



**HILL**  
**ENGINEERING**

Predict. Test. Perform.

# The Future of BAMF

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Sept 20, 2017

# What is MuPMuC BAMF?

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**BAMF**

MultiPoint MultiCrack  
Broad Application for Modeling Failure

# BAMF Background

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## Broad Application for Modeling Failure (BAMF)

### Overview:

- BAMF is a software plug-in that couples FEA stress intensity calculations (StressCheck) with a crack growth engine (AFGROW)
- Originally developed by USAF (T-38 & A-10)

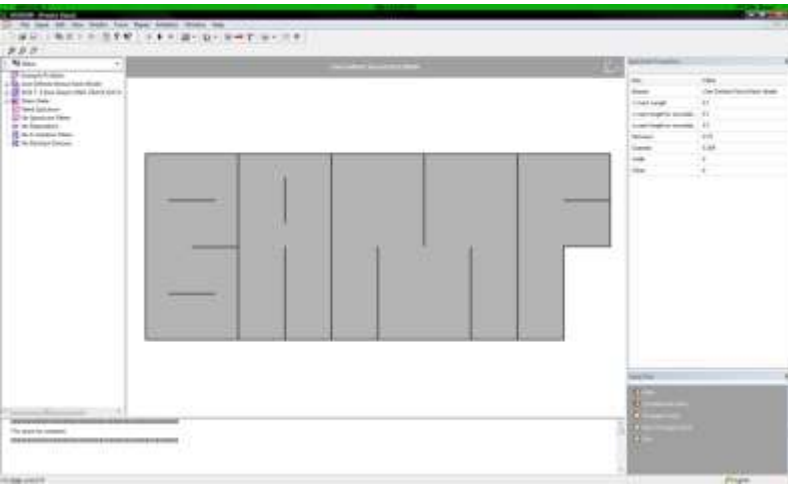
### Motivation:

- Need tool for addressing non-handbook-type configurations



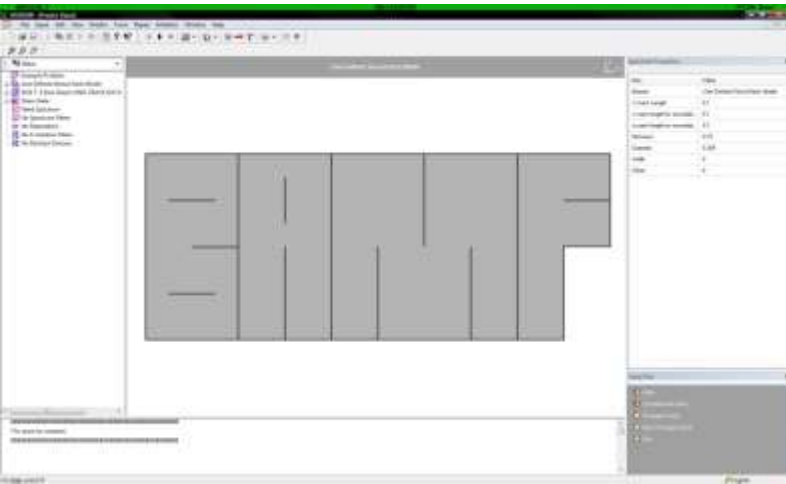
# What does MuPMuC do for you?

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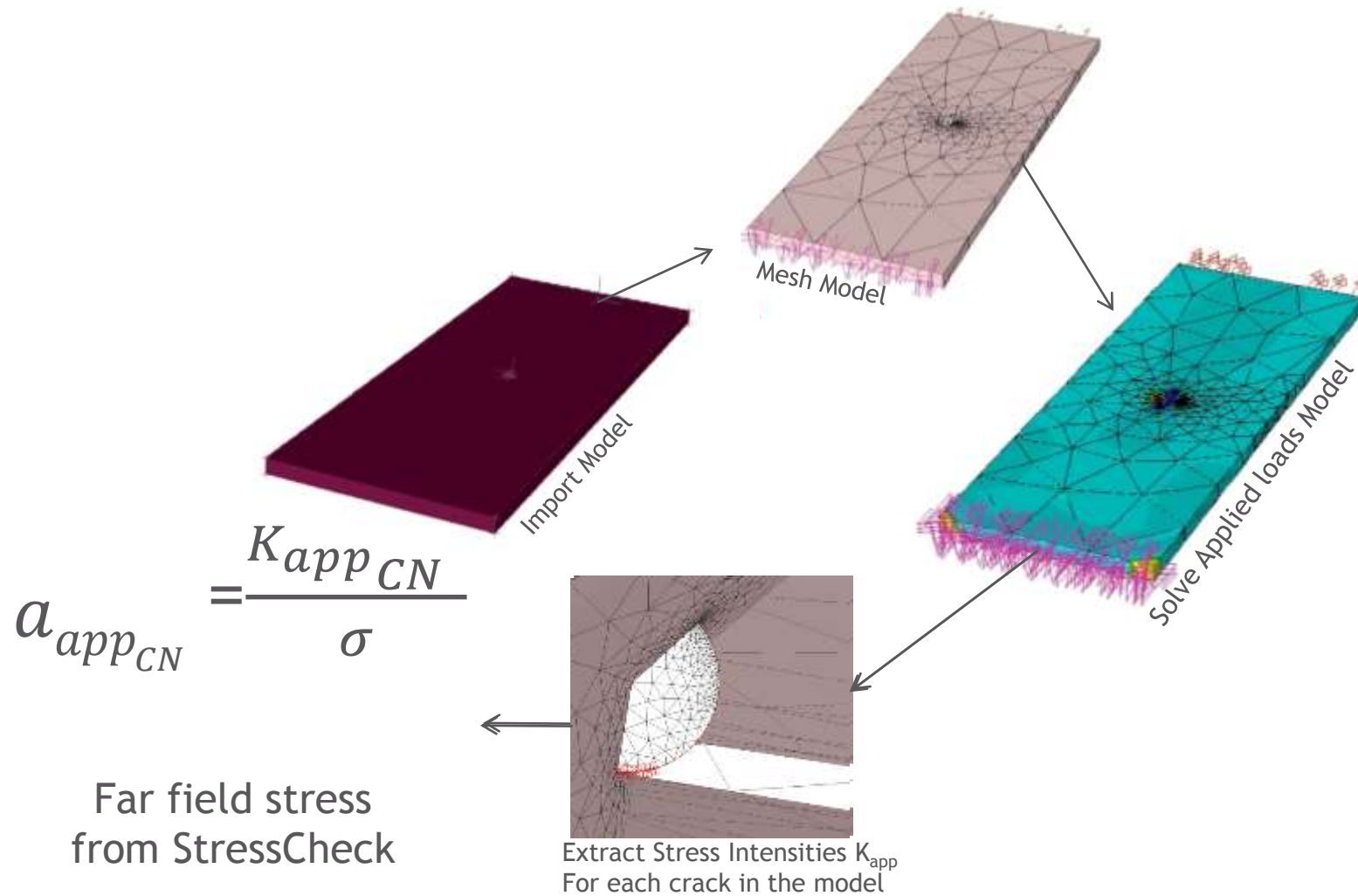


