NCSX

Design Basis Analysis

VV Assembly Fixture Structural Analysis

NCSX-CALC-12-009-000

24 Sept. 2005

Prepared by:

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Contributers:

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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:

Tom Brown 2005.10.07 13:09:04 -05'00'

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T. Brown, PPPL Engineer

Analysis of the NCSX VV Turning Fixture Supports

Executive Summary:

An FEA analysis of the NCSX Vacuum Vessel assembly fixture support was performed to verify the adequacy of the design. The maximum deflection calculated was 0.067"at the vessel shell end perimeters. (see appendices A & B for further details on single period vessel deflections during assembly).The peak Tresca stress in the structure is 5.1 ksi at the trunion-cradle intersection and is the result of a combined bending and compression/tension. The AISC allowable for A36 (the most common structural steel), is 16.6 ksi bending and 19.8 ksi in simple tension, providing generous margins in this design. Appendix C provides some basic turning fixture force calculations. An acceptable 17 lb load was calculated as the load needed to turn the vacuum vessel using a 12" diameter worm gear hand wheel. Although the Hilti anchor bolts were found to be sufficient to support the vessel turning fixture, an additional lateral support was added to one side to increase the overall unit lateral stiffness.

Methods:

The analysis of the assembly structure was carried out using the MSC/Nastran finite element analysis program (sol 101 – linear static analysis).

Assumptions:

Material properties of an ASTM A36 steel alloy was assumed for all rolled and extruded structural shapes. A total assembly weight of 5,079 lbs uniformly distributed in the shell was assumed. This was modeled by assuming a density 30% higher than the typical value for A36 steel. A 1-g vertically downward gravity load was assumed without consideration of any vertical or lateral seismic acceleration loads. The boundary conditions applied assumed a completely rigid floor and anchor bolt connection.

References:

PPPL CAD Drawing No. NCSX-SE184-002 shts. 1 thru 3
PPPL CAD Drawing No. NCSX-SE184-003 sht. 1
Nastran input file: ncsx-vv-suppts-ad2.bdf
Nastran database file: ncsx-vv-suppts-ad2.DBALL

Introduction:

An FEA analysis of the NCSX Vacuum Vessel assembly fixture support was performed to verify the adequacy of the design. Figure 1 shows the support and vessel shell model used in the analysis. The support structure weldment is comprised of 4" x 4" x 1/4" thick wall and 4" x 6" x 1/4" thick box beams of A36 steel. The base plates, mounting plates, and axel cradles and ribs are also fabricated from 0.75" thick A36 steel. The base plates are anchored to the floor with (6) 0.75"dia. steel bolts into Hilti concrete anchors in 4000 lb concrete. The supports were modeled with standard 8 & 6-node brick elements (CHEXA & CPENTA) in Nastran. The density of the vessel was increased by 30% to account for the additional weight of the heating and cooling tubes and closure end plates, producing a total assembly weight of 5,079 lbs. The boundary conditions applied translation fixity in the three principle orthogonal directions at the 6 anchor bolt locations on the lower surfaces of each of the base plates. A 1-G gravity acceleration (386.4 in/sec2) was applied in the negative X direction.

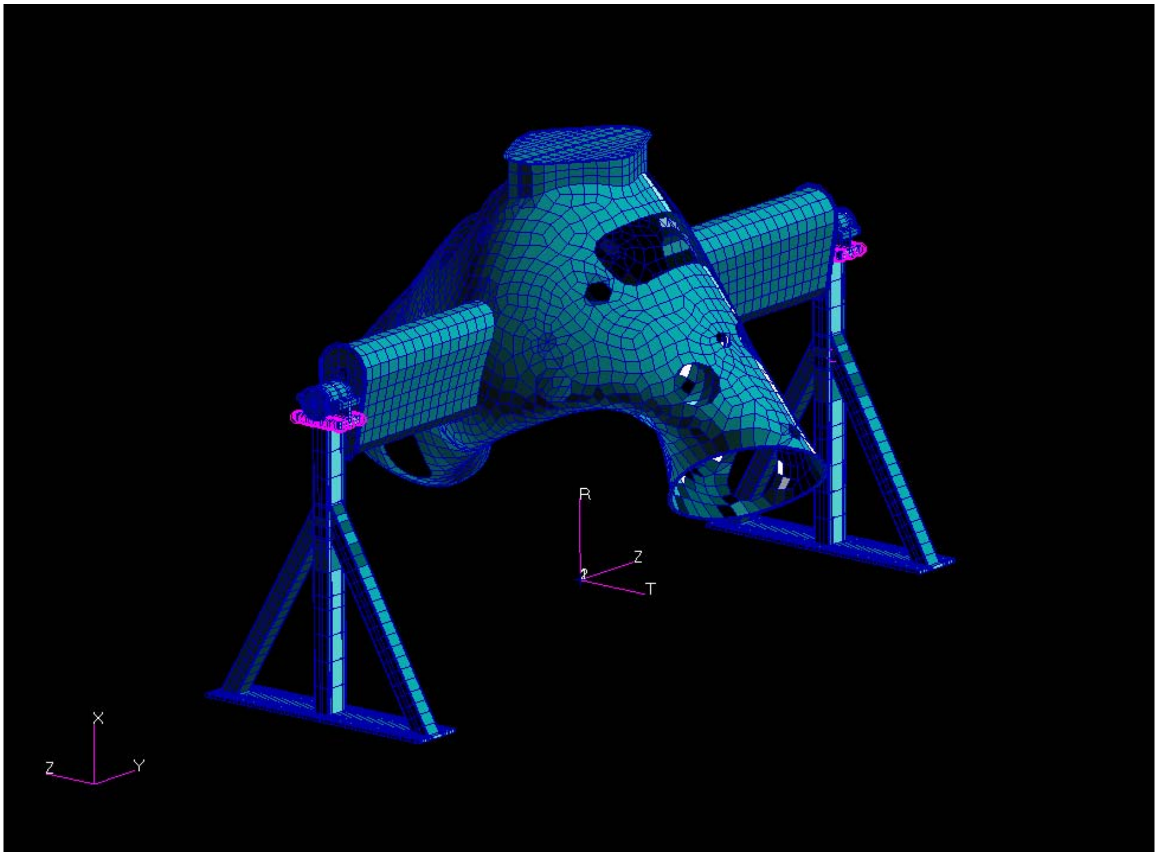


Figure 1. FEA Model of the V.V. Assembly Support Fixture

The displacement contours of the linear analysis are shown in figures 2 & 3. Figure 2 is the SRSS displacement contour plot and shows a maximum displacement of 0.067" at the vessel shell end perimeters. This result would be somewhat less if the stiffness of the closure end plates were included in the model.

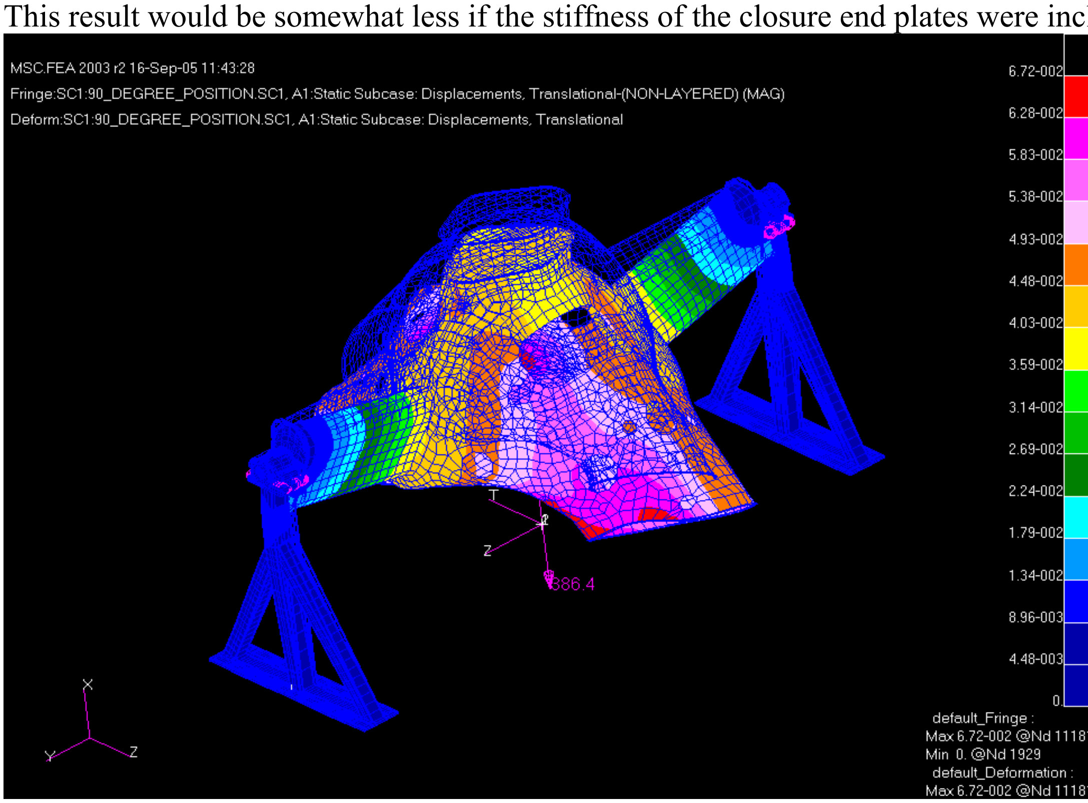


Figure 2. Displacement magnitude (SRSS) of the assembly due to a 1-G gravity loading.

