AFGROW.NET

AFGROW Workshop 2026

Progress in AFGROW FEA Handbook Development

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LexTech

Simmetrix Inc. Enabling Simulation-Based Design

Current Available K_I Solutions

- **Closed-form, tabular or combination of both solution:** Uniform stress distribution, idealized model geometry, covers wide rage of geometry variations (r/t for example).
- **Weight function solution, hybrid weight function with the tabular stress distribution data or beta correction applied on existing closed-form or tabular solution:** Non-uniform stress distribution, idealized model geometry, covers wide rage of geometry variations.
- **User-defined solution:** Non-uniform stress distribution, real model geometry, limited to only one set geometric properties and one or two interconnected crack grows direction.
- **Using on demand FEA tool to calculate K_I:** Non-uniform stress distribution, real model geometry, multiple crack and crack directions

AFGROW has the capability to add additional K solutions by using the COM plug-in.

Plug-ins allow user-defined custom solutions

- Proprietary
- Closed-Form
- Tabular / Interpolative / Extrapolative
- External-K_I

AFGROW FEA Plug-in Capability Overview

- AFGROW FEA based K solver plug-in capability is a mature and proven technology that was successfully applied to solve the complex fracture mechanics problems.
- The solutions that are based on AFGROW FEA based K solver plug-in capability are accepted and used by Air Force, Air Force contractors and the industry. The popularity of these solutions is growing every year.
- Only organizations that can have access the modern FEA packages can benefit from this AFGROW functionality.
- The development of the interface between plugin and FEA package require significant investment of time and manpower as well as FEA analyst expertise.
- The damage tolerance analysis community stands to gain significantly from the Handbook of FEA crack growth solutions in AFGROW—designed to be accurate, efficient, and user-friendly

Advantages of Having Handbook of FEA Crack Growth Solutions

- Use FEA to calculate K on demand
- Eliminate some modeling error sources due to curve fitting, interpolation and analytical formulations
- Improve solution accuracy by using multiple points for the crack front definition
- Reduce time-consuming new model development or additions to existing models
- Geometry agnostic
- Simple to use than currently available solutions that are based on AFGROW FEA K solver plug-in capability. The Handbook models work in a similar fashion as the closed-form models. Based on user's input (dimensions, loading conditions) the application will create the model and perform the simulations with no additional input from the user.

AFGROW FEA Handbook

Joint effort of Simmetrix and LexTech with an objective to develop a Handbook of FEA models for a relatively simple structural geometries and load conditions that are to complex or too time consuming to implement otherwise.

Goals

- Integrate AFGROW with the help of plug-in with SimModeler™ software tool.
- Demonstrate that it is possible to create a crack growth analysis tool that will benefit from using on demand FE analysis without require the user to be an FEA expert
- Ensure that this tool could be accessible (affordable) to a wide range of AFGROW users

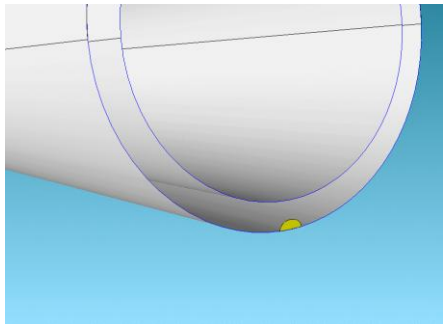
SimModeler™ is a pre-processing tool that streamlines the generation of analysis input decks for a variety of analysis packages starting from geometric data. It can be easily customized and extended to produce run-ready input for additional solvers.

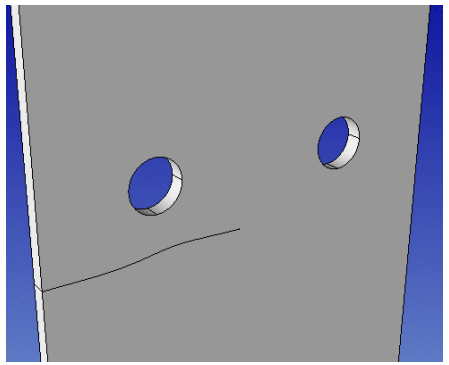
AFGROW will direct SimModeler™ via plug-in to generate the mesh of the model geometry and re-mesh the model as crack grows. The input from it can be used as an input to multiple FEA solvers such as ANSYS, Abaqus and CalculiX.

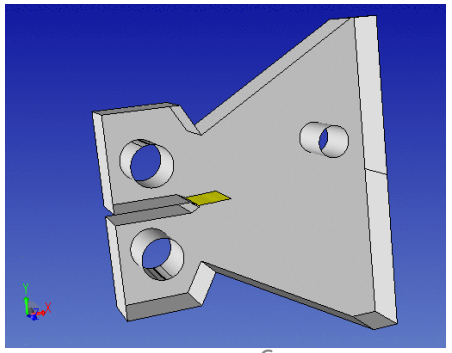
SimModeler ™

The Mesh/Pre/Post Engine behind AFGROW's Parametric multi-DoF Modeling Capability

New AFGROW's Handbook capability takes advantage of the fatigue crack growth modeling and general CAE modeling functionality developed over the past 20 years at Simmetrix Inc.







Geometry

- Direct interface to CAD geometry
- Demonstrated component level functionality for crack insertion and propagation
- Geometry-mesh associativity maintained for crack growth solutions

Meshing

- Unstructured meshing and automatic compatibility with structured meshes
- Structured meshing process: boundary layer, thin-section, extrusion
- Automatic surface and volumetric meshing
- Meshing capabilities demonstrated for: single and multiple crack propagation simulation, crack at material interface, generic surface for crack definition in a solid model

Interface

- Plugins for different structural solvers: Abaqus, Ansys, calculiX
- Customers can write plugins to extend SimModeler to support specific modeling workflows

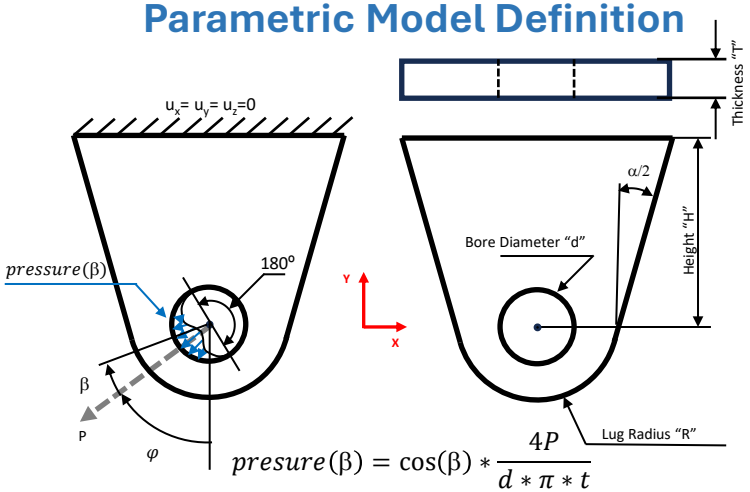
For more information, please send email to: loghin@simmetrix.com or info@simmetrix.com

AFGROW FEA Handbook: How Does it Work

- Building of 3D geometry w/ and w/o crack using a parametric definition
- Model based identification of crack location and orientation
- Control of number of DoF (points) in crack front definition
- 3D model generation for each crack growth increment
- Input deck generation for model processing
- Solver execution
- FEM solution post-processing
- FE solution-based KI calculation
- Linkage with AFGROW functionality
- Crack front increment definition
- Comes with its own FEA mesher and solver and does not need a separate FEA software package
- Could be configured to use separate FEA tools such as Ansys or Abaqus

Example of Model Implementation: Corner Crack in a Tapered Lug under Off-axis Tensile Loading

Parametric Model Definition



$$presure(\beta) = \cos(\beta) * \frac{4P}{d * \pi * t}$$

β = [-π/2, π/2] relative to the direction of the equivalent pin-bore concentrated load "P"

Input

- Lug geometry
  - Lug Diameter
  - Hole Diameter
  - Lug Thickness
  - Lug Height
  - Lug taper angle
  - Crack length C direction
  - Crack Length A direction
- Loading angle

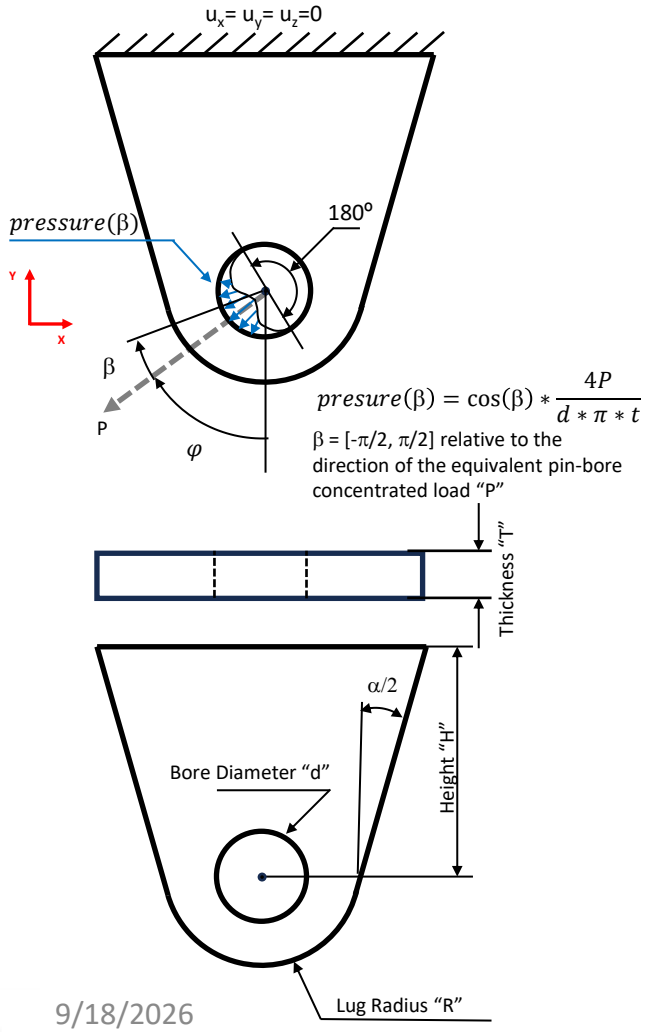
Load modeled using cosine pressure distribution that is a more realistic representation of the pin loaded lug*. The pin load can be added, if necessary, by modifying FEA model.

*

AFRL-VA-WP-TR-2006-3043
CRACK GROWTH AND STRESS INTENSITY PREDICTION TECHNIQUES
Delivery Order 0004: Implementing Models and Libraries
Craig Brooks, Kyle Honeycutt, and Scott Prost Domasky
Analytical Processes/Engineered Solutions (AP/ES), Inc.

