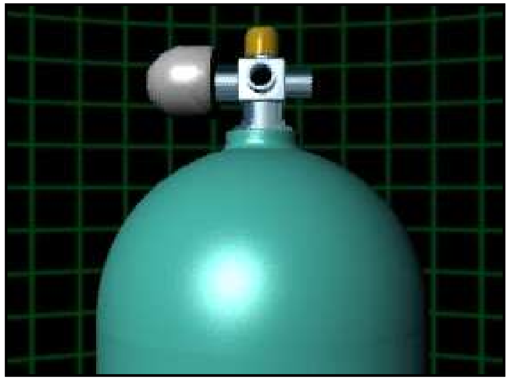
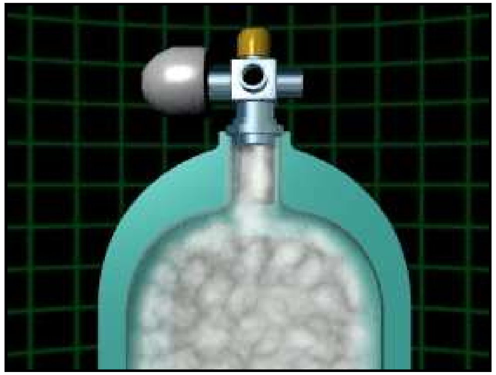
SECTION 9

SCUBA TANK





SCUBA TANK

- Topics covered in this section
  - Axisymmetric modeling techniques
  - Importing Geometry
  - Mesh Density Control
  - Perform quality checks on stress results
  - Create and manipulate viewports

SCUBA TANK

- Problem Description
  - Scuba tanks are designed to withstand cyclic pressurization and depressurization loads. They must also survive loads induced during transportation and actual service. You are asked to analyze a new scuba tank design.
- Analysis Objectives
  - Determine stresses in the scuba tank under an internal pressure of 3000 psi. The maximum stress must be below the yield point of the tank material.

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- Getting started on the scuba tank analysis
  - The scuba tank is a thick shell structure. We expect the state of stress to be 3 dimensional in the tank shell. Solid elements should be used.
  - Solid element models tend to get large and take a lot of CPU time to solve. This is especially true for non-linear or transient analysis. It is often advisable to simplify the model in order to speed up the analysis process.
  - Several ways to simplify finite element models are presented next.

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- Simplifying Finite Element Models
  - Finite element models can be simplified by using a 2D (planar) representation of a 3D model. There are three ways to do this:
    - Plane Stress
    - Plane Strain
    - Axisymmetric
  - Finite element models can also be simplified by taking advantage of symmetry. There are two primary types of symmetry - reflective symmetry and cyclic symmetry. Symmetry techniques will be presented in detail in the advanced course.

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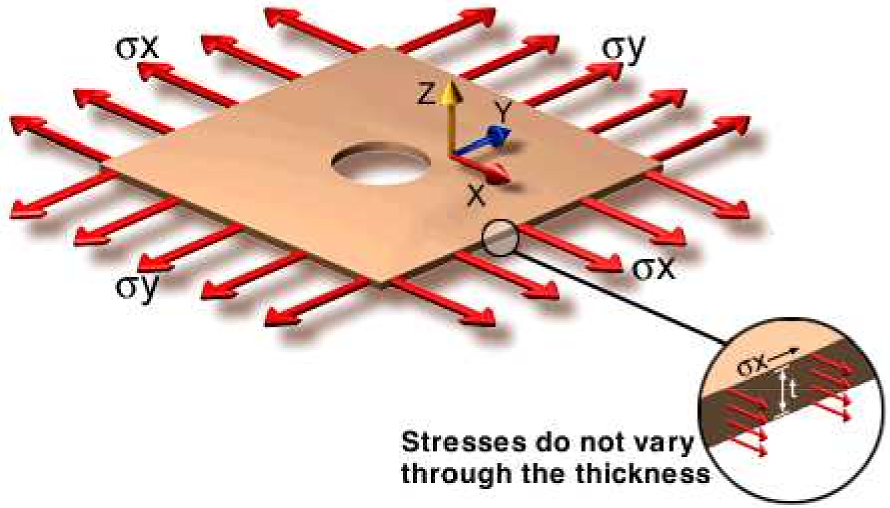
- The Plane Stress Model
  - Assumptions:
    - Z stress is zero
    - Stresses do no vary through the thickness
  - One way to identify a plane stress model is to look for structures in which the thickness is small compared to the other two dimensions.



$$\sigma_z = 0$$
$$\tau_{yz} = \tau_{xz} = 0$$
$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}$$
$$\varepsilon_z = \frac{\nu}{1-\nu}(\varepsilon_x + \varepsilon_y)$$

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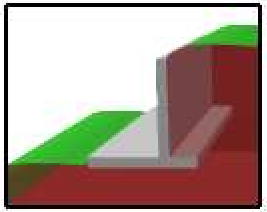
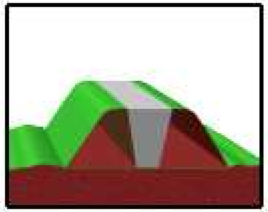
- The Plane Strain Model
  - Assumptions:
    - Z strain is zero
  - The depth of the plane strain model is large compared to the cross section.
  - Plane strain problems are common in civil engineering and are used to model retaining walls or dams.