# What does MuPMuC do for you?

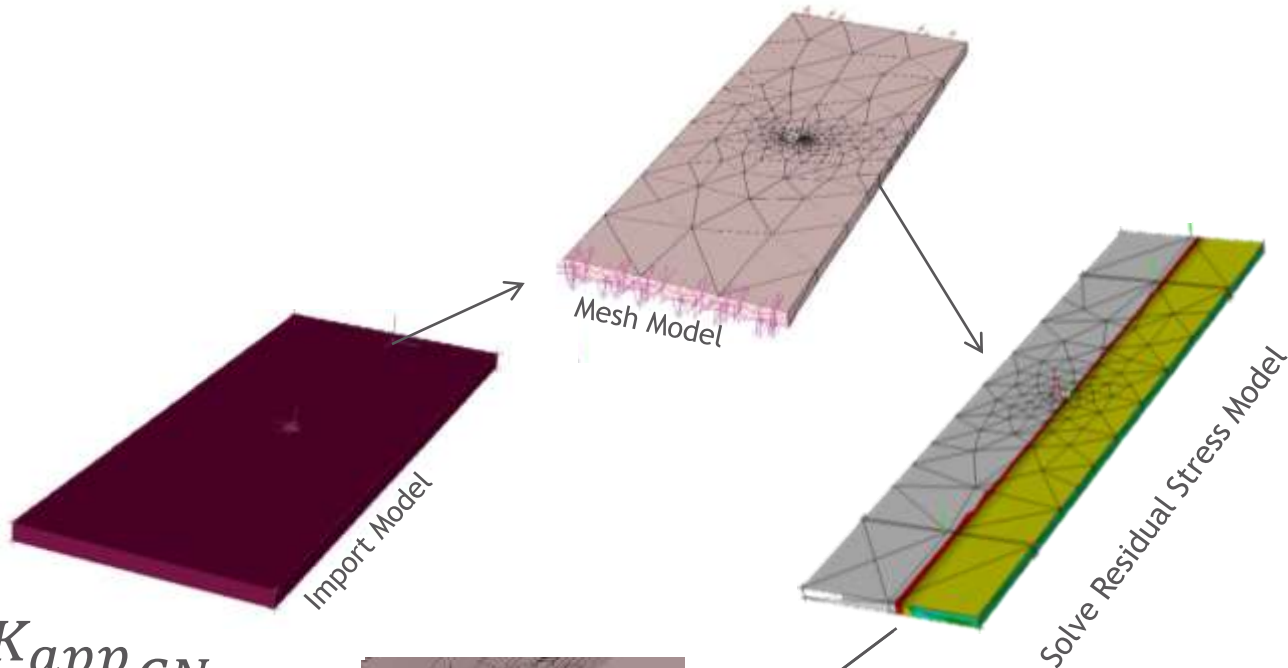
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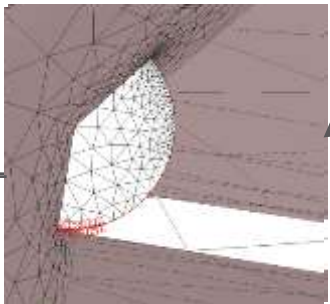
# What does MuPMuC do for you?