Automatic Model Creation

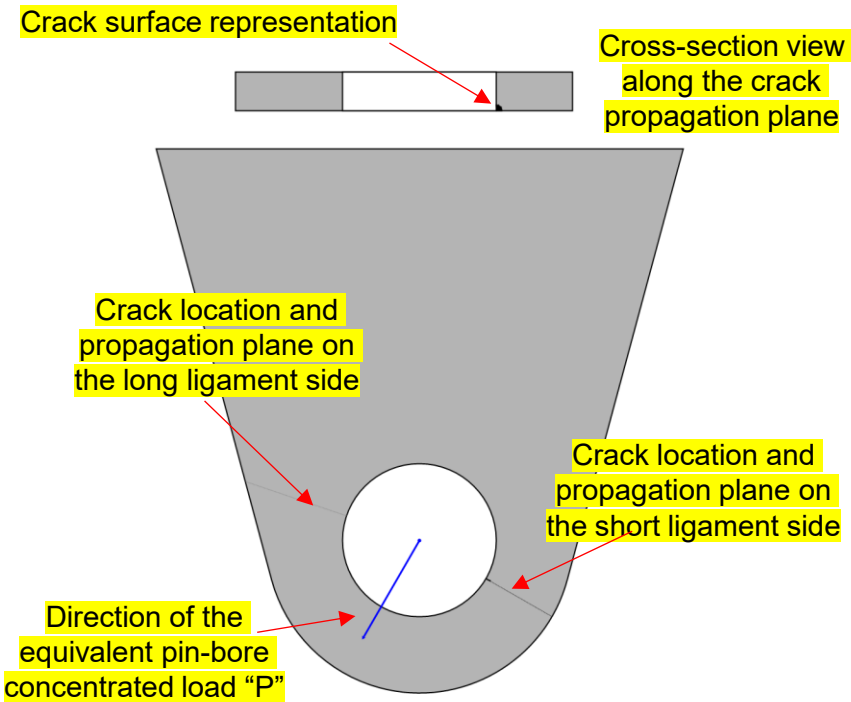
Parametric Model Definition



User's access to model definition

Parameters		
(Name)		Off-Axis Loaded Lug
Lug Diameter		0.160000
Thickness		0.020000
Lug Hight		0.204000
Hole Diameter		0.080000
Taper Angle	◆	**30.000000**
Crack Length (C Dir...	◆	**0.003000**
Crack Length (A Dir...	◆	**0.003000**
Loading Angle	◆	**30.000000**
Calculate Crack Dir...		Enabled ...
Long Ligament Sid...		18.632690
Short Ligament Sid...		30.103925
Crack Direction		Short Ligament Side

Graphical feedback for the end-user



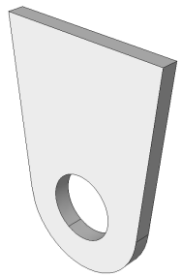
Example of New Model Implementation: Corner Crack in a Tapered Lug under Off-axis Tensile Loading

Pre crack growth analysis

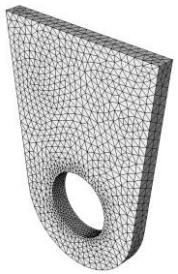
Automatic crack growth analysis

Crack locations and propagation planes (short/long ligament sides) are identified automatically from a 3D FEA solution. Any error associated with an analytical formulation between crack plane and loading direction is eliminated.

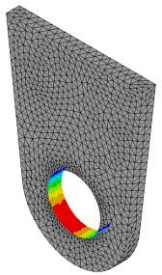
CAD Model



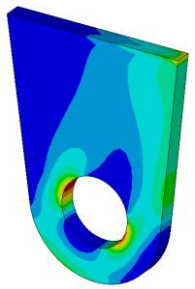
Mesh

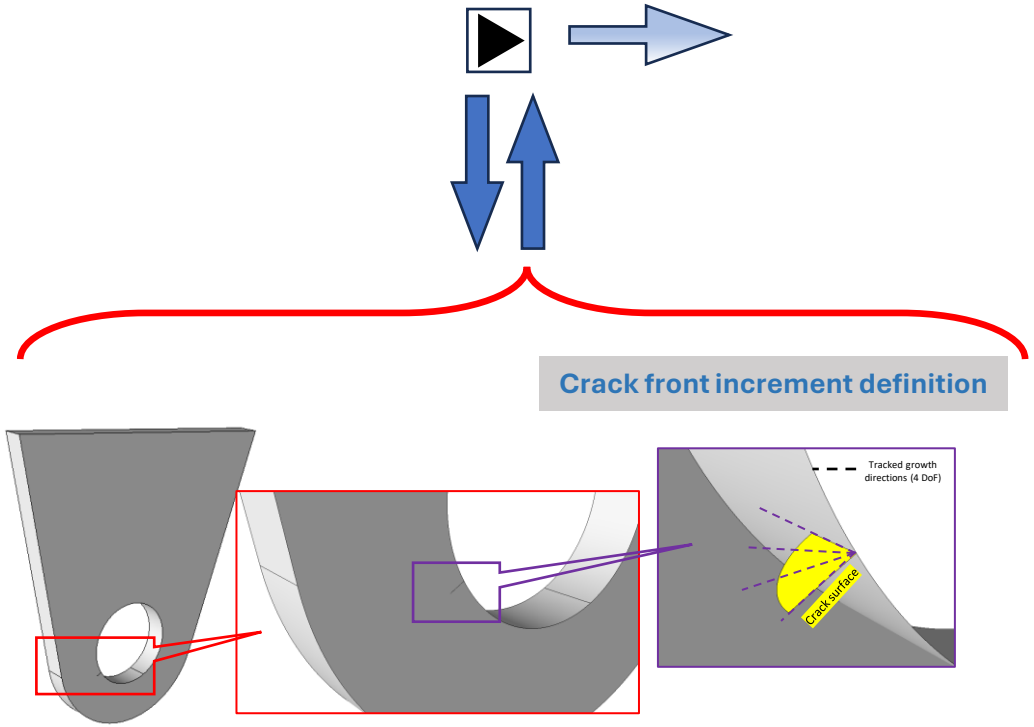


Load



FEM solution





Case Studies and Solution Verification/Validation Goals

- The goal is not only to verify Tapered Lug Model but to establish the process of adding the solution for any model to the Handbook
- Use Ansys and Stress Check at every step as verification tool for CalculiX, verify AFGROW plugin crack growth life predictions using SimModeler with the understand SimModeler applicability
- Verify the KI solution from new 3D FEA-based model implementation against the legacy 2d lug solution in AFGROW
- Use two solvers (calculiX, Ansys) and demonstrate that the remaining useful life solution (using the multi-DoF 3DFEA) does not change. (AFGROW Plugin currently uses calculiX solver but, with a minimal update, Ansys or Abaqus solvers can be added as different processors)
- Start verification with the straight lug under 90 degrees loading and then transition to more complicated models
- Demonstrate solution convergence with an increased number of points on the crack front (DoFs)
- Verify corner crack transition to oblique crack and oblique crack propagation
- Find optimal number of points on the crack front
- Find optimal number of elements on the hole bore when calculation the crack location
- Find optimal number of elements on the hole bore for life prediction calculation
- Validate Tapered Lug Model against real life tests

Problem Setup

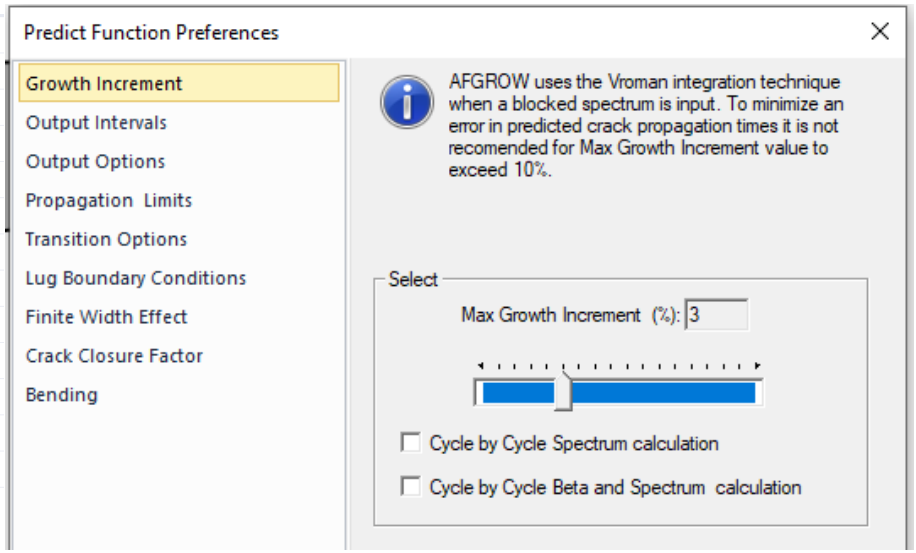
AFGROW.NET

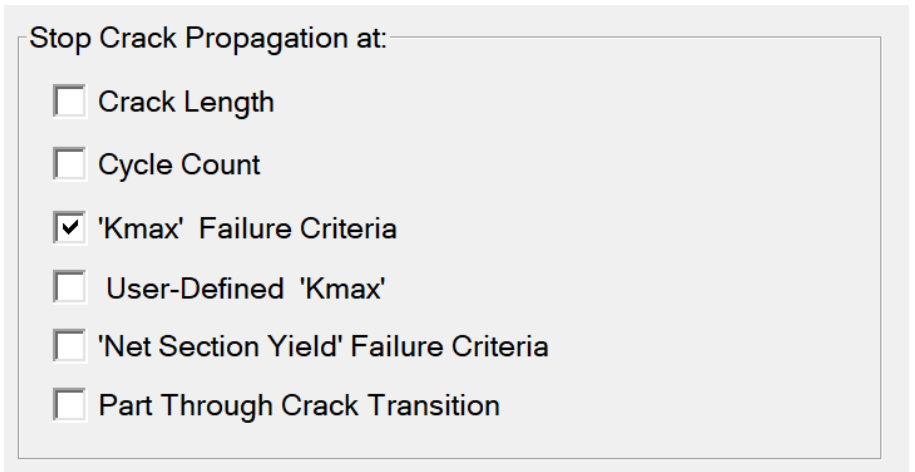
Model Properties

(Name)	Lug Model
Lug Diameter	0.160000
Thickness	0.020000
Lug Hight	0.200000
Hole Diameter	0.080000
Taper Angle	30.000000
Crack Length (C Direction)	0.001000
Crack Length (A Direction)	0.001000
Loading Angle	30.000000
Calculate Crack Direction Angles	Enabled
Long Ligament Side Angle	0.000000
Short Ligament Side Angle	0.000000
Crack Direction	Short Ligament Side

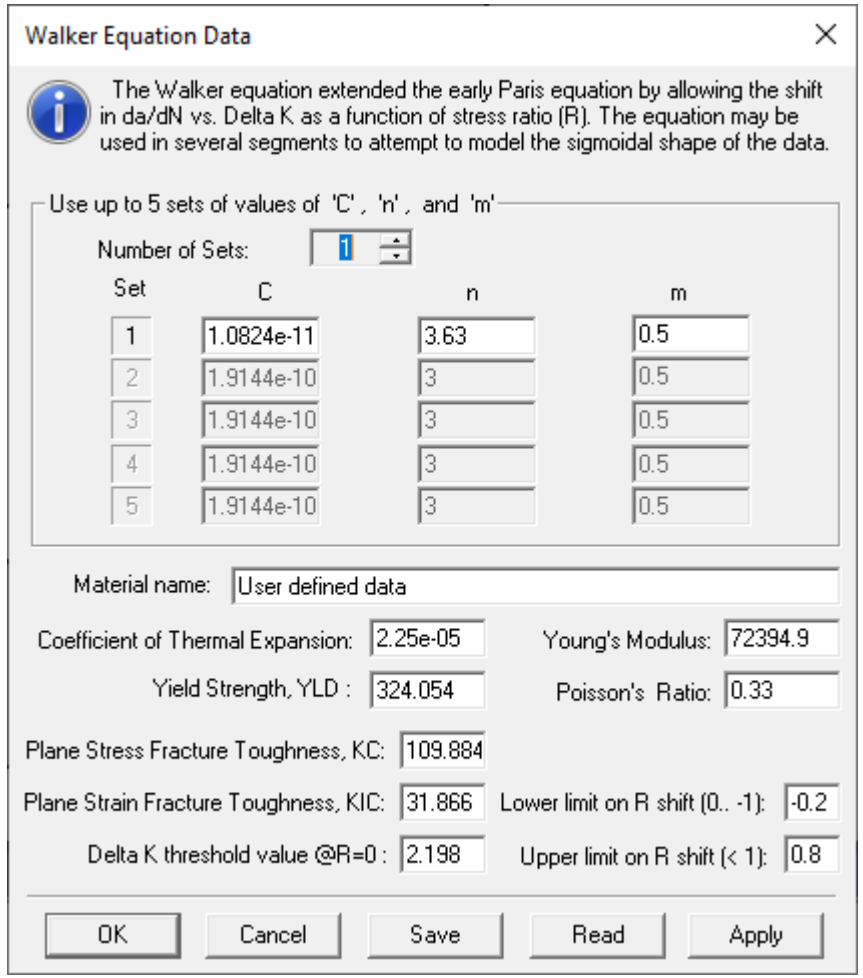
Constant Amplitude Load

Predict Preferences





Material (Paris Equation)



