NCSX
Design Basis Analysis

Cryostat Thermal/Stress Analysis

NCSX-CALC-17-001-00

05 April 2005

Draft A

Prepared by:

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F. Dahlgren, PPPL

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct. I concur with analysis methodology and inputs and with the reasonableness of the results and their interpretation.

Reviewed by:

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G. Gettelfinger, PPPL Engineer

Executive summary:

A FEA analysis was performed to determine the temperature distribution and thermally induced stresses in the NCSX cryostat upper pan components. The most severe thermal gradients exist in the closed corner segments of the cryostat assembly. The peak thermally induced Tresca stress in the panel is 45.1 MPa (6.54 ksi) at the 90-degree corner, with additional, slightly lower stresses in the range of 40 MPa (5.8 ksi) at the top mid-span in the region of the bolt pattern. Applying a stress concentration factor of 1.5 at the bolt hole yields a peak stress intensity of 60 MPa in this location. Since the ultimate strength of the G-10CR at room temperature is greater than 200 MPa* the peak stresses are below the room temperature allowable if we apply the 1/3rd ultimate stress criteria.

Details:

A FEA steady-state non-linear thermal analysis was performed for the three typical components of the NCSX cryostat structure. Only the worst case corner closed pan will be reported on here. The models were generated from the Pro-E derived Iges files referenced in Appendix I. The geometry was imported into Patran when it became apparent that the Iges geometry primitives could not be properly modified or edited within ANSYS Workbench. To properly model the fixed temperature boundary conditions in Patran it was necessary to delete and re-model several geometric entities including the elimination of all the bolt holes. The resulting solids were then iso-map meshed generating the regular hex (8-node brick) mesh shown in Figure 1 (for the outer corner pan model: cryo-closed5 & cryo-closed5s).

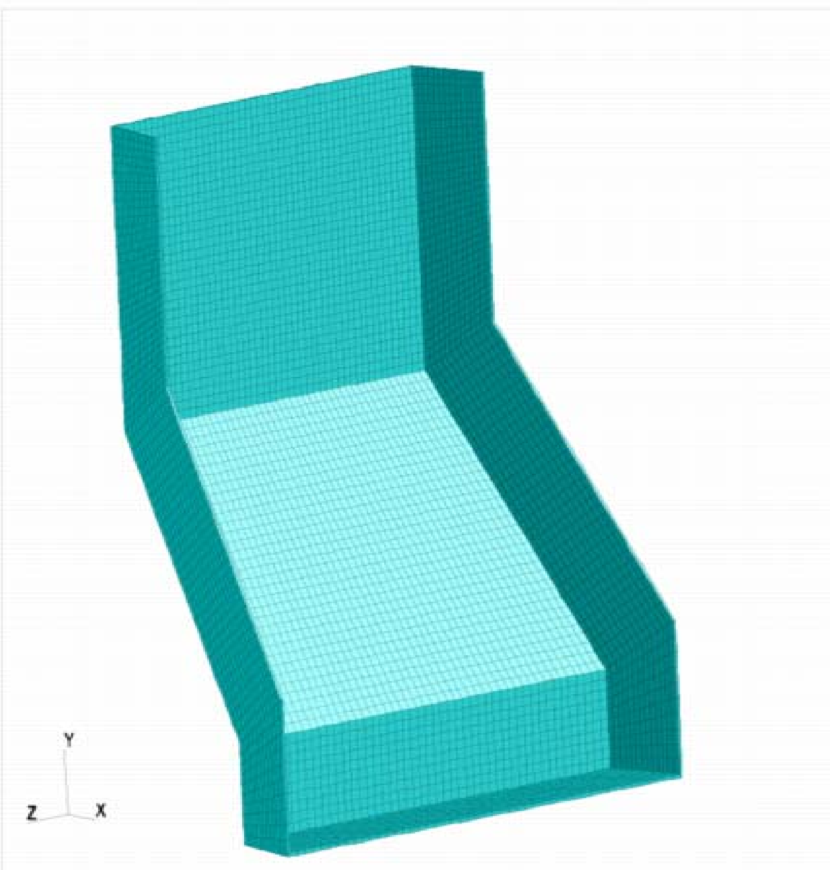

Figure 1. FEA model of a typical closed corner cryostat pan (cryo-closed5)

