Stress Intensity Factors for Finite Width Plates

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AFGROW Workshop 2012

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Acknowledgements

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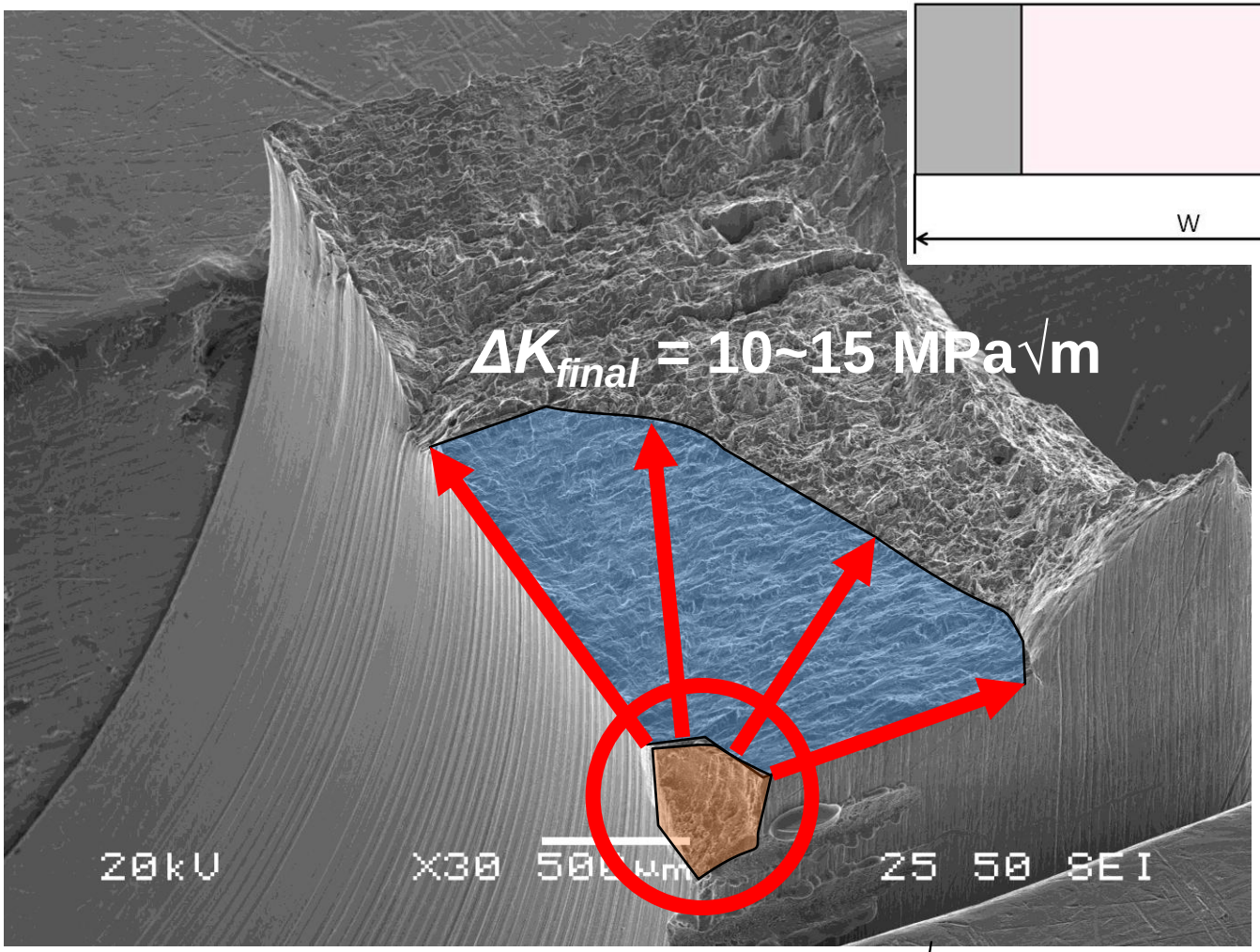
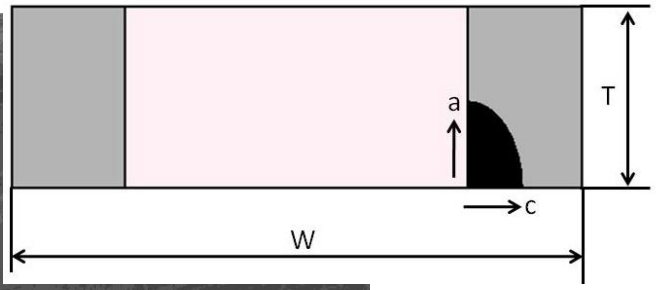
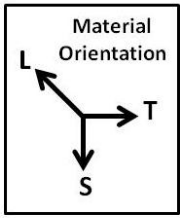
Background

- **Current stress intensity factor solutions (*K*) for corner cracks in narrow finite width plates are inaccurate**
  - **Can improve correlation of predicted vs. measured**
    - **Crack shapes**
    - **Crack growth lives**
- **Extrapolating to small plate width / plate thickness (W/D) ratios is inaccurate**
- **Newly calculated finite width *K*s for corner cracks at holes in narrow plates will reduce the uncertainty in inspection intervals and life limits**

