Validation testing and analysis of cracked hole continuing damage solutions

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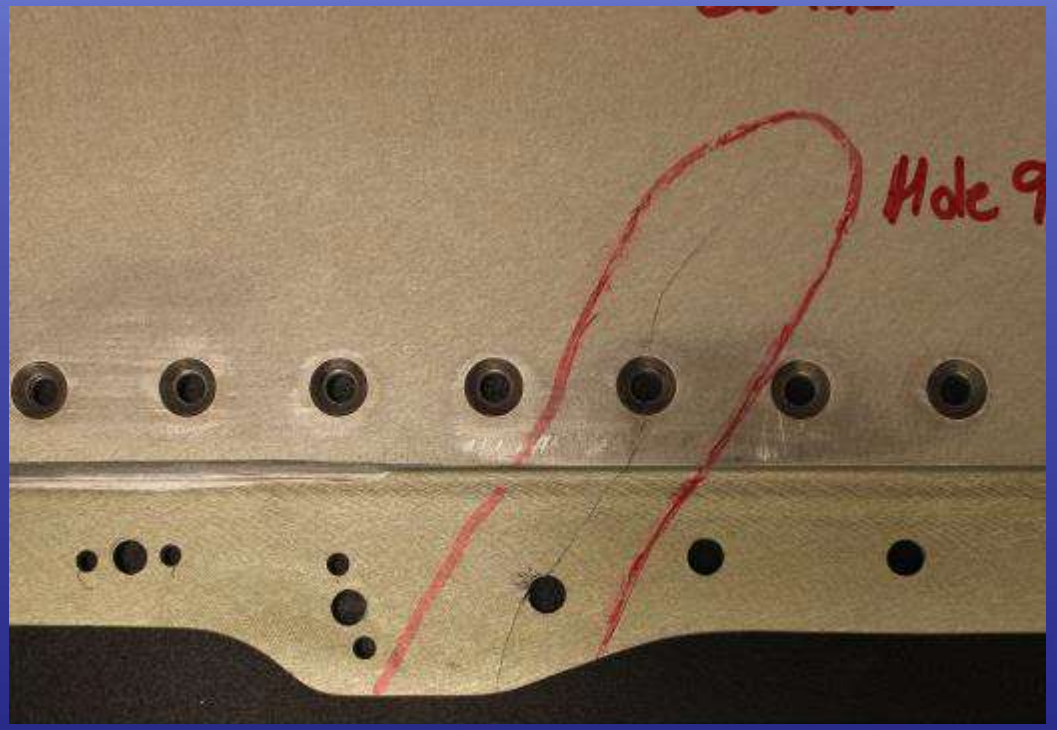
Purpose of Effort

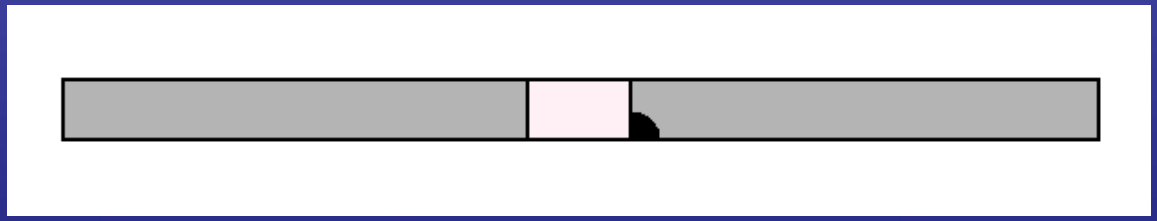
- Our damage tolerance analyses of aircraft structures often require investigation of continuing damage (after the primary ligament is severed)



Purpose of Effort

- Validation of stress intensity factors recently developed for continuing damage scenarios

- Validation of retardation parameters developed via centered hole spectrum testing



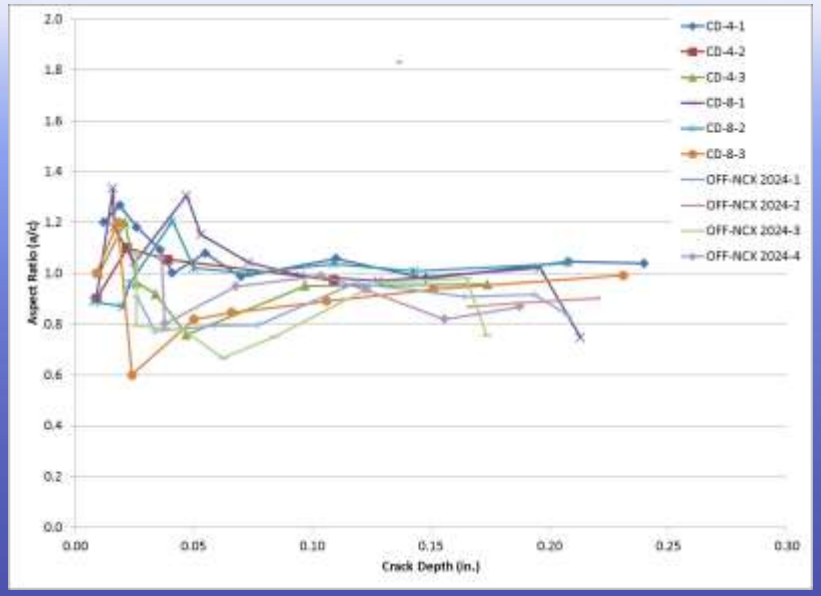
Test Matrix

- **Two types of testing:**
  - Constant amplitude: two geometries
  - Spectrum loading: four combinations of geometry, material, and loading spectrum

