
U.S. AIR FORCE

# A-10 Auxiliary Longeron Damage Modeling and Repair

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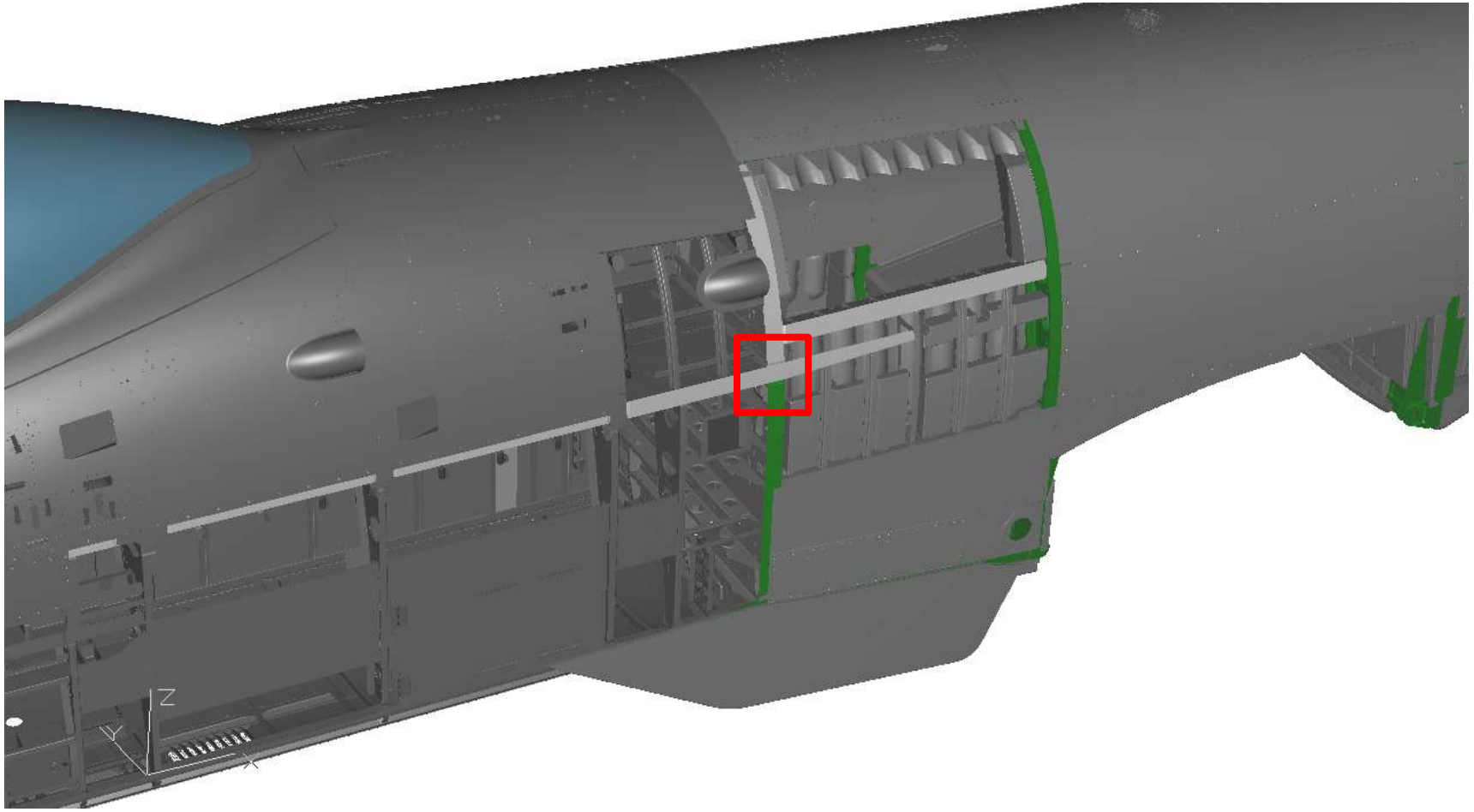
**A-10 Structural Analysis, USAF**
**13 Sept 2021**

# Background

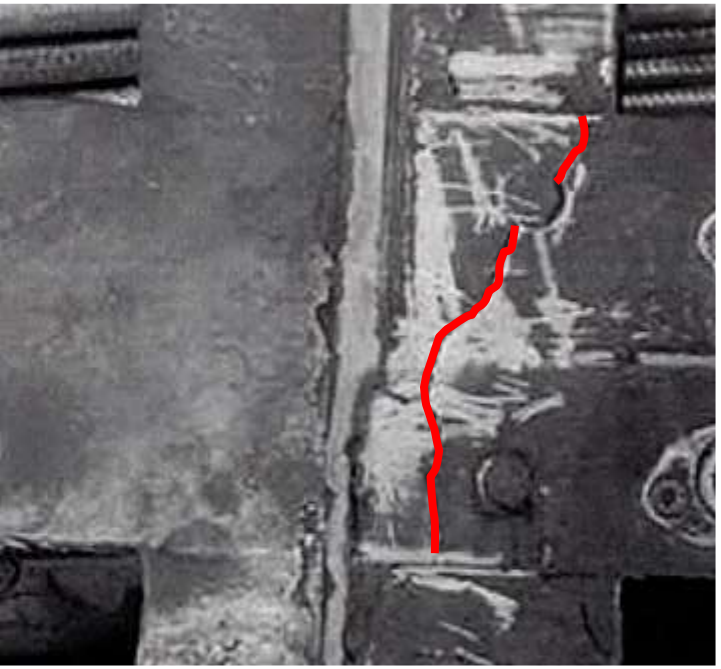
- **Significant cracking found in upper auxiliary longeron**