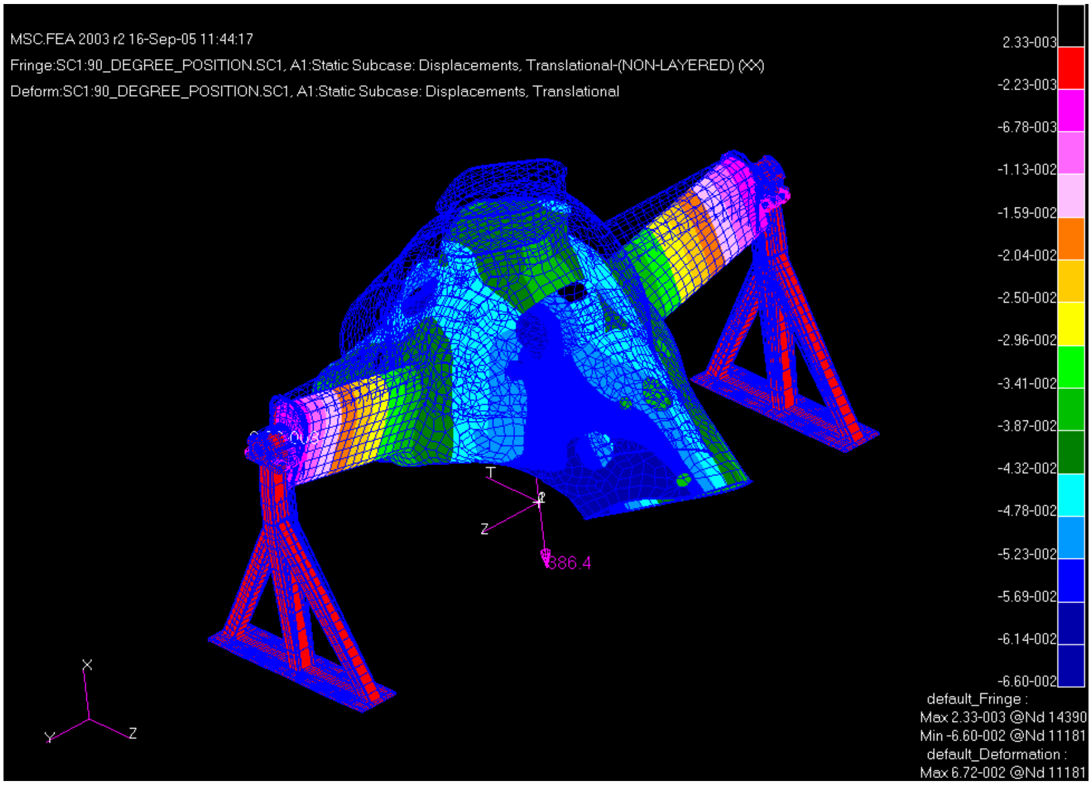


Figure 3. Vertical Displacements Due to a 1-G gravity loading

Figure 3 shows the vertical (X-direction) displacement contours with the maximum of 0.066" again at the outer end portions of the vessel shell. Figure 4 below is a contour plot of the Tresca stresses in the assembly. The peak stress of 5.12 ksi occurs at the trunion/ cradle location as seen in greater detail in figure 5.

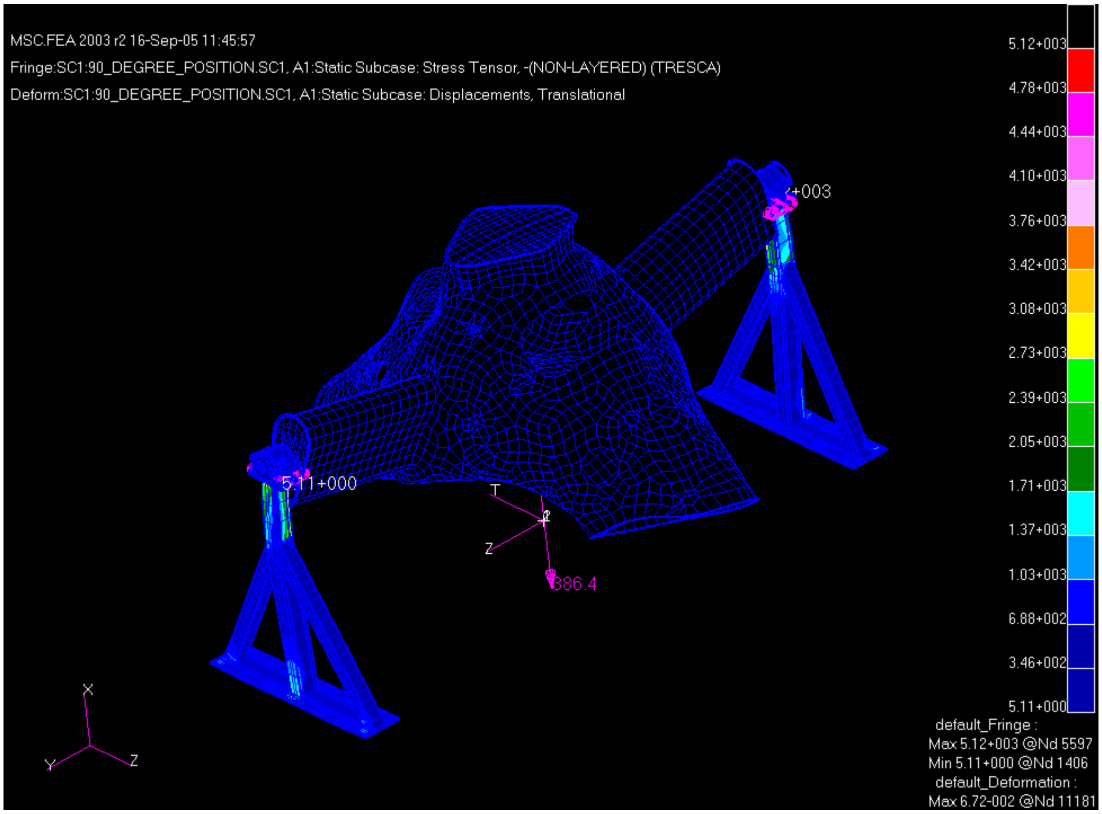


Figure 4. Tresca stress contours due to a 1-G gravity loading

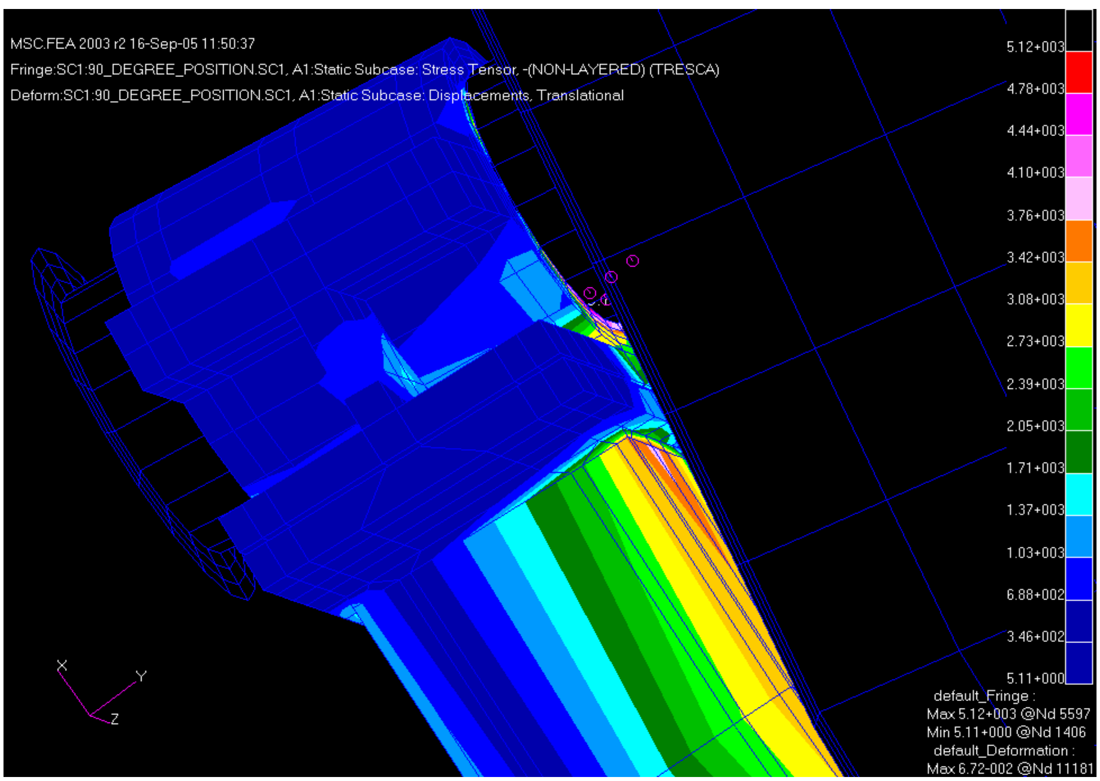


Figure 5. Location of the peak Tresca stress in the area of the cradle- trunnion interface

Figure 6. shows a contour plot of the Major Principle Stress in the support assembly. The maximum principle stress is seen to be 3.3 ksi at the cradle/mounting plate weld.

