U.S. AIR FORCE

When a Single Crack Becomes Two: Modeling Through Crack Transition Using BAMF

Approved for public release: Unlimited distribution
Reference: 2020-09-10 WAA-0009 75abw-2020-0029

Connor Hood
A-10 Engineering Analysis, USAF
15 September 2020

Presentation Overview

- When is the through thickness transition necessary?
- Why the example geometry requires BAMF
- What happens if BAMF continues to run after the crack has grown through the thickness of the part?
- How to restart a BAMF model once the crack has grown through the thickness of the part

When Transitioning to a Through Crack is Necessary

- When a crack propagates through the thickness of your part and fracture toughness has NOT been exceeded.
- Occurs when the cross-section that the crack is growing within has a high aspect ratio

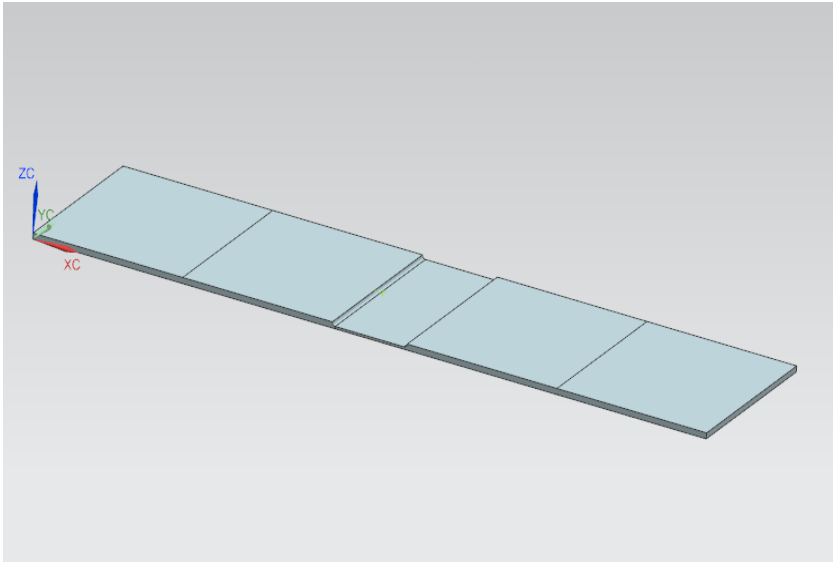


Figure 1: Model Example Isometric View

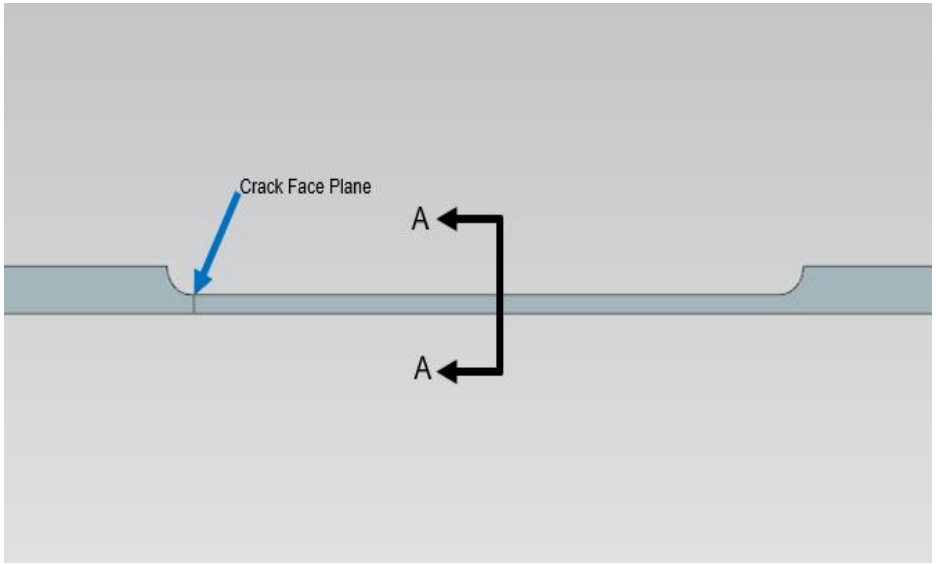


Figure 2: Model Example Front View

Model Example

- **When a center semi-elliptic surface flaw is placed within the crack plane the crack will propagate through the thickness of the part before the fracture toughness is exceeded.**

