2007 Aircraft Structural Integrity Program Conference

The Effect of Stress Intensity Factor Models on Inspection Intervals

Lt Col Scott Fawaz
Center for Aircraft Structural Life Extension
United States Air Force Academy

U.S. AIR FORCE

Integrity - Service - Excellence

Acknowledgements

- Dr. Börje Andersson - Swedish Defense Research Agency
- Daniel Hill – CAStLE Research Engineer
- Dr. R. A. Saravanan – CAStLE Metallurgist
- Jim Harter – *AFGROW* Lead Engineer
- Alex Litvinov – *AFGROW* Software Engineer

Outline

- *K* Solutions
  - Geometric & Loading Parameter Space
  - Verification
  - Validation
- Fatigue Life Predictions Using New *K* Solutions
  - Fatigue Life
  - Continuing Damage Scenario
    - Phase I Life
    - Crack Size
  - Effect of r/t
- Conclusions

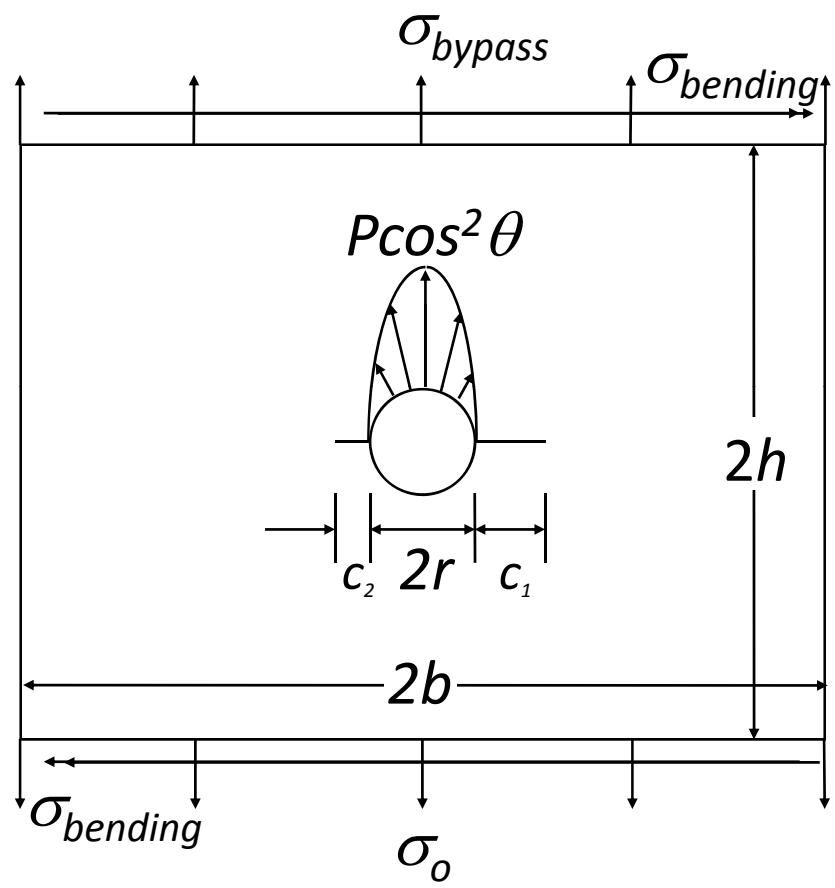
Small differences in *K* Solutions yield large cumulative differences in fatigue life

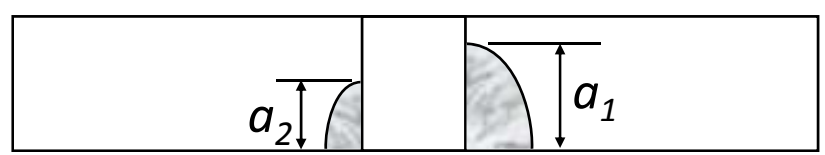
…and large differences in K solutions yield even a larger cumulative difference in fatigue life

Parameter Space

K-Solutions, ≈ 1.0 million CPU Hours

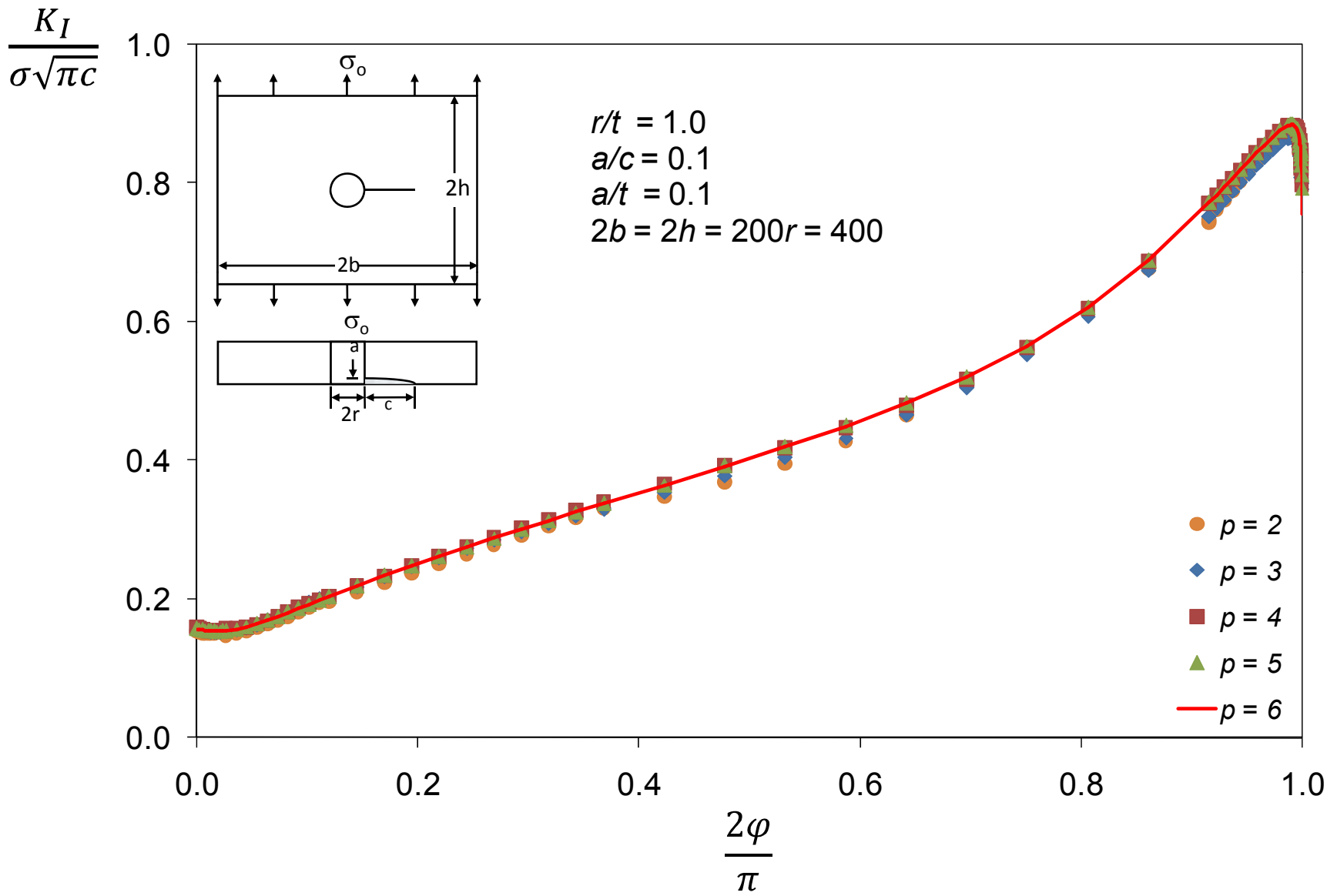
- Geometry
  - Centrally Located Straight Shank Hole
  - $0.1 \le r/t \le 10.0$
    - 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 1.667 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 **(r/t = 0.5, 1.0)**
  - Finite Width/Height Plate
    - r/h = 0.0025
    - r/b = 0.0025
- Crack Shapes
  - $0.1 \le a/c \le 10.0$
    - 0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 1.0, 1.25, 1.333, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 **(a/c = 0.2, 0.5, 0.8, 1.0, 2.0)**
  - $0.1 \le a/t \le 0.99$
    - 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99 **(a/t = 0.2, 0.5, 0.8)**
- Load Conditions
  - Tension
  - Bending
  - Pin Loading (Bearing)
- *5,672,700* solutions