# What does MuPMuC do for you?

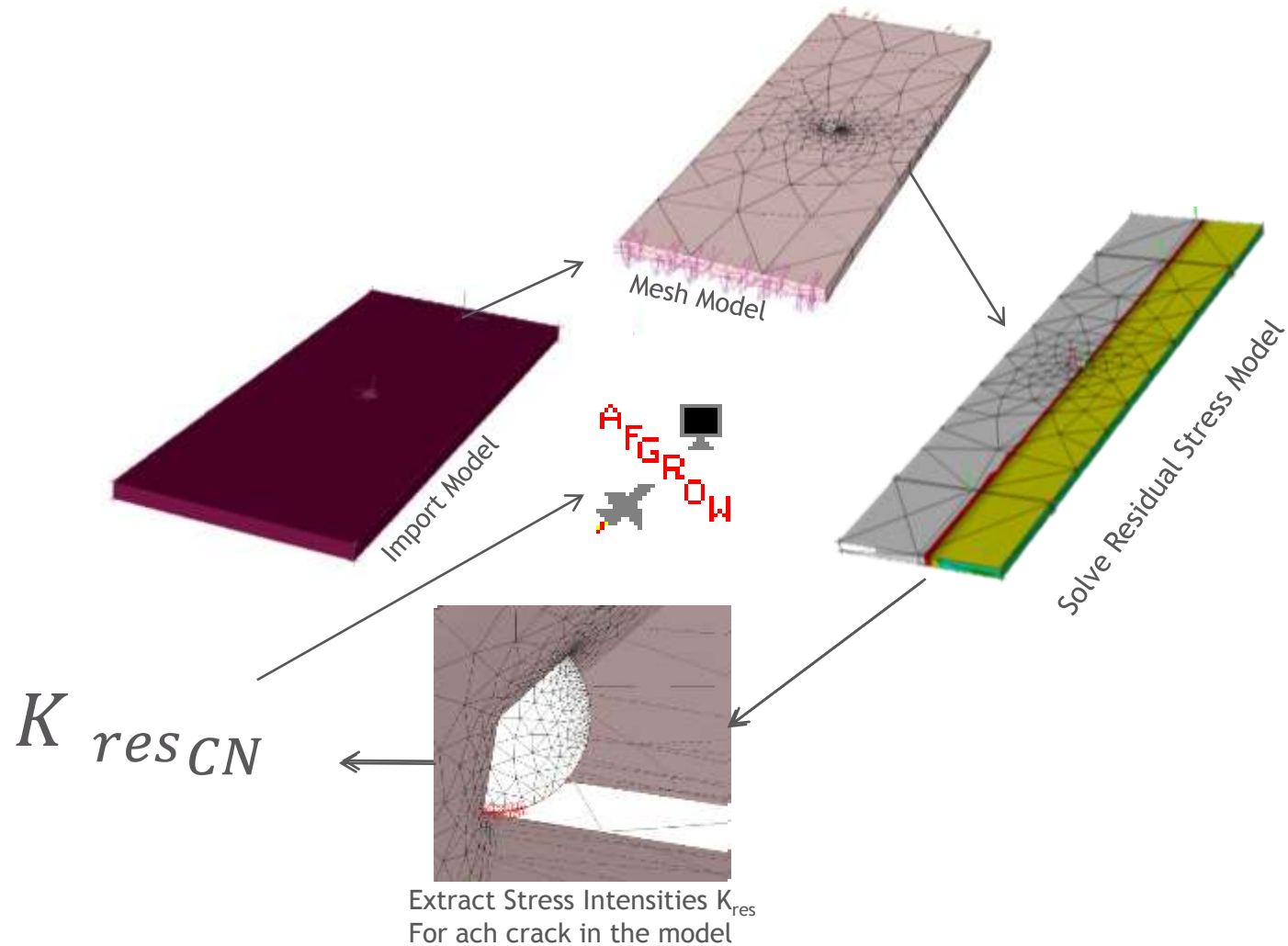


$$a_{appCN} = \frac{K_{appCN}}{\sigma}$$
$$K_{resCN}$$



Extract Stress Intensities  $K_{res}$   
For each crack in the model

# What does MuPMuC do for you?





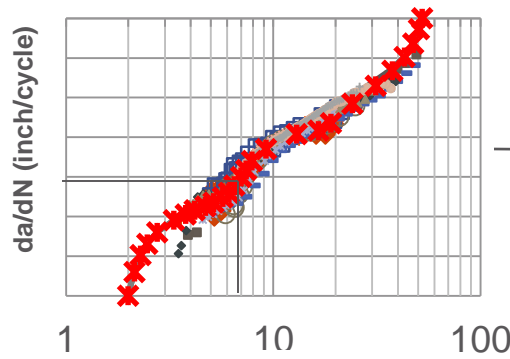
# What does BAMF do for you?

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

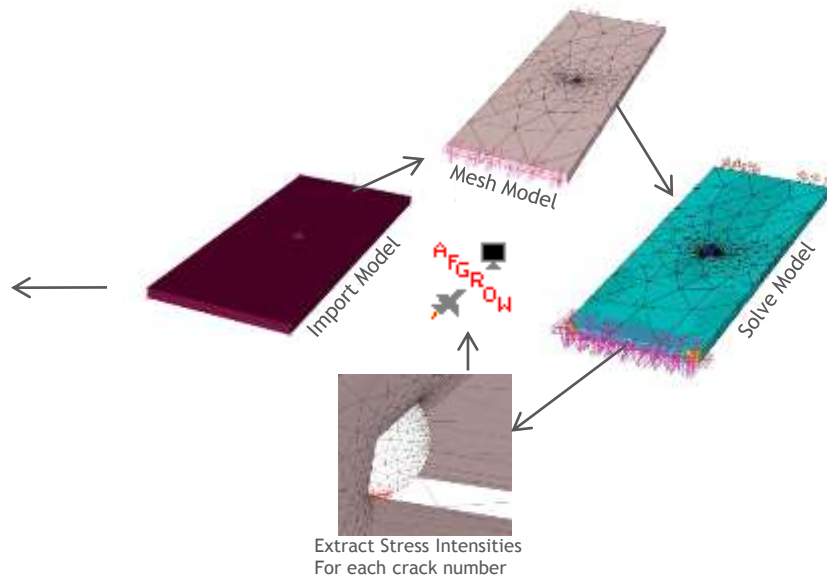
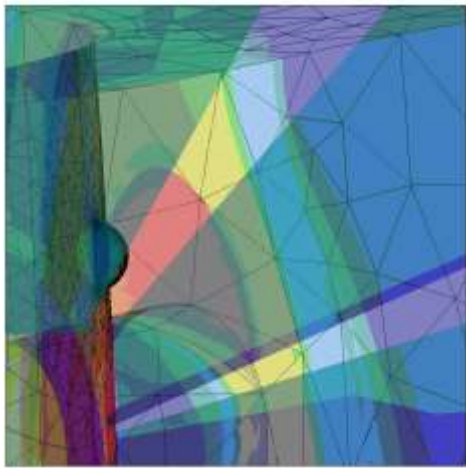
$$K_{max_{CN}} = a_{app_{CN}} \sigma_{max} + K_{res_{CN}}$$