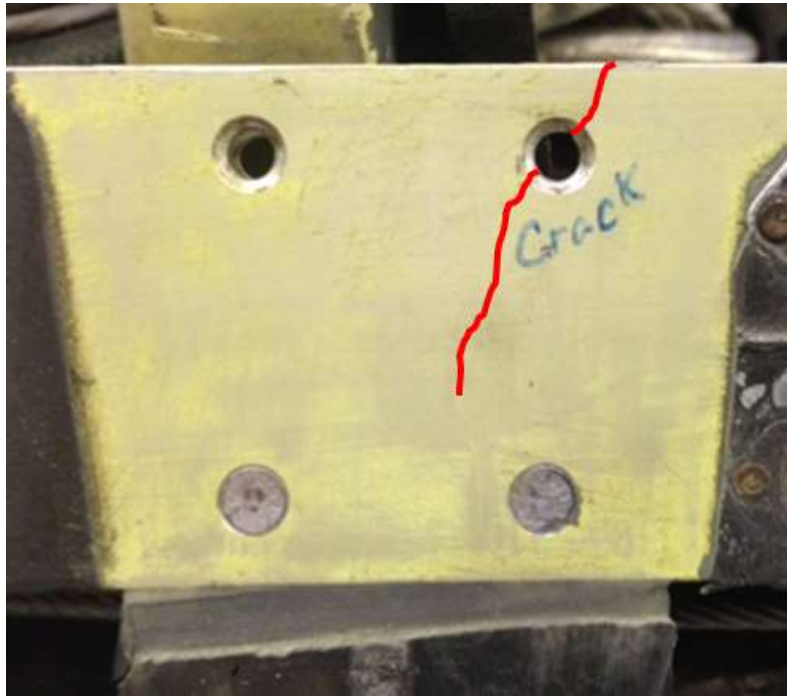


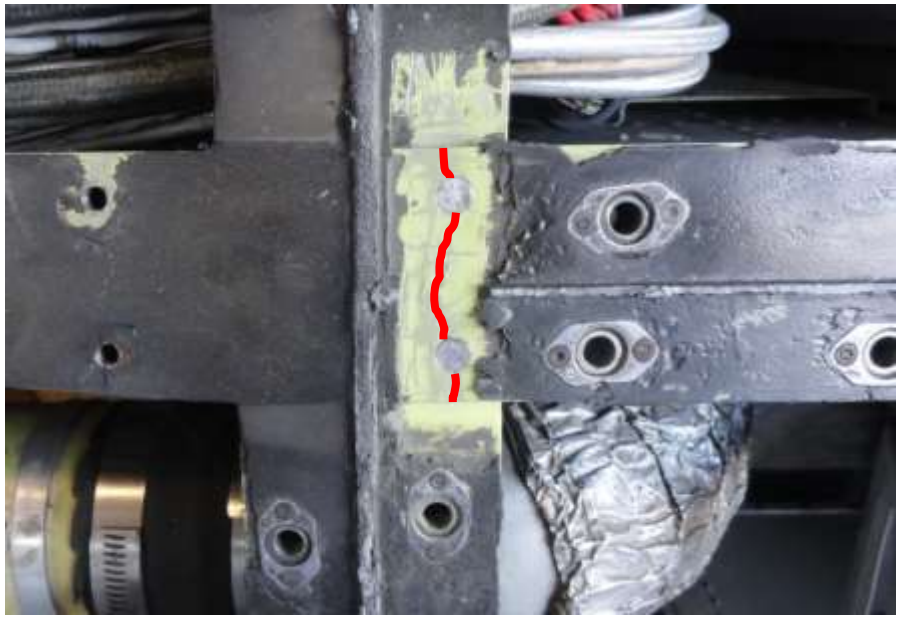
# Background

- **Examples of severe cracking**

FWD in all pictures





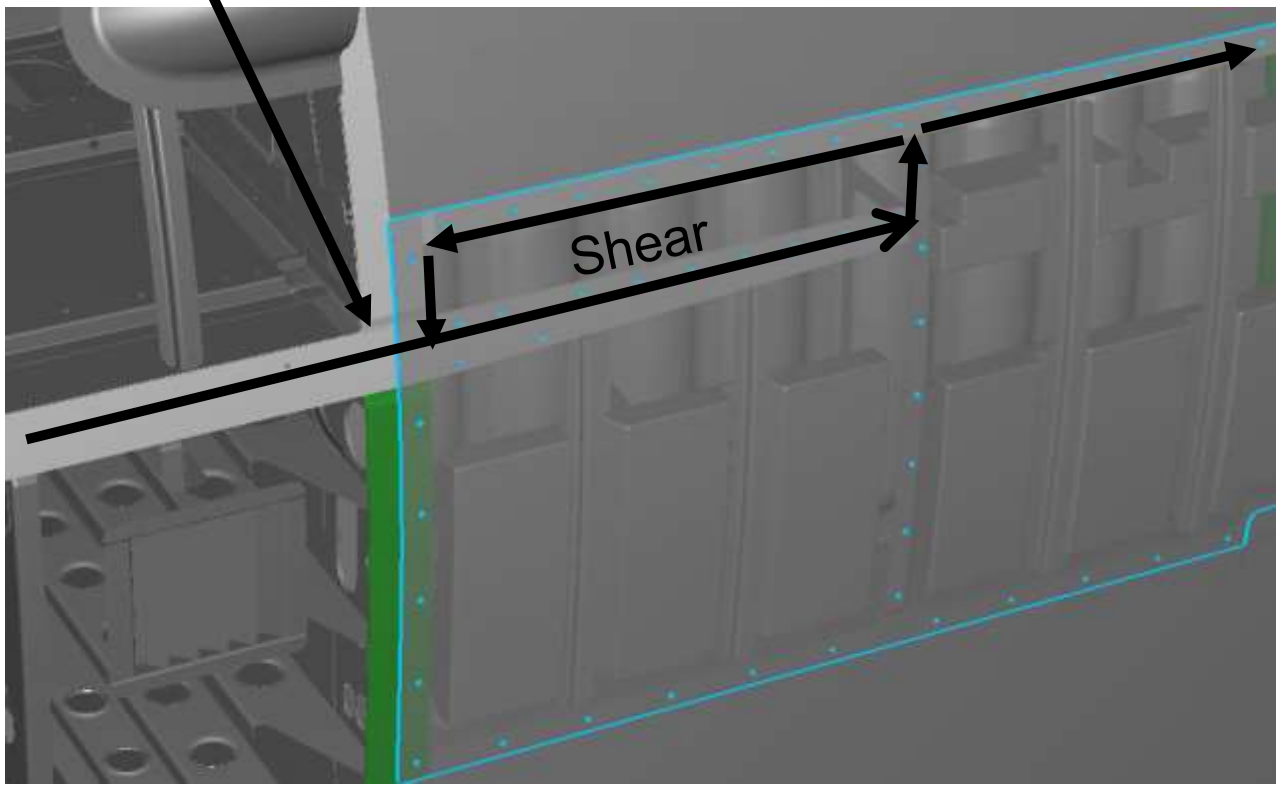
# Root Cause

- **Poorly designed load path transferring load between FWD fuselage auxiliary longeron cap to the center fuselage longeron cap.**
  - **Load intended to shear through a skin panel**
  - **Skin panel is access panel with nutplates**
  - **Clearance fit holes provide insufficient stiffness**
  - **Load transfers through frame strap instead**