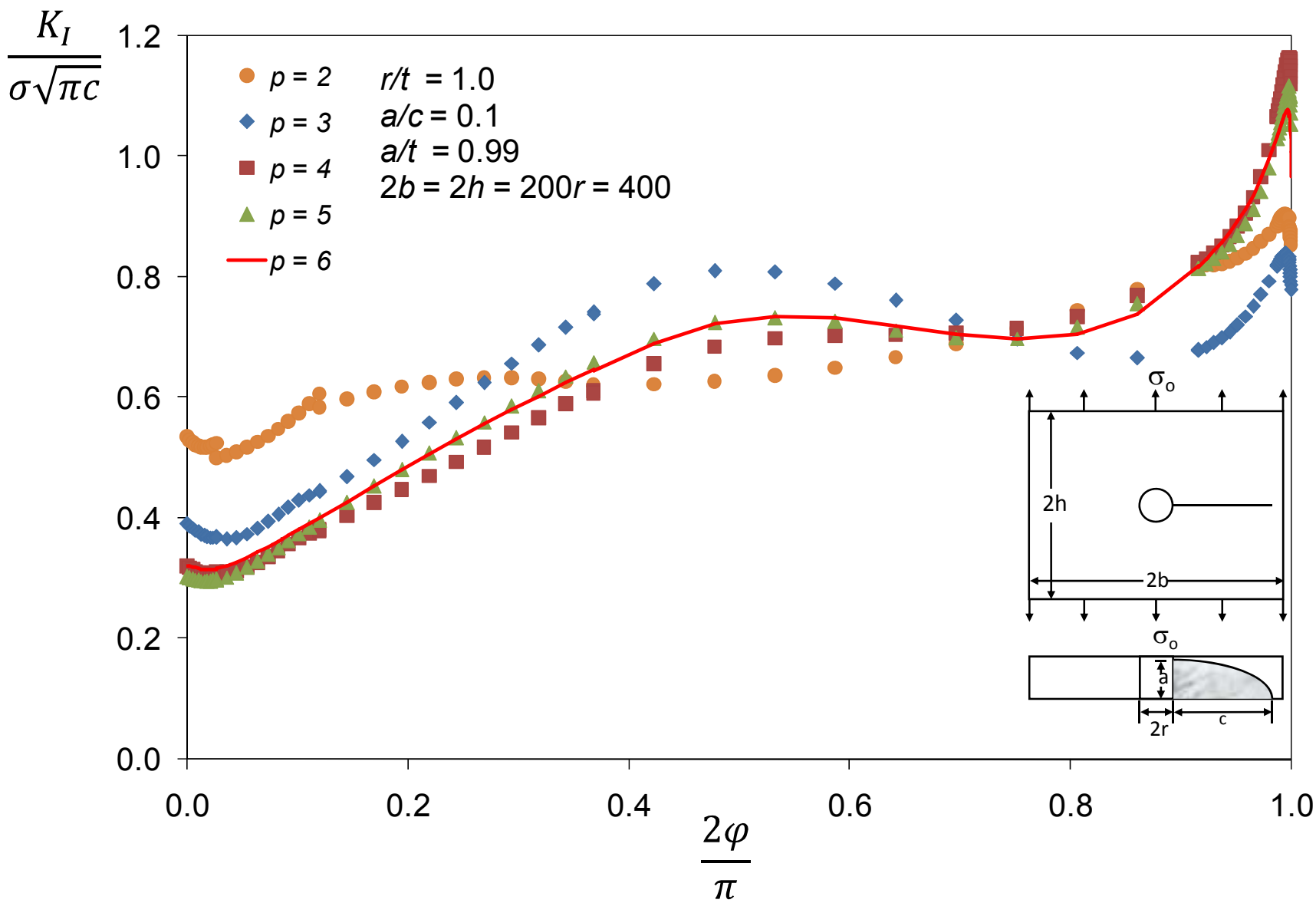


K-Solution Verification

Convergence: Shallow Crack

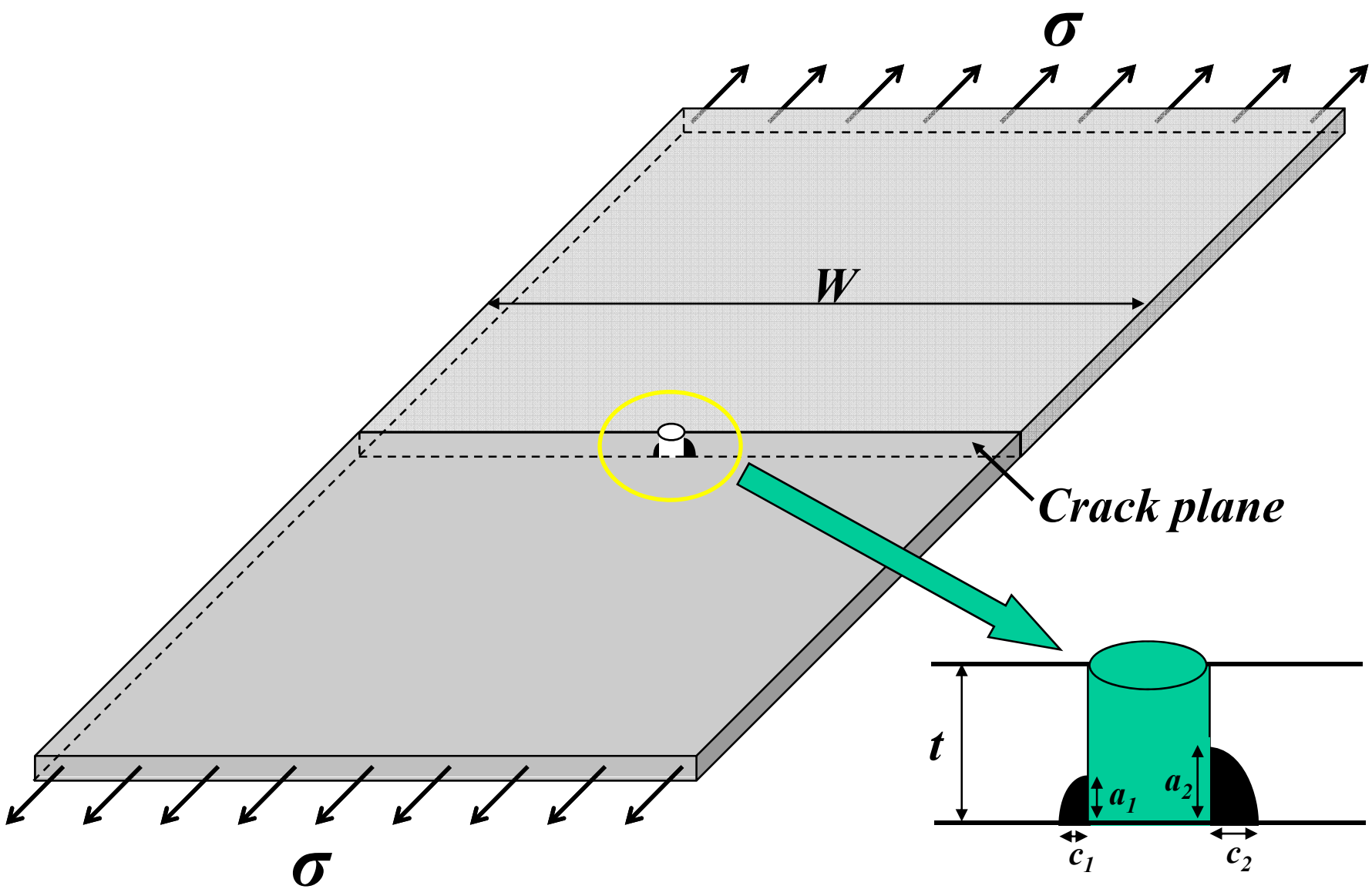


Convergence: Deep Crack

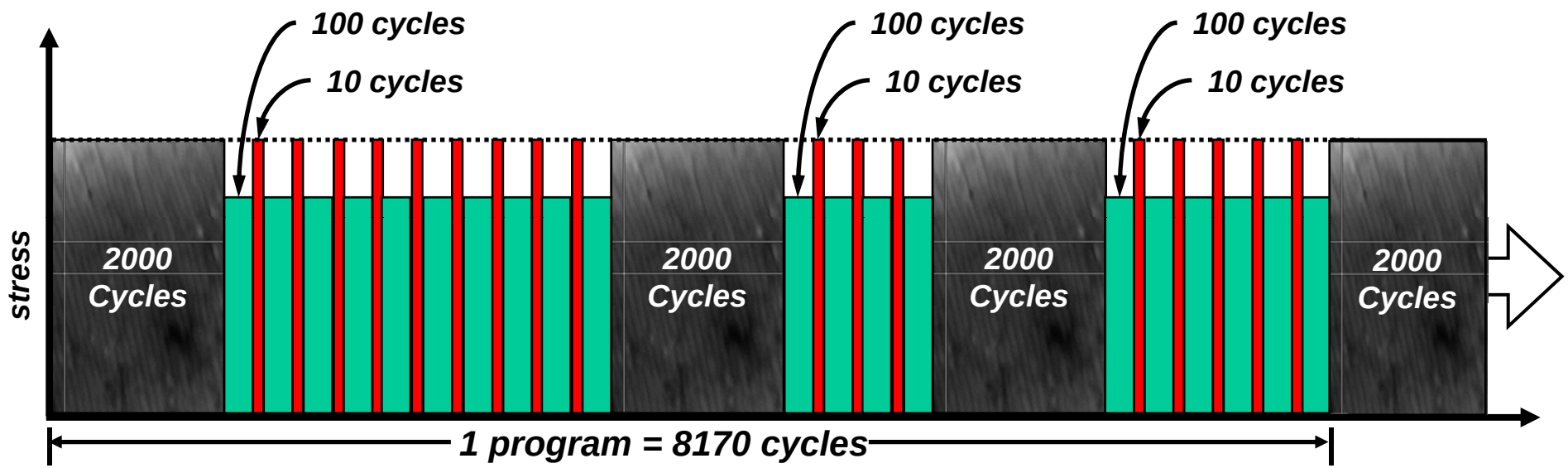


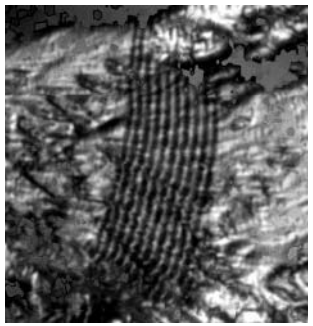
K-Solution Validation

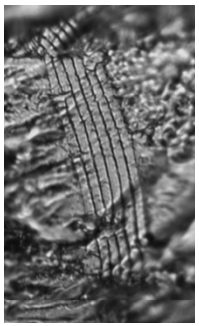
Test Specimen Configuration



