



U.S. AIR FORCE

A-10 Aft Cowl Cracking Analysis: An Example of Structural Digital Engineering

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A-10 Structural Analysis, USAF
AFGROW Users Workshop
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Acknowledgements

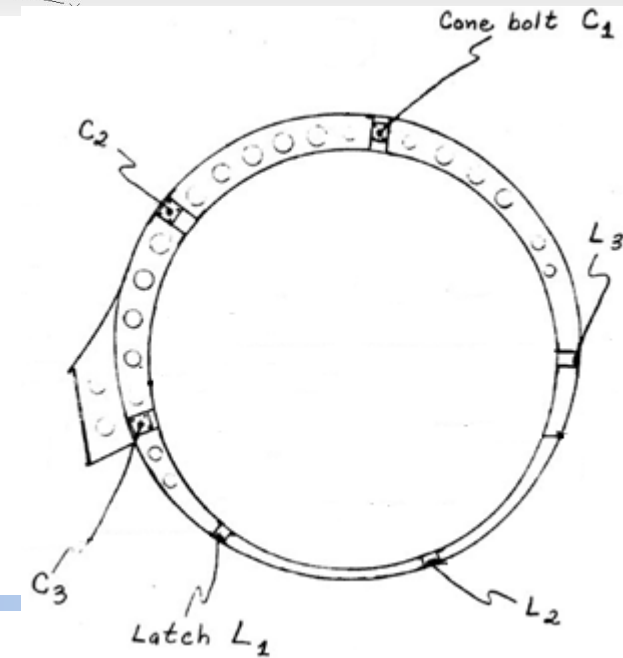
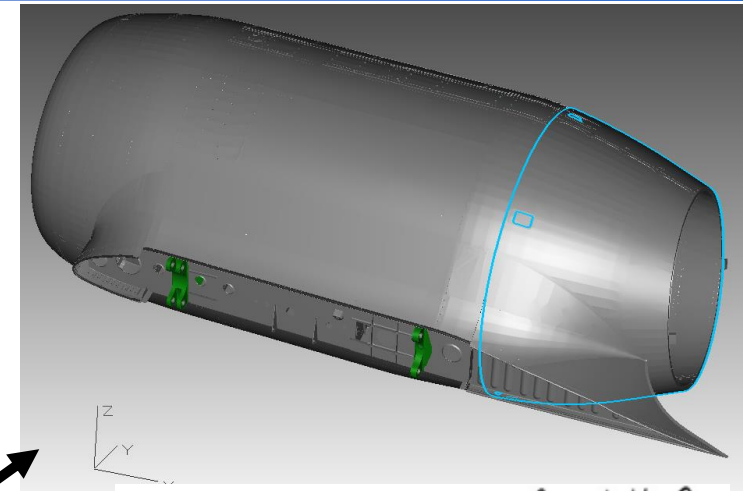
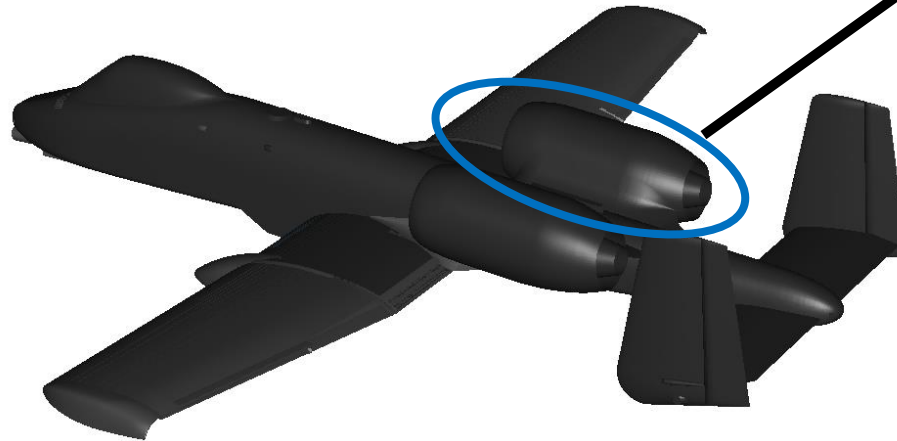
- Nathan Phillipps
- Jake Warner
- Tim Allred
- Reed Fawcett
- Lt Jim Demboski
- Greg Stowe
- Mike Worley
- Likely others I have missed...

***Team Effort
Thanks all!***



Background

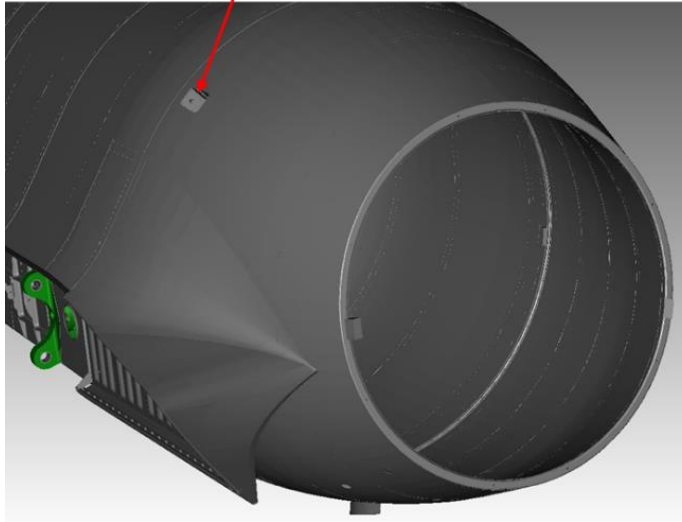
- Fleet inspection TCTO found significant cracking in aft cowl attachment locations
 - Aft cowl attached at 6 points
 - 3 cone fittings
 - 3 latches
 - Cracking located in support fitting and intercostals for cone fittings



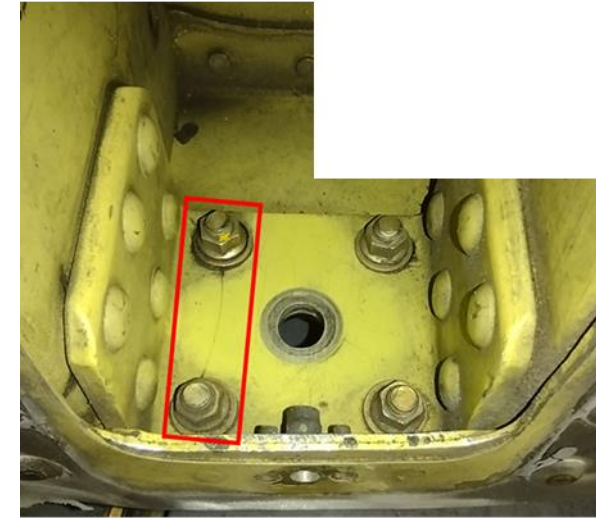
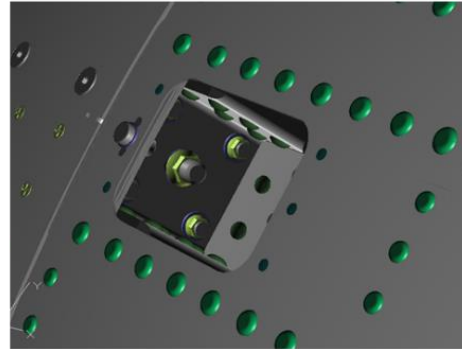


