



HILL
ENGINEERING

Predict. Test. Perform.

BAMF Workshop 2019

September 11, 2019

Agenda

- ❑ **BAMF Overview**
- ❑ **Major Events**
- ❑ **Updates and Bug Fixes**
- ❑ **BAMF Utilization: From the User Community**
 - Kaylon Anderson: NTSB, Oddities seen when running BAMF
 - Brian Boeke: Upper Longeron BAMF Simulation
 - Renan Ribeiro/Mike Hill: Fatigue crack growth testing and modeling of coupons with quench-induced residual stress
 - A-10/Hill Engineering: Re-lifing Ain't all its Cracked up to be
 - Scott Carlson: Analytical Comparisons of Determination Methods
- ❑ **New Release Features**
- ❑ **BAMF Future**
 - Proposed Features and Upgrades

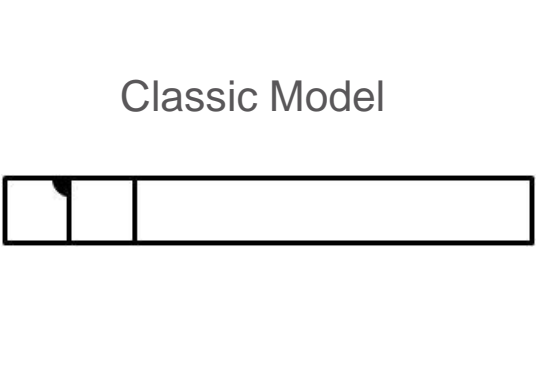
What is BAMF?



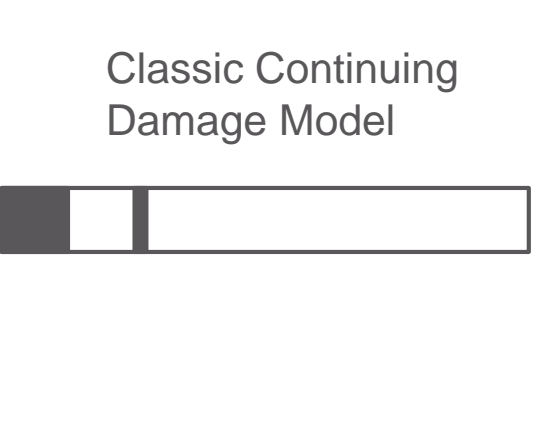
Broad Application for Modeling Failure

Motivation



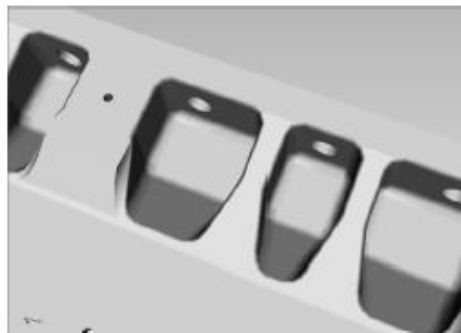
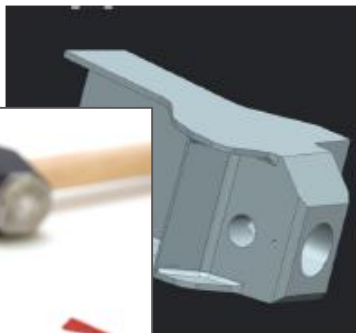

Classic Model



Classic Continuing Damage Model

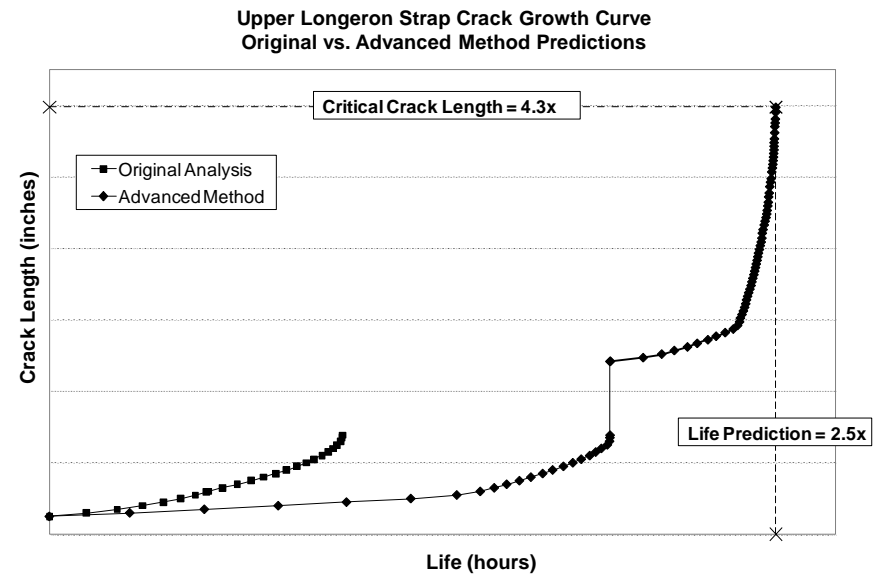
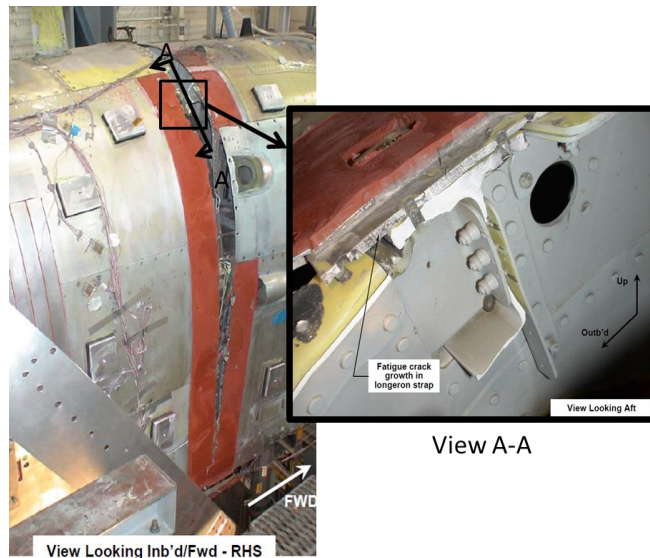


The diagram illustrates two models of structural damage. The 'Classic Model' shows a beam with a localized crack, while the 'Classic Continuing Damage Model' shows a beam with a large shaded area representing damage. The photographs show a cracked metal part and a deformed metal part, respectively.