Experimental Results

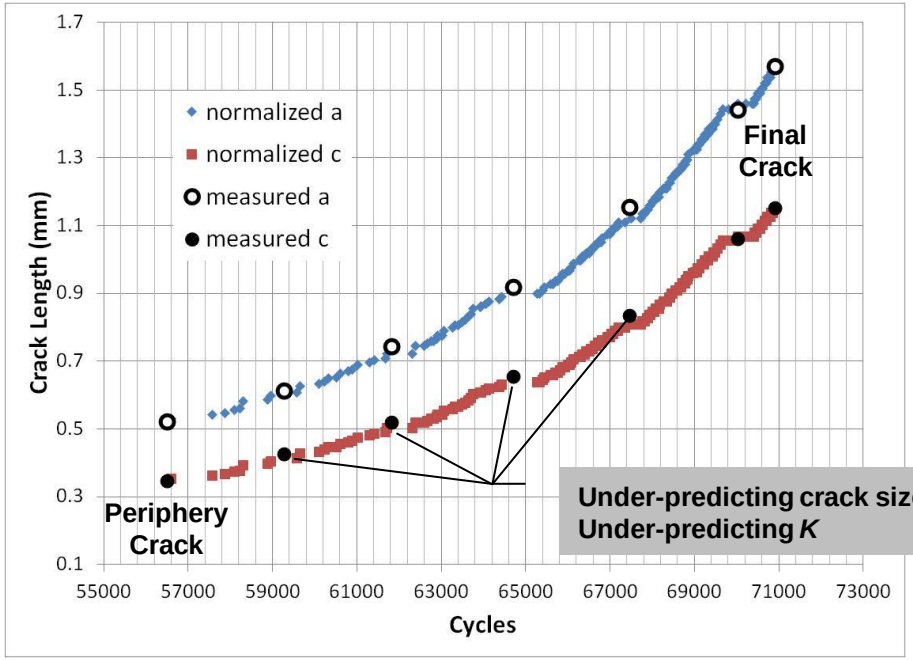






$\Delta K_{initial}$ = ~3 MPa√m

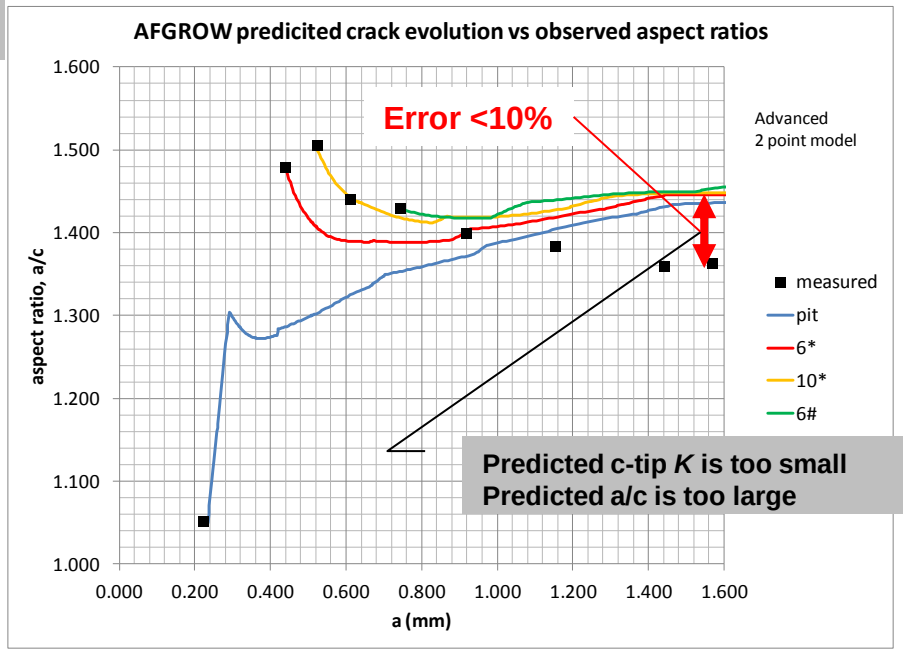
Specimen Validation



- **Predictions not perfect**
  - **Improve *K* solution**
  - **Improve da/dN input data**
    - **Using *R* = 0.65 data**
    - **Tests are variable amplitude**

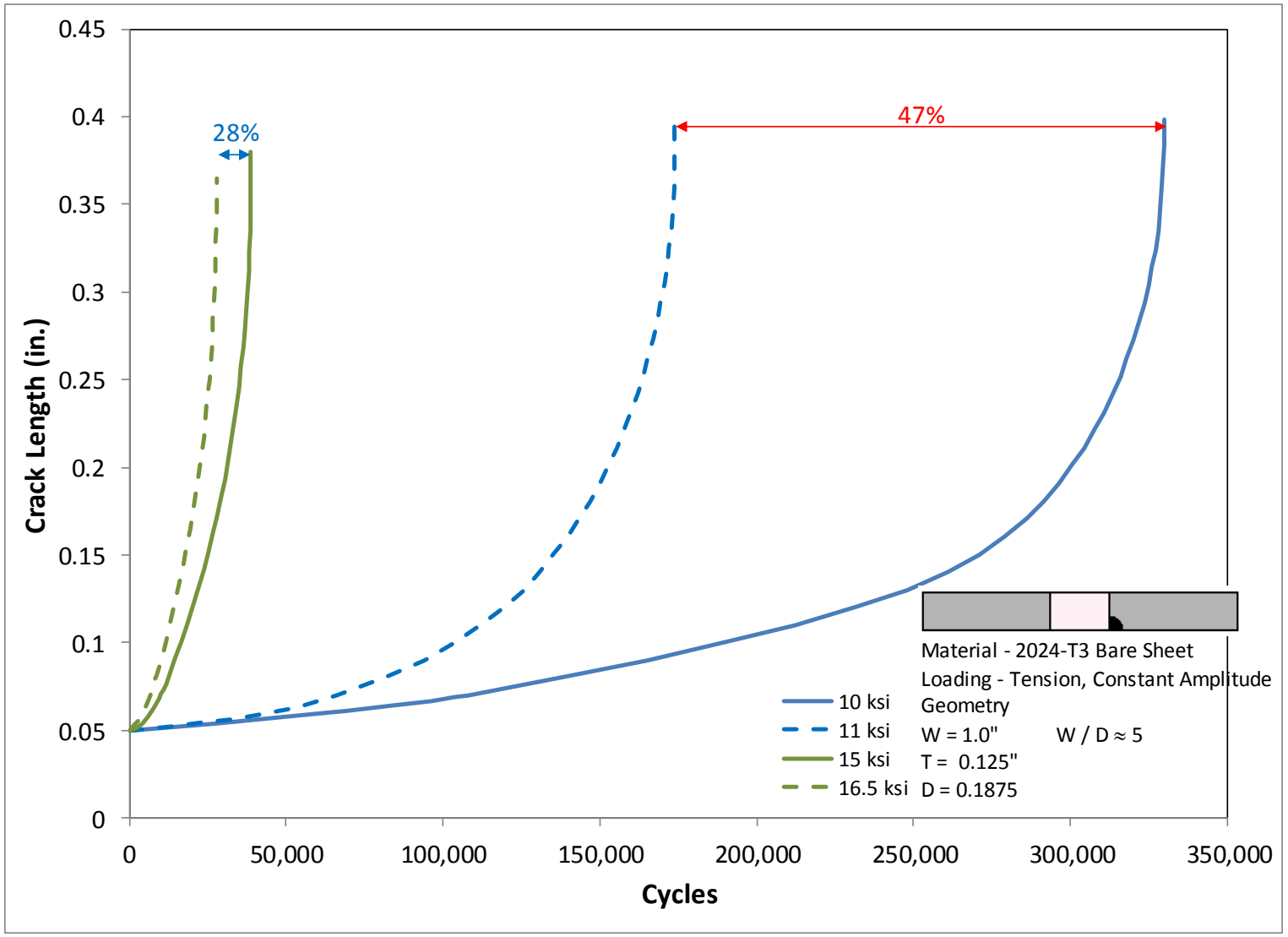
- **Hypothesis - If crack shape predictions are good, crack length predictions are too**

Using the pit dimensions as the initial flaw size is inappropriate



Marker band measurements confirm dcPD calculations

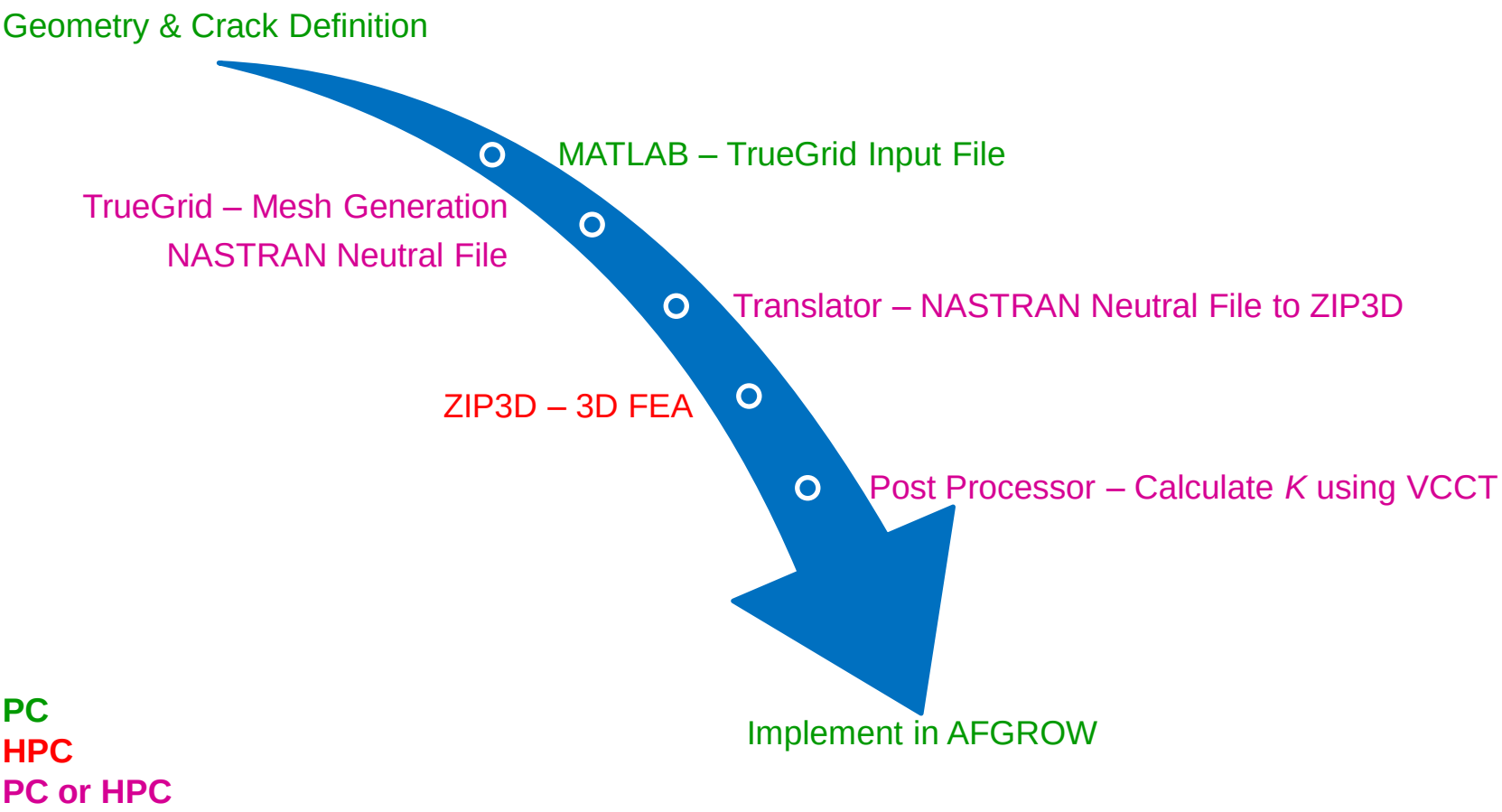
Does 10% Error in *K* Matter?