The thermal boundary conditions imposed are shown in figure 2 below:

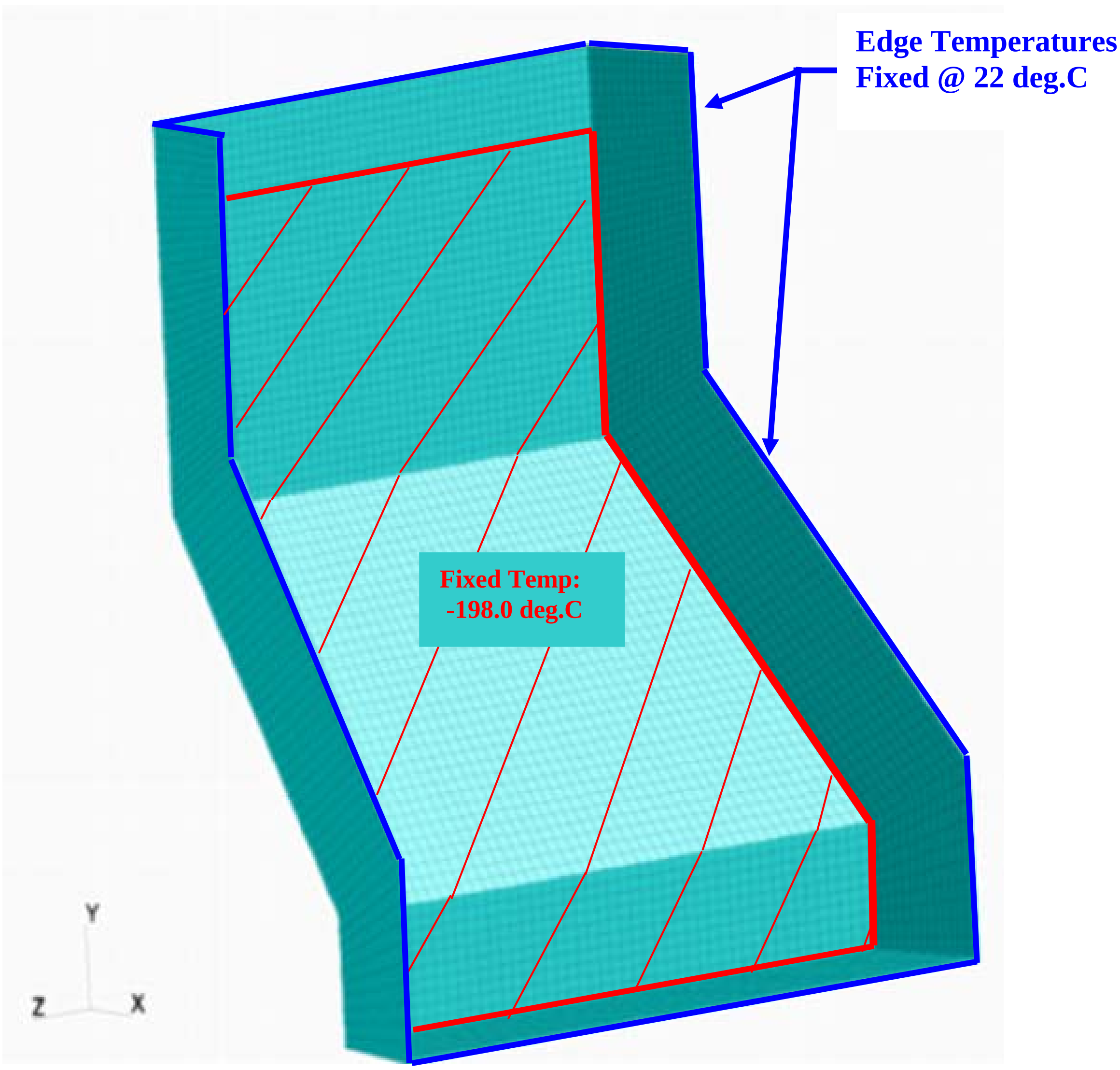

Figure 2. Thermal model Fixed Temperature Boundary Conditions.