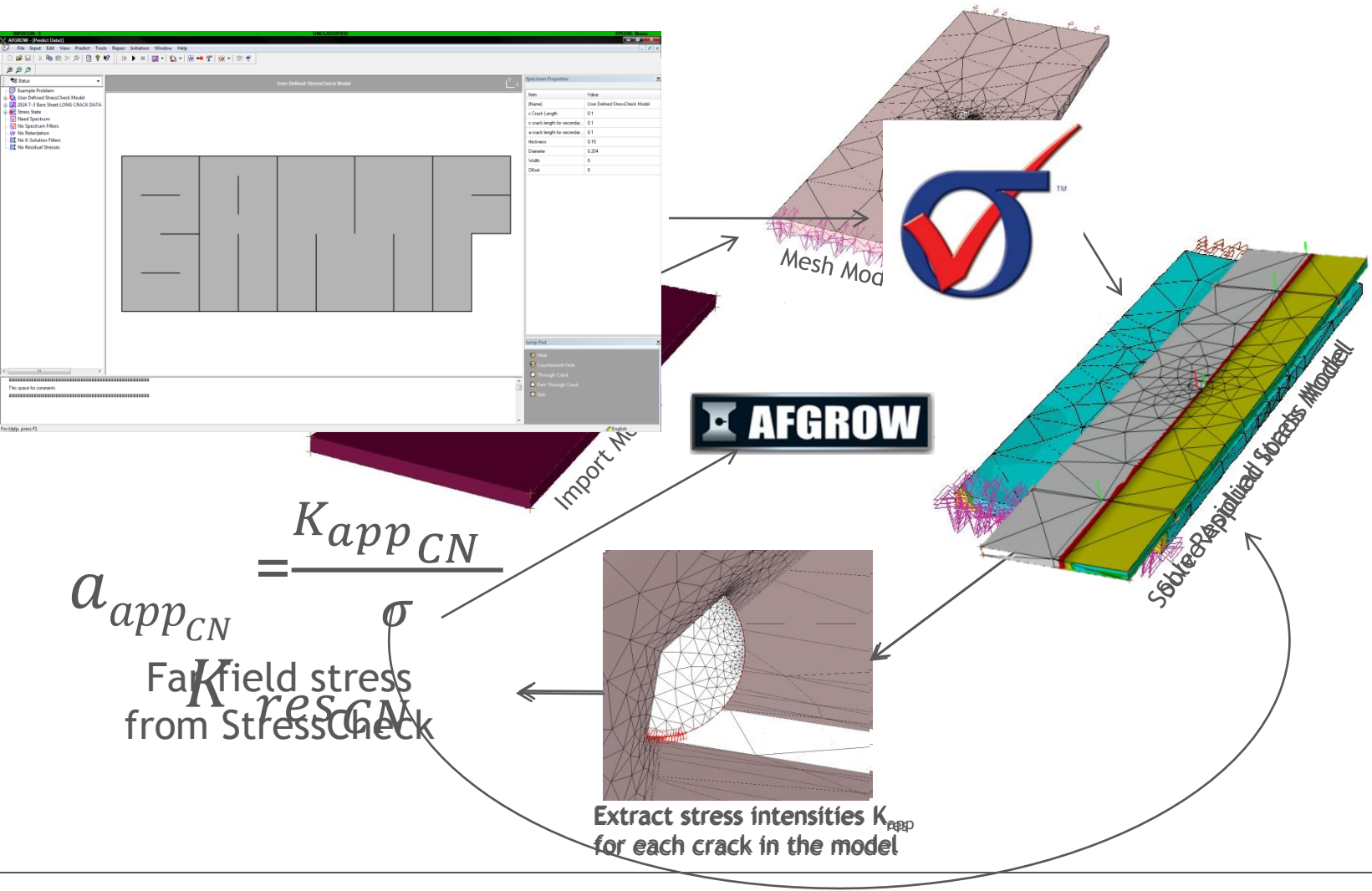
Motivation

- ❑ Conservative assumptions can often result in analyses that drive “Ground the Fleet” decisions
- ❑ How do we minimize the assumptions we must make and increase the accuracy of our analytical predictions?



Ref: AFGROW Workshop 2010, A-10 Modeling Methods to Support Damage Tolerance Analyses, Fleet Sustainment and Repairs, Pilarczyk, Sedgwick, Stowe.

BAMF Process Flow



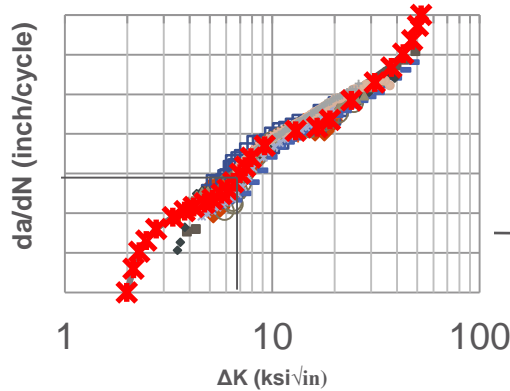
BAMF Process Flow

$$K_{min_{CN}} = a_{app_{CN}} \sigma_{min} + K_{res_{CN}}$$

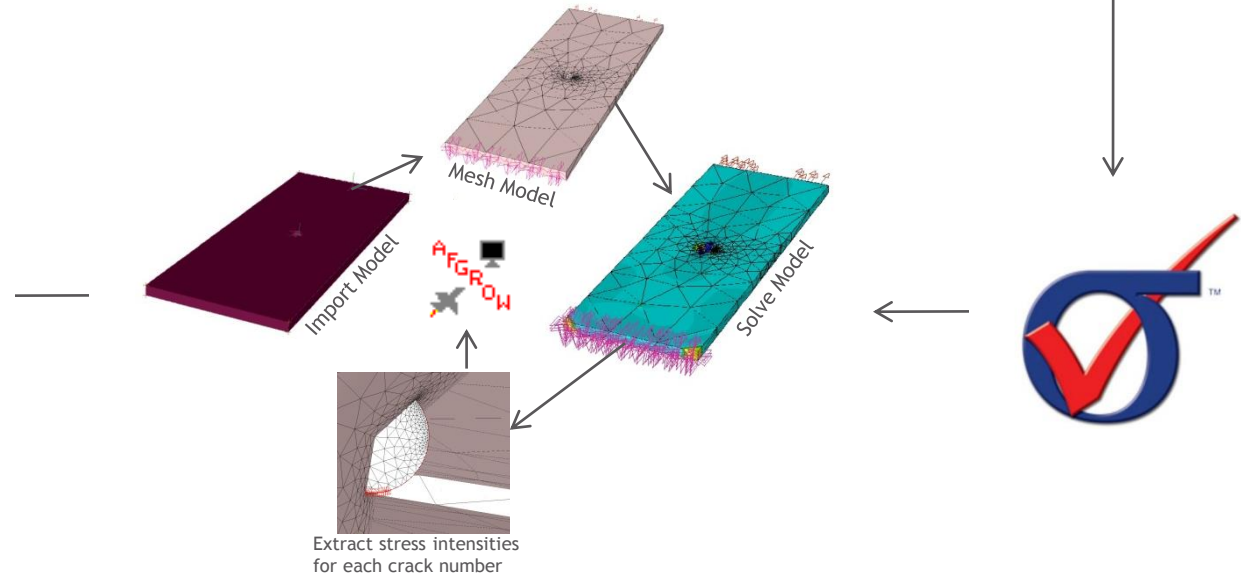
$$K_{max_{CN}} = a_{app_{CN}} \sigma_{max} + K_{res_{CN}}$$

Where $\sigma_{min/max}$ is the AFGROW spectrum stress

$$R_{CN} = K_{min_{CN}} / K_{max_{CN}}$$



→ New Crack Lengths



Major Events

- ❑ **BAMF Release 6.0 (February 2019)**
- ❑ **AFGROW 5.3 (March 2019)**
- ❑ **StressCheck 10.5 (June 2019)**
- ❑ **AFGROW/StressCheck/BAMF Joint Webinar (July 17, 2019)**
 - ESRD website has webinar highlights and recording
 - 30 minute presentation on BAMF, including a model building demo
 - <https://www.esrd.com/resource-library/webinars/3dcrackgrowthsimulation/>
- ❑ **BAMF Release 7.0 (Soon)**
- ❑ **AFGROW/BAMF Training Class (ASIP 2019, Dec. 2 13:00-17:00)**

Version 6.0 Released February 12, 2018

BAMF V6.0 - FEATURES

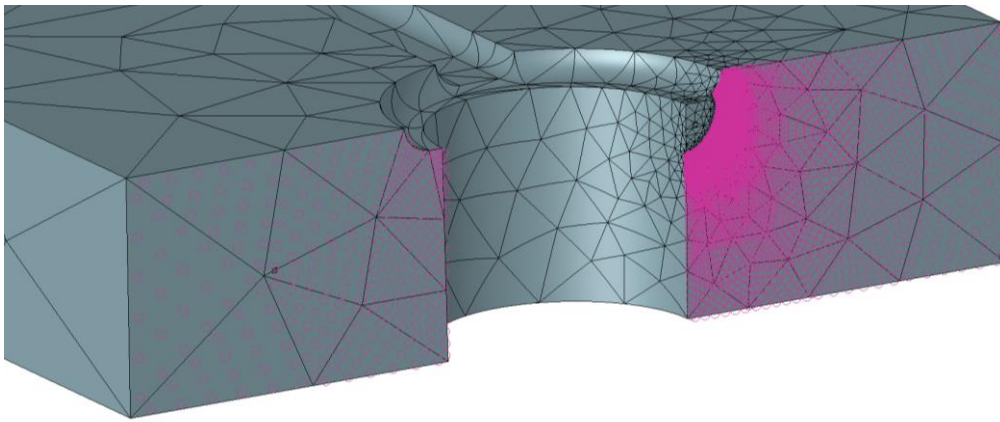
Features

- ❑ Symmetry on Crack Plane
- ❑ Updated Mesh Refinement Capability
- ❑ Automated K-Convergence Checking
- ❑ Updated Model Builder
- ❑ BAMF Model Debugger
- ❑ AFGROW Failure Criteria Capability

