Stress Analysis for the Corner Flexure to Grid Attachment Concept

Factors and Allowables:

Factors

MUF := 1.15  (Model Uncertainty Factor)

FS := 1.12  (Factor of Safety on Qualification loads: Qualification levels are 25% higher than design levels ... giving a factor of 1.4 on design loads, as required)

Allowables

\( \sigma_{\text{ult,A286}} := 130000 \text{psi} \)  (S-Basis, MIL-HDBK-5H allowable for A286)

\( \sigma_{\text{yield,A286}} := 85000 \text{ psi} \)  (S-Basis, MIL-HDBK-5H allowable for A286)

\( \sigma_{\text{cy,A286}} := 85000 \text{ psi} \)  (S-Basis, MIL-HDBK-5H allowable for A286)

\( \tau_{\text{ult,A286}} := 85000 \text{ psi} \)  (S-Basis, MIL-HDBK-5H allowable for A286)

\( \sigma_{\text{yield,Ti}} := 120000 \text{ psi} \)  (A-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)

\( \sigma_{\text{cy,Ti}} := 124000 \text{ psi} \)  (A-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)

\( \tau_{\text{ult,Ti}} := 79000 \text{ psi} \)  (A-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)

\( \sigma_{\text{bru.1.5}} := 214000 \text{ psi} \)  (e/D=1.5, B-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)

\( \sigma_{\text{bru.2}} := 276000 \text{ psi} \)  (e/D=2.0, B-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)

\( \sigma_{\text{bru.1.5}} := 179000 \text{ psi} \)  (e/D=1.5, B-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)

\( \sigma_{\text{bru.2}} := 212000 \text{ psi} \)  (e/D=2.0, B-Basis, MIL-HDBK-5H allowable for 6Al-4V Titanium)
Corner Flexure Stress Analysis

**Corner Flexure-to-Grid Interface Forces (Taken from Detailed TKR FEM)**

\[ \text{factor} := \frac{24}{27} \]  
\[ P_{\text{corner,lat}} := 980 \times \text{factor} \text{ N} \]  
\[ P_{\text{corner,vert}} := 4124 \times \text{factor} \text{ N} \]  
\[ P_{\text{shear,max}} := \sqrt{P_{\text{corner,lat}}^2 + P_{\text{corner,vert}}^2} \text{ lbf} \]

(Scale factor for load relief - 3dB Notching of RV spectrum around fundamental frequency)

\[ P_{\text{corner,lat}} = 195.834 \text{ lbf} \]
\[ P_{\text{corner,vert}} = 824.1 \text{ lbf} \]
\[ P_{\text{shear,max}} = 847.048 \text{ lbf} \]

**Torque and Preload Requirements for a #10-32 Screw**

Torque := 30in-lbf  
Dia\(_{10}\) := 0.19in  
K := .2  

Preload\(_{\text{nom}}\) := \[ \frac{\text{Torque}}{K \times \text{Dia}_{10}} \]  
(Ref: Equation per NASA Manual RP-1228)  
Preload\(_{\text{nom}}\) := 789.474 lbf

Preload Uncertainty for using a Torque wrench is +/-25% per NASA RP-1228 Table 7

\[ \text{Preload}_{\text{min}} := \text{Preload}_{\text{nom}} \times .75 \]  
\[ \text{Preload}_{\text{max}} := \text{Preload}_{\text{nom}} \times 1.25 \]

Preload\(_{\text{min}}\) := 592.105 lbf  
Preload\(_{\text{max}}\) := 986.842 lbf

Preload that will be used in the following calculations (user defined to verify margins against load uncertainty)

Preload := Preload\(_{\text{nom}}\)  
Preload := 789.474 lbf

**Tensile Stress on Fastener**

\[ A_{\text{stress,1032}} := .02 \text{in}^2 \]  
\[ \sigma_{\text{axial},10} := \frac{\text{Preload}}{A_{\text{stress,1032}}} \]  
\[ \sigma_{\text{axial},10} = 3.947 \times 10^4 \text{ psi} \]

\[ MS_{\text{yield},10} := \frac{\sigma_{\text{yield,A286}}}{\text{FS-MUF} \times \sigma_{\text{axial},10}} - 1 \]  
\[ MS_{\text{yield},10} = 0.672 \]

\[ MS_{\text{ult},10} := \frac{\sigma_{\text{ult,A286}}}{\text{FS-MUF} \times \sigma_{\text{axial},10}} - 1 \]  
\[ MS_{\text{ult},10} = 1.557 \]

\[ \% \text{ yield} := \frac{\sigma_{\text{axial},10}}{\sigma_{\text{yield,A286}}} \]  
\[ \% \text{ yield} = 46.44 \% \]
Corner Flexure Hoop Stress Calculations (All Four Corners)

