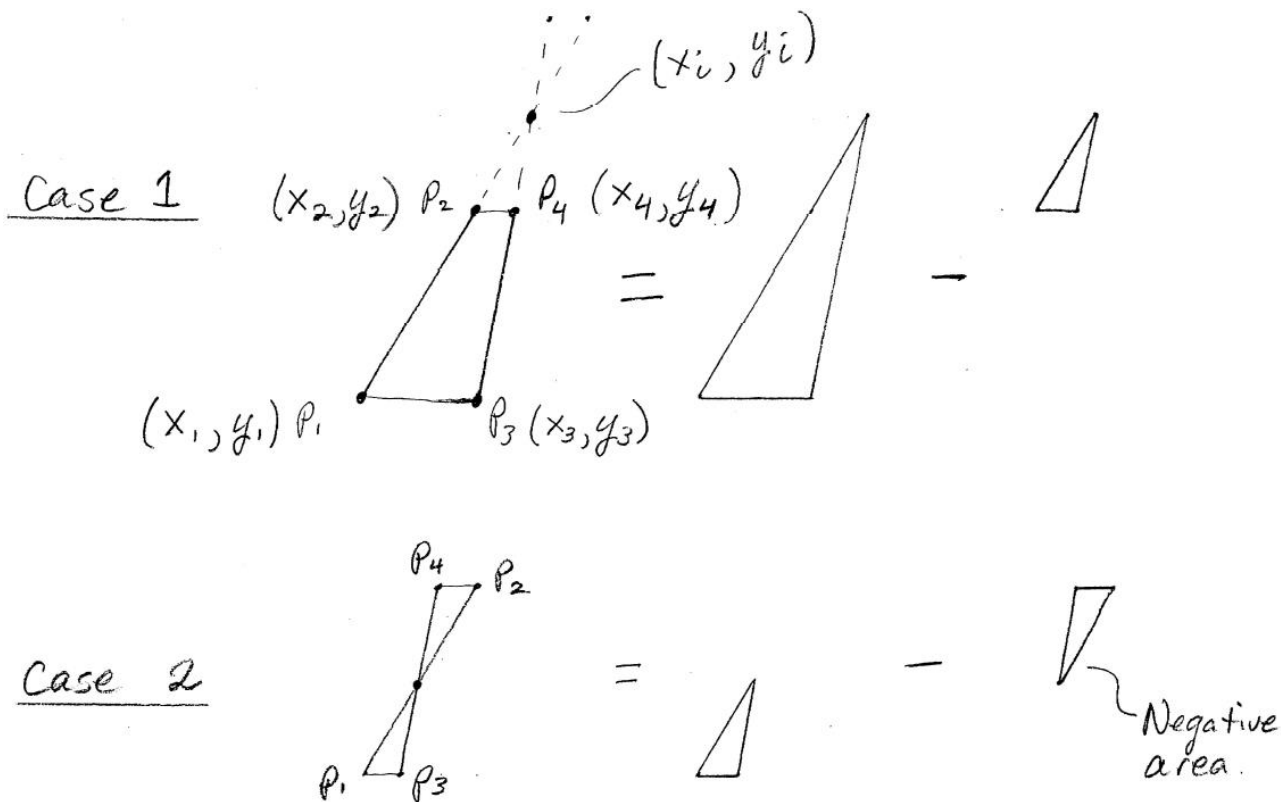


# Correlation Approach



- Method of calculating an area segment:

$$A_i = A_1 - A_2$$





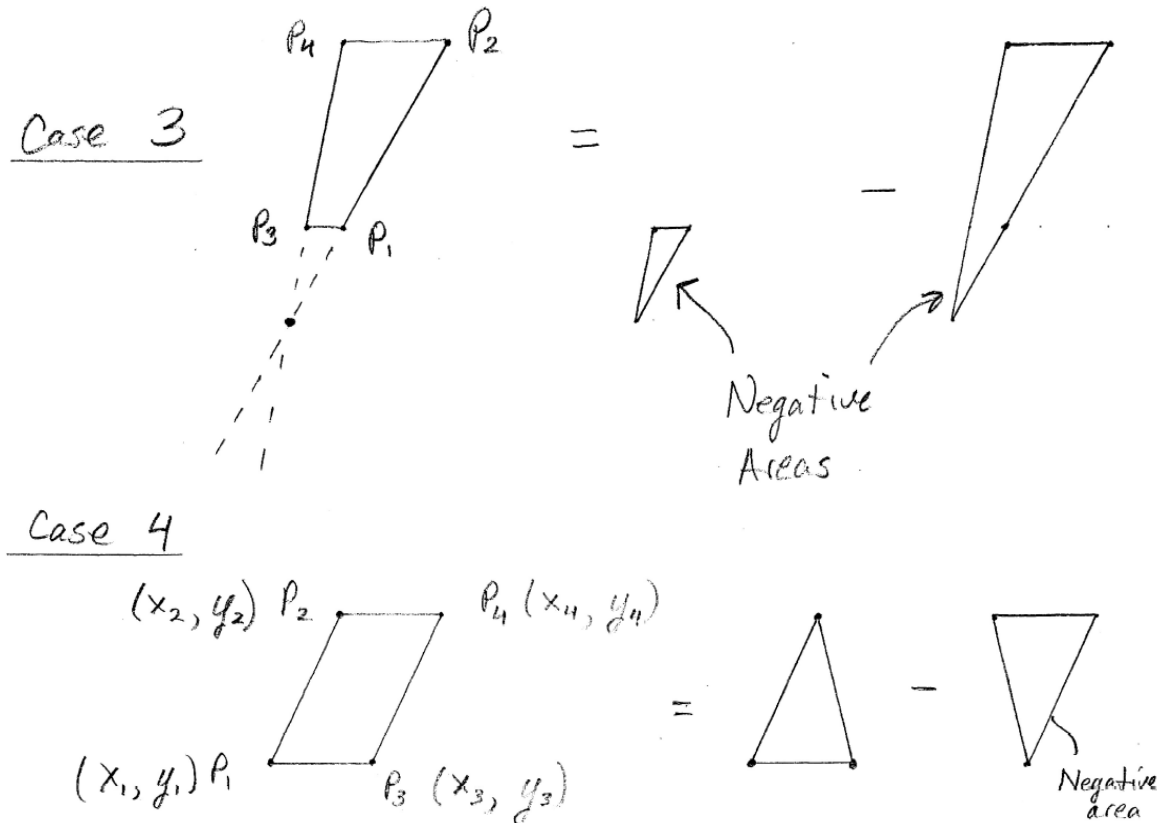


# Correlation Approach



- Method of calculating an area segment:

$$A_i = A_1 - A_2$$





# Correlation Approach



## ■ Mean Squared Error

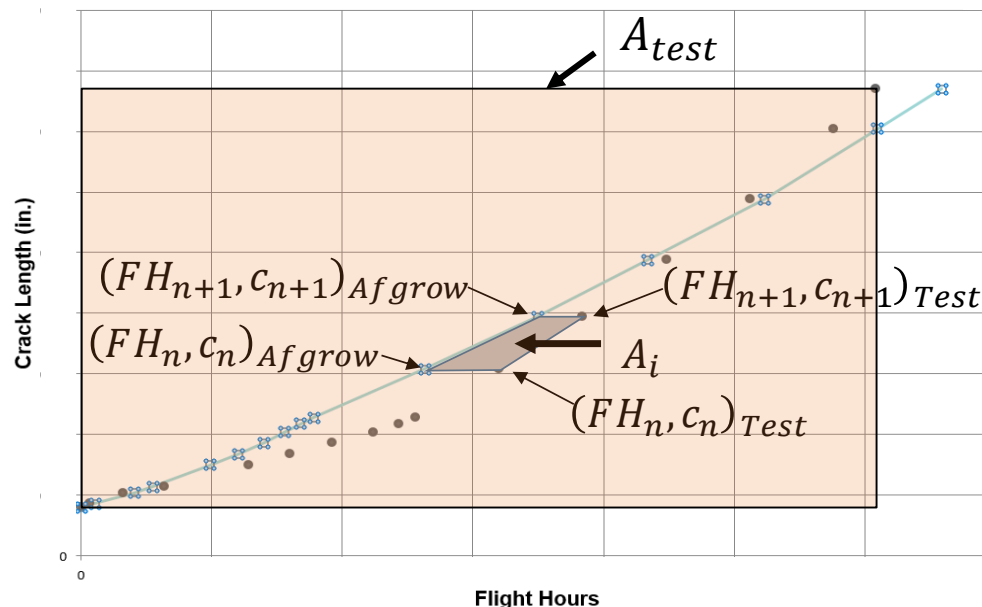
$$A_{Error} = \sum_{i=1}^{N-1} A_i$$

$$A_{test} = (c_{final} - c_{initial})(L_{final} - L_{initial})$$

$$MSE = \left( 100 * \frac{A_{Error}}{A_{test}} \right)^2$$

## ■ Usefulness of

$$\sqrt{MSE}$$

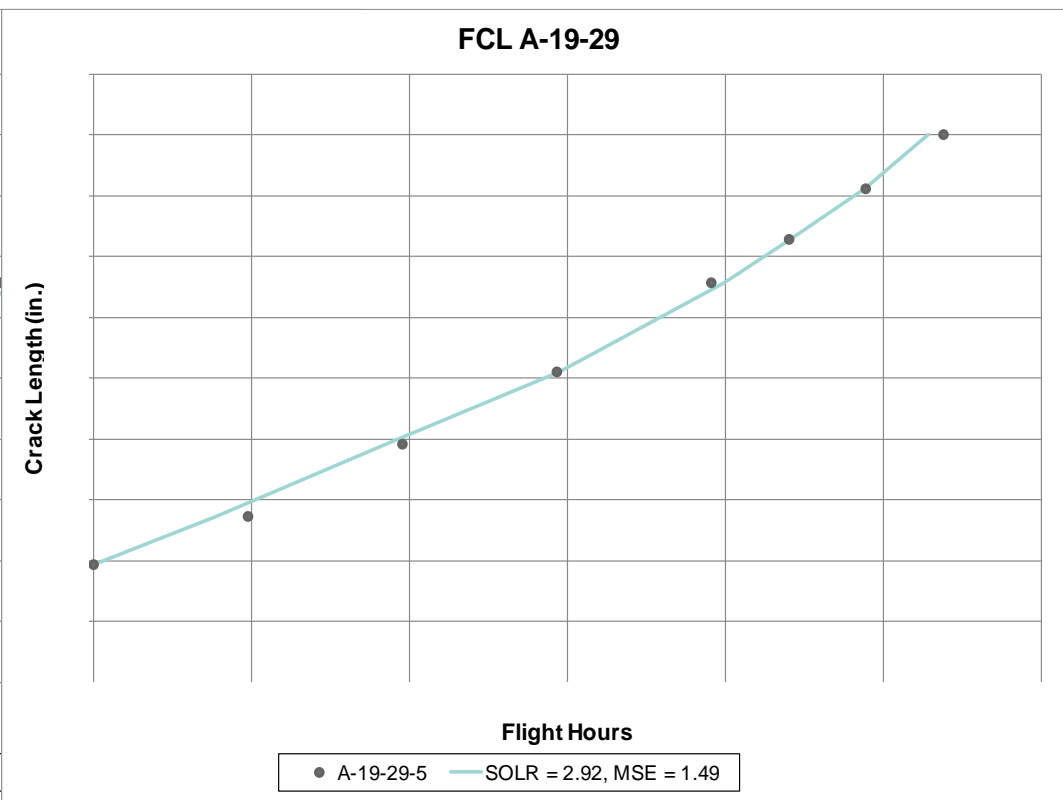
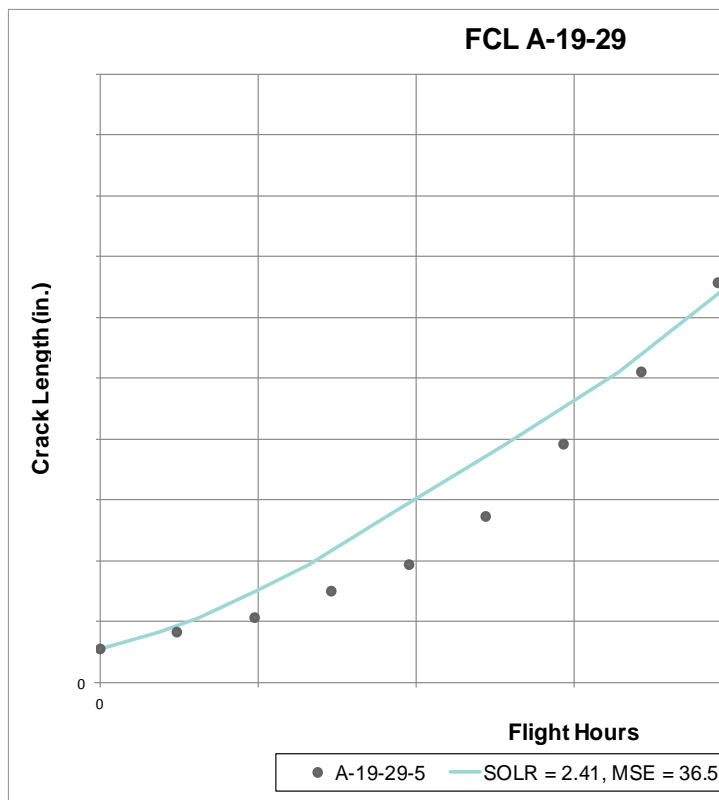




# Correlation Approach



- Test Data Selection:
  - Initial data point selection





# Correlation Approach



- **Test Data Selection:**
  - **Final data point selection**
    - Final test data point
    - Secondary crack begins on the opposite side of a hole
    - Thru-crack transition region issues
    - Critical crack length of the FCL
  - **Documentation**
    - The data points selected for all test specimens are recorded together with rationale for their selection in the correlation COM.



# Correlation Approach



- **Optimization**
  - **Golden Section Search method**
    - **Tri-section method coded by Will Campbell**
  - **Objective function uses MSE equation based on:**
    - **Shape Matching**
      - **Entire Curve**
      - **Optionally could use only a portion of the curve**
    - **End Matching**
      - **Only final area segment**