<u>Feature</u>	<u>Description</u>
Crack Failure	Stop analysis when a user defined number of points reach K_c
Abort Analysis	A button that allows the user to ABORT a run in the middle of the run
Multi-Channel Loading	Solve for multiple loading scenarios
Multi-directional material properties	Use directional material properties to grow each point
Integration with other FE tools	Ansys, NX (Funding Sources Phase 2 landing gear, A-10)
Model Builder Automation	Update the Excel based model builder to use local coordinate systems
K extrapolation	Extrapolate K to 0 using two different K extractions
K convergence checker	Solve for many p-levels and output K so user can confirm convergence
Multi-Crack Auto-Coalescence	(MCAC) When crack fronts intersect-automatically coalesce cracks
Crack Plane Symmetry	Crack Plane Symmetry

Crack Face Symmetry

- ❑ Symmetry on a crack plane
 - Utilize built in function BAMF_SymCrack#, where # is the crack number
- ❑ Can have multiple cracks on a symmetry plane
- ❑ Sets must define the symmetry boundary condition
 - Set should be far away from expected crack growth path
- ❑ Capability to include both symmetric crack faces and non-symmetric crack faces in the same model



StressCheck Model Information

Name	Description	Expression	Value	Lim
BAMF_SymCrack1			0.0000e+000	
BL_Layers1	BL_Layers for Crack 1		2.0000e+000	
BL_Ratio1	BL_ratio for Crack 1		6.2516e-002	
BL_T01	BL_TO for Crack 1		2.7075e-003	
BL_Ttotal1	BL_TTtotal for Crack 1		1.0830e-002	
C1PX0			1.2033e-001	
C1PY1			1.2012e-001	

Accept Delete Auto Step: 0.2

Input Settings

Updated K extraction smoothing

- ❑ Updated K smoothing to have a defined meaning
- ❑ Default utilizes 4 points to smooth K
- ❑ User has capability to modify smoothing parameter to increase or decrease the number of points used from the extraction

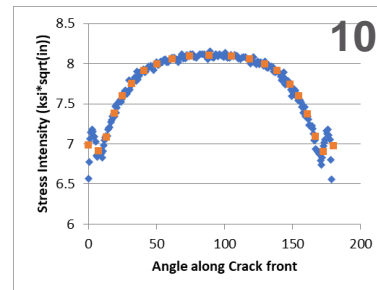
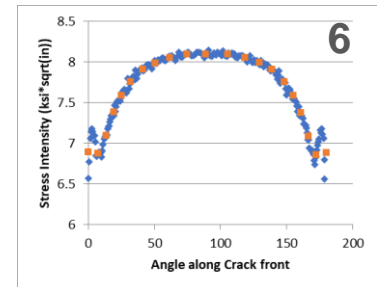
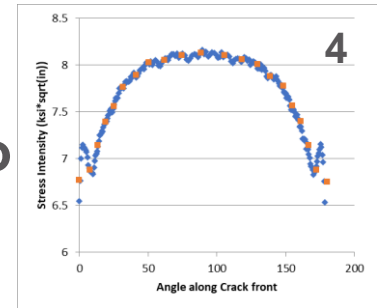
Parameter Name	Parameter Description	Default Value	Recommendations
BAMF_ElementCF	Controls the number of elements along the crack front. It is a multiplication factor that multiplies the number of points by this parameter to get number of elements.	1.25x number of points (PointsCrack#)	1.25 – 5.00
BAMF_Ktol	Sets the tolerance value for K extraction smoothing, i.e. the number of extraction points averaged to calculate the discrete values passed to AFGROW	0.004	0.002 – 0.008 Outputs should average appx 4-10 extraction points. Column I in the excel output defines the number of points averaged to calculate the output stress intensity
BAMF_Layers	Changes the number of layers in the mesh	2	2 - 4

Previous

Parameter Name	Parameter Description	Default Value	Recommendations
BAMF_ElementCF#	Controls the number of elements along the crack front. It is a multiplication factor that multiplies the number of points by this parameter to get number of elements.	1.25x number of points (PointsCrack#)	1.25 – 5.00
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BAMF_Layers#	Changes the number of layers from	2	2 – 4

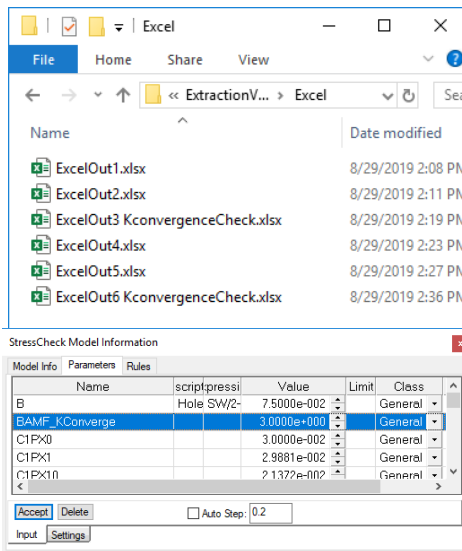
Updated

Ktol

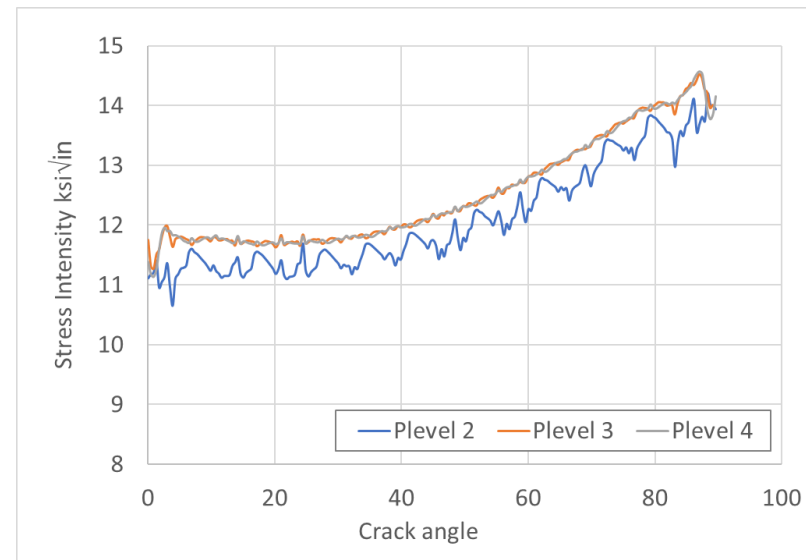


Automated K-Convergence Checking

- ❑ Capability has been added to periodically check K convergence
- ❑ Implemented through StressCheck parameters
 - Parameter name: BAMF_Kconverge
 - Parameter value: The number of iterations in between convergence checking
 - Extracts stress intensities at 1 level above and below the defined p-level
- ❑ Utilized in post processing of results