# Root Cause

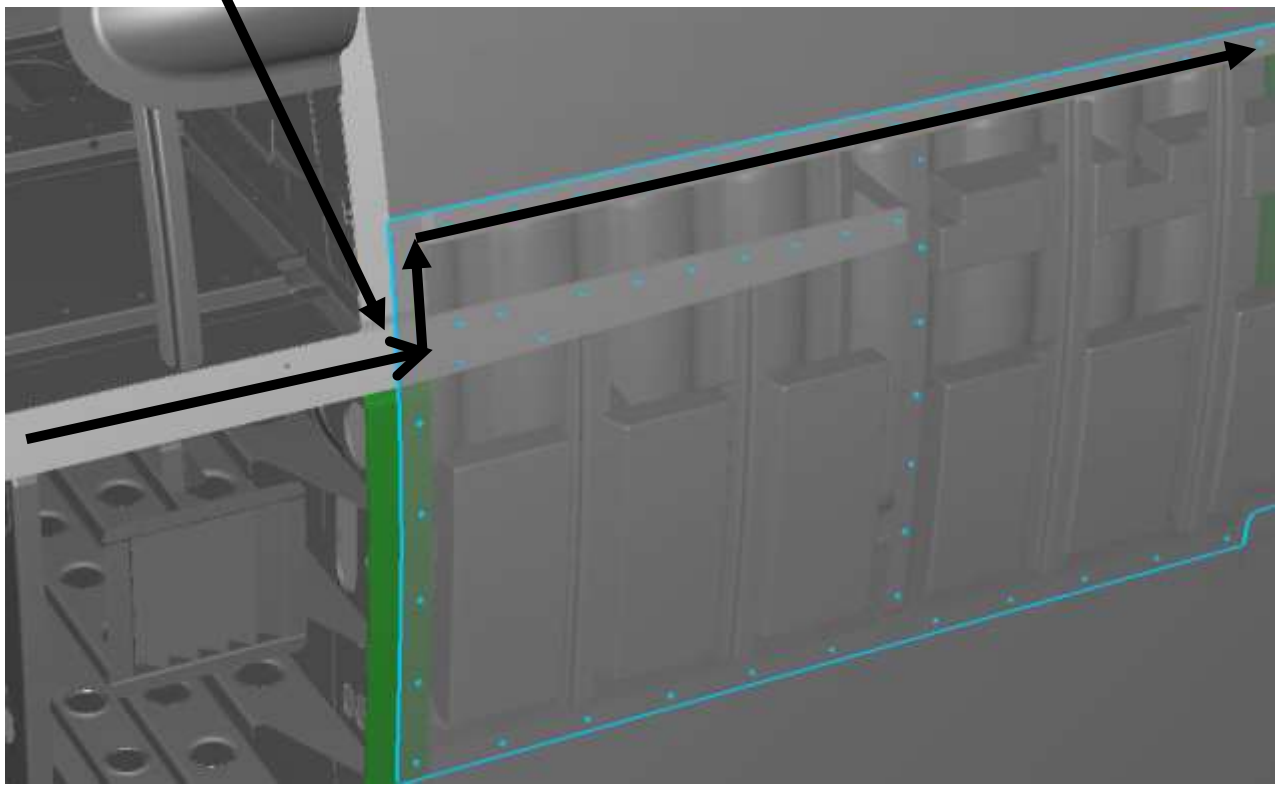
Intent

Critical Hole



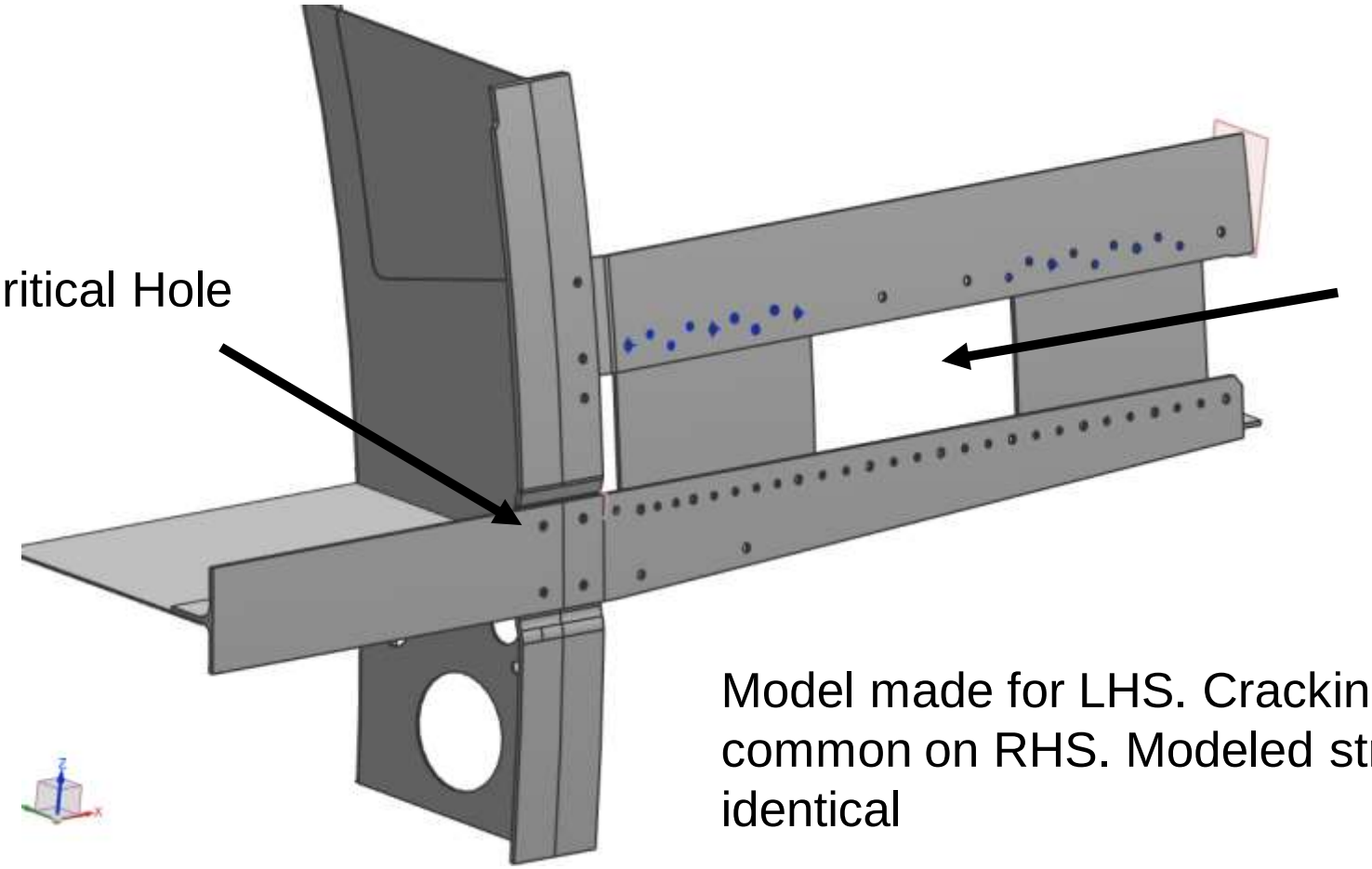

Reality

Critical Hole



# Repair

- **Install shear plates with Hi-Loks (located between nutplates) aft of frame**




Model made for LHS. Cracking more common on RHS. Modeled structure is identical

# Model

- A Finite Element Model (FEM) was created for nominal and repair configurations
- Parts modeled with 3D elements
- 1D elements used for fasteners
- CGAP elements used for nutplates
  - Gap based on the difference between the average bolt diameter and average hole diameter
  - Allows for progressive loading of fasteners as the structure displaces due to load
    - Outermost fasteners load first, inner fasteners load has structure experiences additional load
  - Shows how load path changes with load magnitude

# Pin Load Results

- **TSF and BSF drastically change at varying load levels for nominal condition**
- **Very high vertical (z-axis) load in fastener due to offset load path**
- **Comparing repair vs. nominal at max load level misses most of benefit**

