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# SunEarth Inc. CompRail Structural Engineering Report

Monday, March 22nd 2004

The SunEarth CompRail PV mounting structure has been analyzed using Finite Element Analysis (FEA) with NSC Nastran V2001.0.9. The modeled configuration of the CompRail assembly consisted of:

- A 120" free-span of CompRail between anchor points or footings.
- A 30" cantilever of CompRail beyond the last anchor point.
- A 300 lbf/ft linear loading on the Comprail, which represents the racking of 72" long photovoltaic (PV) modules with a 50 psf uplift and downforce loads applied normal to the module.

These conditions represent the maximum allowable spans and linear loading recommended by SunEarth Inc. for the CompRail structure. A highlight of the structural findings includes:

- The maximum Von Mises stresses in the CompRail extrusions reaches 33,000 psi at the attachment anchor point and under the compression bolt nearest the anchor. These stresses approach the ultimate strength for the material at 34,800 psi. Since the yield strength of the material (31,200 psi) is exceeded, the fatigue life of the structure is not infinite.
- The plastic strain within the CompRail extrusions shows a maximum of 5% within the 120" free-span and 1% within the 30" cantilevered section. These plastic strains are well within the 12% plastic limit for the material.
- Compression bolt stresses reach 33,500 psi within the 120" free-span and are limited to 16,100 psi on the 30" cantilevered section in the uplift condition. These stresses are well below the yield stress of the 18-8 stainless steel material of the bolts.
- In uplift, maximum deflections of the CompRail structure are 2.2" at the center of the 120" free-span and 0.6" at the tip of the 30" cantilevered section. In Downforce, maximum deflections of the CompRail structure are 1.9" at the center of the 120" free-span and 0.6" at the tip of the 30" cantilevered section.

These structural findings confirm that the CompRail structure can withstand repeated applications of the loading arrangement outlined above so long as the following conditions are met:

- The maximum distance between anchor points is 120" or less along the CompRail axis.
- The maximum distance the CompRail extends beyond the last anchor point is 30" or less.
- The maximum linear loading in uplift or downforce along the CompRail is 300 lbf/ft or less.

These conditions are accurately described and met in the SunEarth 'CompRail Structural Engineering Guidelines' report control number 031604-1 dated March 16th, 2004. This work was done under the guidance and supervision of SunEarth, Inc. and, as such, all liability for the applicability of these results is the responsibility of SunEarth, Inc.

George Laird II, Ph.D., P.E.
President, Predictive Engineering Inc.

# SunEarth CompRail™ Structural Engineering Guidelines

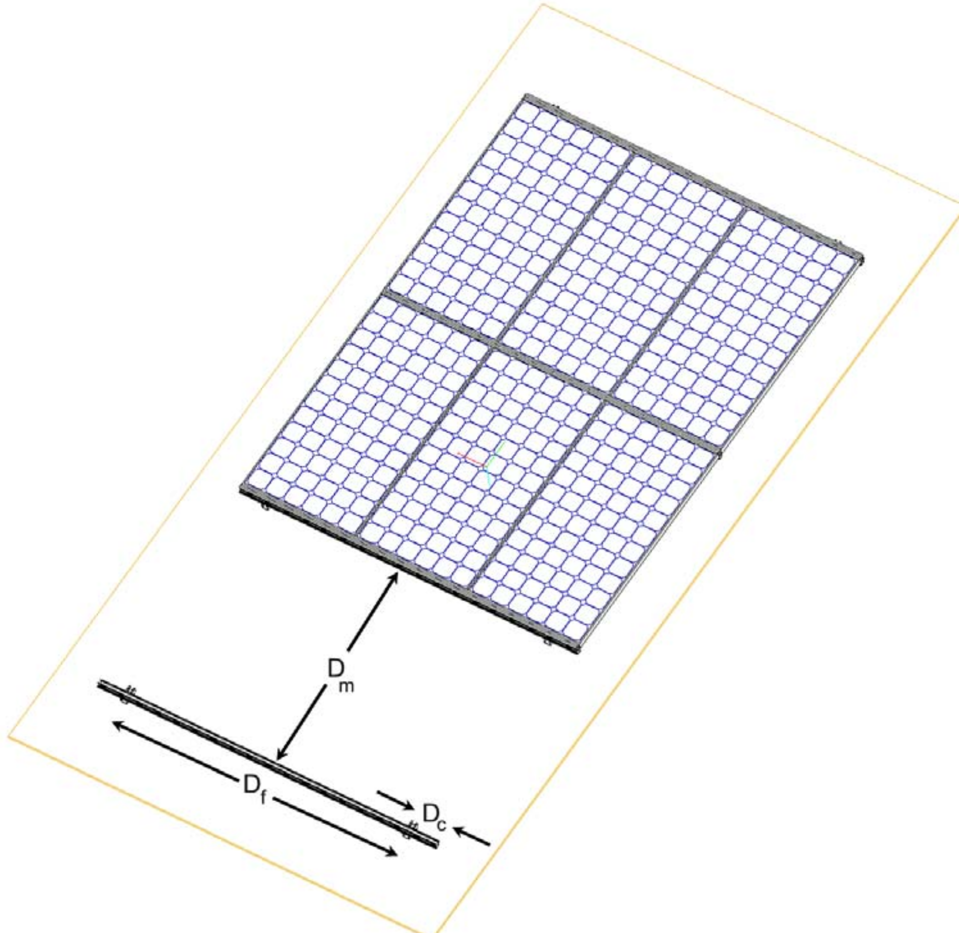
**Monday, March 22nd, 2004**
**Control Document 032204-1**

The SunEarth Inc. CompRail photovoltaic mounting hardware has undergone extensive structural analysis to verify that it can withstand repeated applications of wind pressures of 50 PSF exerted as both a positive and negative pressure with respect to the face of the array.

These Guidelines are meant to serve as a reference for installers and system designers who wish to install the CompRail system. The report outlines the methodology used for calculating the linear loading for the CompRail system, the free-span between footings on the interior of the array, and the cantilevered extension beyond the last footing. These values may then be compared to the maximum design values presented to verify if the configuration being analyzed is structurally adequate.