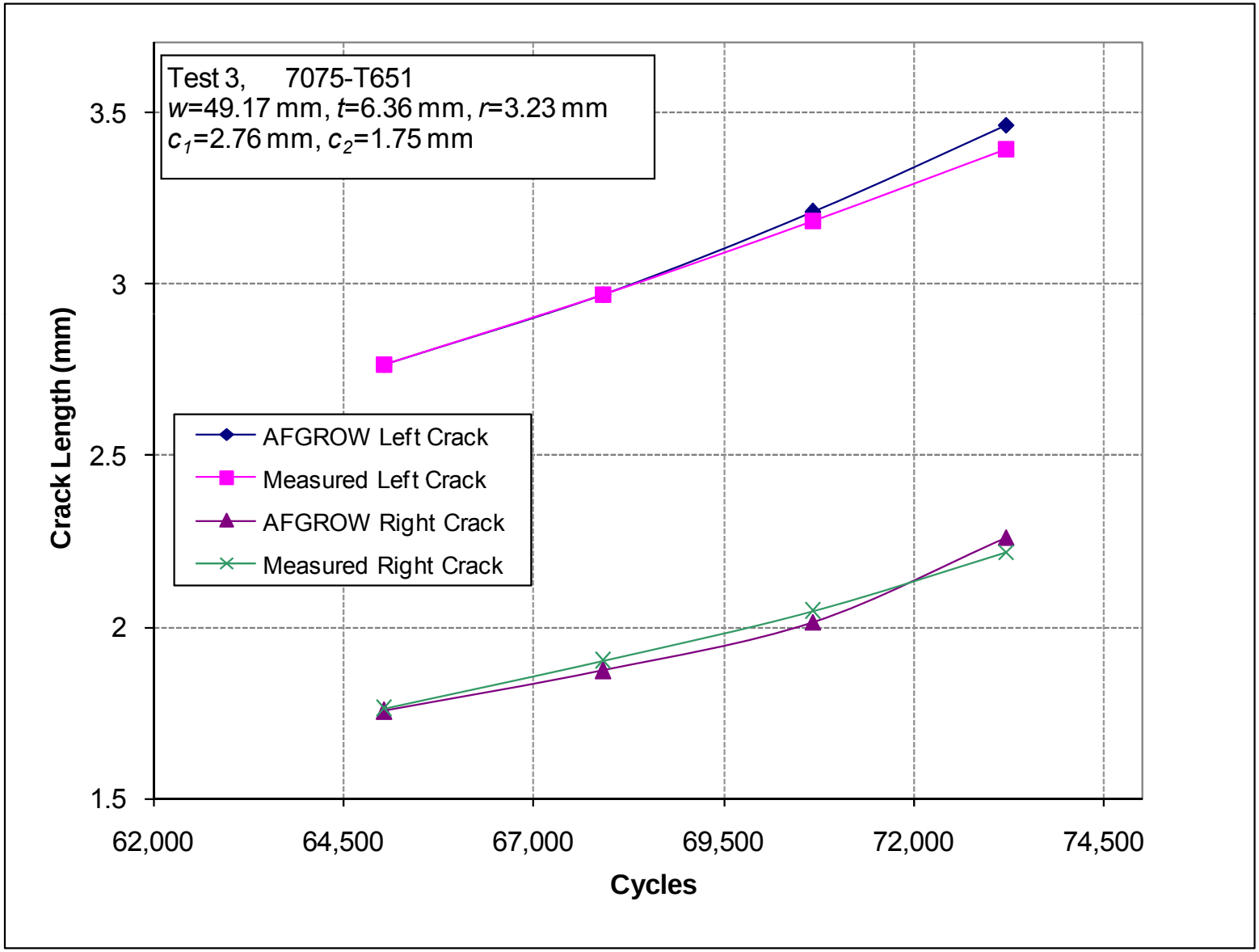
Marker Load Spectrum



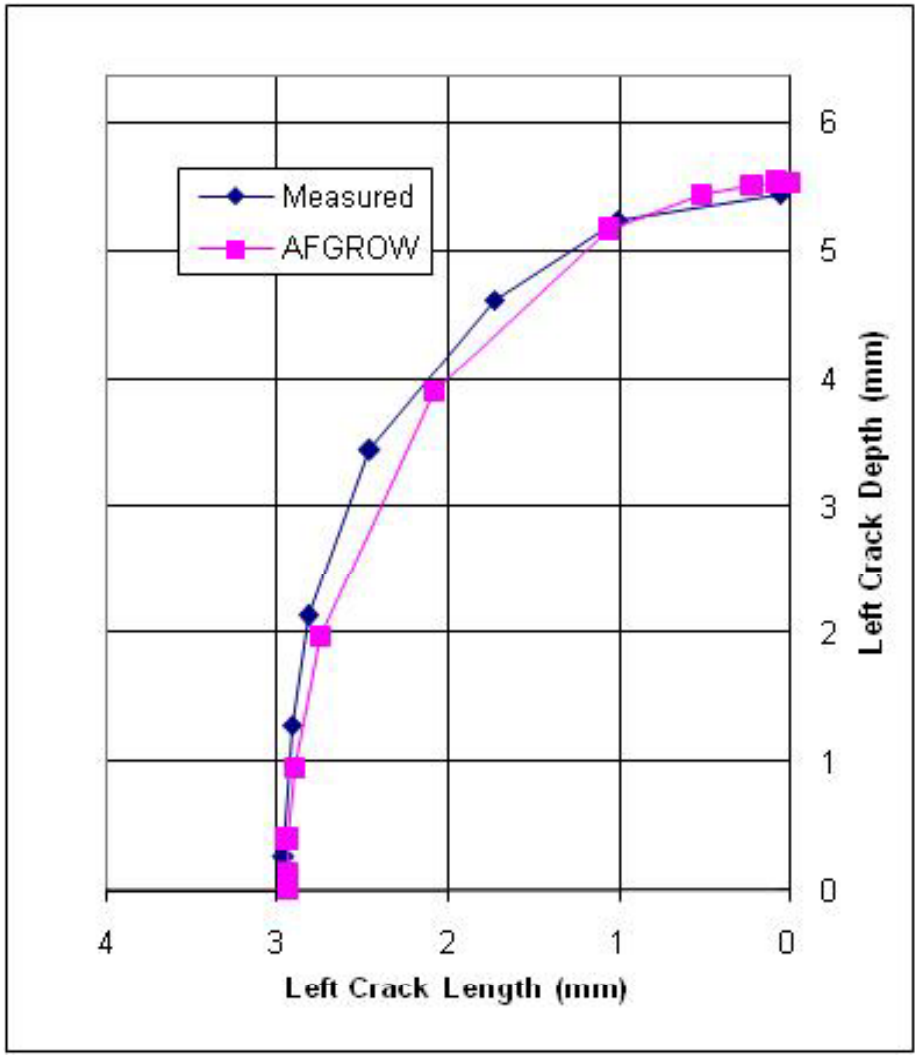


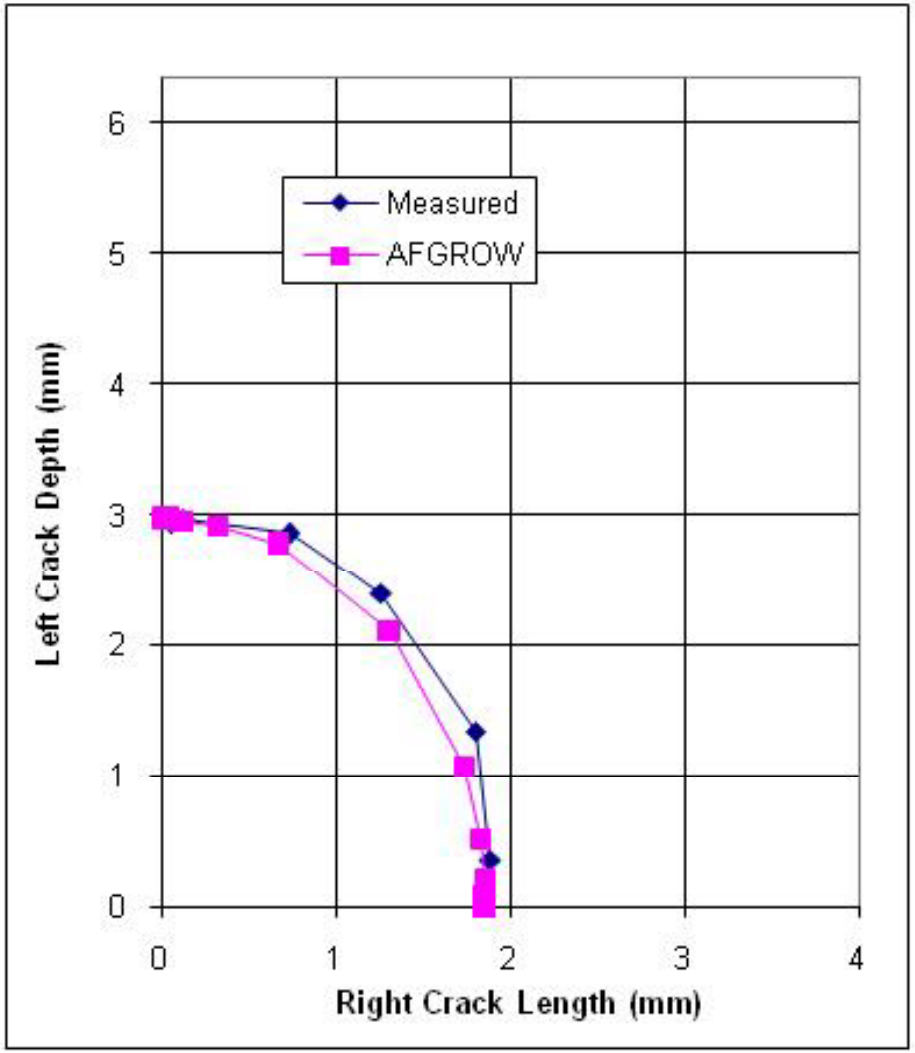


Fatigue Life Prediction

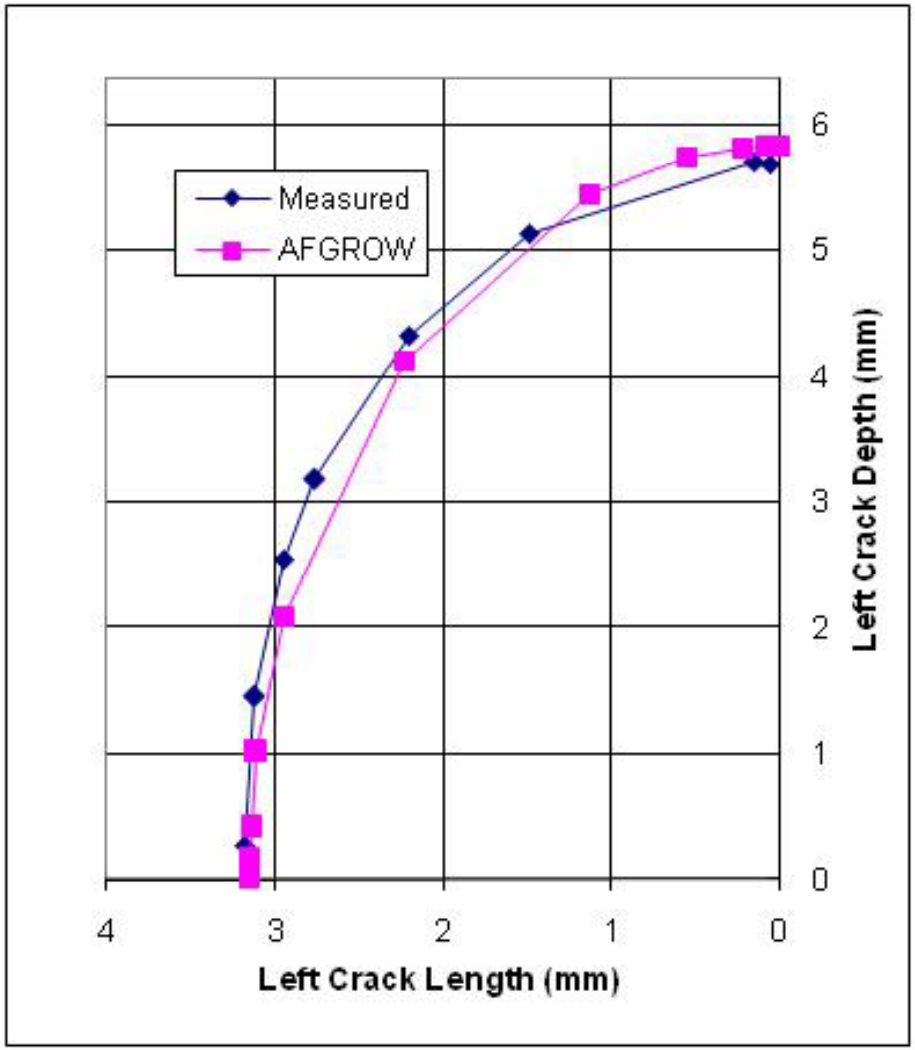


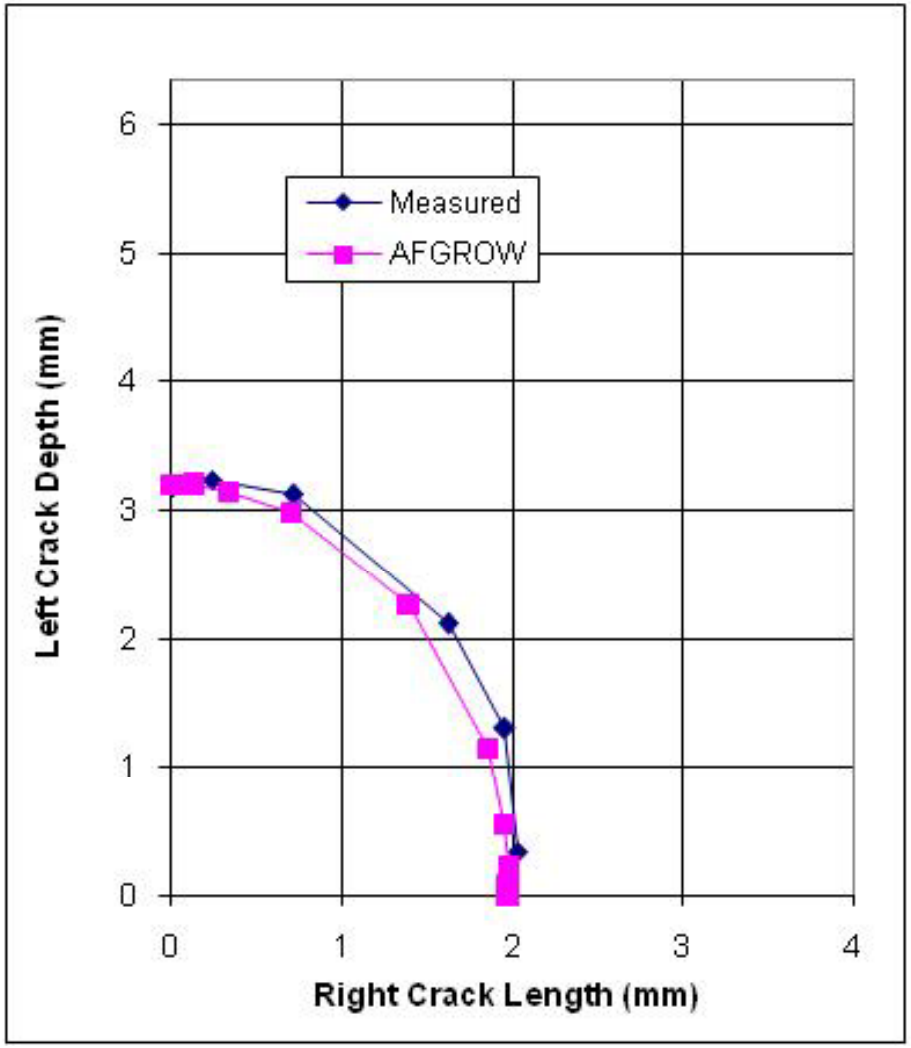
Crack Shape Development



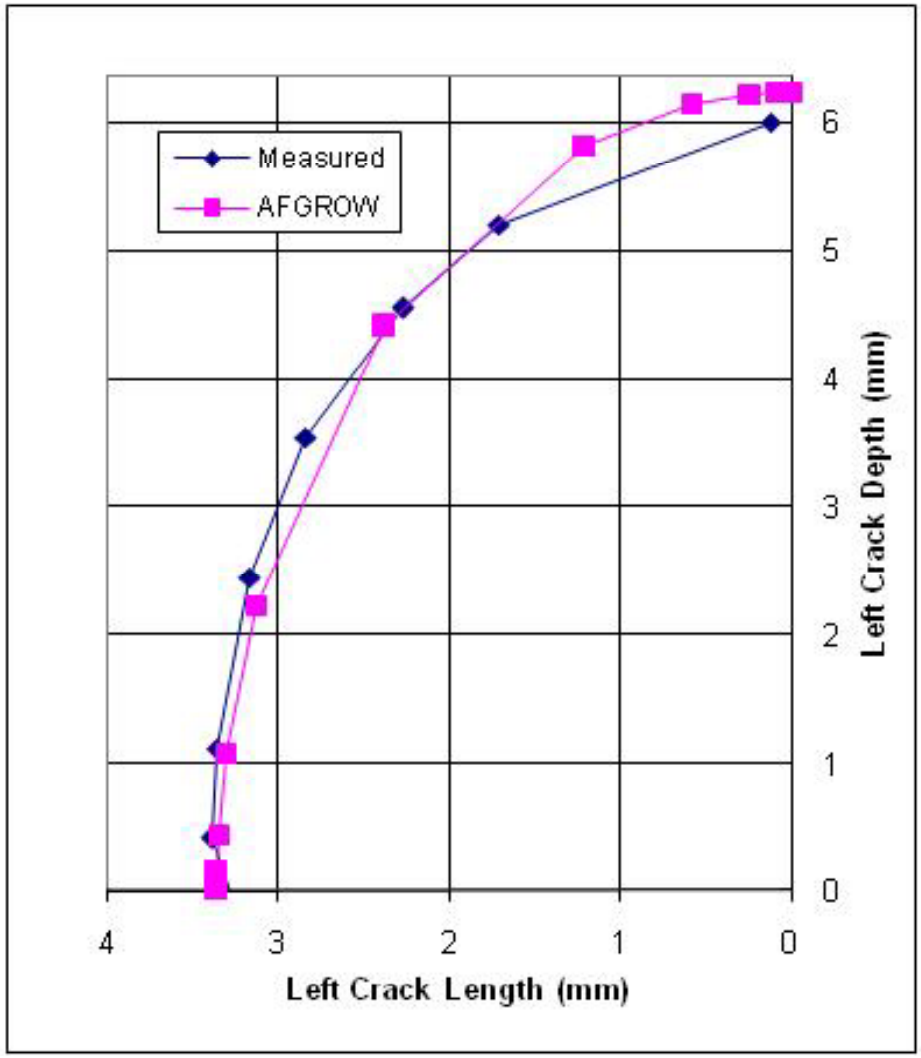