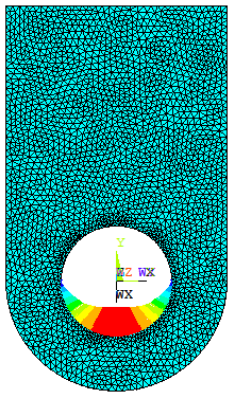
LexTech

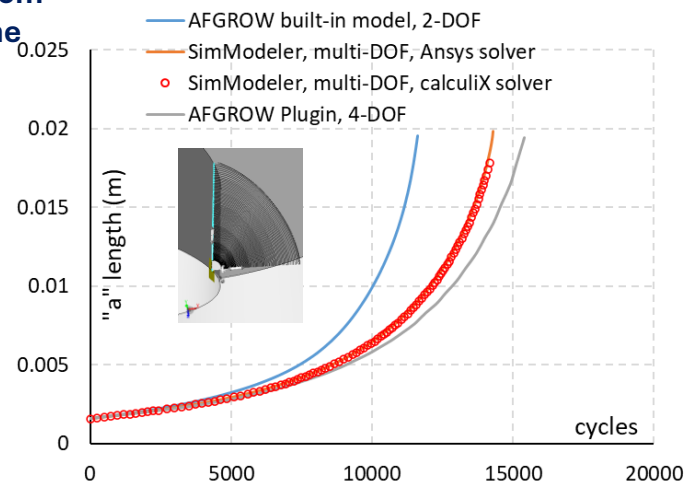
Simmetrix Inc. Enabling Simulation-Based Design

Straight Lug Verification –2023

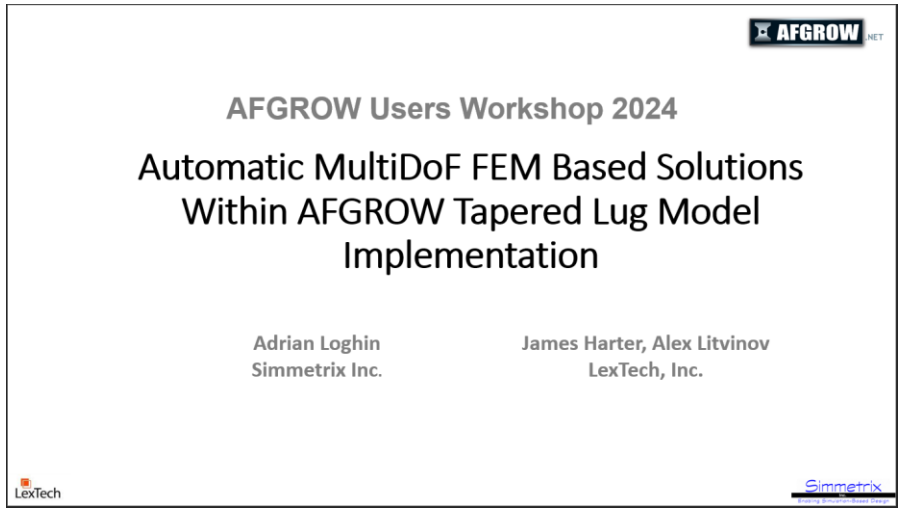
- New lug model development was introduced.
- Verification of K_I solution from new 3DFEA-based model implementation was made against the legacy 2-DoF solution
- Four baseline cases (one straight lug geometry, four different loading directions), were used to pass K_I and remaining useful life verification benchmarking for a 4-DoF AFGROW solution (multi-DoF 3DFEA/SimModeler used as a reference)
- All verification conclusions were made only for part-through cracks (up to transition to an oblique-edge crack shape)
- Both long-ligament and short-ligament crack locations were used for verification benchmarking purposes
- Solution convergence was demonstrated for the 4-DoF AFGROW solution as well as the multi-DoF 3DFEA/SimModeler solution
- Using two solvers (calculiX, Ansys), it was demonstrated that the remaining useful life solution (using the multi-DoF 3DFEA) does not change. AFGROW Plugin uses calculiX solver but, with a minimal update, Ansys or Abaqus solvers can be added as different processors.
- Automatic AFGROW modeling process using 3DFEA-based modeling process was reported (up to crack shape transition, from corner to edge)

Loading Axis at 0º from the symmetry plane

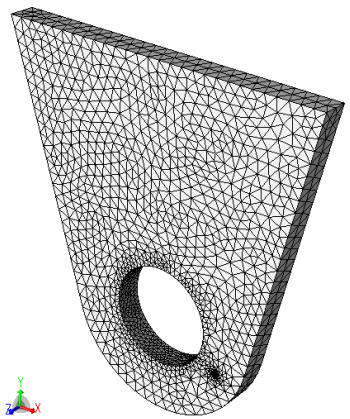


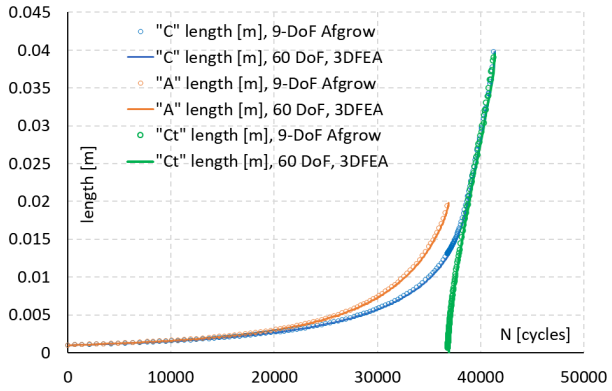


Tapered Lug Verification –2024



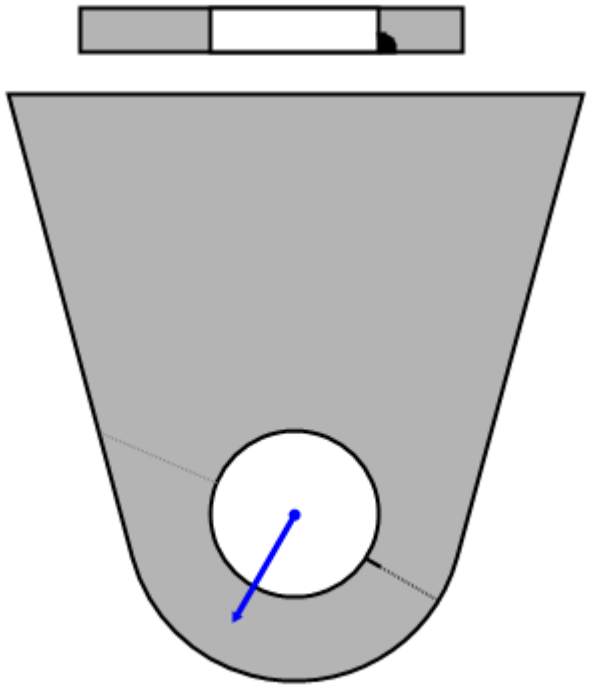
Loading Axis at 30º from the symmetry plane



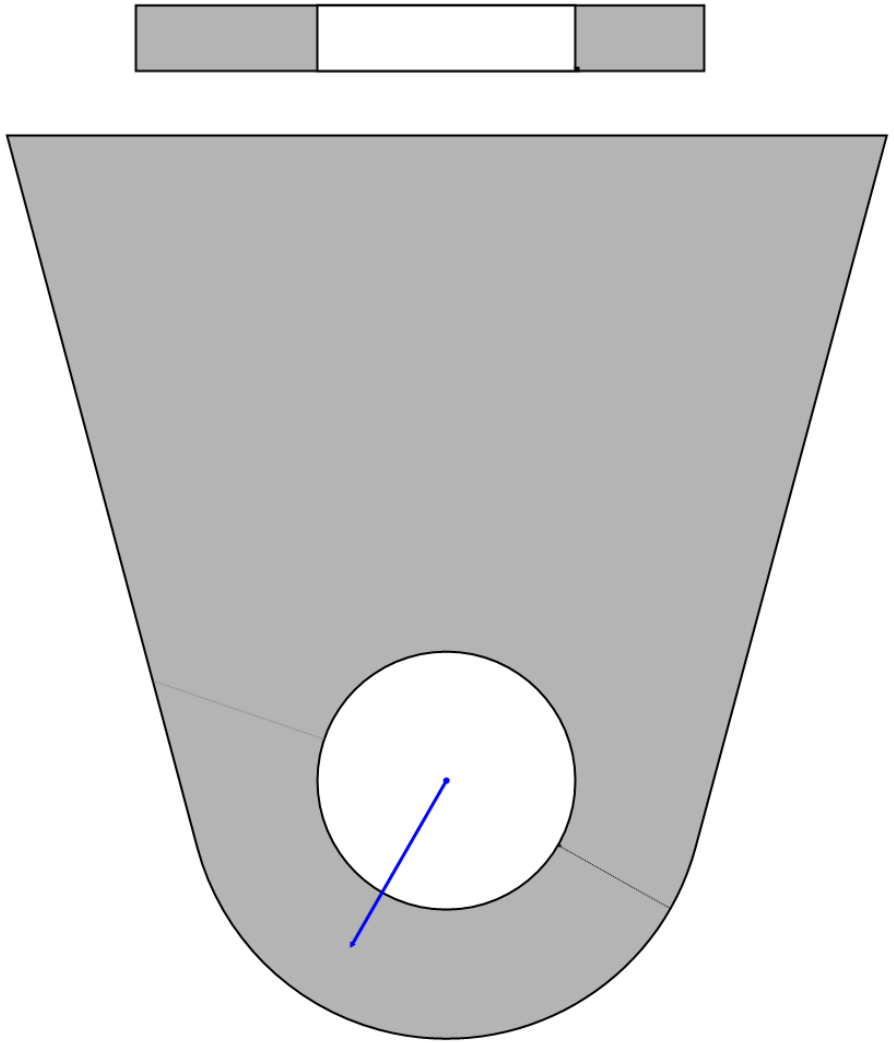


- Eight baseline cases (two different lug taper angles, four different loading directions), were used to pass K_I and remaining useful life verification benchmarking for a 9-DoF AFGROW solution (multi-DoF 3DFEA/SimModeler used as a reference)
- All verification conclusions were made for part-through and oblique-edge cracks. Both long-ligament and short-ligament crack locations were used for verification benchmarking purposes
- Solution convergence was demonstrated for the 9-DoF AFGROW solution as well as the multi-DoF 3DFEA/SimModeler solution
- The process of finding locations and propagation planes (short/long ligament sides) was developed and verified
- Using two solvers (calculiX, Ansys), it was demonstrated that the remaining useful life solution (using the multi-DoF 3DFEA) does not change. AFGROW Plugin uses calculiX solver but, with a minimal update, Ansys or Abaqus solvers can be added as different processors
- Demonstrated the solution convergence with an increased number of points on the crack front (DoFs).
- Optimal number of elements on the hole bore for calculation the crack location and life prediction calculation was identified.