	A	B	C	D	E	F	G	H
	Plevel 1	Plevel 2	Plevel 3	X	Y	Z	Extraction Number	
1	11.11617	11.74968	11.38319	4.81E-14	0.030806	-2.6E-17	-1.7E-33	1
2	11.18179	11.30446	11.17758	0.436233	0.030819	0.000235	1.44E-20	2
3	11.21179	11.26442	11.13266	0.872043	0.03083	0.000469	-8.9E-16	3
4	11.41021	11.5054	11.2577	1.307373	0.030841	0.000704	4.31E-20	4
5	10.96329	11.58517	11.58345	1.742188	0.030851	0.000938	5.75E-20	5
6	11.05344	11.7981	11.86308	2.176479	0.030859	0.001173	-8.9E-16	6
7	11.13741	11.9574	11.95816	2.610254	0.030865	0.001407	8.62E-20	7
8	11.36775	11.98421	11.89801	3.043547	0.030869	0.001641	1.01E-19	8
9	10.97697	11.80786	11.90318	3.476413	0.03087	0.001875	1.15E-19	9
10	10.65773	11.63381	11.83124	3.908928	0.030868	0.002109	1.29E-19	10
11	11.11027	11.76246	11.83356	4.341192	0.030863	0.002343	1.43E-19	11
12	11.17992	11.78779	11.81118	4.773325	0.030853	0.002576	1.58E-19	12
13	11.27327	11.80626	11.78385	5.205469	0.030839	0.00281	1.72E-19	13
14	11.29232	11.78934	11.7393	5.63777	0.030821	0.003043	1.86E-19	14
15	11.32894	11.76377	11.71839	6.070311	0.030798	0.003275	2.01E-19	15
16	11.55297	11.73864	11.70252	6.503143	0.030772	0.003508	2.15E-19	16
17	11.6104	11.6646	11.7824	6.936294	0.030742	0.00374	2.29E-19	17



Excel Model Builder

- ❑ **Outputs a working file or a parameter file for a BAMF analysis**
- ❑ **Requires user to create nucleation systems for each crack**
- ❑ **Required input parameters**
 - Number of cracks
 - Angle of each crack
 - Depth of each crack
 - Length of each crack
 - # of points defining each crack front
- ❑ **Instructions included in the Model Creator Excel sheet**
- ❑ **Demonstration!!!**

Model Debugger

- ❑ Provides outputs at each point in the BAMF model program flow
- ❑ Outputs extensive information on crack points to excel outputs
- ❑ Used to aide BAMF Technical Support in quickly solving model related issues
- ❑ Excel output review

StressCheck Model Information

Name	Description	Value	Limit	Class	Sort
B	Hole SW/2	7.5000e-002		General	
BAMF_Debug		0.0000e+000		General	
C1PX0		3.0000e-002		General	
C1PX1		2.9881e-002		General	
C1PX10		2.1372e-002		General	
C1PX11		1.9398e-002		General	
C1PX12		1.7634e-002		General	
C1PX13		1.5771e-002		General	
C1PX14		1.3820e-002		General	

Accept Delete Auto Step: 0.2

Input Settings

LMCX SEM

Name	Date modified	Type	Size
ExtractionValues	8/29/2019 2:53 PM	File folder	
ExtractionValues_Contour Method	8/22/2019 3:07 PM	File folder	
ExtractionValues_ERS Toolbox	8/29/2019 2:45 PM	File folder	
2024-T351_051019.lkpx	5/10/2019 7:39 AM	LKPX File	9 KB
LM_CX_Short Edge.dax	8/21/2019 4:07 PM	Problem Definition	14 KB
LM_CX_Short_Edge_No_RS.scw	8/29/2019 2:44 PM	StressCheck SCW ...	219 KB
LM_CX_Short_Edge_No_RSextract1.scp	8/29/2019 2:56 PM	StressCheck SCP file	7,669 KB
LM_CX_Short_Edge_No_RSOfBSpPostOffsetPoints1.scp	8/29/2019 2:53 PM	StressCheck SCP file	7,375 KB
LM_CX_Short_Edge_No_RSOfBSpreOffsetPoints1.scp	8/29/2019 2:53 PM	StressCheck SCP file	7,370 KB
LM_CX_Short_Edge_No_RSplot.scp	8/29/2019 2:56 PM	StressCheck SCP file	7,670 KB
LM_CX_Short_Edge_No_RSsolved.scp	8/29/2019 2:56 PM	StressCheck SCP file	7,669 KB
LM_CX_Short_Edge_No_RSsolvedfinal.scp	8/29/2019 2:56 PM	StressCheck SCP file	7,670 KB
LM_CX_Short_Edge_No_RSstart.scw	8/29/2019 2:54 PM	StressCheck SCW ...	222 KB
LM_CX_Short_Edge_No_RSStartExtract.scp	8/29/2019 2:56 PM	StressCheck SCP file	7,713 KB

14 items | 1 item selected 13.8 KB

BAMF/AFGROW Failure Criteria

❑ Version 6.0 utilizes:

- BAMF will stop prediction when all points are above Plain Stress K_c
- User input value when *User-Defined “Kmax”* is selected

❑ Version 7.0 will utilize:

- No failure criteria when nothing is selected
- Plain Stress K_c when “Kmax” Failure Criteria is selected
- User input value when User-Defined “Kmax” is selected

Predict Function Preferences

Growth Increment

Output Intervals

Output Options

Propagation Limits

Transition Options

Lug Boundary Conditions

Crack Closure Factor

Bending

Stop Crack Propagation at:

Crack Length

Cycle Count

'Kmax' Failure Criteria

User-Defined 'Kmax' Value:

'Net Section Yield' Failure Criteria

Part Through Crack Transition

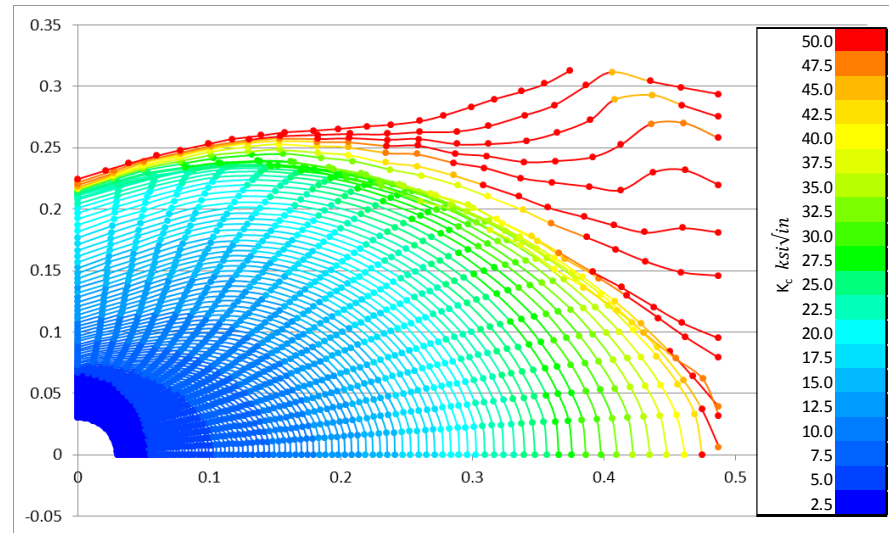
Number of times the spectrum will be repeated

Spectrum Reps (Max: 9999999):

Minimum crack growth after one pass of the spectrum

Minimum crack growth:

OK Cancel Save Default



Version 6.0 Released February 12, 2018

BAMF V6.0 - REPORTED BUGS AND ISSUES

Bug: Units

- ❑ Units were added early in the development of 6.0
 - Failure criteria was added later in the 6.0 release
 - AFGROW uses base units of m; StressCheck uses base units of mm
- ❑ $K_{failure}$ routine did not account for the mm to m conversion
 - Caused failure after first iteration
- ❑ Work around uses *User-Defined “Kmax” with units of mm√MPa*
- ❑ BAMF Release 7.0 addresses the issue



Bug: Multi-Crack Issues

- ❑ Bug: Extraction radius for multiple cracks would utilize parameters for a single crack
 - Code utilized extraction radius for crack 1 for all cracks
 - Code was updated so all meshing and extraction parameters were a function of crack number
 - Updates were released in version 6.0