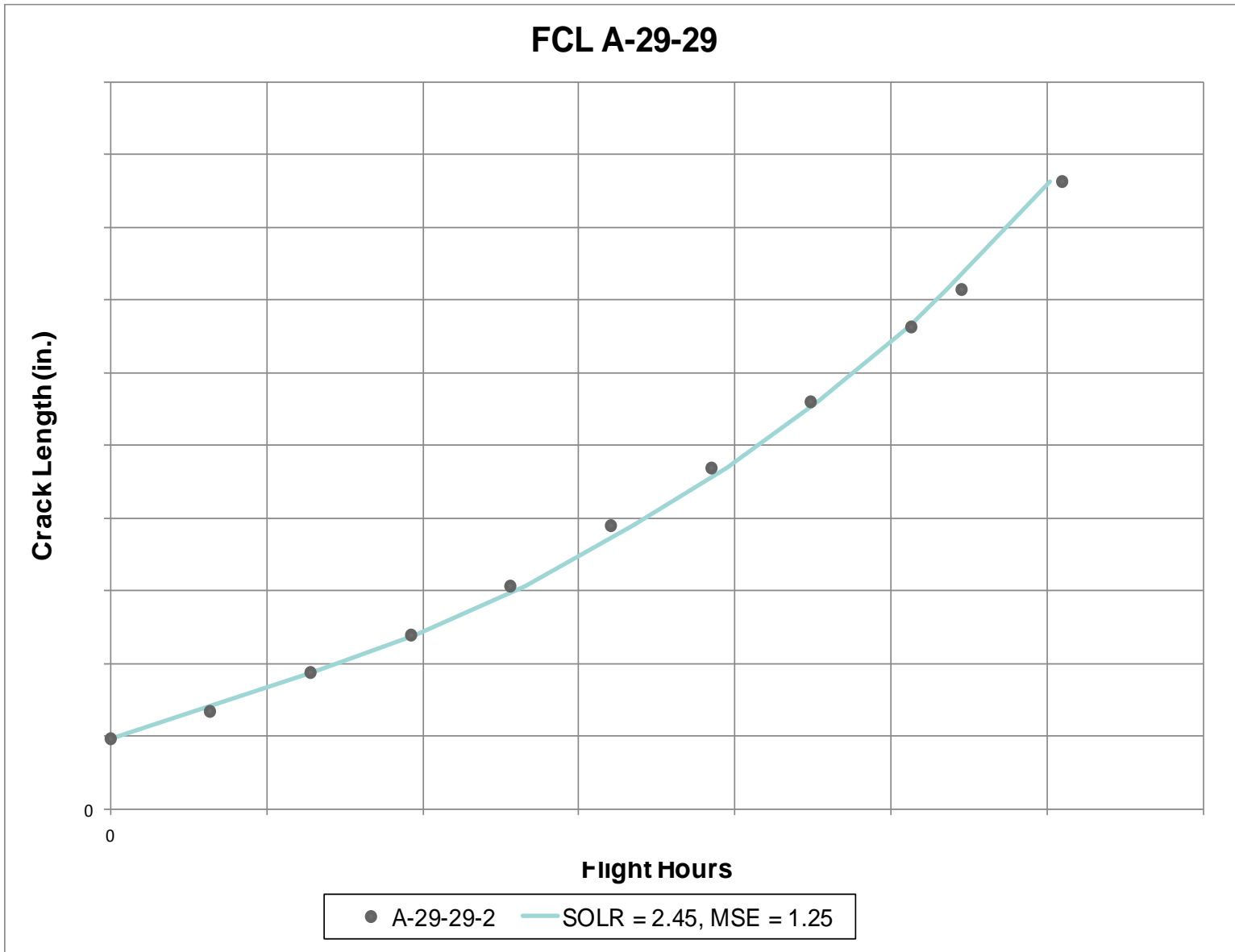
# Correlation Approach



- **Engineering Judgement**
  - **Engineer examines correlation curve outputs and determines whether there should be a change to the correlation approach/inputs.**