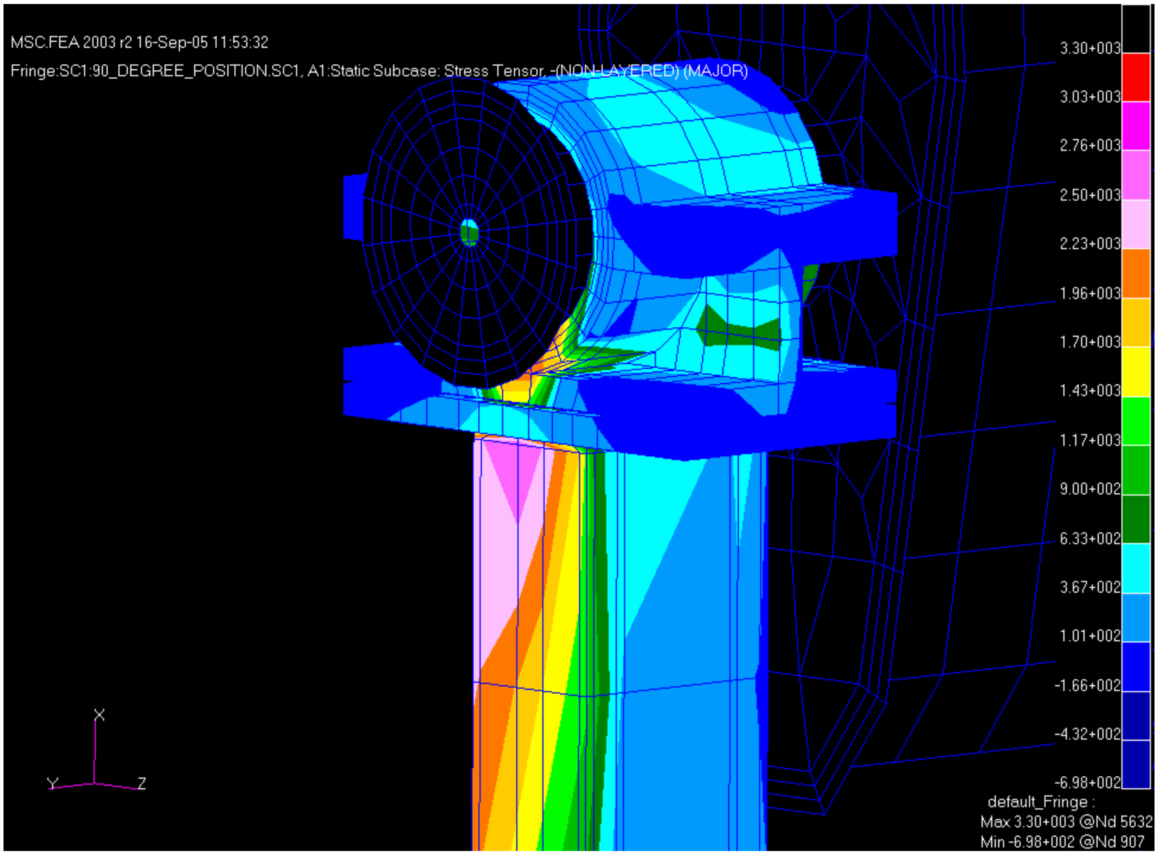


Figure 6. Contours of the Major Principle Stress in the supports

Disscussion & Conclusions:

The vessel assembly fixture support weldment exhibits relatively small deflections and the calculated stress levels are well below AISC allowables for mild structural steels. The margins are greater than 4x in all portions of the structure and are adequate for the purpose intended. ASTM minimum values for A36 structural shapes are 36 ksi yield and 58-80 ksi tensile. The AISC minimum allowable for bending and tension for A36 structural box shapes is 0.55 Sy = 19.8 ksi in tension or 16.6 ksi in bending.

An design alternative, fabricating the cradle weldment from a 2024-T6 aluminum alloy was also investigated and found to yield deflection results similar to the A36 steel cradle (the peak vertical displacement was -0.0679" vs. -0.0660" for the steel).

APPENDIX A

NCSX Vacuum Vessel assembly tooling study

Objective: To determine the relative displacements of the NCSX single field period vessel segment under gravity loading conditions and various orientations during assembly.

Method: A single field period FEA model (without ports) was created which included the proposed trunnion supports at the ends of the vertical port-12. Various orientations and support locations were considered.

Results: The results of the study are shown in the following figures of the displacement contours on the shell field period. The ranges of the various plots have been adjusted to provide maximum resolution (maximum number of contours) in the shell region. In general, the least relative shell displacement results when the shell is supported from the two parting flanges (figure 4), although this could be the most difficult and expensive support condition to accomplish, particularly if the shell is required to rotate during measuring and installation of the coil loops. Figures 1 & 3, with support off the trunnion and NB port flange may provide a more workable alternative for most orientations.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 1 is a contour plot of the displacement magnitude on the shell field period rotated 30 degress, due to a 1-g gravity (30 degree-positive-downward Z) load with vertical Z-direction constraints applied at the trunnion supports. The magnitude of the displacements are calculated as the square root of the sum of the squares of displacements in the X, Y, & Z directions. The range of the displacements on the shell is 0.050” to 0.061” or about 0.011” relative displacement with the major contribution coming from the flexure of the shell due to bending moments at the port-shell interface. This range is fairly typical of the shell flexure at any rotational angle (slightly higher at 0 degrees and slightly lower at 90 degrees), when supported off the trunnions attached to the vertical ports (port-12).

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 2. Vertically restrained at the vertical port flange (model21bbexx2h001)

The magnitude displacement contours shown in figure 2 are for a 1-g loading acting in the negative Y direction (ie. vertically downward in the figure). The vertical constraints are applied at the lower trunnion support (shown as blurred light cyan arrows at the lower trunnion in the figure). The range of displacements on the shell for this support configuration is 0.001" to 0.035" with the maximum shown as the red contour. It can be seen in the figure that the upper half of the shell and vertical port are deflecting the most, with the lower portion showing relatively smaller (0.001-0.027") displacements. While this is the worst relative shell displacement of any of the support configurations analyzed, a support at the upper flange could reduce the overall shell displacements substantially.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 3. Vertically restrained at the N.B. flange (model21bbexx2i001)

Figure 3. shows the range of displacements for a 1-g loading condition (gravity acting in the positive X direction in this model), with verical constraints applied at the Neutral Beam parting flange. The displacement contours are again the magnitude, or square root of the sum of the squares of the displacements in the three orthoginal directions X, Y, &Z. The displacements range from of 0.002" at the NB flange to ~0.012" shown as the red spot on the left side of the shell in figure 3. This displacement pattern is stellerator-symmetric (dyhedral symmetry).

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 4. Vertically restrained at the parting flange (model21bbexx2j001)

Figure 4 shows the magnitude of displacements for a vertically (x-dir) restrained vessel field period with a 1-g applied load and the constraints applied at the parting flanges. The range of displacements on the shell are between 0.000” and 0.005” with the minimum deflection at the flanges and the maximum at the mid-plane of port 4.

APPENDIX B

Vacuum Vessel Field Period Assembly Support Fixture – Deflection Analysis

An FEA analysis was performed to determine the deflections of a single period segment of the NCSX vacuum vessel under gravity load while being supported with the single period assembly stand. The single field period support model is shown in figure 1. Four anticipated vessel orientations were evaluated as shown in figures 2a-d. The direction of gravity is vertically down in the four figures below and the basic model rectangular coordinate system and the displacement coordinate systems vary for the various models.