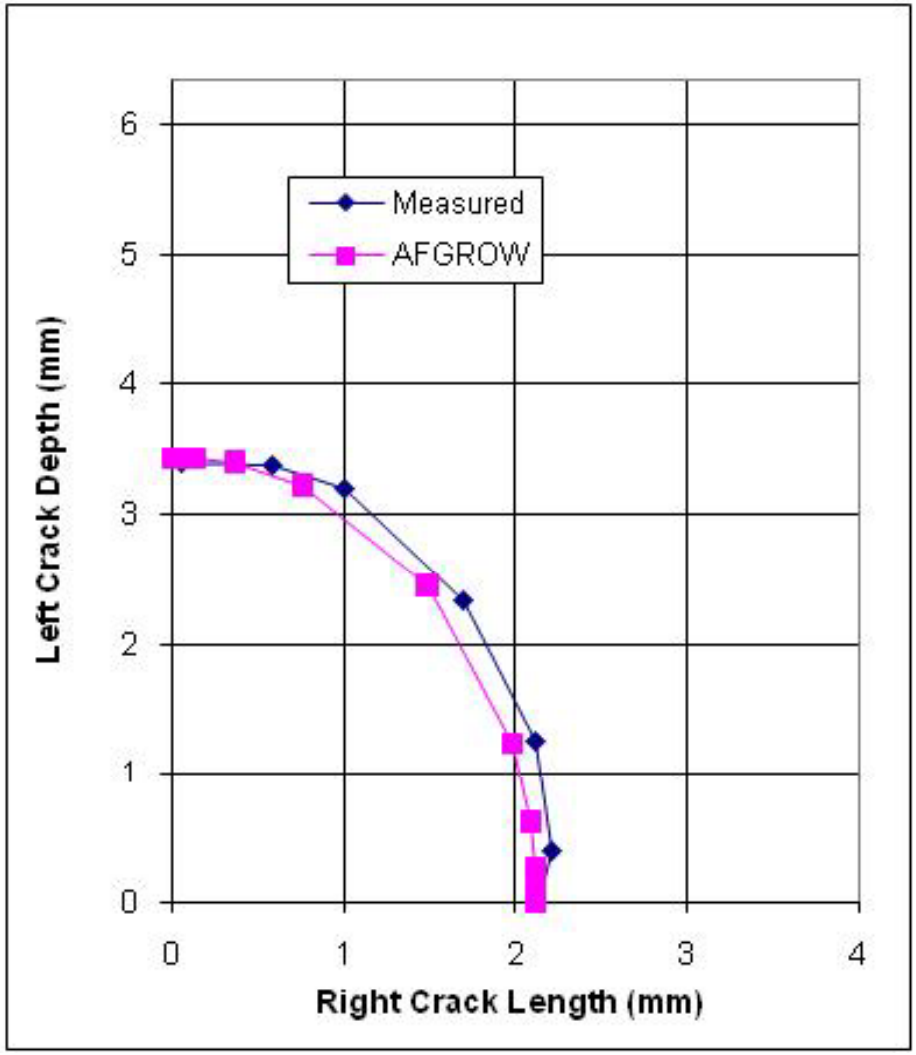
Crack Shape Development





Crack Shape Development





Fatigue Life Predictions Using New *K* Solutions

Geometry for Assessing Effect on Life

Small Crack – Thin Sheet

W = 1.14 in, t = 0.063 in, D = 3/16 in

a_i = 0.01 in, c_i = 0.01 in, a_i/t = 0.2

a_i/c_i = 1.0, r/t = 1.5

TSR = 1.0, BSR = 0.4

