

Newman-Raju Limits Study



U.S. AIR FORCE

Exceeding Thickness to Diameter Upper Bound

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Overview



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- **Issue**
- **Approach**
- **Finite Element Analysis Solution**
- **AFGROW Solution (Implementation)**
- **Centered Hole (Newman-Raju) Comparison**
- **Offset Hole Comparison**
- **Conclusions**

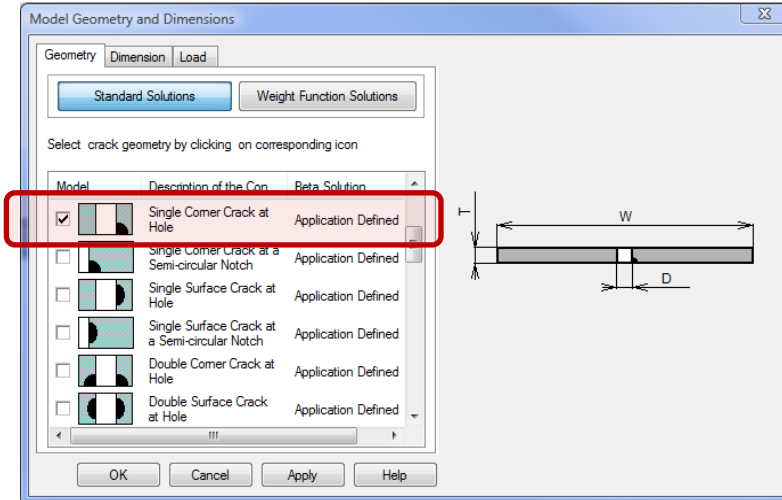


Issue



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- **AFGROW Classic Model, *Single Corner Crack at Hole*, uses the Newman-Raju Solutions**
 - *Thru Crack at Hole Solution* is not Newman-Raju
- **Newman-Raju Solutions**
 - FEA solutions for a wide range of several parameters
 - Fit equations to FEA solutions; e.g.



$$K = (S_t + H_{ch} S_b) \sqrt{\pi a / Q} F_{ch} (a/c, a/t, r/t, r/b, c/b, \phi)$$

Reference: Newman, J.C., and Raju, I.S., "Stress Intensity Factor Equations for Cracks in Three-Dimensional Bodies Subjected to Tension and Bending Loads," Chapter 9, Computational Methods in the Mechanics of Fracture, Elsevier Science Publishers B.V., 1986

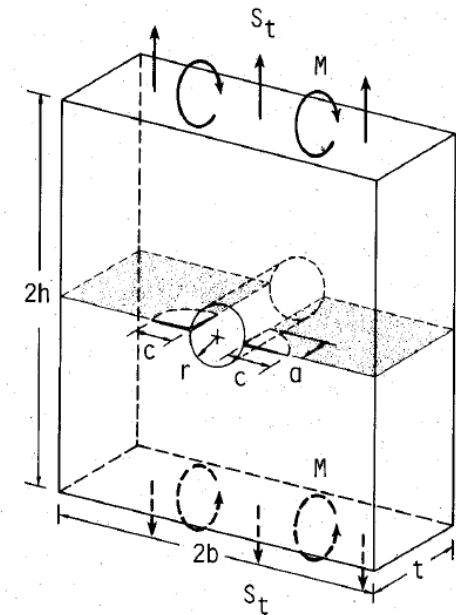


Issue (con't)

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■ Newman-Raju (N-R) FEA Limits

Parameter	Lower Bound	Upper Bound
ϕ	0.0	$\pi/2$
a/t	—	1.0
a/c	0.2	2.0
r/t	0.5	2.0
$(r+c)/b$	—	0.5



■ $r/t > 0.5 \implies t/D < 1$

■ Bounds can be exceeded in AFGROW

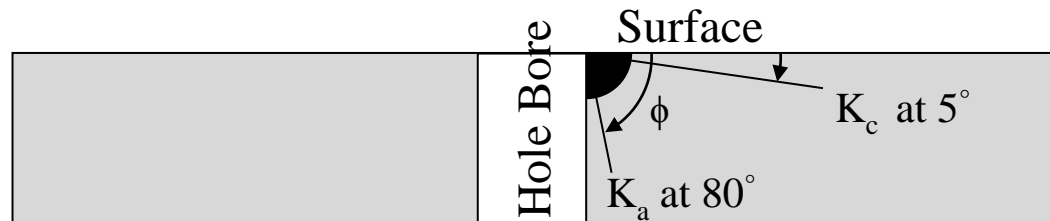
What is the impact on the solution when $t/D > 1$?



Approach

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- **Assumptions**
 - **Corner Crack Solutions Only**
 - **Crack Aspect Ratio $a/c = 1$**
 - **Tensile Loading Only**
 - **Angles**



- **Compare FEA Solution and Classic Solution**
 - **Beta Factors and Crack Growth Life**



Approach (con't)

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- Matrix of Parameters Analyzed
- Selection Made Based on Actual FCLs