# Correlation Examples

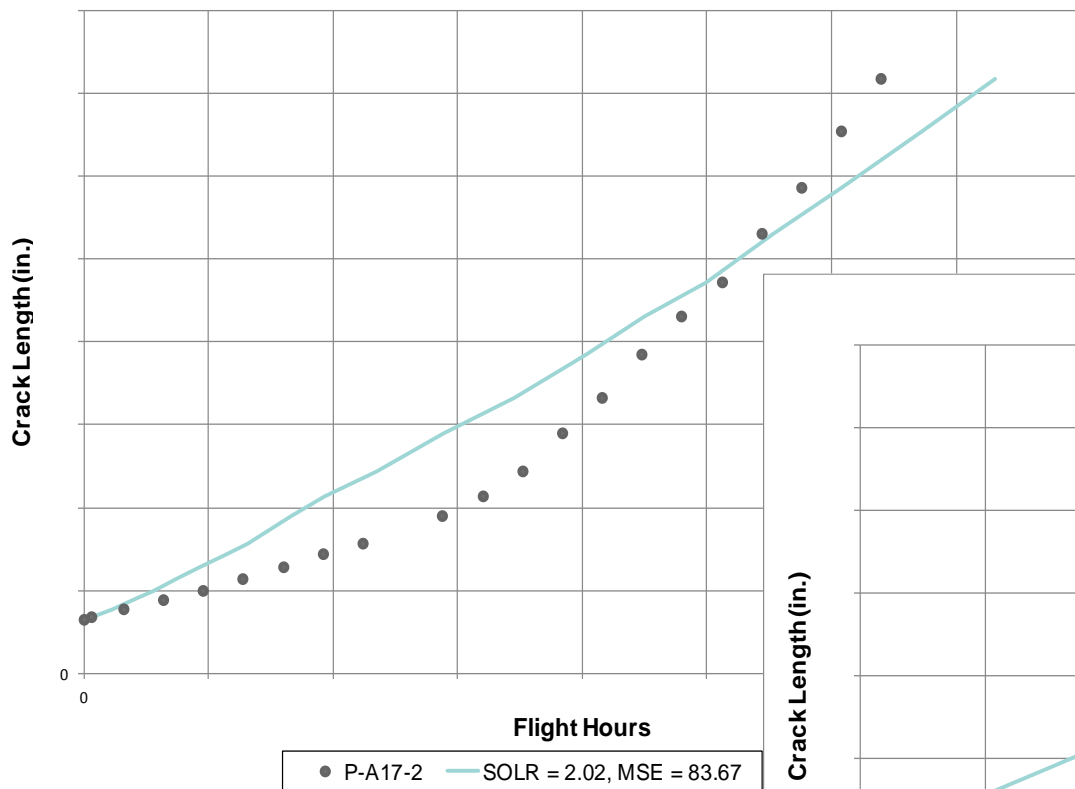




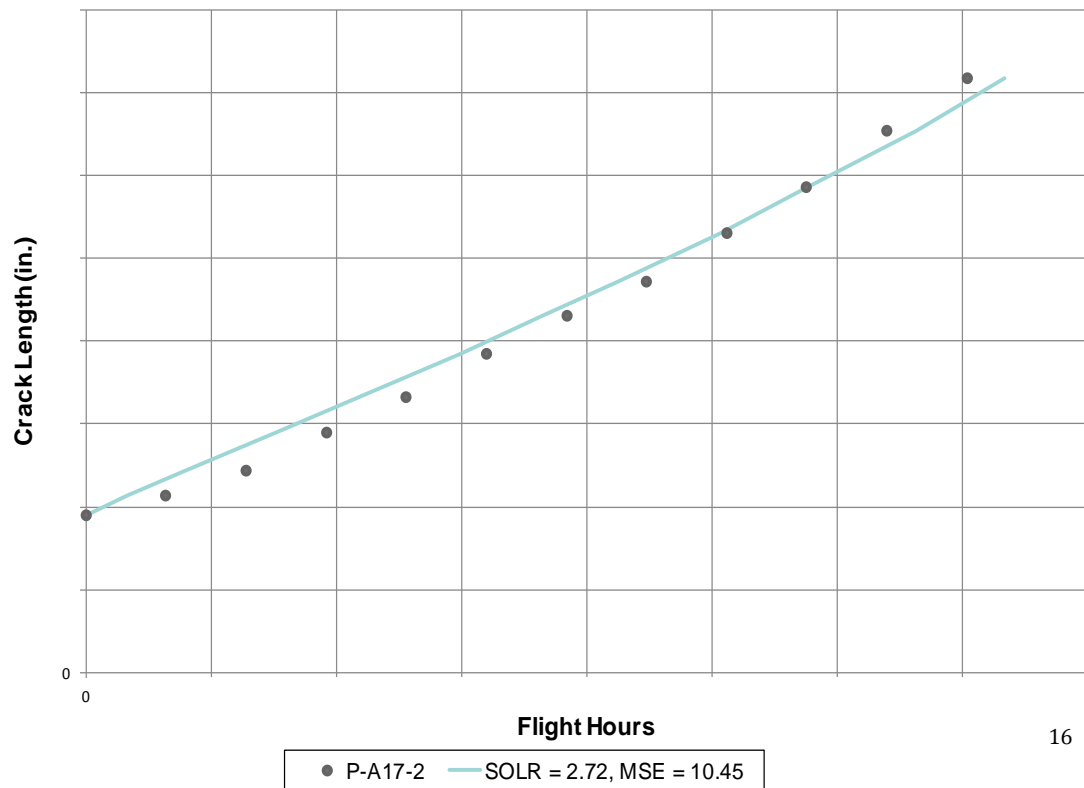
# Correlation Examples



FCL A-17



FCL A-17



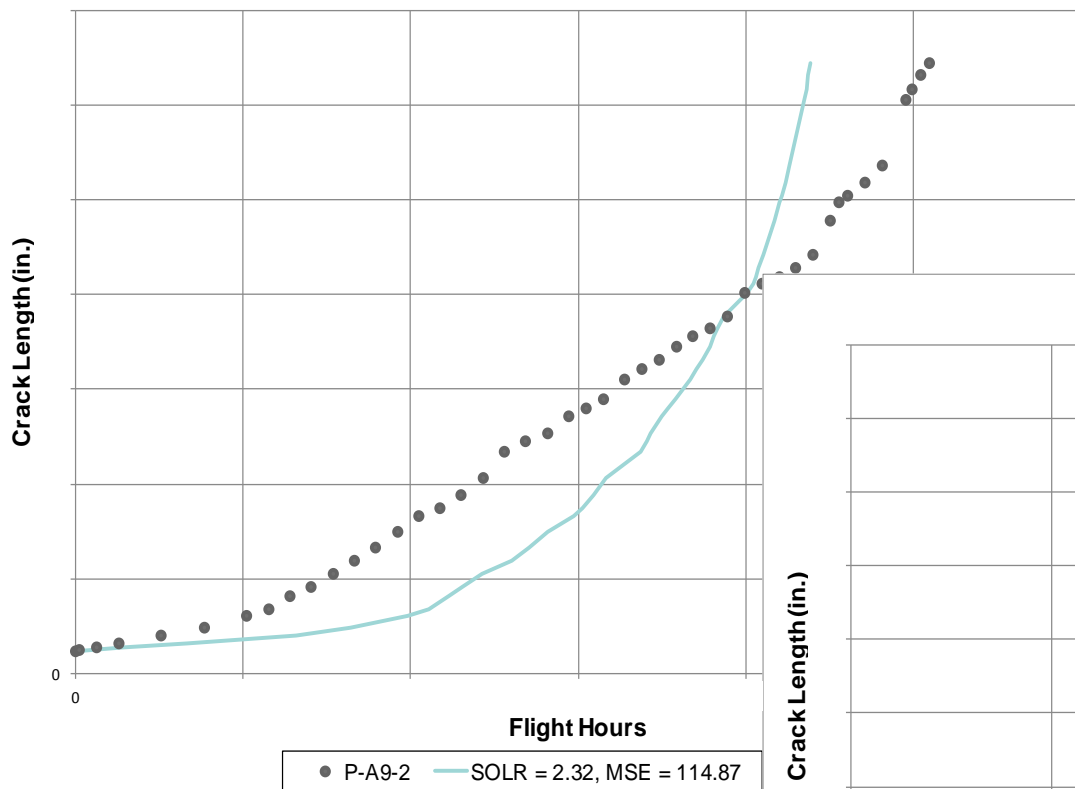




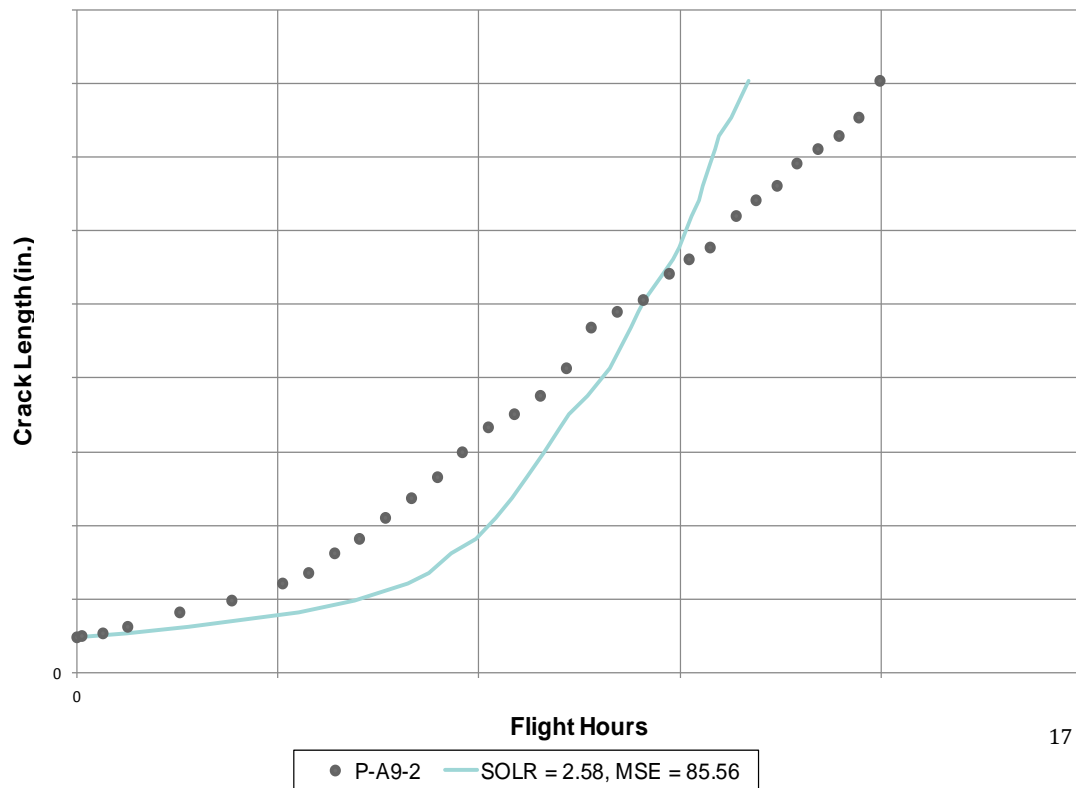
# Correlation Examples



FCL A-9

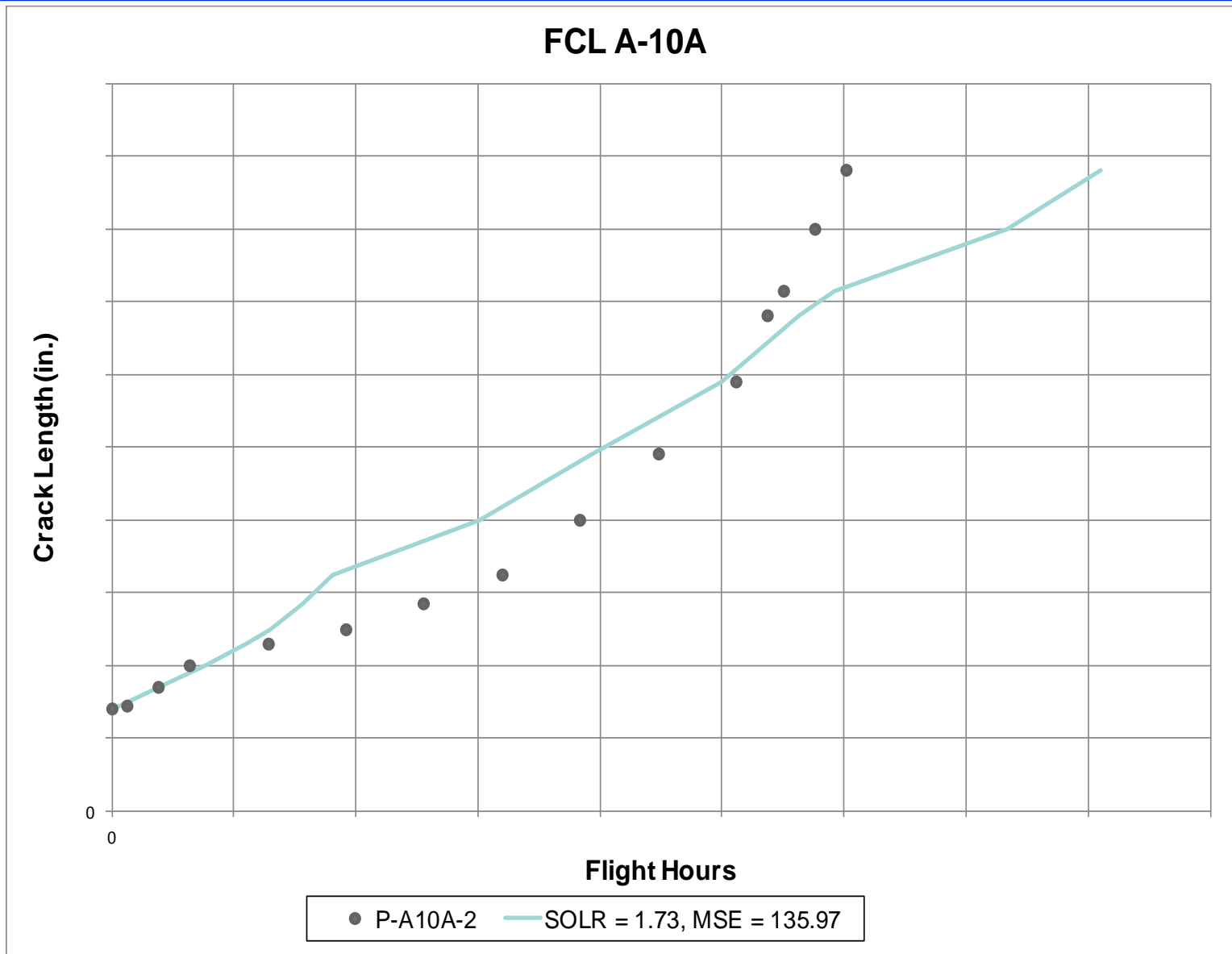


FCL A-9





# Correlation Examples

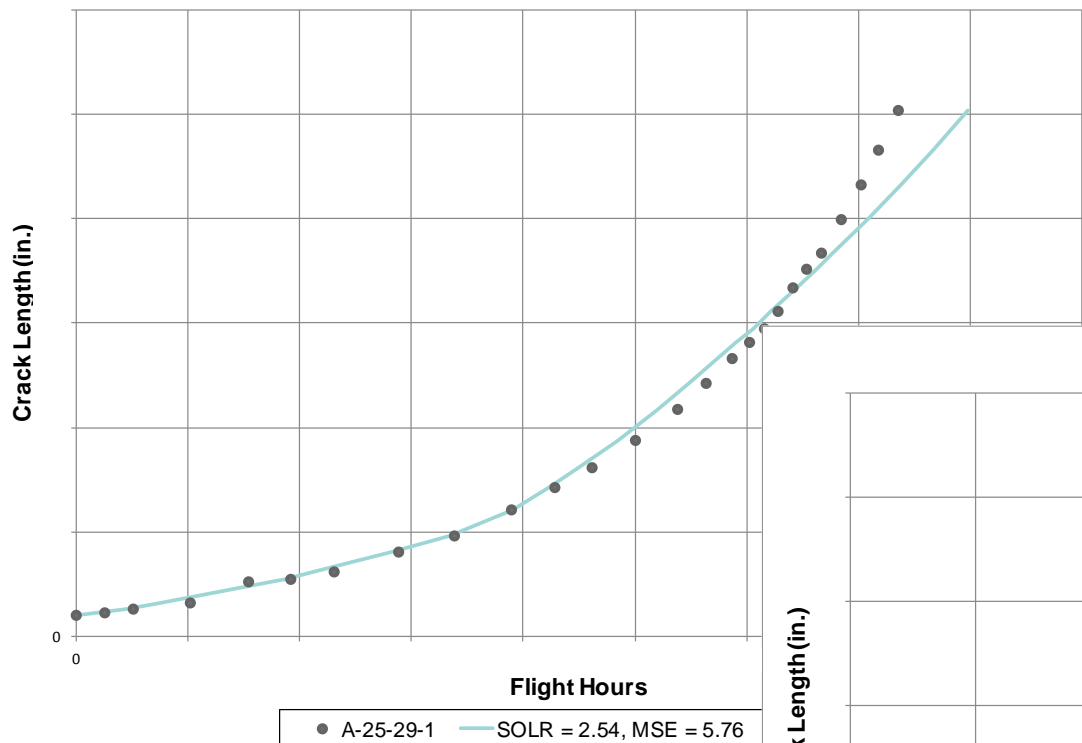




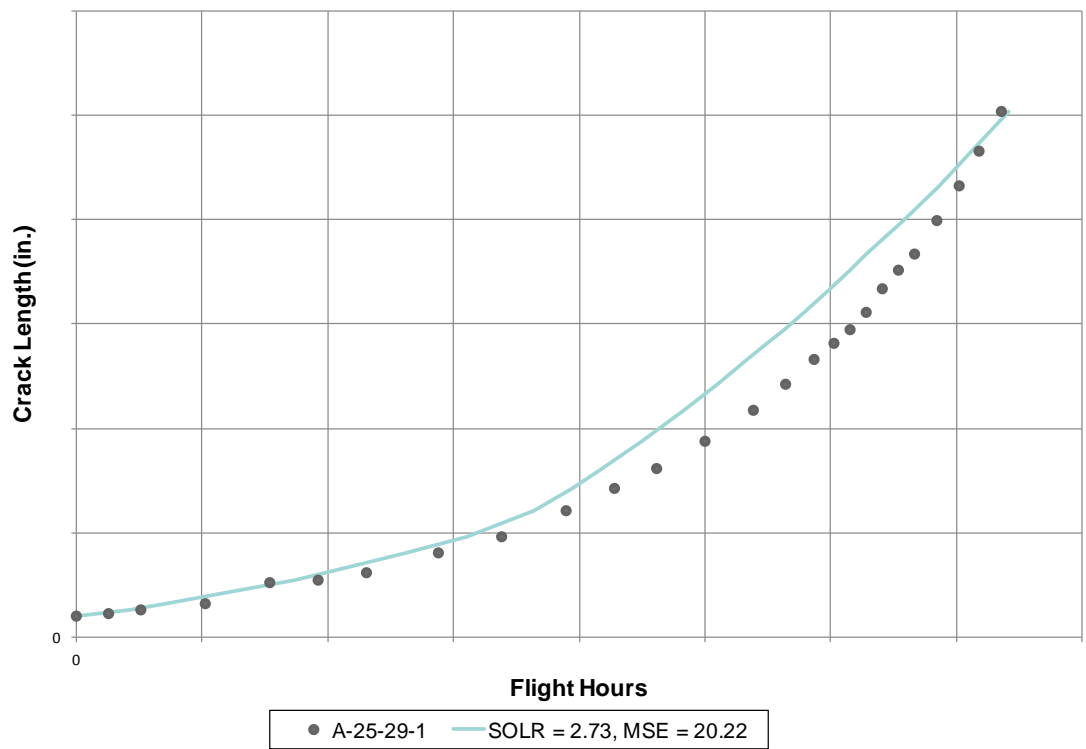
# Correlation Examples



FCL A-25-29



FCL A-25-29





# SOLR Selection



- Of the test coupon correlation results, the highest SOLR was selected
- Results in a conservative retardation model for most FCLs

FCL	Specimen ID	Correlated SOLR	MSE
A-4-29	P-A4-1	2.42	3.4263