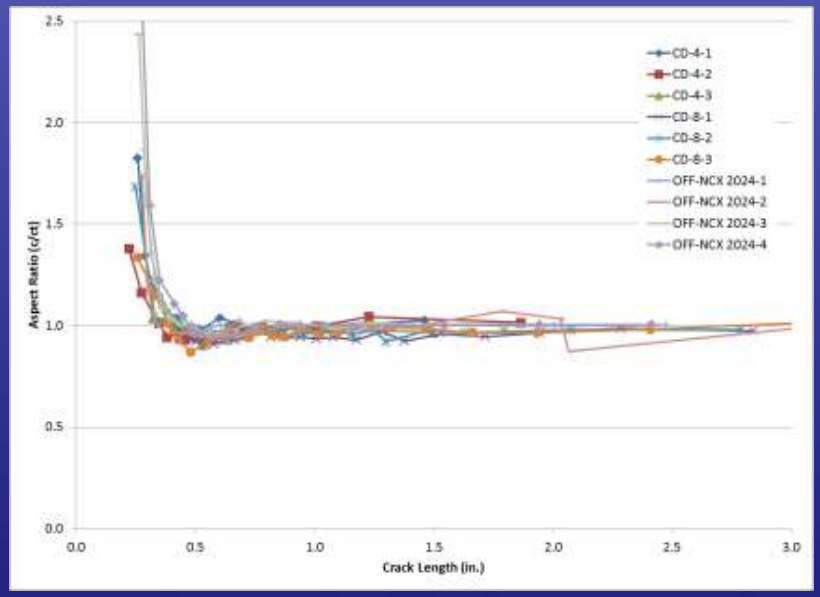
Loading	Material	Max Stress (ksi)	Qty	Thick (in.)	Hole Dia (in.)	Edge Dist (in.)	Width (in.)
Constant Amp	2024-T351	10.0	7	0.25	0.50	0.60	4.00
Constant Amp	2024-T351	10.0	3	0.25	0.50	0.75	8.00
Wing spectrum	2024-T351	27.9	3	0.30	0.50	0.75	8.00
Wing spectrum	2024-T351	35.0	3	0.30	0.50	0.75	8.00
Wing spectrum	2024-T3511	35.0	3	0.32	0.25	0.62	4.00
Wing spectrum	7075-T6	32.0	3	0.10	0.25	0.62	8.00

Initial Review of Constant Amplitude Testing

- Crack aspect ratios:
  - Corner cracks:
    (a/c)
    (bore/surface)

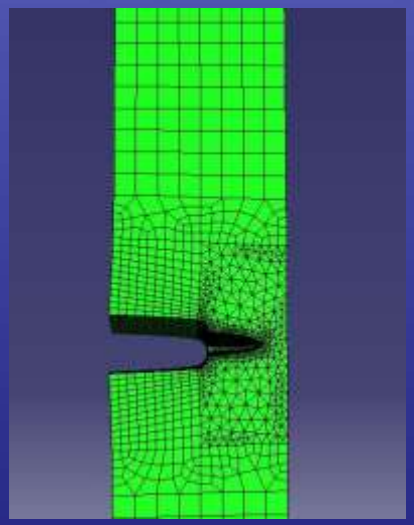


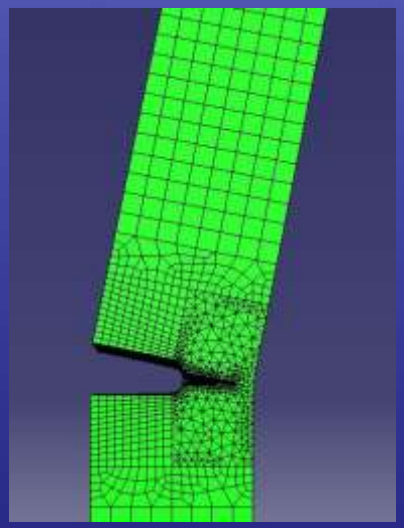
  - Through cracks:
    (c/c_t)
    (front surface/back surface)

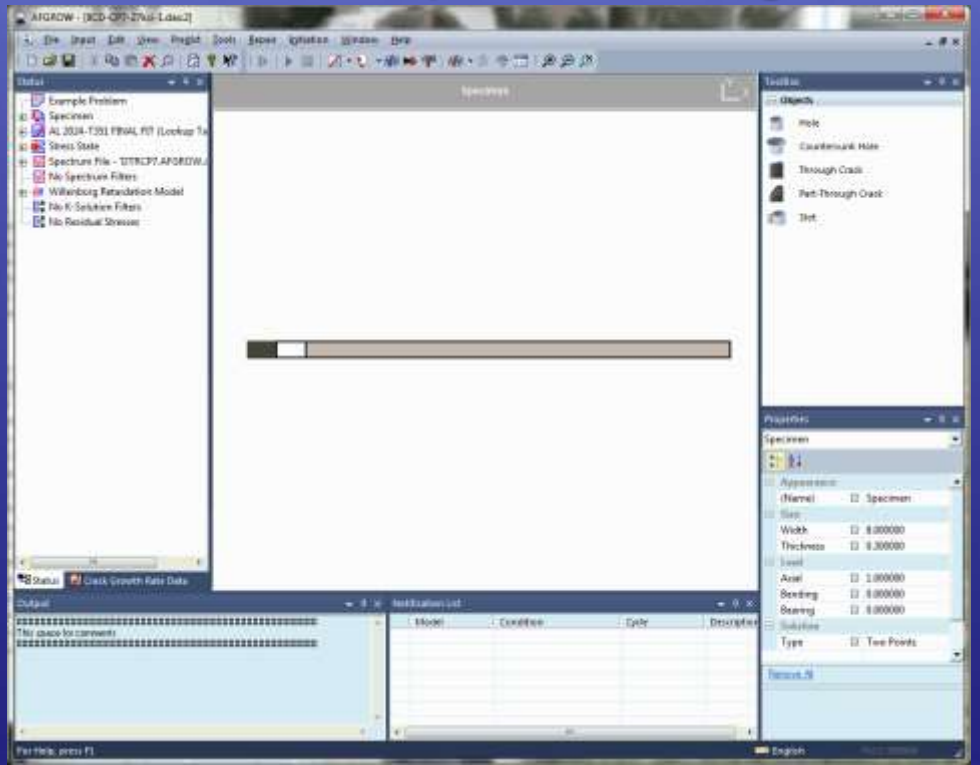


AFGROW Comparison to Constant Amplitude Testing

- Initial comparison used AFGROW v5
  - Advanced model with offset hole and slot in place of severed ligament
  - SIFs developed by Harter in 2010
  - Model allows user to either constrain in-plane bending or leave unconstrained