Linear load values for presently available PV modules are provided as are standard lag screw withdrawl values. While these values are deemed reliable, they are not guaranteed. System installers and designers should verify these values before installation

# Determination of Freespan, Cantilever Extension, & Linear Load




The figure above shows a small sample array using CompRail of three modules per row and three rows high. The PV modules have been removed from the lowest row to illustrate the dimensions of interest.

**CompRail Freespan ($D_f$):**
The free-span $D_f$ is the unsupported distance spanned by the CompRail between footings. In residential applications $D_f$ is usually restricted to multiples of rafter spacing (16" or 24" on center). The free-span $D_f$ may also relate to spacing between roof mounted curbs or structural members on a carport or trellis that the CompRail is structurally anchored to. ***Under no circumstances shall the free-span $D_f$ exceed 120" in any application.***

**Cantilever Extension ($D_c$):**
The cantilever extension $D_c$ is the distance the CompRail extends beyond the last anchor/footing. ***Under no circumstances shall the cantilever extension $D_c$ exceed 30" in any application.***

**Linear Load ($F_L$):**
The linear load $F_L$ the CompRail assembly is subject to is determined by the height of the module being racked $D_m$ and the pressure the module is exposed to $P_m$. The linear load $F_L$ is calculated as:

$$F_L\ (lbf/ft) = D_m\ (ft) \bullet P_m\ (lbf/ft2)$$

As an example, a 6' high module exposed to a 50 psf wind pressure oriented normal to the array would have a linear load of 300 lbf/ft. ***Under no circumstances shall the linear load $F_L$ exceed 300 lbf/ft in any application.***

# Tabulated Values for the Linear Load for Various PV Modules

Tabulated linear load values ($F_L$) for major manufactures of PV modules are presented in the table below for reference. These values are calculated assuming that the panels are racked such that the long dimension (the height) of the panel is the racked dimension $D_m$. This arrangement minimizes the number of rails required to rack a given array. If lower linear loads are desired, it is possible to rack the PV modules on their short dimension and the equation for $F_L$ outlined in the previous section should be used.

The linear load $F_L$ expressed in lbf/ft is calculated for three load cases: 30, 40, and 50 psf applied normal to the face of the module. Installers and designers should consult local or national building codes to determine the particular load case that applies to the installation. The values presented in the table are for reference only and designers/installer should check the dimensions on the panels they plan to use.

| Module | 30 psf | 40 psf | 50 psf |
|---|---|---|---|
| ***Astropower*** | | | |
| AP-30 | 70 | 93 | 116 |
| AP-45, 50 | 85 | 113 | 141 |
| AP-65, 75 | 118 | 157 | 197 |
| AP-100, 110, 120 | 145 | 194 | 242 |
| ***BP Solar*** | | | |
| SX 40, 50 | 93 | 123 | 154 |
| SX 60 | 109 | 146 | 182 |
| SX 70 TU, 75 TU | 119 | 158 | 198 |
| 275, 375, 380 | 119 | 158 | 198 |
| 580, 585 | 119 | 158 | 198 |
| SX 120 | 143 | 191 | 239 |
| MSX 120 | 109 | 145 | 182 |
| SX 140 B, 150 B, 160 B | 157 | 209 | 261 |
| 3150, 3160 | 157 | 209 | 261 |
| 4150, 4160, 4170 | 157 | 209 | 261 |
| ***Evergreen*** | | | |
| EC-47, 51, 55 | 80 | 107 | 134 |
| EC-94, 102, 110 | 156 | 208 | 260 |
| ***Kyocera*** | | | |
| KC 35, 40, 45, 50 | 64 | 86 | 107 |
| KC 60 | 74 | 99 | 123 |
| KC 70 | 85 | 114 | 142 |
| KC 80 | 96 | 128 | 160 |
| KC 120, 125G | 140 | 187 | 234 |
| KC 158G, 167G | 127 | 169 | 212 |

| Module | 30 psf | 40 psf | 50 psf |
|---|---|---|---|
| ***Photowatt*** | | | |
| PW 750-70, 75, 80, 85, 90 | 122 | 162 | 203 |
| PW 1250-115, 125, 135 | 122 | 162 | 203 |
| PW 1650-155, 165, 175 | 121 | 161 | 201 |
| ***RWE Schott*** | | | |
| ASE-300-DGF/50, DGF/17 | 186 | 248 | N/A |
| ***Sharp*** | | | |
| NE-80E1U (80 W) | 118 | 158 | 197 |
| ND-L3E1U (123 W) | 148 | 197 | 246 |
| NE-Q5E2U (165 W) | 155 | 207 | 258 |
| NT-S5E1U (185 W) | 155 | 207 | 258 |
| ***Sanyo*** | | | |
| HIT 167, 175, 180 | 130 | 173 | 217 |
| ***Shell/Siemens*** | | | |
| ST 36, 40 | 127 | 170 | 212 |
| SM 50-H | 120 | 160 | 200 |
| SM 55 | 127 | 170 | 212 |
| SQ 70, 75, 80 | 118 | 157 | 197 |
| SM 110 | 130 | 173 | 216 |
| SQ 140, 150, 160 | 160 | 213 | 266 |
| ***Unisolar*** | | | |
| US-64, 32 | 135 | 179 | 224 |
| US 42, 21 | 92 | 122 | 153 |

# Calculating Anchor/Footing Resultant Load

The linear load supported by the CompRail assembly must be restrained by anchor assemblies or footings placed along the rail. The resultant footing load ($F_f$) on the interior anchors/footings, which represent the worst case within the array, can be expressed as:

$$F_f \text{ (lbf)} = F_L \text{ (lbf/ft)} \bullet D_f \text{ (ft)}$$

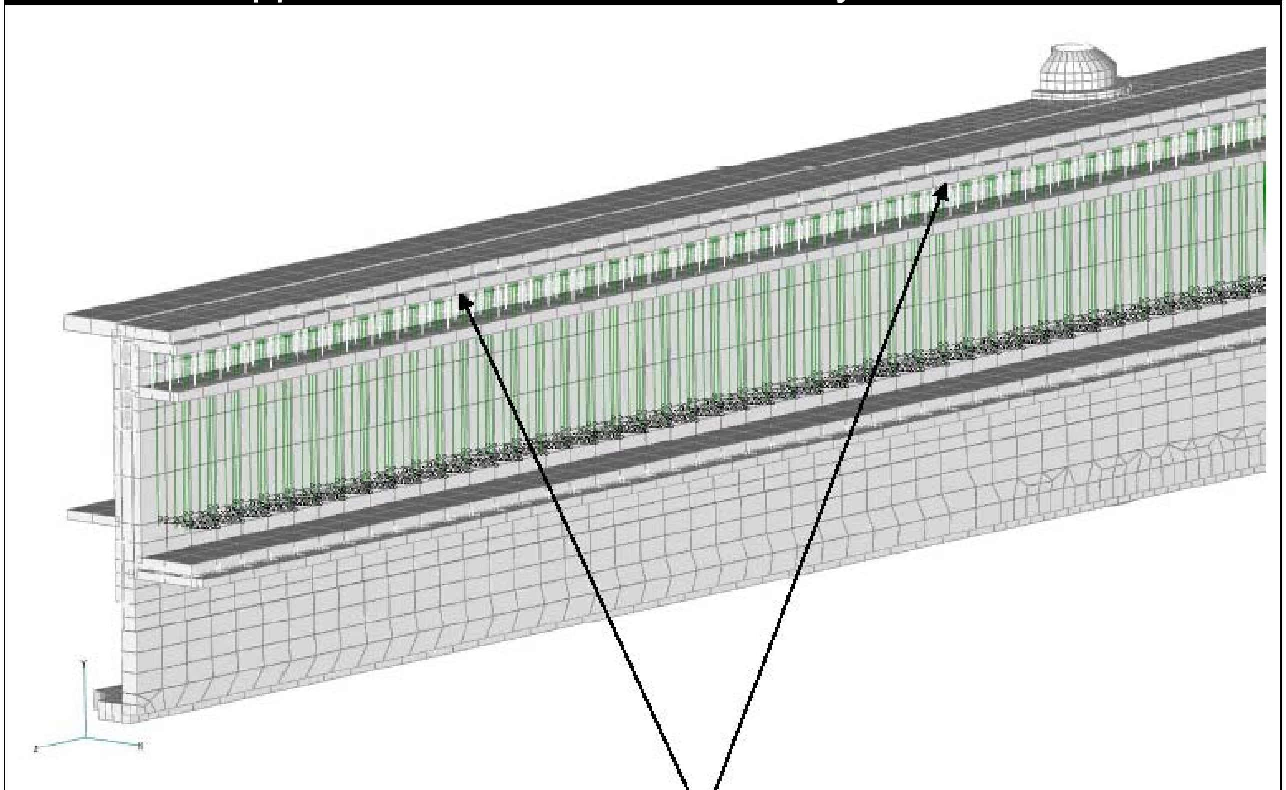
Under worst-case design conditions for the CompRail assembly, each anchor/footing must withstand a 300 lbf/ft linear load over a 10' free-span. This configuration would result in a 3,000 lbf point load that the anchor/footing must be capable of resisting. In many cases, the footing load is much less than that calculated under the maximum design rating for the CompRail system. As an example, the linear load for a Shell SP-150 at 30 PSF design pressure is only 160 lbf/ft. If this was installed in a residential application with footings placed at 4' centers to hit the rafters, the anchor/footing load would be only 640 lbf (640 = 160 * 30).

Tabulated values for withdrawal strengths of 5/16", 3/8", and 1/2" lag bolts and hangar bolts, which may be used as anchors, are provided below based on section 8.3.5 of the 2002 APA Engineered Wood Handbook. Withdrawal strength is expressed in terms of lbf per inch of full threaded depth. As an example, a 3/8" lag with a full threaded depth of 2.28" (this is the full theaded depth of a 4" lag) installed in a coast type Douglas Fir would provide a withdrawal strength of 592 lbf.

**These values are provided for reference only and utilize assumptions specified in the 2002 APA Engineered Wood handbook. The system installer or designer is responsible for verifying that the footing to be used is capable of withstanding the resultant anchor/footing load $F_f$.**

| Wood Type | Specific Gravity | 5/16" Lag | 3/8" Lag | 1/2" Lag |
|---|---|---|---|---|
| Douglas Fir – Coast Type | 0.45 | 227 | 260 | 323 |
| Fir – Balsam | 0.32 | 136 | 156 | 194 |
| Fir – Grand | 0.35 | 156 | 179 | 222 |
| Fir – Noble | 0.37 | 169 | 194 | 241 |
| Fir – Pacific Silver | 0.39 | 183 | 210 | 261 |
| Fir – White | 0.37 | 169 | 194 | 241 |
| Hemlock – Western | 0.42 | 205 | 235 | 291 |
| Hemlock – Eastern | 0.48 | 250 | 287 | 356 |
| Pine – Loblolly | 0.47 | 242 | 278 | 345 |
| Pine – Longleaf | 0.54 | 299 | 342 | 425 |
| Pine – Shortleaf | 0.47 | 242 | 278 | 345 |
| Pine – Lodgepole | 0.39 | 183 | 210 | 261 |
| Pine – Ponderosa | 0.39 | 183 | 210 | 261 |
| Pine – Red | 0.42 | 205 | 235 | 291 |
| Pine – Sugar | 0.34 | 149 | 171 | 212 |
| Pine – Western White | 0.35 | 156 | 179 | 222 |
| Redwood | 0.39 | 183 | 210 | 261 |
| Spruce – Black | 0.38 | 176 | 202 | 251 |
| Spruce – Engelmann | 0.33 | 143 | 164 | 203 |
| Spruce – Sitka | 0.38 | 176 | 202 | 251 |
| Cedar – Eastern Red | 0.46 | 235 | 269 | 334 |
| Cedar – Western Red | 0.48 | 250 | 287 | 356 |

# Appendix A: Finite Element Analysis Results



**CompRail FEA Model Description:**
The 6063-T6 extruded Aluminum CompRail structure was modeled using a combination of plate, solid, and beam elements. The Aluminum extruded sections were modeled using plate elements. The bolt head and nut were modeled using brick (solid) elements. The main sections of the bolts were simulated with beam elements. The beam elements were attached to the plate and solid elements with rigid links. Contact behavior between the bolt and the extrusion sections were enforced with gap elements. All analysis work was performed using MSC.Nastran V2001.0.9. An iterative nonlinear solution technique was required due to the use of gap elements and material plasticity.