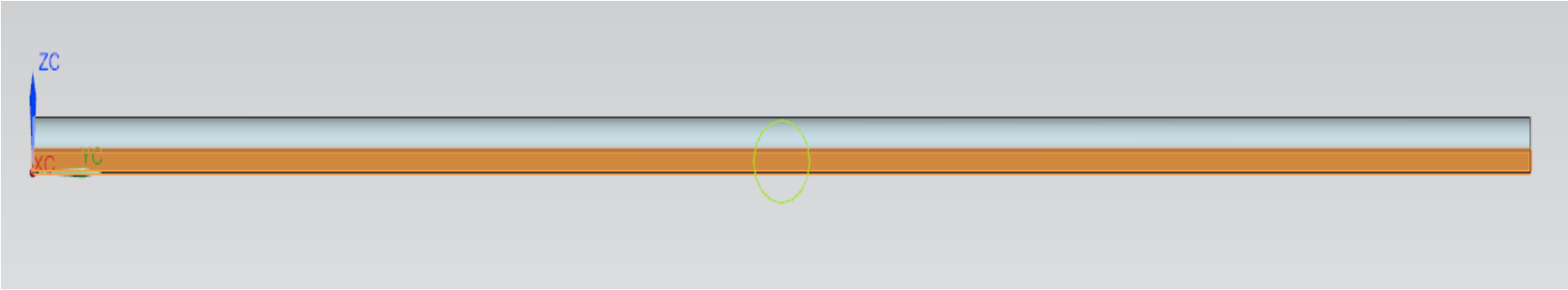
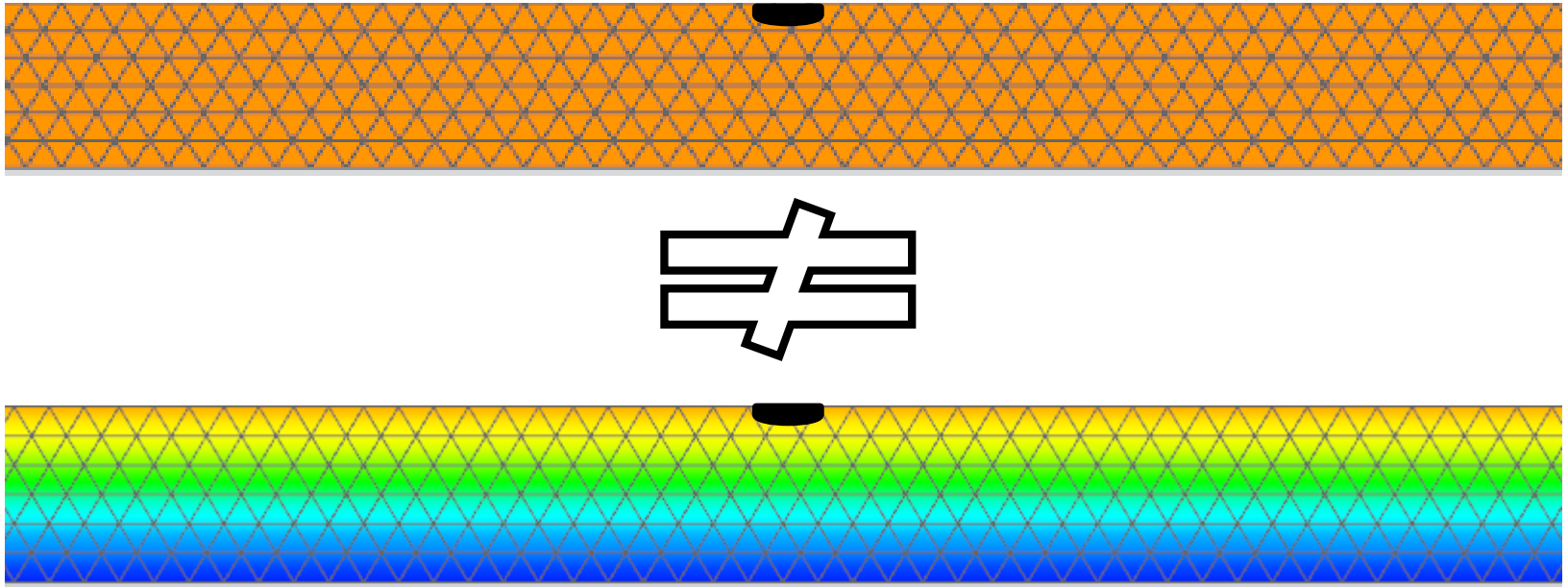


Figure 3: Section A-A from Figure 2. Crack Growth Plane highlighted in orange.

Figure 4: Example of Center Semi-elliptic Surface Flaw (image from AFGROW Application)

Why BAMF is Necessary

- Due to the part geometry stress within the crack plane varies through the thickness. Therefore, a classic AFGROW model will not suffice.
- Advanced AFGROW model can account this but what if the stress field varies along the length?



BAMF: Crack Propagation Through Thickness

- BAMF was used to model the crack propagation through the thickness of the material
- Model Parameters:
  - Crack type: semi-elliptic surface flaw
  - Initial flaw size: 0.030”