Hoop Stress in the Flexure: this analysis looks at the minimum area and assumes that all the axial force is reacted through the smallest area. The preload from the bolt is reacted out through two sides of the cone. The diameter of the inner cone is 0.485" maximum and 0.381" minimum. The angle of the taper is 8 degrees. The lateral reaction force becomes:

\[ A_{\text{flex, top}} := 0.0475 \text{in}^2 \]

Area 1: The bottom area calculation below includes a 0.5mm chamfer only, versus the top area calculation.

\[ A_{\text{flex, bot, 1}} := 0.0473 \text{in}^2 \]

Area 2: The bottom area calculation below includes a 0.5mm chamfer and 0.5mm reduction to the cross section to account for the dimension changes made by SLAC (Grid & Tracker Lead Engineers).

\[ A_{\text{flex, bot, 2}} := 0.0345 \text{in}^2 \]

\[ \theta_{\text{collar}} := 8 \text{deg} \]

\[ F_{R,\text{flex}} := \frac{2 \times \text{Preload}}{\tan(\theta_{\text{collar}})} \]

\[ F_{R,\text{flex}} = 2.809 \times 10^3 \text{lbf} \]

The load will be shared equally on both sides of the hole. Therefore, the highest stress will be at the bottom of the corner flexure base. The minimum margin will be:

Margin Calculation using Area 1 above

\[ \sigma_{\text{hoop, flex, 1}} := \frac{1}{2} F_{R,\text{flex}} \quad \frac{1}{\min(A_{\text{flex, top}}, A_{\text{flex, bot, 1}})} \]

\[ \sigma_{\text{hoop, flex, 1}} = 2.969 \times 10^4 \text{psi} \]

\[ \text{MS}_{\text{flex, hoop, 1}} := \frac{\sigma_{\text{yield, Ti}}}{FS \cdot \text{MUF} \cdot \sigma_{\text{hoop, flex, 1}}} - 1 \]

\[ \text{MS}_{\text{flex, hoop, 1}} = 2.138 \]

Margin Calculation using Area 2 Above

\[ \sigma_{\text{hoop, flex, 2}} := \frac{1}{2} F_{R,\text{flex}} \quad \frac{1}{\min(A_{\text{flex, top}}, A_{\text{flex, bot, 2}})} \]

\[ \sigma_{\text{hoop, flex, 2}} = 4.071 \times 10^4 \text{psi} \]

\[ \text{MS}_{\text{flex, hoop, 2}} := \frac{\sigma_{\text{yield, Ti}}}{FS \cdot \text{MUF} \cdot \sigma_{\text{hoop, flex, 2}}} - 1 \]

\[ \text{MS}_{\text{flex, hoop, 2}} = 1.289 \]
Corner Flexure Bearing Stress Analysis (All Four Corners)

The section is tapered, therefore three calculations will be made to estimate the bearing stress and MS at the largest, middle, and smallest diameters, respectively. The load is assumed to be constant along the bearing length.

\[
D_{\text{taper, max}} := .485\text{in}
\]

\[
D_{\text{taper, min}} := .381\text{in}
\]

\[
D_{\text{taper, mid}} := \frac{D_{\text{taper, max}} + D_{\text{taper, min}}}{2}
\]

\[
D_{\text{taper, mid}} = 0.433 \text{ in}
\]

\[
L_{\text{taper}} := .369\text{in}
\]

\[
e := .2953\text{in}
\]

\[
w_{L} := \frac{P_{\text{corner, vert}}}{L_{\text{taper}}}
\]

\[
w_{L} = 2.233 \times 10^{3} \frac{\text{lbf}}{\text{in}}
\]

Maximum Diameter

Knockdown factors for edge distance <1.5

\[
e_{\text{overD, max}} := \frac{e}{D_{\text{taper, max}}}
\]

\[
e_{\text{overD, max}} = 0.609
\]

\[
\sigma_{\text{bru, all, max}} := \left( e_{\text{overD, max}} - .5 \right) \frac{\sigma_{\text{bru, 2}}}{2 - .5}
\]

\[
\sigma_{\text{bru, all, max}} = 2.003 \times 10^{4} \text{ psi}
\]

\[
\sigma_{\text{bry, all, max}} := \left( e_{\text{overD, max}} - .5 \right) \frac{\sigma_{\text{bry, 2}}}{2 - .5}
\]

\[
\sigma_{\text{bry, all, max}} = 1.539 \times 10^{4} \text{ psi}
\]