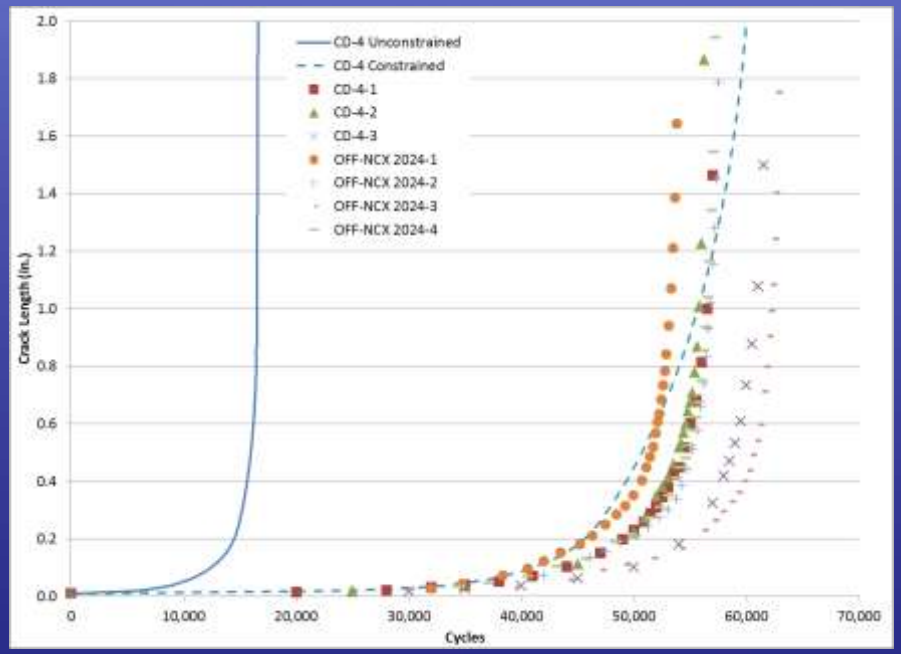


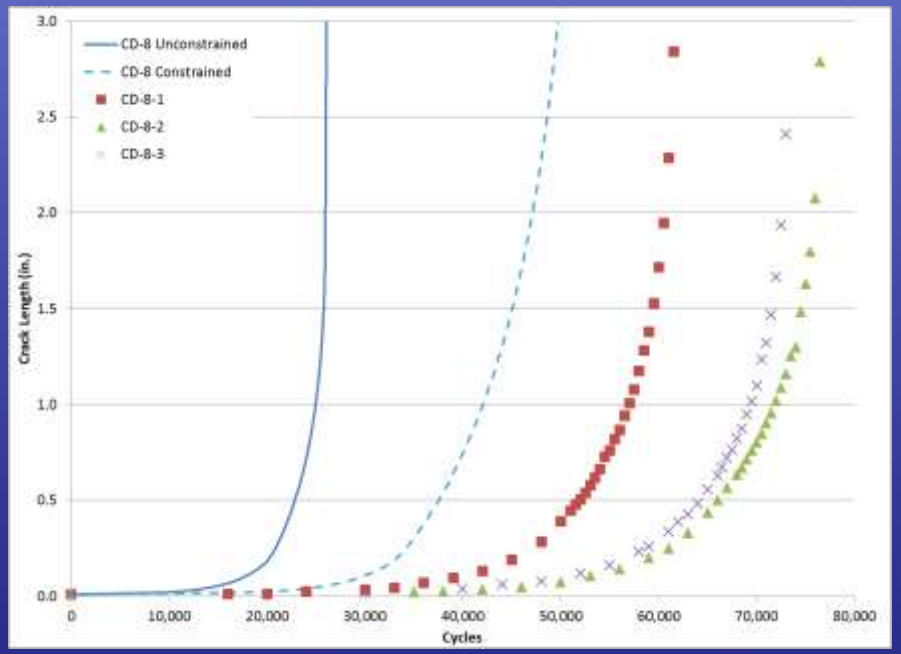




AFGROW Comparison to Constant Amplitude Testing

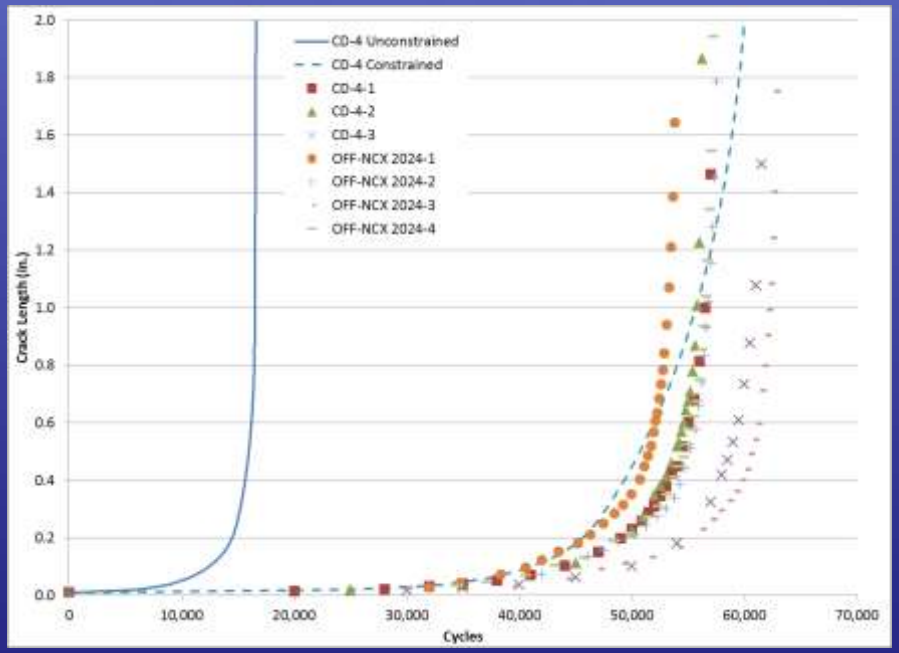
- **Crack growth lives:**
  - Unconstrained model consistently too short
  - Constrained model gives good results for 4 inch geometry and slightly conservative for 8 inch geometry