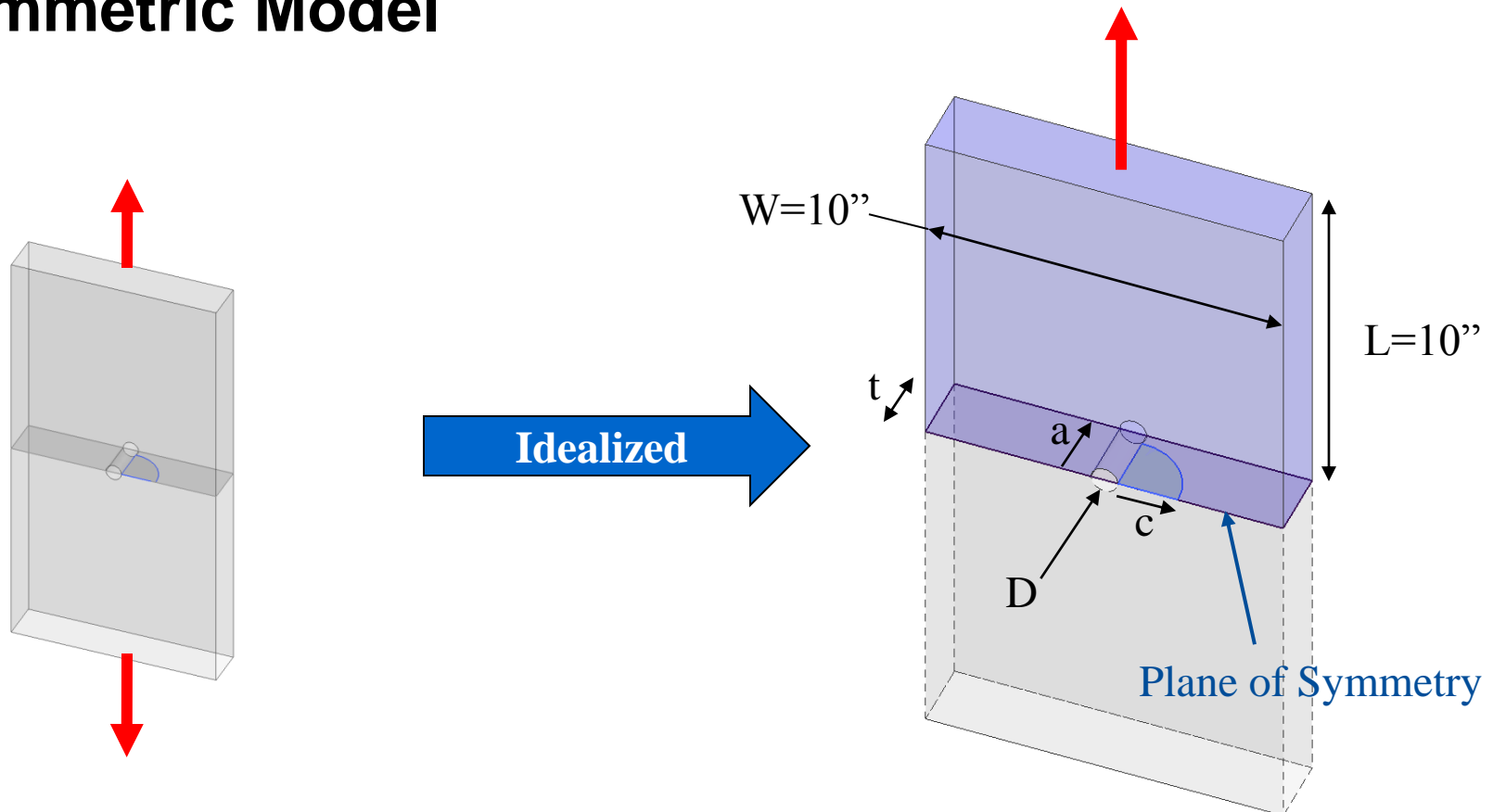
Case	Thickness (t, [in])	Diameter (D, [in])	t/D	Crack Length (a, c [in])
1	0.580	0.190	3.05	0.05 to 0.550
2	0.600	0.250	2.40	0.005 to 0.570
3	0.520	0.250	2.08	0.005 to 0.500
4	0.498	0.276	1.80	0.005 to 0.473
5	0.596	0.375	1.59	0.005 to 0.575
6	0.428	0.276	1.55	0.005 to 0.405
7	0.345	0.276	1.25	0.005 to 0.328
8	0.200	0.197	1.02	0.005 to 0.190
9	0.248	0.276	0.90	0.005 to 0.235



Finite Element Analysis

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- **Corner Crack at Hole in Plate, Tension Load**
- **Symmetric Model**

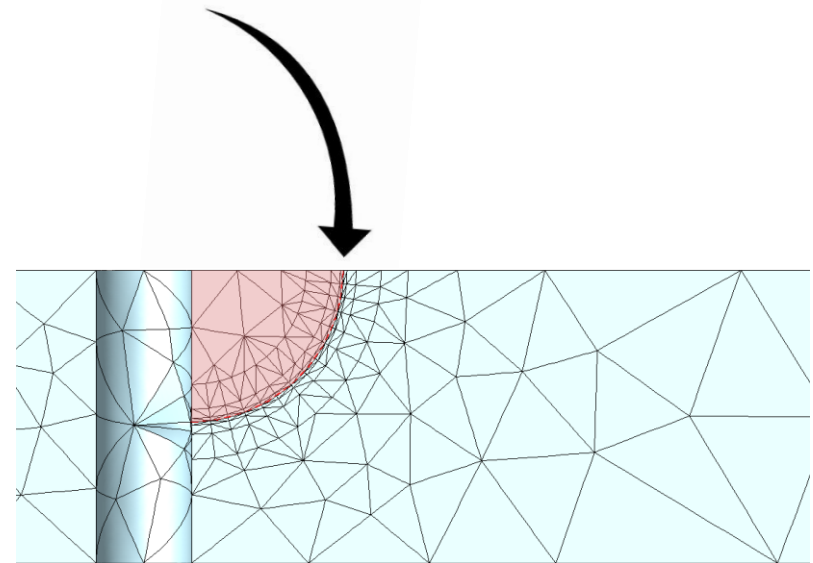
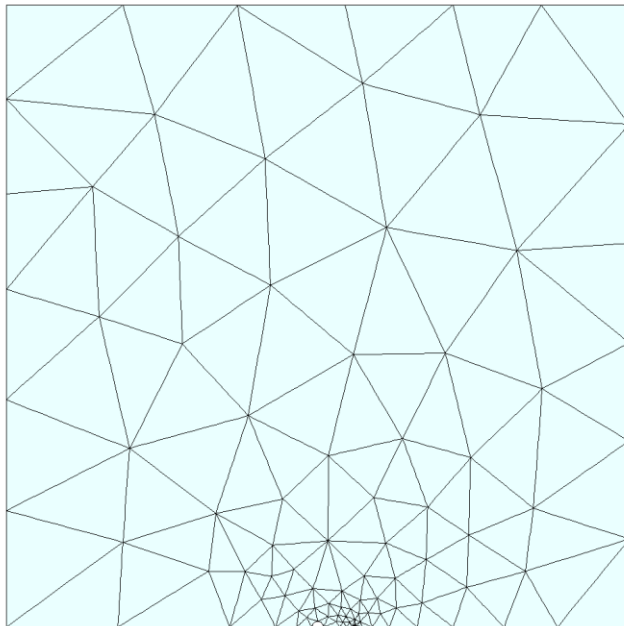