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

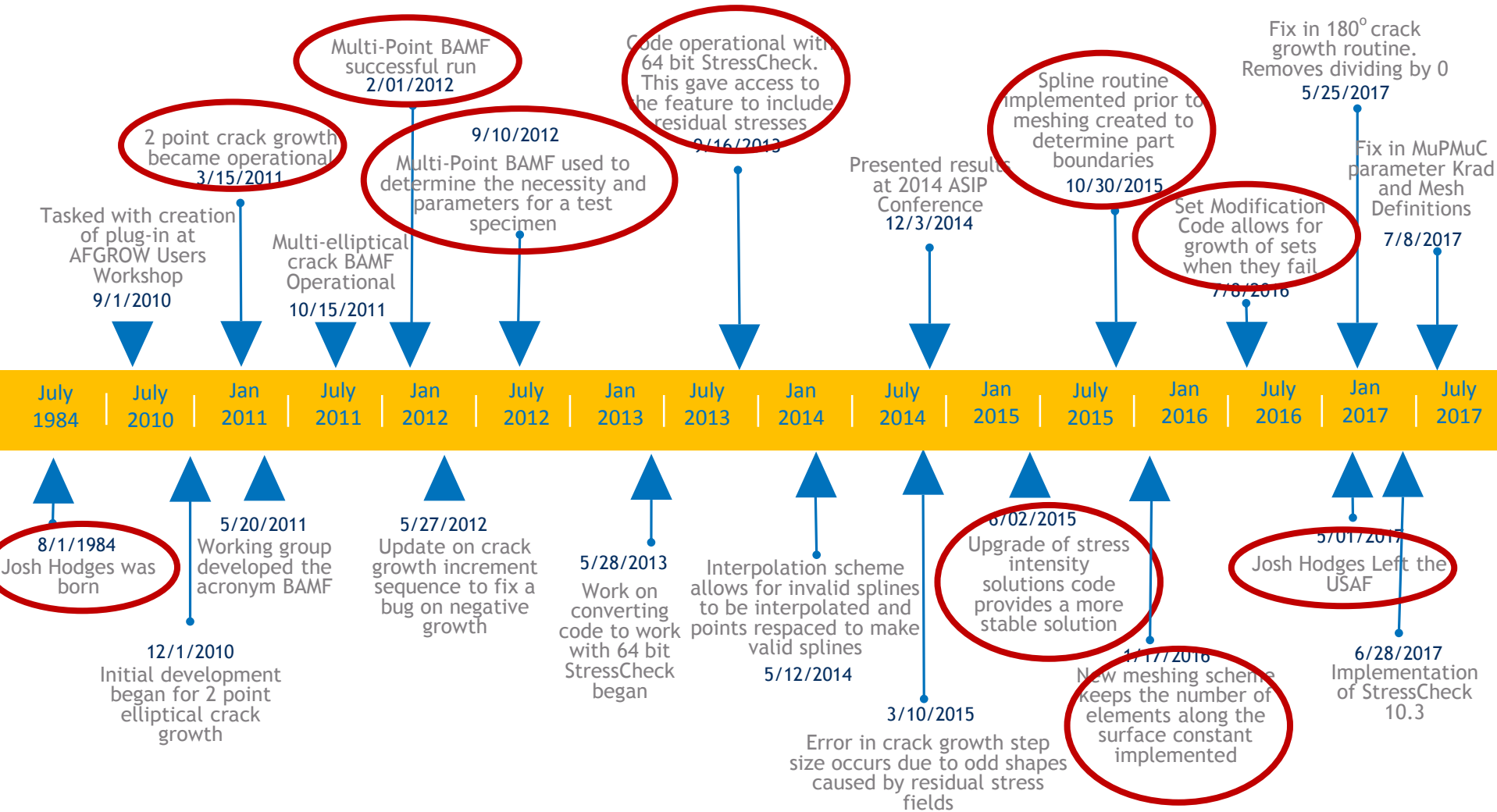
$$R_{CN} = K_{min_{CN}} / K_{max_{CN}}$$



→ New Crack Lengths



# The Complete History of BAMF



# BAMF Transition

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**BAMF was primarily developed by Josh Hodges while at T-38 USAF**

- Josh recently moved from the USAF to Hill Engineering

**To facilitate the continued viability of BAMF for use by USAF (and others) Hill Engineering plans to continue to update and maintain the software**

- We are currently developing a plan that specifies the project details
- We are actively looking for input from the user community