K Calculation Error Sources

- **Interpolation within the *K* solution space**
  - **Mitigation – dense solution space**
- **Extrapolation outside the *K* solution space**
  - **Mitigation – plate and crack geometry ranges cover expected aircraft structural cracking scenarios**
- **FEM Discretization**
  - **Mitigation**
    - **Convergence study → numerically converged solutions**
    - **Mesh density study → adequate representation of vertex**
  - **Degrees of freedom 150K – 2.4M**

Analysis Process

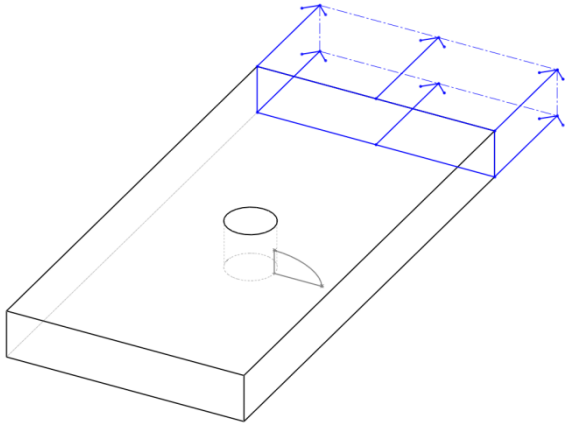


Solution Space

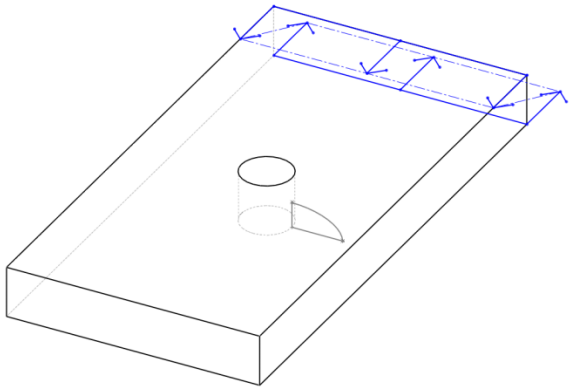
- **Single corner crack at a centrally located hole in a plate of varying width → new finite width correction factor**

- **Three load types are considered**

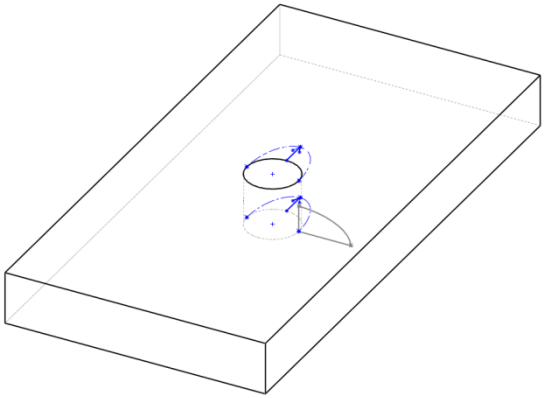
Remote Tension



Remote Bending



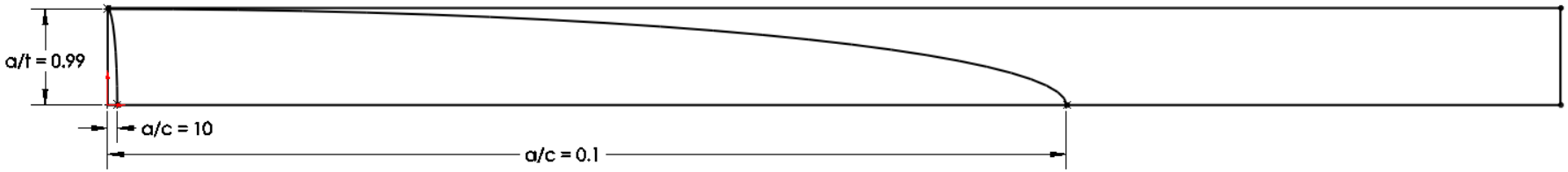
Pin Loading
$P*\cos^2(\theta)$



Solution Space - Crack Geometry

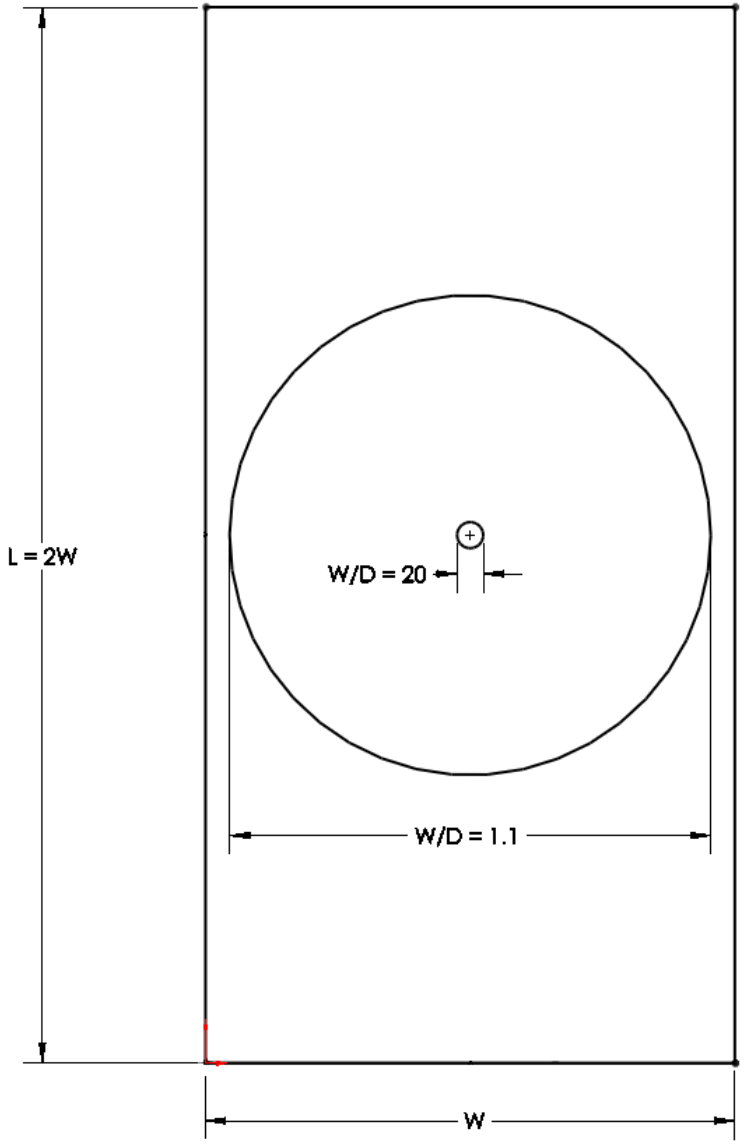
- **a/t ϵ [0.01, 0.99]**
  - **a/t = [0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99]**

- **a/c ϵ [0.1, 10]**
  - **a c = [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, 1.25, 1.333, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10]**