FEA (con't)

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- **StressCheck Software Used**
- **Mesh**
 - **~5000 Tetrahedral Elements per FEM**
 - **3 Layer Refinement at Crack Front**

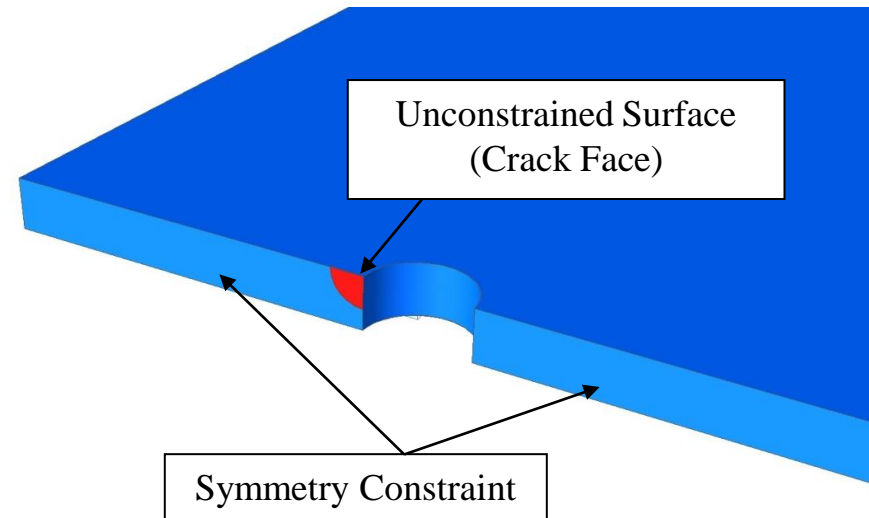
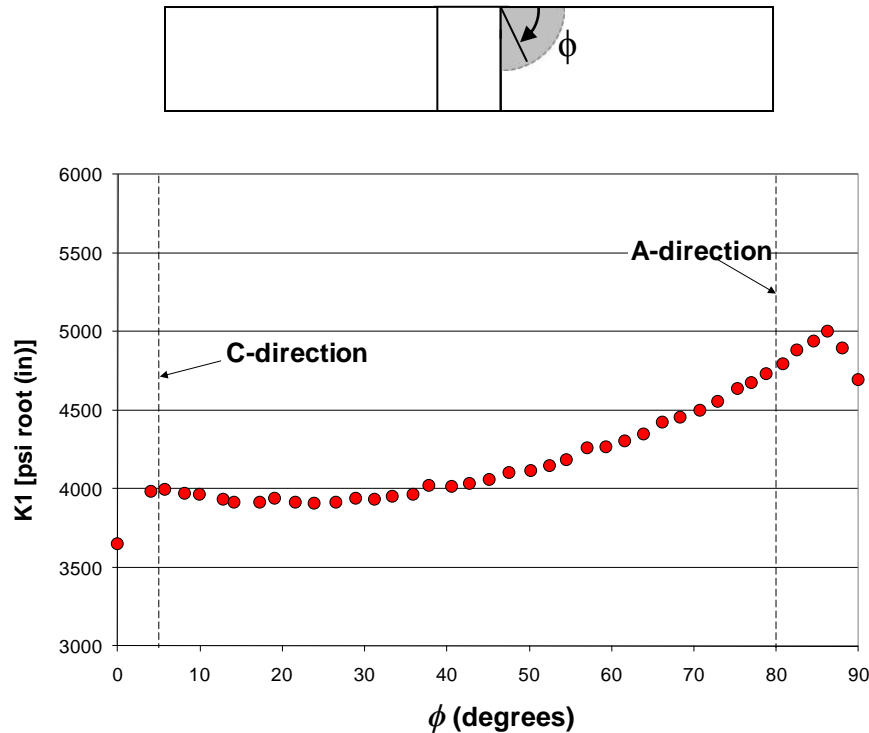




FEA (con't)

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- Boundary Conditions
- P-Level = 4, Convergence of <1%
- Result = Stress Intensity Factor





AFGROW “Solution”

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■ AFGROW Implementation Includes Many Factors

$$\beta_{AFGROW} = \beta_{N-R} F_w F_{offset}$$

- β_{N-R} = Beta Factor, Newman-Raju Solution
- F_w = Width Correction Factor
- F_{offset} = Hole Offset Correction Factor