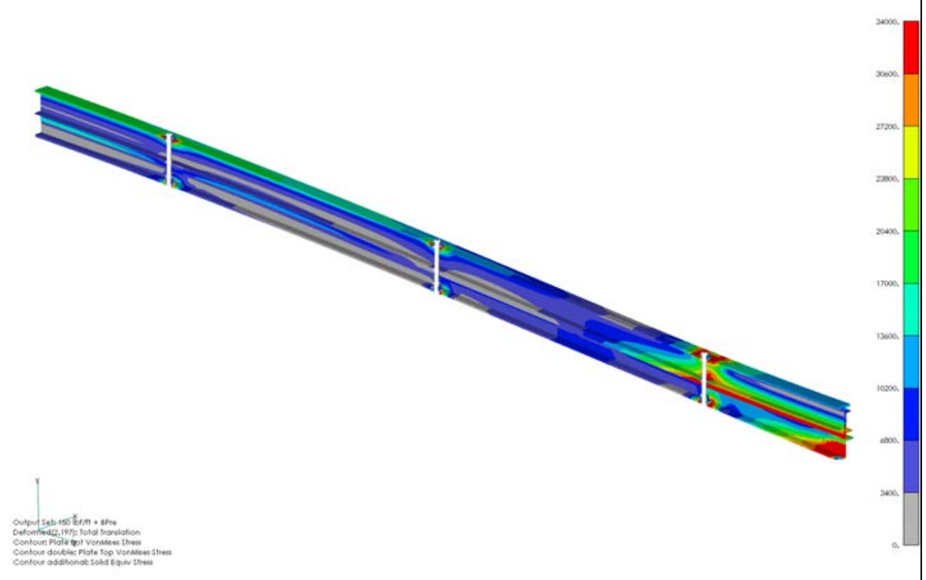
**CompRail FEA Model Loading:**
The load was applied in a manner to simulate both the uplift and downforce actions of the solar photovoltaic (PV) panels. It was assumed that the structure was symmetrically loaded. That is, the 150 lbf-ft design load was acting on both longitudinal sides of the CompRail structure to create a combined linear load of 300 lbf-ft. This design load was applied as a uniform pressure on the appropriate surface of the glass receiving channel in the PV module frame as indicated by the green arrows shown in the model above. These two loading conditions (uplift and downforce) are intended to simulate positive and negative wind loadings with respect to the PV modules.

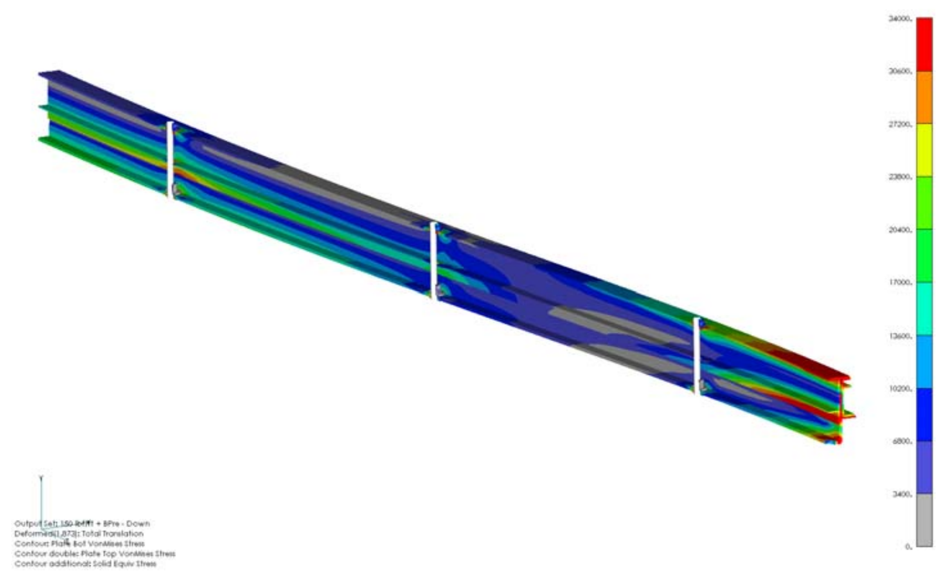
**Results Summary:**
Stresses in the CompRail structure reached a peak of around 33,000 psi. Although near the ultimate strength of the 6063-T6 aluminum, failure is not predicted under the 300 lbf-ft linear load considering that the peak plastic strain is only around 5% with an ultimate allowable of 12% for the aluminum. Based on this low plastic strain, the simulation would indicate that the CompRail structure should survive the repeated, but not consistent, application of a 300 lbf-ft linear load. Complete results are provided in the following pages.

# 120” Free-Span Stress Analysis

The figures below represent the FEA analysis of Von Mises stresses in the CompRail assembly for a 120” free-span at 300 lbf/ft loading along the rail axis. The figure represents a quarter symmetry model where the rail is secured to a footing at the right edge and the left edge is at a plane of symmetry representing the center of the 120” free span. Additionally, the rail is cut down the centerline to mirror the left/right symmetry of the extrusions. Maximum stresses in the extruded rail occur at both the base of the lower extrusion where it is anchored to the footing as well as at the contact surfaces for the first bolted connection. Maximum Von Mises stresses in the aluminum do not exceed 33,000 psi in either load case, which is below the ultimate strength of the 6063-T6 Aluminum used. The legends for both figures are capped at 34,000 psi.