Optimal number of Elements on the Hole Bore When Calculating the Crack Location



Solution Convergence Demonstration



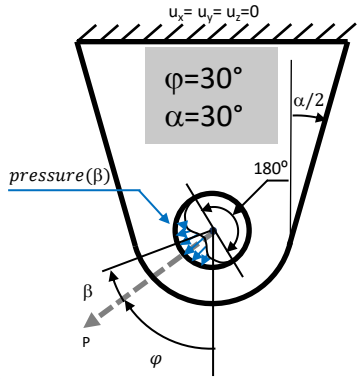
Parametric angles of the points on the crack front

4 points:
0 °, 30°, 60°, 90°.

6 points:
0°, 10°, 30°, 60°, 80°, 90°.

9 points:
0°, 10°, 20°, 30°, 45°, 60°, 70, 80 °, 90°

Convergence Study to Demonstrate Solution Convergence with an Increased Number of DoFs



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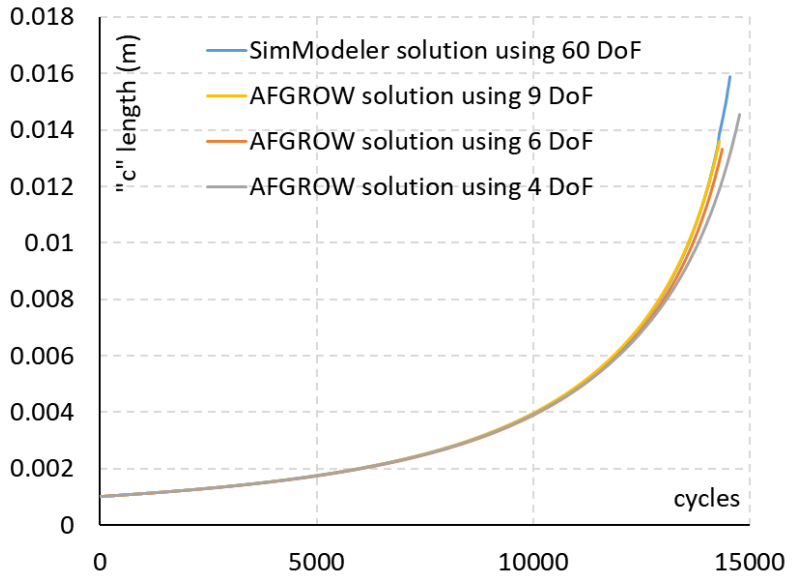
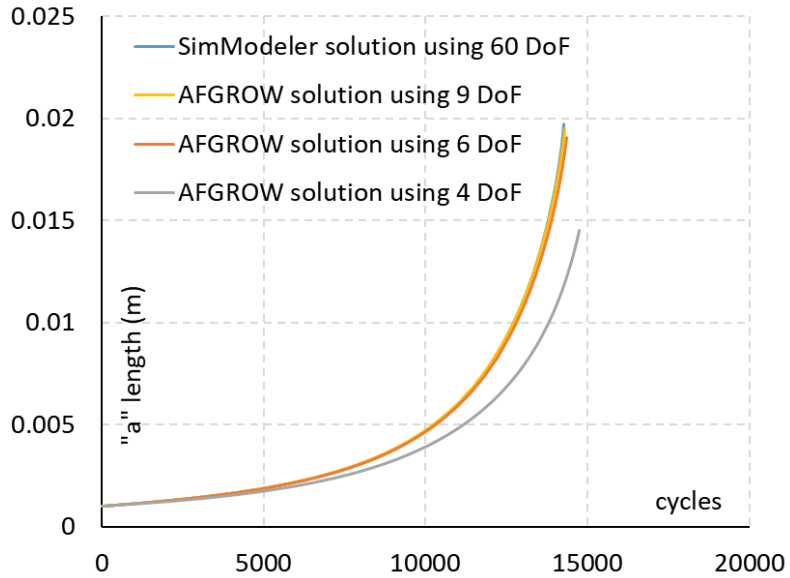
(Name)	Lug Model
Lug Diameter	0.160000
Thickness	0.020000
Lug Hight	0.200000
Hole Diameter	0.080000
Taper Angle	30.000000
Crack Length (C Direction)	0.001000
Crack Length (A Direction)	0.001000
Loading Angle	90.000000
Calculate Crack Direction Angles	Enabled
Long Ligament Side Angle	0.000000
Short Ligament Side Angle	0.000000
Crack Direction	Short Ligament Side

Length [m]
Angle [deg]

{C, n} = {1.0825e-11, 3.63}
Units: ΔK [MPa*m^0.5], da/dN [m/cycles]

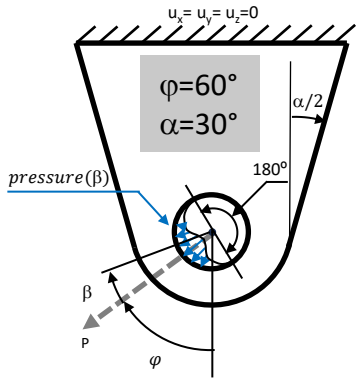




For the same mesh density, AFGROW's 9-DoF solution captures accurately the 60-DoF solution (SimModeler)

AFGROW Model Verification (φ=60°, α=30°)

Model input



Parameters	
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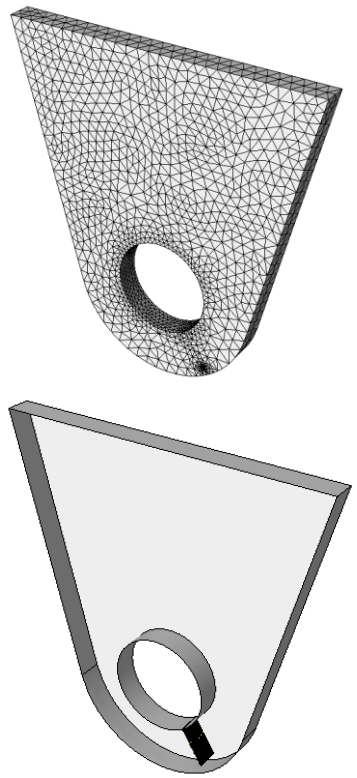
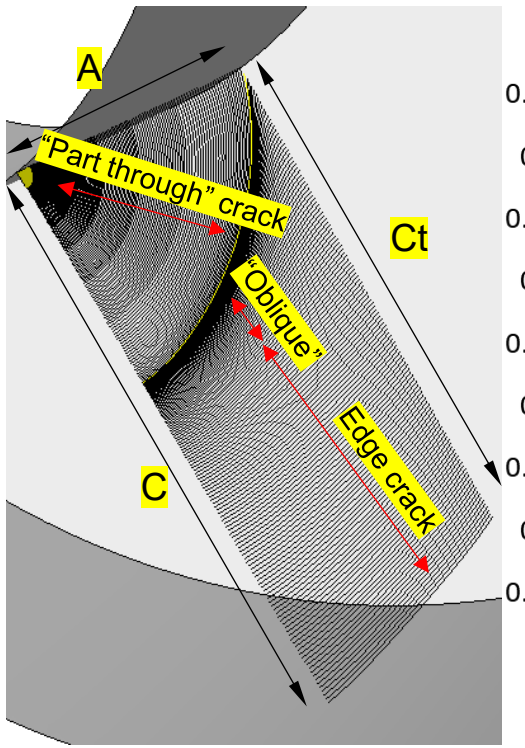
Lug Hight	0.200000
Hole Diameter	0.080000
Taper Angle	30.000000
Crack Length (C Direction)	0.001000
Crack Length (A Direction)	0.001000
Loading Angle	90.000000
Calculate Crack Direction Angles	Enabled
Long Ligament Side Angle	0.000000
Short Ligament Side Angle	0.000000
Crack Direction	Short Ligament Side

Length [m]
Angle [deg]

{C, n} = {1.0825e-11, 3.63}
Units: ΔK [MPa*m^0.5], da/dN [m/cycles]

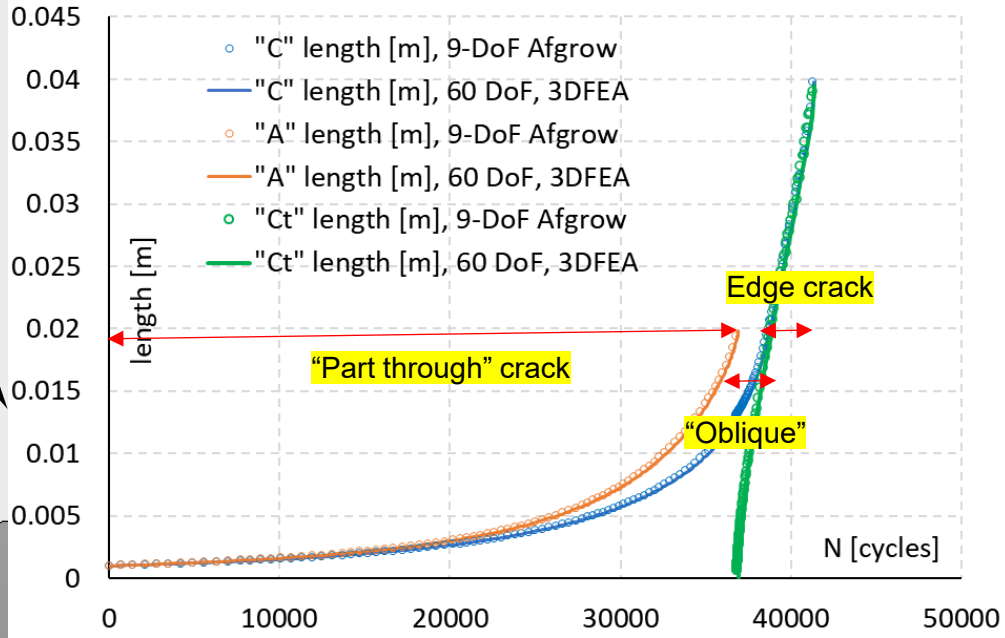
3D FEA Solution used as a reference





Runtime/increment = 15 sec

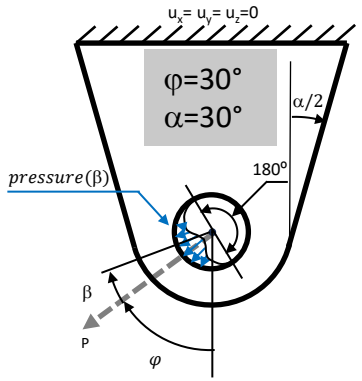
9-DoF AFGROW solution vs. 60-DoF 3DFEA Solution verification



For the same mesh density, AFGROW's 9-DoF solution captures accurately the 60-DoF solution (SimModeler)

AFGROW Model Verification (φ=30°, α=30°)