Bearing Calculation: Assume a cosine distribution around the hole

\[
\sigma_{\text{br, act, max}} := \frac{4 \cdot w_{L}}{\pi D_{\text{taper, max}}}
\]

\[
\sigma_{\text{br, act, max}} = 5.863 \times 10^{3} \text{ psi}
\]

\[
MS_{\text{flex, bru, max}} := \frac{\sigma_{\text{bru, all, max}}}{FS \cdot MUF \cdot \sigma_{\text{br, act, max}}} - 1
\]

\[
MS_{\text{flex, bru, max}} = 1.653
\]

\[
MS_{\text{flex, bry, max}} := \frac{\sigma_{\text{bry, all, max}}}{FS \cdot MUF \cdot \sigma_{\text{br, act, max}}} - 1
\]

\[
MS_{\text{flex, bry, max}} = 1.038
\]
Aside of the median diameter:

**Knockdown factors for edge distance <1.5**

\[
e_{\text{overD,mid}} := \frac{e}{D_{\text{taper,mid}}} \quad \text{overD}_{\text{min}} = 0.682
\]

\[
\sigma_{\text{bru,all,mid}} := \left( e_{\text{overD,mid}} - 0.5 \right) \cdot \frac{\sigma_{\text{bru,2}}}{2 - 0.5} \quad \sigma_{\text{bru,all,mid}} = 3.349 \times 10^4 \text{ psi}
\]

\[
\sigma_{\text{bry,all,mid}} := \left( e_{\text{overD,mid}} - 0.5 \right) \cdot \frac{\sigma_{\text{bry,2}}}{2 - 0.5} \quad \sigma_{\text{bry,all,mid}} = 2.572 \times 10^4 \text{ psi}
\]

**Bearing Calculation: Assume a cosine distribution around the hole**

\[
\sigma_{\text{br,act,mid}} := \frac{4 \cdot w_{\text{L}}}{\pi \cdot D_{\text{taper,mid}}} \quad \sigma_{\text{br,act,mid}} = 6.567 \times 10^3 \text{ psi}
\]

\[
\text{MS}_{\text{flex,bru,mid}} := \frac{\sigma_{\text{bru,all,mid}}}{\text{FS-MUF} \cdot \sigma_{\text{br,act,mid}}} - 1 \quad \text{MS}_{\text{flex,bru,mid}} = 2.959
\]

\[
\text{MS}_{\text{flex,bry,mid}} := \frac{\sigma_{\text{bry,all,mid}}}{\text{FS-MUF} \cdot \sigma_{\text{br,act,mid}}} - 1 \quad \text{MS}_{\text{flex,bry,mid}} = 2.041
\]

Aside of the minimum diameter:

**Knockdown factors for edge distance <1.5**

\[
e_{\text{overD,min}} := \frac{e}{D_{\text{taper,min}}} \quad \text{overD}_{\text{min}} = 0.775
\]

\[
\sigma_{\text{bru,all,min}} := \left( e_{\text{overD,min}} - 0.5 \right) \cdot \frac{\sigma_{\text{bru,2}}}{2 - 0.5} \quad \sigma_{\text{bru,all,min}} = 5.061 \times 10^4 \text{ psi}
\]

\[
\sigma_{\text{bry,all,min}} := \left( e_{\text{overD,min}} - 0.5 \right) \cdot \frac{\sigma_{\text{bry,2}}}{2 - 0.5} \quad \sigma_{\text{bry,all,min}} = 3.888 \times 10^4 \text{ psi}
\]

**Bearing Calculation: Assume a cosine distribution around the hole**

\[
\sigma_{\text{br,act,min}} := \frac{4 \cdot w_{\text{L}}}{\pi \cdot D_{\text{taper,min}}} \quad \sigma_{\text{br,act,min}} = 7.463 \times 10^3 \text{ psi}
\]

\[
\text{MS}_{\text{flex,bru,min}} := \frac{\sigma_{\text{bru,all,min}}}{\text{FS-MUF} \cdot \sigma_{\text{br,act,min}}} - 1 \quad \text{MS}_{\text{flex,bru,min}} = 4.265
\]

\[
\text{MS}_{\text{flex,bry,min}} := \frac{\sigma_{\text{bry,all,min}}}{\text{FS-MUF} \cdot \sigma_{\text{br,act,min}}} - 1 \quad \text{MS}_{\text{flex,bry,min}} = 3.044
\]
Check Margins against the new dimension (i.e. 0.5mm reduction)

e_2 := .2756in  
\( w_L = 2.233 \times 10^3 \text{ lbf/in} \)