Detailed Location and Cracking

C2 location with cover plate removed



C2 location with cover plate removed close-up

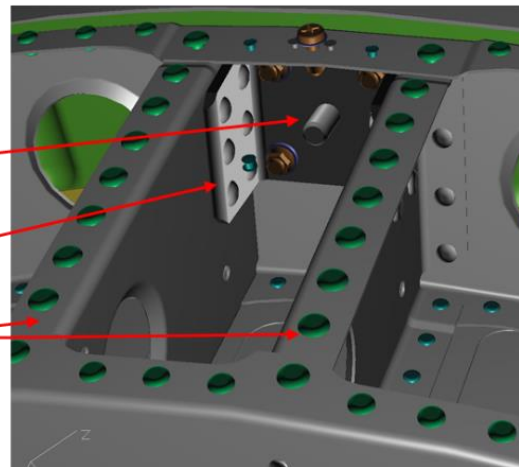


Support Fitting Cracking

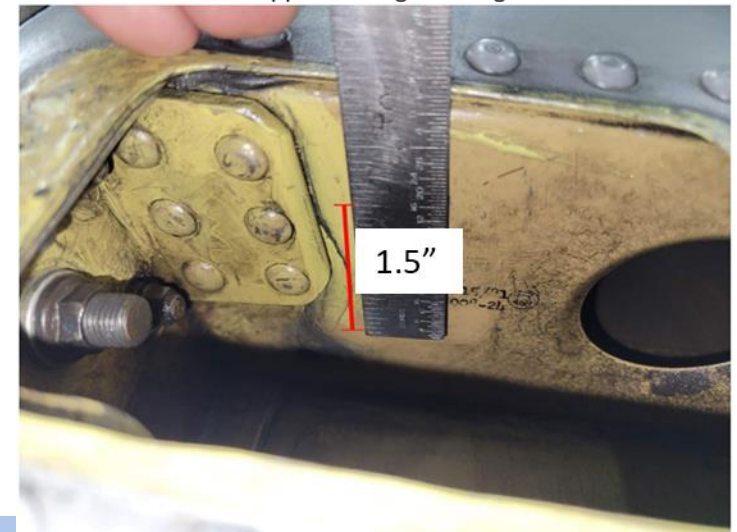
Attachment Cone

Support Fitting

Intercostals



C2 with skin removed



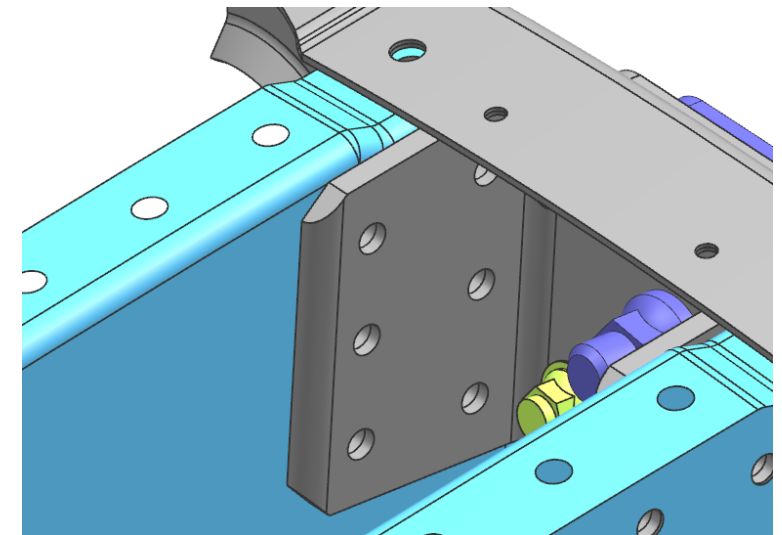
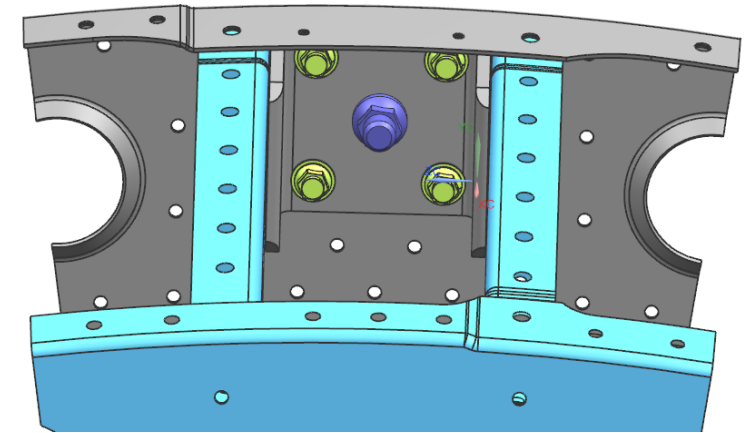
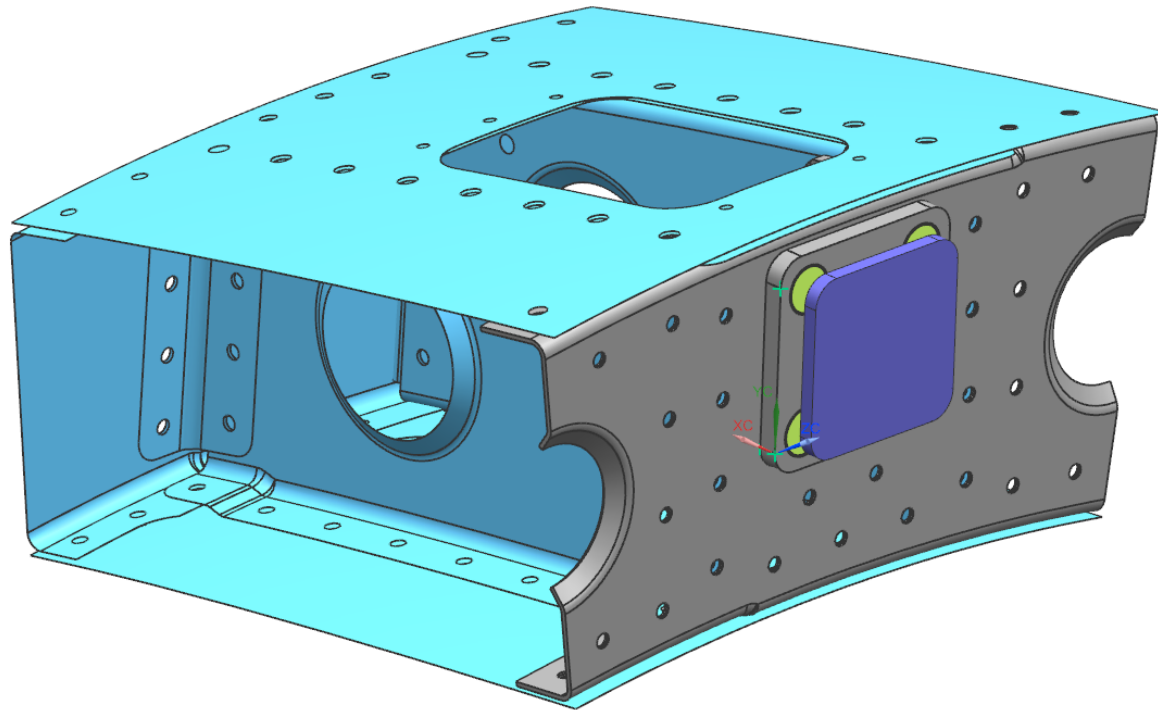
Intercostal Cracking

See Distribution Statement on Title Slide



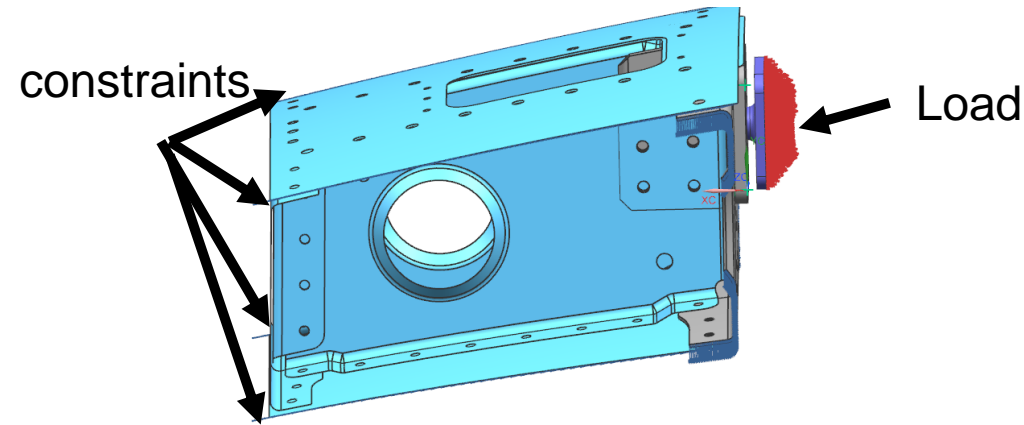
Sub Assembly Model

- Created Nastran model to understand reactions to applied load and load redistribution due to cracking
- Existing models enabled quick development

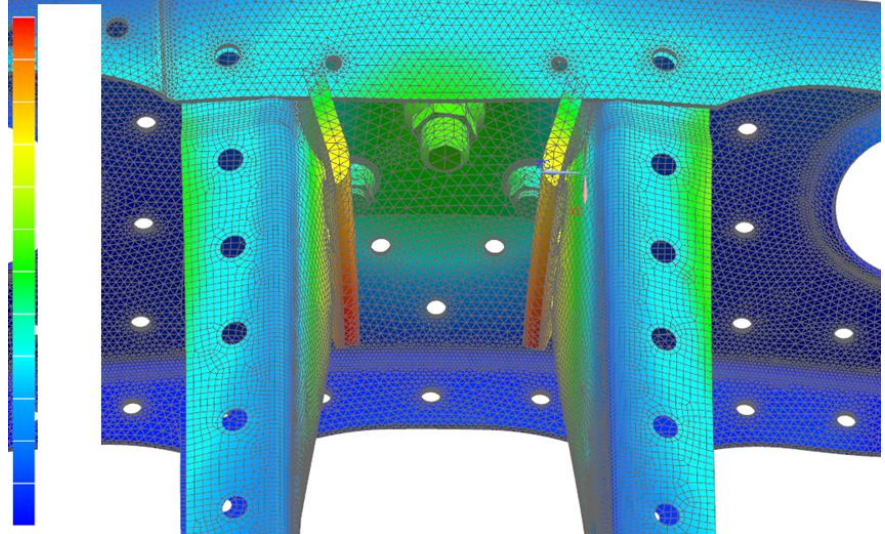




Sub Assembly Results

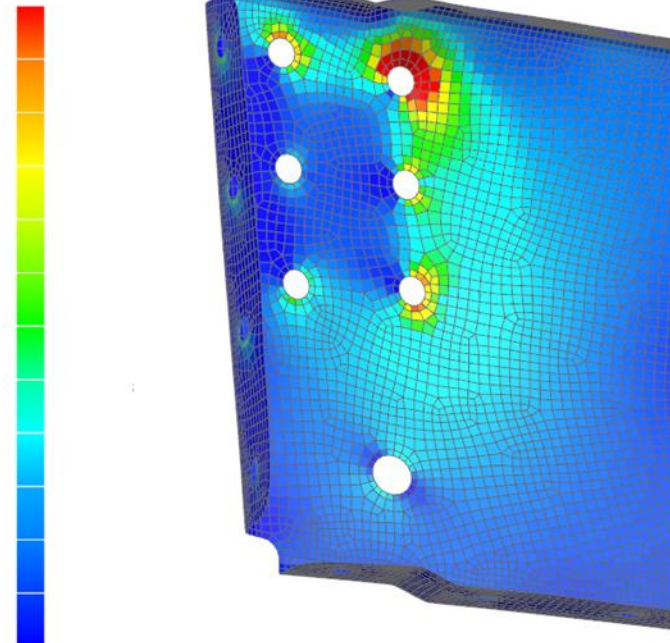


CF_con_nom_1D_2570 lbs : 2900 lbs Result
 Subcase - Static Loads 1, Static Step 1
 Displacement - Nodal, Magnitude
 Min : 0.000, Max : 0.132, Units = in
 Deformation - Displacement - Nodal, Magnitude

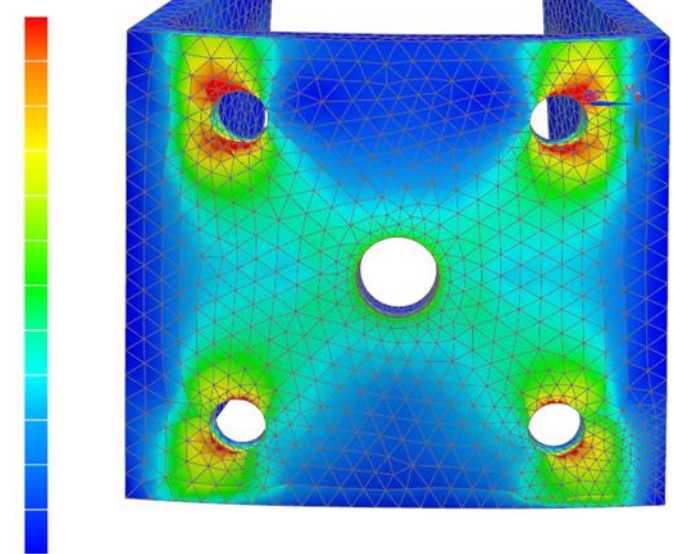


Intercostal Max Principal Stress

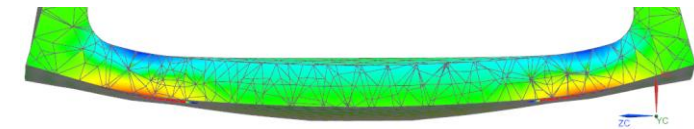
Beam Coord sys : Local
 Deformation : Displacement - Nodal, Magnitude



Beam Section : Recovery Point C, Shell Section : top
 Min : -211783, Max : 341103, Units = lb/in²
 Beam Coord sys : Local
 Deformation : Displacement - Nodal, Magnitude



Support Fitting Max Principal Stress



Support Fitting Worst Principal Stress
 (blue is compression, red tension)

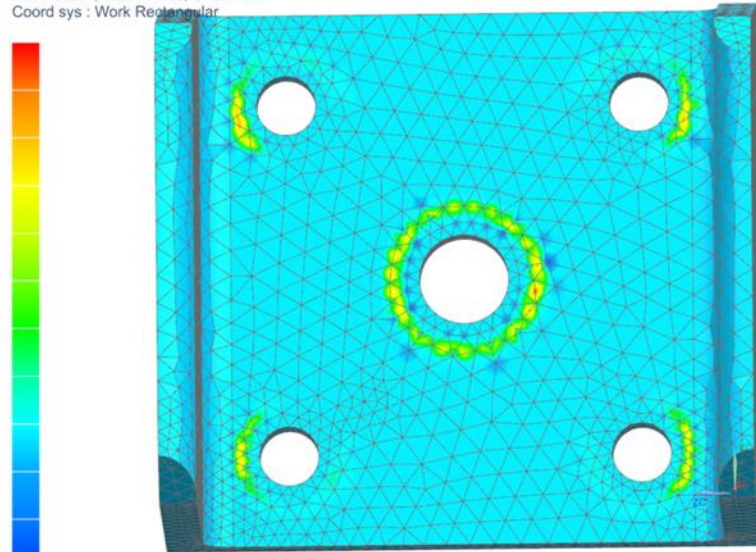


Loading in StressCheck

- All exterior grid point forces used as applied load in StressCheck
 - Imported as TLAPs
 - TLAP scale parameter used to scale loads to simulate different applied loads

GP Force on Aft Face

CF_con_nom_1D_2570 lbs : 2900 lbs Result
Subcase - Static Loads 1, Static Step 1
Grid Point Force - Element-Nodal, Sum, X
Min : -33.97, Max : 84.46, Units = lbf
Coord sys : Work Rectangular