| Uplift | Downforce |
| --- | --- |

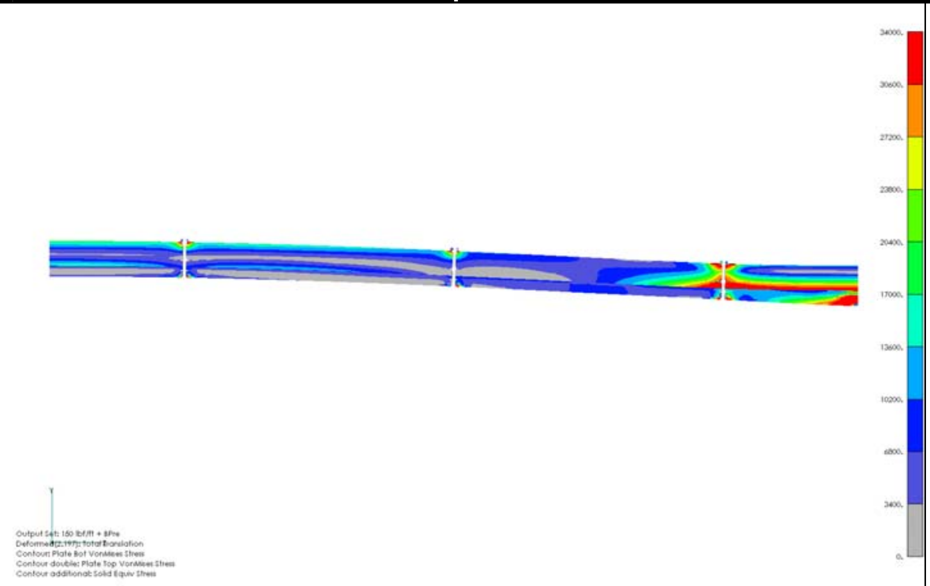


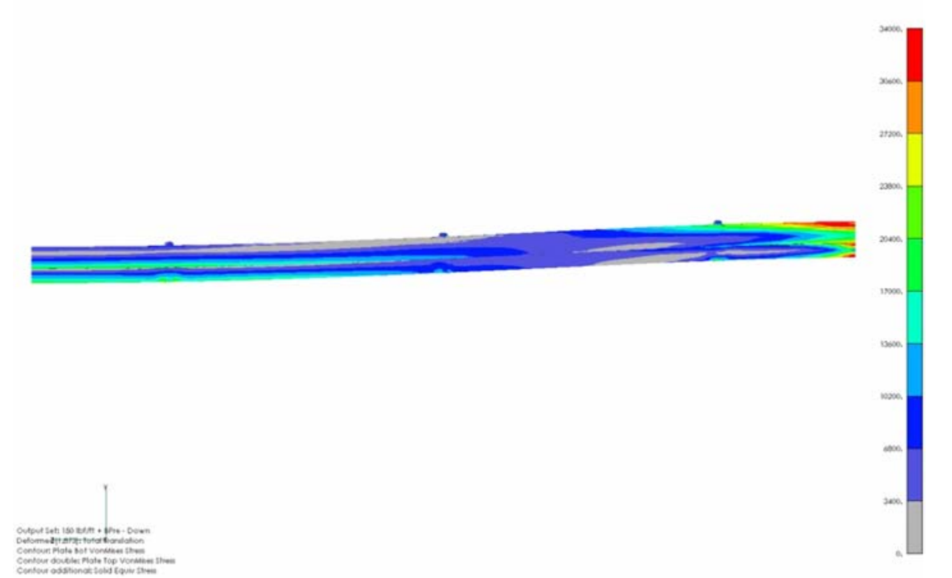
# 120” Free-Span Deflection Analysis

The figures below represent a side view of the Von Mises stresses and deflection of the 120” free-span. In the uplift condition, the deflection at the center of the span is 2.2”. In the downforce condition, the deflection at the center of the span is 1.9”. Again the figures show the rail anchored at the lower right with the left edge of the rail representing a plane of symmetry at the center of the span. The legends for the von Mises Stresses are capped at 34,000 psi in both figures.

## Uplift

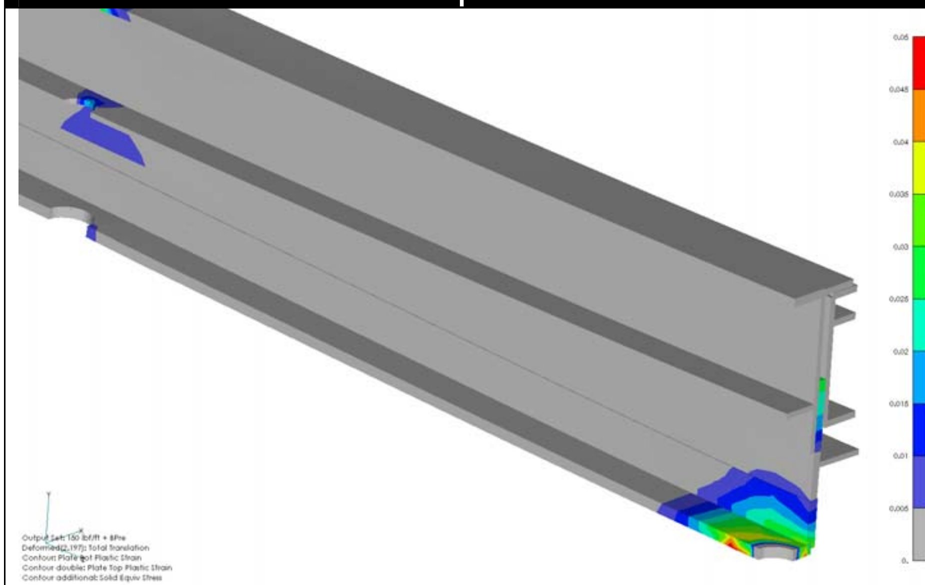
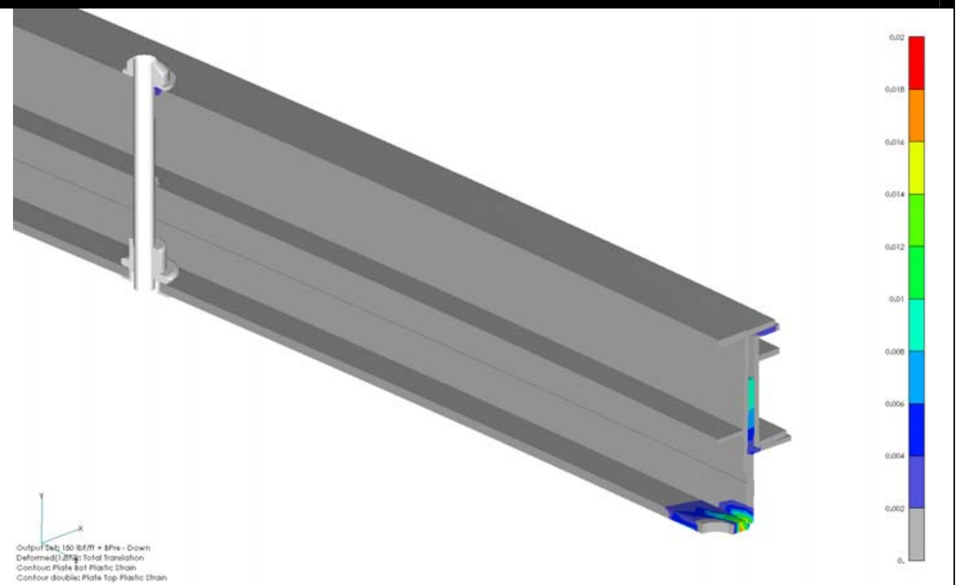