Solution Space - Plate Geometry

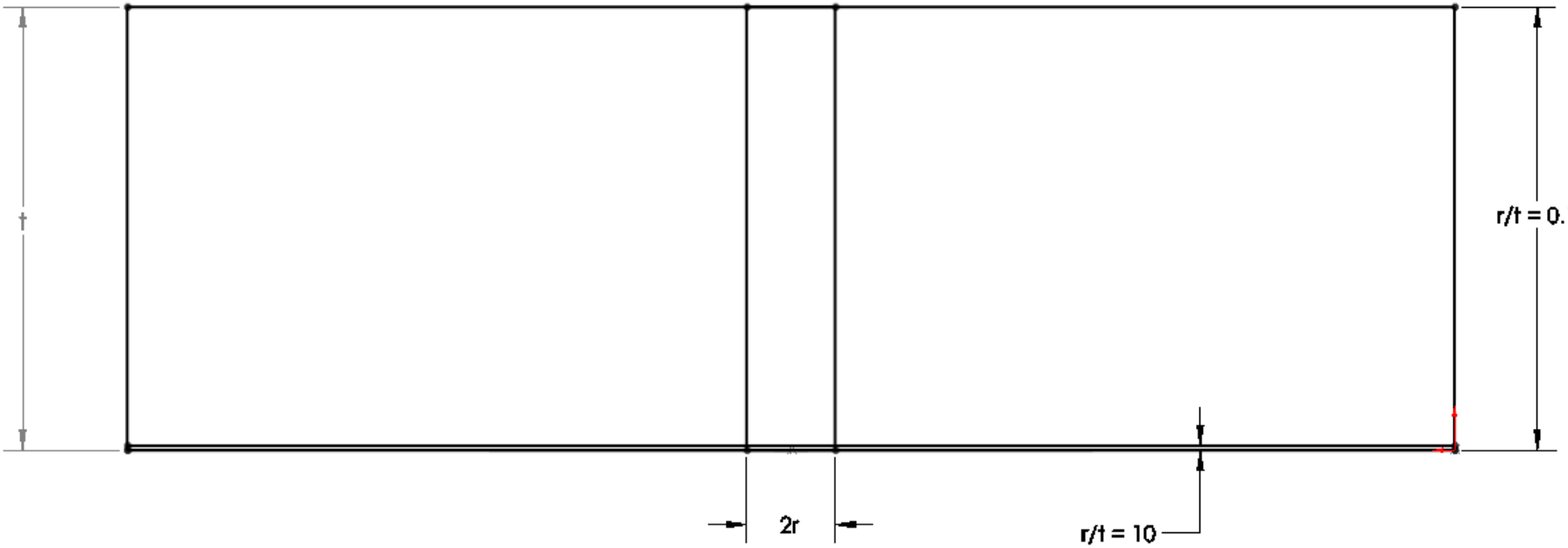
- L/W = 2 (fixed)
  - Eliminate finite height effect
- W/D ϵ [1.1, 20]
  - W/D = [1.1, 1.25, 1.5, 1.667, 2, 3, 4, 10, 20*]



*** Large W/D ratio used for comparison to existing AFGROW solutions**

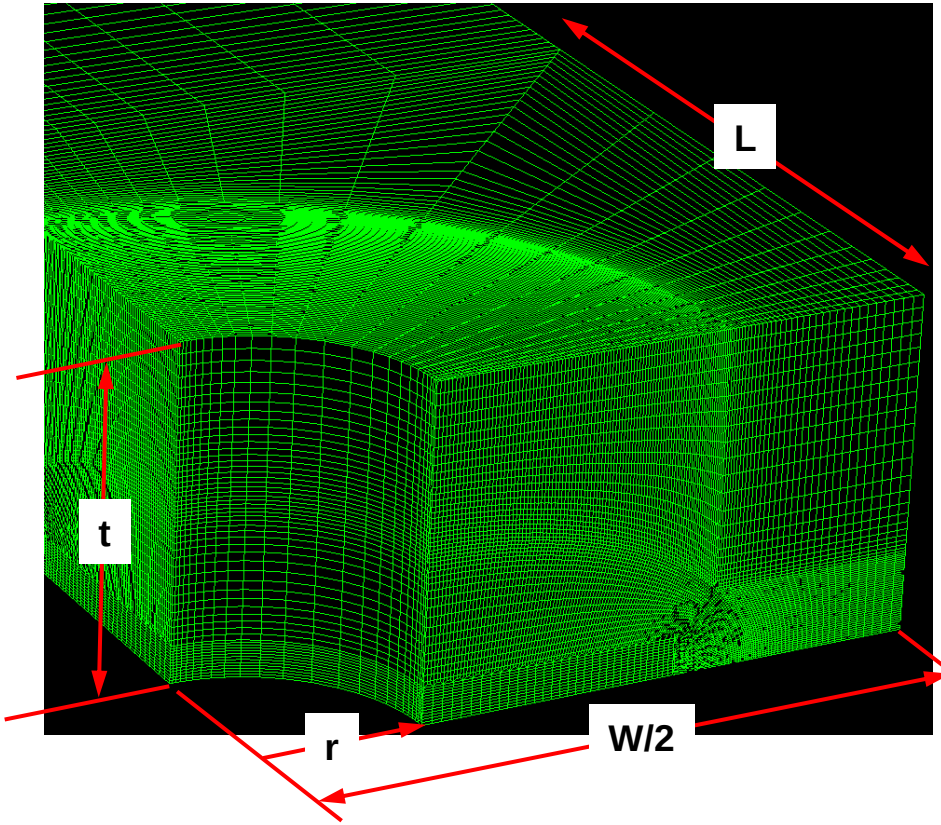
Solution Space - Plate Geometry

- **r/t ϵ [0.1, 10]**
  - **r/t = [0.1, 0.111, 0.125, 0.1428, 0.1667, 0.2, 0.25, 0.333, 0.5, 0.667, 0.75, 0.8, 0.9375, 1, 1.25, 1.333, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10]**