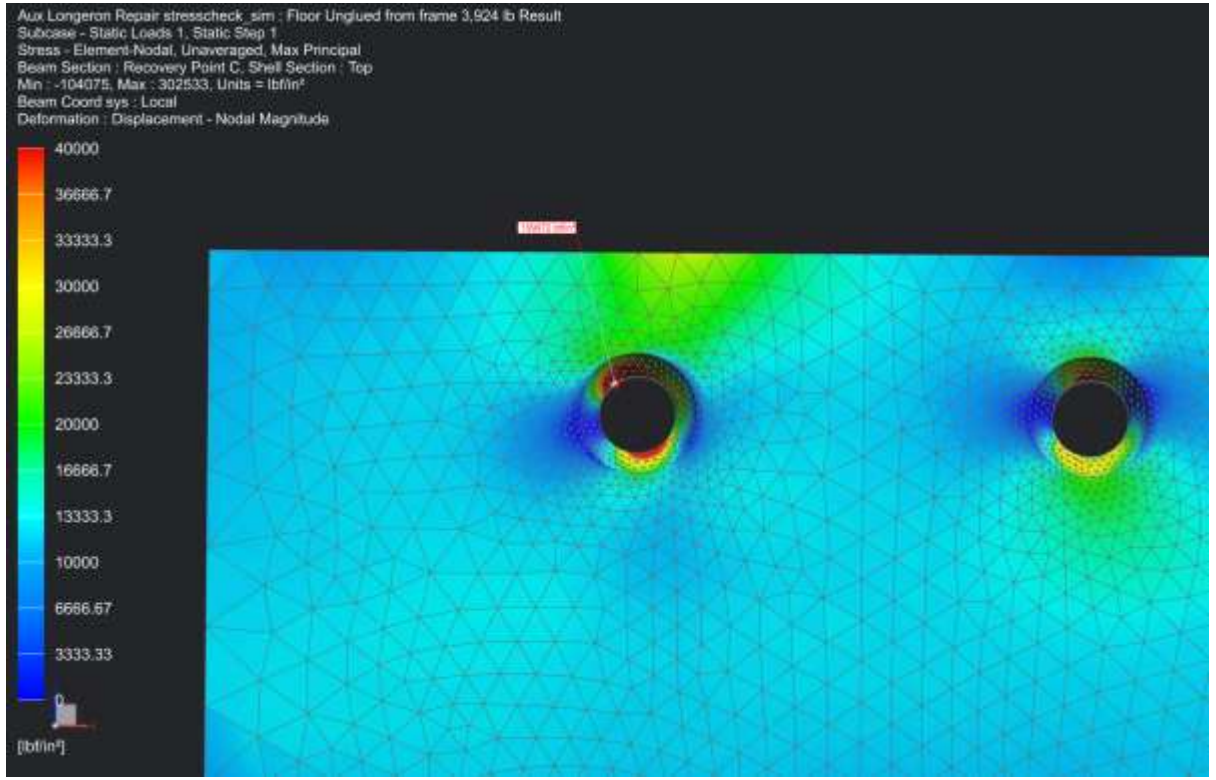
| applied load to model (lbs) | fwd aux cap stress (psi) | critical fastener resultant load nominal configuration (lbs) | critical fastener resultant load repair configuration (lbs) | % load reduction | critical fastener axial load nominal configuration (lbs) | critical fastener axial load repair configuration (lbs) | resultant nominal config TSF | resultant repair config TSF | resultant nominal config BSF | resultant repair config BSF | axial nominal config BSF | axial repair config BSF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 1529 | 646 | 122 | 81.1% | 175 | 52 | 0.65 | 0.90 | 23.84 | 4.50 | 6.46 | 1.92 |
| 1000 | 3058 | 735 | 245 | 66.7% | 220 | 103 | 0.78 | 0.90 | 13.56 | 4.52 | 4.06 | 1.90 |
| 1500 | 4587 | 814 | 367 | 54.9% | 255 | 155 | 0.83 | 0.90 | 10.01 | 4.52 | 3.14 | 1.91 |
| 2000 | 6116 | 890 | 489 | 45.1% | 300 | 206 | 0.85 | 0.90 | 8.21 | 4.51 | 2.77 | 1.90 |
| 3000 | 9174 | 1039 | 701 | 32.5% | 360 | 299 | 0.88 | 0.90 | 6.39 | 4.31 | 2.21 | 1.84 |
| 3924 | 12000 | 1172 | 847 | 27.7% | 432 | 367 | 0.89 | 0.91 | 5.51 | 3.98 | 2.03 | 1.73 |