Maximum Diameter

Knockdown factors for edge distance <1.5

\[ e_{overD_{max,2}} := \frac{e_2}{D_{taper,max}} \quad e_{overD_{max,2}} = 0.568 \]
\[ \sigma_{bru.all,max,2} := \left( e_{overD_{max,2}} - .5 \right) \cdot \frac{\sigma_{bru,2}}{2 - .5} \quad \sigma_{bru.all,max,2} = 1.256 \times 10^4 \text{ psi} \]
\[ \sigma_{bry.all,max,2} := \left( e_{overD_{max,2}} - .5 \right) \cdot \frac{\sigma_{bry,2}}{2 - .5} \quad \sigma_{bry.all,max,2} = 9.646 \times 10^3 \text{ psi} \]

Bearing Calculation: Assume a cosine distribution around the hole

\[ \sigma_{br.act.max,2} := \frac{4 \cdot w_L}{\pi \cdot D_{taper,max}} \quad \sigma_{br.act.max,2} = 5.863 \times 10^3 \text{ psi} \]

\[ MS_{flex.bru,max,2} := \frac{\sigma_{bru.all,max,2}}{FS \cdot MUF \cdot \sigma_{br.act.max,2}} - 1 \quad MS_{flex.bru,max,2} = 0.663 \]
\[ MS_{flex.bry,max,2} := \frac{\sigma_{bry.all,max,2}}{FS \cdot MUF \cdot \sigma_{br.act.max,2}} - 1 \quad MS_{flex.bry,max,2} = 0.277 \]

Corner Flexure Tearout Stress Analysis

\[ \tau_{tearout.avg} := \frac{P_{\text{corner.vert}}}{2 \cdot e \cdot L_{taper}} \quad \tau_{tearout.avg} = 3.781 \times 10^3 \text{ psi} \]
\[ MS_{flex.tearout} := \frac{\tau_{\text{ult.Ti}}}{FS \cdot MUF \cdot \tau_{tearout.avg}} - 1 \quad MS_{flex.tearout} = 15.22 \]

Knockdown factors for edge distance <1.5

\( e_{overD_{max,2}} := \frac{e_2}{D_{taper.max}} \)
\( \sigma_{bru.all,max,2} := \left( e_{overD_{max,2}} - .5 \right) \cdot \frac{\sigma_{bru,2}}{2 - .5} \)
\( \sigma_{bry.all,max,2} := \left( e_{overD_{max,2}} - .5 \right) \cdot \frac{\sigma_{bry,2}}{2 - .5} \)

Bearing Calculation: Assume a cosine distribution around the hole

\[ \sigma_{br.act.max,2} := \frac{4 \cdot w_L}{\pi \cdot D_{taper.max}} \]

Check Margins against the new dimension (i.e. 0.5mm reduction)
Conical Collar Stress Analysis (Corners #1, #2 & #3)

\[ D_{o,\text{collar}} := 0.3428 \text{in} \]
\[ D_{l,\text{collar}} := 0.199 \text{in} \]

**Collar Shear Stress**

\[ \tau_{\text{collar}} := \frac{P_{\text{shear, max}}}{\pi \left( D_{o,\text{collar}}^2 - D_{l,\text{collar}}^2 \right)^{0.5}} \]
\[ \tau_{\text{collar}} = 1.384 \times 10^4 \text{ psi} \]

**Collar Bending Stress**

\[ L_{\text{bend, collar}} := 0.065 \text{in} \]

The conical end is assumed to be guided. It is capable of reacting out a moment through the conical head.

\[ M_{\text{collar}} := \frac{1}{2} P_{\text{shear, max}} L_{\text{bend, collar}} \]
\[ M_{\text{collar}} = 27.529 \text{ in-lbf} \]

\[ c_{\text{collar}} := \frac{D_{o,\text{collar}}}{2} \]
\[ c_{\text{collar}} = 0.171 \text{ in} \]

\[ I_{\text{collar}} := \frac{\pi}{64} \left( D_{o,\text{collar}}^4 - D_{l,\text{collar}}^4 \right) \]
\[ I_{\text{collar}} = 6.009 \times 10^{-4} \text{ in}^4 \]

\[ \sigma_{\text{collar}} := \frac{M_{\text{collar}} c_{\text{collar}}}{I_{\text{collar}}} \]
\[ \sigma_{\text{collar}} = 7.853 \times 10^3 \text{ psi} \]