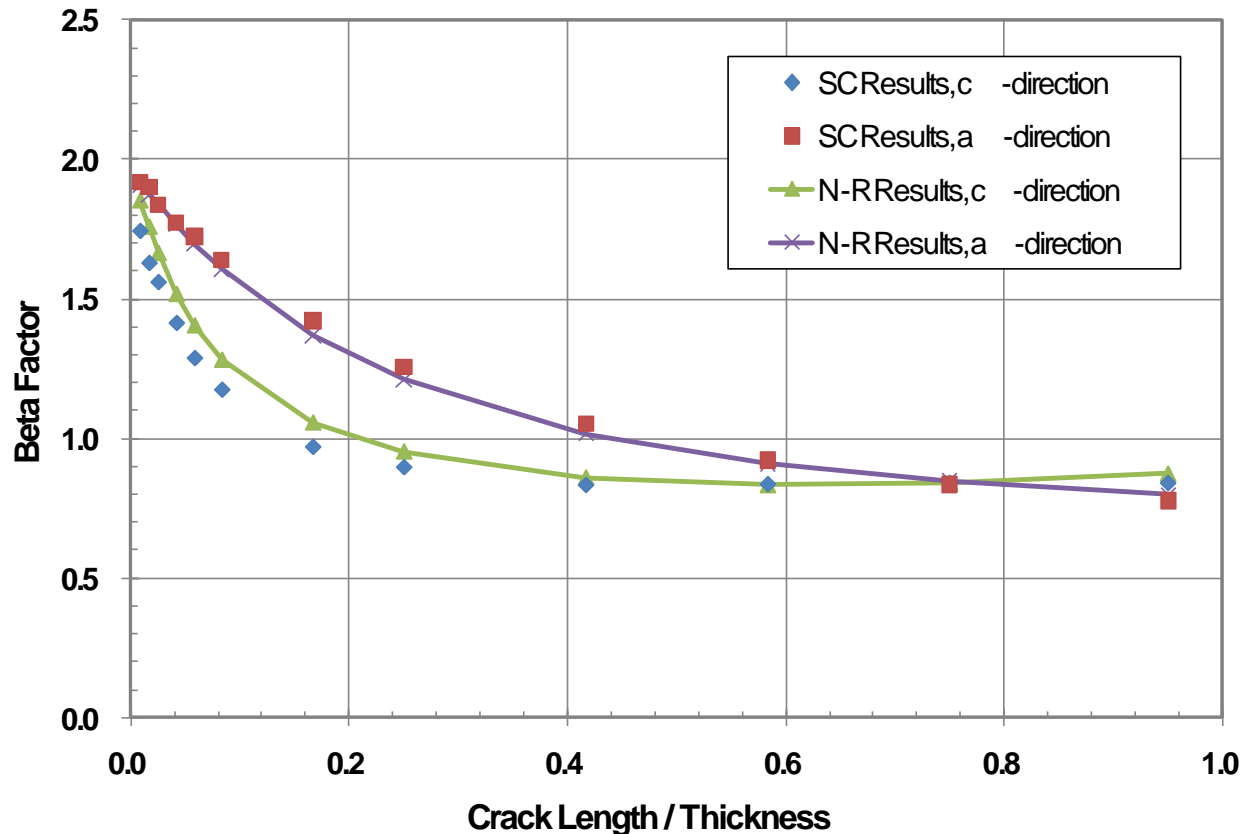


Centered Hole

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■ Typical Beta Factor Comparison

($t/D = 2.40$, $t = 0.600"$, $D = 0.250"$)



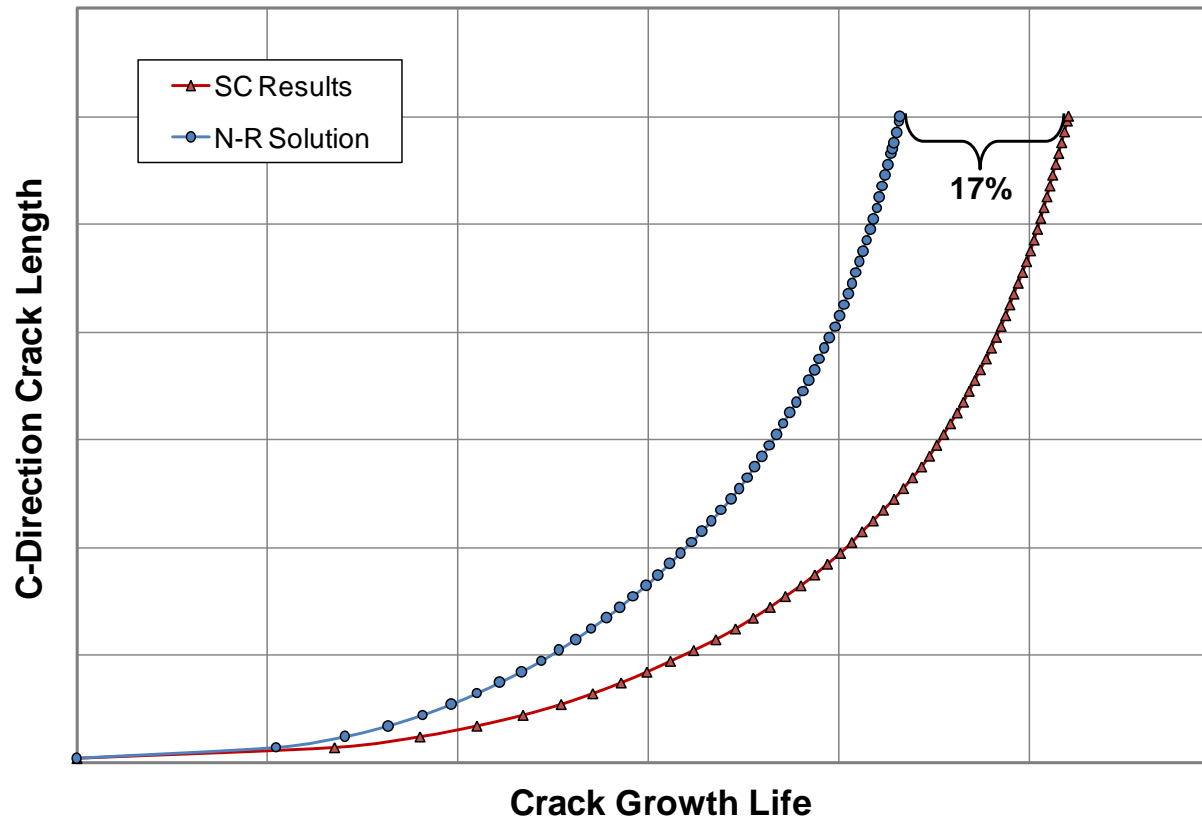


Centered Hole

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■ Typical Crack Growth Life Comparison

($t/D = 2.40$, $t = 0.600$ " , $D = 0.250$ ")





Relative Error

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- (+) Error = N-R is conservative
- (-) Error = N-R is unconservative