# Two Primary Issues with Model

- Large “off-axis” load in fastener hole
  - Stresscheck
- Varying TSF and BSF with load level
  - Multi-Channel Spectrum

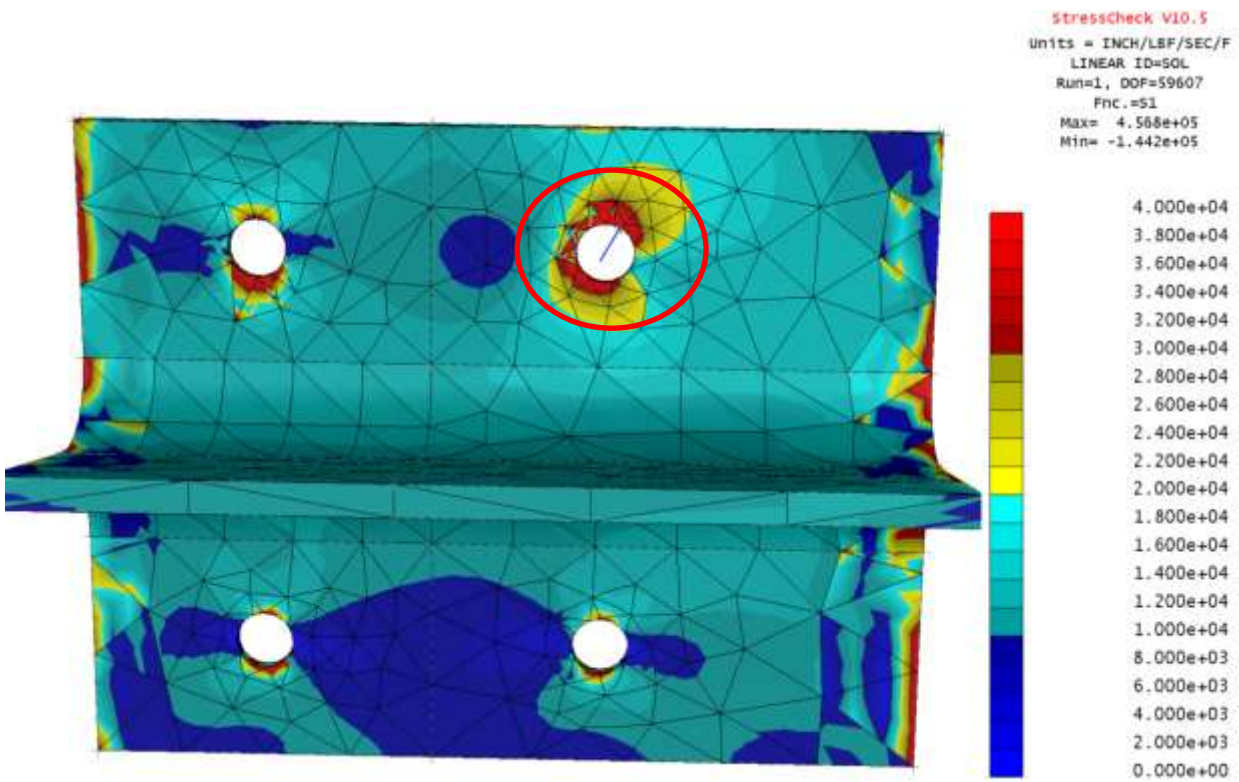
# Stresscheck

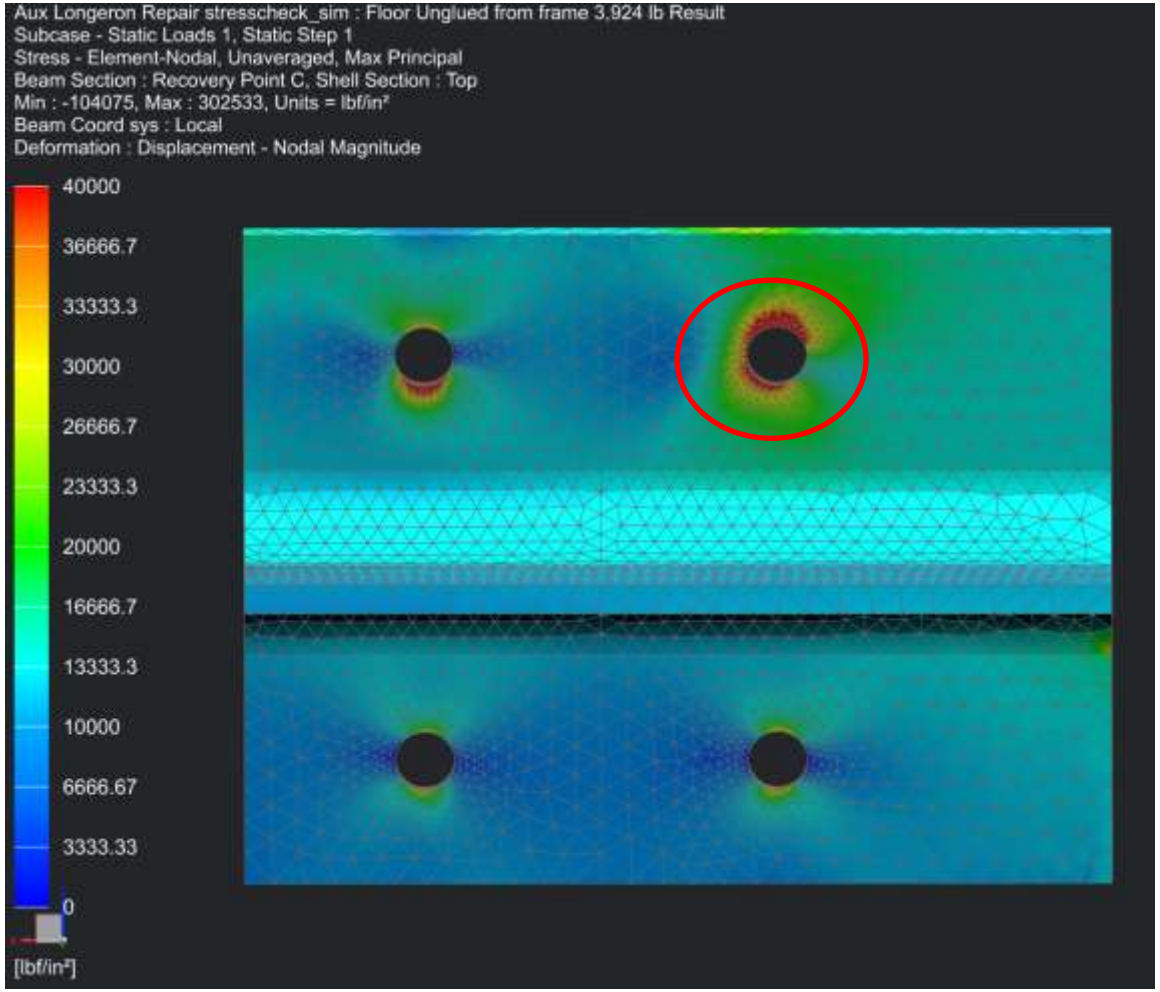
- AFGROW not capable of determining impact to off-axis load
- Two SC models built:
  - Crack plane corresponding to max principal stress in hole bore
  - Crack plane perpendicular to hole
- Displacements from cut faces and hole forces from NX used to model fastener loading