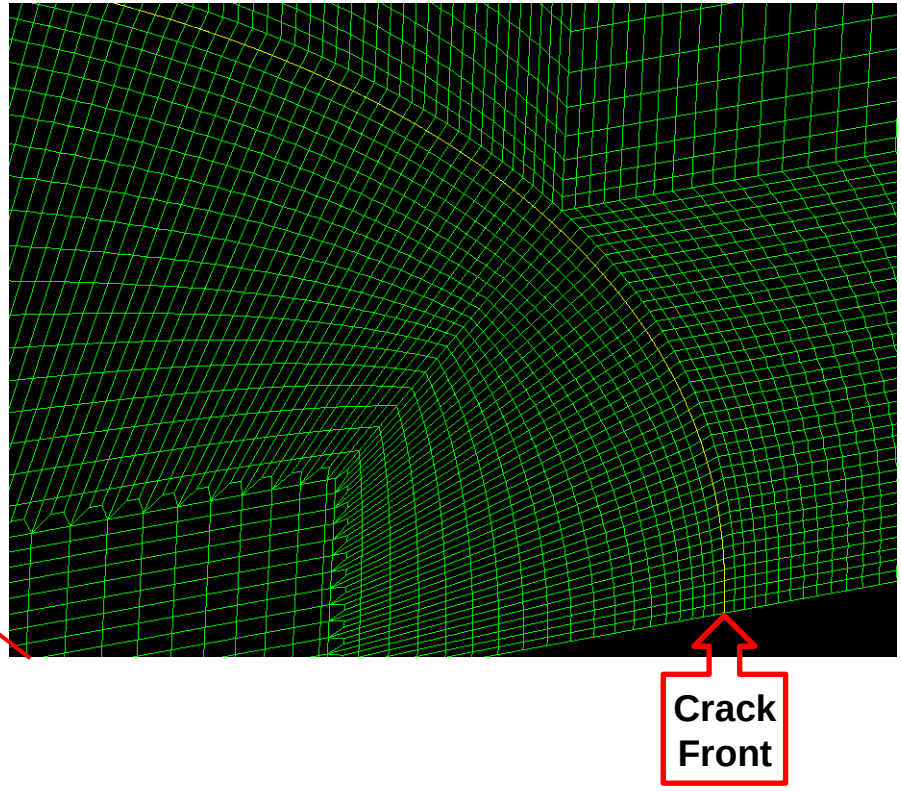


FE Automatic Mesh Generation

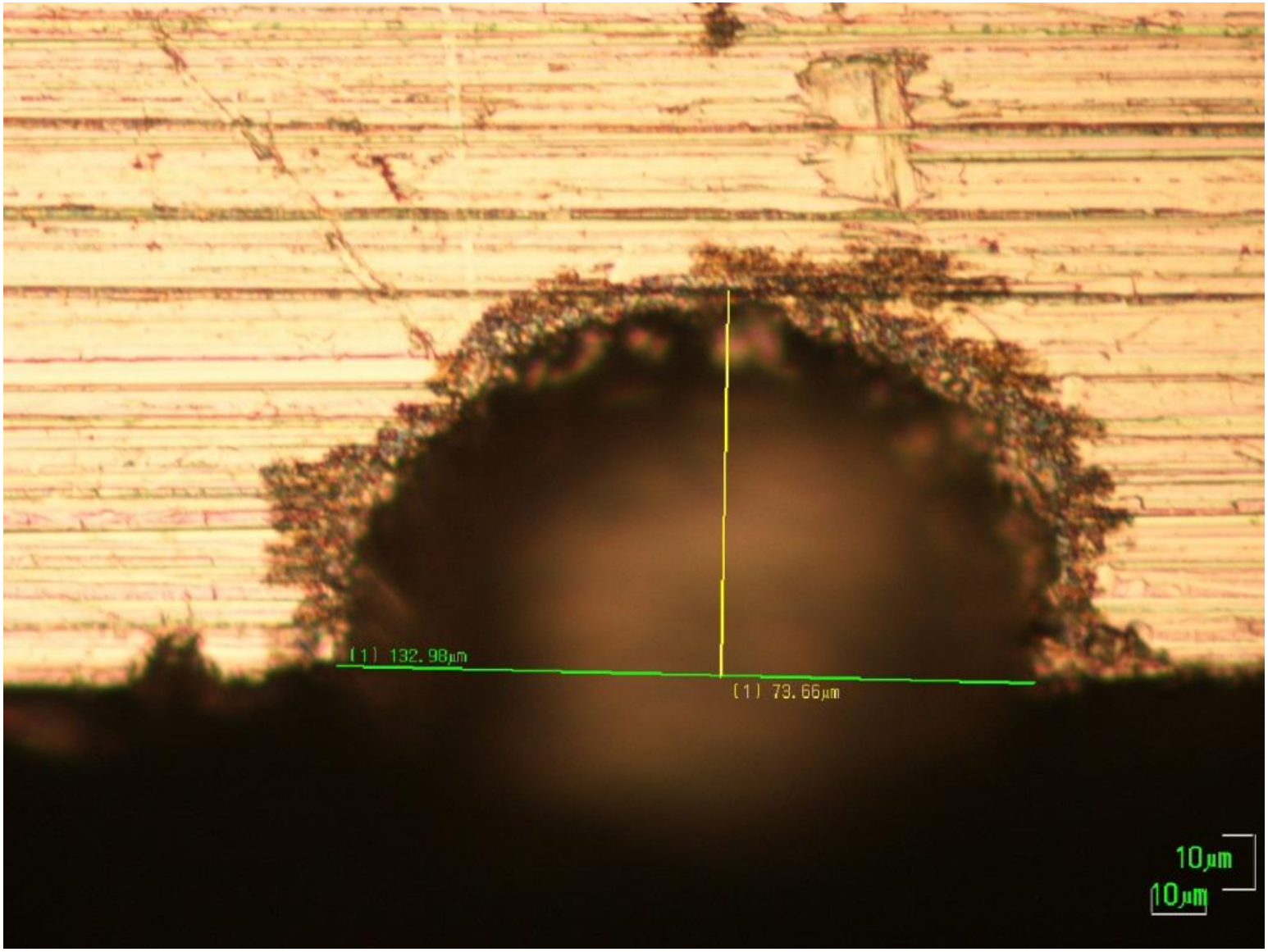
Crack Plane w/ Auto-Mesh



Crack Front w/ Auto-Mesh



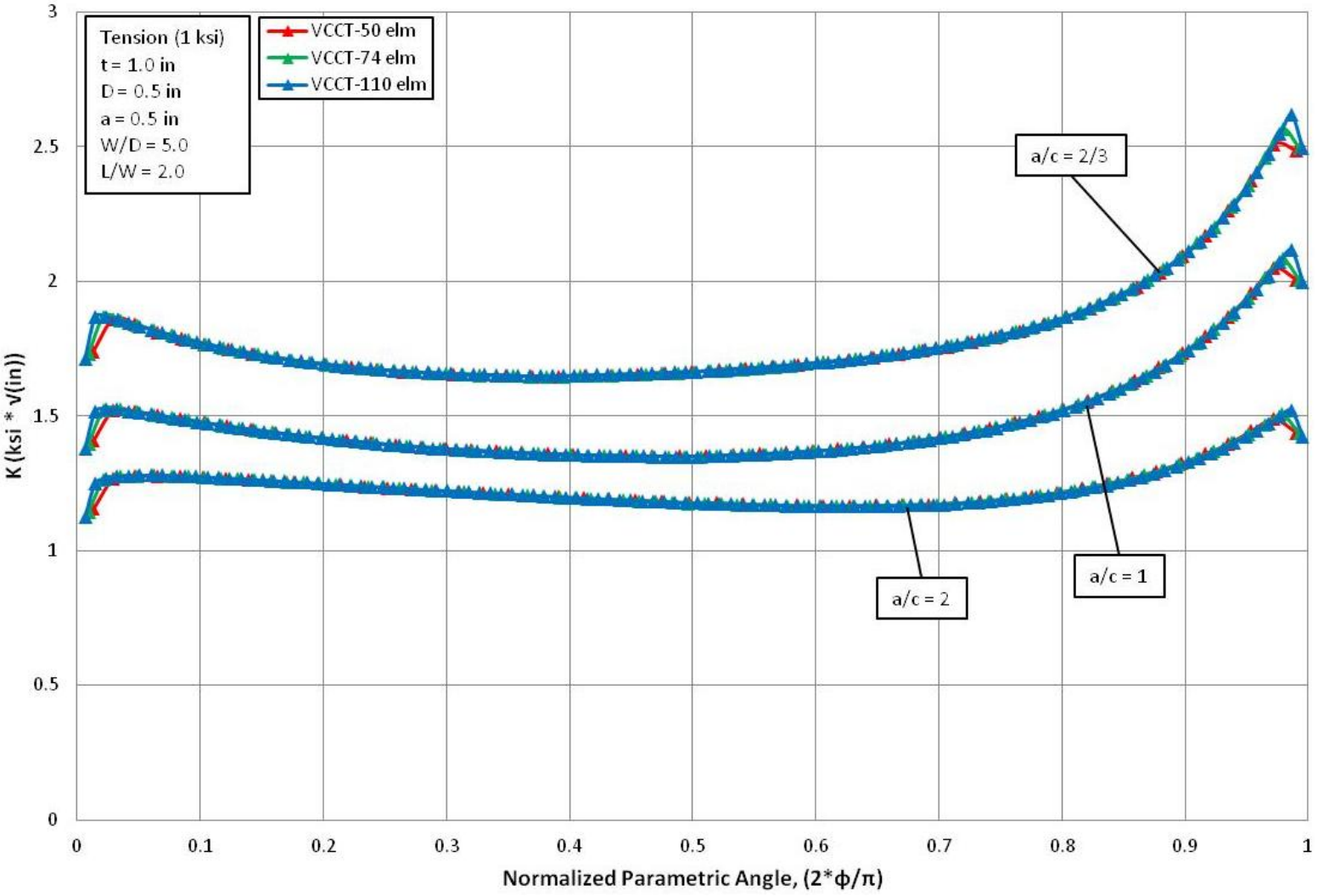
Stress Intensity Factor Vertex



Pit dimensions: 2c = 132 µm; a = 73 µm

FEA Convergence