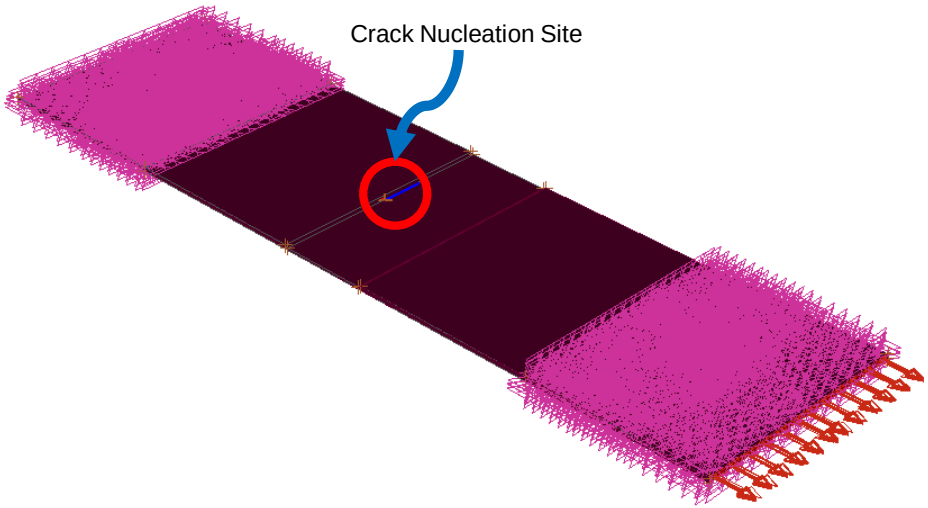


Figure 4: StressCheck model used with BAMF

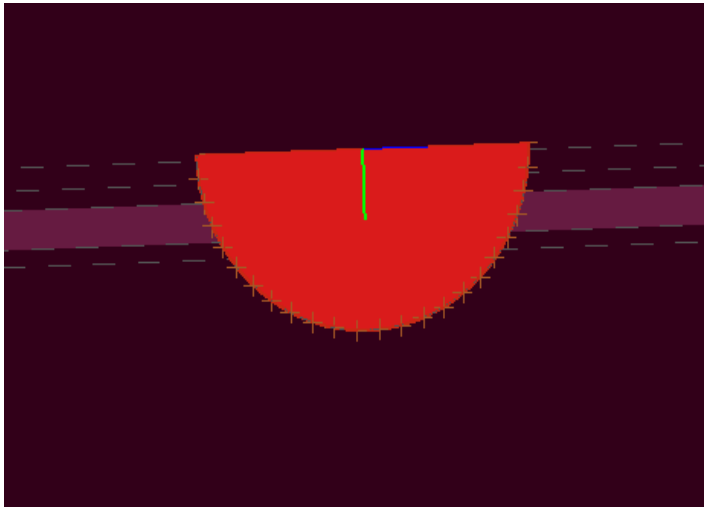


Figure 5: Initial Crack Geometry

Results: Crack Propagation Through Thickness

- The crack propagates through the thickness as displayed with Figure 6 and 7
- Maximum stress intensity: 18,437 $\mathbf{psi}\sqrt{in}$
- Fracture toughness: 32,000 $\mathbf{psi}\sqrt{in}$

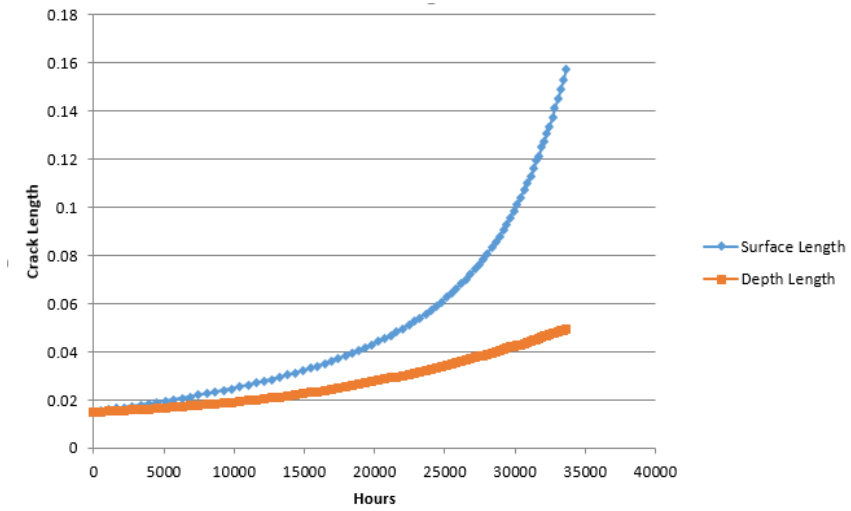


Figure 6: Crack Length vs. Flight Hours

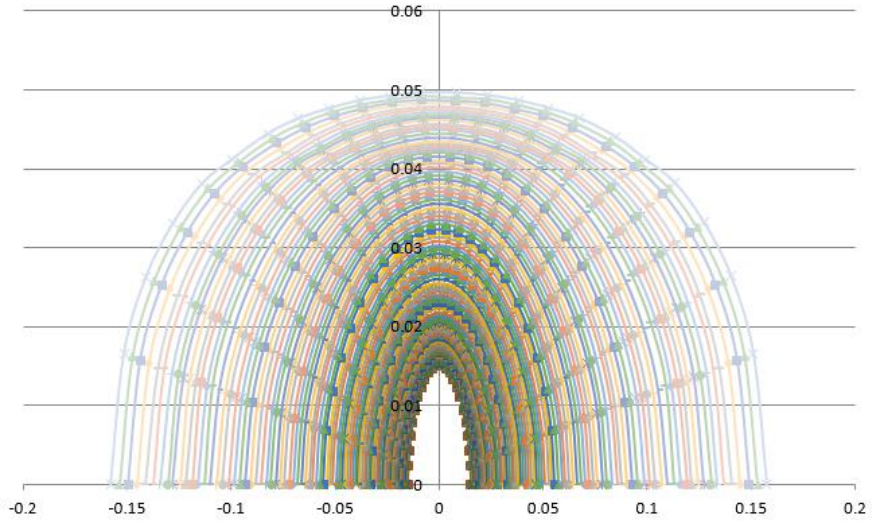


Figure 7: Crack Front Beachmarks

What Happens When the Model Continues to Run?