# Near-Term Plan

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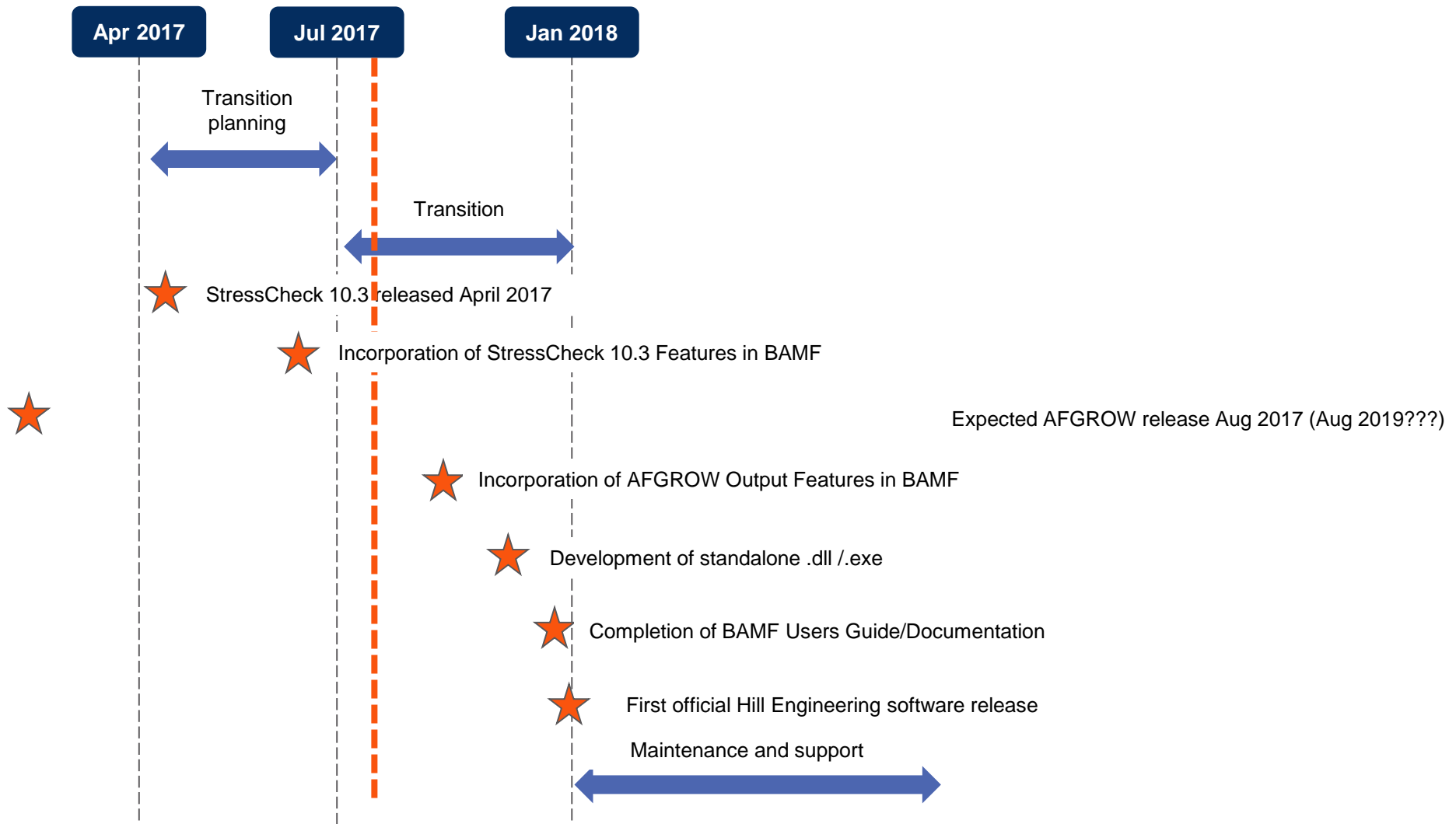
## Phase 1: Transition (Target completion: January 2018)

- Prepare updated software for release and distribution
  - Users Guide
  - Standalone .dll files
  - Handbook Models
- Provide interim releases to maintain compatibility with new StressCheck/AFGROW releases that occur in 2017
- Develop project funding

## Phase 2: Maintenance and support

- Release regular software updates to maintain compatibility with new StressCheck/AFGROW releases on an ongoing basis
- Provide software technical support, as available
- Identify opportunities for improvement/enhancement

# Near-Term Schedule



# BAMF Consortium

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## Hill Engineering will organize a software consortium to provide input and support of BAMF development

- Provides a mechanism for Hill Engineering to interact with core user group
- Provides a stable and ongoing revenue source
- Mimics AFGROW business plan

## Consortium benefits

- Connect with BAMF developers
- Receive priority support
- Invitation to participate in annual BAMF consortium meeting
- Ability to identify and prioritize desired new BAMF capabilities

# User Questionnaire

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## How frequently are you currently using BAMF

- How do you see your usage changing in the future
- How many others in your organization use BAMF
- What are some current limitations that prevent you from using BAMF more frequently

## What is your most typical BAMF application

- What is your most typical BAMF analysis (Multi-site damage, contact, residual stress, primary/secondary crack growth, etc...)

## What improvements would you like to see made to BAMF

- What would be the benefits of these improvements
- What type of complex analysis would you like to see improved on (Multi-site damage, contact, residual stress, primary/secondary crack growth, etc...)

## Are you interested to be a member of the consortium

- What is your process/timeline for funding

## Do you know any others who we should contact about introducing BAMF

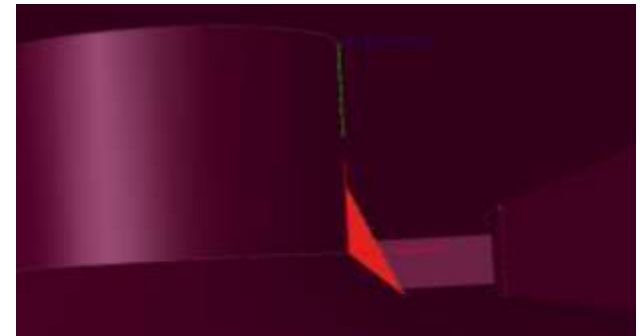
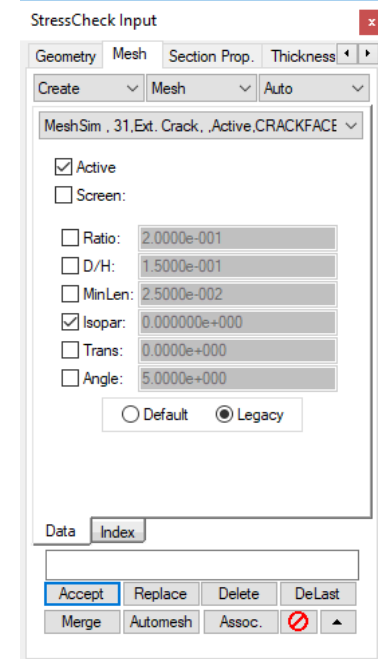
# Recent Updates

## StressCheck 10.3 Implementation

- StressCheck 10.3 has a new automesh
  - Option for legacy automesh still exists (Use Legacy until next SC Update)

## Set Creation

- StressCheck 10.3 allows for creation of sets programmatically using local coordinate system
- Sets can be created programmatically using the Nucleation set
- This feature will replace the need to build CRACKFRONT and CRACKFACE sets
  - Nucleation set and boundary condition sets will still required
- The feature is currently under testing to help understand the stability and effectiveness of set creation prior to full implementation.