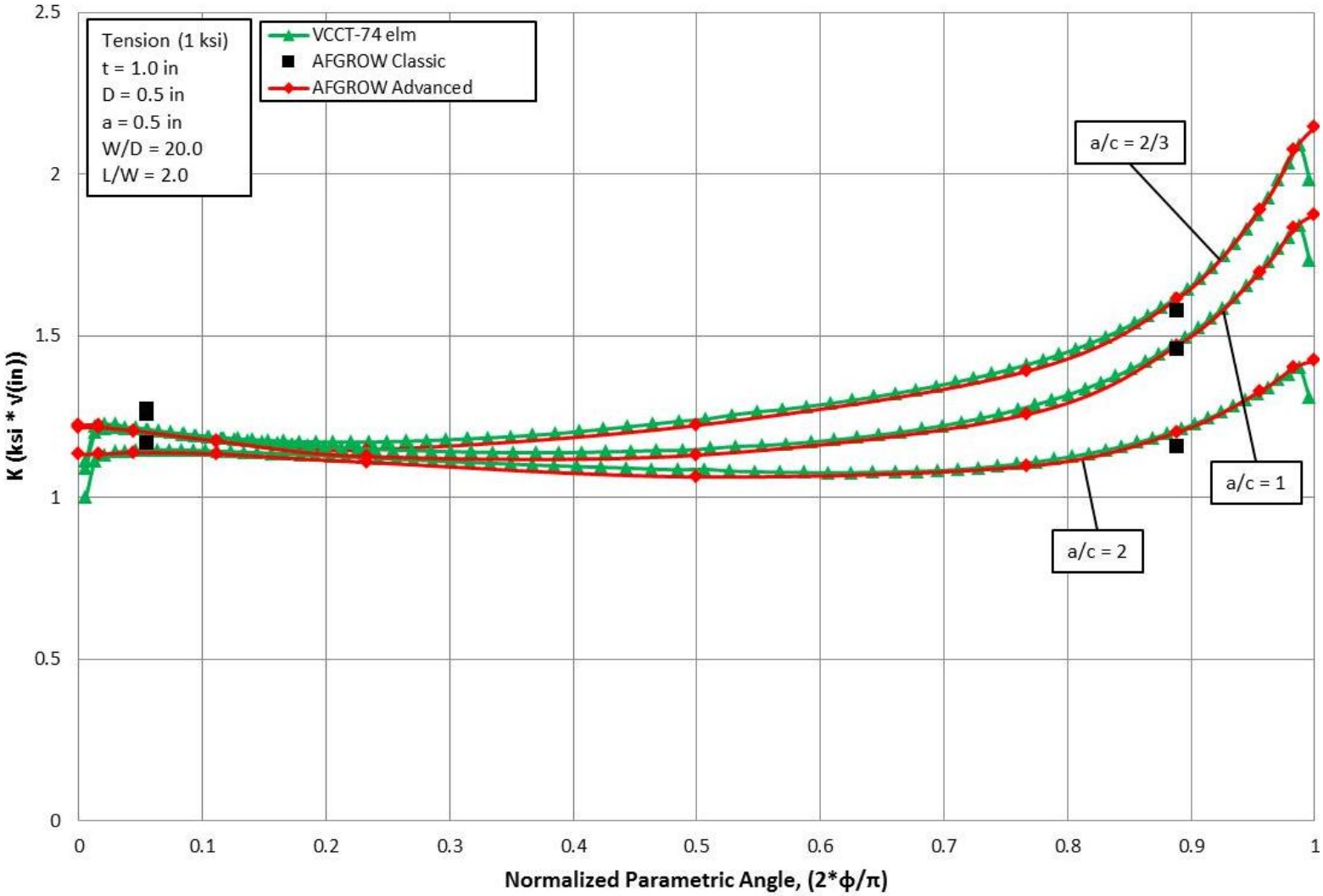
USAF Academy Center for Aircraft Structural Life Extension (CAStLE)



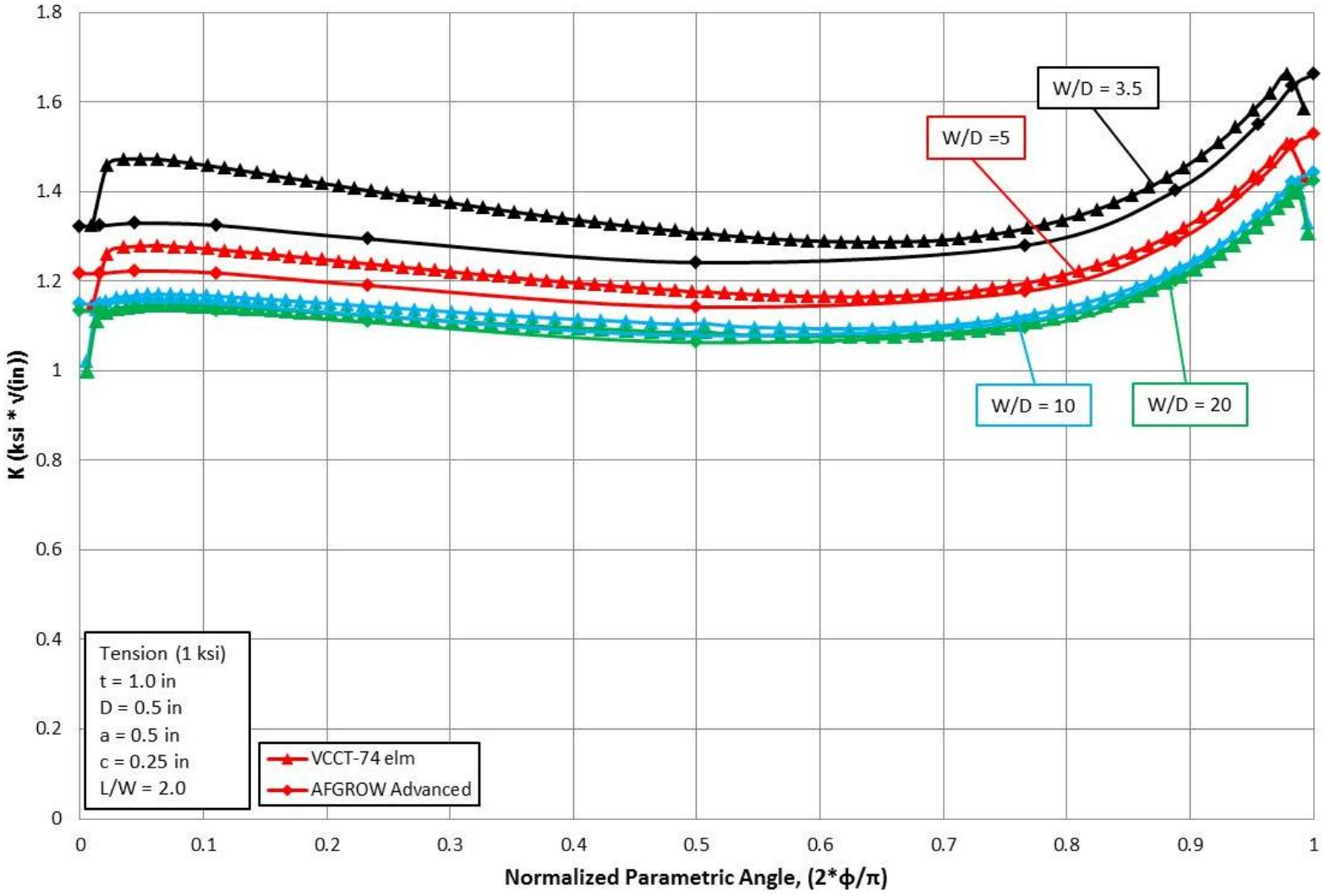
Vertex behavior captured with ≥ 74 elements along the crack front

Verification / Correlation

USAF Academy Center for Aircraft Structural Life Extension (CAStLE)