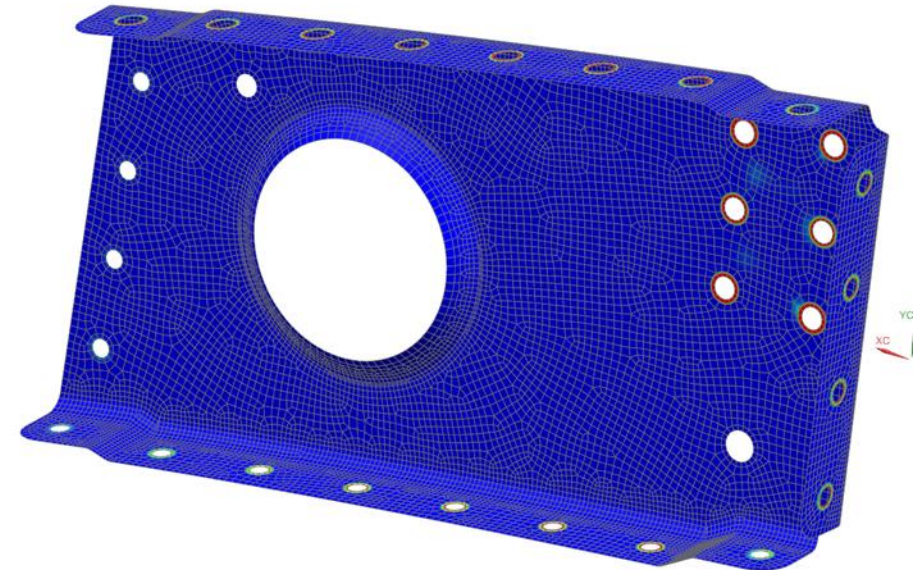


[lbf]

CF_con_nom_1D_2570 lbs : 2900 lbs Result
Subcase - Static Loads 1, Static Step 1
Grid Point Force - Element-Nodal, Sum, Magnitude
Min : 0.00, Max : 25.39, Units = lbf
Coord sys : Work Rectangular



[lbf]



See Distribution Statement on Title Slide

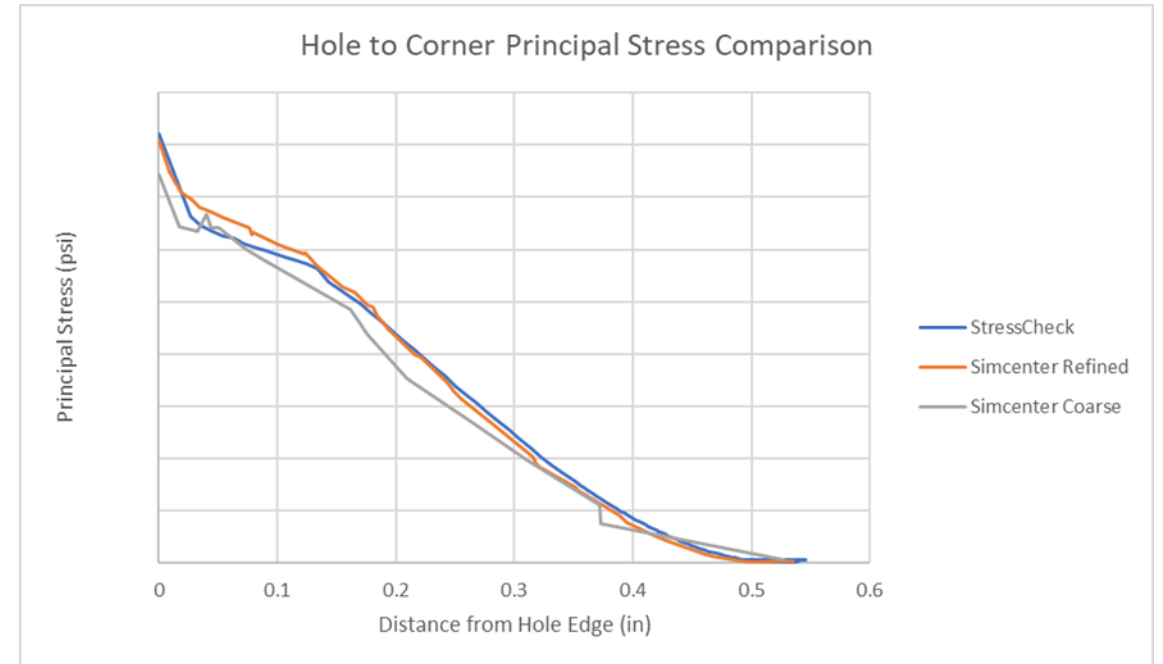
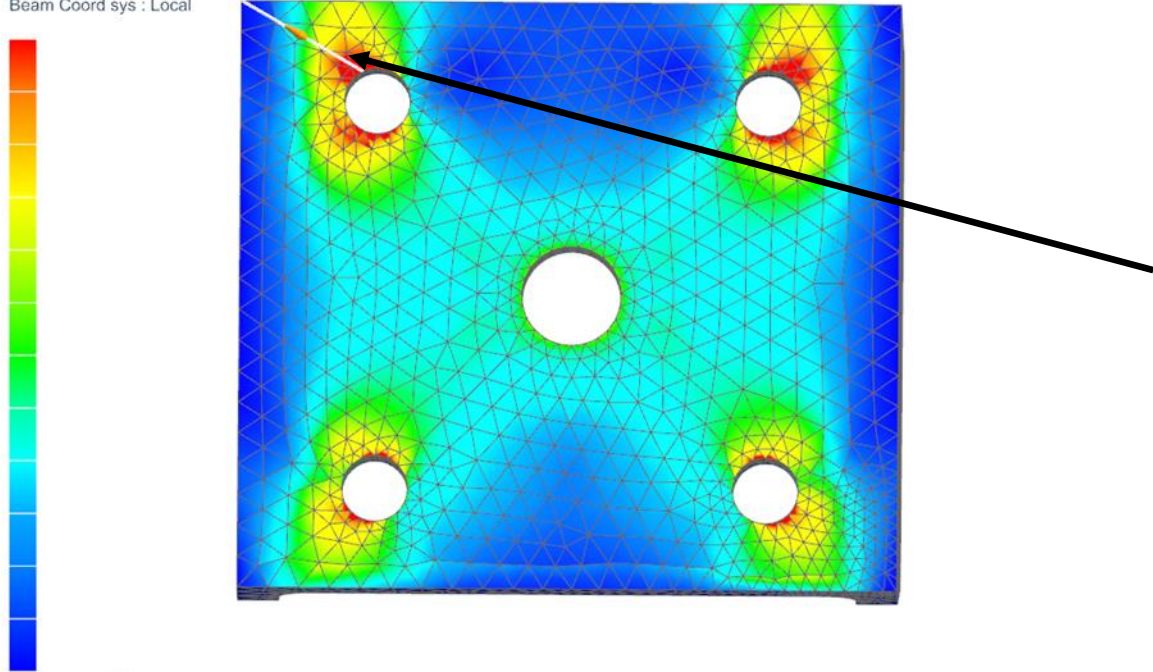


StressCheck vs Simcenter – Support Fitting



- Stresses along two paths compared to show StressCheck and Simcenter results are equivalent

CF_con_nom_1D_2570 lbs : 2900 lbs Result
Subcase - Static Loads 1, Static Step 1
Stress - Element-Nodal, Unaveraged, Max Principal
Beam Section : Recovery Point C, Shell Section : Top
Min : -211783, Max : 341103, Units = lbf/in²
Beam Coord sys : Local



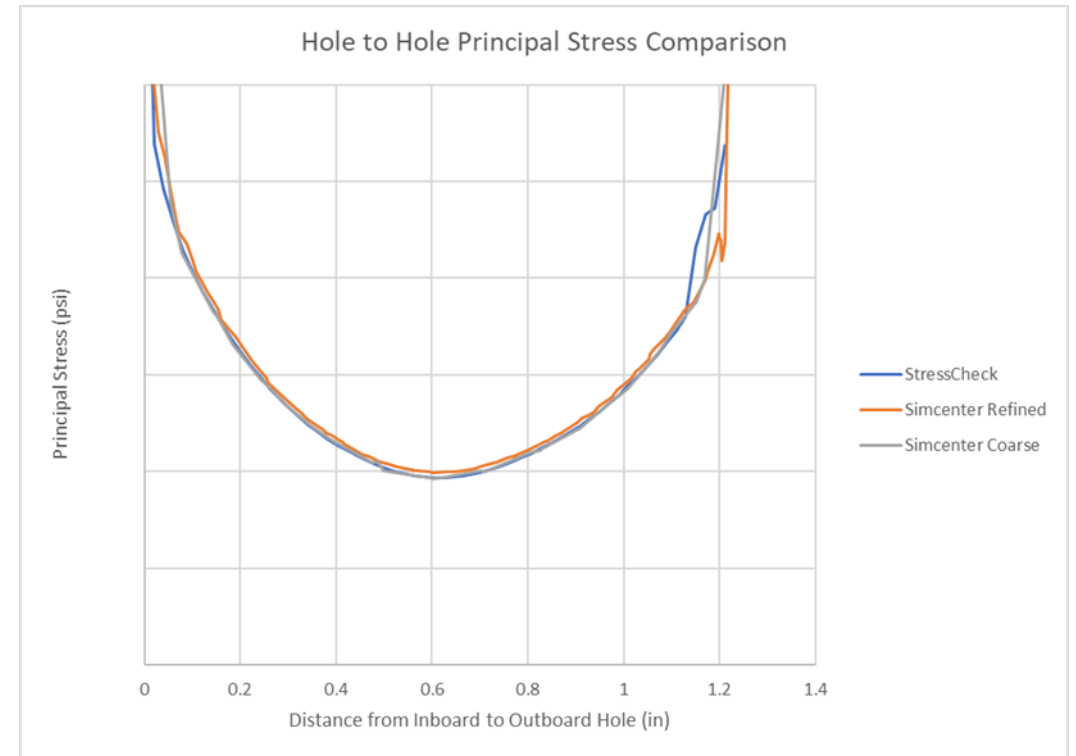
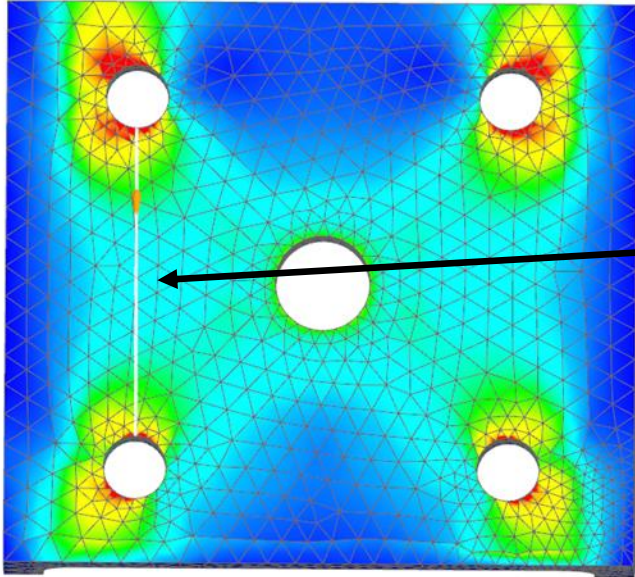