Retaining Wall



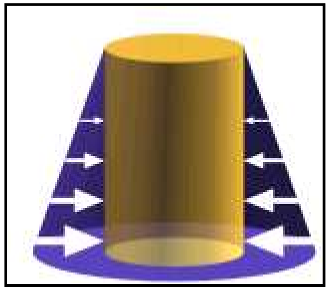
Earth Dam

$$\varepsilon_z = 0 \qquad \gamma_{xz} = \gamma_{yz} = 0$$

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & 1-\nu \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}$$

SCUBA TANK

- The Axisymmetric Model
  - Assumptions:
    - The geometry, loads, and boundary conditions are not a function of q.
    - Another way to state this is that the geometry, loads, and boundary conditions do not vary in the circumferential direction.
  - Axisymmetry is commonly used to analyze pressure vessels and tanks.



$$\begin{Bmatrix} \sigma_r \\ \sigma_z \\ \sigma_\theta \\ \tau_{rz} \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & 1-\nu \end{bmatrix} \begin{Bmatrix} \varepsilon_r \\ \varepsilon_z \\ \varepsilon_\theta \\ \gamma_{rz} \end{Bmatrix}$$

SCUBA TANK

- Simplification of the scuba tank model
  - Since the scuba tank is axisymmetric and the pressure load is axisymmetric, we can simplify the problem using axisymmetry. We will solve this problem using two different axisymmetric methods:
    - Build a sector of the tank using 3D solid elements
    - Build the tank cross section using 2D solid elements

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- Creating the geometry for the tank
  - A geometry file for the scuba tank generated by a CAD package is available so there is no need to re-create the geometry.
  - Use File/Import to import the geometry file directly into PATRAN.

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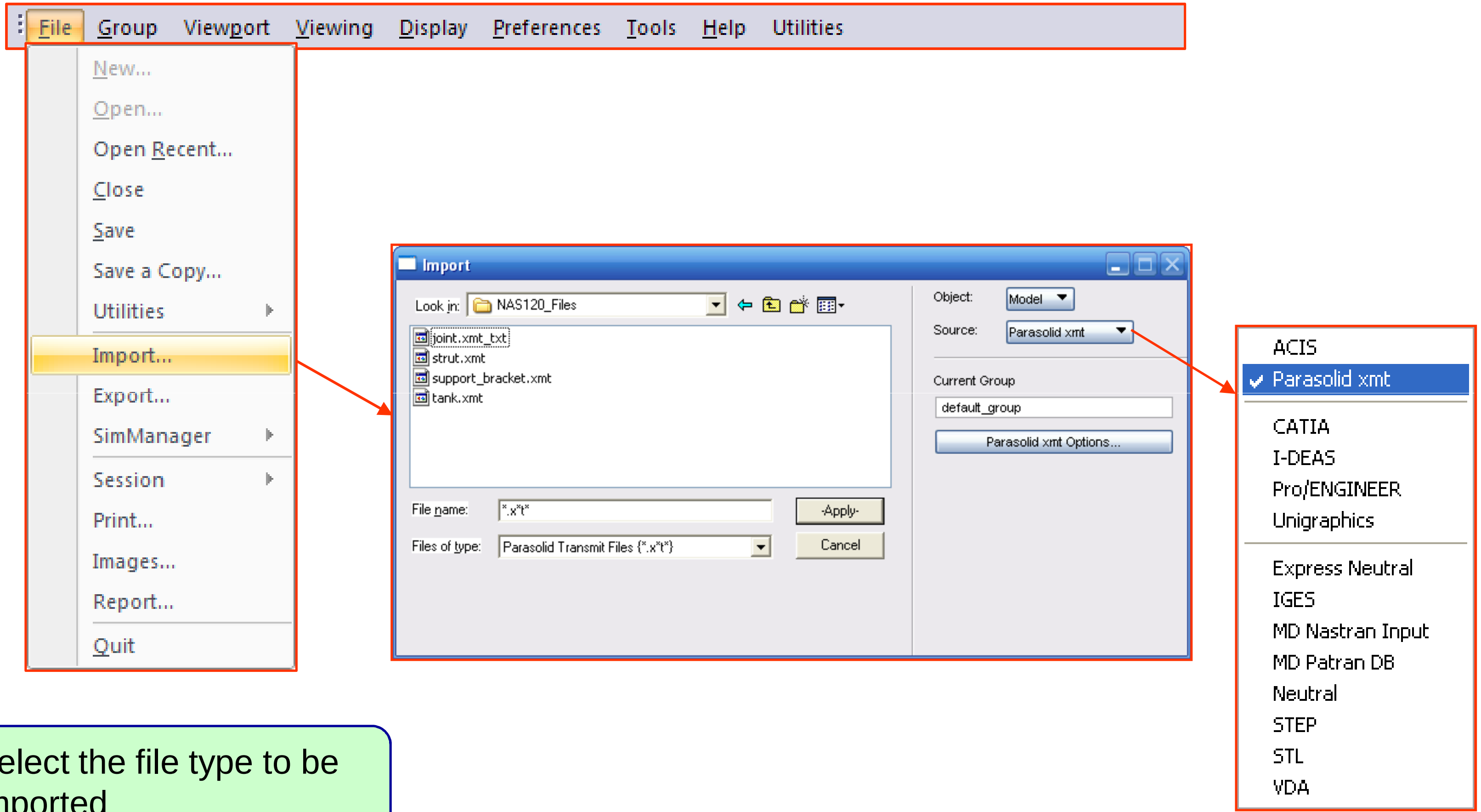