# Recent Updates

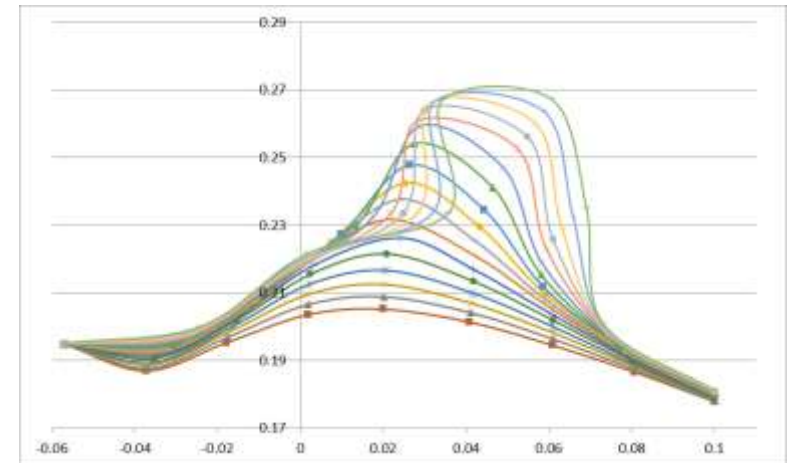
## 180° Crack Growth Bug Fix

- Crack growth was halting during crack growth of countersunk fasteners.
  - Occurs when a crack point was being divided by 0.  
$$Py(\text{Count} + 1, k, i) = Py(\text{Count}, k, i) - \text{delta}P(i, k) / \text{Sqrt}(\text{Slope}P(i) ^ 2 + 1) * (Py(\text{Count}, k, i) / \text{Math.Abs}(Py(\text{Count}, k, i)))$$
  - Removed  $(Py(\text{Count}, k, i) / \text{Math.Abs}(Py(\text{Count}, k, i)))$  and replaced with an if statement looking at the direction of the slope.
- X-direction crack growth with unique shapes was also providing negative growth
  - Added check for negative X step
  - Added check for a negative Y value

```
Output
P0= 0.049498 Beta Tension= 1.0428 Beta Compression= 1.0428 R(k)=13.6673 R(final)=0.1000 Delta k=6.0557e-001 D(I)/DN=0.0000e+000 Residual K=9.2633
P10= 0.2 Beta Tension= 0.5188 Beta Compression= 0.5188 R(k)=13.6673 R(final)=0.1000 Delta k=6.0557e-001 D(I)/DN=0.0000e+000 Residual K=9.2633
Max stress: 24.000. i = 0.10. 160000 Cycles. Constant amp. 161. Paso: 161

Clock #1
P0= 0.13047 Beta Tension= 1.1014 Beta Compression= 1.1014 R(k)=2.1915 R(final)=0.1000 Delta k=4.7839e+000 D(I)/DN=3.3006e-007 Residual K=12.1801
P1= 0.12788 Beta Tension= 1.1608 Beta Compression= 1.1608 R(k)=2.1915 R(final)=0.1000 Delta k=4.7839e+000 D(I)/DN=3.3006e-007 Residual K=12.1801
P2= 0.11166 Beta Tension= 1.1722 Beta Compression= 1.1722 R(k)=3.7854 R(final)=0.1000 Delta k=2.9592e+000 D(I)/DN=1.0714e-007 Residual K=12.7594
P3= 0.092006 Beta Tension= 1.3935 Beta Compression= 1.3935 R(k)=4.6943 R(final)=0.1000 Delta k=2.6958e+000 D(I)/DN=9.3965e-008 Residual K=14.3306
P4= 0.073285 Beta Tension= 1.6106 Beta Compression= 1.6106 R(k)=4.9792 R(final)=0.1000 Delta k=2.6575e+000 D(I)/DN=9.1784e-008 Residual K=14.9975
P5= 0.055326 Beta Tension= 1.8813 Beta Compression= 1.8813 R(k)=5.3359 R(final)=0.1000 Delta k=2.5748e+000 D(I)/DN=8.7143e-008 Residual K=15.5514
P6= 0.041324 Beta Tension= 2.3256 Beta Compression= 2.3256 R(k)=6.1468 R(final)=0.1000 Delta k=2.3491e+000 D(I)/DN=7.4964e-008 Residual K=16.3045
P7= 0.028164 Beta Tension= 2.9438 Beta Compression= 2.9438 R(k)=8.5377 R(final)=0.1000 Delta k=1.9354e+000 D(I)/DN=5.1304e-008 Residual K=18.5753
P8= 0.02013 Beta Tension= 2.1676 Beta Compression= 2.1676 R(k)=13.5670 R(final)=0.1000 Delta k=1.0526e+000 D(I)/DN=0.0000e+000 Residual K=15.9845
P9= 0.049498 Beta Tension= 1.0392 Beta Compression= 1.0392 R(k)=13.7143 R(final)=0.1000 Delta k=6.0157e-001 D(I)/DN=0.0000e+000 Residual K=9.2337
P10= 0.2 Beta Tension= 0.5170 Beta Compression= 0.5170 R(k)=13.7143 R(final)=0.1000 Delta k=6.0157e-001 D(I)/DN=0.0000e+000 Residual K=9.2337
Max stress: 24.000. i = 0.10. 165000 Cycles. Constant amp. 166. Paso: 166

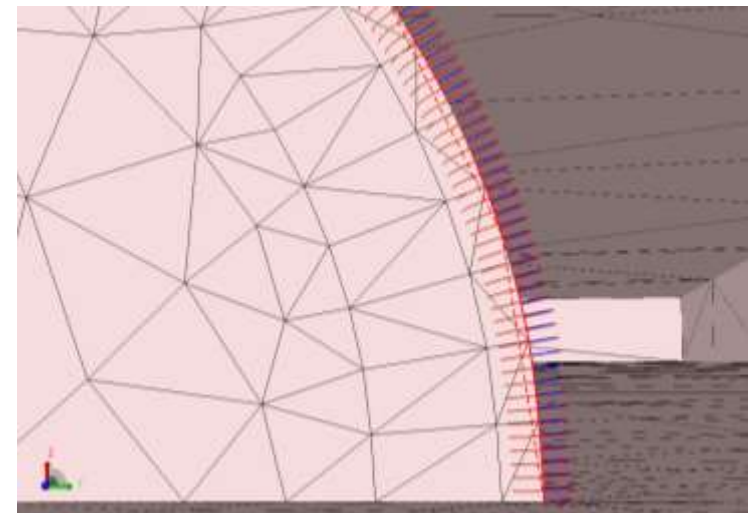
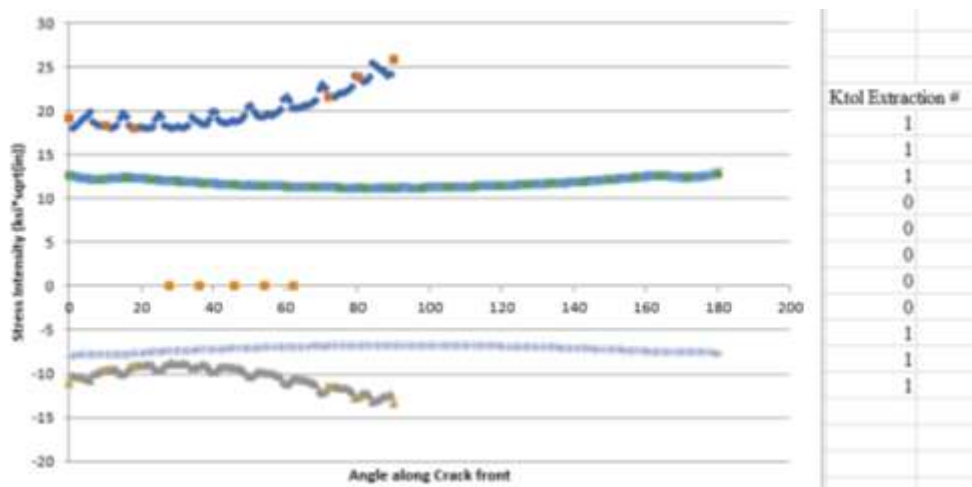
After the pass of the spectrum, growth was less than 1e-013. Total cycles (270000) Program halted.
```