Small Crack – Thick Sheet

W = 4.53 in, t = 0.25 in, D = ¾ in

a_i = 0.05 in, c_i = 0.05 in, a_i/t = 0.2

a_i/c_i = 1.0, r/t = 1.5

TSR = 1.0, BSR = 0.4

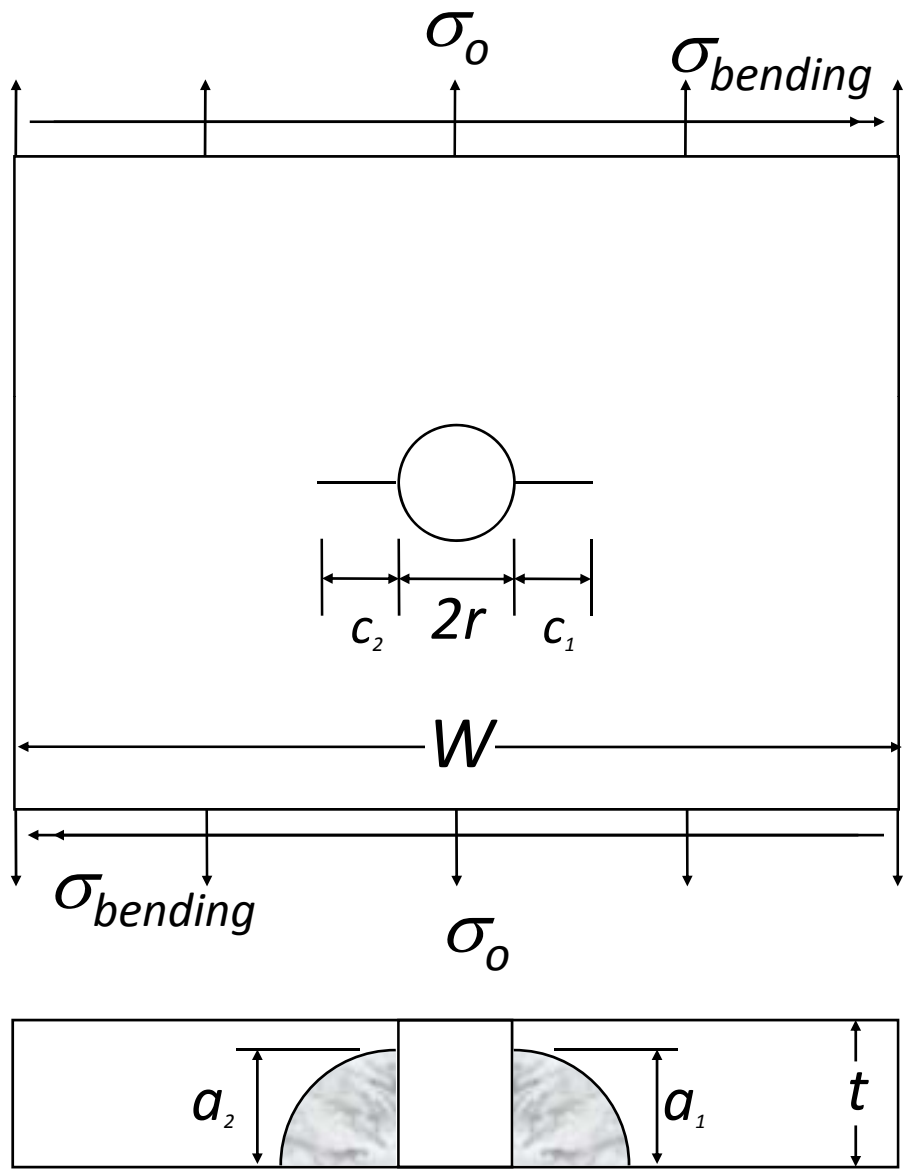
Large Crack – Thin Sheet

W = 1.14 in, t = 0.063 in, D = 3/16 in

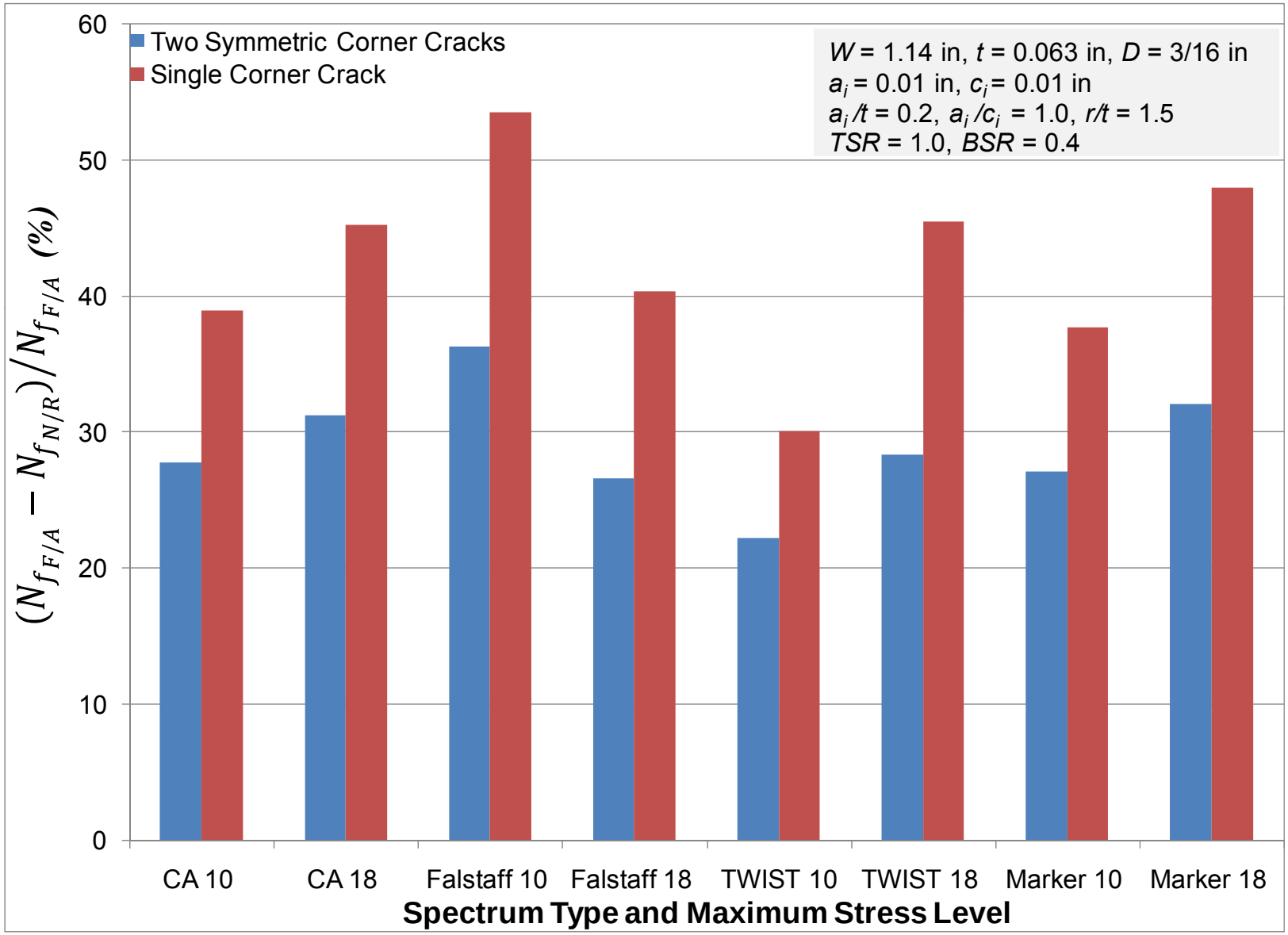
a_i = 0.05 in, c_i = 0.05 in, a_i/t = 0.8