Select the file type to be imported

SCUBA TANK

- Models created by the following CAD packages can be imported into PATRAN:
  - CATIA
  - Unigraphics
  - Pro/ENGINEER
  - EUCLID 3
  - I-DEAS

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- Additional types of geometry files can also be imported into PATRAN
  - ACIS solid geometry files
    - Typical file extension is .sat
    - Generated by CAD systems such as Autocad, SolidEdge, and Mechanical Desktop
  - Parasolid solid geometry files
    - Typical file extension is .xmt
    - Generated by CAD systems such as SolidWorks
  - IGES geometry files
    - Typical file extension is .igs
    - Generated by most CAD systems
  - STEP geometry files
    - Typical file extension is .stp
    - Generated by CAD systems such as CATIA

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- The scuba tank geometry file we have is a parasolid solid geometry model. Let's import this file into PATRAN.

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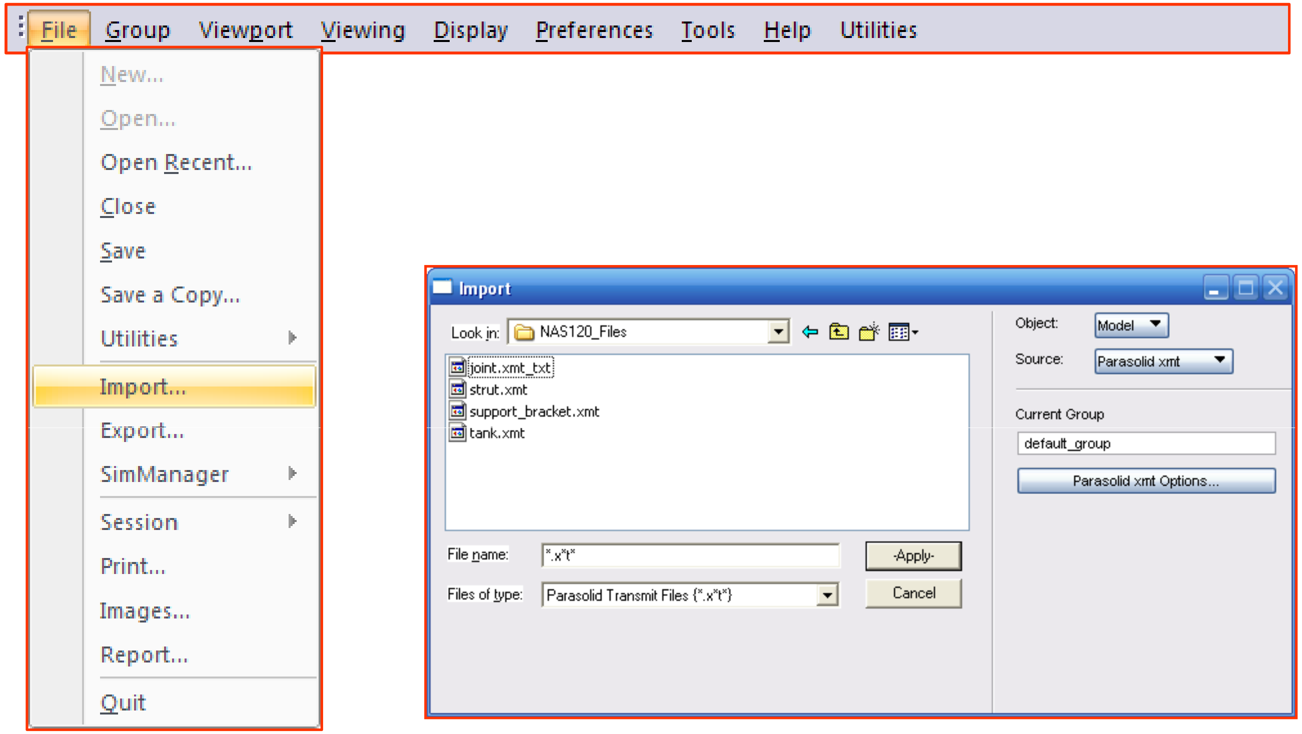
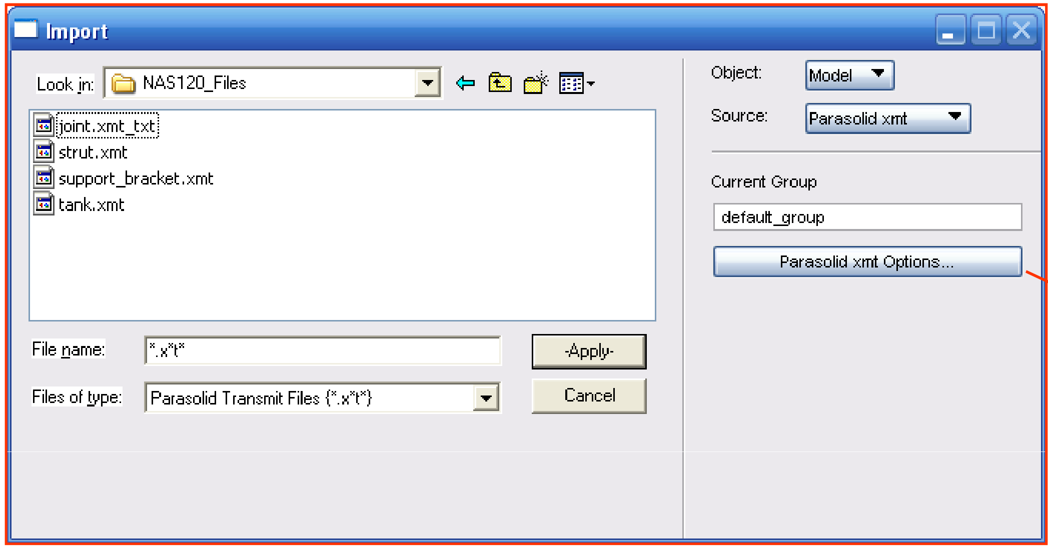
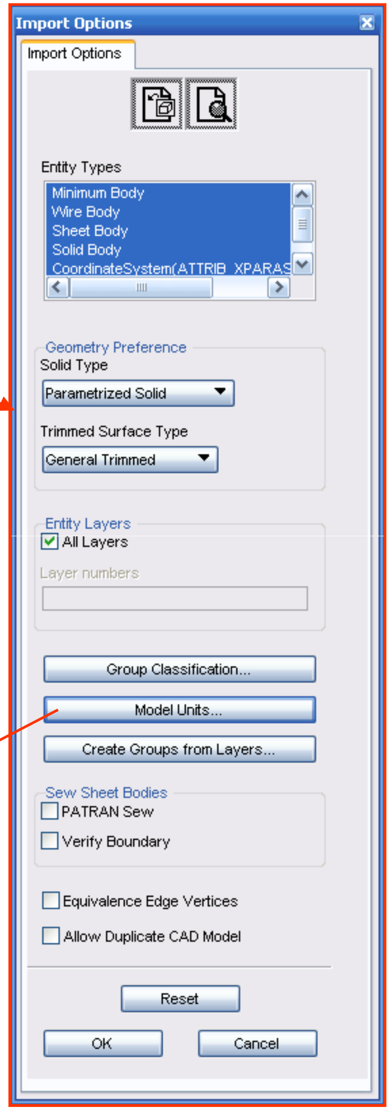