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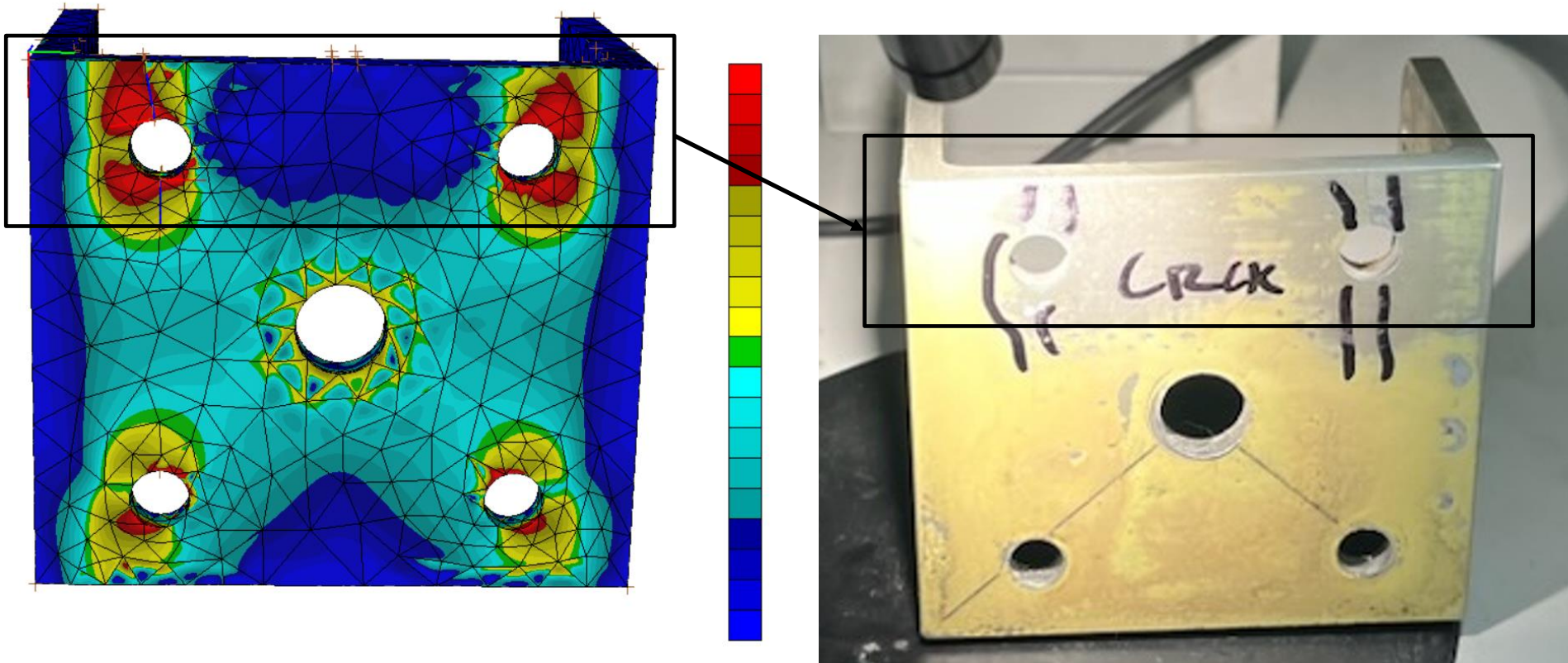
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Beam Section : Recovery Point C, Shell Section : Top
Min : -211783, Max : 341103, Units = lbf/in²
Beam Coord sys : Local





Representative of Cracking

- High stresses coincide with most common cracking





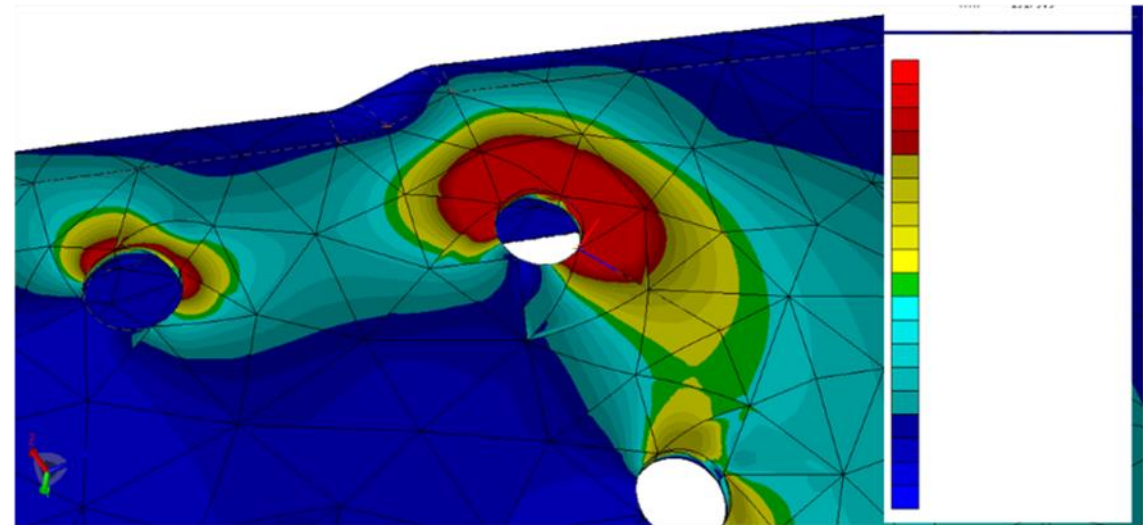
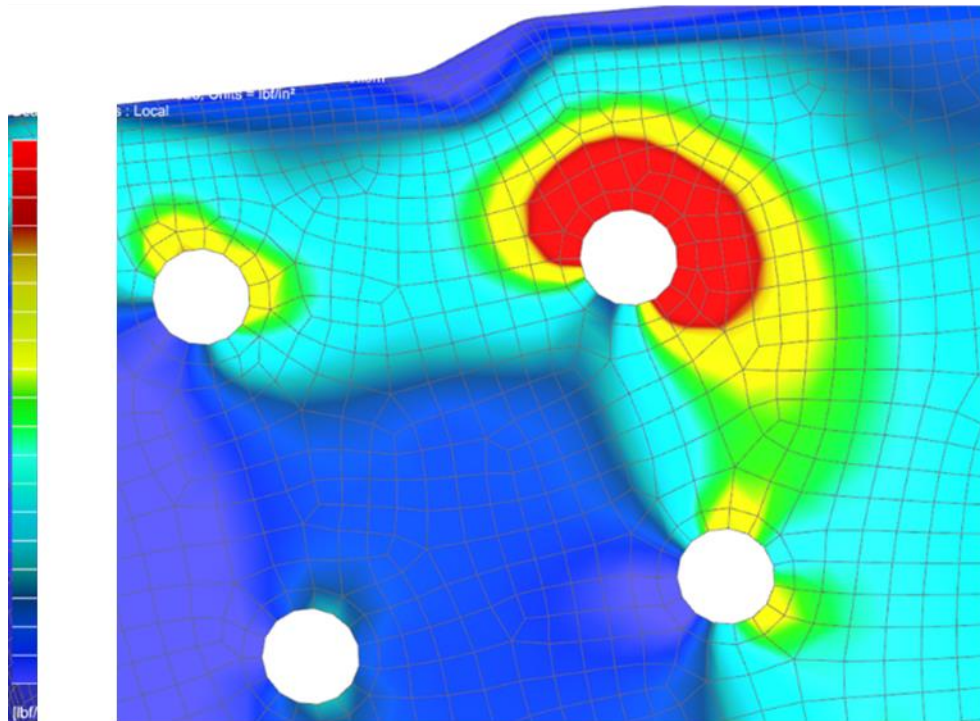
StressCheck vs Simcenter – Intercostal



- Same process used for support fitting was applied to intercostal. A simple stress contour comparison completed

Simcenter

StressCheck



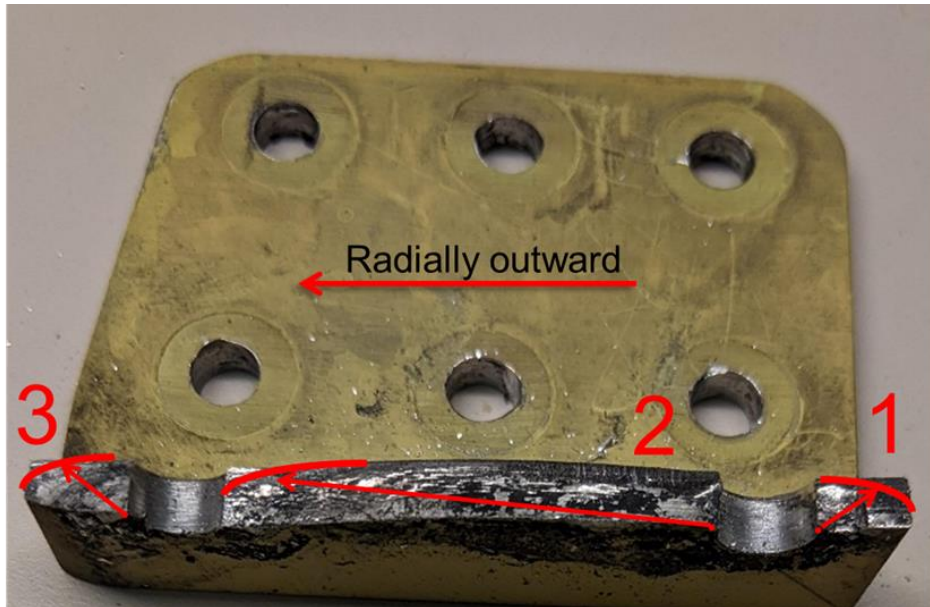
See Distribution Statement on Title Slide



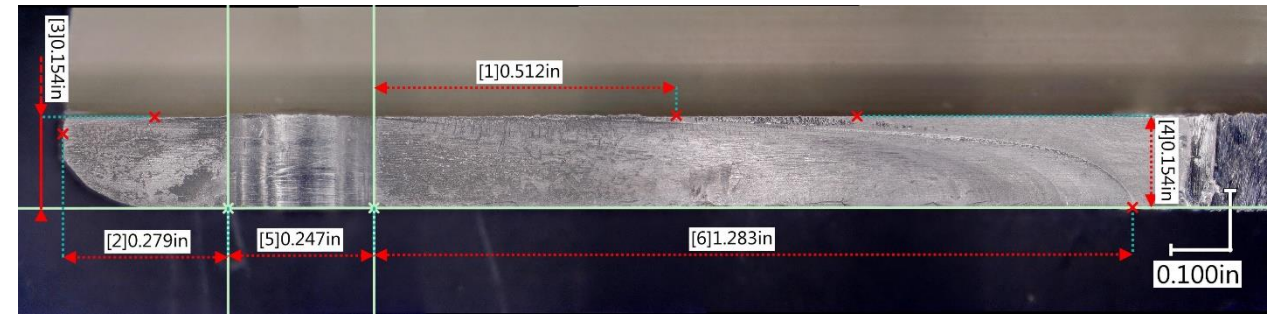
Crack Growth Measurements

- Three cracked support fittings were used to develop the appropriate load for BAmPF analysis