a_i/c_i = 1.0, r/t = 1.5

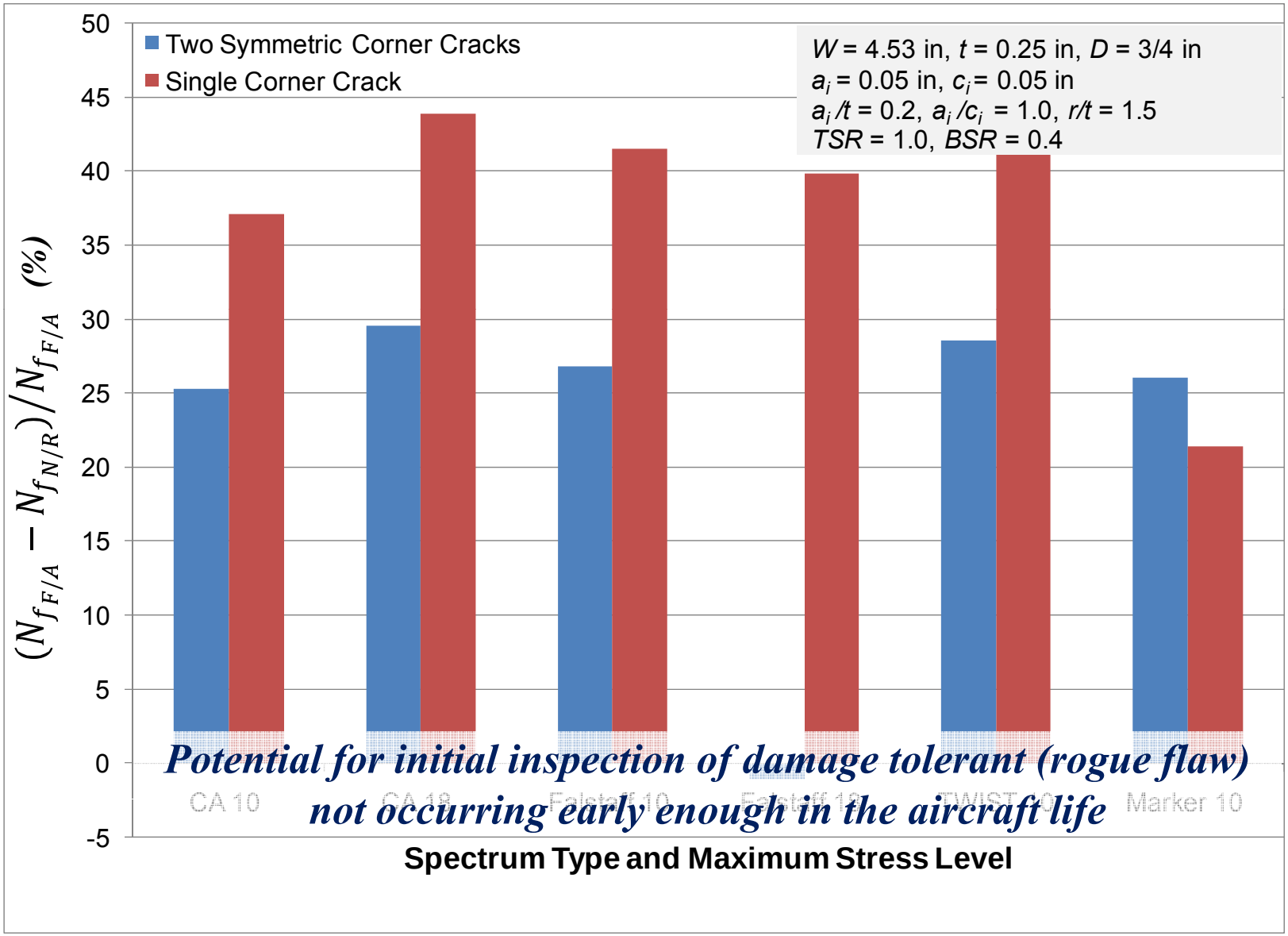
TSR = 1.0, BSR = 0.4



Effect on Life – Small Crack, Thin Sheet

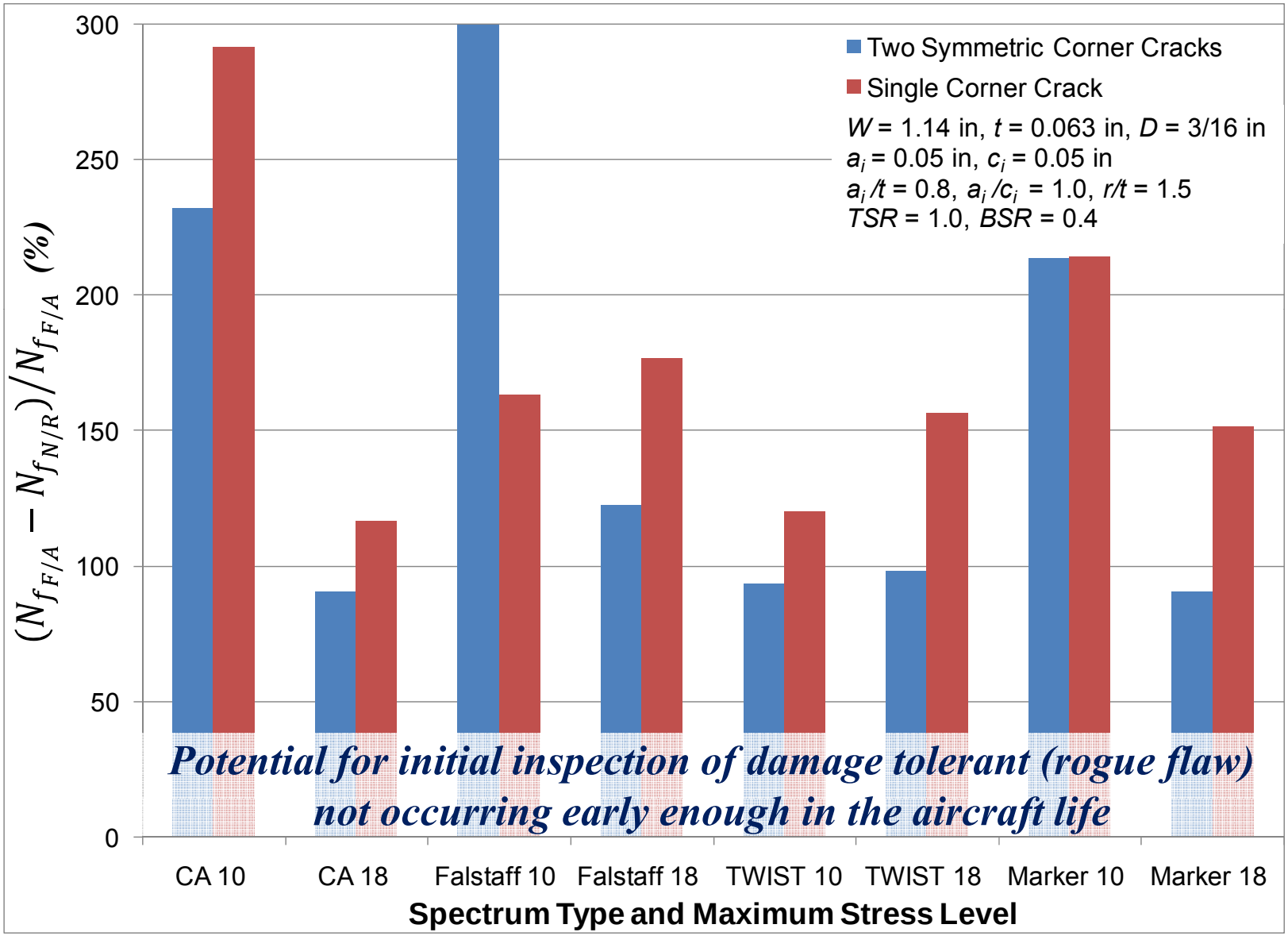


Effect on Life – Small Crack, Thick Sheet



Potential for initial inspection of damage tolerant (rogue flaw) not occurring early enough in the aircraft life