Import the parasolid model tank.xmt

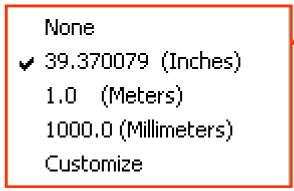
SCUBA TANK

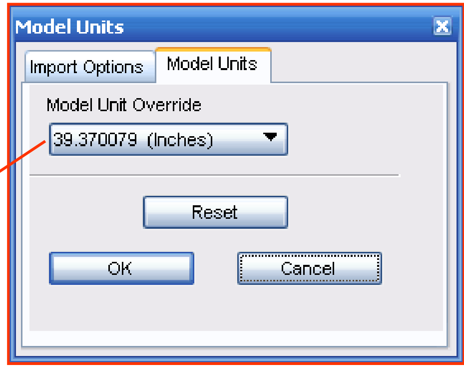




Select Parasolid xmt options and select Model Units.

Select Inches. This converts the units in the parasolid model from meters to inches.





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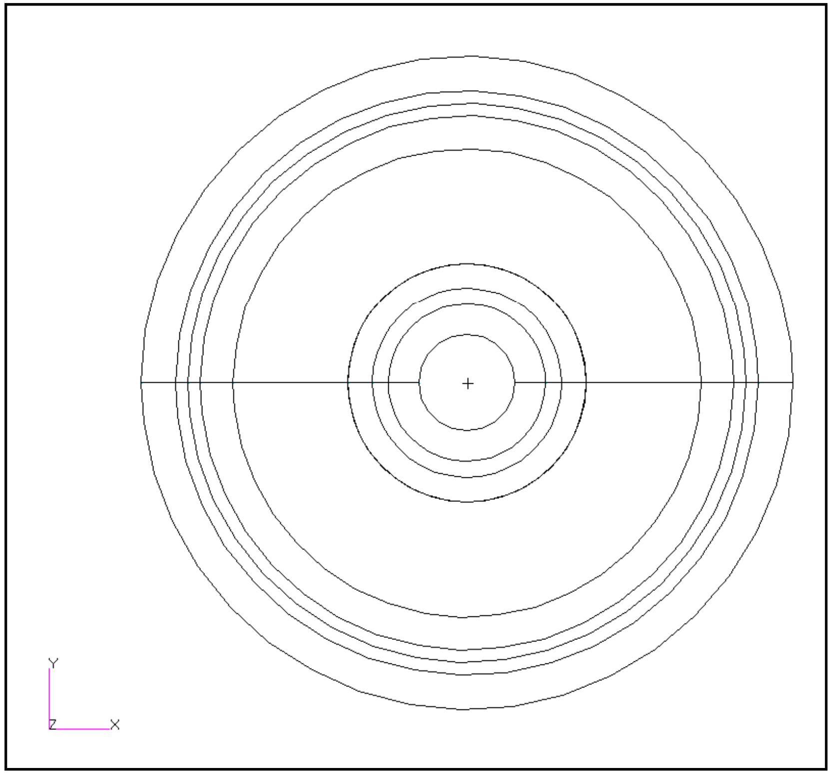
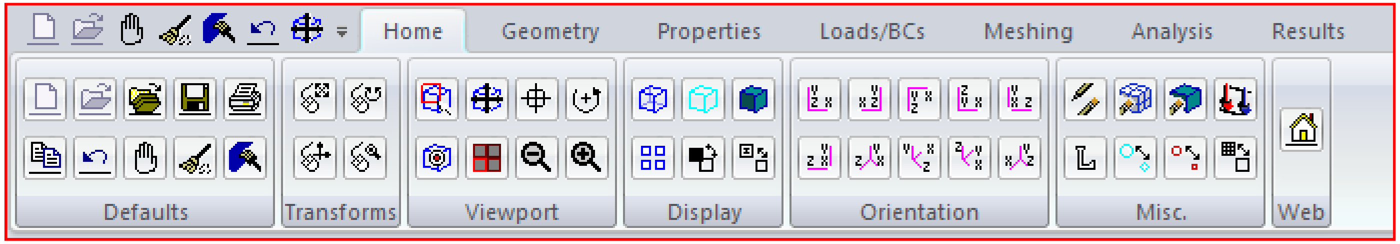
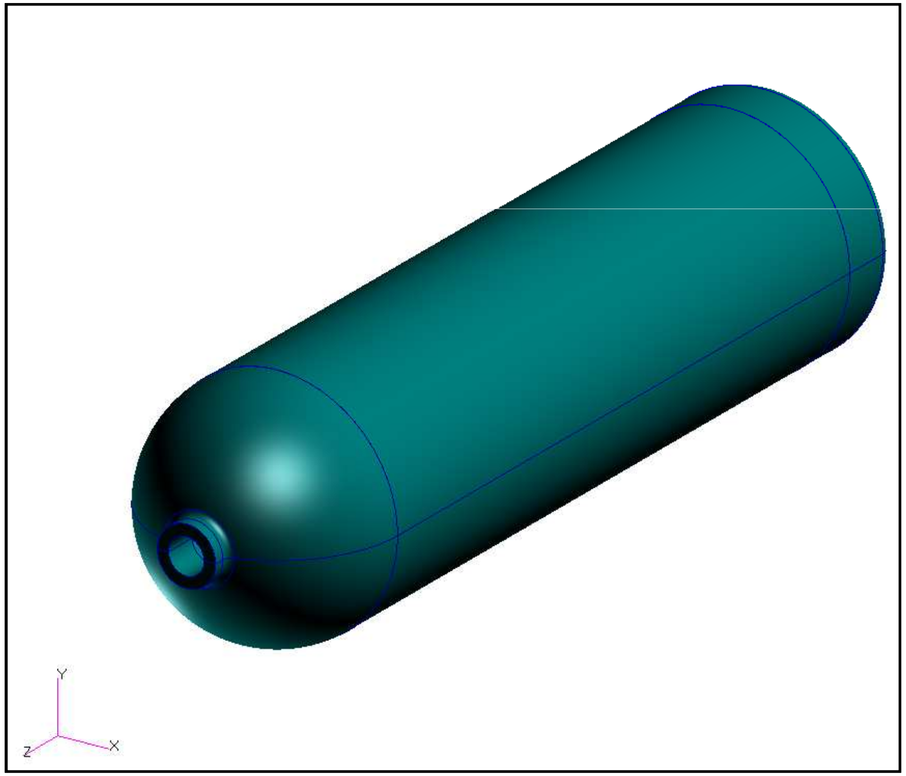
Finish importing the parasolid model