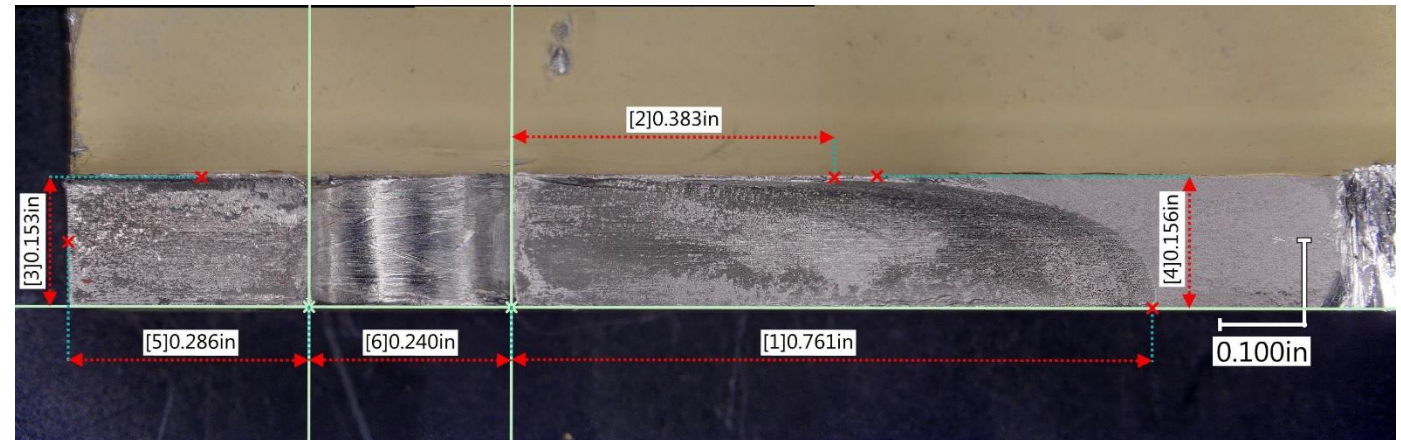
Specimen A



Specimen B



Specimen C





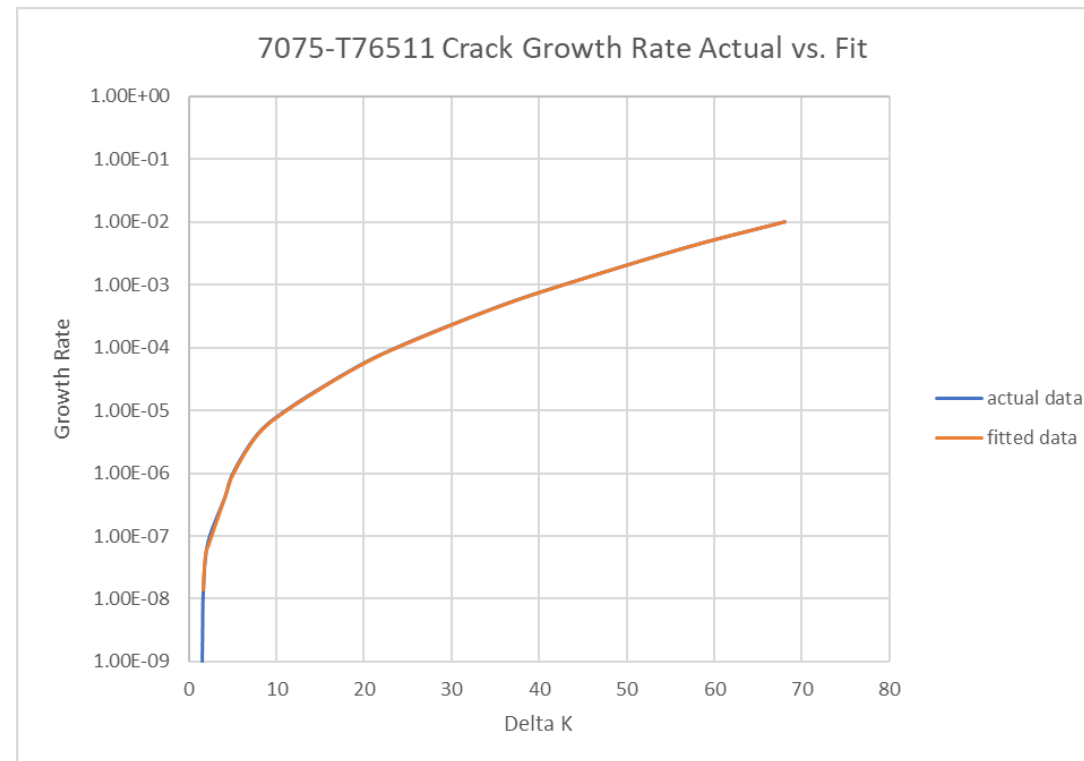
Spectrum

- **Aft Cowl primarily loaded from engine thrust**
- **Minor throttle variation through mission reported by pilots**
- **Constant Amplitude spectrum used**
 - **1 cycle = 1 flight**
 - **$R = 0$**
- **Load correlation from crack growth measurements dependent upon spectrum assumption**
 - **Calculated load may not be representative of true load, but combined with spectrum assumption, should provide decent accuracy for crack growth simulation**



Material

- Used latest 7075-T76511 tabular lookup file for A-10, with $R = 0$
- Created a polynomial fit to tabular data to determine appropriate ΔK for a given crack growth rate



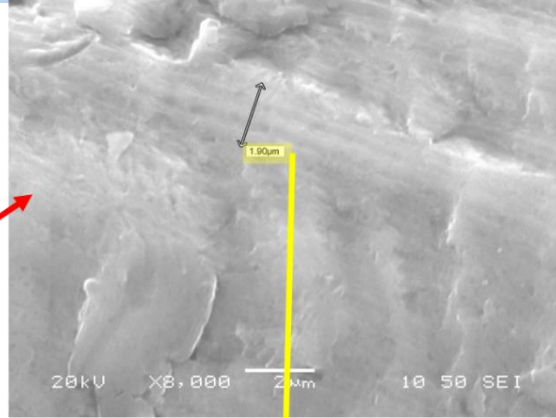
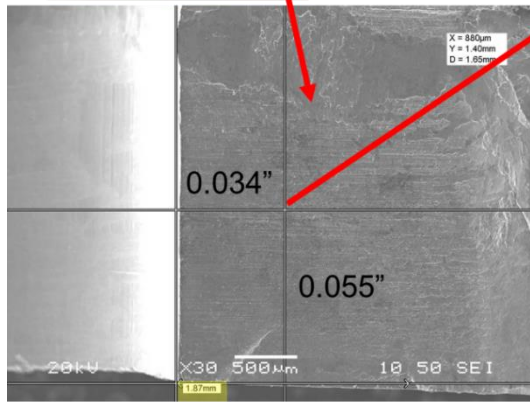
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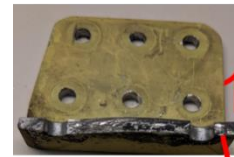
Specimen A



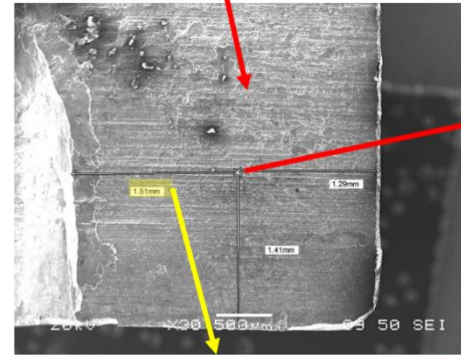
Crack 1
Point 1



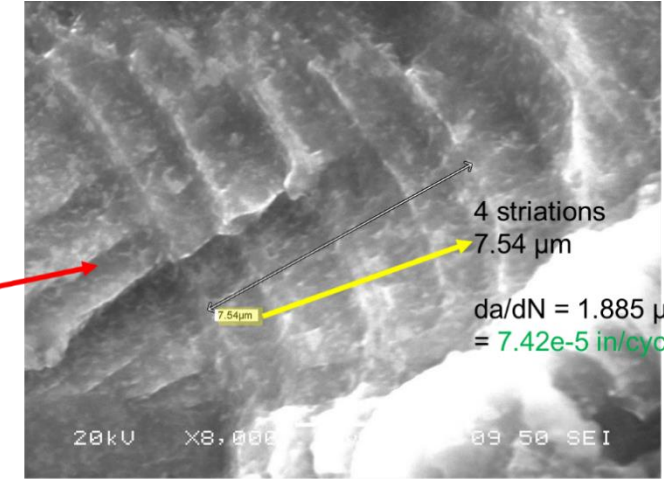
4 striations
1.9 μm
 $da/dN = 0.475 \mu\text{m}/\text{cycle}$
 $= 1.87\text{e-}5 \text{ in}/\text{cycle}$



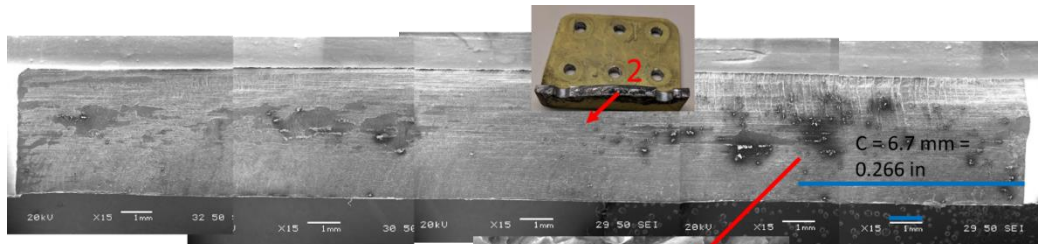
Crack 1
Point 2



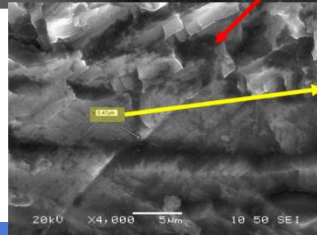
$C = 1.51 + 2.81 \text{ mm} = 4.32 \text{ mm}$ from hole edge



4 striations
7.54 μm
 $da/dN = 1.885 \mu\text{m}/\text{cycle}$
 $= 7.42\text{e-}5 \text{ in}/\text{cycle}$



Crack 2
Point 1



7 striations
5.47 μm
 $da/dN = 0.78 \mu\text{m}/\text{cycle} = 3.07\text{e-}5 \text{ in}/\text{cycle}$

Point	X (from crack origin, in)	Y (from crack origin, in)	Growth Rate (in/cycle)	Stress Intensity
Crack 1, Point 1	0.034	0.055	1.87e-5	14.13
Crack 1, Point 2	0.17	0.055	7.42e-5	21.76
Crack 2, Point 1	0.266	0.044	3.07e-5	16.66

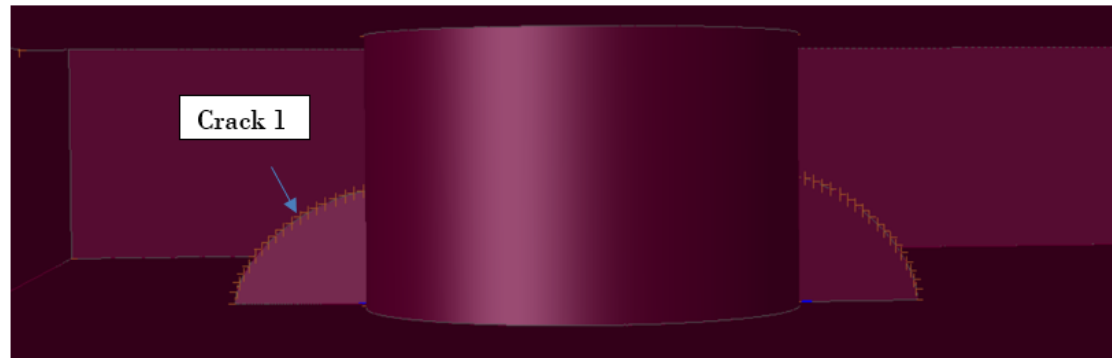


Analysis Simulation of Measurements

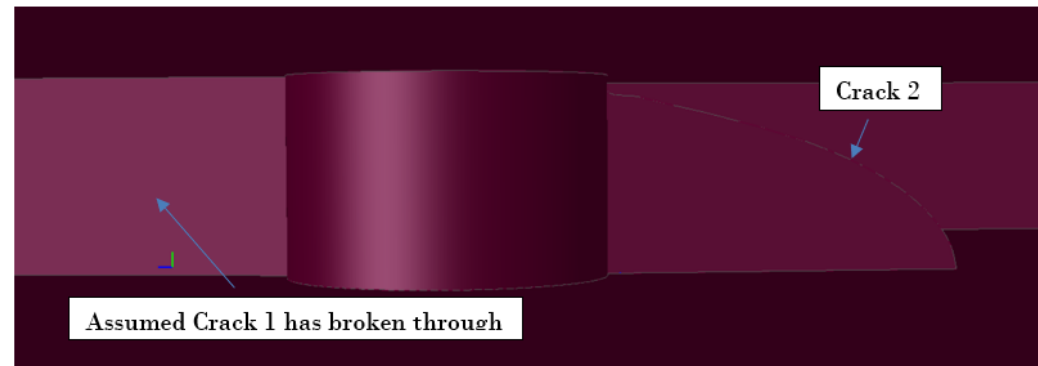
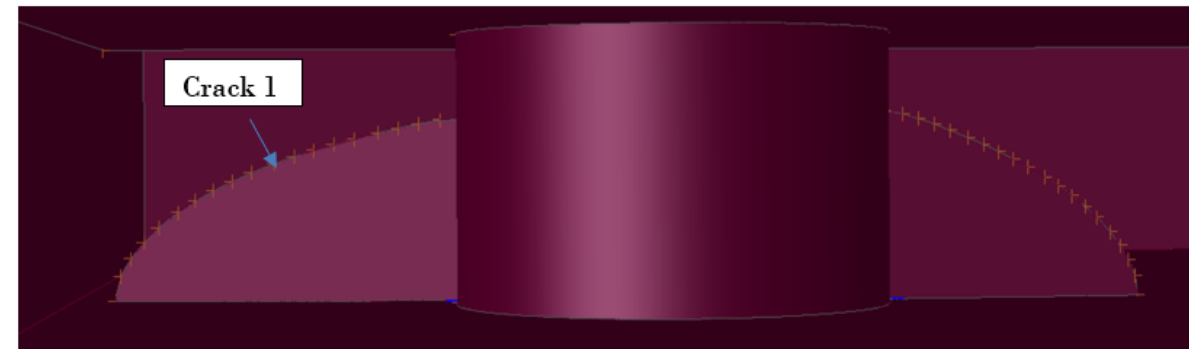