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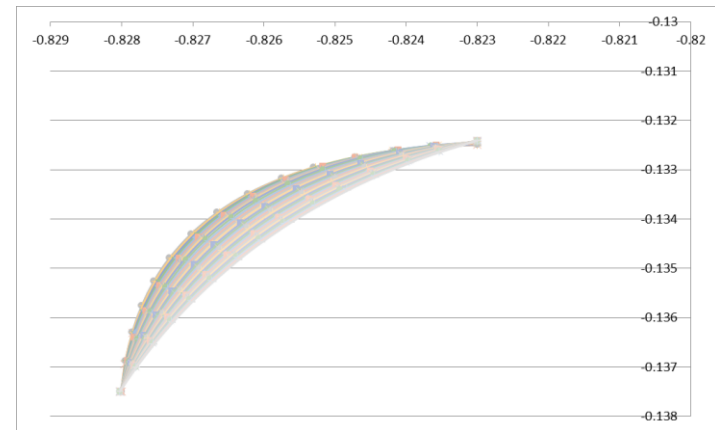
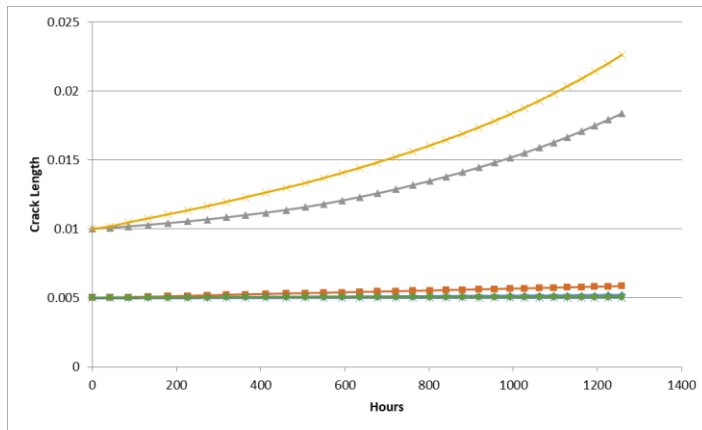
Previous

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Updated

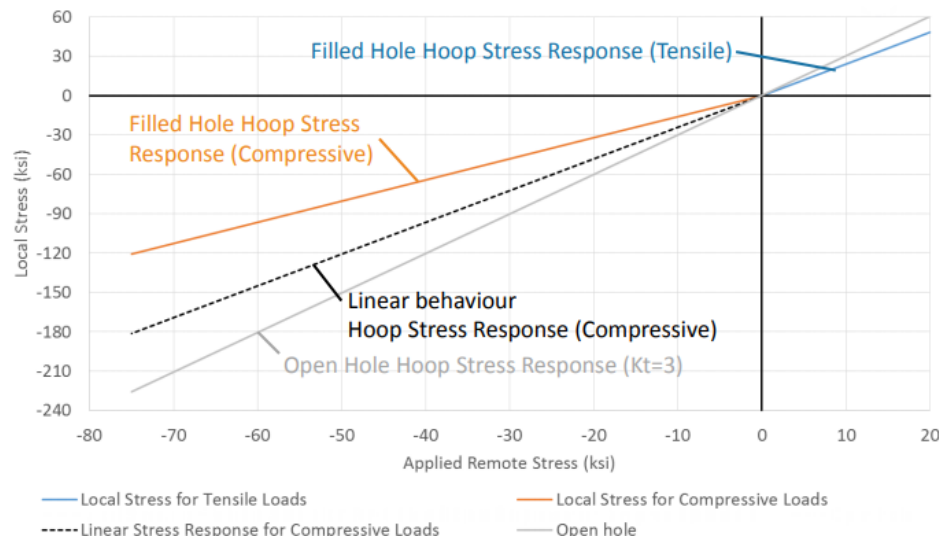
Bug: Multi-Crack Issues

- ❑ **Bug: Small secondary cracks would reduce in size during primary crack growth**
 - Small/no growth lengths would cause an error in the re-splining code causing ΔP to reduce in size and flatten out over several iterations
 - Code written to utilize proper crack lengths if negative growth flag is tripped
 - Updates were released in version 6.0
- ❑ **Bug: Graphs are not updated when negative growth flag is tripped**
 - Plotting of secondary cracks stops working when above bug fixed was implemented

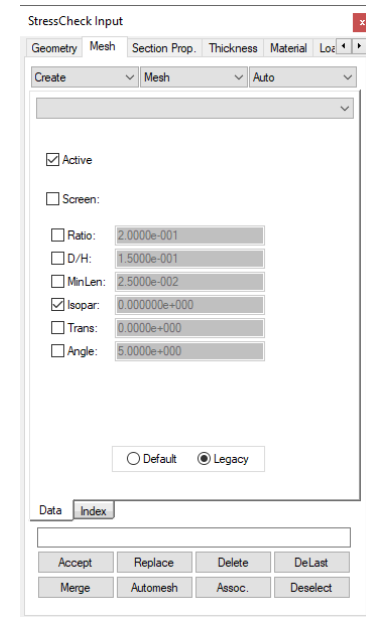


Other Reported Bugs and Issues

- ❑ BAMF takes an incredibly long time to initialize on USAF network
- ❑ Can't use cracks that are greater than 180 degrees
 - In development, planned for 7.0 release
- ❑ Incorrect analysis when performing contact and interference
- ❑ Default auto-mesh does not appear to work properly



Yan Bombardier, et al, Prediction of fatigue crack growth at cold expanded fastener holes with ForceMate bushings. AFGROW 2018



BAMF UTILIZATION CASES

Recent Examples of BAMF Utilization

❑ **Kaylon Anderson**

- NTSB, Oddities seen when running BAMF

❑ **Scott Carlson/Josh Hodges**

- Analytical Comparisons of Determination Methods

❑ **Brian Boeke**

- Upper Longeron BAMF Simulation

❑ **Renan Ribeiro/Mike Hill**

- Fatigue crack growth testing and modeling of coupons with quench-induced residual stress

❑ **Joshua Hodges**

- “Re-lifing isn’t all its cracked up to be”

Release September 31, 2019

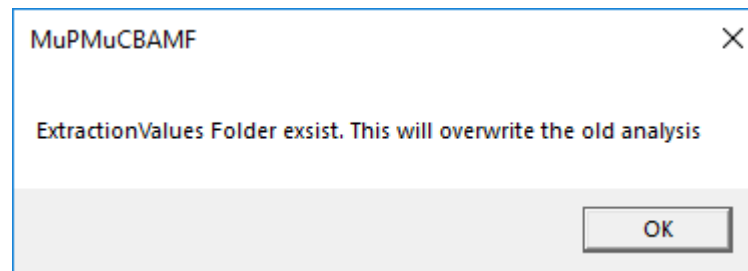
BAMF RELEASE 7.0 - UPGRADES

Features

<u>Feature</u>	<u>Description</u>
Crack Failure	Stop analysis when a user defined number of points reach K_c
Abort Analysis	A button that allows the user to ABORT a run in the middle of the run
Multi-Channel Loading	Solve for multiple loading scenarios
Multi-directional material properties	Use directional material properties to grow each point
Integration with other FE tools	Ansys, NX (Funding Sources Phase 2 landing gear, A-10)
Model Builder Automation	Update the Excel based model builder to use local coordinate systems
K extrapolation	Extrapolate K to 0 using two different K extractions
K convergence checker	Solve for many p-levels and output K so user can confirm convergence
Multi-Crack Auto-Coalescence	(MCAC) When crack fronts intersect-automatically coalesce cracks
Crack Plane Symmetry	Crack Plane Symmetry
BAMF360	When Cracks are greater than 180-degrees
Incorrect Analysis with Contact	K_{max} and K_{min} may not be linear when contact (neat/interference fit)
Units Causing K-Critical Failure	When using metric units $K_{critical}$ is 1000 less then it should be
Multi-Crack Extraction	Extraction parameters were not a function of crack number
3-D crack growth	Crack turning, out of plane crack growth