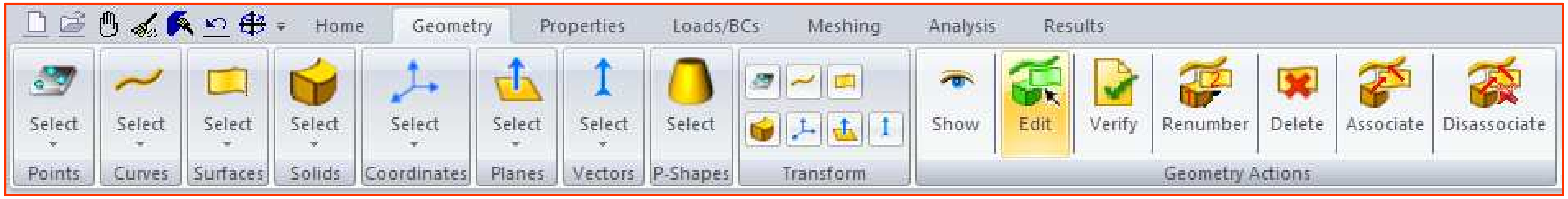
SCUBA TANK



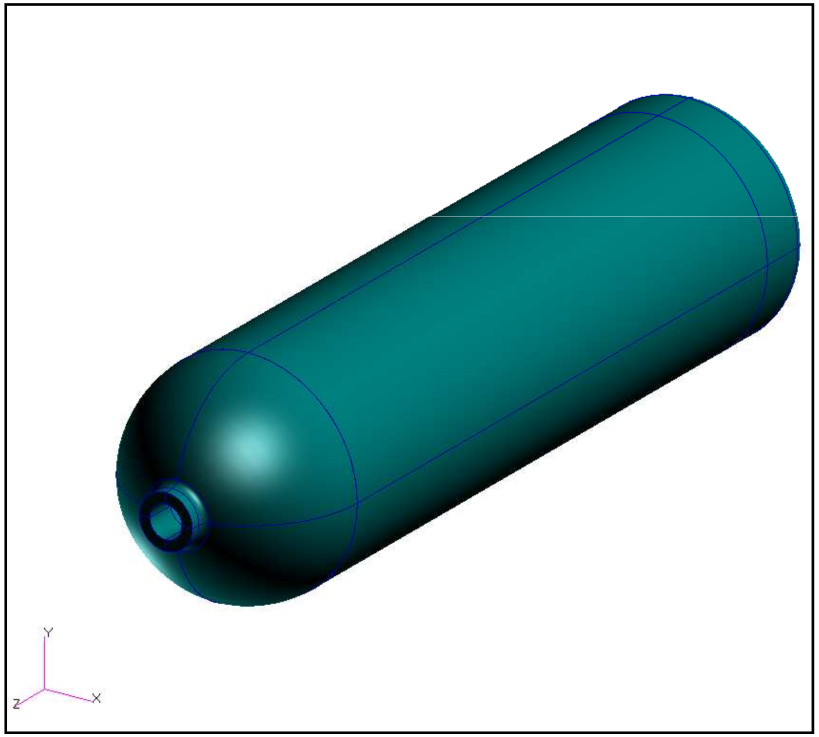
Rotate and shade the model

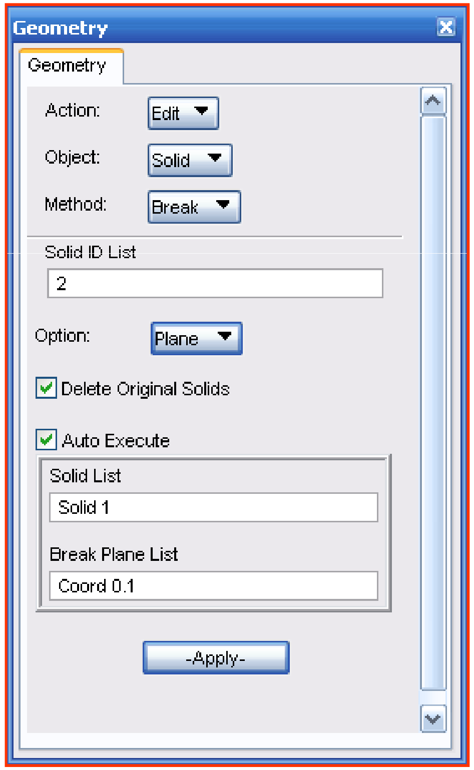


SCUBA TANK

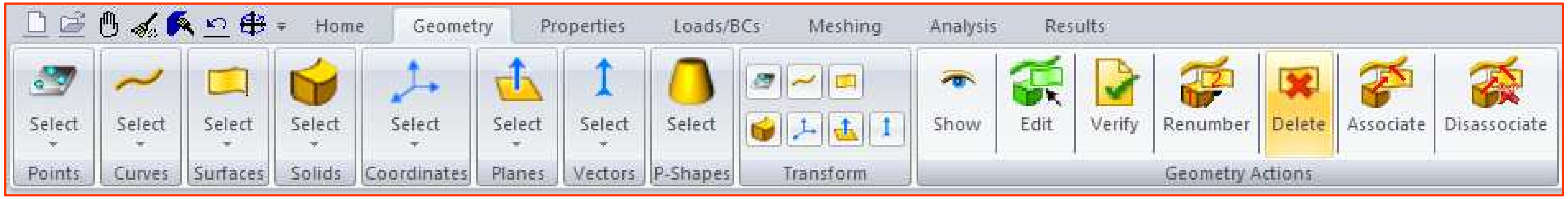