A-4-29	P-A4-2	2.7	3.0616
A-4-29	P-A4-3	2.87	4.0563
A-4-29	P-A4-4	3.39	5.2759
A-4-29	P-A4-5	2.89	2.3308
A-4-29	P-A4-6	2.69	7.3306
A-5-29	A-5-29-1 - 1DPR	2.27	0.7543
A-5-29	A-5-29-2 - 1DPR	2.27	0.4322
A-5-29	A-5-29-3 - 3DPR	1.83	1.6845
A-5-29	A-5-29-4 - 3DPR	2.33	1.2831
A-5-29	A-5-29-5	2.1	5.405
A-5-29	A-5-29-6 - 2DPR	2.6	5.3508
A-9-29	P-A9-1 - Up to CCL	2.64	61.223
A-9-29	P-A9-2 - Up to CCL	2.58	85.559
A-9-29	P-A9-3 - Up to CCL	2.31	78.674
A-9-29	P-A9-4 - Up to CCL	2.88	90.407
A-9-29	P-A9-5 - Up to CCL	2.85	84.178
A-9-29	P-A9-6 - Up to CCL	2.85	64.683



# DADTA Update Results



- **How do the SOLR values of 2019 compare with those of 2017?**
  - **Test Coupons**
    - **11.6% increase in SOLR value**