The edge temperatures of the pan are fixed at room temperature (22 deg.C) and the interior portion of the insulated panel is fixed at the LN2 temperature (the nominal cryostat internal temperature is -198.0 deg.C). These boundary conditions were deemed to produce the most severe thermal gradients in the pan and therefore the most extreme thermally induced stresses. The non-linear thermal properties of G-10CR taken from reference 1 were used in this thermal analysis. The Nastran non-linear thermal solution 153 was used to establish the steady state temperature distribution in the pan.

Figures 3 and 4 are front and back views of the resulting temperature distribution for the equilibrium (steady-state) condition. The peak thermal gradients occur between the fixed edge temperatures of 22 deg.C and the fixed interior surfaces (prescribed to be fixed at -198 deg.C).

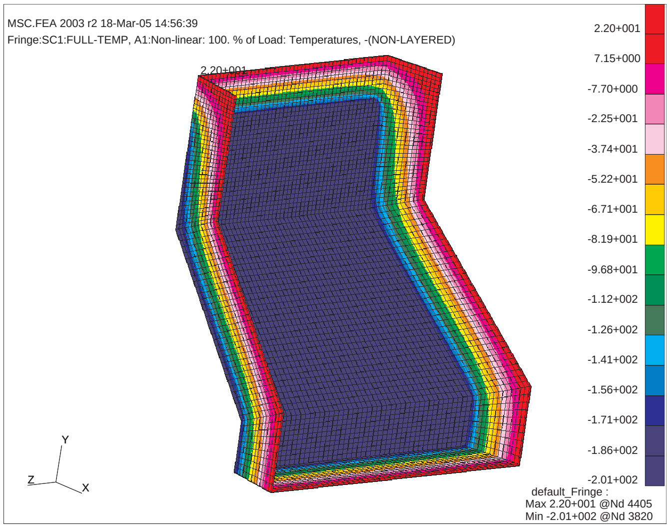

Figure 3. Thermal distribution – front view

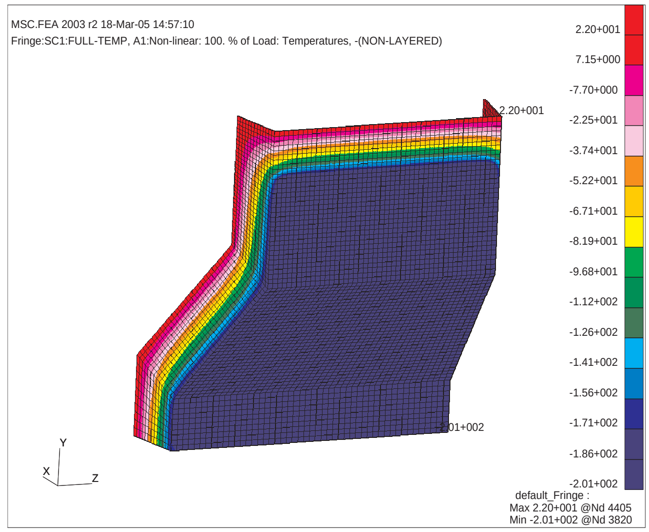

Figure 4. Thermal distribution – interior view

Thermal Stress Analysis:

Using the equilibrium temperature distribution , a thermal stress analysis was run to determine the stresses induced by the thermal gradients in the panel. Anisotropic , elastic properties were used for the G-10 material. Figures 5 & 6 are Tresca stress contours of the thermal stresses induced in the panel as a result of the temperature gradients.