Break the solid into two halves

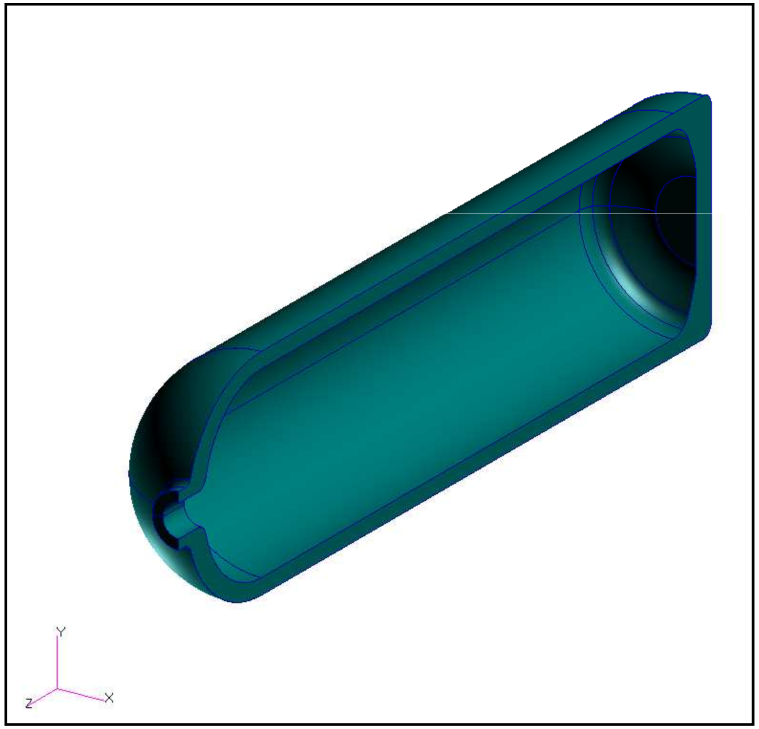


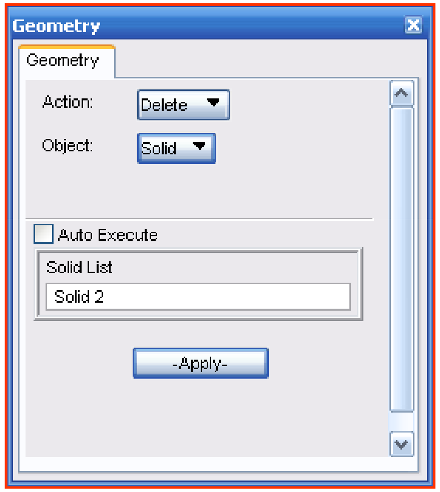


SCUBA TANK



Delete half the tank





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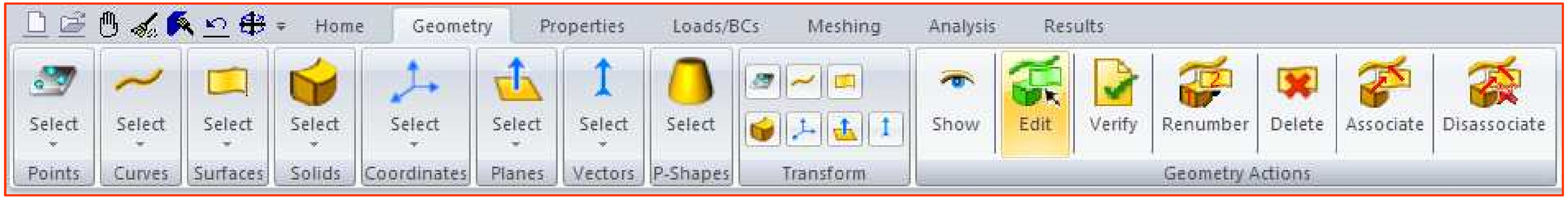