# Recent Updates

## MuPMuC mesh and K-extraction not working properly

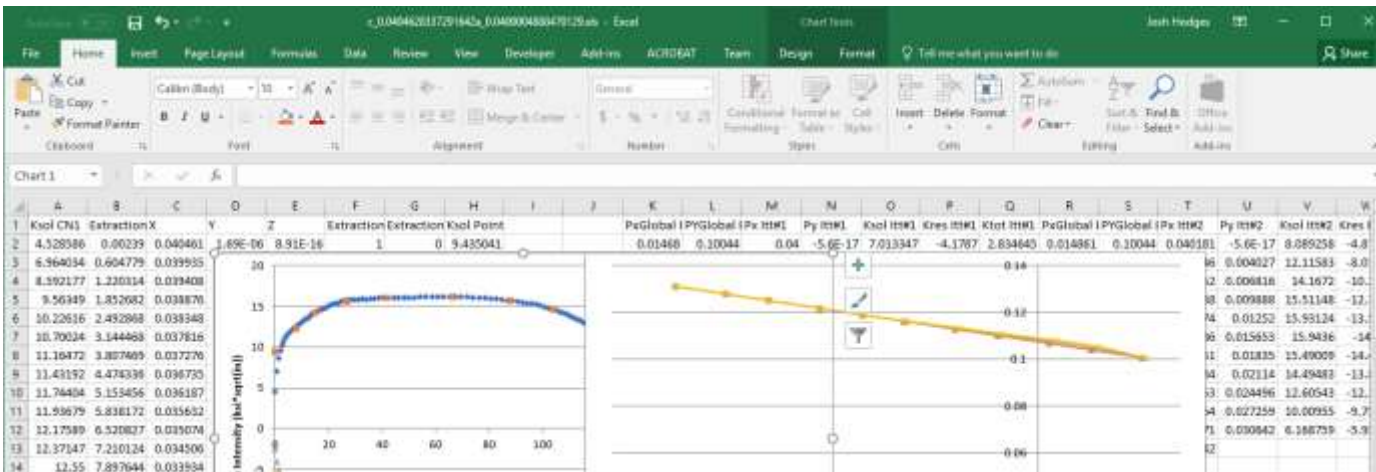
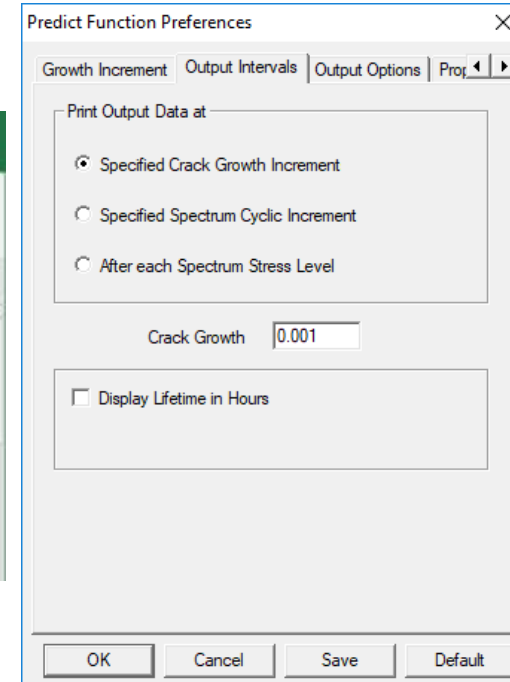
- $K_{tol}$  and  $K_{rad}$  were not vectors and were redefined using the dimensions of the secondary crack
- Two issues combined here to cause issues
  - $K_{rad}$  was too small causing extractions to be within the sacrificial elements
  - $K_{tol}$  was too small that for some points there was no K assigned
- Vectorizing parameters based on crack number solved the issue