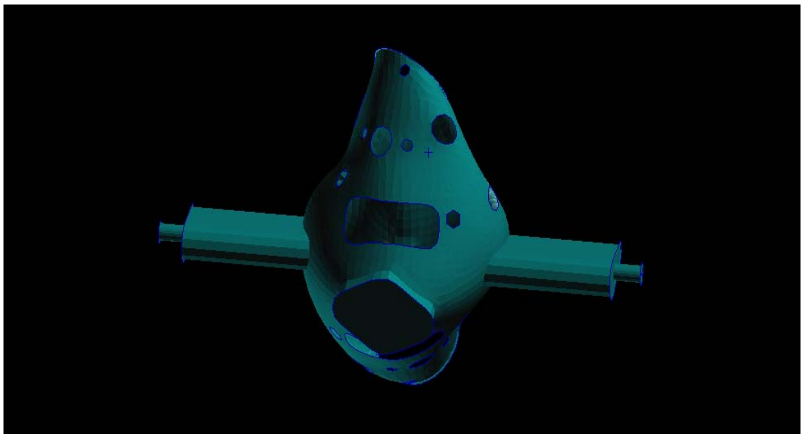


Figure 1. Model of single period VV with support Trunions

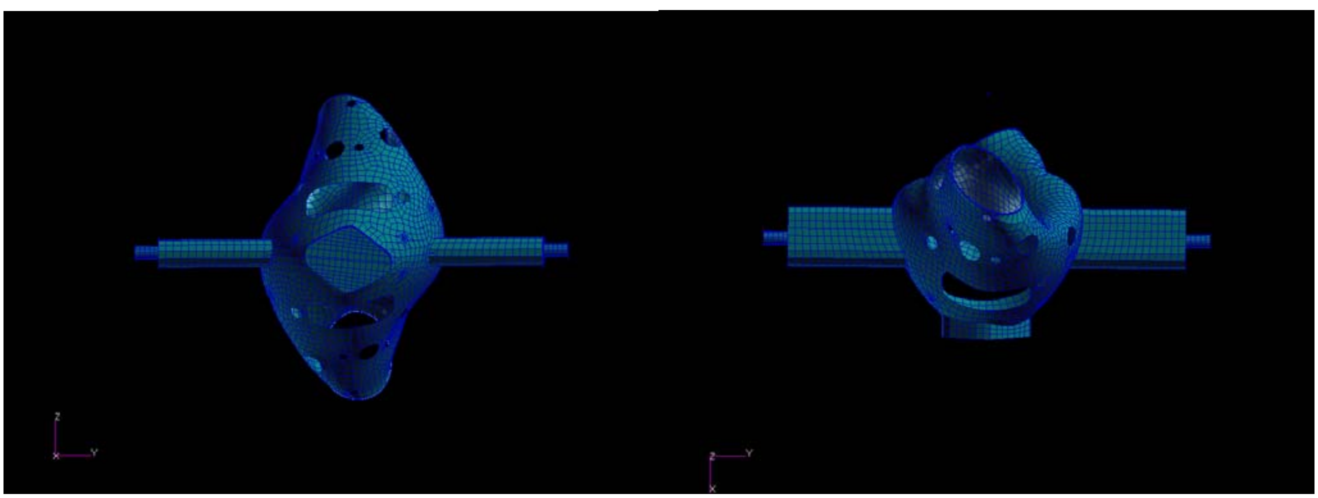


Figure 2a. 90 degrees file:model21bbexx2e1.bdf **Figure 2b. 0 degrees file:model2bbexx2f1.bdf**

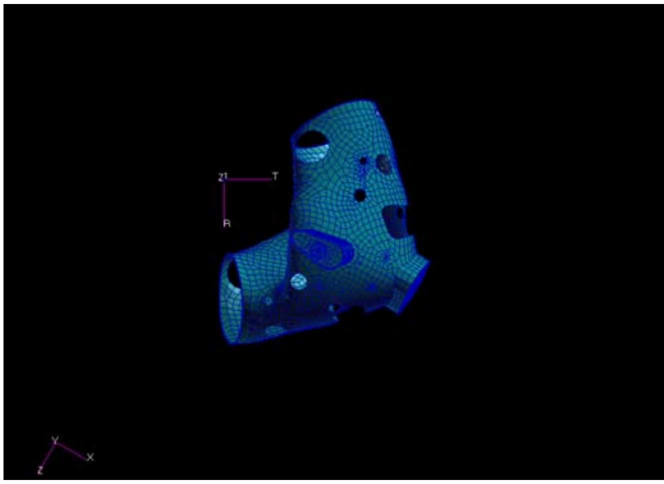


Figure 2c. 30 degrees – file:model21bbexx2g1.bdf

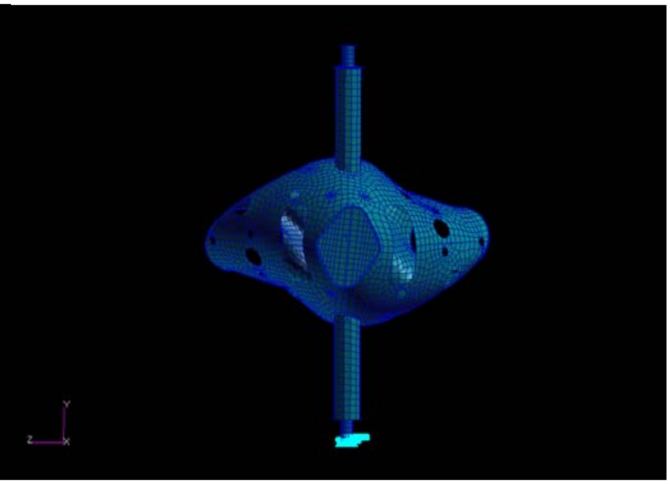


Figure 2d. Vertical – file:model21bbexxh1.bdf

90 – Degree Orientation:

The boundary conditions on the model provide vertical support at the lower surface of the two trunions and horizontal (X-dir.) constraints at the upper portion to prevent rotations about the Y-axis. A single Y-direction constraint is applied to remove rigid body translations in that direction. These constraints reflect the assumption of an infinitely rigid supporting structure which implies a built-in end condition at the trunion-support cradle, and assumes adequate friction at the trunion-cradle interface to inhibit rotation about the Y-axis. Since the compliance of the supporting structure is not included these results will slightly underestimate the total deflection of the vessel but should have little if any effect on the metrics on the shell. Deflections for the 90 degree orientation (gravity in the –Z direction) are shown below (figures 3a-3d), with contours of the vector sum displacements (Mag), and the three orthogonal component directions (X, Y, Z):