**Margin Calculation using Tension-Shear Interaction Equations**

\[ MS_{\text{yield, collar}} := \frac{1}{\sqrt{\left( \frac{FS \cdot MUF \cdot \sigma_{\text{collar}}}{\sigma_{\text{yield, A286}}} \right)^2 + \left( \frac{FS \cdot MUF \cdot \tau_{\text{collar}}}{\tau_{\text{ult, A286}}} \right)^2}} - 1 \]
\[ MS_{\text{yield, collar}} = 3.147 \]

\[ MS_{\text{ult, collar}} := \frac{1}{\sqrt{\left( \frac{FS \cdot MUF \cdot \sigma_{\text{collar}}}{\sigma_{\text{ult, A286}}} \right)^2 + \left( \frac{FS \cdot MUF \cdot \tau_{\text{collar}}}{\tau_{\text{ult, A286}}} \right)^2}} - 1 \]
\[ MS_{\text{ult, collar}} = 3.47 \]
#10-32 Bolt Analysis under Operational Loads (All Four Corners)

Operational loads induce an axial load in the bolt due to the taper in the conical collar. These loads are reviewed here and margins are calculated to determine the operating stress in the bolt. All forces are reacted out as axial loads on the bolt, i.e. there are no shear forces to include in this analysis. Friction is neglected. Corner #4 will see these axial loads and this analysis is acceptable for the threaded portion of the pin only.

Note: The maximum load and axial stress area is the same for all four corners. Therefore, the margins are also the same.

\[ P_{\text{screw,axial}} := P_{\text{shear,max}} \tan(\theta_{\text{collar}}) \]
\[ P_{\text{screw,axial}} = 119.045 \text{ lbf} \]
\[ P_{\text{tot,screw}} := P_{\text{screw,axial}} + \text{Preload}_{\text{nom}} \]
\[ P_{\text{tot,screw}} = 908.519 \text{ lbf} \]
\[ \sigma_{\text{tot,screw}} := \frac{P_{\text{tot,screw}}}{A_{\text{stress,1032}}} \]
\[ \sigma_{\text{tot,screw}} = 4.543 \times 10^4 \text{ psi} \]
\[ MS_{\text{yield,screw}} := \frac{\sigma_{\text{yield,A286}}}{FS \cdot MUF \cdot \sigma_{\text{tot,screw}}} - 1 \]
\[ MS_{\text{yield,screw}} = 0.453 \]
\[ MS_{\text{ult,screw}} := \frac{\sigma_{\text{ult,A286}}}{FS \cdot MUF \cdot \sigma_{\text{tot,screw}}} - 1 \]
\[ MS_{\text{ult,screw}} = 1.222 \]

1/4″ Pin Stress Analysis (Corner #4)

\[ D_{\text{pin}} := .249 \text{ in} \]
\[ A_{\text{pin}} := \frac{\pi}{4} D_{\text{pin}}^2 \]
\[ A_{\text{pin}} = 0.049 \text{ in}^2 \]

Pin Shear Stress

\[ \tau_{\text{pin}} := \frac{P_{\text{shear,max}}}{A_{\text{pin}}} \]
\[ \tau_{\text{pin}} = 1.739 \times 10^4 \text{ psi} \]

Pin Bending Stress

\[ L_{\text{bend,pin}} := 0.065 \text{ in} \]
\[ M_{\text{pin}} := \frac{1}{2} P_{\text{shear,max}} L_{\text{bend,pin}} \]
\[ M_{\text{pin}} = 27.529 \text{ in-lbf} \]
\[ c_{\text{pin}} := \frac{D_{\text{pin}}}{2} \]
\[ c_{\text{pin}} = 0.125 \text{ in} \]
\[ I_{\text{pin}} := \frac{\pi}{64} (D_{\text{pin}}^4) \]
\[ I_{\text{pin}} = 1.887 \times 10^{-4} \text{ in}^4 \]
\[ \sigma_{\text{bend}} := \frac{M_{\text{pin}} c_{\text{pin}}}{I_{\text{pin}}} \]
\[ \sigma_{\text{bend}} = 1.816 \times 10^4 \text{ psi} \]
Pin Axial Stress (from operational loads)

\[ P_{\text{axial}} := P_{\text{tot.screw}} \quad P_{\text{axial}} = 908.519 \text{lbf} \]

\[ \sigma_{\text{axial}} := \frac{P_{\text{axial}}}{A_{\text{pin}}} \quad \sigma_{\text{axial}} = 1.866 \times 10^4 \text{psi} \]