# Recent Updates

## Post Processing

- Labels!!!
- Until next AFGROW release output every 0.001" to allow for comparisons of BAMF output/AFGROW output
- New AFGROW Output will be at same crack length of BAMF output



# Recent Updates

## USAF unable to load Visual Studio express on their computers

- Need a way to change parameters in code without having the code available
- Currently modifiable parameters
  - Number of elements along the crack front-BAMF\_ElementCF (18)
  - Tolerance of K-selection-BAMF\_Ktol (0.001)
  - Number of extraction points along the crack front-BAMF\_ExtractionPoints (45)
- Other default parameters to change?

Name	Description	Expressible	Value	Limit	Class	Sort
Px0			5.8800e-002		General	
Px1			4.5900e-002		General	
Px10			0.0000e+000		General	
Px2			4.8900e-002		General	
Px3			3.1900e-002		General	
Px4			7.8000e-002		General	
Px5			2.5900e-002		General	
Px6			7.8000e-002		General	
Px7			1.5900e-002		General	
Px8			1.8000e-002		General	
Px9			5.8800e-003		General	
<b>Px18</b>			<b>0.0000e+000</b>		<b>General</b>	
Py1			6.8800e-003		General	
Py10			5.8800e-002		General	
Py2			1.8800e-002		General	
Py3			1.5900e-002		General	
Py4			2.8800e-002		General	
Py5			2.5900e-002		General	
Py6			3.8900e-002		General	
Py7			3.8900e-002		General	
Py8			4.8800e-002		General	
Py9			4.5900e-002		General	
SL	Specimen Length		1.3000e+001		General	
Stress			2.4000e+001		General	
SW	Specimen Width		8.2000e+001		General	
Thickness			2.1000e+001		General	
TL	Total Length		1.5000e+001		General	
v			3.3800e-001		General	
_useipflag			1.0000e+000		General	
BAMF_Jtol			1.8800e-003		General	
BAMF_ElementCF			3.6000e+001		General	

# Summary

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**Hill Engineering intends to provide maintenance and support for BAMF**

- Effective immediately and extending into the future

**We are currently working to formulate a transition plan and would appreciate input from users of the software**

- Engage current users to understand their needs and priorities

**In the near-term Hill Engineering will use IR&D funding to update and maintain BAMF to be compatible with new StressCheck and AFGROW releases**

**Hill Engineering will develop a users document and handbook models for use with the program**

**Hill Engineering is forming a software consortium to provide direction/input and a stable funding source**

**First Hill Engineering BAMF release planned for Jan 2018**

**Awesome things are happening**



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# Thank You

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# Contact Information

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# Backup Slides

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The following slides are included for possible backup support:



# BAMF Features

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## Key features:

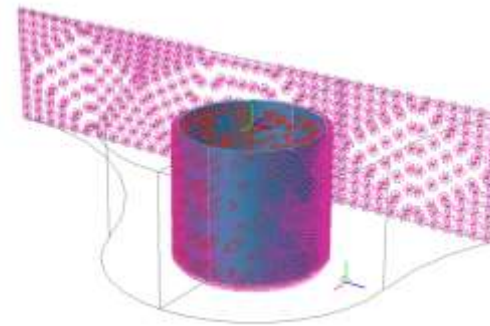
- 2-D planar growth
- Arbitrary crack shape evolution
- Many analysis points along crack front
- Full suite of AFGROW capabilities
  - Materials, spectra, retardation, etc.
- Multiple crack front support
- Surface based application of crack face traction



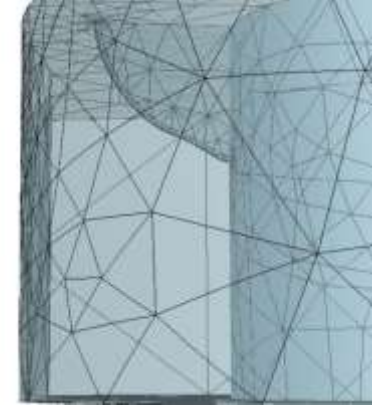
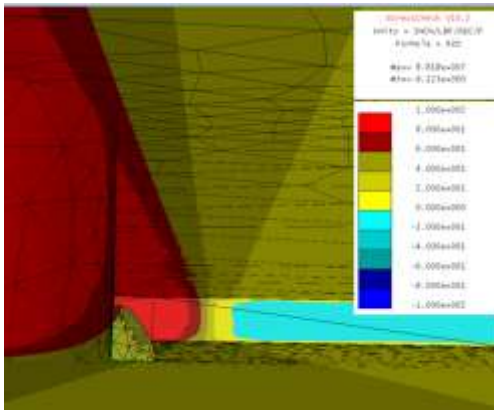
# BAMF Geometry, Loading, and Mesh

## Modeling capability:

- Full utilization of StressCheck™
  - Contact Solutions
  - Residual Stresses via CIM-LC



Fully automated mesh updating and refinement



# Example Crack Front Estimate

## Multi-Point Multi-Crack shape evolution

- 1-5 Cracks
- 2-45 points defining the crack front
- Points grow normal to the surface
- Growth defined by local stress intensity