## Downforce



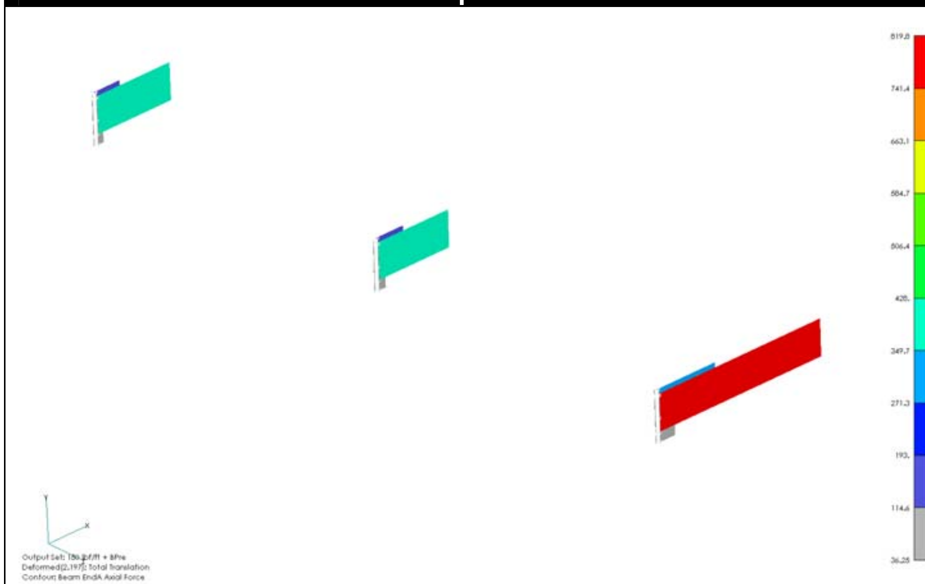
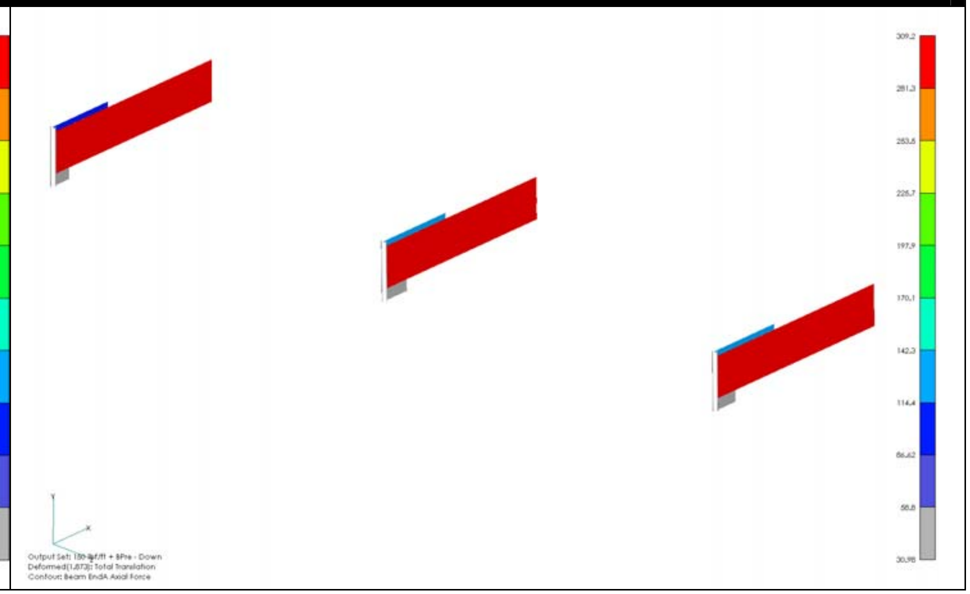
# 120” Free-Span Plastic Strain

An analysis of the plastic strain within the 120” free-span shows a maximum of less than 5% at the lower rail anchor point and first compression bolt in the uplift condition. Plastic strain in the downforce condition is reduced below 2% occurring at the lower rail anchor point. The maximum allowable plastic strain for the material is 12% verifying that the CompRail structure can withstand the imposed 300 lbf/ft loading conditions. Legends for the plastic strain are capped at 5% under uplift and 2% in downforce.

| Uplift | Downforce |
|---|---|
|  |  |

# 120” Free-Span Compression Bolt Stress Analysis

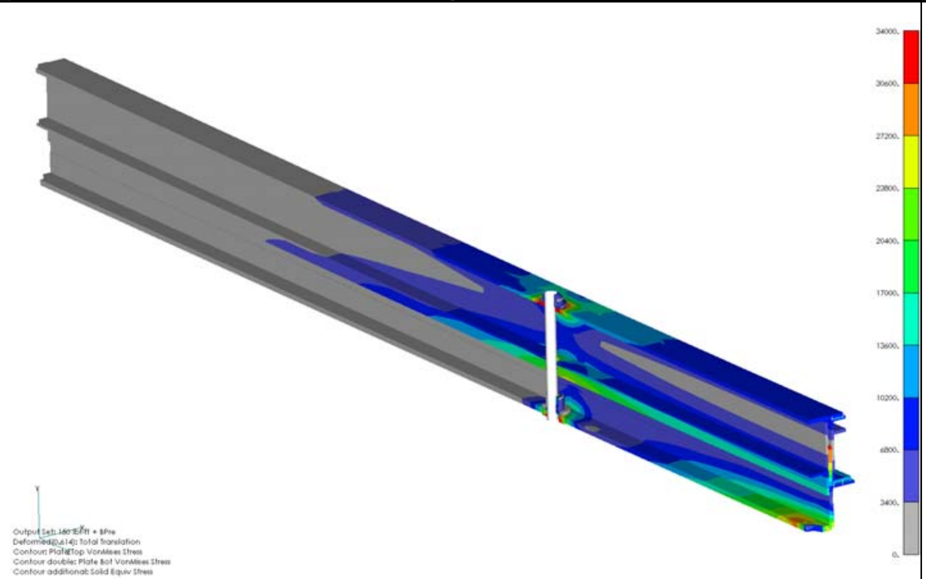
An analysis of the bolt loads and stresses indicate that a maximum bolt load of 1,640 lbf occurs in the compression bolt closest to the anchor point during the uplift condition. In the downforce condition, the bolt loads remain at their nominal 620 lbf preload. The resultant stress in the bolt material is calculated at 33,500 psi for the nominal diameter of the 5/16”-18 bolt closest to the anchor point in uplift. This is well below the yield stress for the18-8 stainless steel bolt material. Legends for bolt loadings are capped at 820 lbf for the upload condition and 310 lbf for the downforce condition. Actual loading values need to be doubled to account for the half-symmetry modeling of the bolts.