- **The crack only progresses in one direction providing inaccurate results**

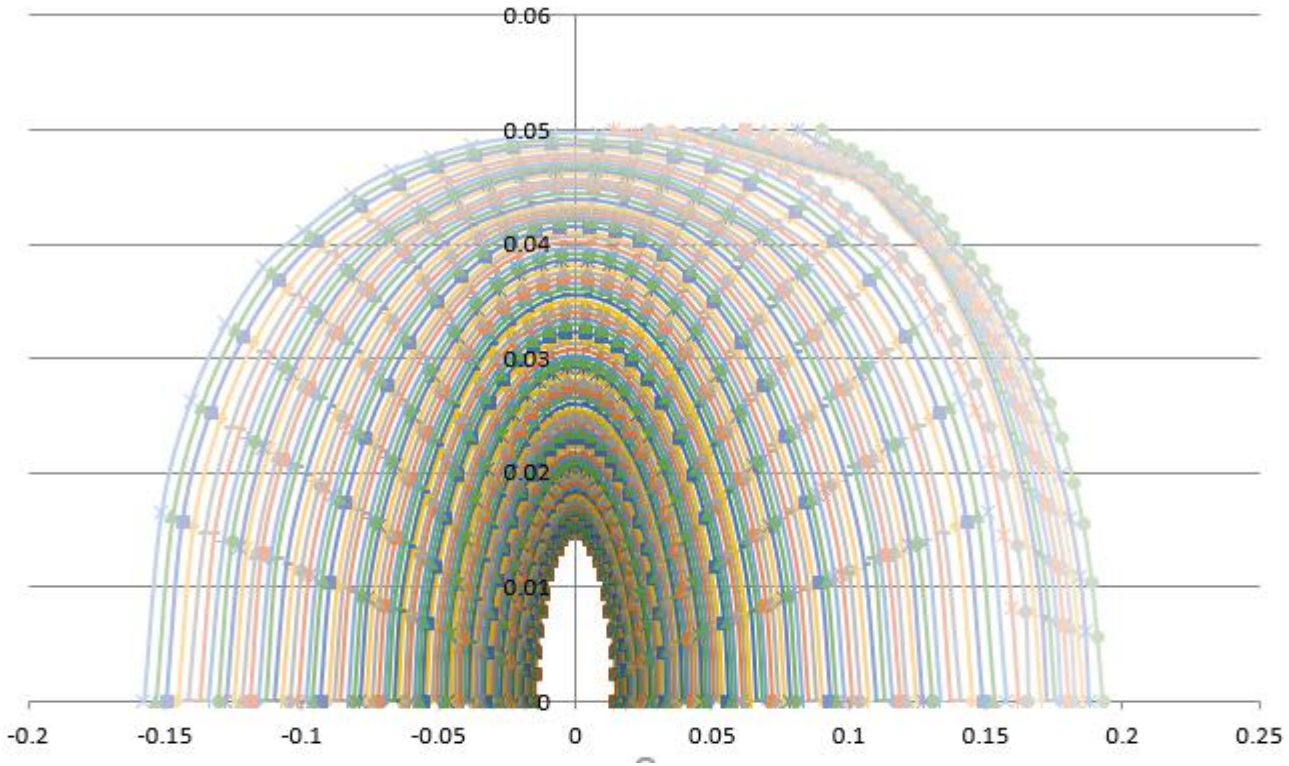


Figure 8: Resulting Crack Front Beachmarks if BAMF Proceeds Growing Crack

Why Does This Happen?

- **There is only one crack defined within the parameters of the StressCheck file, therefore, the crack only progresses in one direction**

StressCheck Model Information

Model Info | Parameters | Rules

Name	Description	Expression	Value	Limit	Class
C1PY12			1.4847e-02		General
C1PY13			1.4392e-02		General
C1PY14			1.3644e-02		General
C1PY15			1.2619e-02		General
C1PY16			1.1336e-02		General
C1PY17			9.8229e-03		General
C1PY18			8.1096e-03		General
C1PY19			6.2312e-03		General
C1PY2			4.2260e-03		General
C1PY20			4.2260e-03		General
C1PY21			2.1347e-03		General
C1PY22			-0.0000e+00		General
C1PY3			6.2312e-03		General
C1PY4			8.1096e-03		General
C1PY5			9.8229e-03		General
C1PY6			1.1336e-02		General
C1PY7			1.2619e-02		General
C1PY8			1.3644e-02		General
C1PY9			1.4392e-02		General
CrackAngle1			1.8000e+02		General
Cracks			1.0000e+00		General
Em			1.0500e+07		General
PointsCrack1			2.3000e+01		General
Stress			2.3714e+04		General
Thickness			5.0000e-02		General
v			3.3000e-01		General

Figure 9: StressCheck Model Parameter List

Modeling 2 Cracks Overview

- Determine parameters for 2 crack model using results from crack growth through thickness model
  - Determine which iteration to start from
  - Extract crack points from parameter file
  - Reassign crack points to new crack face
- Create .scp file for 2 crack model
  - 2 nucleation sites
  - 2 crack fronts
  - 2 crack faces

Determine Which Iteration to Start From

- Look through the “beachmarks” file generated by the single crack front BAMF run.
- Find the last iteration that is symmetric about the y-axis. This is one iteration before the crack starts growing in one direction.