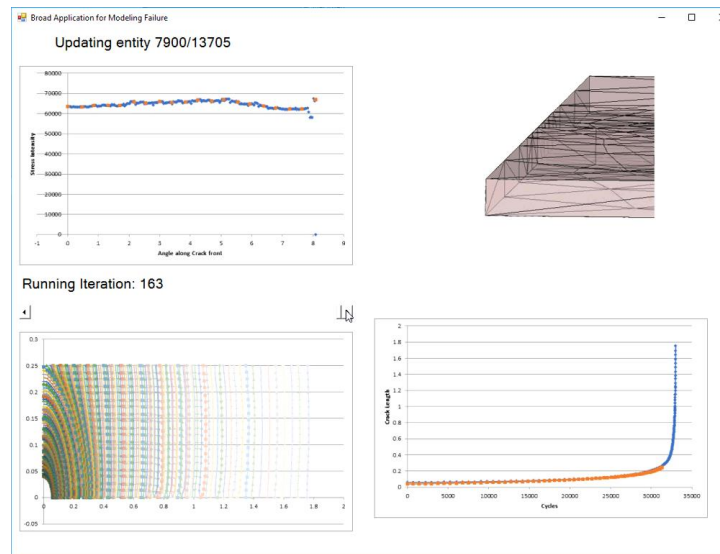
Updated Features

- ❑ **StressCheck 10.5 Compatibility**
 - Updated to account for K extraction output differences
- ❑ **AFGROW 5.3.4.23 Compatibility**
 - Updated to include multi-directional functionality
 - Updated to be backwards compatible with older versions of 5.3
- ❑ **Speed Increase of RS models (2 Times Faster!!!)**
 - Solution times are decreased by 2x for residual stress iterations
 - Corresponds to a 40% decrease in solution time
- ❑ **File Overwrite Warning**



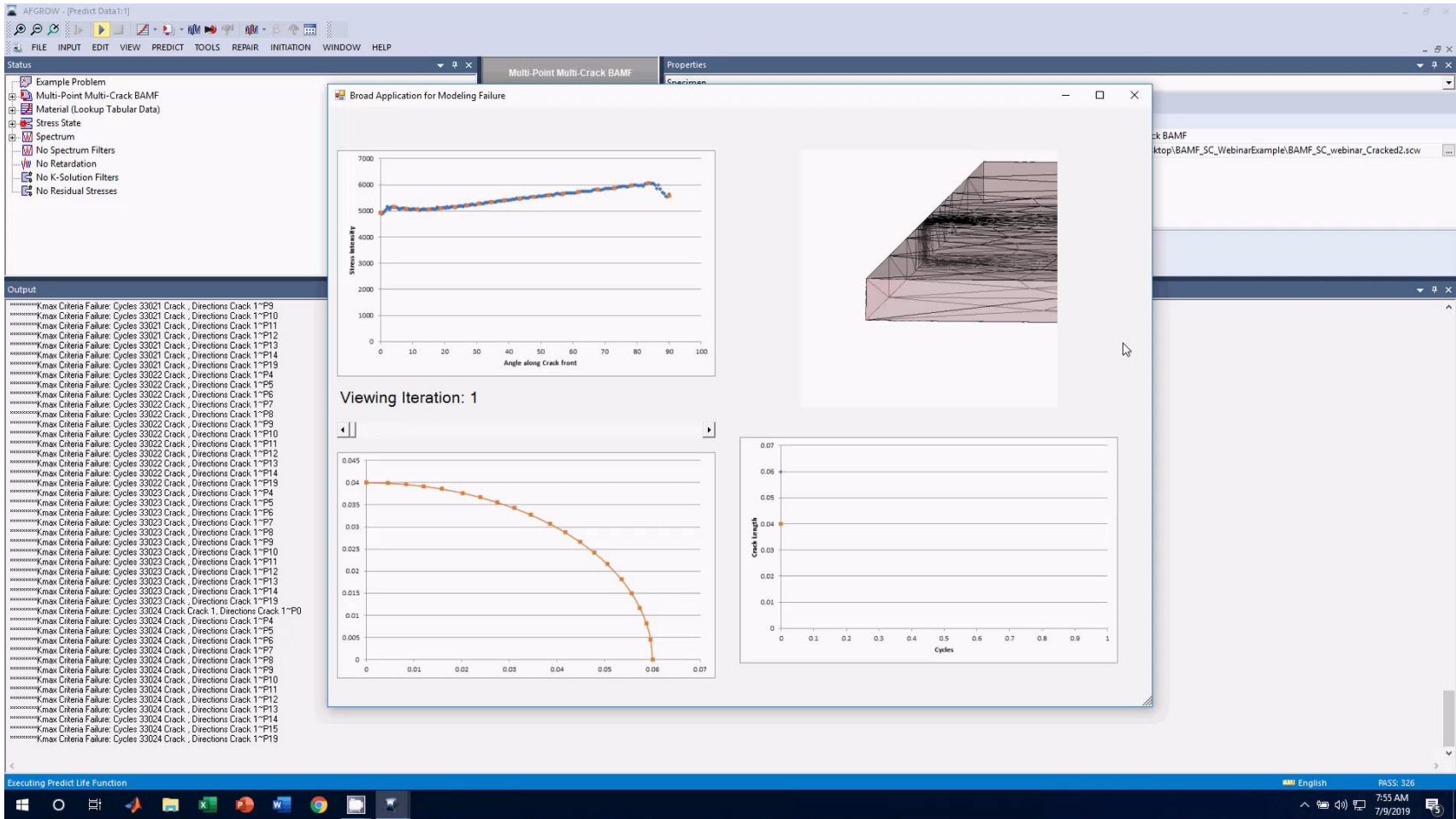
Multi-Threading

- ❑ Previous versions of BAMF
 - BAMF userform was not interactable
 - Update messages and charts would occasionally freeze
 - AFGROW would need to be killed in task manager to stop analysis
- ❑ Updated code to allow multiple processes to occur simultaneously
- ❑ Allows for incorporation of features to review iterations during analysis.



Multi-Threading New GUI

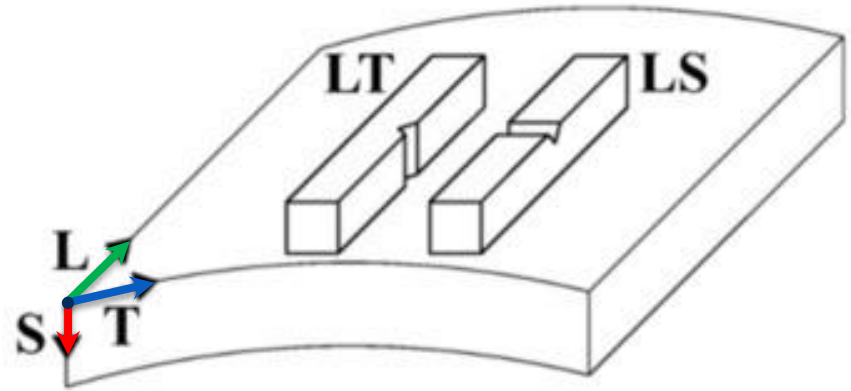
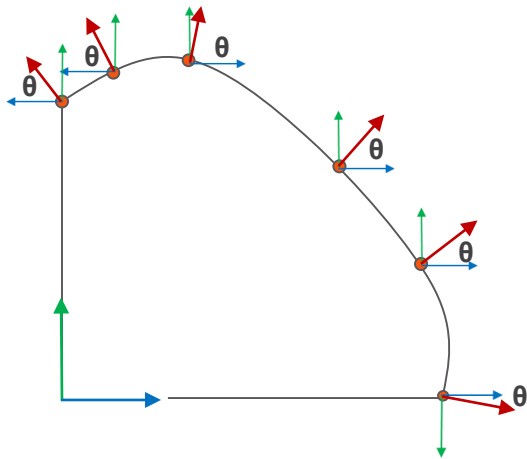
New GUI demonstration!!!