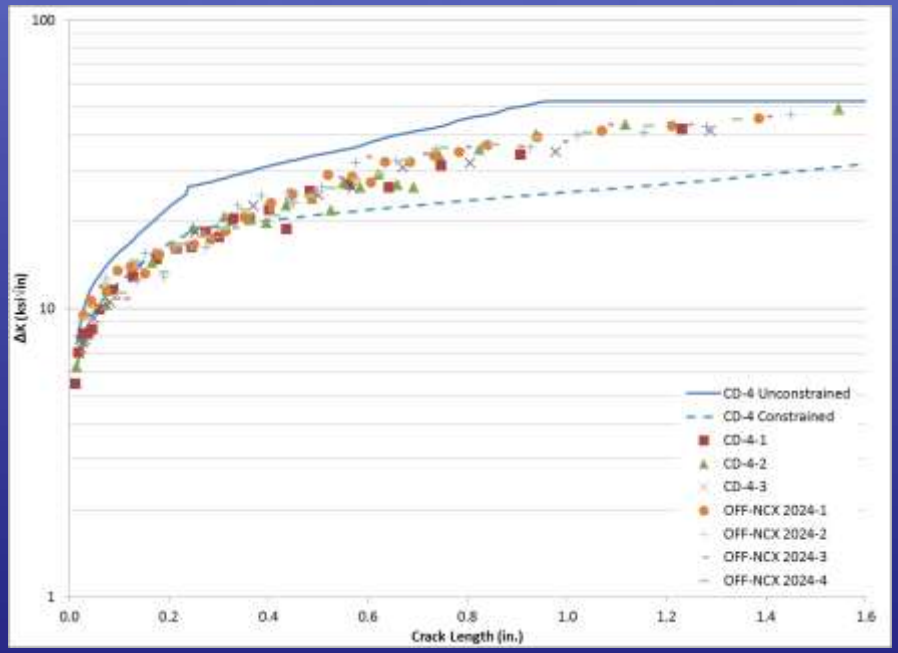




AFGROW Comparison to Constant Amplitude Testing

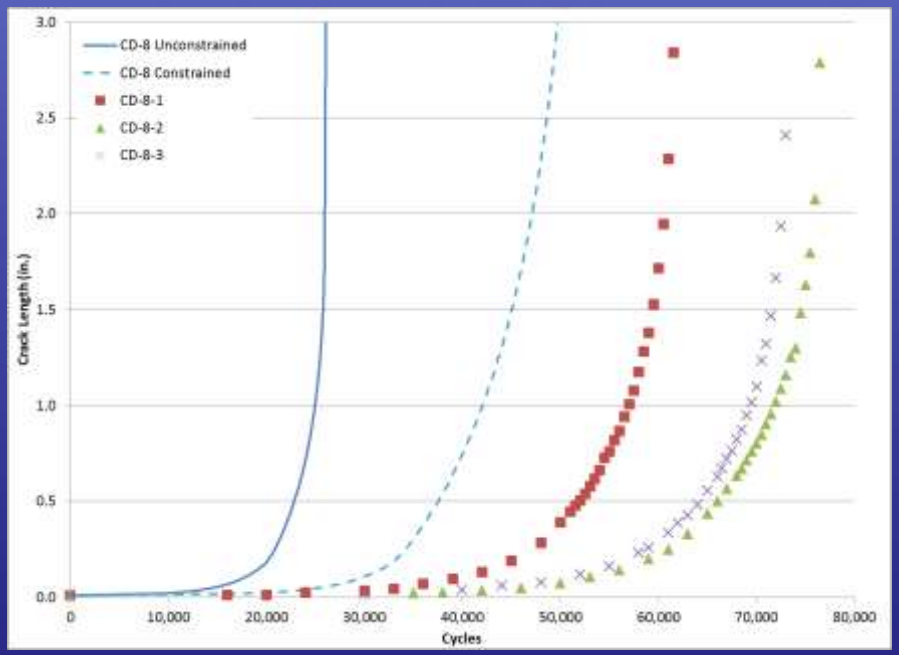
- Stress intensity factors estimated from 2024-T351 crack growth rates and compared to those from analysis
- Results agree with life results: 4 inch coupons

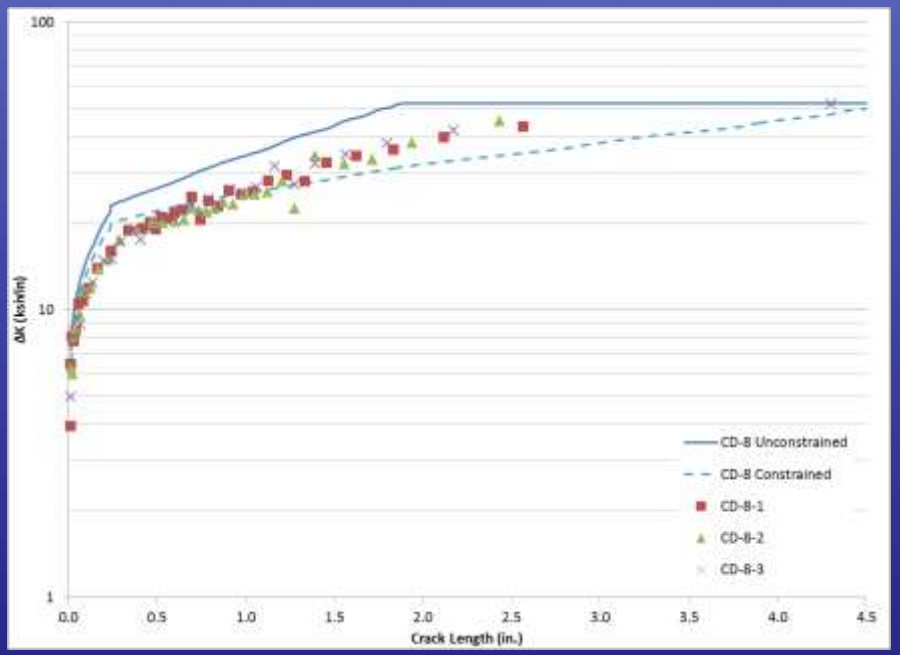




AFGROW Comparison to Constant Amplitude Testing

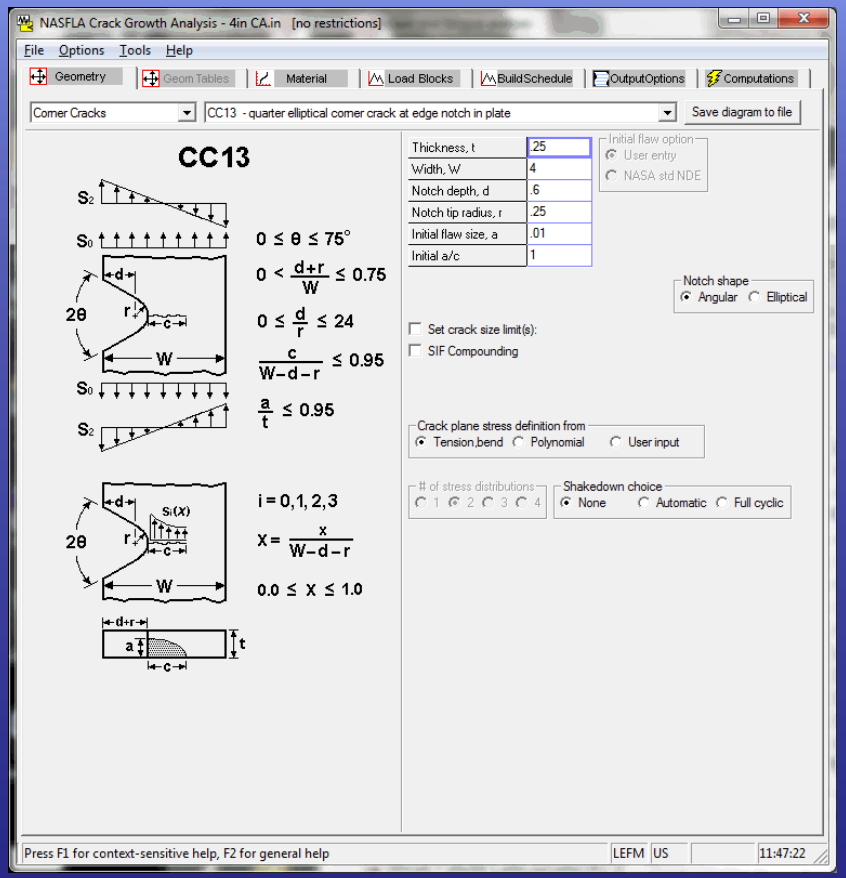
- Stress intensity factors estimated from 2024-T351 crack growth rates and compared to those from analysis
- Results agree with life results: 8 inch coupons