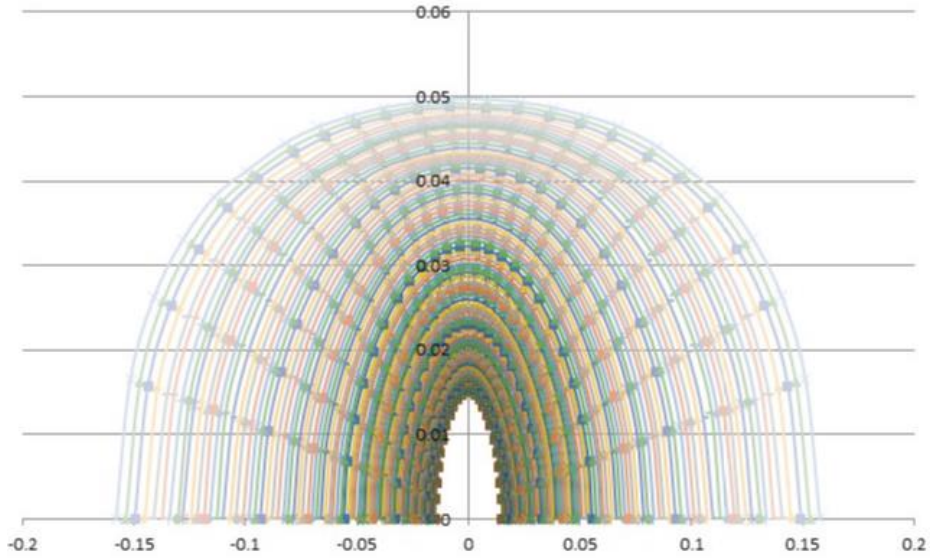


Figure 10: Beachmarks from iteration 79

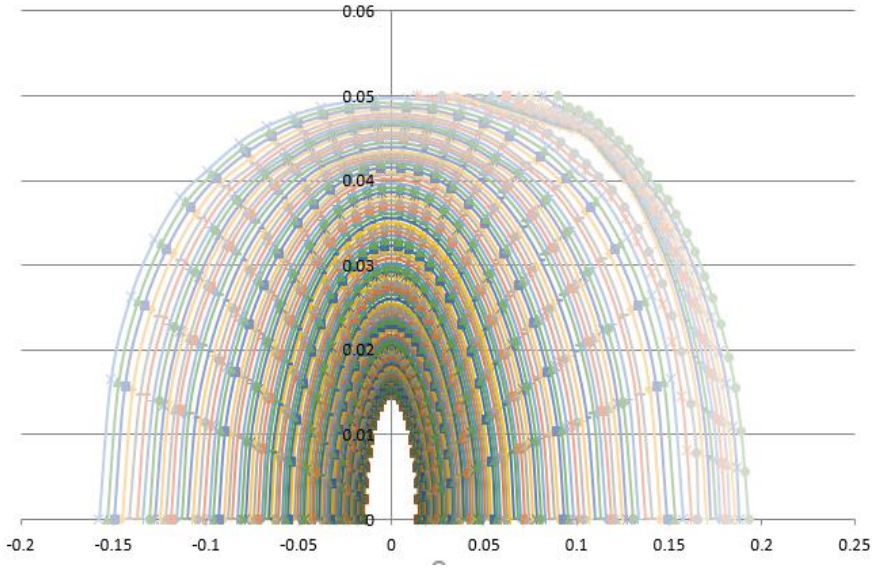


Figure 11: Beachmarks from following iterations

Extract Crack Points from Parameter File

- Open the parameter file for the iteration determined in the previous step (“Iteration_79.par”)
- Input each of these values into an Excel spreadsheet

Crack Front 1 Parameter				
C1PX0	0.15746		C1PY0	0
C1PX1	0.15107		C1PY1	0.016516
C1PX2	0.14033		C1PY2	0.026382
C1PX3	0.12727		C1PY3	0.0332
C1PX4	0.11346		C1PY4	0.03817
C1PX5	0.099093		C1PY5	0.041185
C1PX6	0.084689		C1PY6	0.044044
C1PX7	0.067232		C1PY7	0.046407
C1PX8	0.052062		C1PY8	0.047672
C1PX9	0.037952		C1PY9	0.04865
C1PX10	0.023282		C1PY10	0.049278
C1PX11	0.008603		C1PY11	0.049609
C1PX12	-0.00902		C1PY12	0.049618
C1PX13	-0.02369		C1PY13	0.049215
C1PX14	-0.03837		C1PY14	0.048627
C1PX15	-0.05301		C1PY15	0.047613
C1PX16	-0.06764		C1PY16	0.046344
C1PX17	-0.0822		C1PY17	0.04444
C1PX18	-0.09952		C1PY18	0.04116
C1PX19	-0.11388		C1PY19	0.038127
C1PX20	-0.12768		C1PY20	0.03315
C1PX21	-0.14076		C1PY21	0.026355
C1PX22	-0.15152		C1PY22	0.016524
C1PX23	-0.1579		C1PY23	0

Determine Where Crack Front Intersects Y-Axis

- Plot the crack front data and determine where it intersects the y-axis (in this case it's between points 11 and 12)
- Crack front 1 will be defined by points 0 to 11
- Crack front 2 will be defined by points 12 to 23

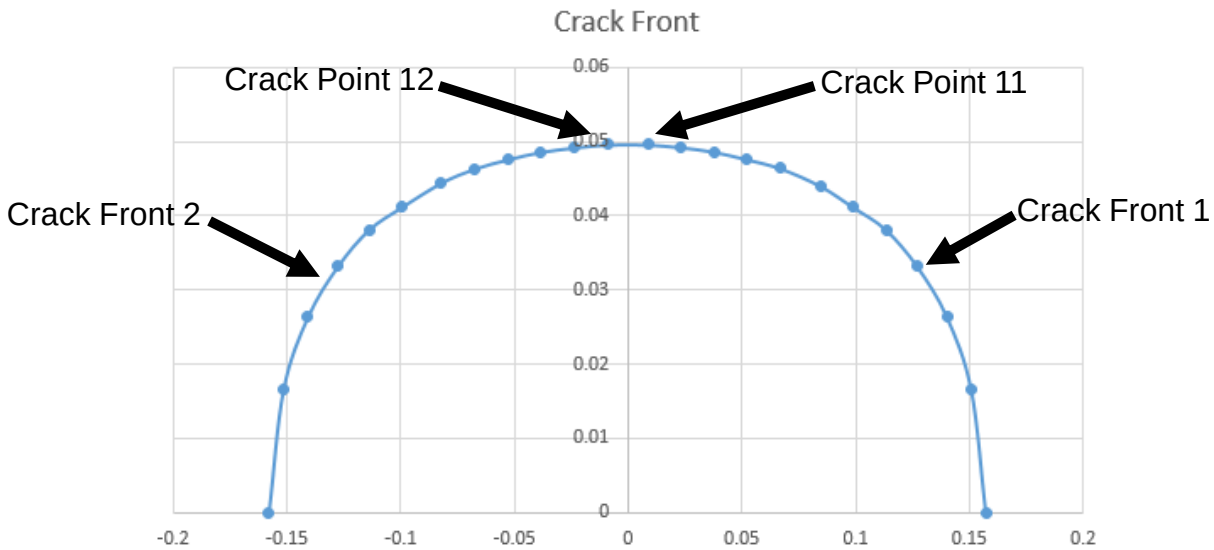


Figure 12: Crack front geometry from iteration 79

Rotate Second Nucleation System

- According to section 2.0.3.2 of Broad Application for Modeling Failure User's Guide Release 7.0 "The first point needs to be aligned with the local X axis"
- Therefore, the nucleation system for the second crack must be rotated 180-degrees about the y-axis of the local coordinate system of crack 1

Reassigning Crack Point Locations

- In order to conform with the BAMF User Guide the points for crack front 2 must be renumbered
- Additionally, each x value must be multiplied by -1