- BAmP was used to allow cracks to evolve based on the loading imported from Simcenter
- Measurement correlation model created from nearest iteration with crack front growing through desired point
- StressCheck model geometry modified to better match specimen

Crack 1 Point 1



Crack 1 Point 2



Crack 2 Point 1



Load Correlation – Specimen A

- Required load for crack 1 points very consistent
- Required load for crack 2 about 30% lower

Point	Growth Rate (in/cycle)	Required Stress Intensity (ksi√in)	Calculated Stress Intensity (ksi√in)	Meas. Location from Origin	Location from Origin	Required Load Scale Factor
Crack 1, Point 1	1.87e-5	14.13	14.67	X = 0.034" Y = 0.055"	X = 0.034" Y = 0.057"	0.963
Crack 1, Point 2	7.42e-5	21.76	21.88	X = 0.170 Y = 0.055	X = 0.170 Y = 0.054	0.994
Crack 2, Point 1	3.07e-5	16.66	24.42	X = 0.266 Y = 0.044	X = 0.264 Y = 0.044	0.682



Load Correlation – Specimens B and C



- Fewer good correlation points on these specimens

Specimen B

Point	Growth Rate (in/cycle)	Required Stress Intensity (ksi $\sqrt{\text{in}}$)	Calculated Stress Intensity (ksi $\sqrt{\text{in}}$)	Meas. Location from Origin	Location from Origin	Required Load Scale Factor
Ligament	8.00e-5	22.25	23.92	X = 0.149" Y = 0.084"	X = 0.147" Y = 0.083"	0.930
Center	5.67e-5	20.10	15.39	X = 0.074 Y = 0.026	X = 0.074 Y = 0.028	1.306

Specimen C

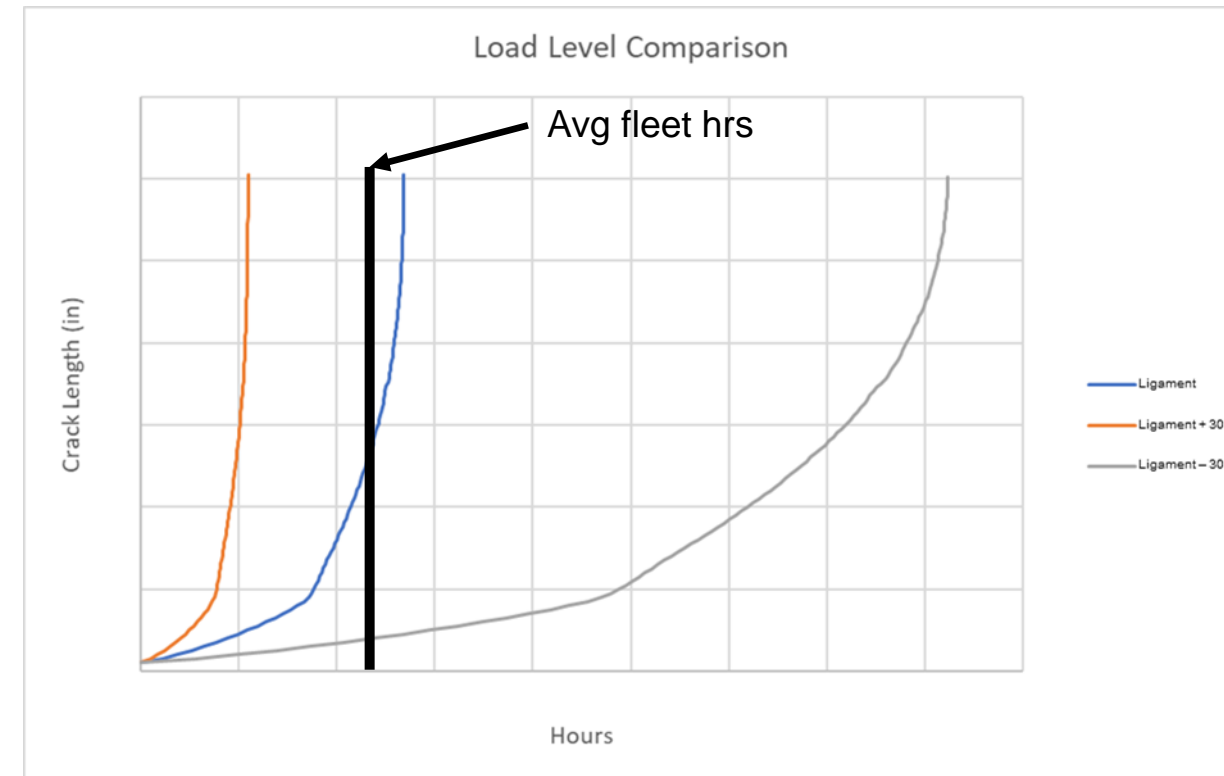
Point	Growth Rate (in/cycle)	Required Stress Intensity (ksi $\sqrt{\text{in}}$)	Calculated Stress Intensity (ksi $\sqrt{\text{in}}$)	Meas. Location from Origin	Location from Origin	Required Load Scale Factor
Center	5.05e-5	19.41	19.94	X = 0.111 Y = 0.088	X = 0.114 Y = 0.088	0.973



Crack Growth Curve Comparison



- Ligament points correlated well together
- Center crack points showed + or - 30%
- AFGROW model developed using BAMpF betas
 - Quickly compare load levels to fleet life
- IFS = 0.02 – stable in BAMpF
- Ligament load compared best to fleet experience



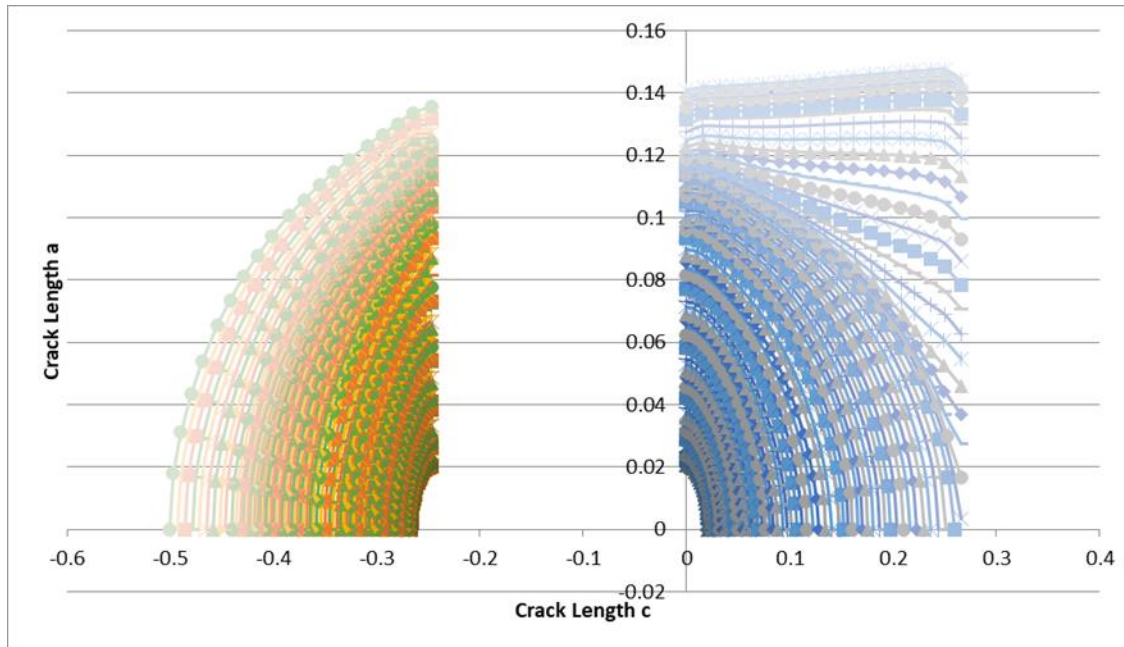


BAMpF Support Fitting

■ Growth in two phases:

- Phase 1: two cracks from inboard hole
- Phase 2: inboard ligament severed, crack 2 grows toward opposite hole