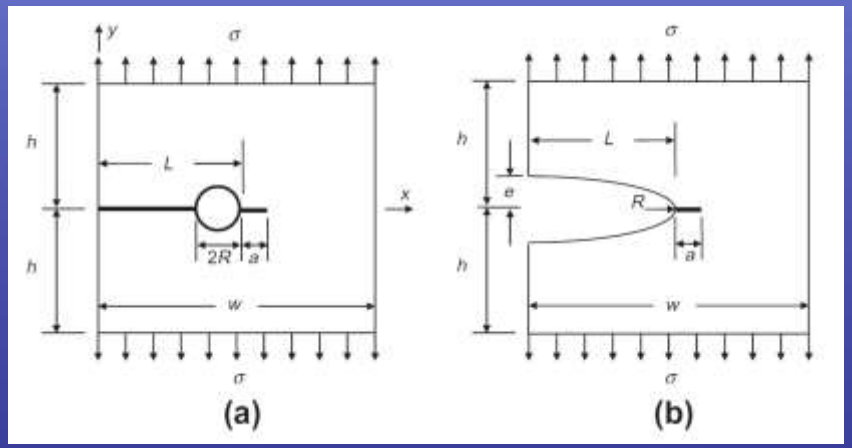
NASGRO Comparison to Constant Amplitude Testing

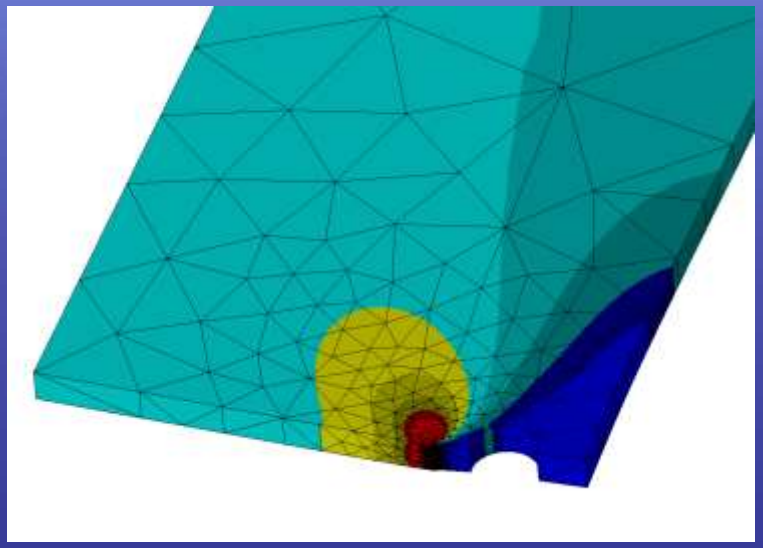
- A similar life and SIF comparison was performed using NASGRO v7.1
  - No bending constraint available
  - Used very large width to prevent bending
- The model predicted large corner crack aspect ratios, which led to faster growth than in tests



Analytical Comparison to Constant Amplitude Testing

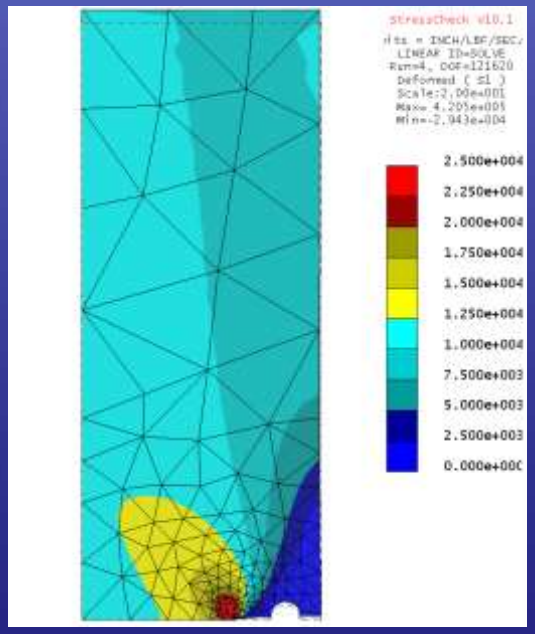
- **Further comparison performed:**
  - SIFs published by Evans, et al (DSTO Australia)
  - Developed FEMs using StressCheck