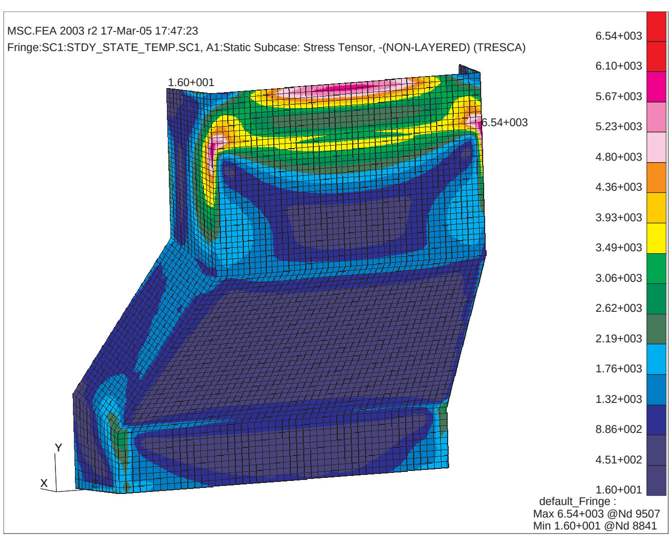

Figure 5. Contour plot of Tresca stresses

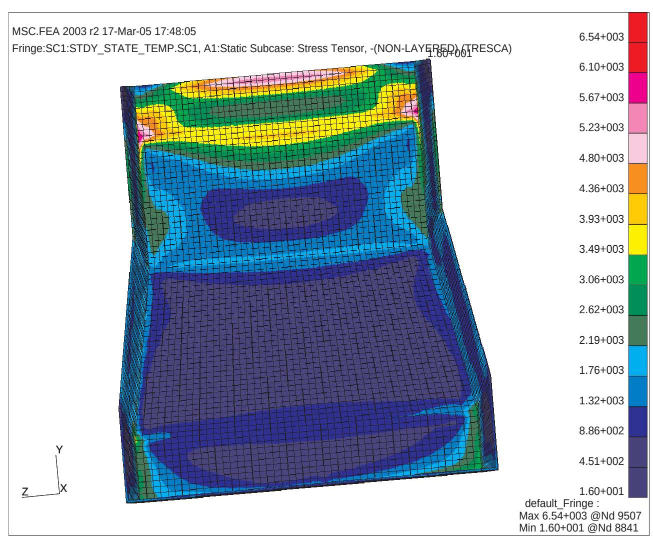

Figure 6. Tresca stresses exterior view

The peak Tresca stresses are located at the 90-degree corners just adjacent to the cold boundary, and at the mid section of the upper (warm) edge. These stresses are in the range of 5 to 6 ksi (40 – 45 MPa). The room temperature allowable for G-10CR is about 20 ksi in the warp direction using a $1/3^{rd}$ ultimate tensile stress criteria, and the allowable at LN2 temperature is at least 80% higher. Ultimate strength values in the fill and transverse directions generally run about 50% lower but still provide sufficient margin above the induced stresses predicted by this analysis.

To evaluate the response of the panel to an interior pressure, a 6.9 kPa (1 psi) uniform pressure was applied to the interior surfaces. Figure 7. is a contour plot of the resulting deflection of the panel showing a peak outward displacement of slightly less than 1.25 cm (0.5”). Figure 8. is a plot of the Tresca stress contours showing a peak stress of 35.8 MPa (5.2 ksi) at the corner bends and 41.3 MPa (5.9 ksi) at corner-flange edges.