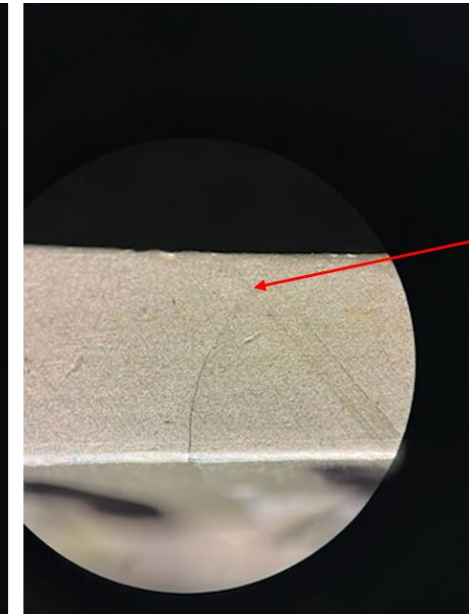
Phase 1 Crack Evolution



Observed Cracking



View looking aft at fwd face



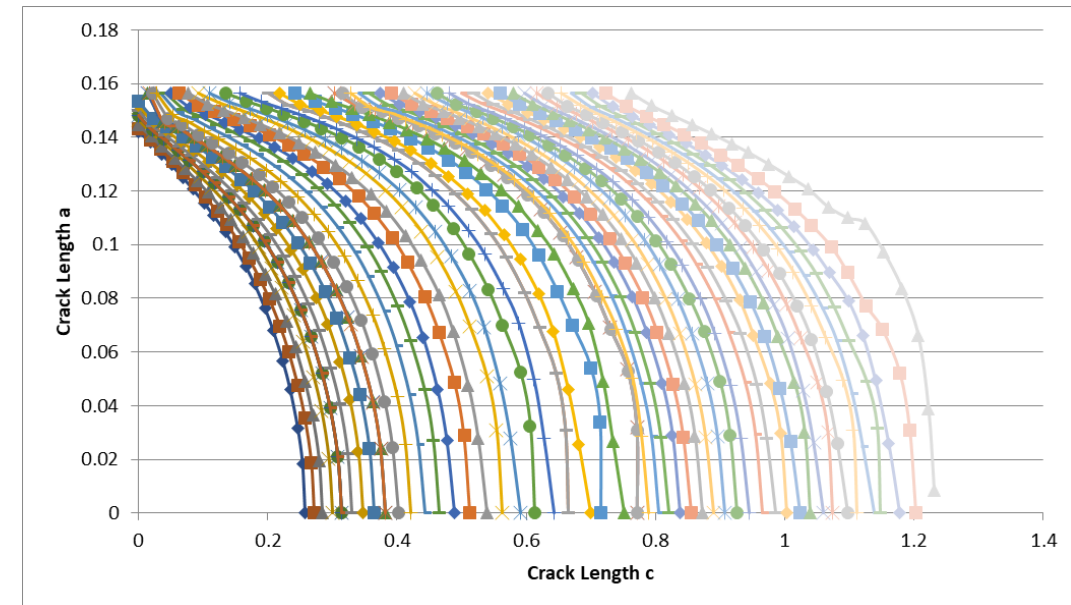
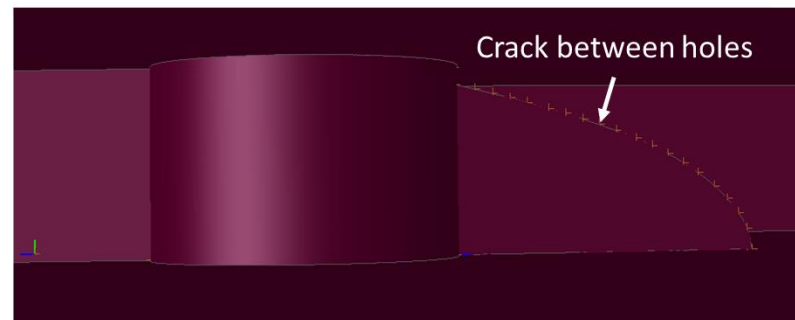
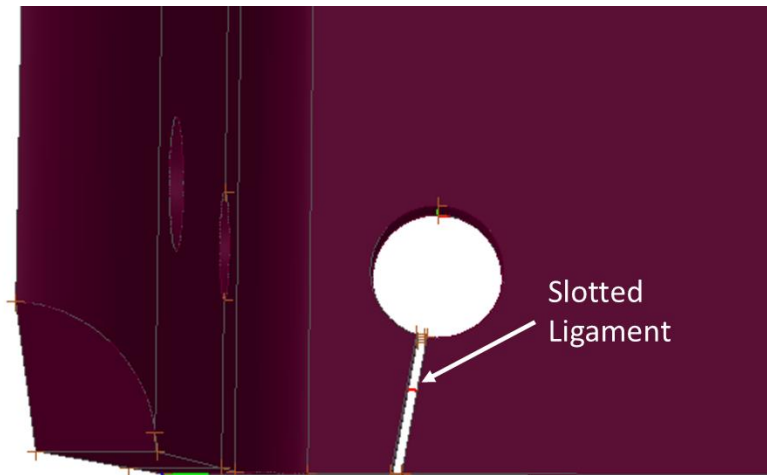
Hasn't broken through to aft face

View looking inbd edge of support fitting



BAMpF Support Fitting

- Phase 2: crack 2 started at size from phase 1 where crack 1 broke through 95% of thickness





Crack Growth Curves

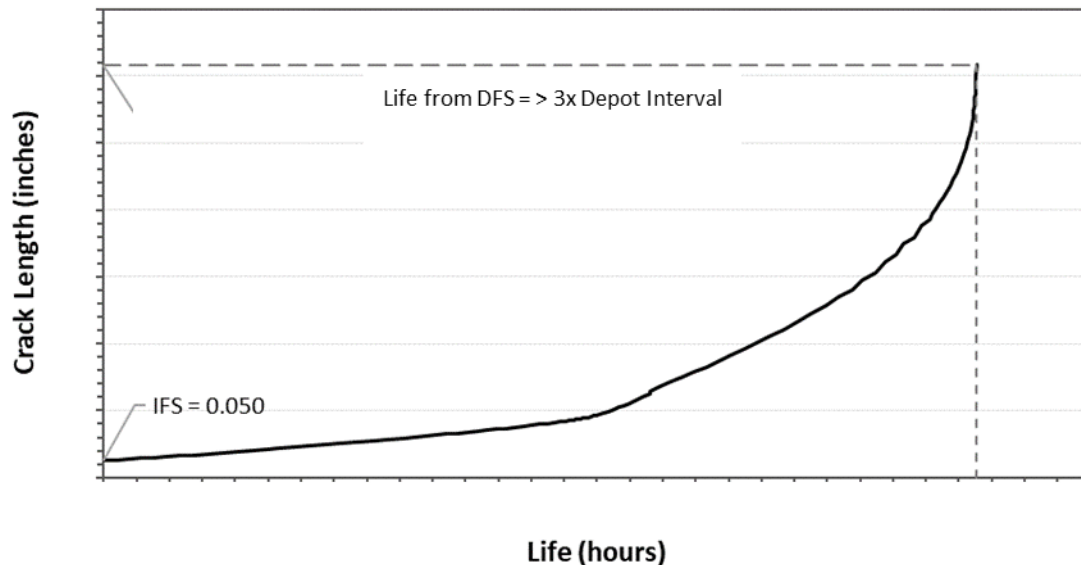
■ Final crack growth curve based on crack 2 (center crack)

- 0.05" DFS for depot level BHEC inspection

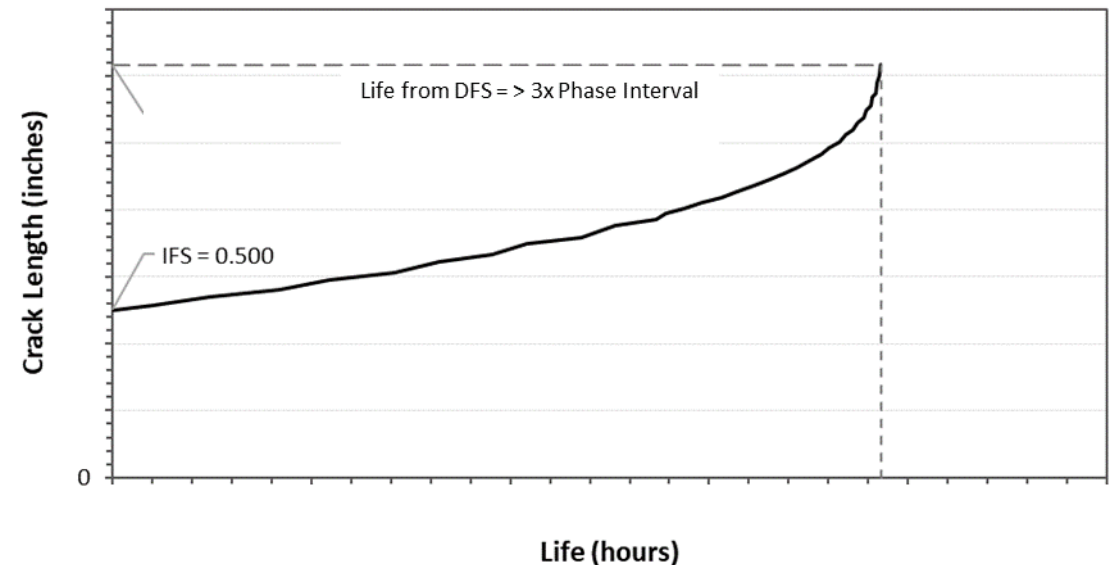
- 0.5" DFS for SEC inspection in field

- Based upon measurement of 15 support fitting cracks on fwd and aft faces. Showed cracks longer than 0.5" broke through aft face and were detectable