Effect on Life – Large Crack, Thin Sheet



Geometry for Assessing Effect on Continuing Damage Scenario

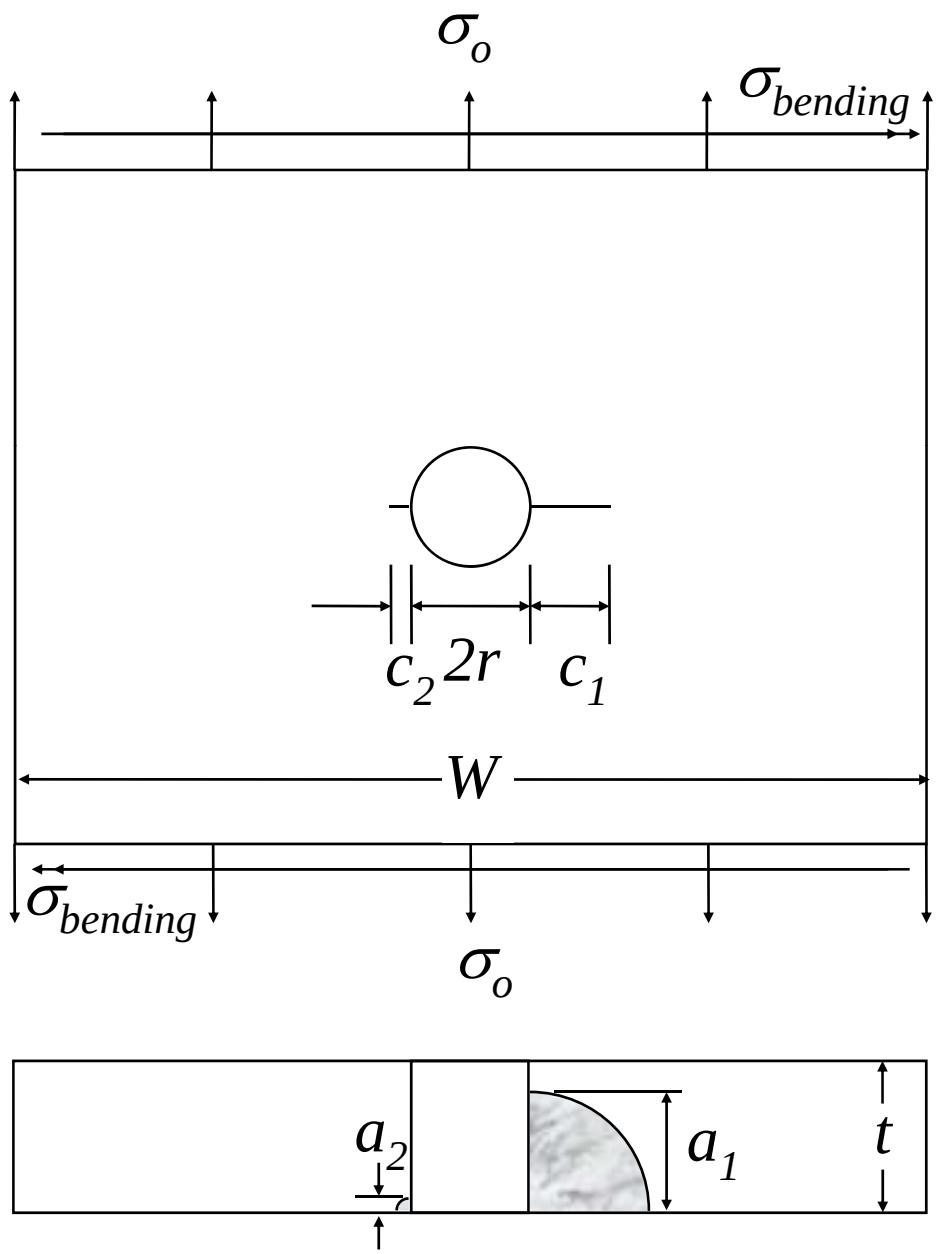
W = 1.14 in, t = 0.063 in, D = 3/16 in

a_1 = 0.05 in, c_1 = 0.05 in

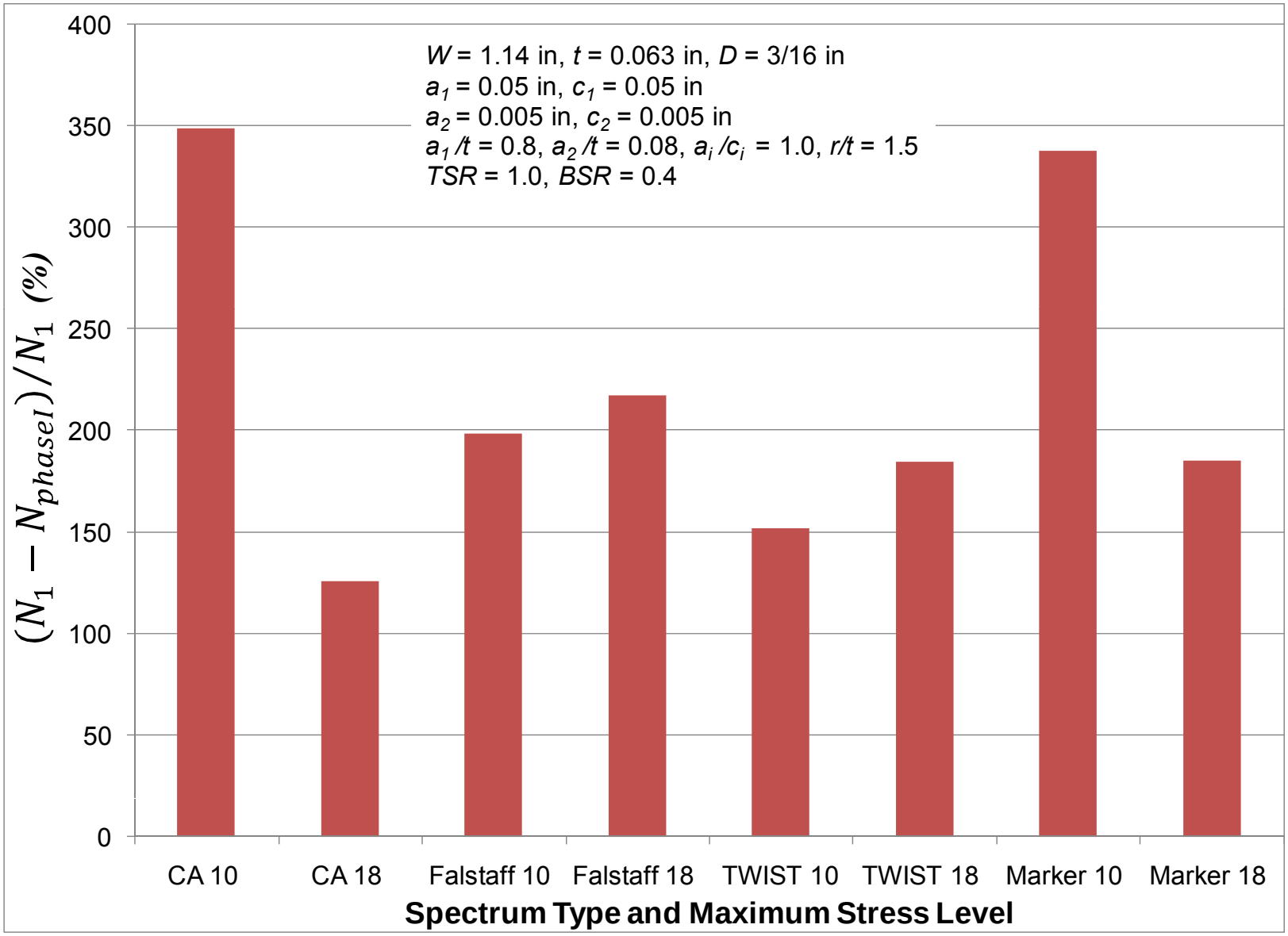
a_2 = 0.005 in, c_2 = 0.005 in

a_1/t = 0.8, a_2/t = 0.08, a_i/c_i = 1.0, r/t = 1.5

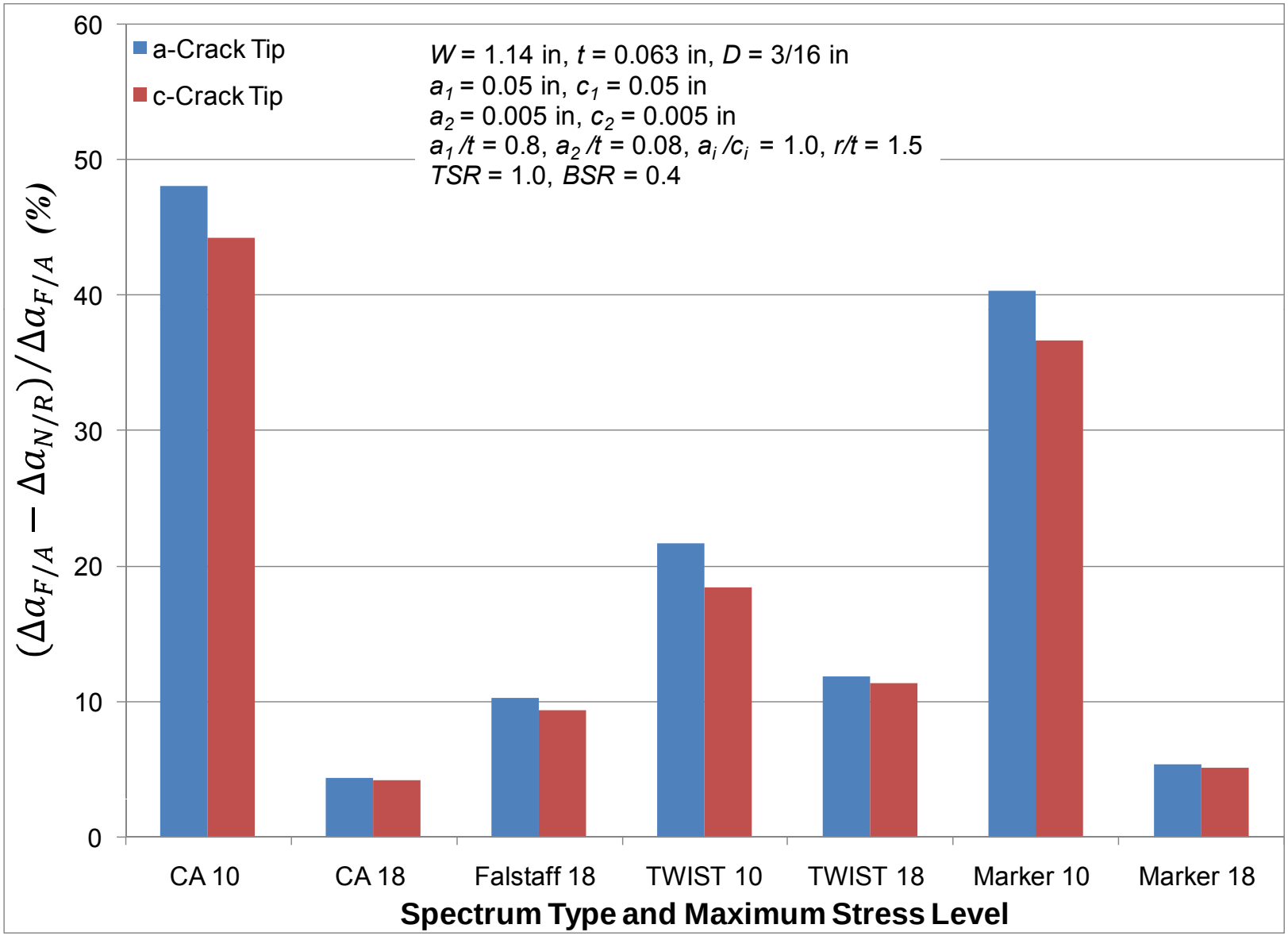
TSR = 1.0, BSR = 0.4



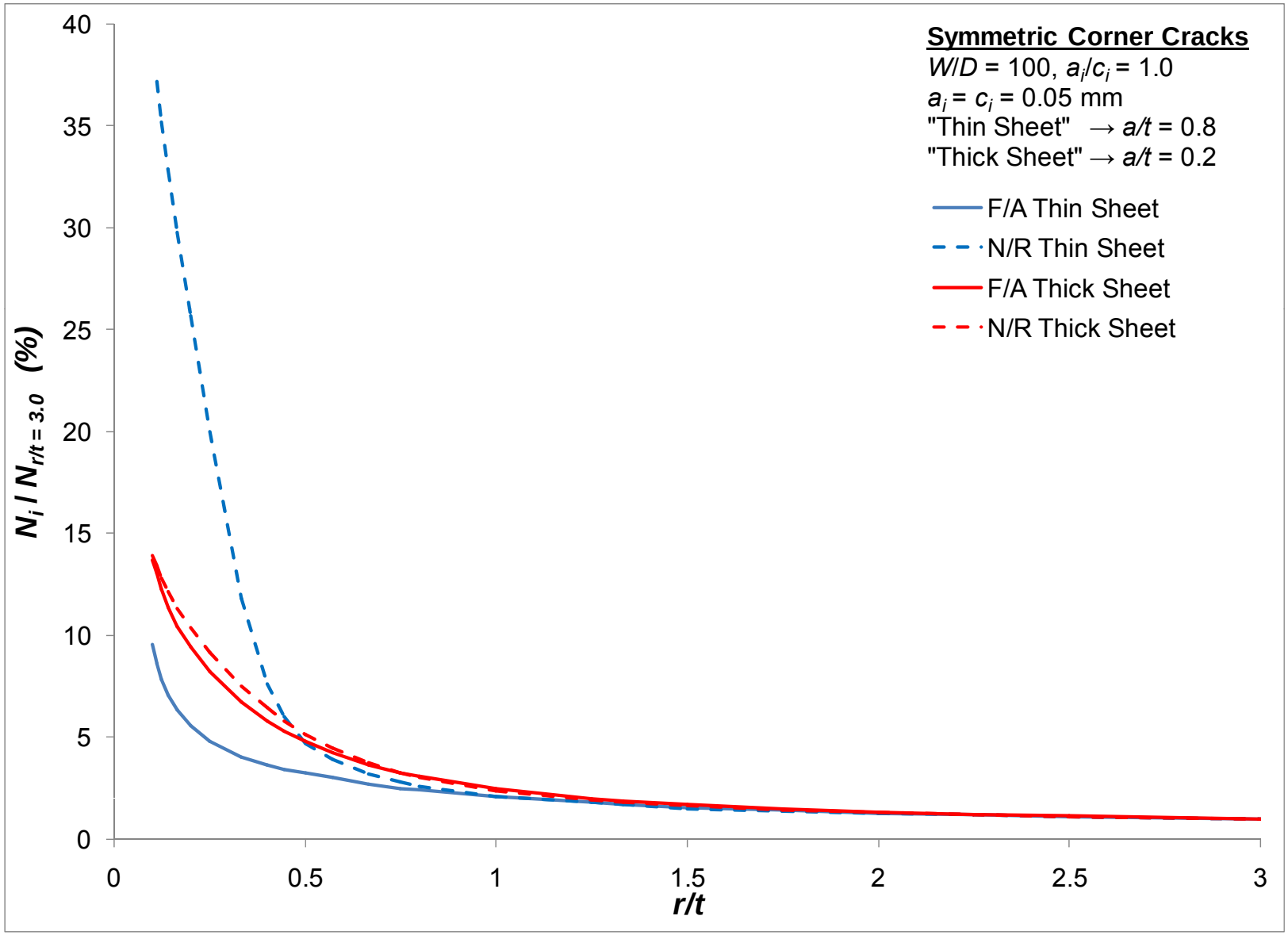
Effect on Continuing Damage Scenario Phase I Life



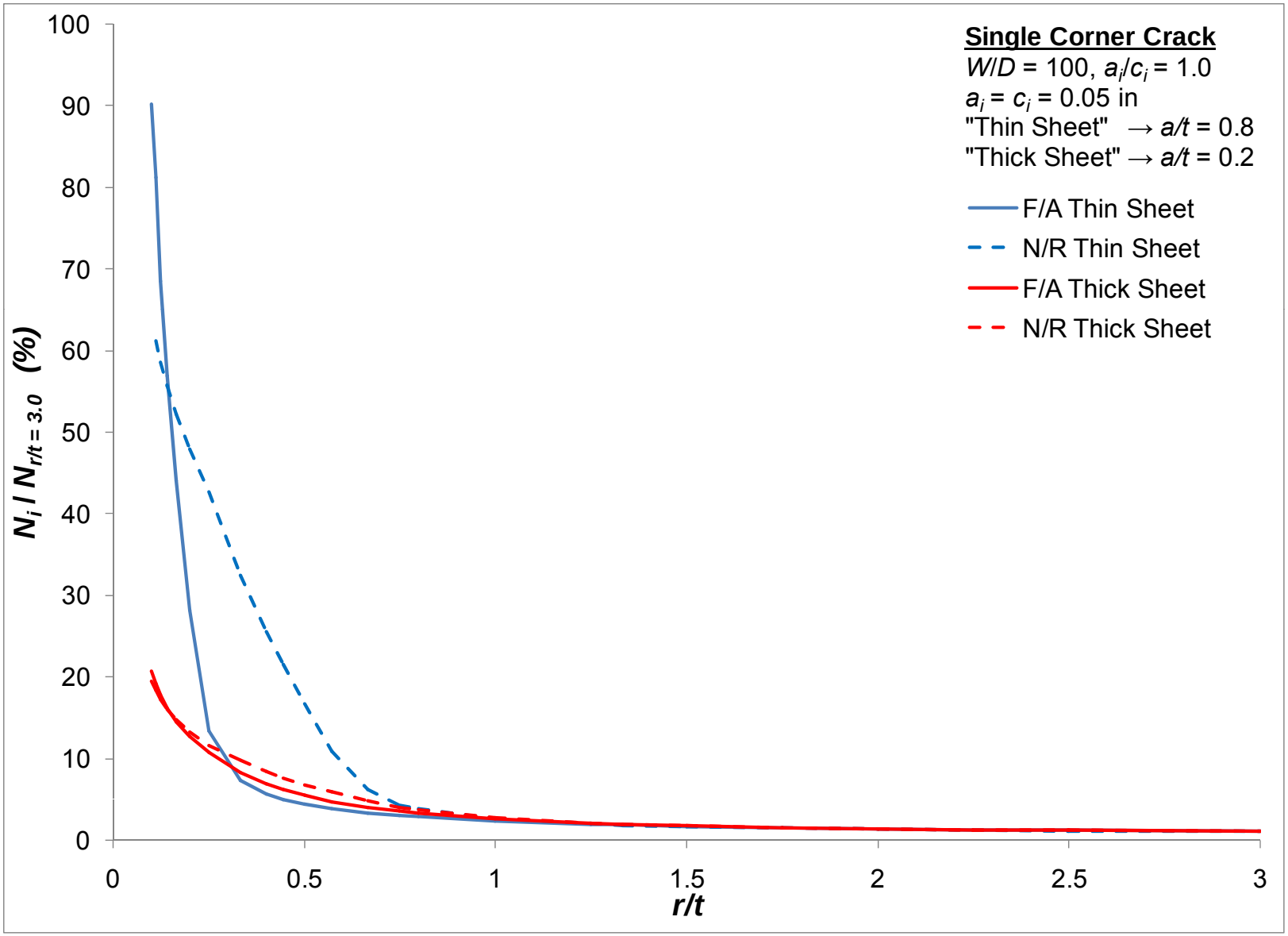
Effect on Continuing Damage Scenario Phase I Crack Length



Effect of *r/t* – Symmetric Corner Cracks



Effect of *r/t* – Single Corner Crack



Conclusions

- Verification
  - *hp*-version FEA + Splitting Scheme = Accurate *K*-Solutions
- Validation
  - Fatigue life predictions are slightly conservative
- 5,672,700 *K* solutions for unsymmetric corner cracks at a hole subject to tension, bending, bearing
  - Solutions available in tabular form – currently in *AFGROW*
    - *75 – 1.5MB ASCII files*
  - Source code for multi-dimensional interpolation also available

Significance

- Single vs. Double Cracks
  - Difference always larger for single cracks
- Effect on Fatigue Life
  - Small cracks in thin sheets: 20-50%
  - Small cracks in thick sheets: 25-45%
  - Large cracks in thin sheets: 90-300%
  - Continuing damage scenario: 125-350%
- Effect on Inspections
  - Possibility of initial inspection not early enough in aircraft life
  - Possibility of recurring inspections not occurring as frequently as required
- Effect of *r/t*
  - Significant for large cracks in thin sheets
  - Negligible for small cracks in thick sheets