$$Error_{\beta} = \frac{\beta_{N-R} - \beta_{SC}}{\beta_{SC}} \times 100$$

$$Error_{Life} = \frac{Life_{SC} - Life_{N-R}}{Life_{SC}} \times 100$$

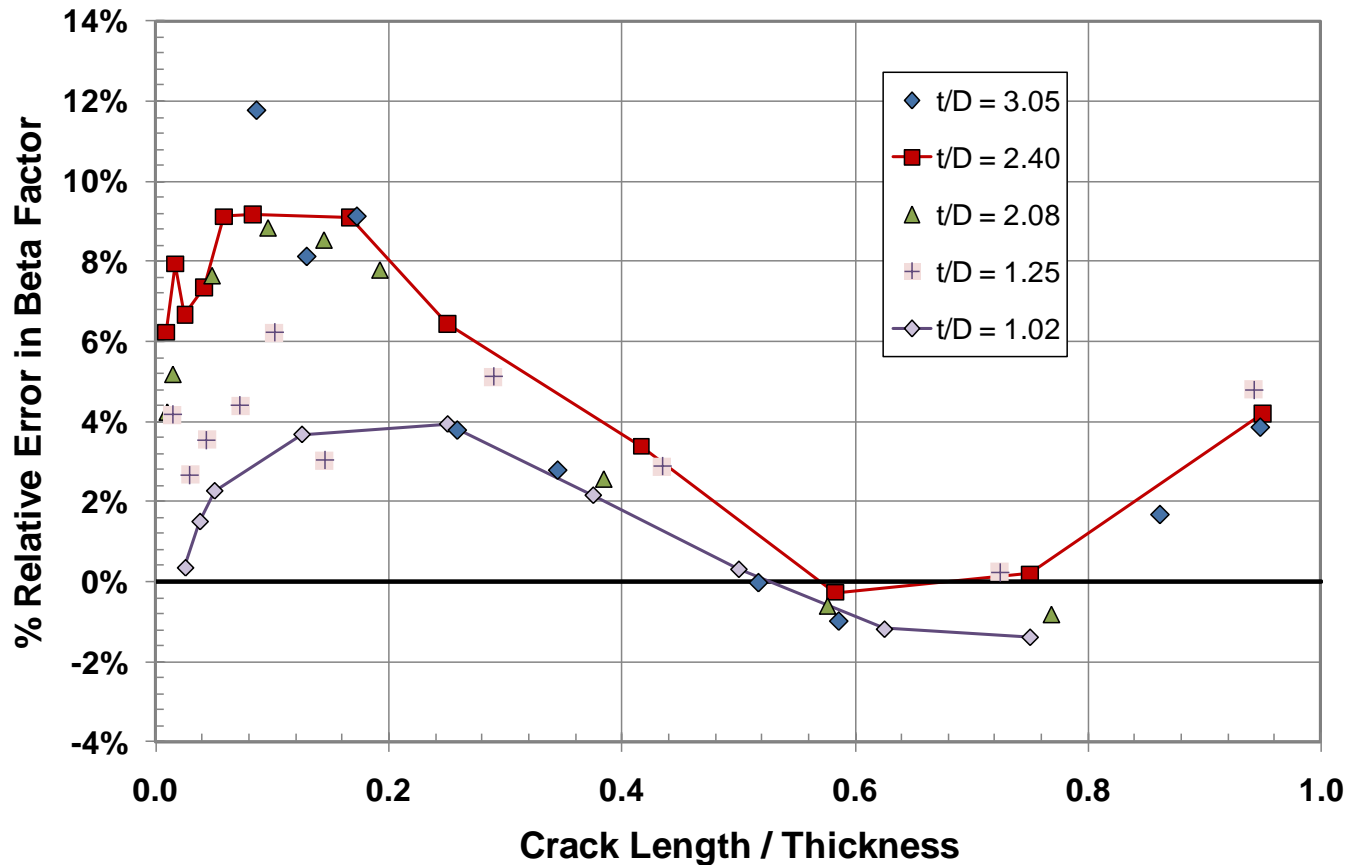


Centered Hole – Beta Factor



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% Relative Error in Beta Factor C-Direction

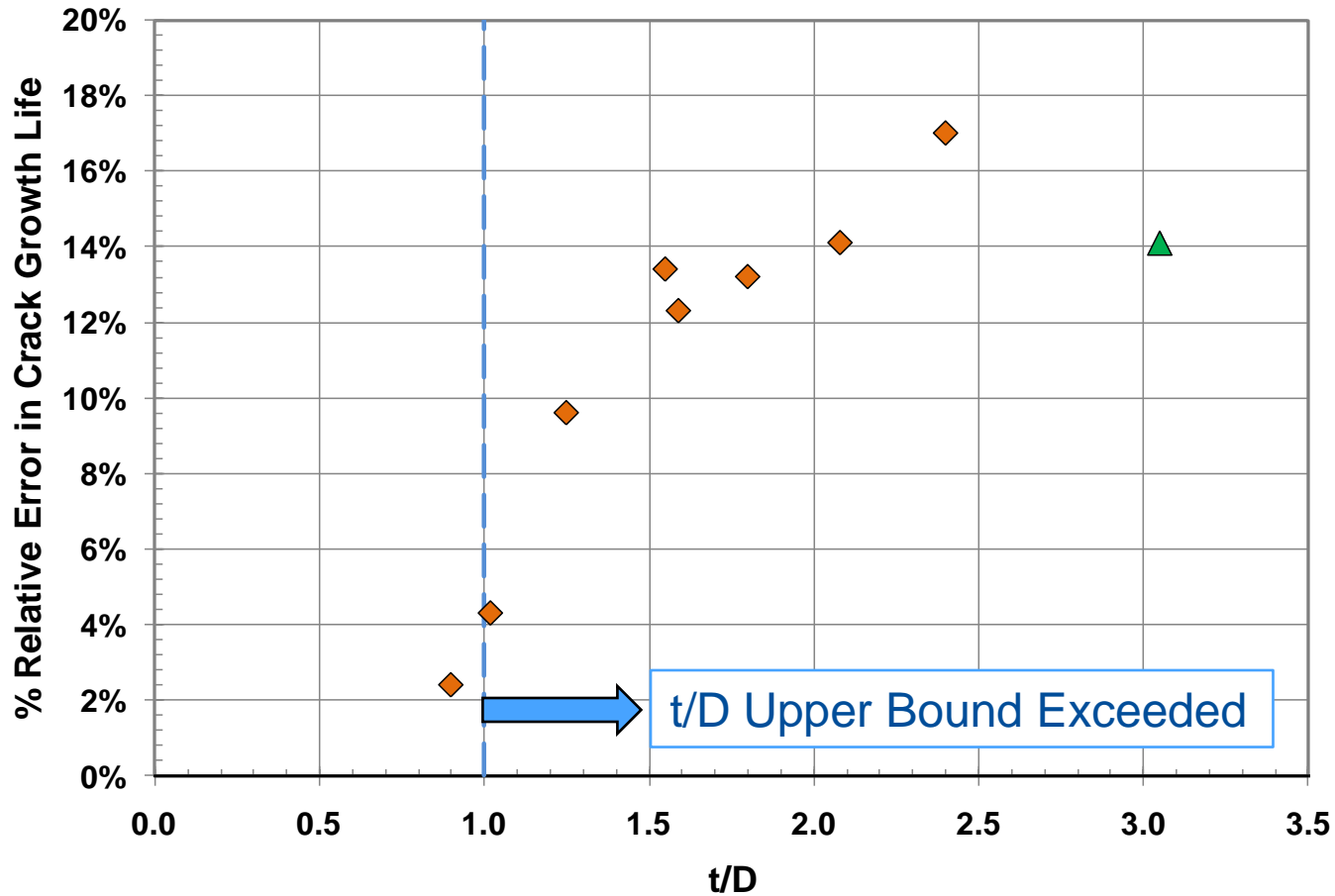




Centered Hole – Life

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% Relative Error in Crack Growth Life