| Uplift | Downforce |
| --- | --- |
|  |  |

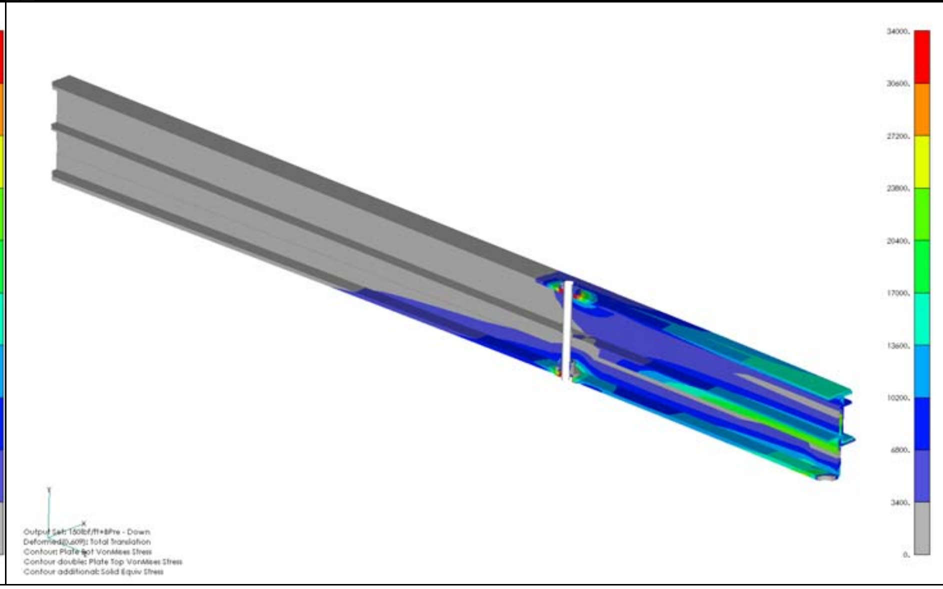
# 30” Cantilevered Section Stress Analysis

The figures below represent the FEA Von Mises stresses for a model of a 30” cantilevered section of CompRail extending beyond the last anchor point. The figure represents a half symmetry model where the rail is secured to a footing at the right edge and the left edge is cantilevered and unrestrained. Maximum stresses in the extruded rail occur at both the base of the lower extrusion where it is anchored to the footing as well as at the contact surfaces for the first bolted connection. Maximum Von Mises stresses in both load cases do not exceed 33,000 psi, which is below the ultimate strength of the 6063-T6 Aluminum used. The legends for the von Mises Stress are capped at 34,000 psi in both figures.

## Uplift

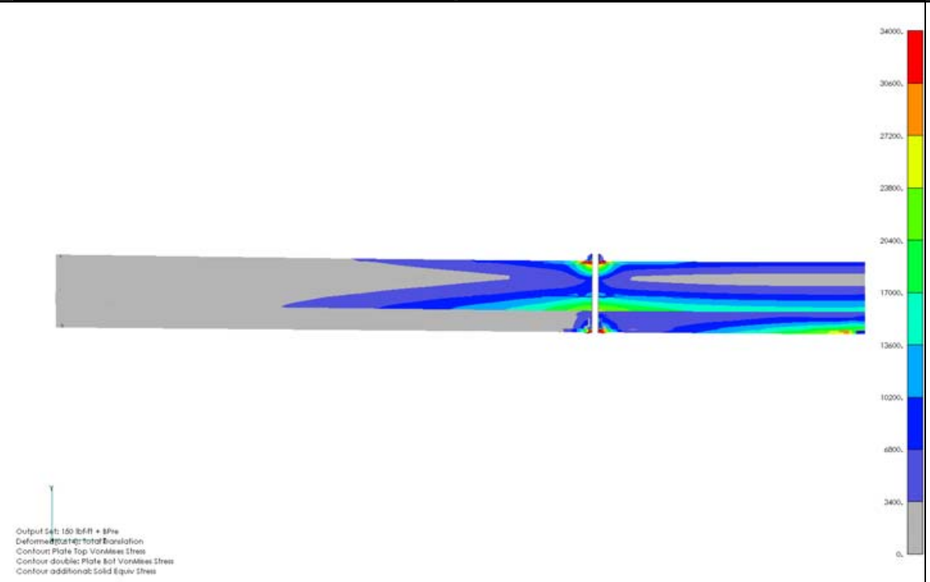
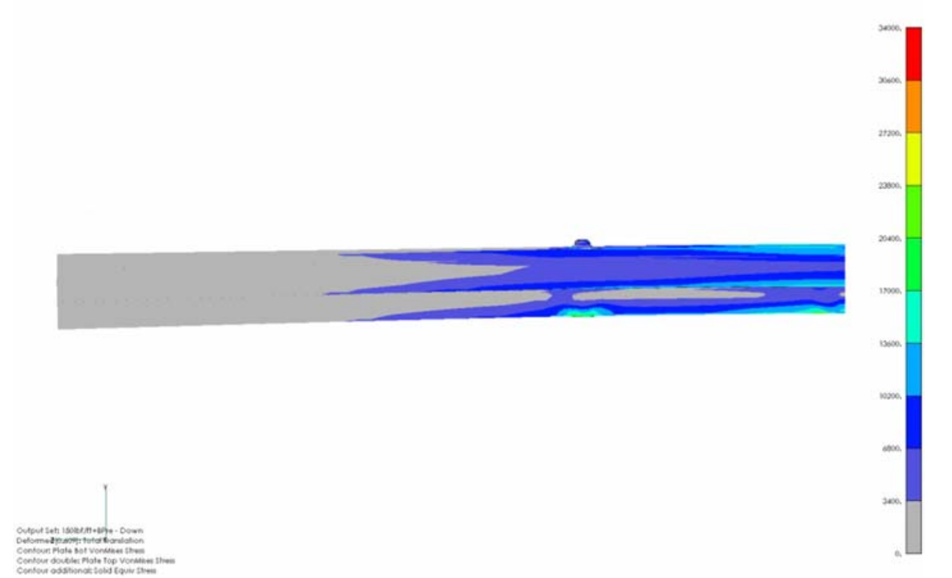