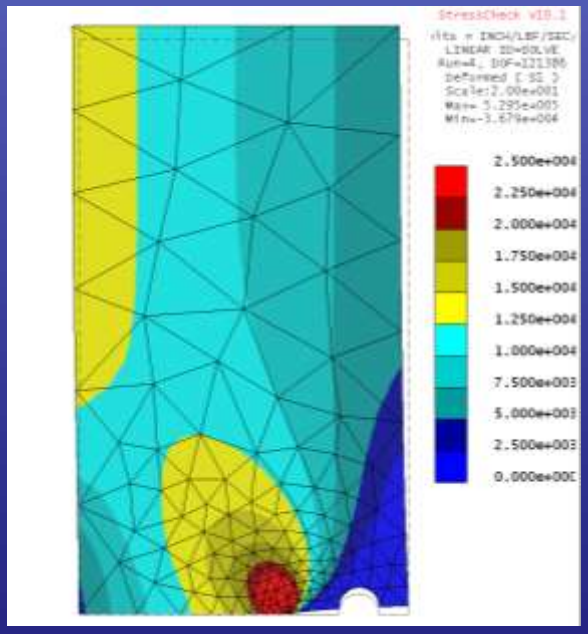




Analytical Comparison to Constant Amplitude Testing

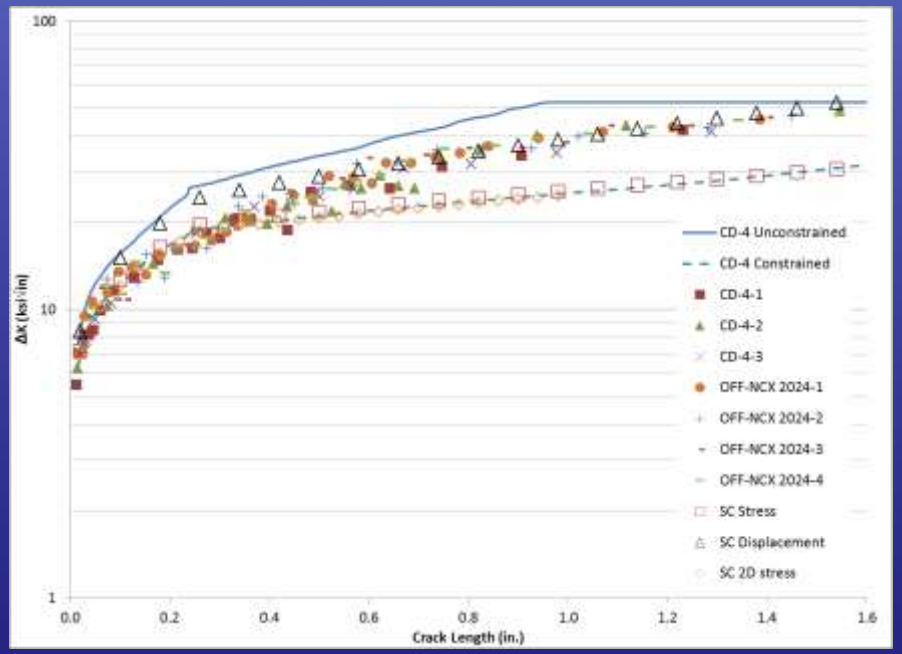
- StressCheck models were created using two types of constraints:
  - Constant stress at end, in-plane bending fully constrained on back face
  - Constant displacement at end, no in-plane bending constraint

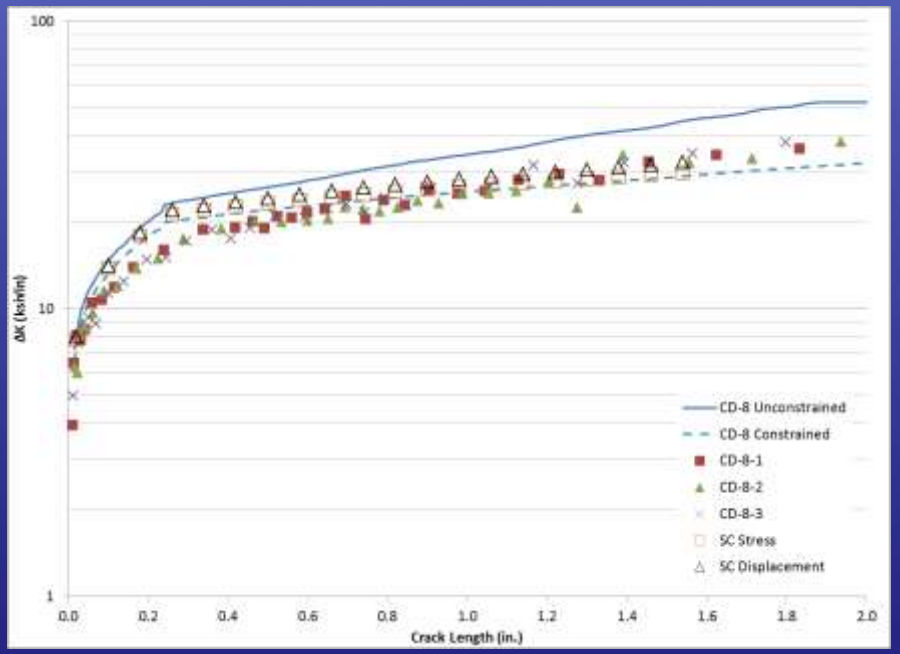




Analytical Comparison to Constant Amplitude Testing

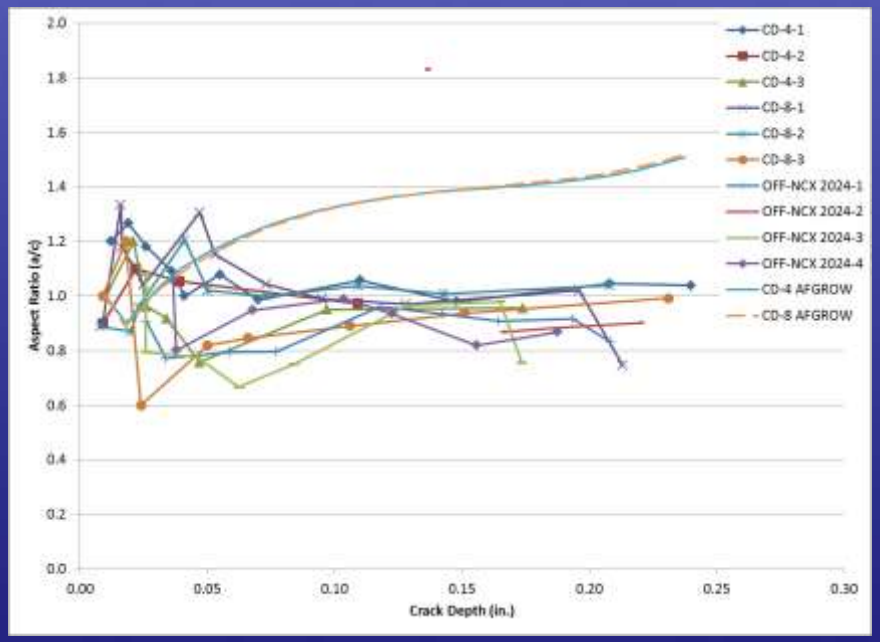
- **Results:**
  - AFGROW constrained, Evans, and StressCheck constrained are consistent and low
  - AFGROW unconstrained is high
  - StressCheck constant displacement is very accurate everywhere except at transition to through crack