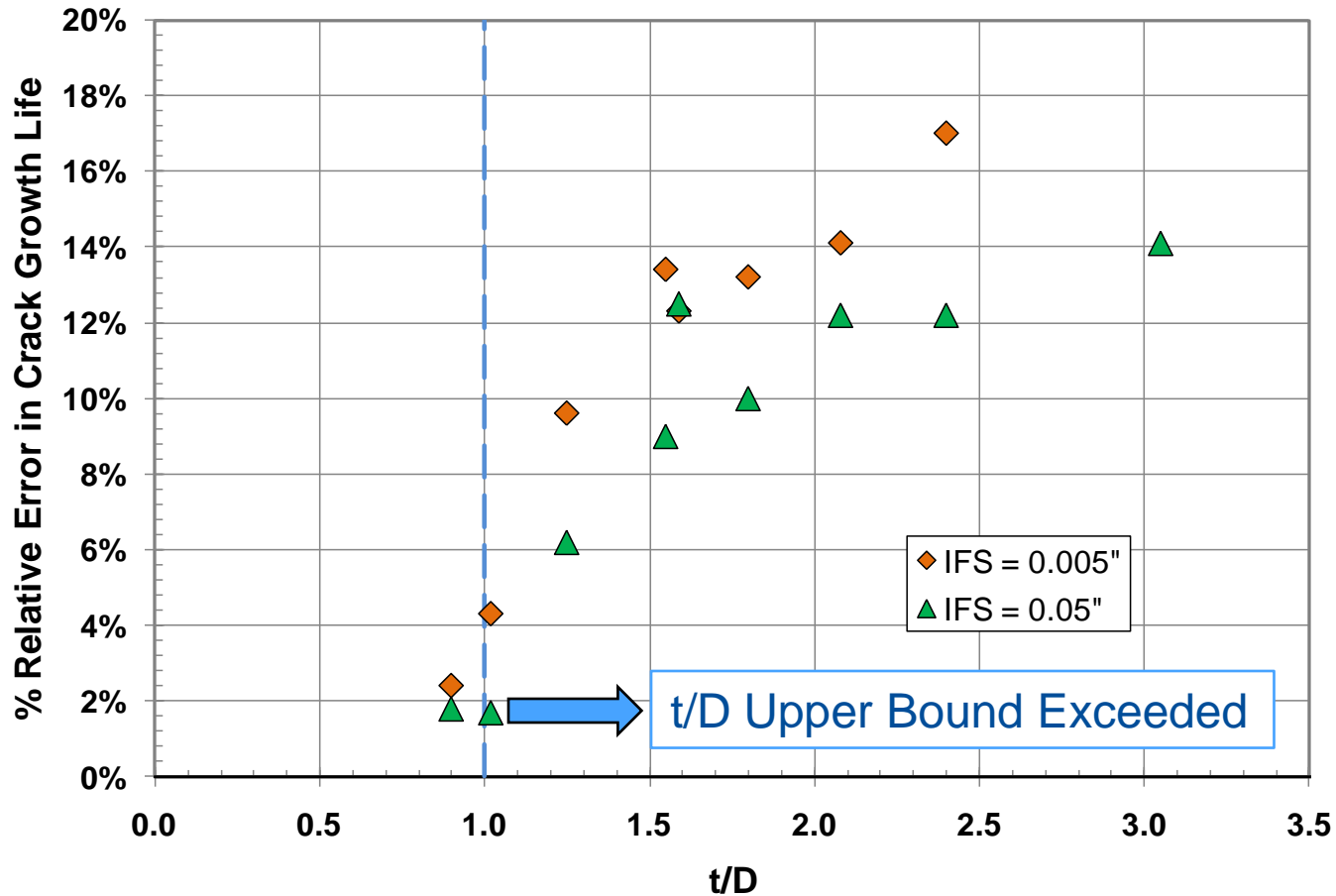




Centered Hole – Life

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% Relative Error in Crack Growth Life





Centered Hole

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- **Exceeding Newman-Raju t/D Upper Limit?**
 - **< 20% Error in Life**
 - **Conservative for Cases Investigated**
 - **Conclusion  Not Critical Issue**



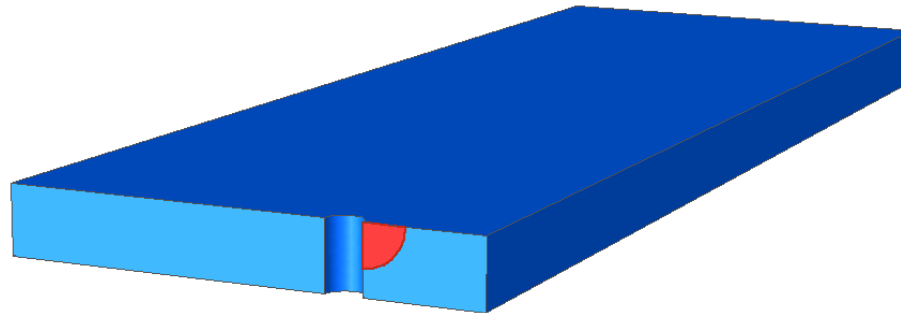
Offset Hole

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- More Direct Comparison to Actual Application
 - Involves all beta factor components

$$\beta_{AFGROW} = \beta_{N-R} F_w F_{offset}$$

- Used Model Width





Offset Hole

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■ Matrix of Parameters Analyzed