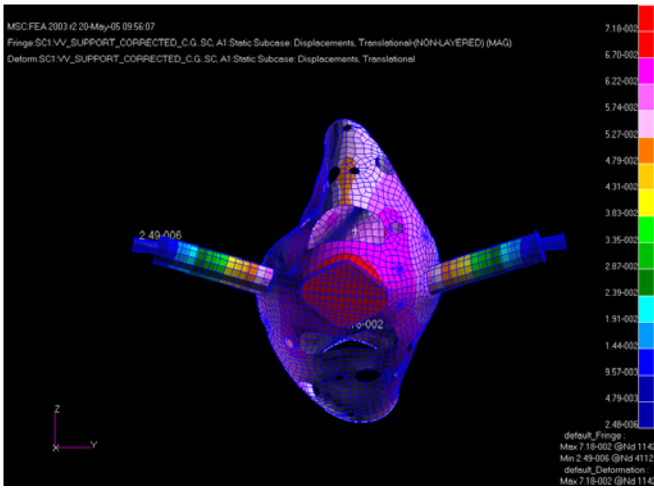


Figure 3a. Vector Sum (SRSS) displacements

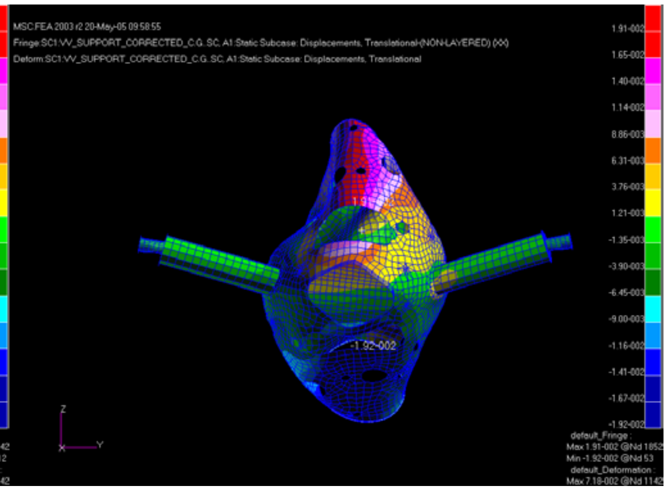


Figure 3b. X displacements

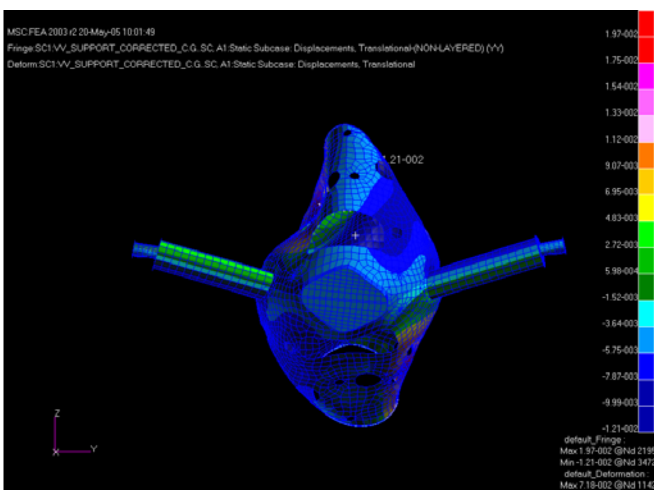


Figure 3c. Y displacements

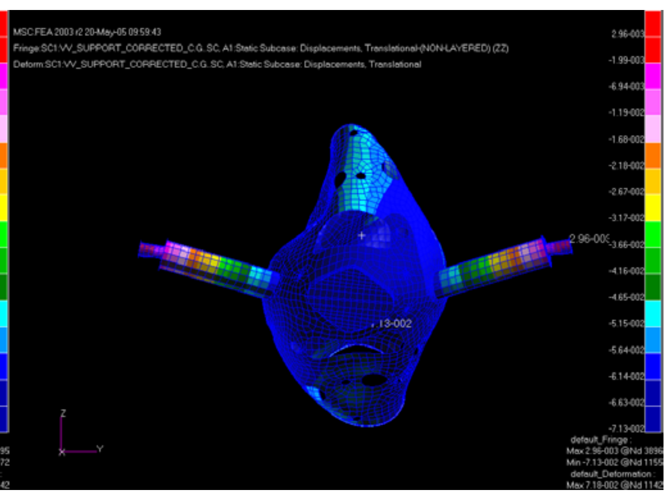


Figure 3d. Z displacements

The peak net deflection under a 1-g gravity load is 0.072" at the neutral beam nozzle and is primarily the result of vertical displacement with some minor rotation about the Y- axis. It can be seen that the major component is a vertical (Z – figure 3d) component of -0.071". The most flexible portion of the vessel is the 3/8" thick shell. The deflection (bending) in the shell is the main source of the vertical displacement, although the slight misalignment of the trunion axis relative to the C.G. of the shell contributes somewhat to the X-axis rotation (~5% of the total deflection).

0 – Degree Orientation:

Figures 4a-d below show the displacement contours for the 0-degree orientation:
(Note these plots also show the undeformed structure represented as a wireframe).

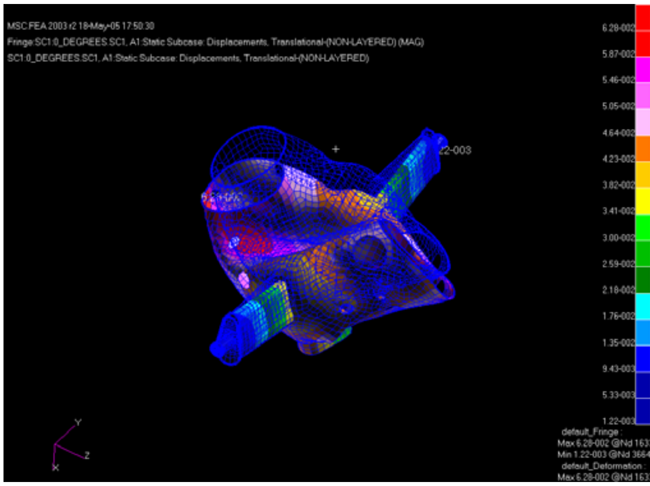


Figure 4a. Vector sum -displ.-0-degree model

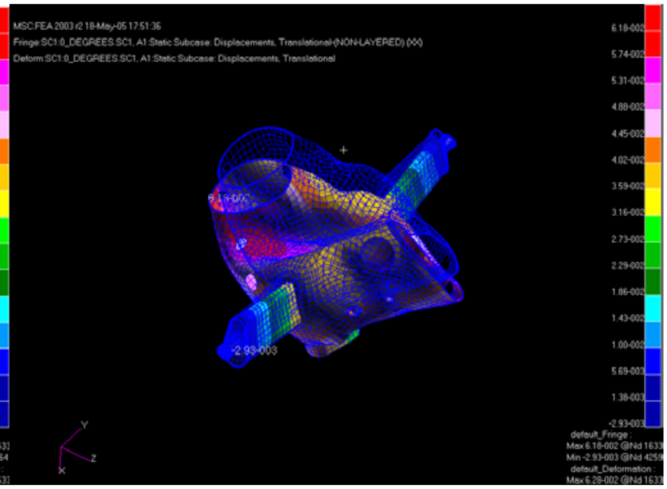


Figure 4b. Xdisplacements – 0-degree model

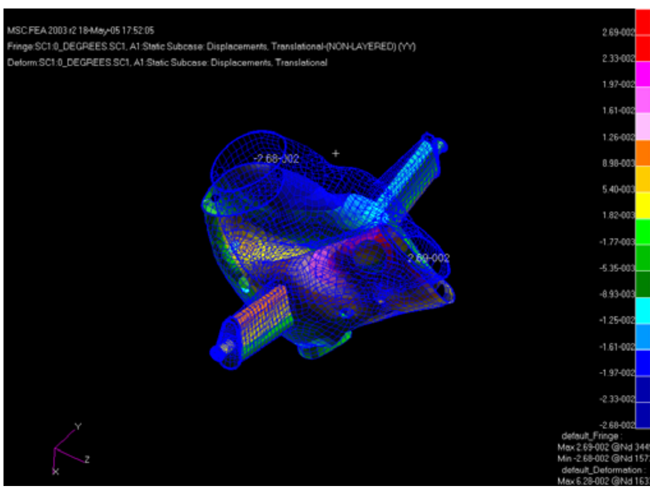


Figure 4c. Y displacements – 0-degree model

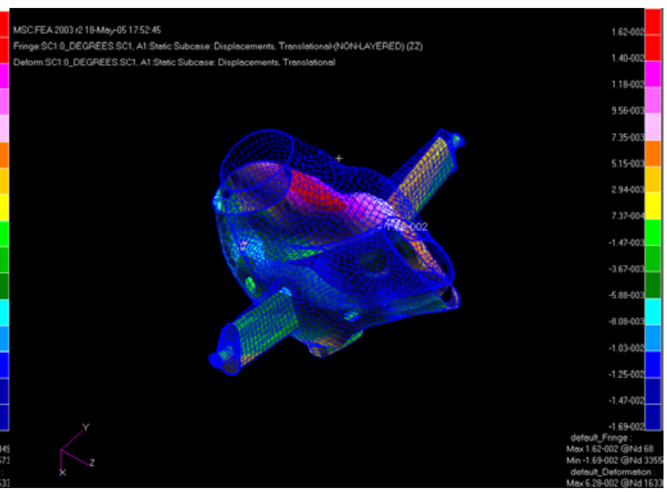


Figure 4d. Z displacements – 0-degree model

The local constraints on the trunion supports are basically the same as the 90 degree model discussed above except the locations have been rotated 90 degrees in this model to align with gravity.
The peak displacements for this orientation is ~0.063". The peak vertical displacement (this model has a positive X-direction for gravity) is shown in Figure 4b as 0.062". A comparison with the vertical displacements of the 90-degree oriented model gives an indication of the relative effect of the vertical port (port 12) – shell interface stiffness. The vertical deflection is approximately 0.009" less when the port nozzle is oriented in the stiffer (0-degree) direction. The difference is due mainly to the nozzle-shell interface being locally stiffer in this orientation. There is very little bending in the 0.5" thick nozzle itself in either orientation.

30 – Degree Orientation:

The 30 degree position was modeled as shown in figure 2c. Again the boundary conditions were rotated to align with the 30 degree direction of the gravity load. The following 4 plots in figures 5a – 5d are the resulting contour plots of the various displacements indicated:

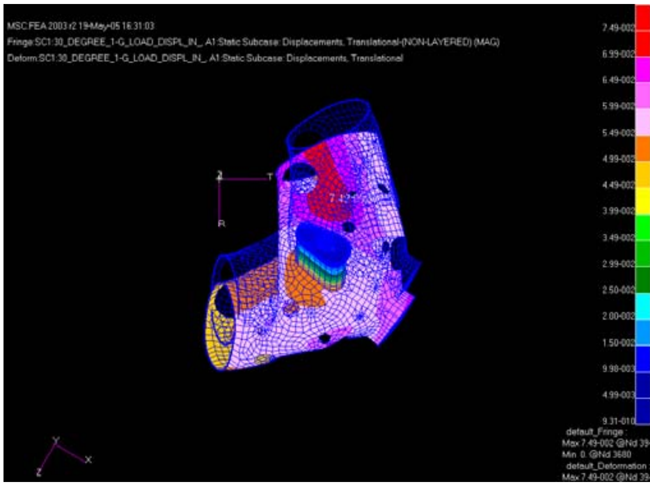


Figure 5a. Vector sum -displ.-30–degree model

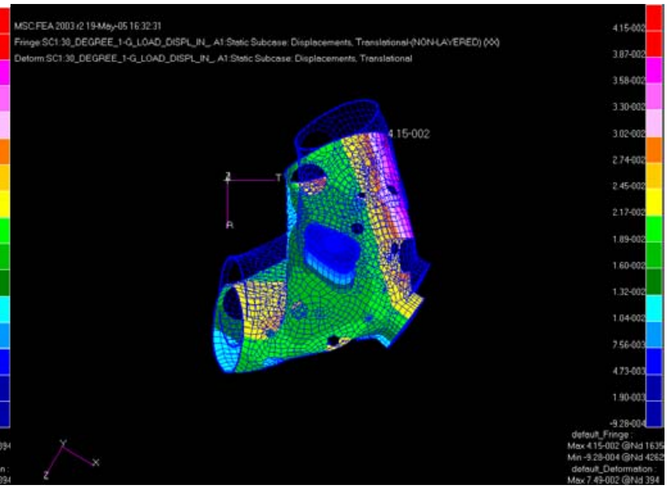


Figure 5b. X displacements – 30–degree model

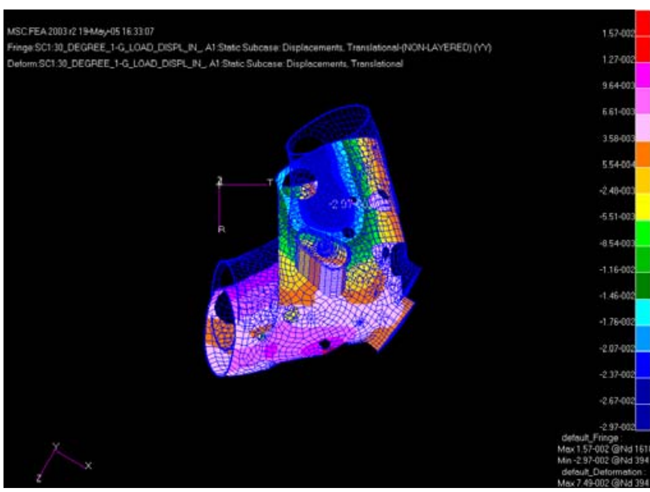


Figure 5c. Y displacements – 30–degree model

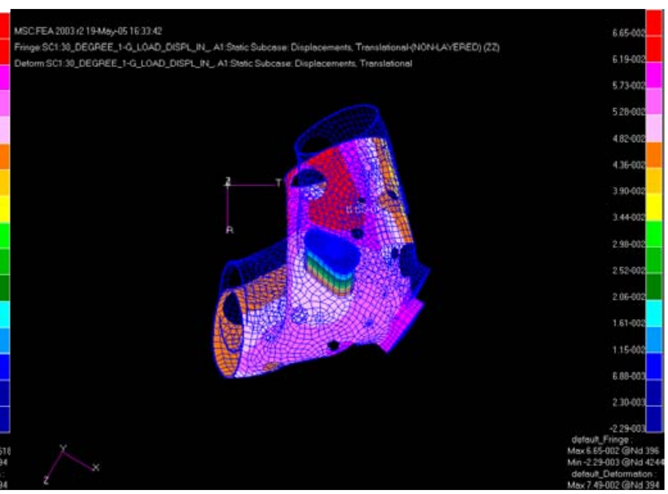
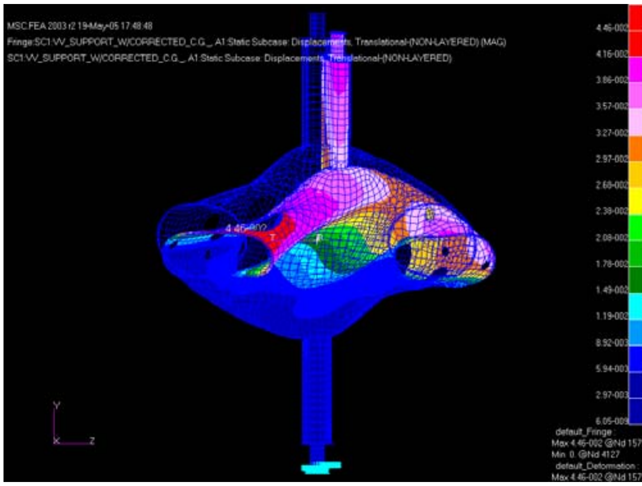


Figure 5d. Z displacements – 30–degree model

The peak vector-sum displacement for this orientation is ~0.075". The peak vertical displacement (this model has a positive R-direction for gravity, labeled as the ZZ direction in the plot) is shown in Figure 5d as 0.067". Note that the displacement coordinate system is cylindrical (ie. Polar) with the theta-zero direction rotated 30 degrees off the rectangular coordinate Z-axis, and the R direction being perpendicular to the Y-axis of the basic rectangular coordinate system (with Z cylindrical axis oriented along the Y rectangular axis)(ie. Polar) .

Vertical Support – Fixed at the Bottom:

This support condition, illustrated in figure 2d, constrains the translations of the lower surface of the vertical port flange in all three directions. Gravity acts in the negative Y-axis direction for this load case.



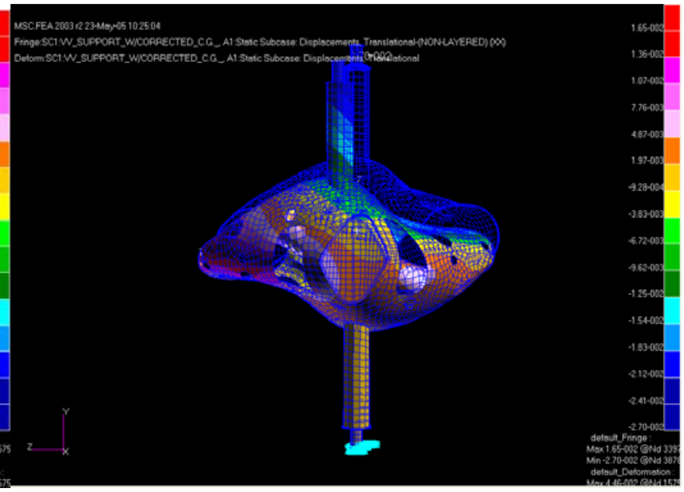
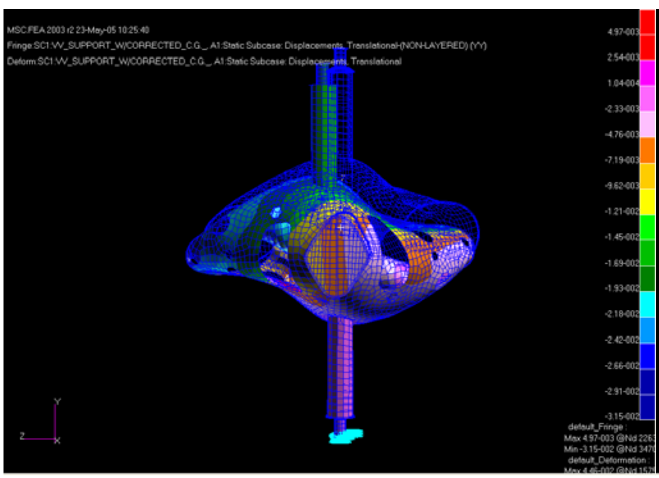


Figure 6a. Mag displ. – Vert.Supp't. Model (view looking radially out from center)

Figure 6b. X displ. – Vert. Supp't. Model



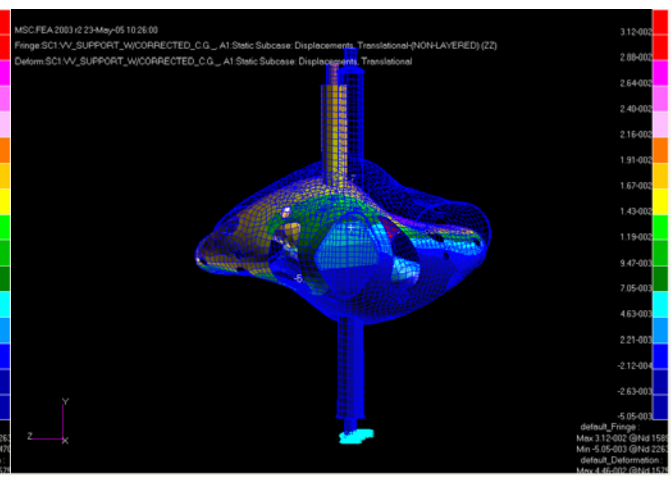
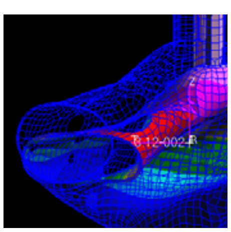


Figure 6c Y displ. – Vert. Supp't. Model

Figure 6d. Z displ. – Vert. Supp't. Model

The peak vector-sum displacement for this orientation is ~0.045" and occurs in the area of the inner shell just outside the minimum radius of curvature of the shell (see the red contoured area in figure 6a).