Crack 2 CGC, 0.05" DFS



Crack 2 CGC, 0.5" DFS

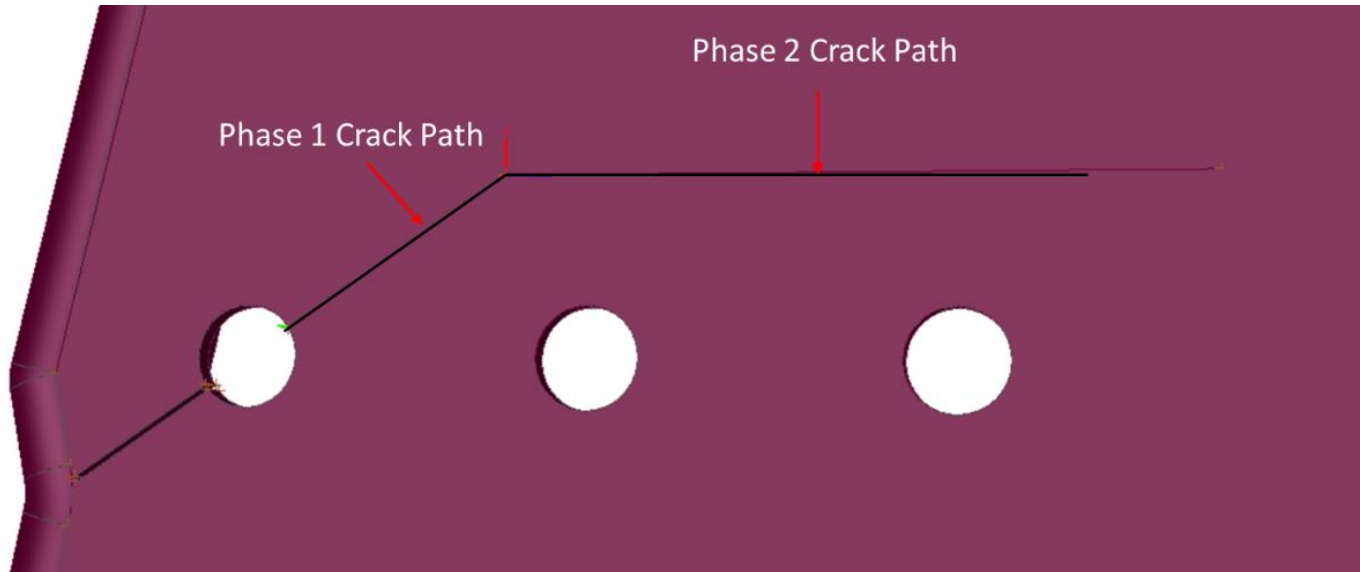




BAMpF Intercostal

■ Also 2 phases

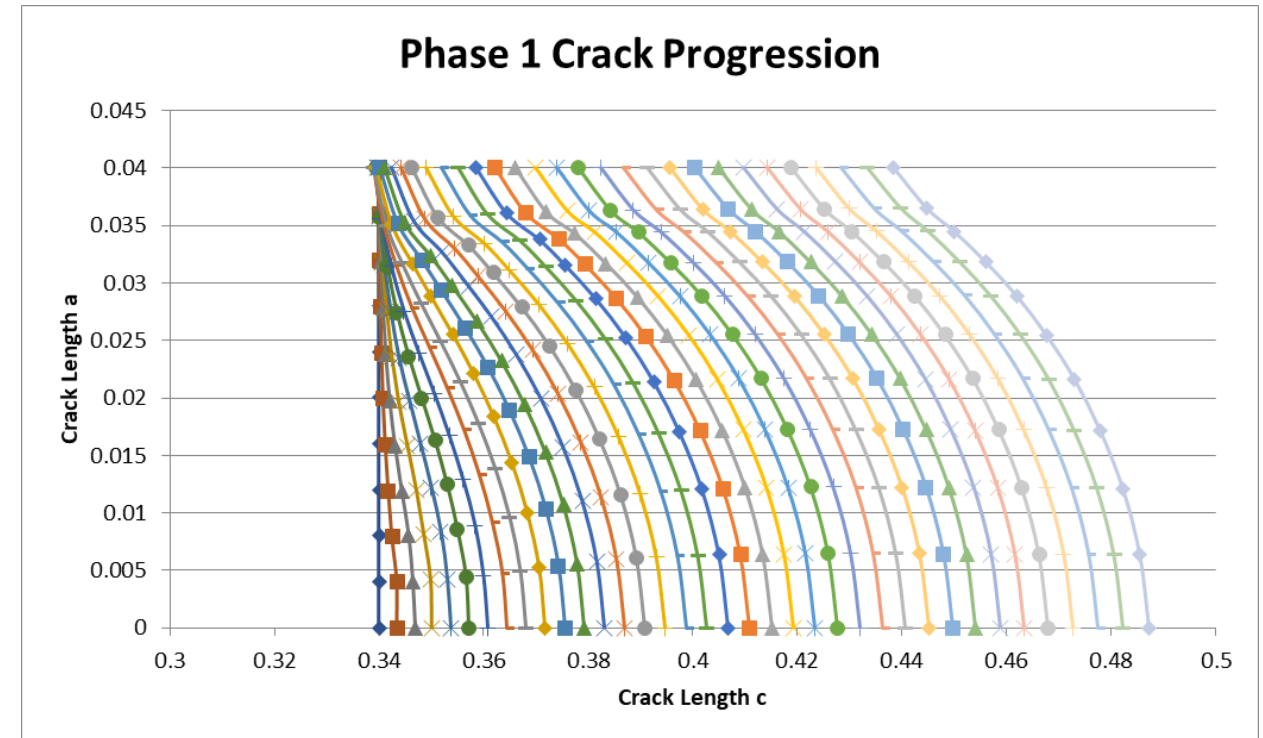
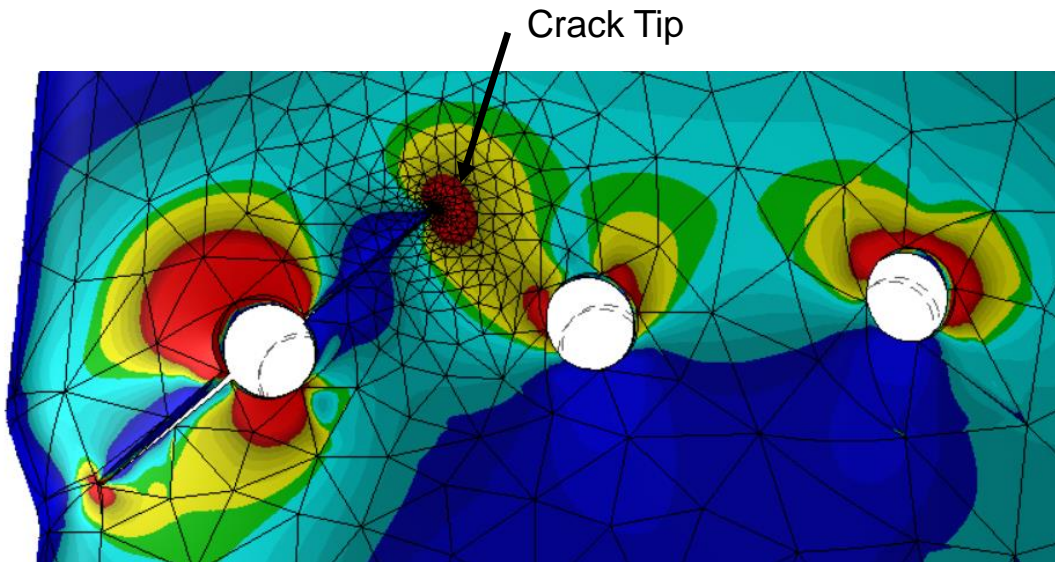
- Phase 1: growth along max principal stress plane until outside support fitting
- Phase 2: growth along edge of support fitting





BAMpF Intercostal

- Phase 1: DFS was 0.34" (surface scan (0.25" DFS) + Fastener head (0.09"))

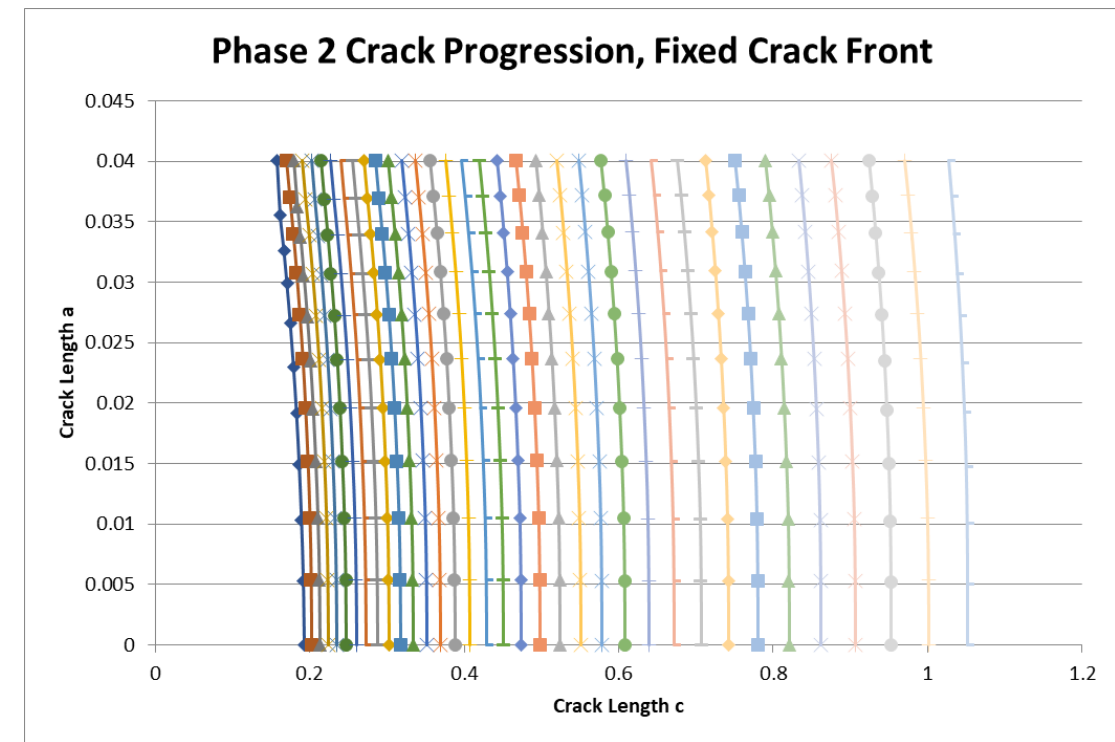
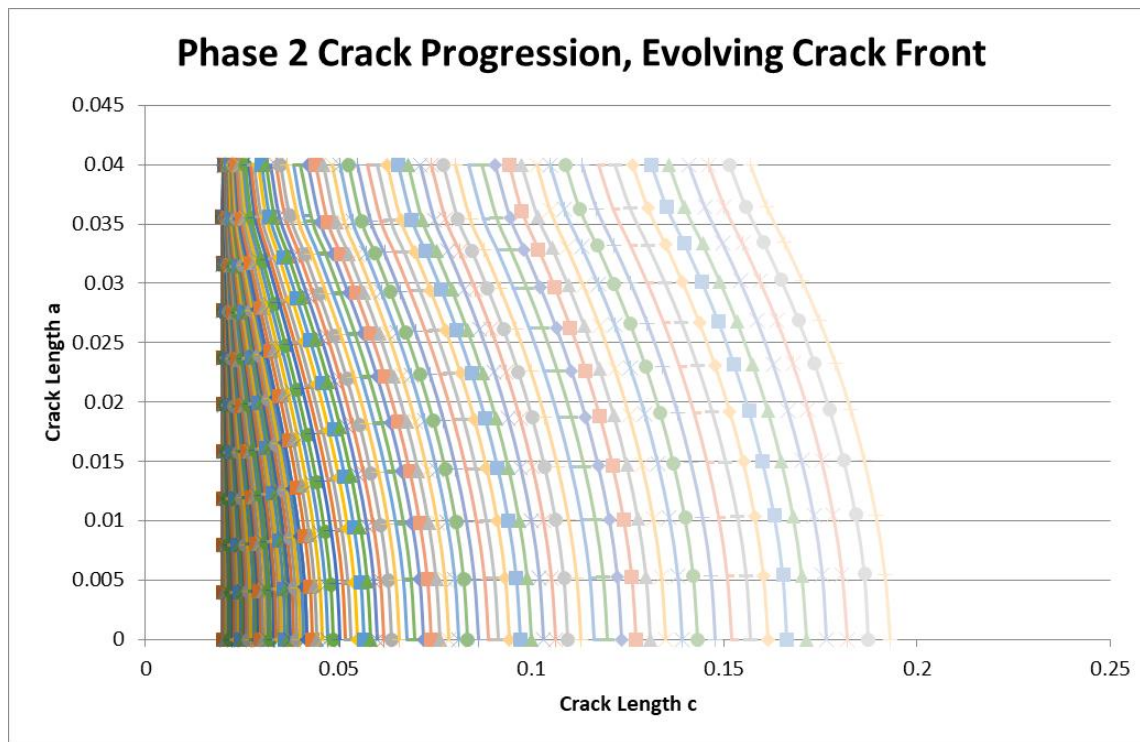




BAMpF Intercostal

■ Phase 2 - run in two segments:

- Evolving crack front
- Fixed crack front based on growth of most critical point
- Note: Crack length does not include length from phase 1

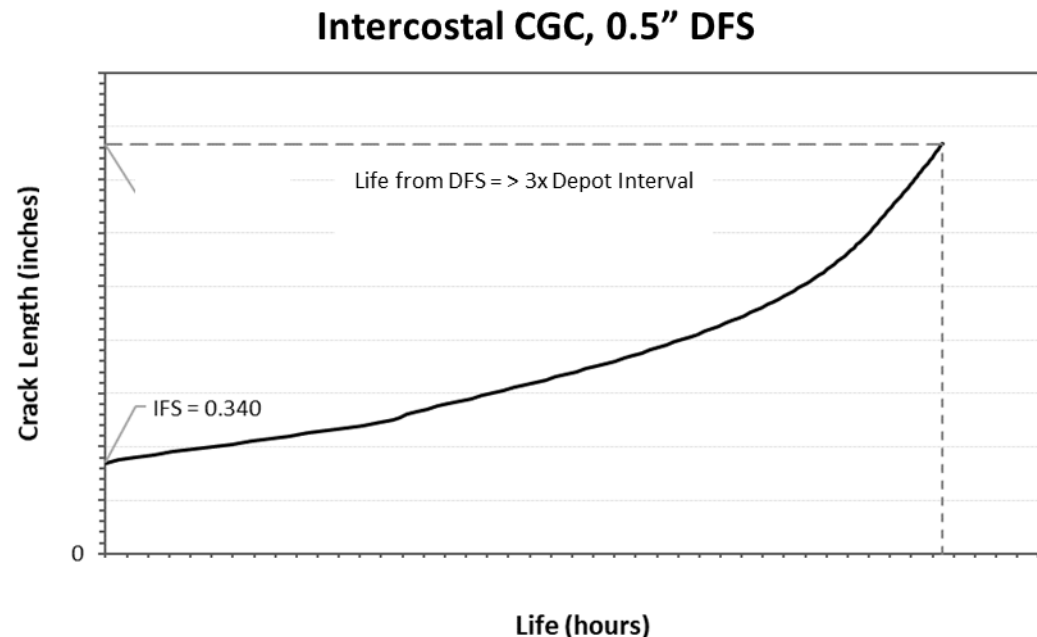


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BAMpF Intercostal

- Crack growth life supports depot level inspection
- Life more than expected compared to fleet experience
 - Potentially different crack path could affect this or Simcenter model change to include local influence of fastener head
 - Considered acceptable since life is divided by 3



See Distribution Statement on Title Slide



Summary

- **Significant cracking found on aft cowl at nacelle attach locations**
- **Existing models enabled quick development of sub-assembly FEM**
- **Loads from sub-assembly used as boundary conditions for StresCheck model**
- **BAMpF used to enable full use of complex stress field and recreate crack front behavior**
- **Crack growth measurements used to develop appropriate loading for crack growth analysis**
- **Final results support phase or depot level intervals based on complexity of inspection**



Questions?



See Distribution Statement on Title Slide