Multi-Directional Material Properties

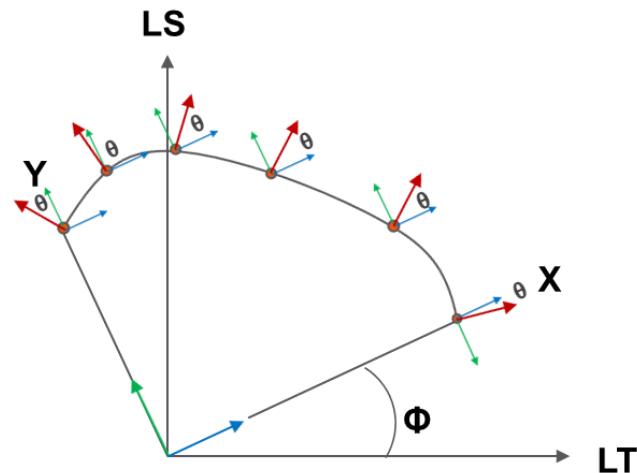
❑ BAMF requirements:

- Definition of material orientations on solid model
 - ❑ This is based on the local nucleation system of the crack
 - ❑ If the c-direction is the x-direction on the local nucleation system no value needs to be defined
- Angle is based on angle used for growth direction.
- Functions for interaction (angles in degrees)
 - ❑ `ISPredictManage.SetCrackDirectionParameter("Crack " & k, "P" & i, "angle", Mat_Dir_Angle(0, k, i))`



Multi-Directional Material Properties

- ❑ User Can Set BAMF_MDCrackAngle# (Φ on this slide) if the LT direction of the material is different from the X axis of the crack
 - BAMF_MDCrackAngle# is defined as the angle the crack nucleation system X axis is above the LT axis of the material
- ❑ For each crack point BAMF_MDCrackAngle is added to the crack growth angle (θ) and the result ($\theta + \Phi$) is passed to AFGROW
 - BAMF modifies the new angle to be between 0 and 90°
- ❑ AFGROW uses the new angle to assign crack growth rates for each point



Multi-Directional Material Properties

StressCheck Model Information

Name	Description	Expression	Value	Limit	Class	Sort
BAMF_Debug			0.0000e+000		General	
BAMF_MDCrackAngle1			3.7000e+001		General	
C1P×0			5.0000e-002		General	
C1P×1			4.9207e-002		General	
C1P×10			7.4799e-004		General	
C1P×11			-8.1908e-003		General	
C1P×12			-1.5451e-002		General	
C1P×13			-2.2365e-002		General	
C1P×14			-2.8781e-002		General	
C1P×15			-3.4553e-002		General	
C1P×16			-4.0451e-002		General	
C1P×17			-4.4380e-002		General	
C1P×18			-4.7315e-002		General	
C1P×19			-4.9207e-002		General	
C1P×2			4.7315e-002		General	
C1P×20			-5.0000e-002		General	
C1P×3			4.4380e-002		General	
C1P×4			4.0451e-002		General	
C1P×5			3.4553e-002		General	
C1P×6			2.8781e-002		General	

Accept Delete Auto Step: 0.2
Input Settings

Materials

Material List

- General
- Data Set
 - C Direction
 - A Direction

Material name: Material
Description: Material Description

Material properties crack direction dependent

Interpolation transition angle: 0

OK Cancel Apply Add Delete Read Save Help

Materials

Material List

- General
- Data Set
 - C Direction
 - A Direction

Input values of Delta_K for da/dN values and up to 10 different R(stress ratio) da/dN values. Input Delta_K for R >= 0, input Kmax for R < 0.0

Name: AL 2024-T351

Number of da/dN Sets: 27 Number of R Sets: 1

da/dN	R	Value
da/dN[1]	1.00e-009	2.8
da/dN[2]	4.00e-009	2.93
da/dN[3]	1.10e-008	3.05
da/dN[4]	2.00e-008	3.15
da/dN[5]	4.00e-008	3.35
da/dN[6]	8.00e-008	3.69
da/dN[7]	1.10e-007	4
da/dN[8]	1.50e-007	4.53
da/dN[9]	1.80e-007	5.18
da/dN[10]	2.30e-007	5.8
da/dN[11]	3.00e-007	6.3
da/dN[12]	4.00e-007	6.6
da/dN[13]	6.00e-007	6.9
da/dN[14]	1.00e-006	7.2
da/dN[15]	1.50e-006	7.6
da/dN[16]	2.50e-006	8.2

OK Cancel Apply Add

Materials

Material List

- General
- Data Set
 - C Direction
 - A Direction

Input values of Delta_K for da/dN values and up to 10 different R(stress ratio) values. Matrix must have at least two R values and two da/dN values. Input Delta_K for R >= 0, input Kmax for R < 0.0

Name: AL 2024-T351

Number of da/dN Sets: 27 Number of R Sets: 1

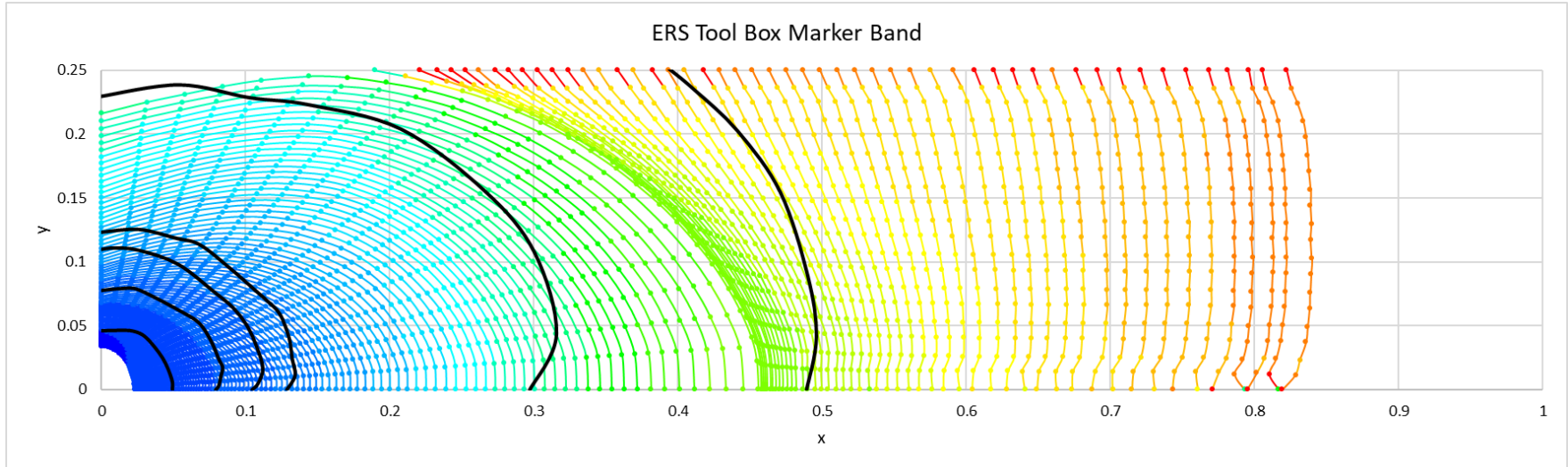
da/dN	R	Value
da/dN[1]	1.00e-009	2.8
da/dN[2]	4.00e-009	2.93
da/dN[3]	1.10e-008	3.05
da/dN[4]	2.00e-008	3.15
da/dN[5]	4.00e-008	3.35
da/dN[6]	8.00e-008	3.69
da/dN[7]	1.10e-007	4
da/dN[8]	1.50e-007	4.53
da/dN[9]	1.80e-007	5.3
da/dN[10]	2.30e-007	6.05
da/dN[11]	3.00e-007	6.75
da/dN[12]	4.00e-007	7.25
da/dN[13]	6.00e-007	7.85
da/dN[14]	1.00e-006	8.65
da/dN[15]	1.50e-006	9.4
da/dN[16]	2.50e-006	10.6

Ultimate Strength: 66
Young's Modulus: 10700
Coefficient of Thermal Expansion: 1.29e-005
Poisson's Ratio: 0.33
Upper limit on da/dN, DADNH: 0.1
Lower limit on da/dN, DADNLO: 1e-009
Plane Stress Fracture Toughness, KIC: 80
Plane Strain Fracture Toughness, KIC: 32
Delta K threshold value @R=0: 2.95
Yield Strength, YLD: 50
Lower limit on R shift (Max): 0.2
Upper limit on R shift (0, 1): 0.85