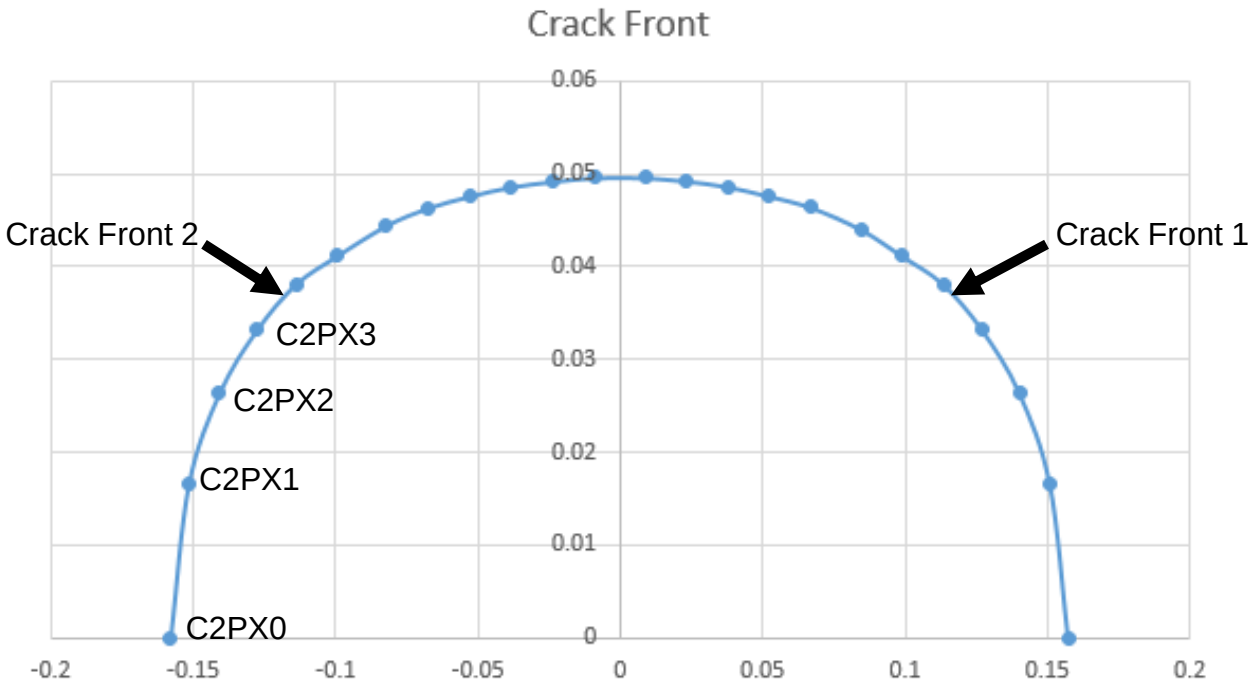


Figure 13: Crack front geometry from iteration 79

Assigning Additional Crack Points

- Add points <u>through thickness</u> at x = 0

Crack Front 1 Parameter				
C1PX0	0.15746		C1PY0	0
C1PX1	0.15107		C1PY1	0.016516
C1PX2	0.14033		C1PY2	0.026382
C1PX3	0.12727		C1PY3	0.0332
C1PX4	0.11346		C1PY4	0.03817
C1PX5	0.099093		C1PY5	0.041185
C1PX6	0.084689		C1PY6	0.044044
C1PX7	0.067232		C1PY7	0.046407
C1PX8	0.052062		C1PY8	0.047672
C1PX9	0.037952		C1PY9	0.04865
C1PX10	0.023282		C1PY10	0.049278
C1PX11	0.008603		C1PY11	0.049609
C1PX12	-0.00902		C1PY12	0.049618
C1PX13	-0.02369		C1PY13	0.049215
C1PX14	-0.03837		C1PY14	0.048627
C1PX15	-0.05301		C1PY15	0.047613
C1PX16	-0.06764		C1PY16	0.046344
C1PX17	-0.0822		C1PY17	0.04444
C1PX18	-0.09952		C1PY18	0.04116
C1PX19	-0.11388		C1PY19	0.038127
C1PX20	-0.12768		C1PY20	0.03315
C1PX21	-0.14076		C1PY21	0.026355
C1PX22	-0.15152		C1PY22	0.016524
C1PX23	-0.1579		C1PY23	0

Crack Front 1				
C1PX0	0.15746		C1PY0	0
C1PX1	0.15107		C1PY1	0.016516
C1PX2	0.14033		C1PY2	0.026382
C1PX3	0.12727		C1PY3	0.0332
C1PX4	0.11346		C1PY4	0.03817
C1PX5	0.099093		C1PY5	0.041185
C1PX6	0.084689		C1PY6	0.044044
C1PX7	0.067232		C1PY7	0.046407
C1PX8	0.052062		C1PY8	0.047672
C1PX9	0.037952		C1PY9	0.04865
C1PX10	0.023282		C1PY10	0.049278
C1PX11	0.008603		C1PY11	0.049609
★ C1PX12	0		C1PY12	0.0505

Crack Front 2				
C2PX0	0.1579		C2PY0	0
C2PX1	0.15152		C2PY1	0.016524
C2PX2	0.14076		C2PY2	0.026355
C2PX3	0.12768		C2PY3	0.03315
C2PX4	0.11388		C2PY4	0.038127
C2PX5	0.099515		C2PY5	0.04116
C2PX6	0.082199		C2PY6	0.04444
C2PX7	0.067642		C2PY7	0.046344
C2PX8	0.053013		C2PY8	0.047613
C2PX9	0.038365		C2PY9	0.048627
C2PX10	0.023694		C2PY10	0.049215
C2PX11	0.009017		C2PY11	0.049618
★ C2PX12	0		C2PY12	0.0505