# SC/NX Stress Comparison

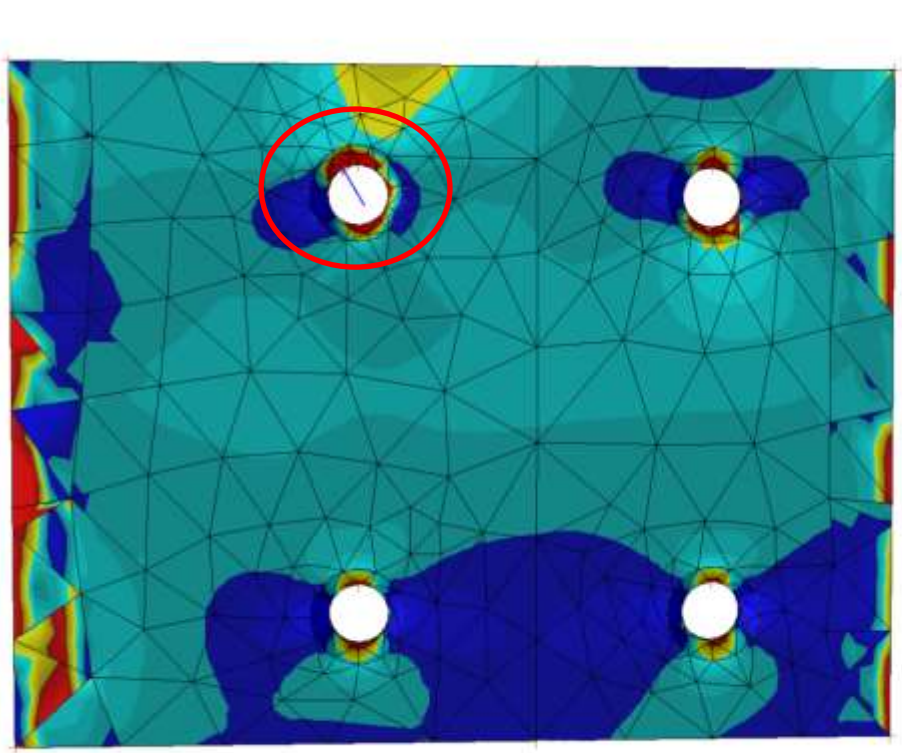
- **Inboard Face**

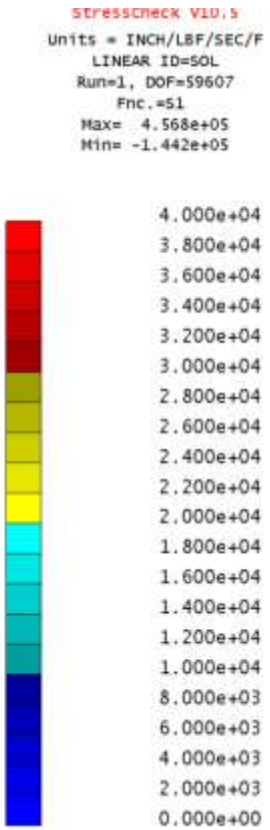


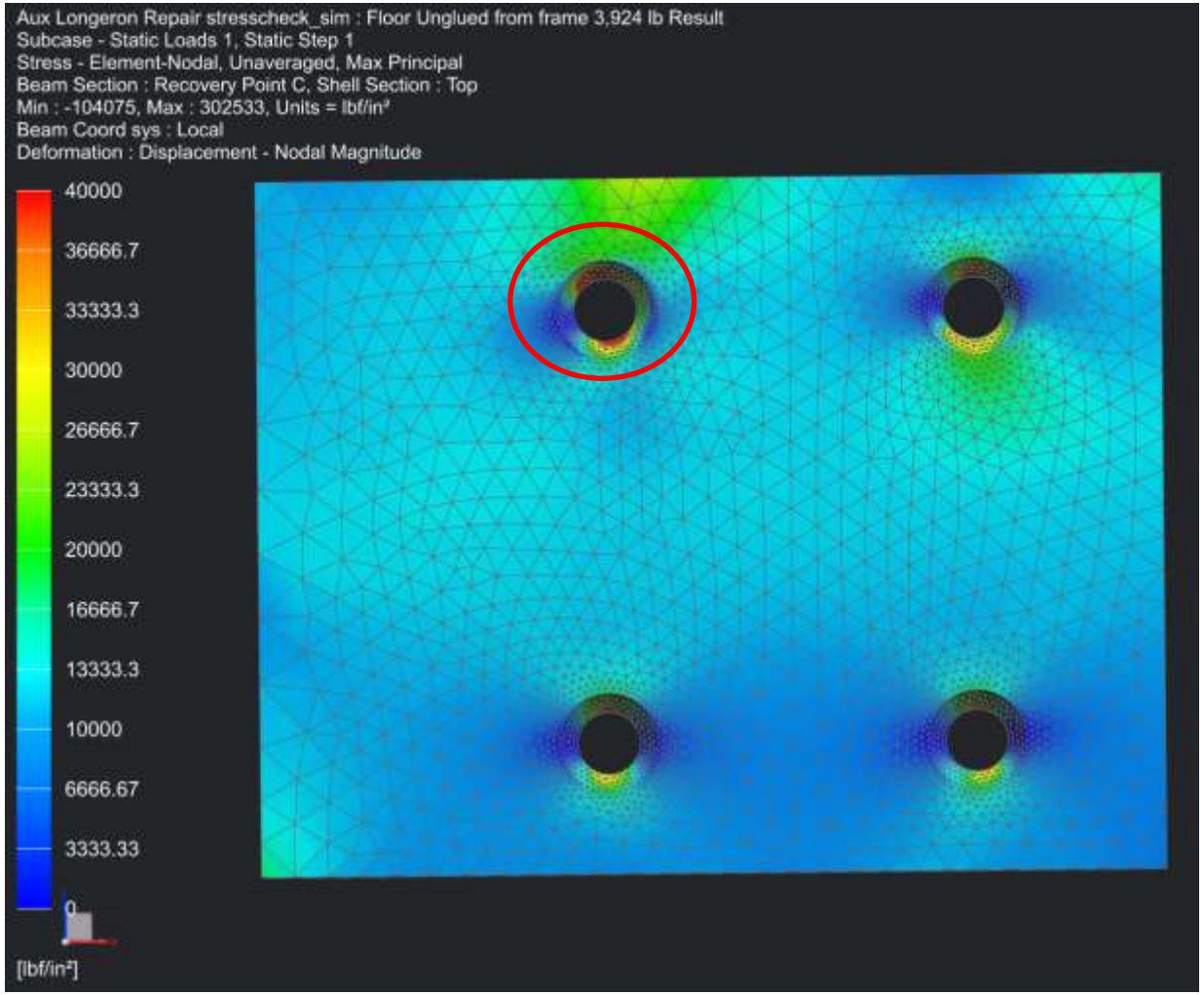



# SC/NX Stress Comparison

- **Outboard Face**



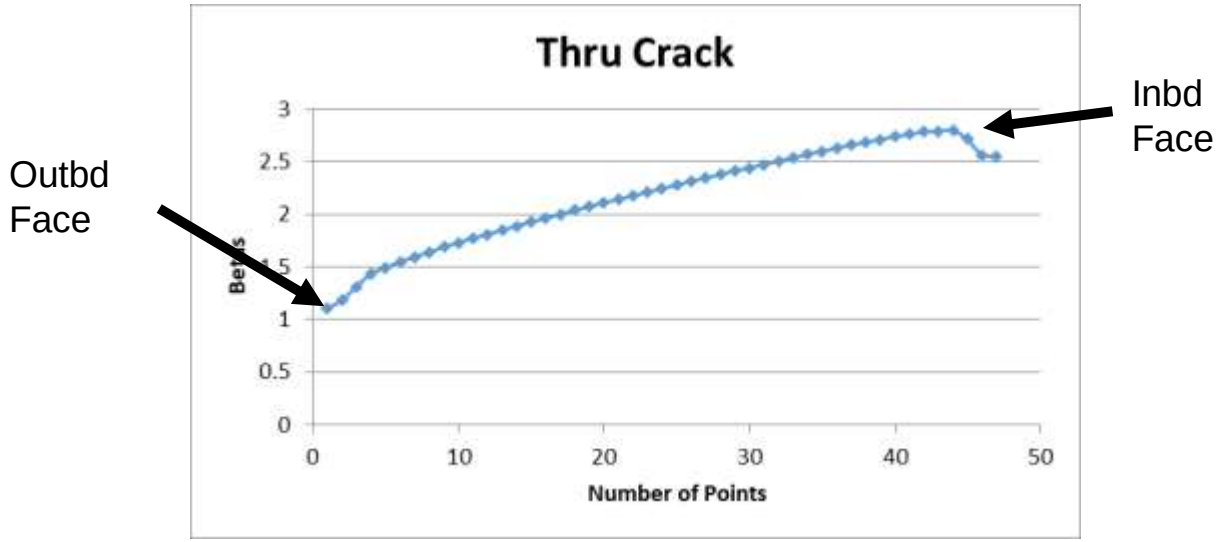


# Preliminary SC Results

- Important to decide best location for stress intensity extraction
  - Max principal plane has higher betas on inboard face (see slide 10)
  - Perpendicular plane has higher average beta
- Even using average beta, max principal plane has shorter life from .01” crack due to proximity to max principal stress
- Starting with .05” crack, perpendicular plane shorter life using average beta
- Currently waiting on strain gage measurements from aircraft to solidify appropriate load for final analysis