Model input



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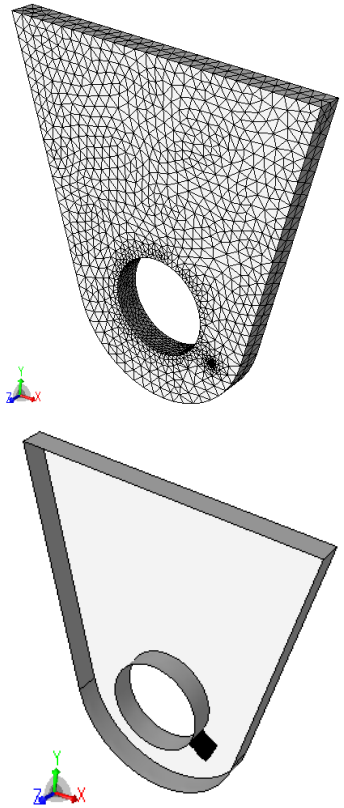
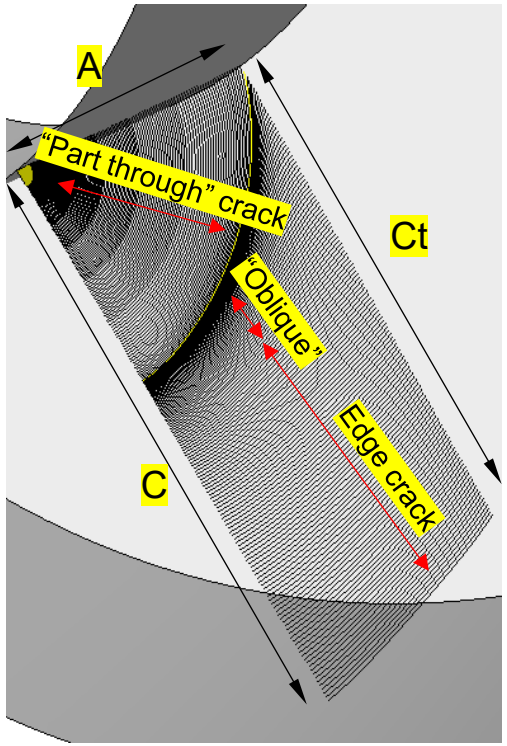
Crack Length (A Direction)	0.001000
Loading Angle	90.000000
Calculate Crack Direction Angles	Enabled
Long Ligament Side Angle	0.000000
Short Ligament Side Angle	0.000000
Crack Direction	Short Ligament Side

Length [m]
Angle [deg]

{C, n} = {1.0825e-11, 3.63}
Units: ΔK [MPa*m^0.5], da/dN [m/cycles]

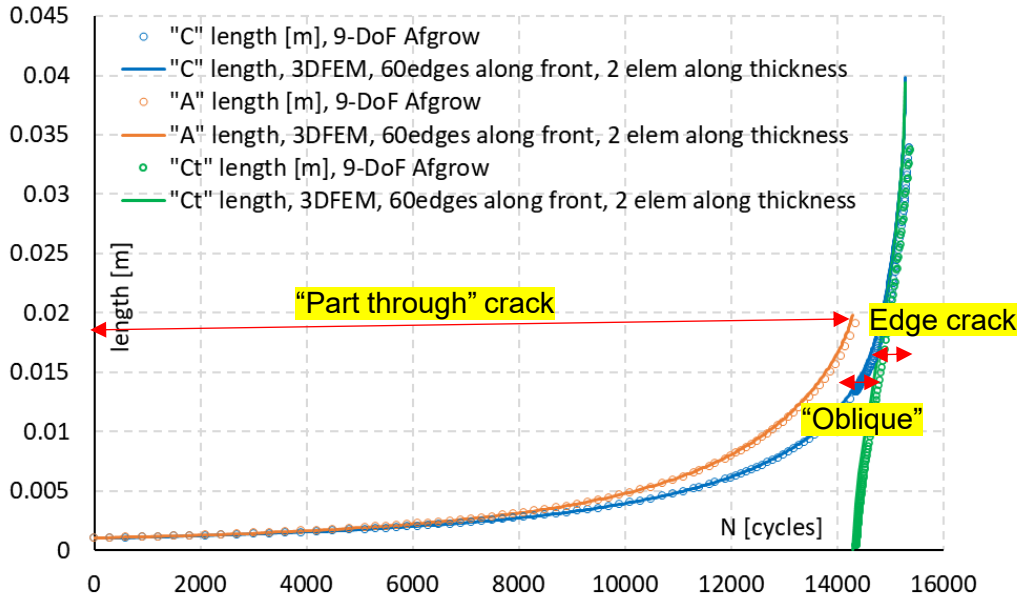
3D FEA Solution used as a reference





Runtime/increment = 15 sec

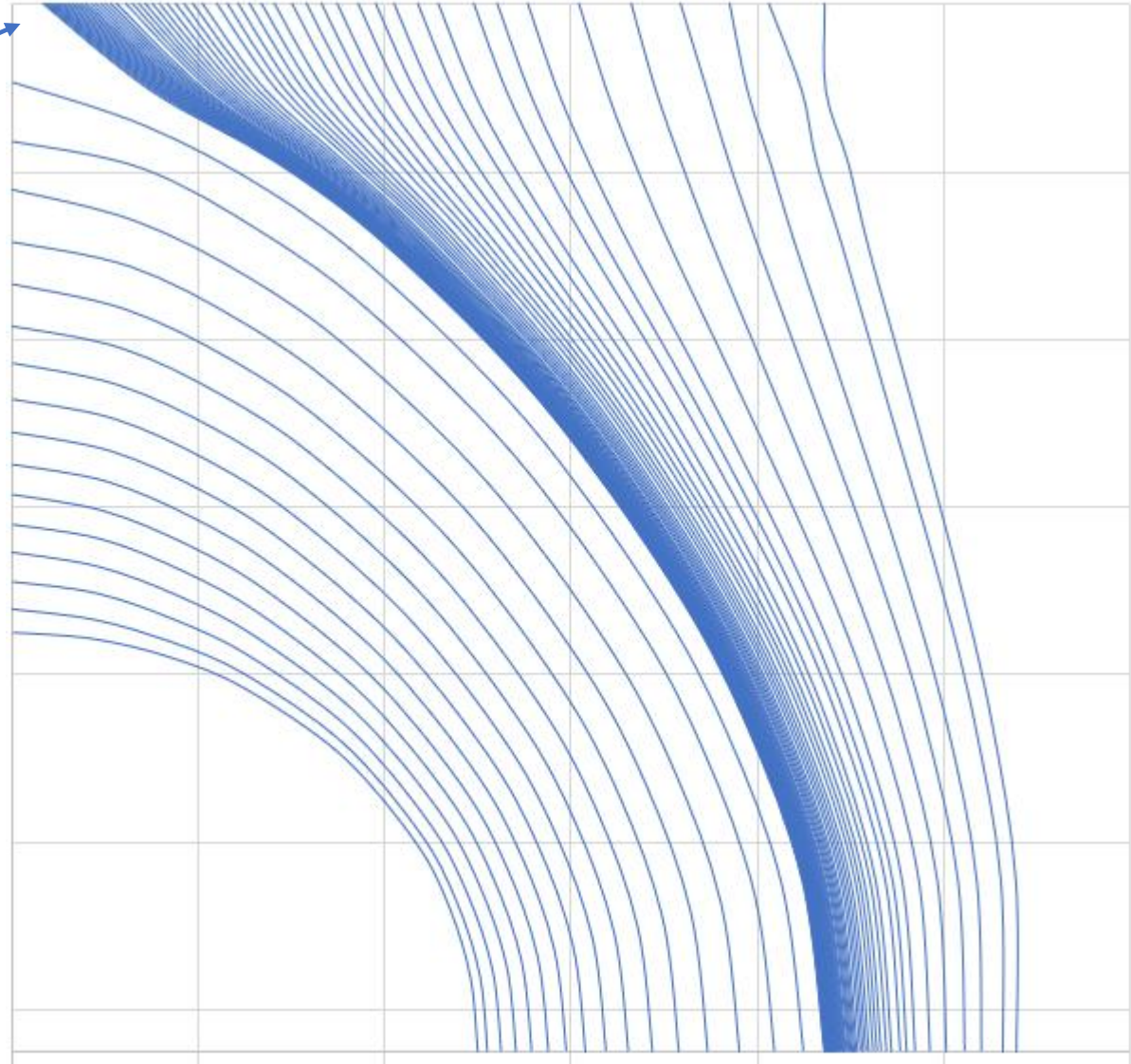
9-DoF AFGROW solution vs. 60-DoF 3DFEA Solution verification



For the same mesh density, AFGROW's 9-DoF solution captures accurately the 60-DoF solution (SimModeler)

Modeling of Crack Shape Transition

95% thickness penetration transition to 1.05*T virtual A, 9 Points



Straight Lug Verification

AFGROW.NET

Data collected from AFWAL-TR-84-3080

Public report

AD-A151 016

AFWAL-TR-84-3080
VOLUME IV

ADVANCED LIFE ANALYSIS
METHODS – Tabulated Test
Data for Attachment Lugs

K. Kathiresan
Lockheed-Georgia Company
Marietta, Georgia 30063

T. R. Brussat
Lockheed-California Company
Burbank, California 91520

September 1984

Final Report for Period 3 September 1980 to 30 September 1984

Specimen identification & Loading conditions

TABLE 1-14. GROUP 1 BASELINE CONSTANT AMPLITUDE CRACK PROPAGATION TESTS

INITIAL FLAW TYPE THRU	INITIAL FLAW TYPE CORNER	MATERIAL ALUM.	MATERIAL STEEL	SPECIMEN ID NO. PREFIX	σ_{max} (KSI)	R = 0.1	R = 0.5	R_o/R_i = 1.50	R_o/R_i = 2.25	R_o/R_i = 3.00	SPECIMEN ID NUMBER SUFFIXES		DATA IN TABLES	
X		X		ABPLC - -	6	X		X			62	63	1-15	1-16
									X		46	93	1-17	1-18
										X	85	89	1-19	1-20
							X	X			64	68	1-21	1-22
									X		47	94	1-23	1-24
										X	84	91	1-25	1-26
			X	SBPLC - -	14	X		X			62	72	1-27	1-28
									X		91	92	1-29	1-30
										X	88	90	1-31	1-32
							X	X			63	71	1-33	1-34
									X		47	48	1-35	1-36
										X	83	89	1-37	1-38
		X		ABPLC - -	15	X		X			66	72	1-39	1-40
									X		48	92	1-41	1-42
										X	87	90	1-43	1-44
							X	X			65	110	1-45	1-46
									X		49	79	1-47	1-48
										X	60	86	1-49	1-50
	X	X		ABPLC - -	6	X		X			17	21	1-51	1-52
									X		30	36	1-53	1-54
										X	6	50	1-55	1-56
							X	X			18	22	1-57	1-58
									X		32	34	1-59	1-60
										X	5	54	1-61	1-62
			X	SBPLC - -	14	X		X			17	20	1-63	1-64
									X		30	32	1-65	1-66
										X	55	79	1-67	1-68
							X	X			18	19	1-69	1-70
									X		31	34	1-71	1-72
										X	5	80	1-73	1-74
								X			19	23	1-75	1-76
									X		31	33	1-77	1-78
										X	8	57	1-79	1-80
		X		ABPLC - -	15	X		X			20	71	1-81	1-82
									X		35	37	1-83	1-84
										X	55	38	1-85	1-86