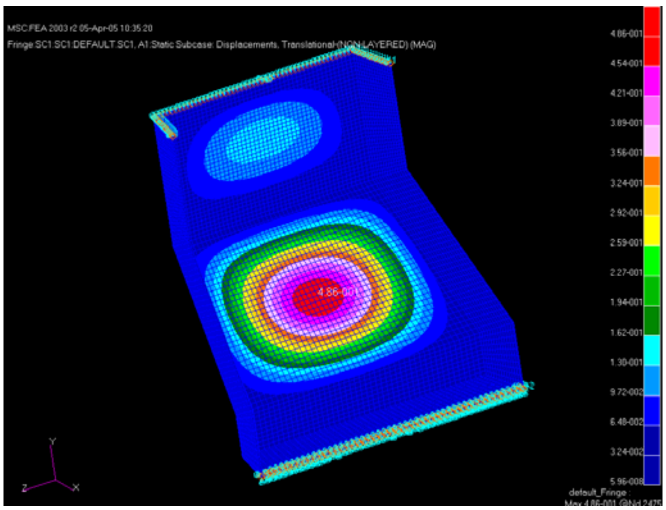

Figure 7. Displacement contours for 1 psi load

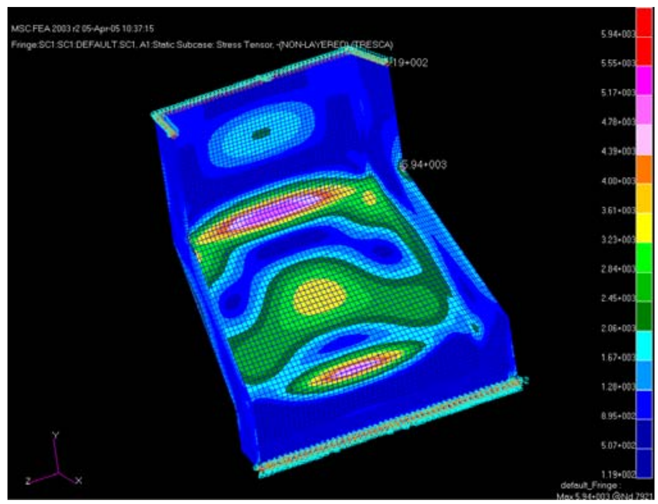

Figure 8. Tresca stress contours for 1 psi loading.

References:

1. Materials Handbook for Fusion Energy Systems, File Code# GA01-2101, Publication Package No. II, page 1.0
2. “Cryogenic Material Properties Database”, E.D. Marquardt, et.al., NIST, Boulder, Co., Presented at the 11^{th} International Cryocooler Conference, 20-22 June, 2000, @ Keystone, Co., http://cryogenics.nist.gov/Papers/Cryo_Materials.pdf
3. “Mechanical and Thermal Properties of Glass-Fiber-Reinforced Composites at Cryogenic Temperatures”, A. Khalil, et.al., University of Wisconsin, Madison, Wis., Advances in Cryogenics, vol. 28

Appendix I:

FEA Model input files:

Thermal Models	Stress Models .
cryo-closed5.bdf	cryo-closed5s.bdf
-	cryo-closed5sp1.bdf (1 psi)
cryo-lowpan1.bdf	cryo-lowpan1Str.bdf
cryo-open2a.bdf	cryo-open2str.bdf

Patran database files:

Thermal Models	Stress Models .
cryo-closed5.db	cryo-closed5s.db
cryo-lowpan1.db	cryo-lowpan1s.db
cryo-open2a.db	cryo-open2str.db

Iges-Pro-E CAD Geometry files:

se171-129-closed.igs
se171-129-open.igs
smm-cryo-lowpan20deg.igs

Appendix II

Open pan module Model:

Figure IIa shows the thermal distribution on the pan modules having an opening for feed-thrus. Note this model used quadrilateral shell elements in place of the solid elements of the cryo-closed5 models.