Modeling 2 Cracks Generating .scp File

- Create an .scp file with the same geometry, boundary conditions, and loads as the single crack model
- Create a nucleation system at the same location as the single crack model
- Create another nucleation system at the same location that is rotated about the y-axis by 180-degrees

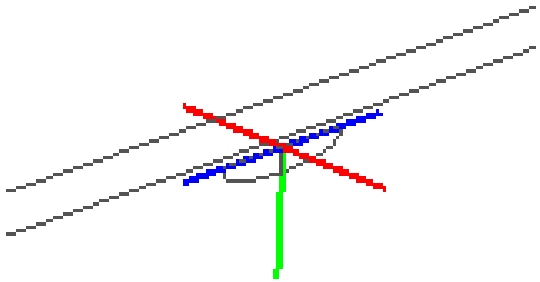


Figure 14: Two StressCheck systems rotated 180-degrees from each other

Modeling 2 Cracks Generating .scp File

- **Offset the second nucleation system by an amount that is greater than the crack length**

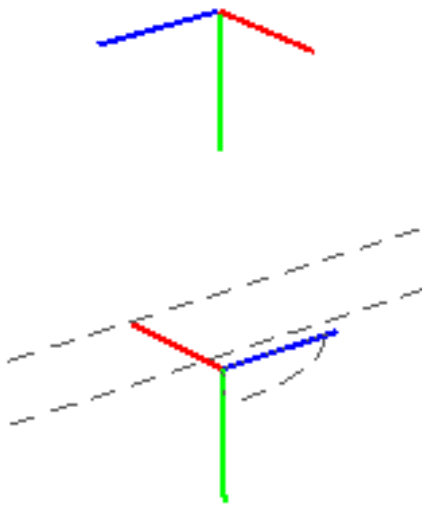


Figure 15: Resulting geometry after offsetting the second nucleation system

Imbedding First Crack

- **Follow the steps from 2.0.3.2 to 2.0.3.4 within the BAMF User's Guide to imbed the first crack**

Broad Application for Modeling Failure

User's Guide

Release 7.0

January 2020

Imbedding Second Crack

- 1. Follow the steps from 2.0.3.2 to 2.0.3.4 within the BAMF User's Guide BESIDES the Boolean Union
  - It's very important each point is created with "Local"
- 2. Update location of the second nucleation system