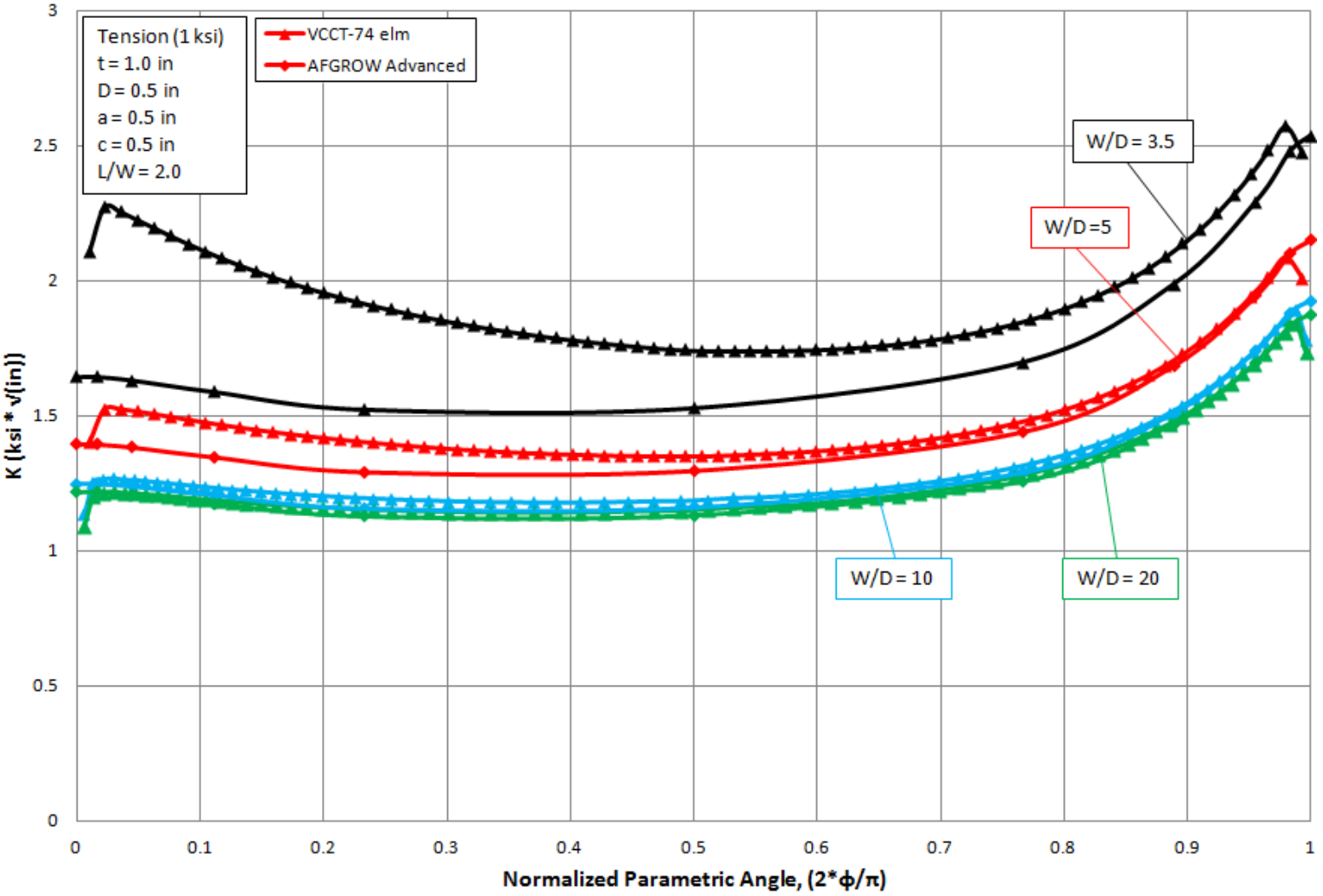


Finite Width Effect: a/c = 2



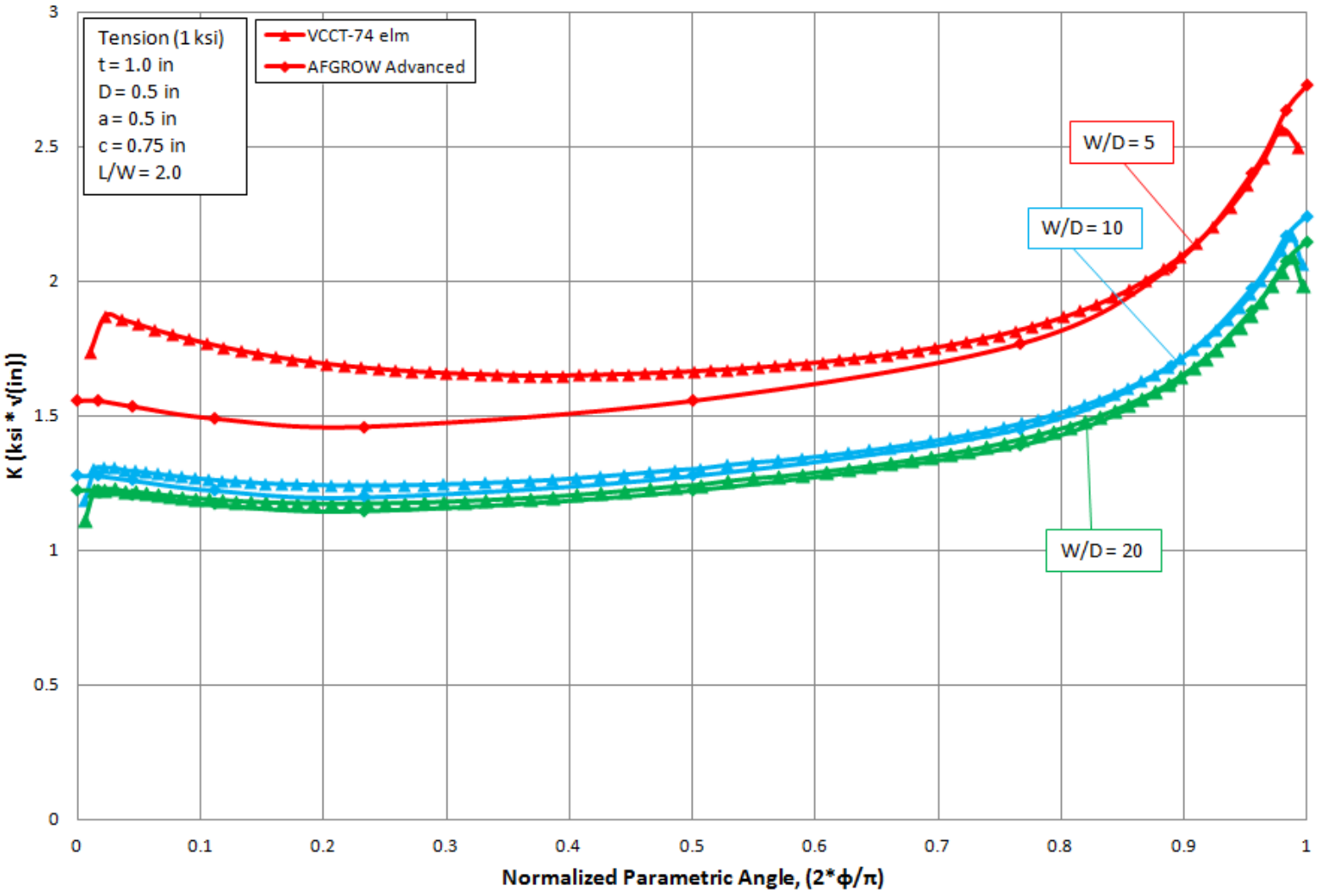
Compare well with wide plates, differences with narrow plates