SBPLC31 & SBPLC34

4340 FCGR from report

TABLE 1-6. CRACK GROWTH RATE DATA
4340 STEEL (H.T. 180-200 KSI), R=0.1

ΔK (KSI√IN)	da/dN (Mi.roinch/Cycle)
6.0	0.0911
8.0	0.1920
12.0	0.7400
16.0	1.6600
20.0	2.9900
24.0	4.7700
28.0	6.9700
32.0	9.4800
38.0	13.5000
56.0	26.8000
74.0	50.0000
88.0	93.5000
98.0	159.0000

TABLE 1-7. CRACK GROWTH RATE DATA
4340 STEEL (H.T. 180-200 KSI), R=0.5

ΔK (KSI√IN)	da/dN (Microinch/Cycle)
4.0	0.0537
5.0	0.106
7.0	0.247
9.0	0.482
11.0	0.833
13.0	1.310
16.0	2.250
20.0	3.930
24.0	6.010
28.0	8.350
35.0	12.800
50.0	29.000
58.0	57.700

Geometry

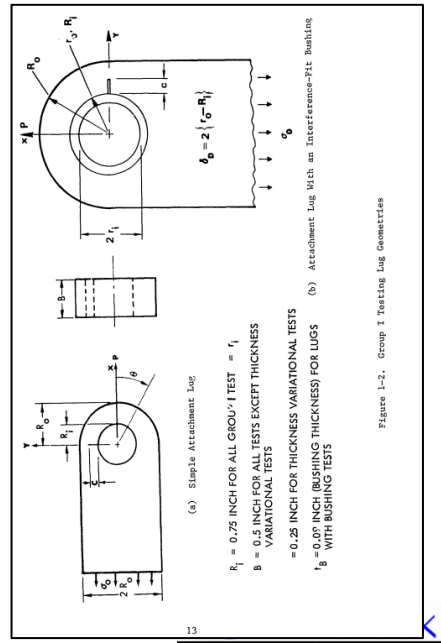


Figure 1-2. Group I Testing Lug Geometries

Length vs. cycles - Validation reference

TABLE 1-71. CRACK GROWTH DATA FOR SPECIMEN SBPLC31

LINE NO.	N (CYCLES)	c (IN.)	a (IN.)	c_B (IN.)	a/c
1	0	0.0250	0.025	0.000	1.000
2	11000	0.0288	-	0.000	-
3	35003	0.0392	-	0.000	-
4	59000	0.0499	-	0.000	-

TABLE 1-72. CRACK GROWTH DATA FOR SPECIMEN SBPLC34

LINE NO.	N (CYCLES)	c (IN.)	a (IN.)	c_B (IN.)	a/c
1	0	0.0250	0.025	0.000	1.000
2	7300	0.0266	-	0.000	-
3	47300	0.0373	-	0.000	-
4	75300	0.0477	-	0.000	-

4043 steel

MATERIAL	F_{TU} (KSI)	F_{TY} (KSI)	F_{CY} (KSI)	K_{app} (KSI √IN) THICKNESS (INCH) 0.5	K_{app} (KSI √IN) THICKNESS (INCH) 0.25 (1)	K_c (KSI √IN) THICKNESS (INCH) 0.5	K_c (KSI √IN) THICKNESS (INCH) 0.25 (1)
7075-T651 ALUMINUM	75.1	74.9	75.6	60.9	78.5	72.4	88.9
4340 STEEL (H.T. 180-200 KSI)	194.0	179.7	188.0	224.7	249.5	250.5	284.0

(1) ADDITIONAL DATA GENERATED USING SPARE MATERIAL

TABLE 1-2. CHEMICAL COMPOSITION OF TEST MATERIALS

MATERIAL	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	P	S	Ni	Mo	Al
7075-T651 ALUMINUM ALLOY	0.07	0.25	1.38	0.04	2.46	0.19	5.60	0.02	-	-	-	-	REM
4340 STEEL H.T. 180-200 KSI	0.20	REM	-	0.79	-	0.90	-	-	0.019	0.003	1.78	0.26	-

MEASURED PERCENT VALUES

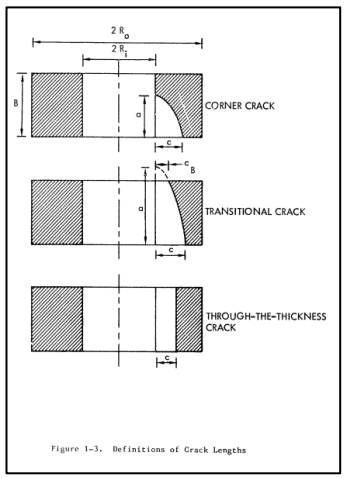
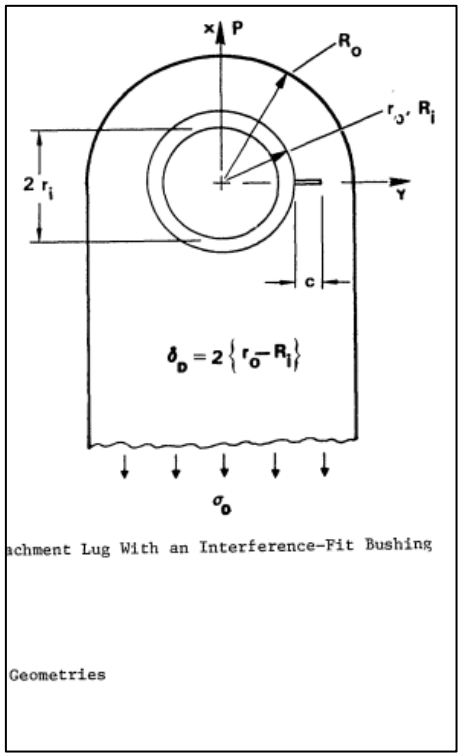


Figure 1-3. Definitions of Crack Lengths

Lextech Inc.
Enabling Simulation-Based Design

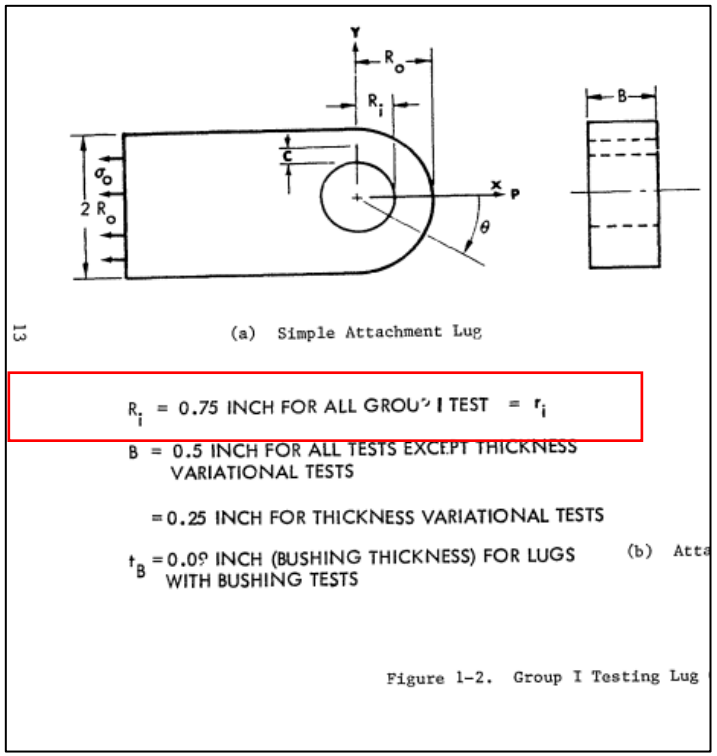
Straight Lug Verification : SBPLC 31 and 34 Measurement Data Used as a Reference

Drawings



achment Lug With an Interference-Fit Bushing

Geometries



(a) Simple Attachment Lug

13

R_i = 0.75 INCH FOR ALL GROUP I TEST = r_i

B = 0.5 INCH FOR ALL TESTS EXCEPT THICKNESS VARIATIONAL TESTS

= 0.25 INCH FOR THICKNESS VARIATIONAL TESTS

t_B = 0.09 INCH (BUSHING THICKNESS) FOR LUGS WITH BUSHING TESTS

(b) Atta

Figure 1-2. Group I Testing Lug

B=0.5”
R_i=0.75”
r_i = 0.75”
R_0/R_i=2.25”
R_0 = 1.6875”