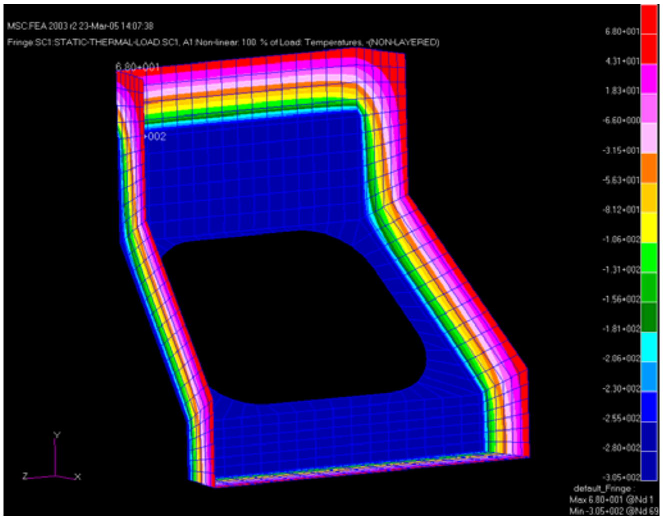

Figure IIa Thermal distribution – cryo-open2a

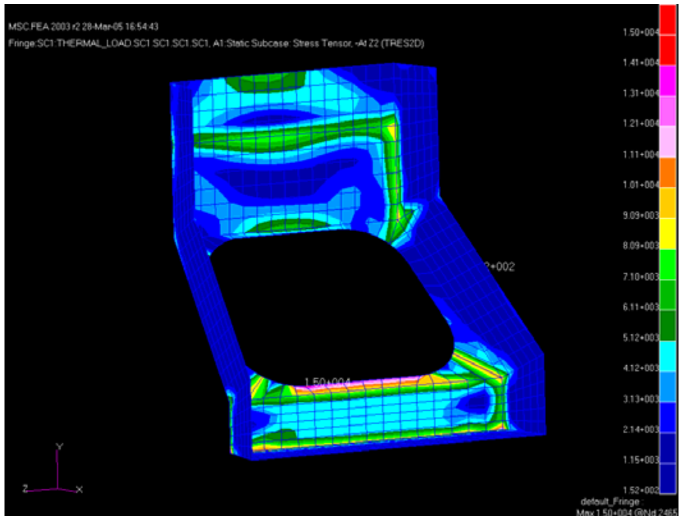

Figure IIb. Tresca stress contours – cryo-open2str

Figure IIb above shows the Tresca stress contours developed for the temperature distribution shown in Figure IIa. The boundary conditions imposed are for an axi-symetric array of pan modules bolted along the pan edges. The stresses are peaking at the lower inner edge of the opening at 103 MPa (15ksi). The allowable stress for G-10CR at 80 deg.K (-305 deg.F) is 248 MPa (36 ksi) in the warp direction. The thermally induced stresses for this pan configuration have a considerable margin of safety.

Lower Pan Model:

Figure IIc Shows the lower pan FEA model which uses solid (orthotropic material property) elements. Figure IId is a plot of the thermal contours when room temperature fixed boundary conditions are applied to the outer edges while the bottom surface temperatures are fixed at -305 deg.F (80 deg.K).