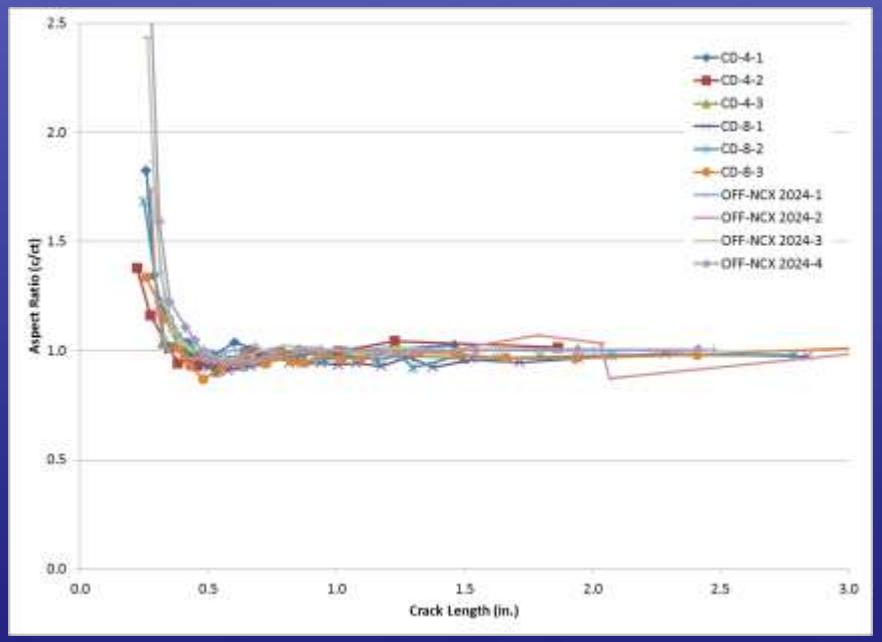




Analytical Comparison to Constant Amplitude Testing

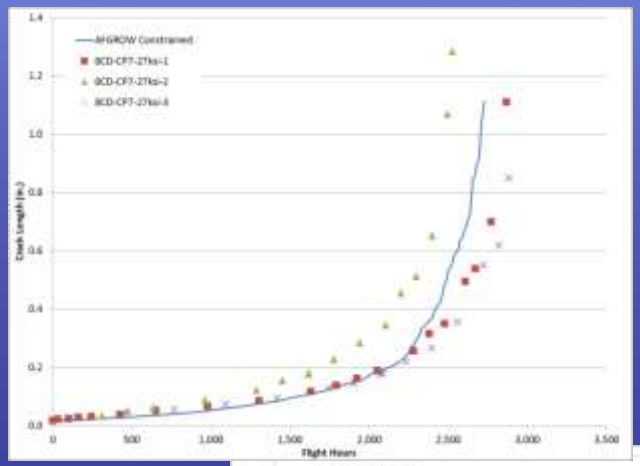
- **Proposed reasons for discrepancies:**
  - Corner crack aspect ratios are lower than expected
    - Both AFGROW and NASGRO expect final a/c ~ 1.51
    - Test (real) SIFs < analytical SIFs as the crack nears transition
  - Through crack aspect ratios do trend towards 1, but they start out much higher
    - Test (real) SIFs < analytical SIFs immediately after transition

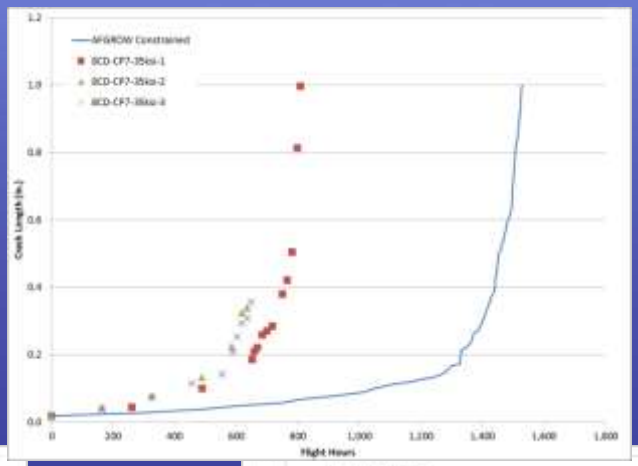


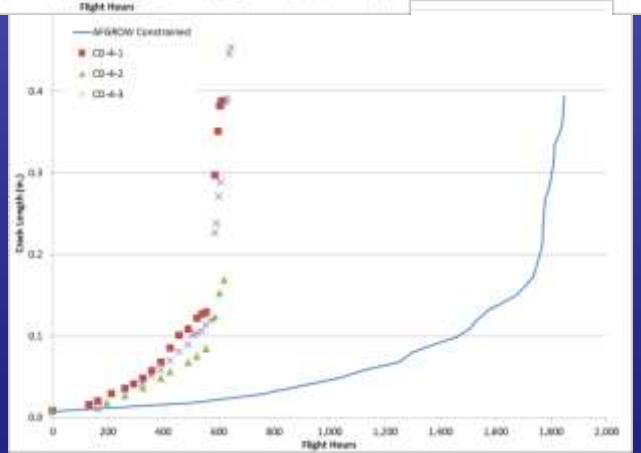


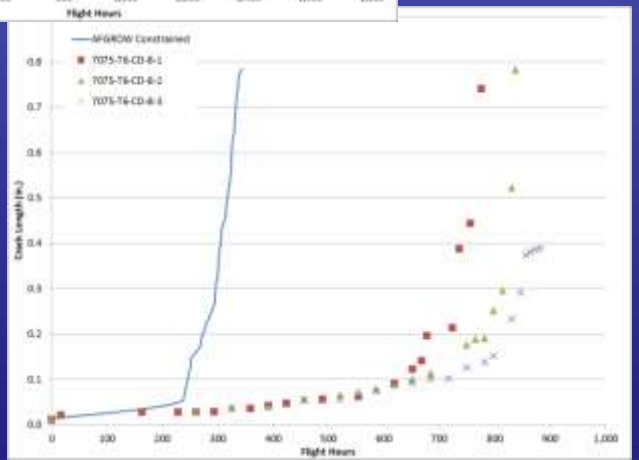
Analytical Comparison to Spectrum Testing

- Comparisons performed using AFGROW constrained model and retardation parameters developed in previous (single crack in centered hole) testing