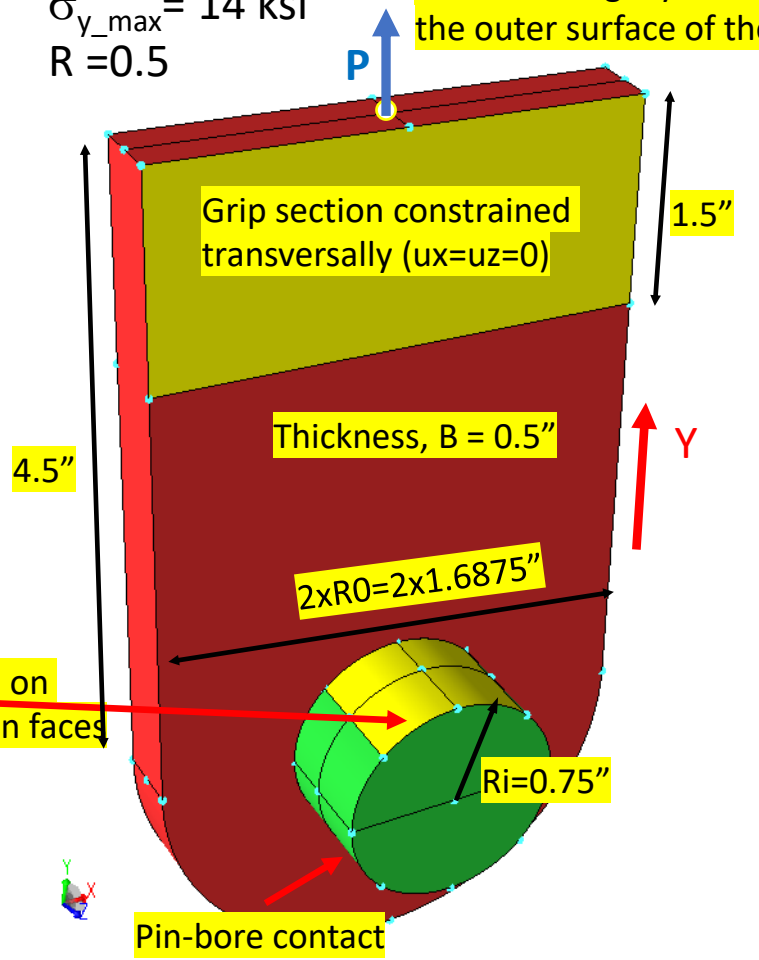
Geometry and FE setup

$P=\sigma_y * B * 2 * R0$

σ_{y_max}= 14 ksi

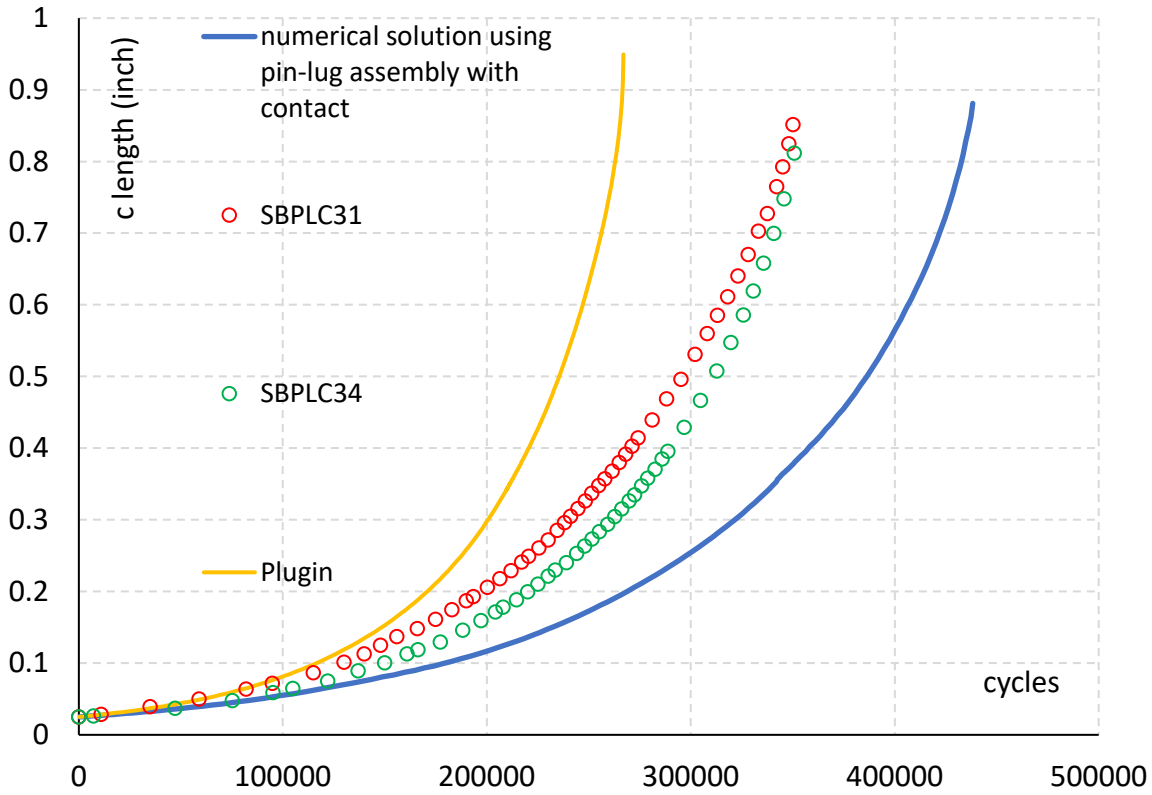
R =0.5

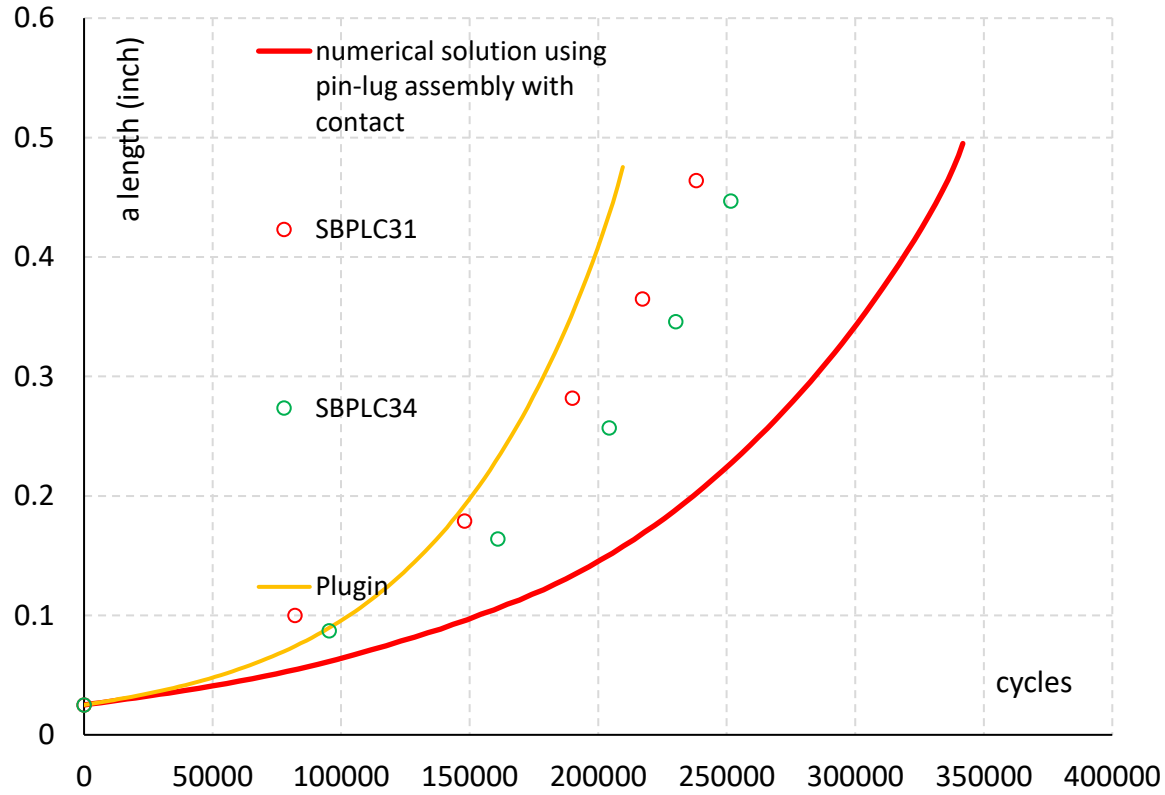
Equivalent concentrated load applied on a pilot node. Pilot node is connected rigidly to the nodes on the outer surface of the grip section



There are different ways we can model the lug assembly in the grips. We will use both Afgrow lug implementation and full 3D to work out this validation benchmark.

Results of the Lug Plugin Data Validation

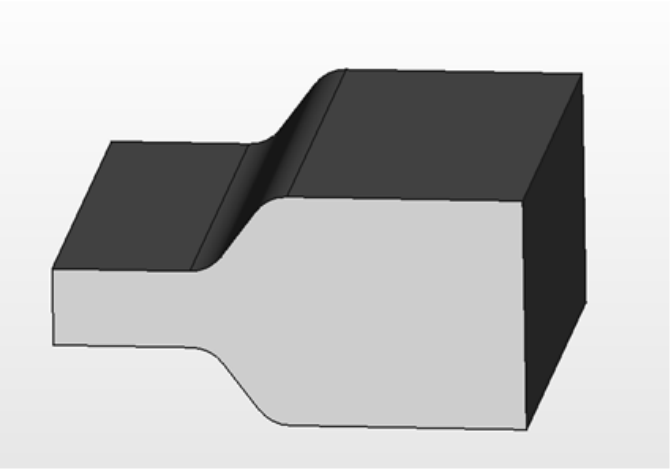


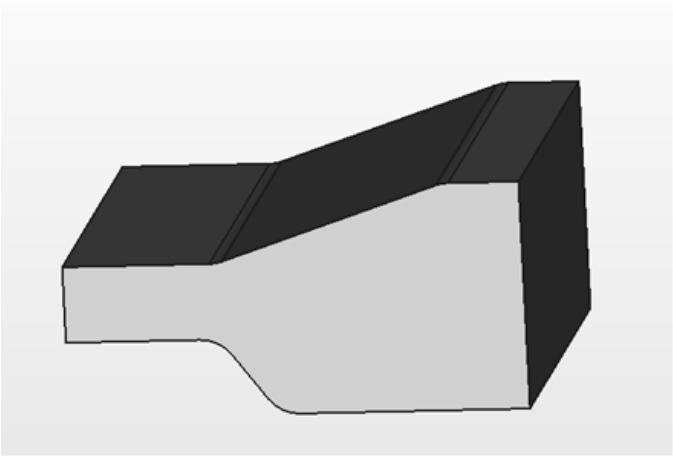


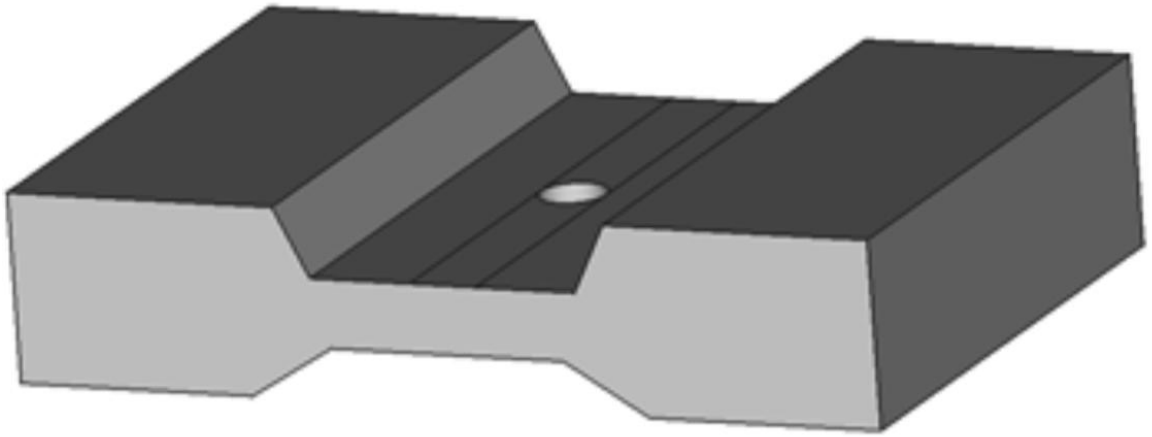
Conclusions

1. Two location scenarios, single crack definition implementation:
   - Crack location on the short ligament side
   - Crack location on the long ligament side
2. The reverse loading solution does not need to be considered in the modeling.
3. For a given load and crack location/orientation based on location/direction of max(s_1), K_{II} and K_{III} magnitudes are very low compared to K_I values for all solutions. No mixed-mode conditions were identified for crack propagation.
4. These models comply to a Mode I fatigue crack growth modeling procedure.
5. Crack propagation solutions (length vs. cycles along predefined directions) for multi-DOE (two solvers) and a 9-DOE AFGROW plug we obtained.
6. Solution verification benchmarking was addressed for K_I calculation and remaining useful life. The multi-DOF solutions from two solvers were used as a reference for the 9-DOF Plugin solutions.
7. Solution convergence with an increased number of points on the crack front (DoFs) was demonstrated.
8. Optimal number of elements on the hole bore for calculation the crack location and life prediction calculation was identified.
9. The Lug Plugin solution was compared against real life test data and multi-DOE pin-loaded lug solution implemented in SimModeler. It was demonstrated that the Lug Plugin solution was conservative but otherwise had a good agreement with the test results. More validation is needed.