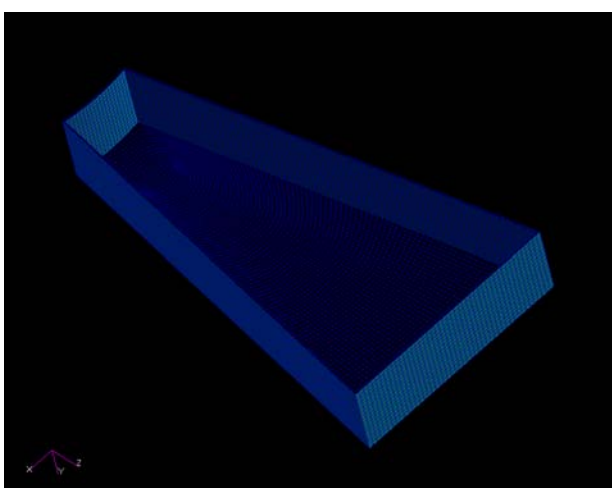

Figure IIc Lower-Pan FEA Model

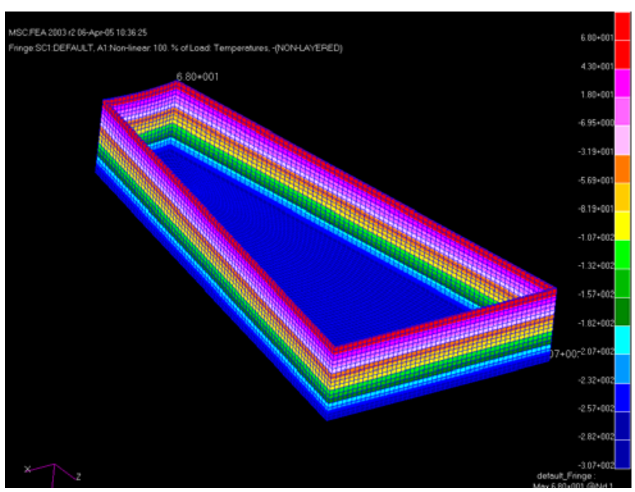

Figure IId. Thermal Gradient – Temperature Contours

Figure IIe is a plot of the displacements resulting from that thermal gradient for an axi-symetric outer radial edge boundary condition. This boundary condition assumes that all the adjacent pans are connected in a circle by radial-edge bolts and have the same thermal gradient. Figure IIf shows the resulting Tresca stress contours.

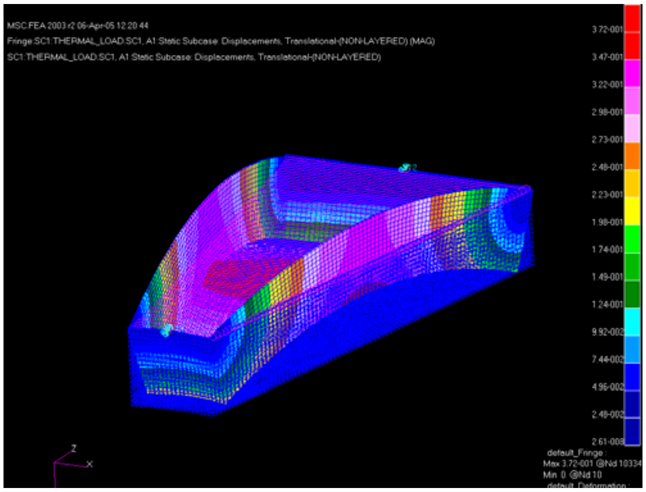

Figure IIe. Displacement contours due to Thermal

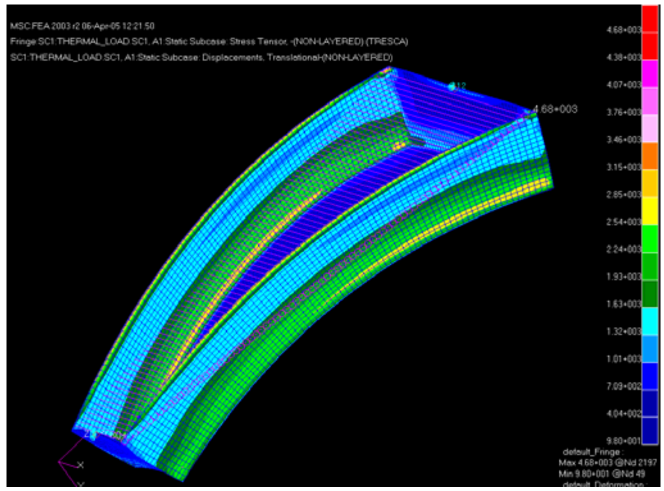

Figure IIf. Tresca Stress Contours – 4.9ksi – Peak

The peak displacement at the pan center is approximately 0.37” (~1 cm). The Peak Tresca stresses of 32.4 MPa (4.7 ksi), occur at the outer corners of the pan.

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