Case	Thickness (t, [in])	Diameter (D, [in])	t/D	Offset (B, [in])	Crack Length (a, c [in])
1	0.580	0.190	3.05	N/A	0.050 to 0.550
2	0.600	0.250	2.40	0.60	0.005 to 0.570
3	0.520	0.250	2.08	1.70	0.005 to 0.500
4	0.498	0.276	1.80	0.92	0.005 to 0.473
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9	0.248	0.276	0.90	1.58	0.005 to 0.235
10	0.143	0.276	0.52	0.97	0.005 to 0.135

Added



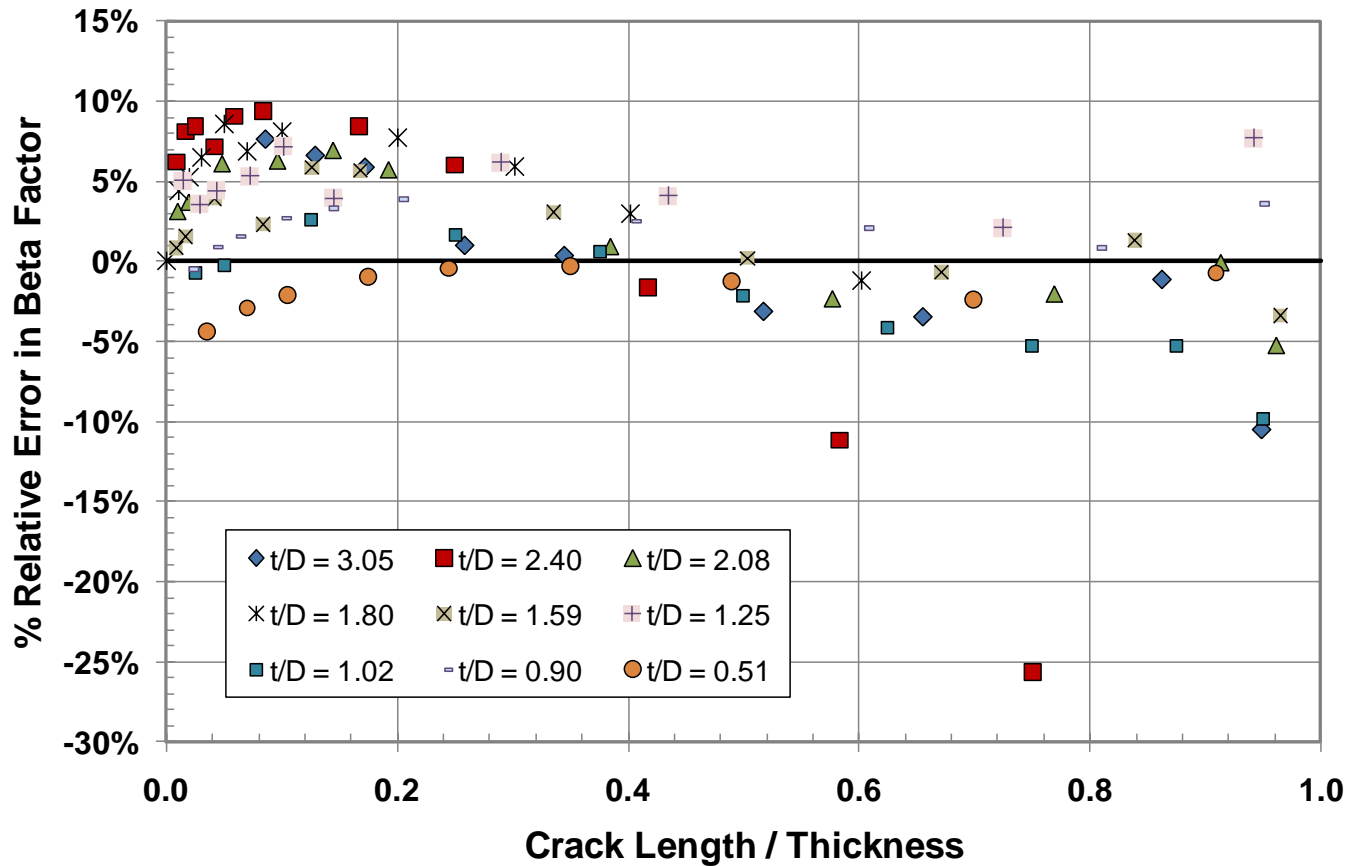


Offset Hole – Beta Factor



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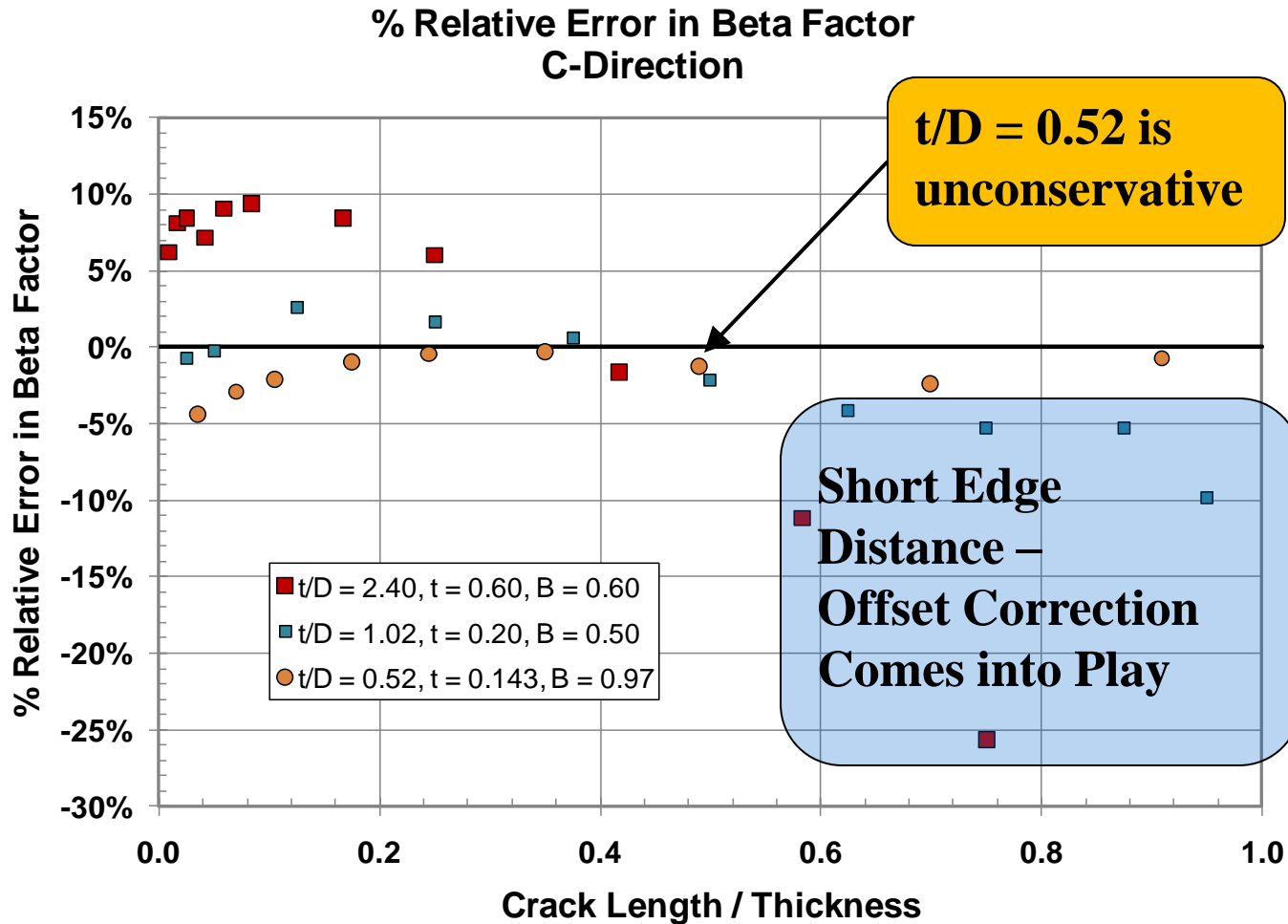
% Relative Error in Beta Factor C-Direction