## Downforce



# Cantilevered 30” Section Tip Deflection

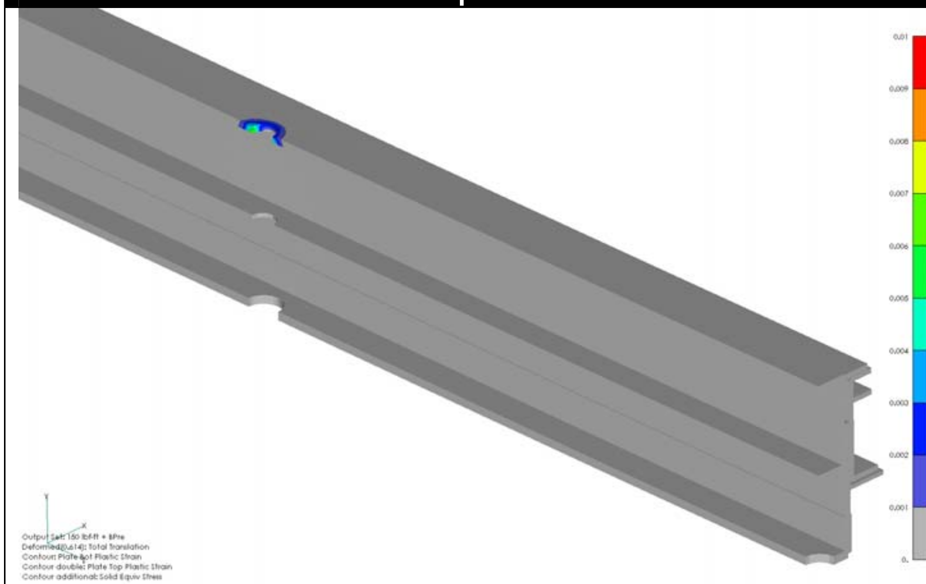
The figures below represent a side view of the Von Mises stresses and deflection of the 30” cantilevered section. In both the uplift and downforce conditions, the deflection at the tip is 0.61”. Again, the figures show the rail anchored at the lower right with the left edge of the rail cantilevered and unrestrained. The legends for the von Mises Stress are capped at 34,000 psi in both figures.

| Uplift | Downforce |
| --- | --- |
|  |  |

# 30” Cantilevered Section Plastic Strain

An analysis of the plastic strain within the 30” cantilevered section shows a maximum of less than 1% at the first compression bolt in the uplift condition. No plastic strain within the material is present in the downforce condition. The maximum allowable plastic strain for the material is 12% verifying that the CompRail structure can withstand the imposed 300 lbf/ft loading conditions. The legend for the plastic strain is capped at 1% for the uplift condition.

## Uplift



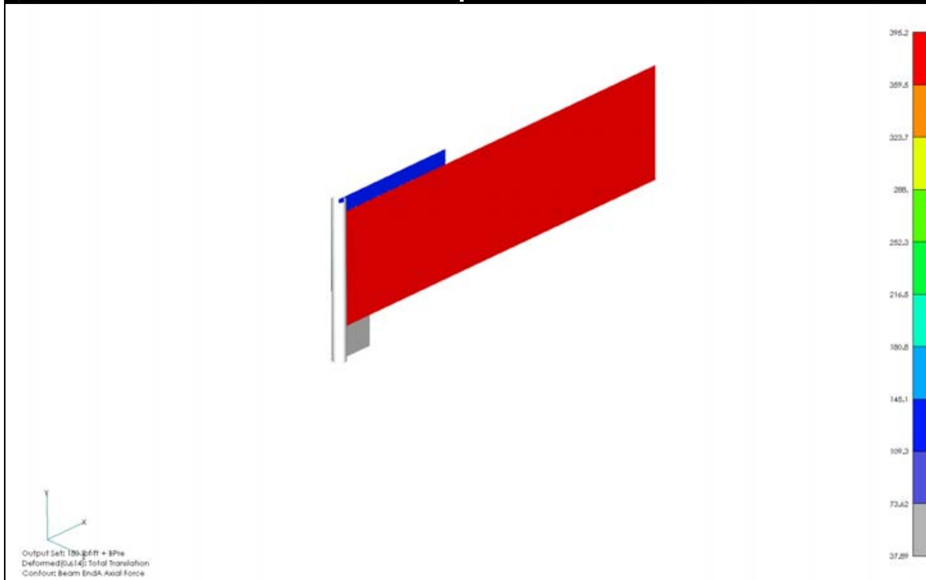

## Downforce

***No Plastic Strain Present***

# 30” Cantilevered Compression Bolt Stress Analysis

An analysis of the bolt loads and stresses indicate that a maximum bolt load of 790 lbf occurs in the compression bolt in the uplift condition. In the downforce condition, the bolt load remains at its nominal 620 lbf preload. The resultant stress in the bolt material are calculated at 16,100 psi for the nominal diameter of the 5/16”-18 bolt in uplift. This is well below the yield stress for the18-8 stainless steel bolt material. Legends for bolt loadings are capped at 395 lbf for the uplift condition and 325 lbf for the downforce condition. Actual loading values need to be doubled to account for the half-symmetry modeling of the bolts.

## Uplift




## Downforce