The figure on the left is a radial outward view of the Z-direction (horizontal) displacement contour showing the peak Z-displacement of the shell surface at this location (dZ= + 0.0312" moving laterally to the right in this view). The lateral deflection in this case is actually larger than the vertical displacements shown in figure 6c above and accounts for a large portion of the peak vector sum displacement.

Two alternative support orientations are shown in figures 7a and 7b below. Figure 7a shows the model with full translational constraints at the bottom Neutral Beam transition flange/closure plate. The constraints on the model shown in figure 7b, are at the angled edge flanges and imply an infinitely rigid supporting frame which would mate to the two flanges at the proper angles and be anchored to the floor (which is also assumed to be rigid).

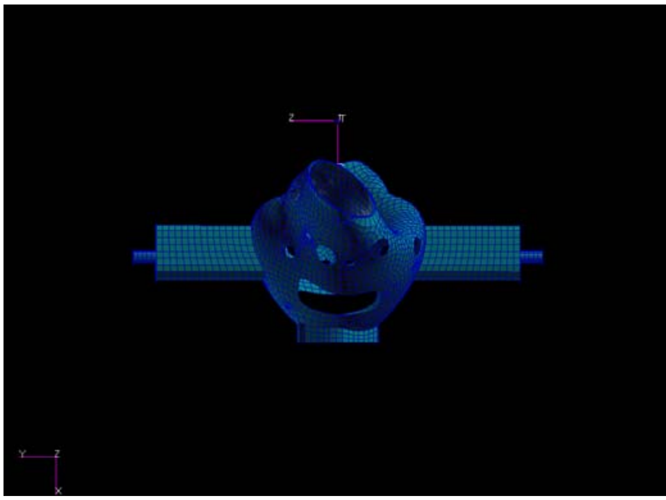
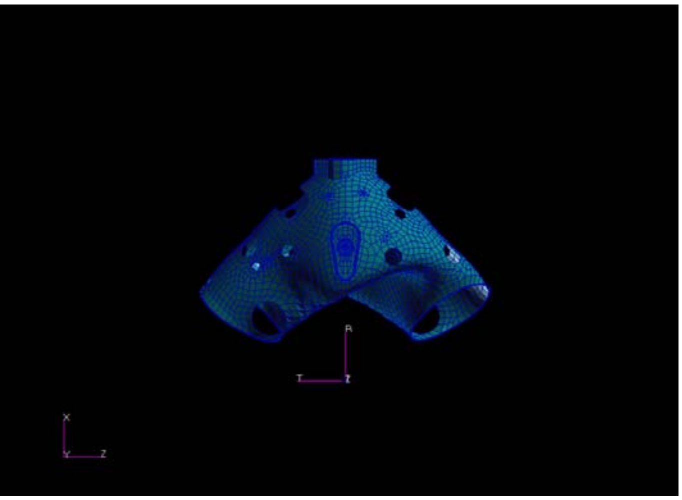



Figure 7a Supported off NB Port Flange **Figure 7b Supported off Period Flanges**

Vertical Support off the NB Port Stub Flange:

The displacement results for the NB flange support model are shown in figures 8a to 8d below:

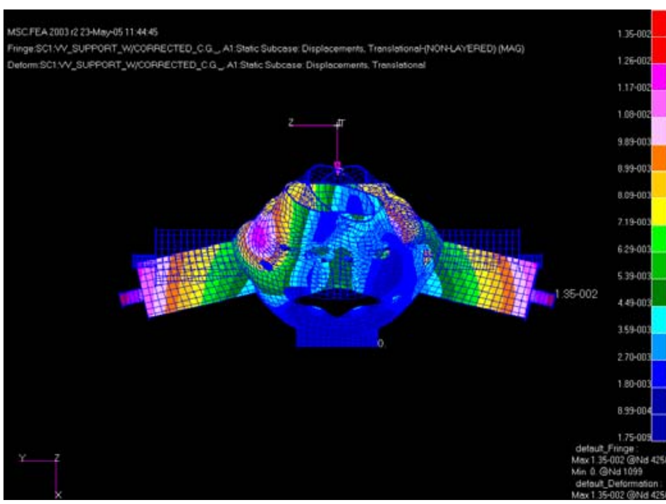
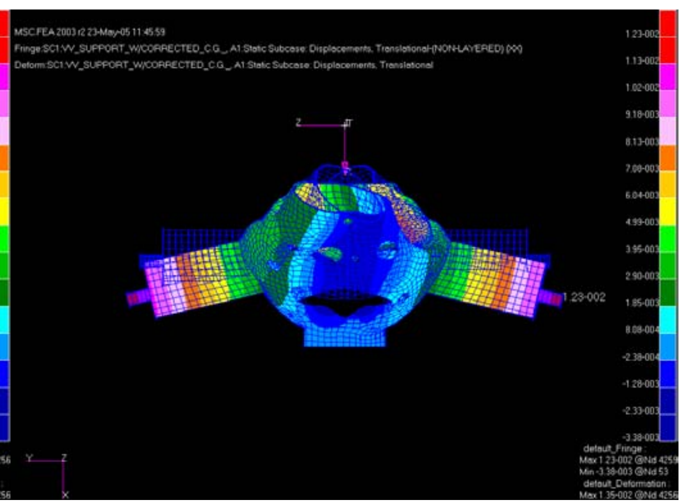
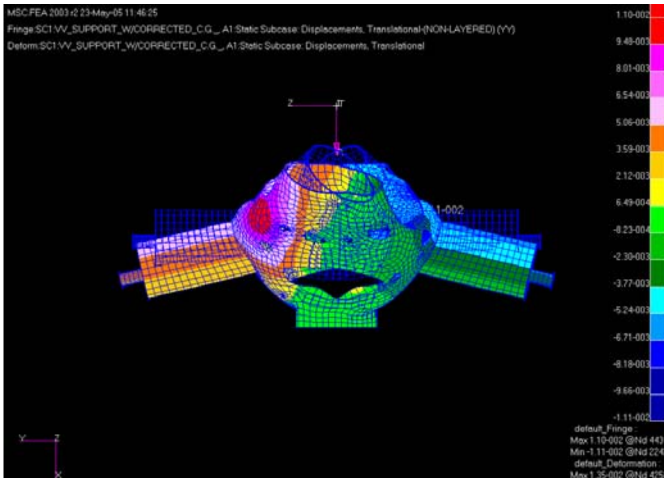



Figure 8a The Vector-Sum Mag displacements **Figure 8b The X-displacements (vertical down)**

Results using the NB flange support is shown in figures 8a to 8d and indicate a maximum vertical displacement of ~.013" downward at the ends of the trunion. The peak vertical displacement of the shell is ~0.008", with relative vertical displacements varying within the shell by -0.003" to +0.008".



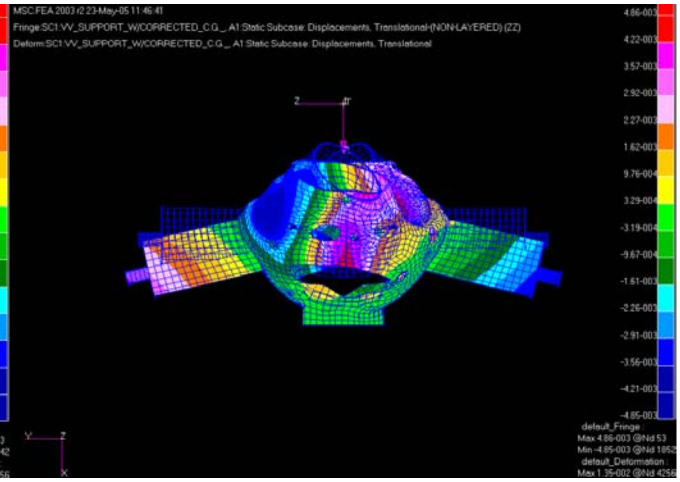
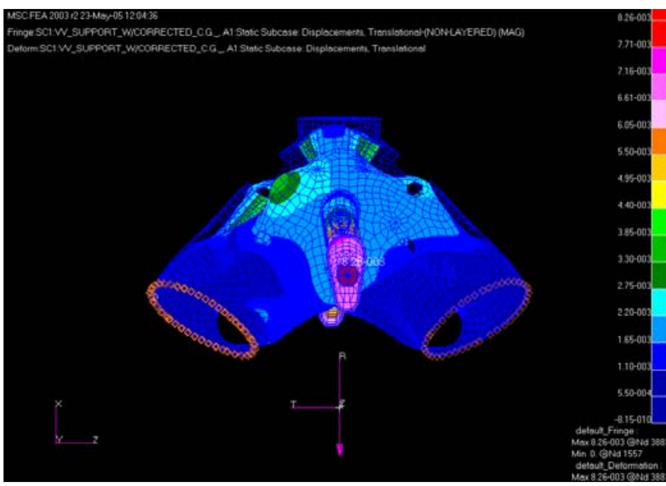


Figure 8c The Y-displacements (horizontal) **Figure 8d The Z-displacements (horizontal)**

The maximum variation in shell deflections is shown in figure 8c for the horizontal displacement contours. These vary from -0.011" to +0.011" (indicated by the red contour for the positive deflection – the dark blue negative contour is hidden on the other side in the rear quadrant of the shell).