OK Cancel Apply Add Delete Read Save Help

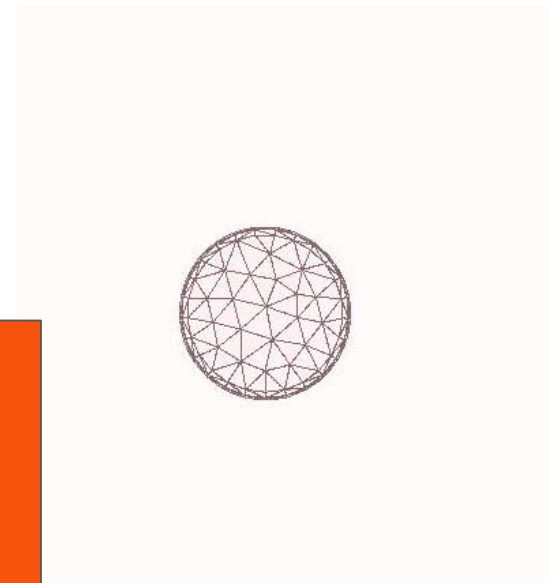
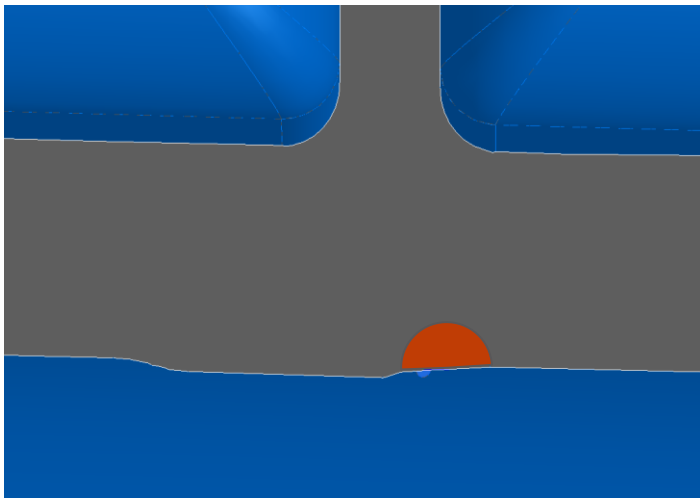
Excel Output

- ❑ Excel outputs have been updated to report the Max Kapp from AFGROW
- ❑ This allows for post-processing crack progression plots with K contours
- ❑ Large iteration counts takes a considerable time to plot figures



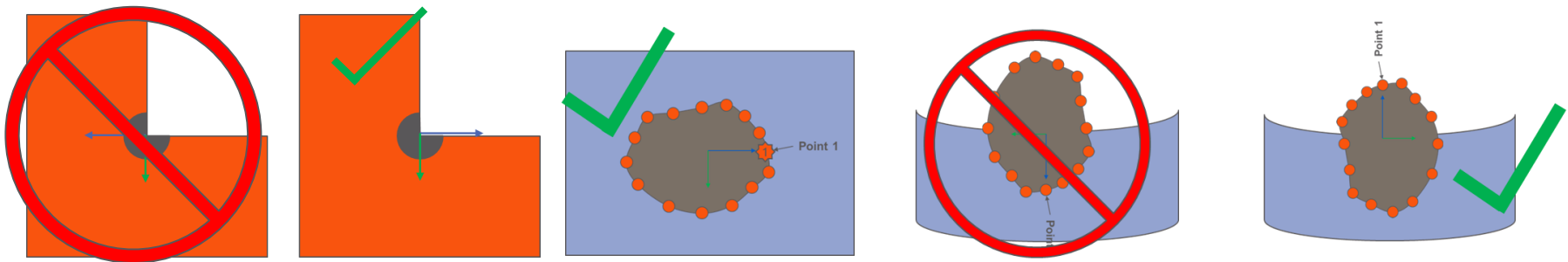
BAMF 360

- ❑ Previous versions of BAMF only allowed for cracks 180° or less
- ❑ Several situations arose where cracks growing through radii or into T sections required crack geometries greater than 180°
- ❑ New feature allows for imbedded cracks or surface cracks exceeding 180°



BAMF 360

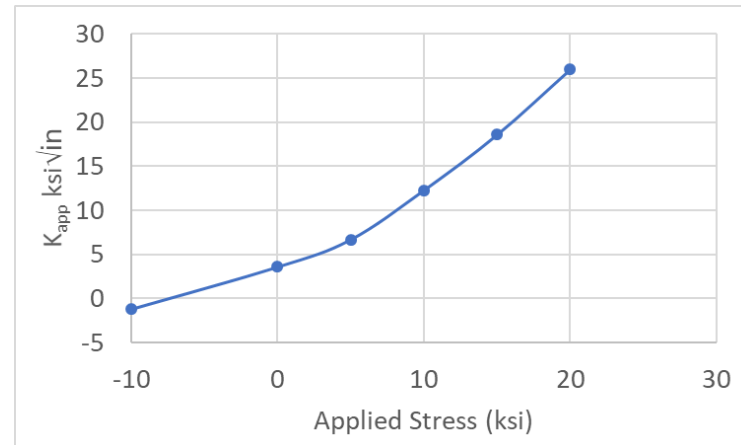
- ❑ Point 1 will remain on the nucleation systems x-axis
- ❑ For non-internal cracks the nucleation systems x-axis needs to be:
 - Outside the body, or
 - On a straight boundary
- ❑ Splines in StressCheck need to be created starting from point 1 and incrementally selecting points finishing at point 1
- ❑ For 360° cracks it is recommended to use 30+ points
- ❑ Code is still under development



BAMF Interference and Contact

- ❑ Traditionally BAMF/AFGROW assumes a linear stress intensity
- ❑ AFGROW is implementing capability to provide a table of stress intensity solutions and applied stresses
- ❑ BAMF will provide the capability to solve for multiple applied stresses and pass the table of stress intensities to AFGROW
- ❑ AFGROW will utilize this table to interpolate to a “correct” stress intensity

Applied Stress ksi	K_{app} ksi \sqrt{in}
-10	-1.2
0	3.6
5	6.7
10	12.3
15	18.6
20	26



BAMF FUTURE

Proposed Feature List from Previous Workshop

<u>Feature</u>	<u>Description</u>
Crack Failure	Stop analysis when a user defined number of points reach K_c
Abort Analysis	A button that allows the user to ABORT a run in the middle of the run
Multi-Channel Loading	Solve for multiple loading scenarios
Multi-directional material properties	Use directional material properties to grow each point
Integration with other FE tools	Ansys, NX (Funding Sources Phase 2 landing gear, A-10)
Model Builder Automation	Update the Excel based model builder to use local coordinate systems
K extrapolation	Extrapolate K to 0 using two different K extractions
K convergence checker	Solve for many p-levels and output K so user can confirm convergence
Multi-Crack Auto-Coalescence	(MCAC) When crack fronts intersect-automatically coalesce cracks
Crack Plane Symmetry	Crack Plane Symmetry
BAMF360	When Cracks are greater than 180-degrees
Analysis with Contact	Kmax and Kmin may not be linear when contact (neat/interference fit)
Units Causing K-Critical Failure	When using metric units $K_{critical}$ is 1000 less then it should be
Multi-Crack Extraction	Extraction parameters were not a function of crack number
3-D crack growth	Crack turning, out of plane crack growth

Proposed Feature List

<u>Feature</u>	<u>Description</u>
Multi-Channel Loading	Solve for multiple loading scenarios
Integration with other FE tools	Ansys, NX (Funding Sources Phase 2 landing gear, A-10)
K extrapolation	Extrapolate K to radius of 0 using two different K extractions
Multi-Crack Auto-Coalescence (MCAC)	When crack fronts intersect-automatically coalesce cracks
Filled Hole Analysis capability	Kmax and Kmin may not be linear when contact (neat/interference fit)
3-D crack growth	Crack turning, out of plane crack growth
K colored plots	Implement K colored plots into AFGROW outputs
Restart Analysis	Utilizing Extraction folder restart at last analysis point
Pause Analysis for UI	Allows user to pause an analysis to update the start.scw file
Custom Output files	Use a customizable .ini file to allow the user to tailor output files
Crack front splitting	When the crack front splits into multiple cracks