Offset Hole – Beta Factor

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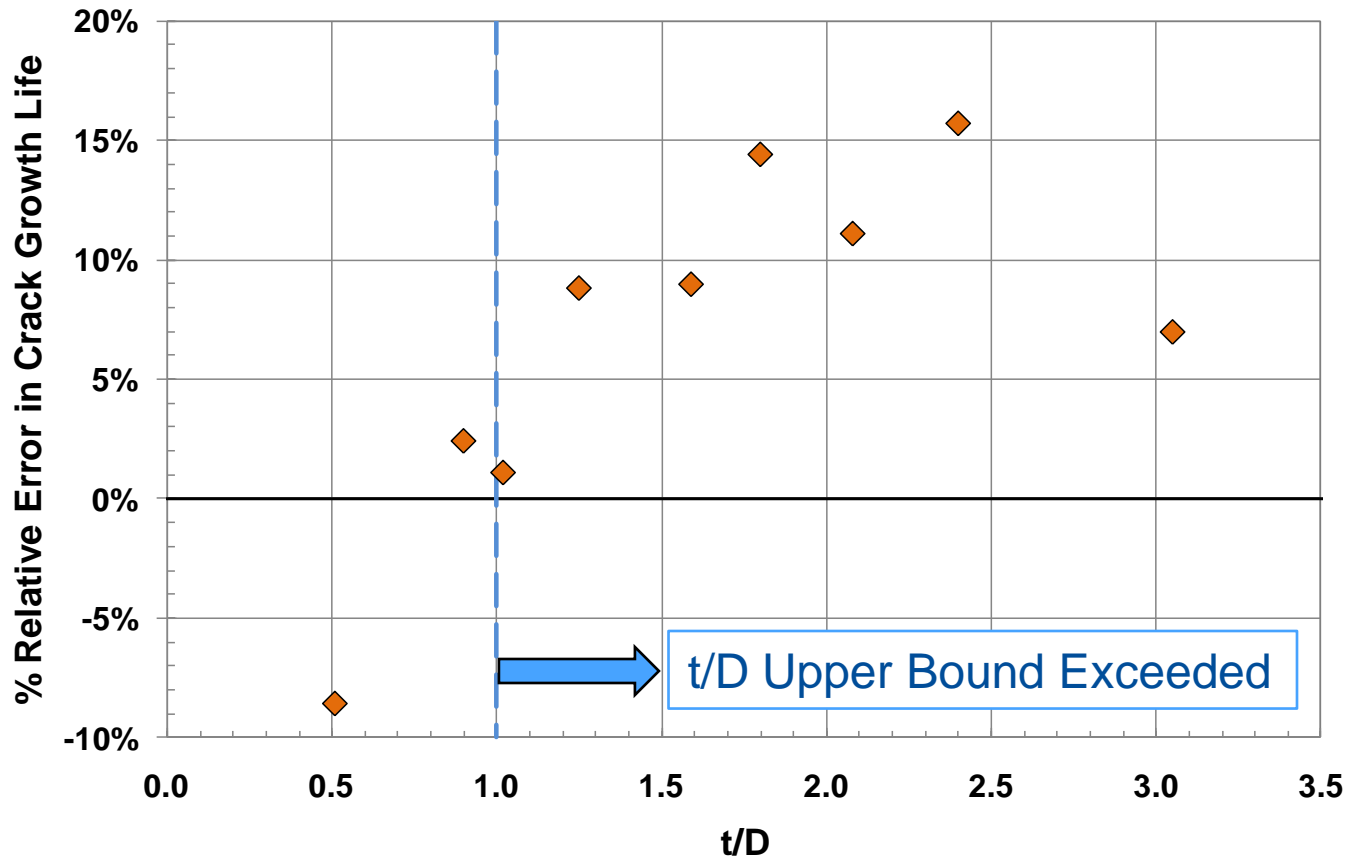




Offset Hole – Life

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**% Relative Error in Crack Growth Life
(Corner Crack Growth Only)**





Conclusions

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- **Exceeding Newman-Raju t/D Upper Limit?**
 - **Conclusion**  **Not Critical Issue for A-10, T-38**

- **Further Work**
 - **AFGROW Advanced Solutions**
 - *a/t* lower bound was exceeded for most cases selected
 - Angles will be slightly different
 - **Thru-Crack Solution**
 - Exceeding any bounds for this solution?