    - **Standard deviation in SOLR change: 12.5%**
  - **FCLs**
    - **20.8% increase in SOLR value**
    - **Standard deviation in SOLR change: 18.7%**



# DADTA Update Results



- **Average Life Predictions of FCLs as compared to 2017 results**
  - IFF: -16.1%
  - SUPT: -23.0%
  
- **Standard deviation of the changes**
  - IFF: 17.1%
  - SUPT: 22.2%



# DADTA Update Results



- **Average Recurring Inspection Interval (RII)  
Changes of FCLs as compared to 2017**
  - IFF: -19.4%
  - SUPT: -25.8%
  
- **Standard deviation of the changes**
  - IFF: 17.0%
  - SUPT: 22.7%



# DADTA Update Results



- **RII Predictions as compared to actual aircraft inspection intervals for the -29 wing**
  - **32 inspection intervals fall within predicted RII**
  - **12 inspection intervals do not**
    - **Either the TO inspection intervals or the DTA need to be updated**
  - **Several analyses are still pending analysis changes**
    - **Examples: A-8b-29, A-34-29, A-21-29, A-24-29**





# Summary and Future Work



- **SOLR correlation completed for the -29 wing using the newly developed material models**
- **Optimization and objective functions discussed**
- **Conservatively selected Highest SOLR for FCLs**
- **DTAs for some FCLs predict that the RII should be reduced in the TOs**
- **Several FCLs need further attention to develop accurate DTAs**



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# Questions?



# Thank You!