Max Principal Plane Beta



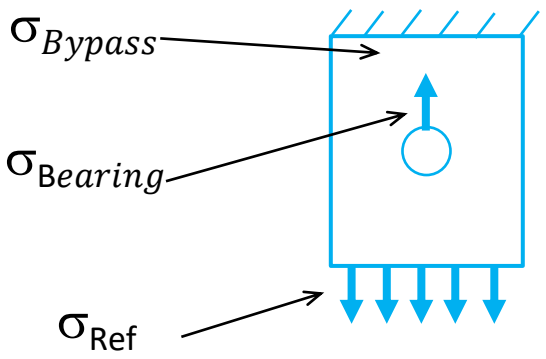
# Multi-Channel Spectrum

$$K_{Total} = K_{Tension} + K_{Bearing}$$

$$(\sigma_{Ref})(\beta_{Total})\sqrt{\pi c} = (\sigma_{bypass})(\beta_{tension})\sqrt{\pi c} + (\sigma_{bearing})(\beta_{bearing})\sqrt{\pi c}$$

$$\beta_{Total} = (TSF)\,\beta_{Tension} + (BSF)\,\beta_{Bearing}$$

$$TSF = \frac{\sigma_{Bypass}}{\sigma_{Ref\ (Far\ field)}} \qquad BSF = \frac{\sigma_{Bearing}}{\sigma_{Ref\ (Far\ field)}}$$

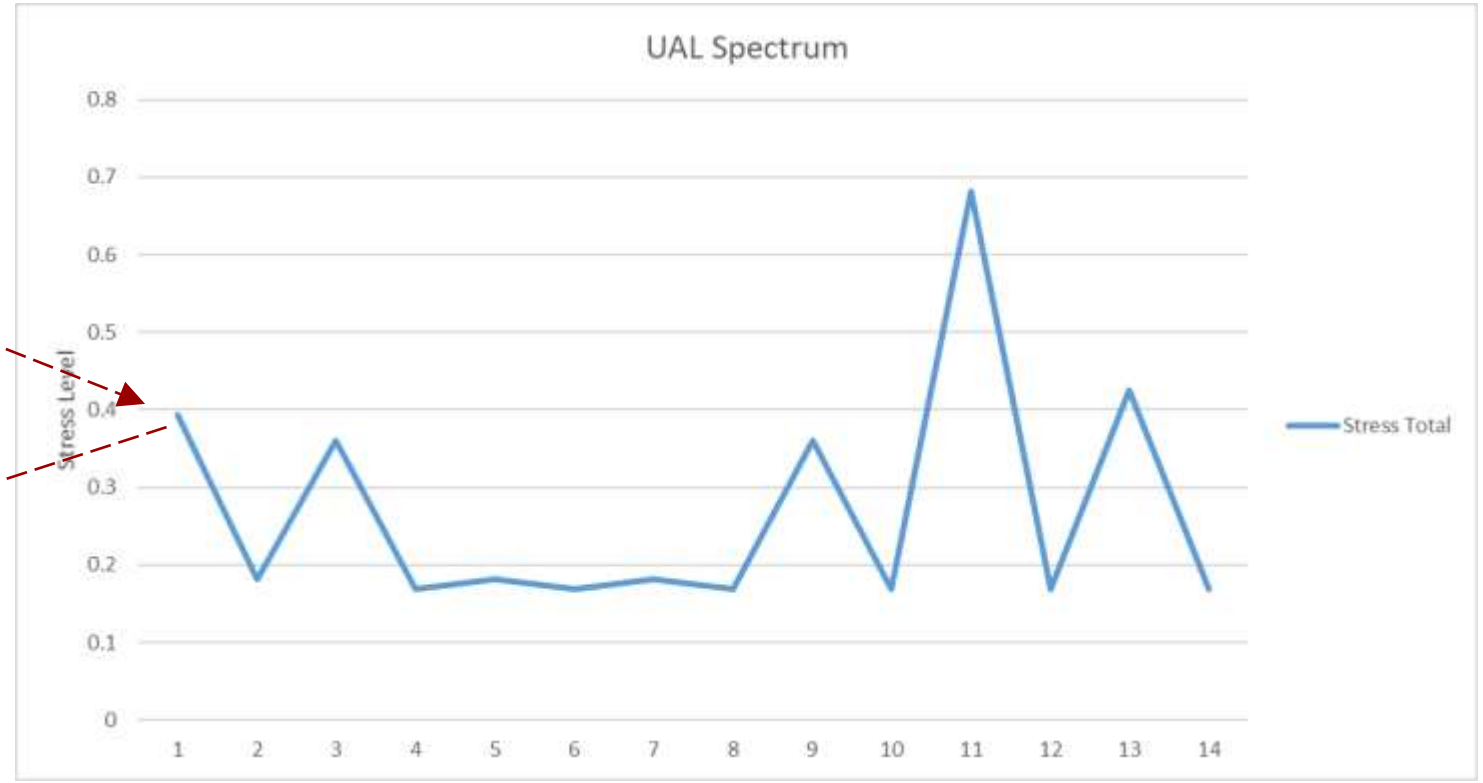



$$TSF(\sigma_{ref}) = \sigma_{bypass} \qquad BSF(\sigma_{ref}) = \sigma_{bearing}$$

TSF and BSF are the amount of bearing / bypass stress relative to the far field stress. This relationship can then be used to split the spectrum into a bearing and bypass spectrum.

# Multi-Channel Spectrum

| Load Level | Reference Stress (Spectrum) |
|---|---|
| 1 | 0.393 |
| 2 | 0.182 |
| 3 | 0.361 |
| 4 | 0.169 |
| 5 | 0.182 |
| 6 | 0.169 |
| 7 | 0.182 |
| 8 | 0.169 |
| 9 | 0.361 |
| 10 | 0.169 |
| 11 | 0.681 |
| 12 | 0.169 |
| 13 | 0.425 |
| 14 | 0.169 |




| Reference Stress (Model) | TSF | BSF |
|---|---|---|
| 1 | 0.8 | 2 |
| 0.75 | 0.6 | 1.2 |
| 0.5 | 0.4 | 1 |
| 0.393 | | |
| 0.25 | 0.2 | 0.6 |
| 0.175 | 0.175 | 0.55 |
| 0.125 | 0.15 | 0.5 |
| 0 | 0.1 | 0.4 |
| -0.2 | 0.2 | 0.3 |

Linear Interploate TSF and BSF, then multiple by Reference Stress

| Stress Tension | Stress Bearing |
|---|---|
| 0.124 | 0.326 |

Follow this process for every max and min in the spectrum

# Main Discussion Points

- **What is best way to handle “off-axis” fastener load? Does AFGROW have some capability in this?**

- **Real-world example of multi-channel spectrum requirement**
  - **Spectrum manager has capability to break out spectrum for tension and bearing**
  - **AFGROW does not have capability to implement**

# Questions?