Example of New Model Implementation: Corner Crack at Hole in a Variable Thickness Plate



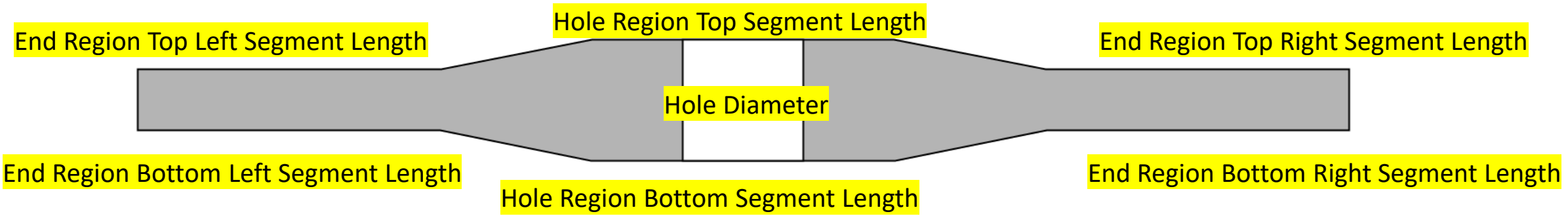


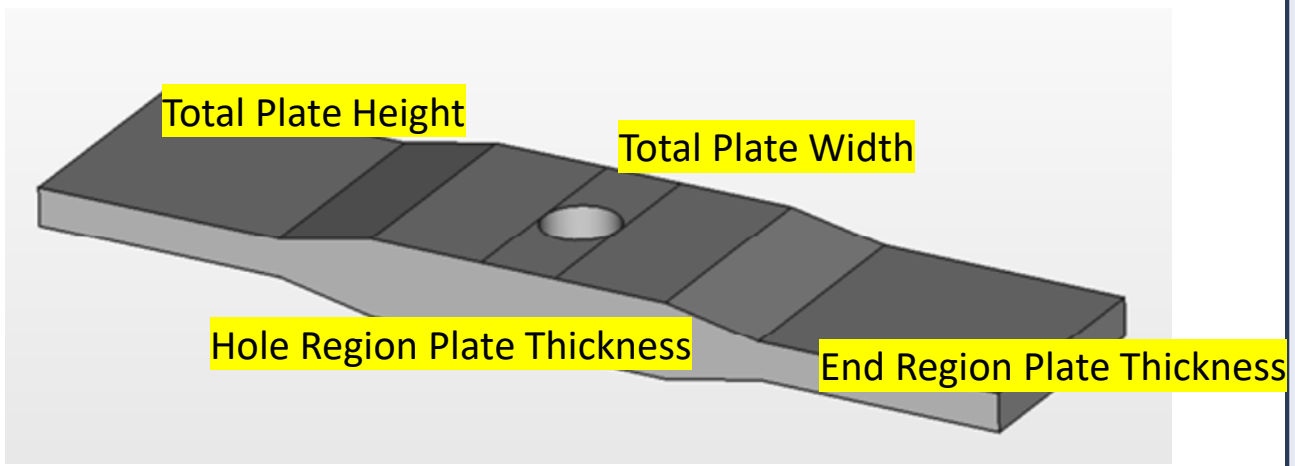


Model geometry

- Total Plate Width
- Total Plate Height
- Hole Region Plate Thickness
- End Region Plate Thickness
- Hole Diameter
- Hole Region Top Segment Length
- Hole Region Bottom Segment Length
- End Region Top Left Segment Length
- End Region Bottom Left Segment Length
- End Region Top Right Segment Length
- End Region Bottom Right Segment Length

Example of New Model Implementation: Configuration parameters





Parameters

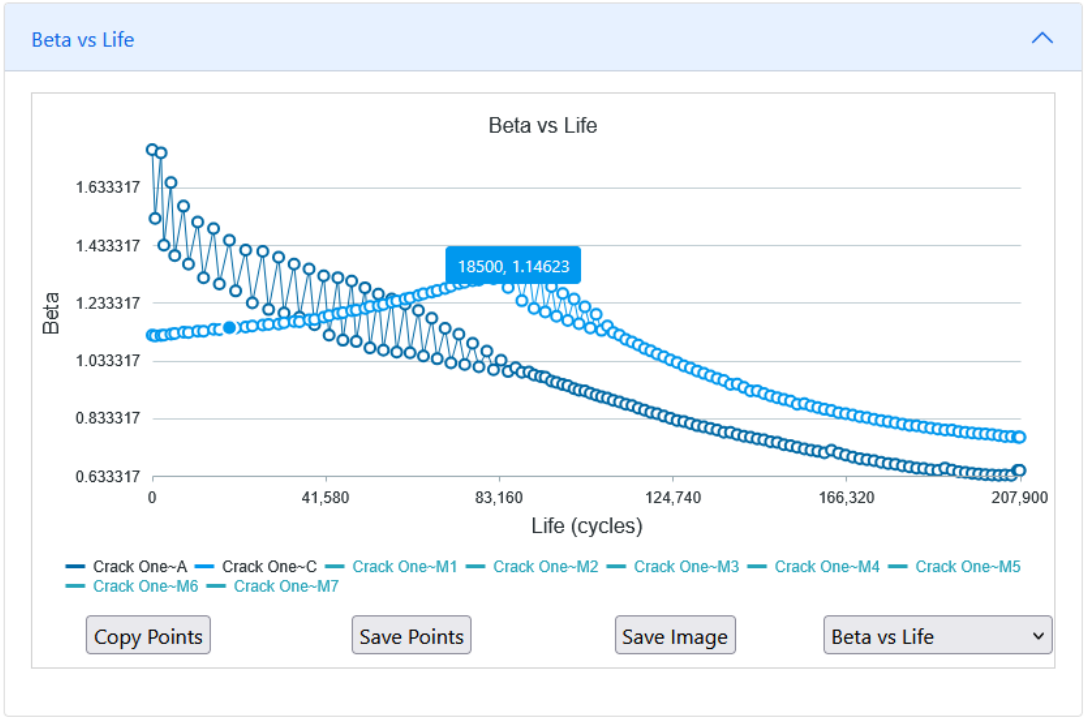
(Name)	Variable Thickness Plate
Total Plate Width	0.200000
Total Plate Height	0.200000
Hole Region Plate Thickness	0.020000
End Region Plate Thickness	**0.010000**
Hole Diameter	**0.020000**
Hole Region Top Segment Length	0.050000
Hole Region Bottom Segment Length	0.050000
End Region Top-Left Segment Length	0.050000
End Region Bottom-Left Segment Length	0.050000
End Region Top-Right Segment Length	0.050000
End Region Bottom-Right Segment Length	0.050000

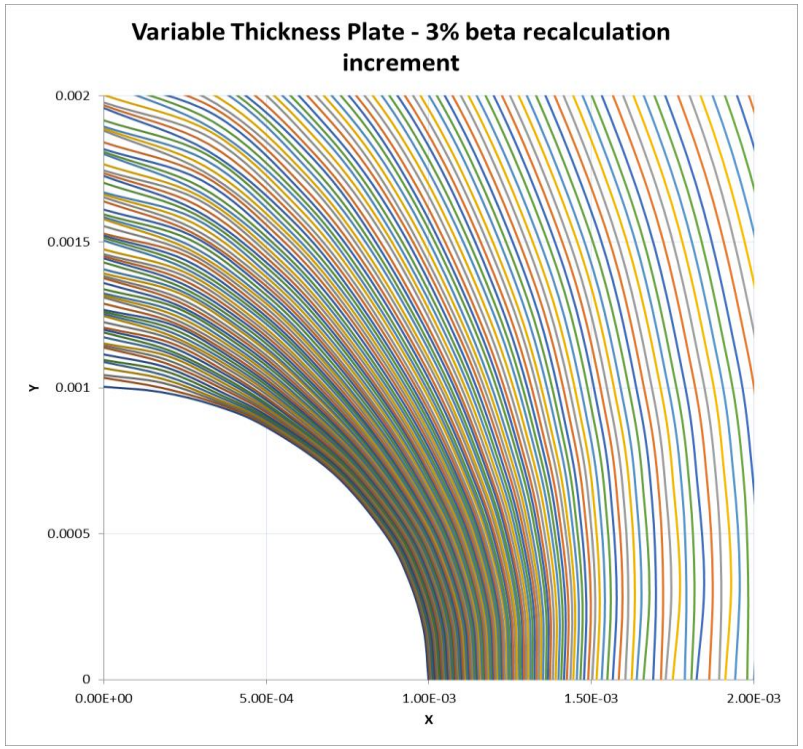
Challenges

1. Determining optimal interval of the FEA K (alpha) recalculation
2. Meaningful representation of internal directions on the crack front
    I. Location (use or do not use parametric angle) – using parametric angles for crack direction locations helps spread them equally over the crack front but can cause the redaction of the crack length
    II. Length or coordinate is the better way to represent direction
3. When to transition: How many directions need to go critical to trigger the crack transition?
4. Crack shape after transition – what is the initial crack shape after the transition to an oblique crack

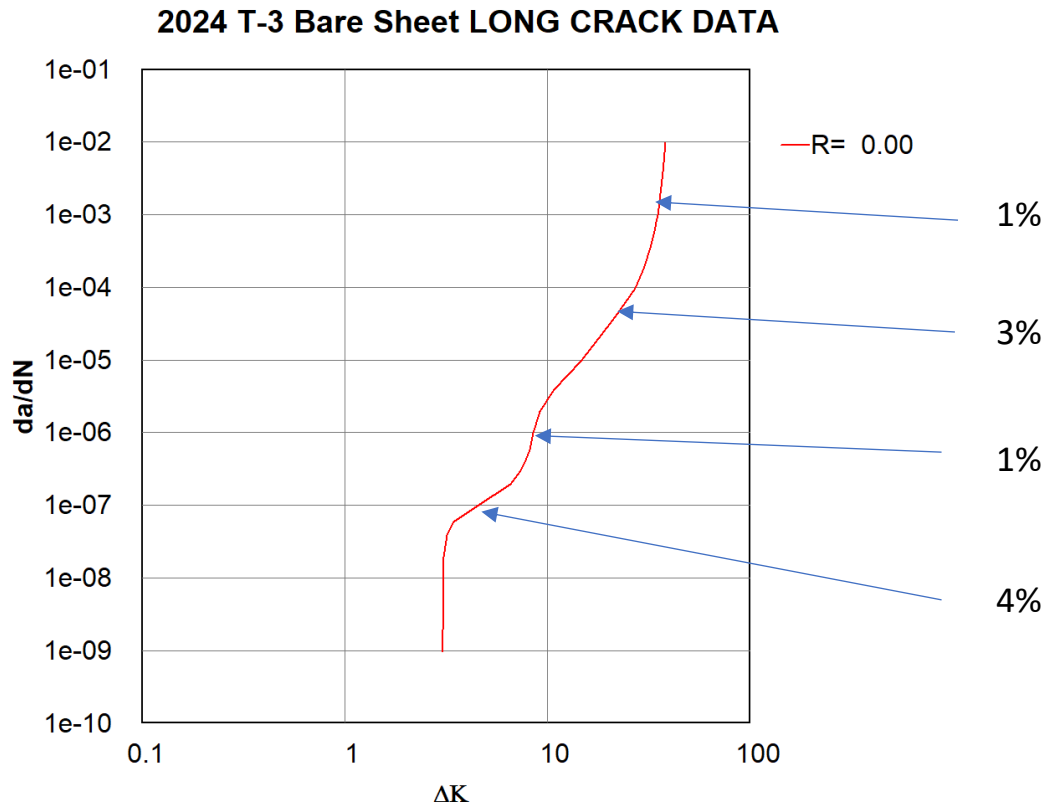
Determining optimal interval of the FEA K (alpha) recalculation

- AFGROW usually recalculates K base on the *Vroman* interval – percent of the initial crack length
- The long Vroman interval causes oscillations in crack shape and beta output





Determining optimal interval of the FEA K (alpha) recalculation



Note: For R < 0.0, Kmax is used instead of Delta K

Oscillations in crack shape and beta output dependent on quality of mesh, shape of the crack growth rate curve and the any crack growth altering mechanisms such as retardation.

Same quality mesh may require different Vroman increment for an accurate analysis

What is Next

1. Add ability for user-controlled mesh density.
2. Add ability to control K (beta) FEA re-calculation by growth rate and mesh density. Currently Vroman increment (% of crack length) is used to control it.
3. Improvements needed for user experience during crack growth analysis.
4. Additional AFGROW plugin screens and reports are considered.
5. Investigate the possibility of running FEA solver on the remote dedicated server.