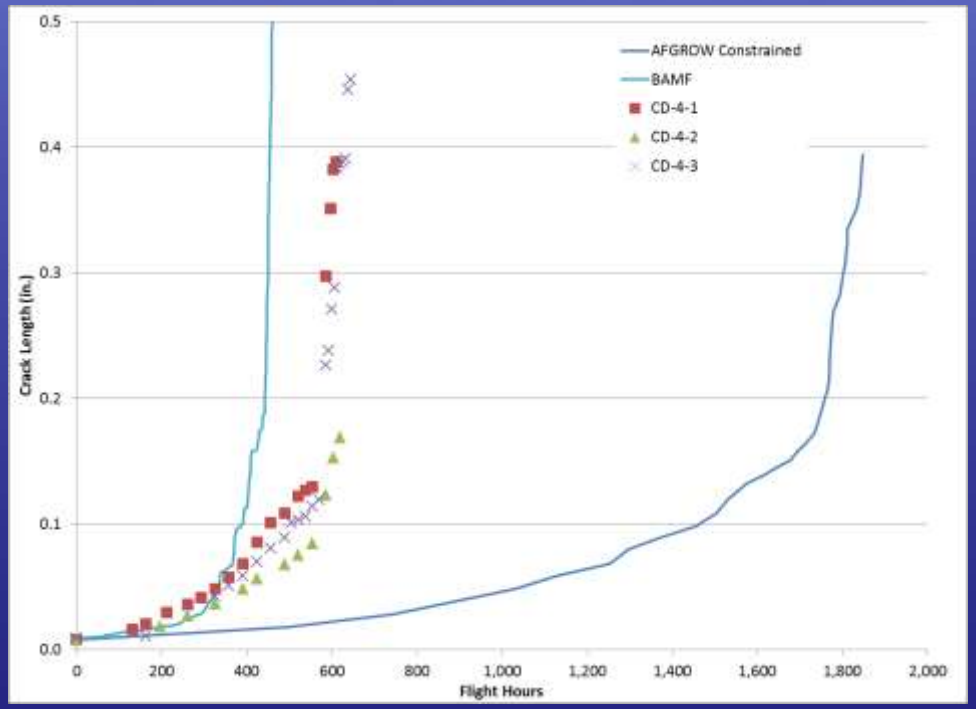






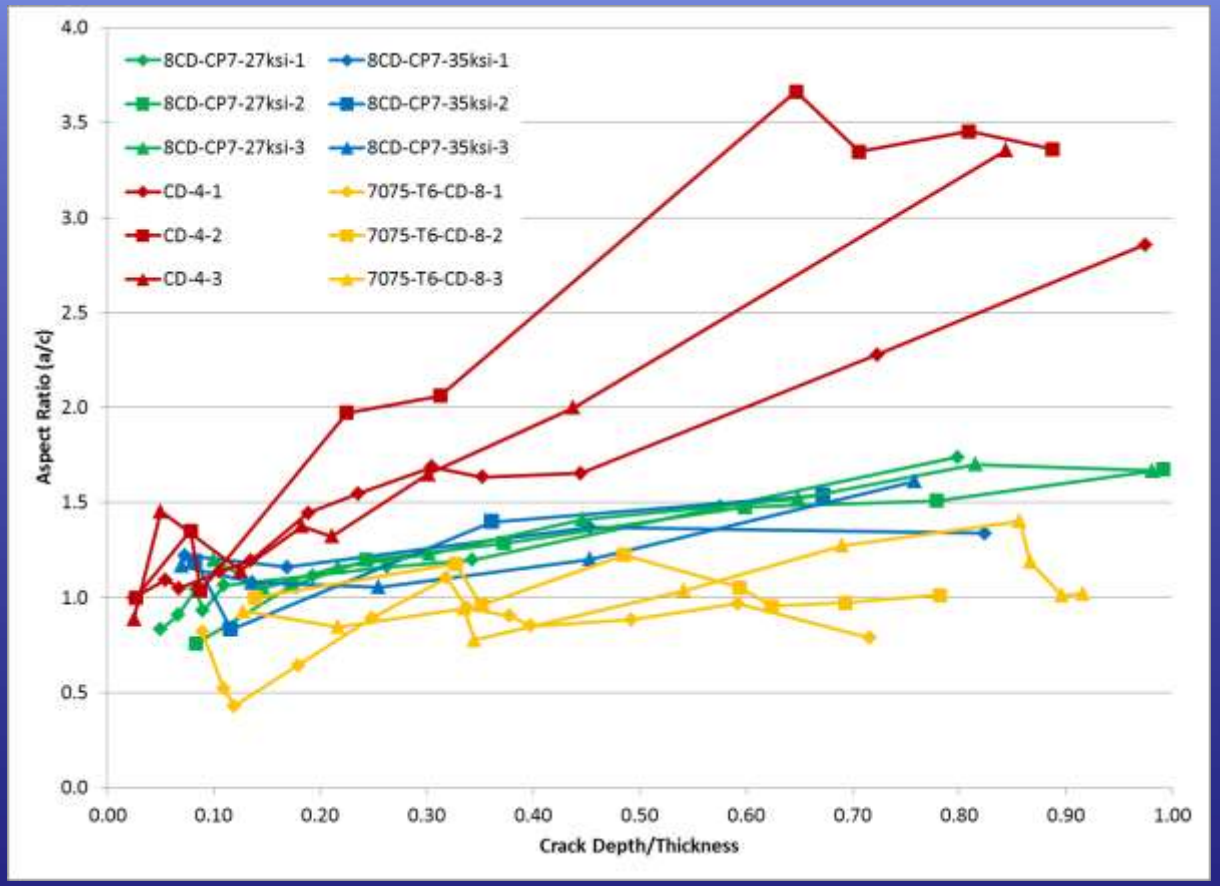
Analytical Comparison to Spectrum Testing

- **USAF-developed BAMF**
  - Iteratively runs StressCheck models during AFGROW run
  - Multi-point calculation of stress intensities
  - Can run any geometry as modeled in StressCheck



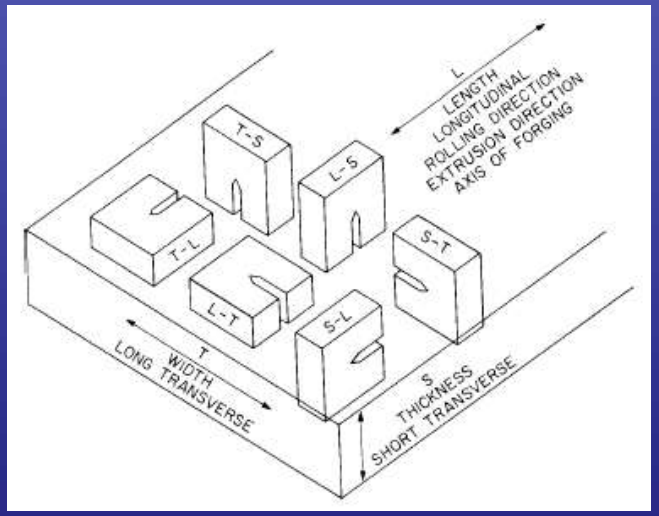
Analytical Comparison to Spectrum Testing

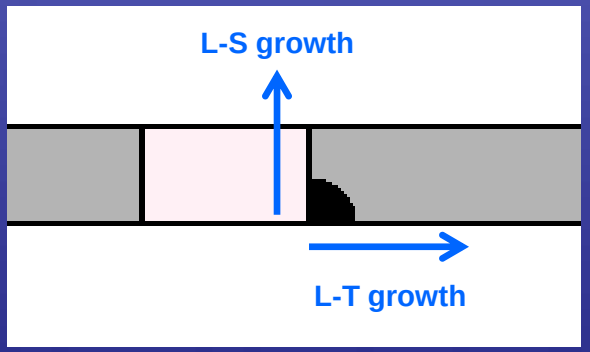
- Corner crack aspect ratios:
  - Different for different test configurations



Conclusions

- Boundary conditions critical in comparisons to test
- Good agreement to stress intensity factors
- More research needed in understanding why aspect ratios vary so widely and analysis does not capture





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