Tension on Pin

\[ \sigma_{\text{tension}} := \sigma_{\text{bend}} + \sigma_{\text{axial}} \quad \sigma_{\text{tension}} = 3.682 \times 10^4 \text{psi} \]

Margin Calculation using Tension-Shear Interaction Equations

\[ MS_{\text{yield.pin}} := \frac{1}{\sqrt{\left( \frac{F\text{-MUF} \cdot \sigma_{\text{tension}}}{\sigma_{\text{yield.A286}}} \right)^2 + \left( \frac{F\text{-MUF} \cdot \tau_{\text{pin}}}{\tau_{\text{ult.A286}}} \right)^2}} - 1 \quad MS_{\text{yield.pin}} = 0.621 \]

\[ MS_{\text{ult.pin}} := \frac{1}{\sqrt{\left( \frac{F\text{-MUF} \cdot \sigma_{\text{tension}}}{\sigma_{\text{ult.A286}}} \right)^2 + \left( \frac{F\text{-MUF} \cdot \tau_{\text{pin}}}{\tau_{\text{ult.A286}}} \right)^2}} - 1 \quad MS_{\text{ult.pin}} = 1.222 \]

Hoop Stresses in Inner Turn Plug (Corner #4)

The Inner Turn Plug will react the radial forces through hoop stresses in the walls. The Inner Turn Plug will compress. The Outer Turn Plug will see reaction forces from the Inner Turn Plug and the Flexure. The Outer Turn Plug will not see significant hoop stresses and react only compression forces through the thickness. This analysis is very preliminary and is being evaluated in greater detail.

\[ A_{\min.plug} := 1.12 \times 0.0143 \text{in}^2 \quad A_{\min.plug} = 0.016 \text{in}^2 \]

\[ F_{\text{R.flex}} = 2.809 \times 10^3 \text{lbf} \]

\[ \sigma_{\text{hoop.plug}} := \frac{1}{2} \frac{F_{\text{R.flex}}}{A_{\min.plug}} \quad \sigma_{\text{hoop.plug}} = 8.768 \times 10^4 \text{psi} \]

\[ MS_{\text{plug.hoop}} := \frac{\sigma_{\text{cy.Ti}}}{F\text{-MUF} \cdot \sigma_{\text{hoop.plug}}} - 1 \quad MS_{\text{plug.hoop}} = 0.098 \]
**Eccentric Washer Design**

Pros: Easy Cleanup/Preparation for Integration
- Stiff Connection

Cons: Risk of Inner Plug getting wedged into place ... May Cause Serious Heartache
- More Parts
- Induced Stress - Humans Do Alignment
- Induced Stresses on Flexures
- Cyclic axial load on bolts - operations
- Amplitude Dependent Stiffness Effects from 0.065" Offset between Grid and Taper
- Higher Cost to Fabricate
- Custom Hardware Components

**Epoxy in Remaining Screws**

Pros: No Induced Stress from Human Alignment/Friction of Joint
- Representative Joint to FEA
- Simple Design
- Simple to Implement
- Easy to Retrofit to EM Tower
- Greater Bearing Surface
- Give Back 0.5mm on Bottom
- Lower Cost to Fabricate
- Off-the-Shelf Hardware

Cons: Messy Cleanup
- Epoxy more compliant than metal (overall stiffness drop, not amplitude dependent)

**Alternate Solution:** Use the side flexures to locate the TKR Tower. Install a 1/4" pin into a side flexure pin location (edge #1) to constrain Z and Y. Install a 1/4" pin in the opposing side flexure pin location (edge #3) to constrain Z and Y. Install a final 1/4" pin into one of the adjacent side flexure pin locations (edge #2) to constrain Z and X. This provides six constraints for six degrees of freedom (3-2-1 constraint). Avoid slippage by making the pins 0.0002" to 0.0004" oversized, causing a slight interference fit. Do the same to the grid. Epoxy in Remaining Nine Screws.

Pros: Simple Design
- Easy to Retrofit
- No Induced Stress on Bottom Tray
- Representative Joint to FEA
- Greater Bearing Surface
- Give Back 0.5mm on Bottom
- Lowest Cost to Fabricate
- Off-the-Shelf Hardware Throughout

Cons: Messy Cleanup
- Epoxy more compliant than metal (overall stiffness drop, not amplitude dependent)