Period Weld Flange Support:

Plots of the displacement contours for this support condition are shown in figures 9a to 9c. The Maximum deflection for the vector sum is shown in 9a and indicates a peak of ~0.008".



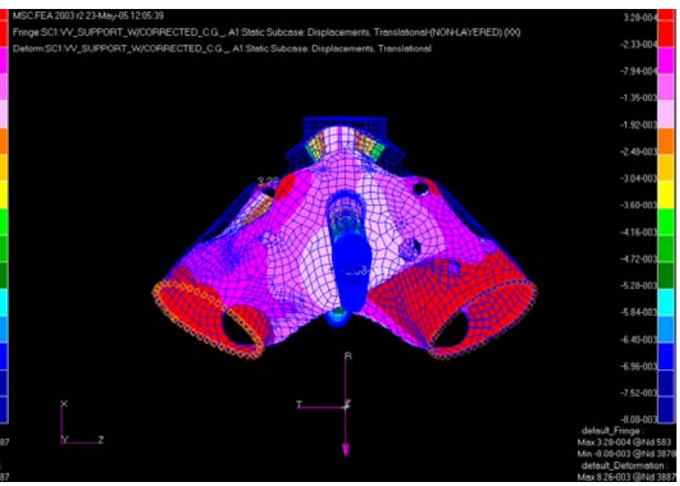
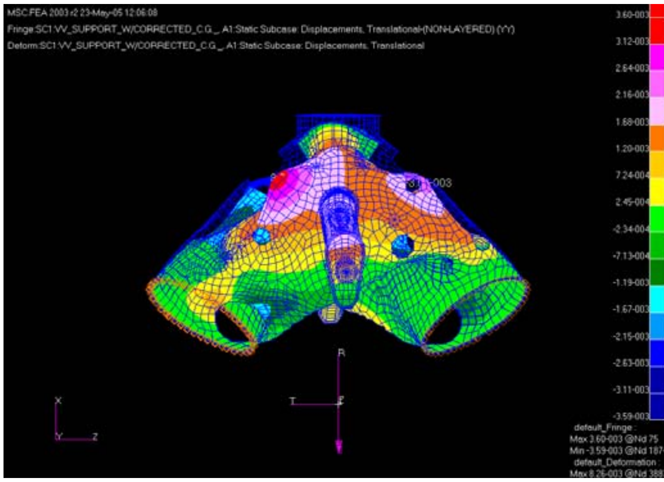


Figure 9a. Weld Flange Support (Vector-Sum) **Figure 9b Weld Flange Support (Vertical-X)**



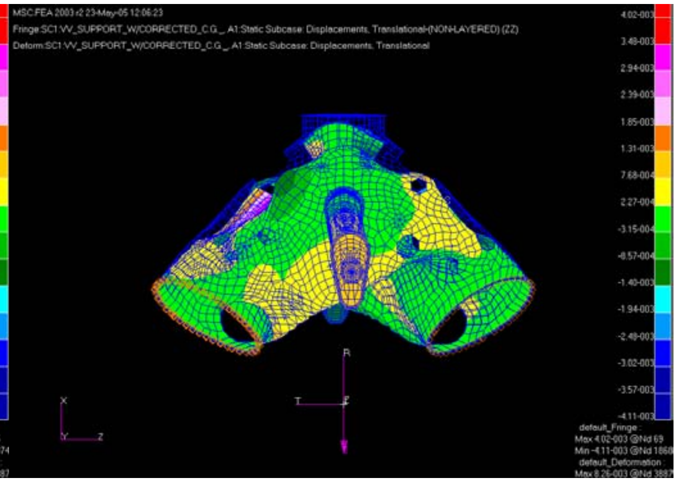


Figure 9c. Weld Flange Support (horizontal-Y) **Figure 9d Weld Flange Support (horizontal-Z)**

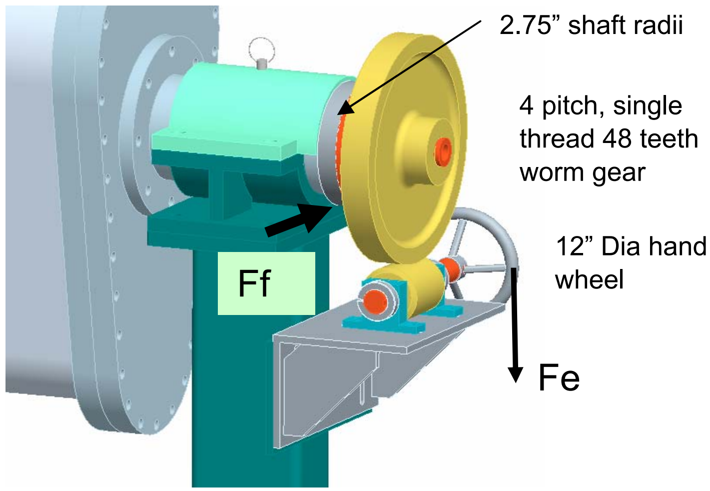
Conclusion:

The support scheme with the least relative deflection in the shell appears to be the weld flange supports but the requirements for rigid attachment to rigid frame is probably not very practical. Supporting the field period off the NB flange appears to be a reasonable alternative approach with the total relative vertical shell deflection being about 0.012” or +/- 0.006”. The lateral deflections of +/-0.011” are probably the best that can be achieved with reasonable costing tooling, although it might be possible to minimize the relative shell deflections using temporary adjustable support columns at the trunions (in addition to the NB flange support) to relieve the cantilevered loading from the port 11 nozzle and flange. To put these deflections in some perspective, it should be recalled that a 10 degree F rise in temperature will increase the total length between the two trunions by about 0.012”.

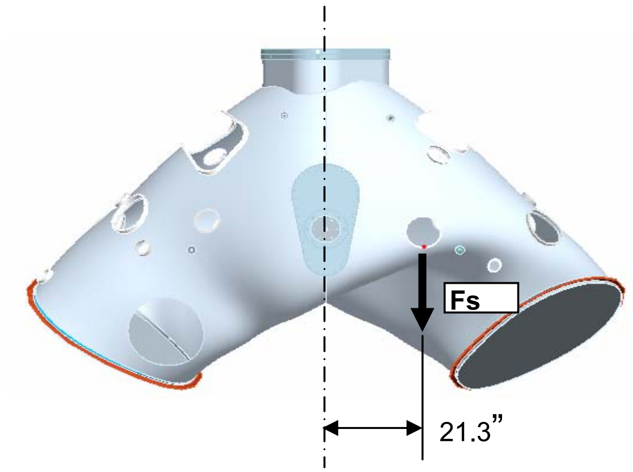
APPENDIX C
NCSX Vacuum Vessel Support Fixture Local Analysis

	To overcome friction of support shaft
4750	Total weight of VV assembly, lbs
0.15	Coef of Friction (assume oil llubricant)
712.5	Friction force (Ft), lbs
6	Hand wheel radius (R), in
2.75	Worm wheel shaft radius (L)
48	Nb of worm wheel teath (n)
6.8	Hand wheel fource to overcome friction load (Fe), lbs
	Fe = Ft x R / (n x L)
	For added services on one side
100	Weight of services, lbs
21.3	CL distance to services, in
2130	Torque due to services
7.4	Additional hand wheel load due to services
	Force needed to accelerate VV
43.76	Radius of gyration about shaft axis, in
12.3	VV mass, lbf/(in/sec^2)
2	Assumed angular acceleraton, degrees/sec^2
0.03491	Angular acceleratin, radians/sec^2
822.6	Torque reqd, T=m(K^2)α, in-lbs
2.9	Hand wheel load to overcome part inertial
17.1	**Total hand wheel load, lbs**
0.49701	worm shaft polor moment of inertia, J (pi x D^4/32)
308.8	Max worm shaft shear (T r / J), psi

1 revolution of worm results in 1/48 rev of wheel
4 turns of worm relusts in 30° turn of wheel



Wheel Pitch Diam, in	12
Worm Pitch Diam	3
Worm shaft Diam	1.5



	Single column stress
	Center support column gerometry, 6" x 4" x .25" thk
4.59	Area of center support column, in^2
517.4	Axial stress, P/A, psi
	Support leg lateral support capability
	Six 1/2" dia x 2" long Hilti anchor bolt per support
6751	Hilti pullout alowable for 4000 psi concrete, lbs
182277	Moment capabiltiy of 3 pair of Hilti's with a 9" separation, in-lbs
859	Maximum permissible axial load on one support assuming that 1/3 of the Hilit's fail, lbs