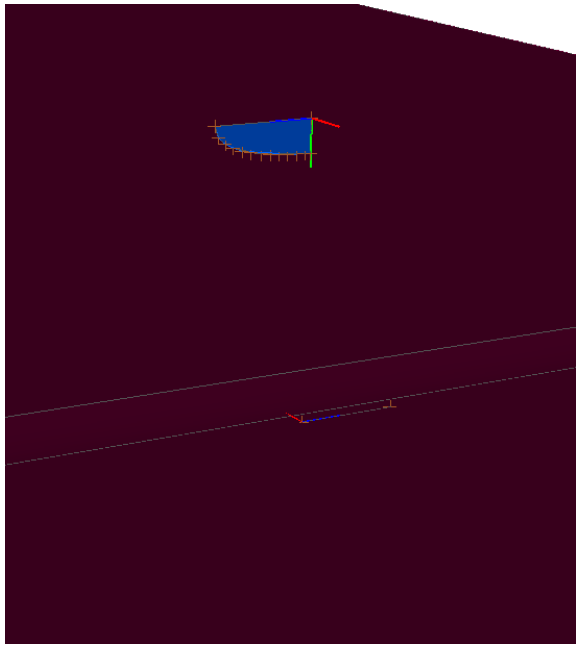


Figure 16: Results Step 1

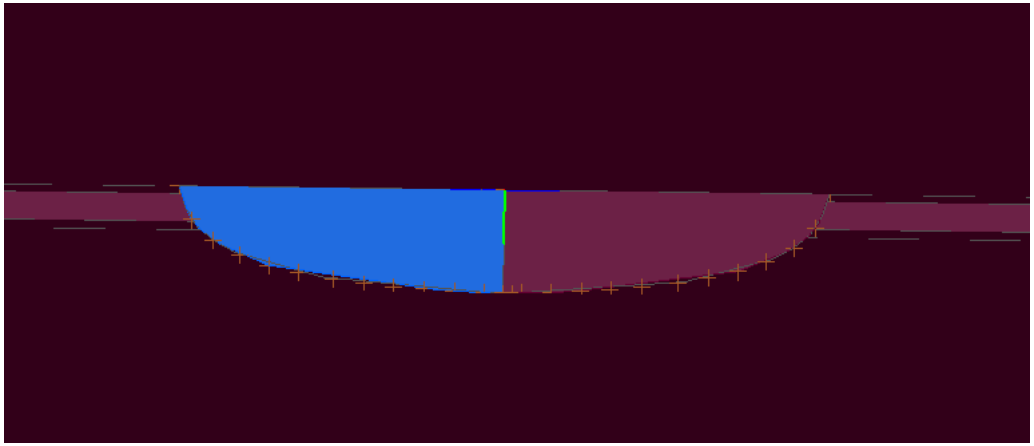


Figure 17: Results Step 2

Imbedding Second Crack

- **Perform Boolean Union between the crack face and other geometry**

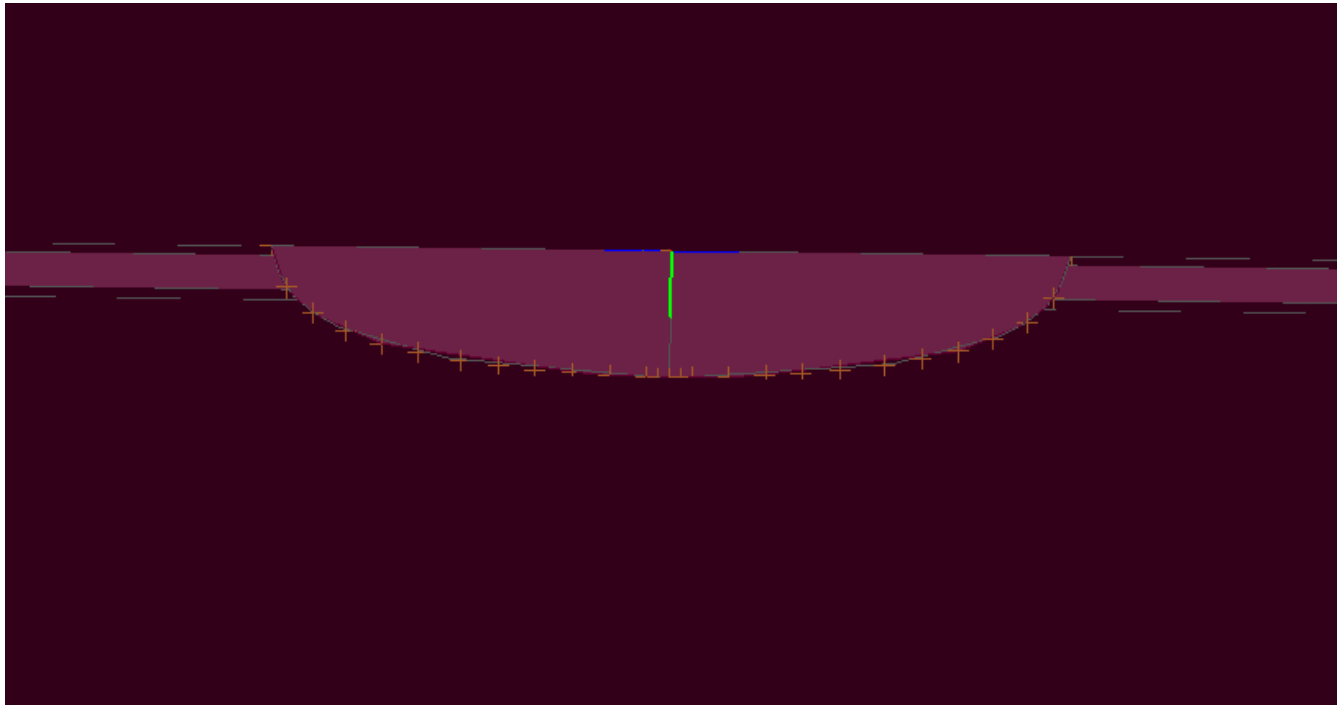


Figure 18: Resulting geometry after Boolean Union

Selection Sets

- **Select the nucleation site, crack face, and crack front for each crack as outlined within the BAMF User's Guide (Sections 2.0.5.1 to 2.0.5.4)**

Broad Application for Modeling Failure

User's Guide

Release 7.0

January 2020

Updating Model Parameters

- **Ensure that the required model parameters are defined within the parameters list**

CrackAngle1			9.0000e+01		General
CrackAngle2			9.0000e+01		General
Cracks			2.0000e+00		General
Em			1.0500e+07		General
PointsCrack1			1.3000e+01		General
PointsCrack2			1.3000e+01		General

Final Steps

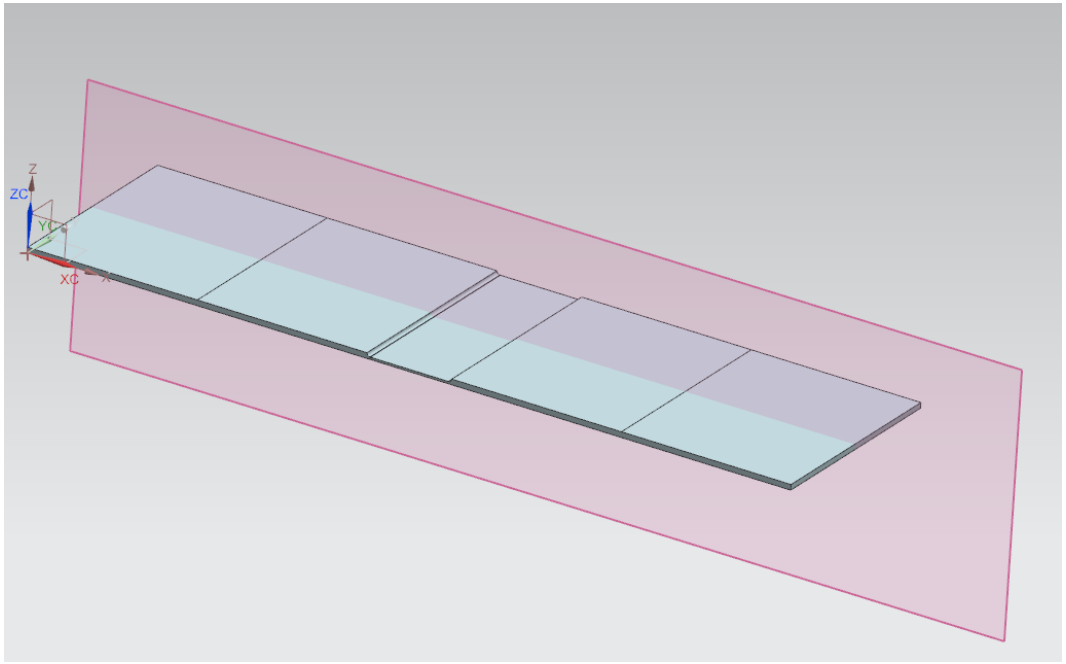
- Save and Close the StressCheck file
- Load the .scp into AFGROW
- Set up model parameters within AFGROW
- Run the model

Questions?

Additional Slides/Images

Restarting BAMF Model with 2 Crack Fronts

- **Disclaimer: For the given geometry the best option would be using a symmetry boundary condition along the center line of the test coupon.**



Restarting with 2 Crack Fronts Example Geometry

- Here is an example where a symmetry boundary condition CANNOT be applied