Finite Width Effect: a/c = 1



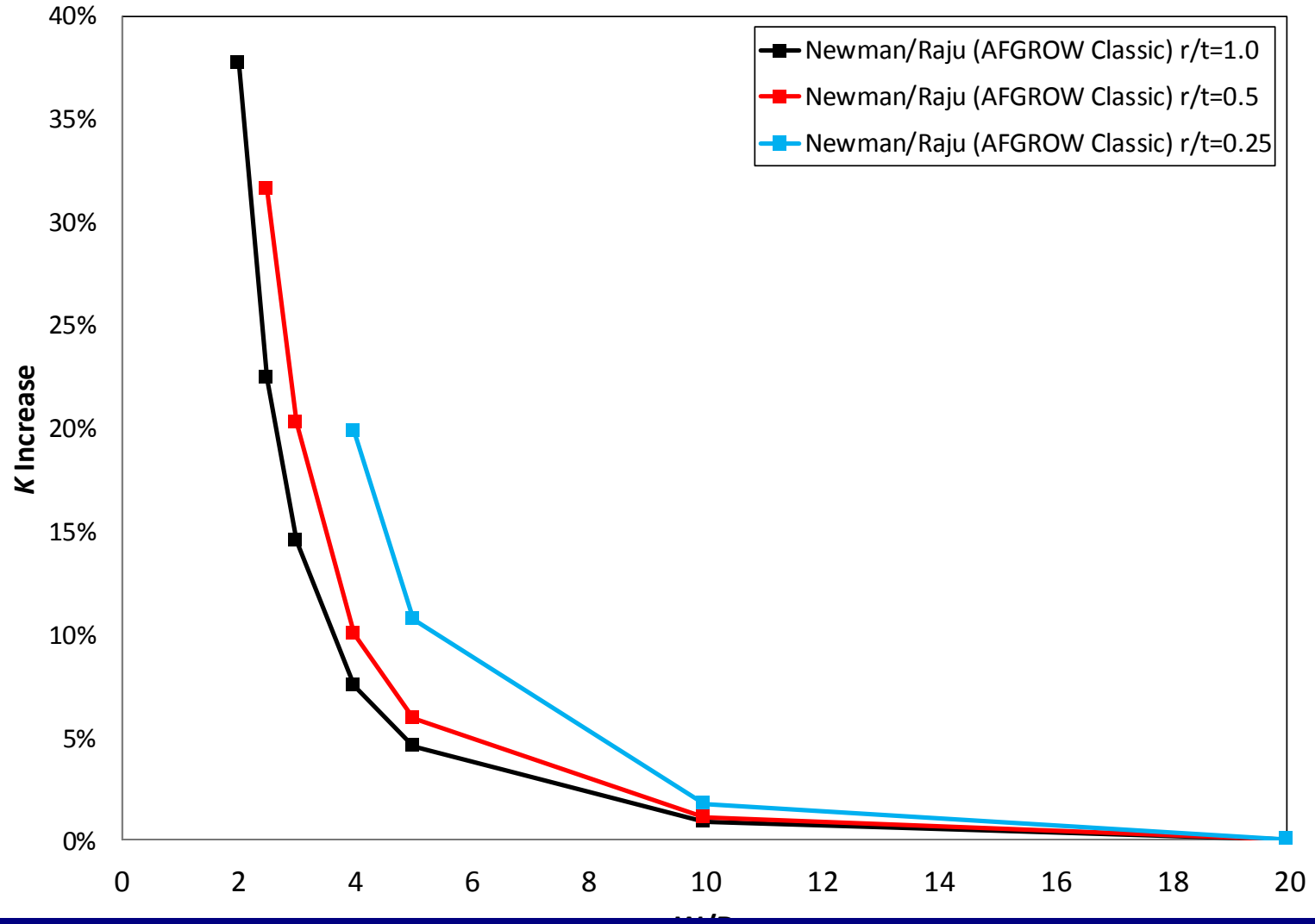
Compare well with wide plates, differences with narrow plates

Finite Width Effect: a/c = 2/3



Compare well with wide plates, differences with narrow plates

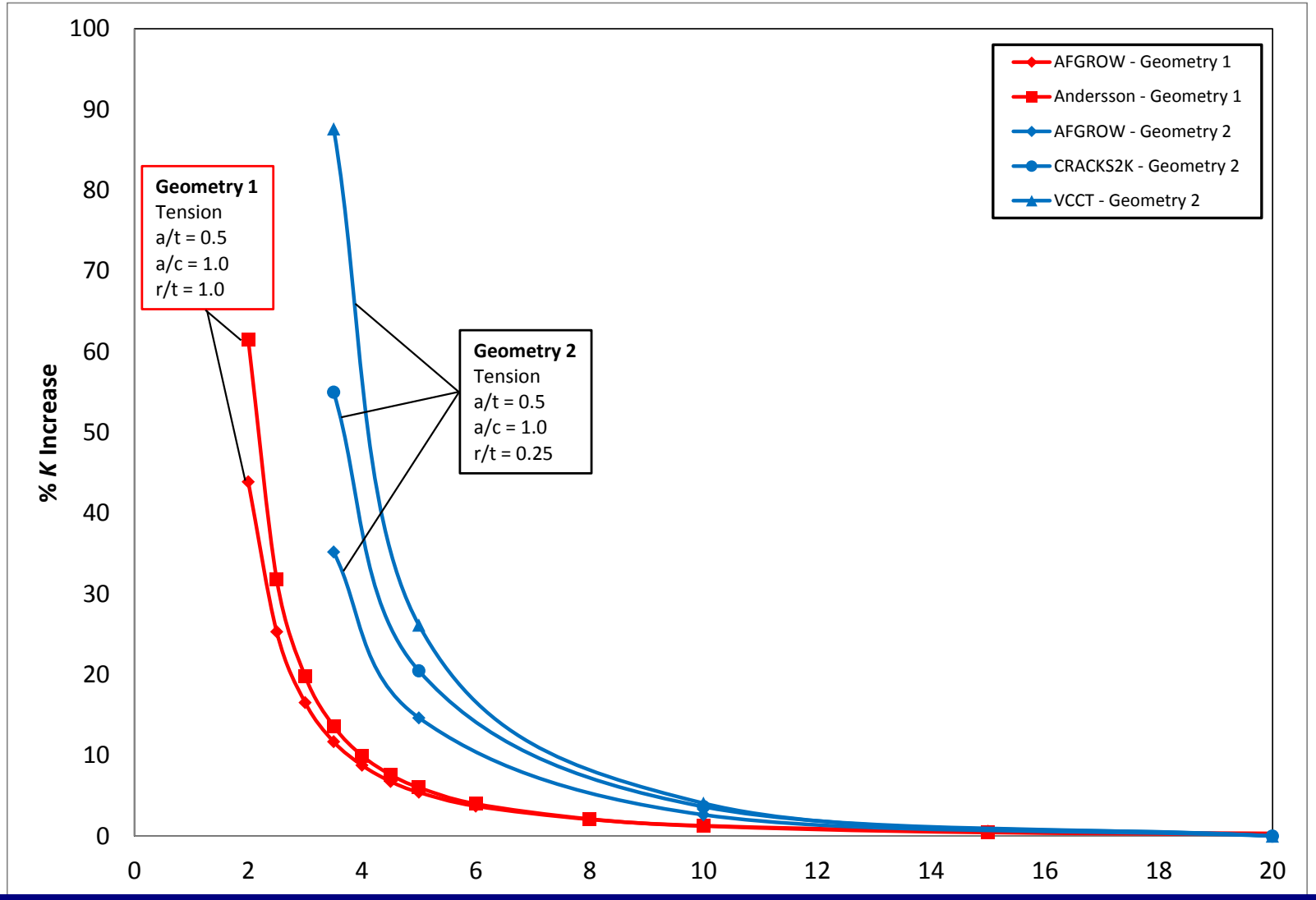
r / t Effect



Caution – r/t effect is inherent in all solutions

Further Correlation

USAF Academy Center for Aircraft Structural Life Extension (CAStLE)



Caution – Know what's in your solution

Conclusions

- **Initial results indicate that part-through crack finite width corrections can be improved**
  - **Improvement relevant to any life prediction code using the Newman/Raju corner crack *K* solutions**
    - **Finite width correction factor is embedded in these solutions**
- **Automated mesh generation**
  - **Reduces FE discretization error**
  - **Aids in *K* error control**
  - **Simplifies additional geometry cases if increased fidelity is needed to reduce *K* interpolation error**
- **Automated run-stream**
  - **Reduced user input**
  - **Robust data management**

Questions?