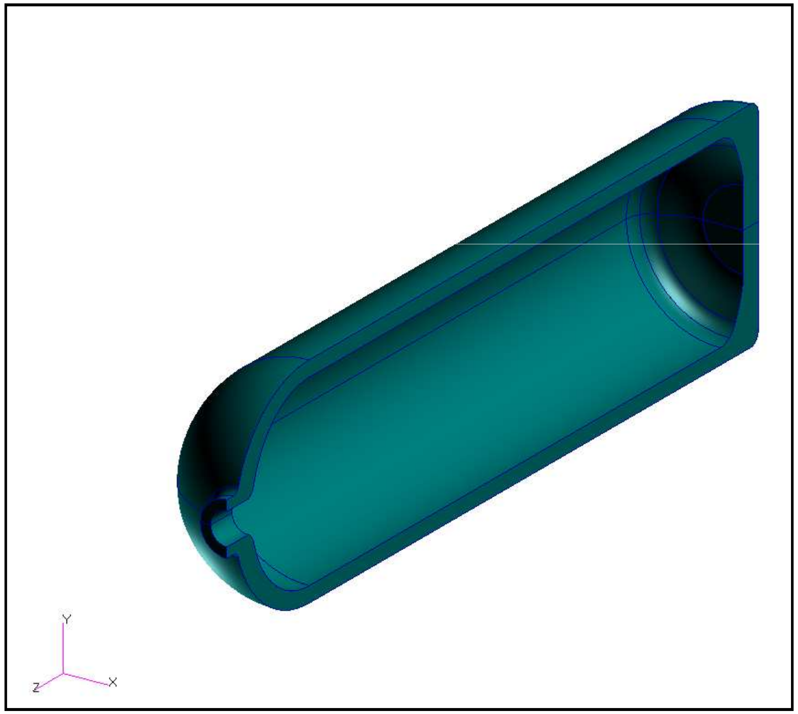

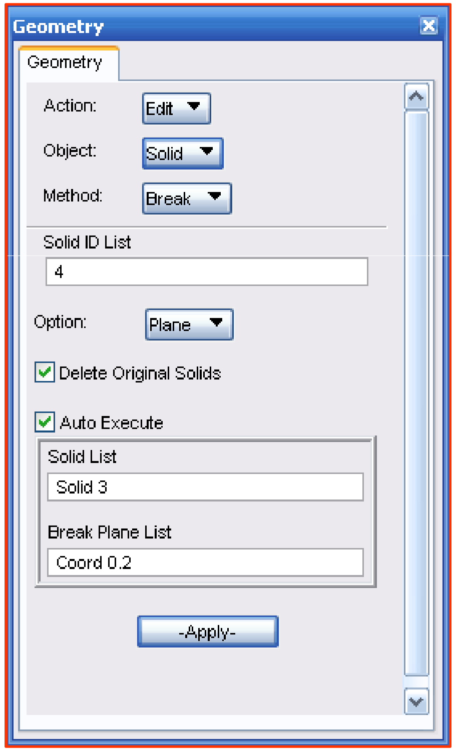

Break the remaining tank into two halves

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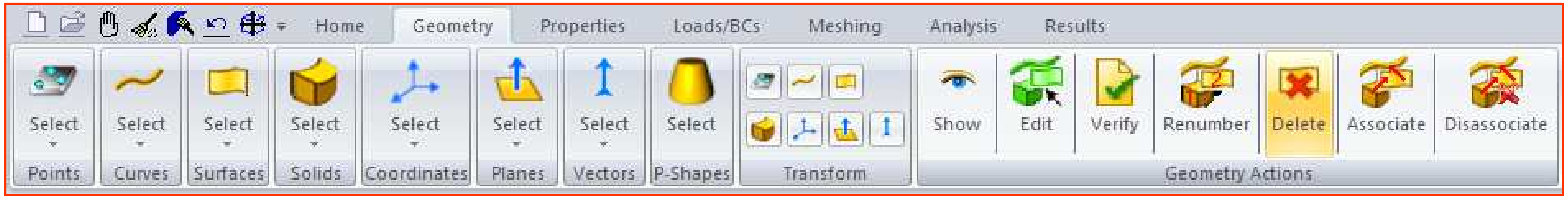
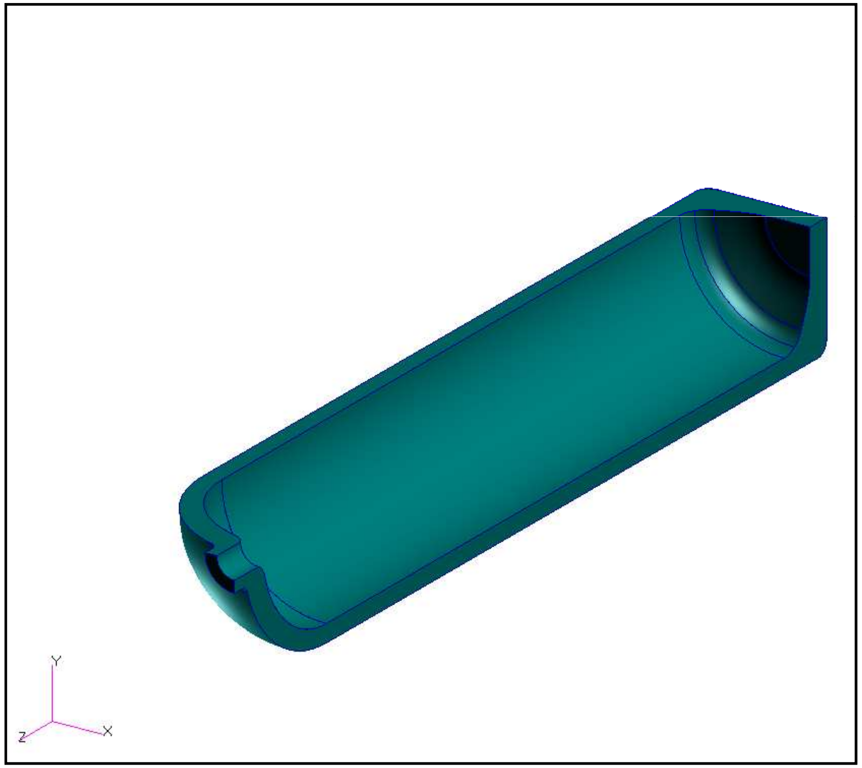
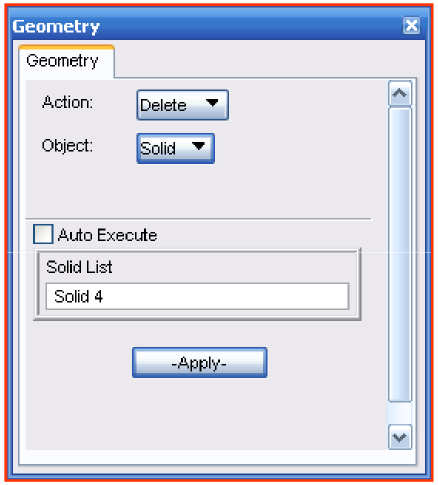
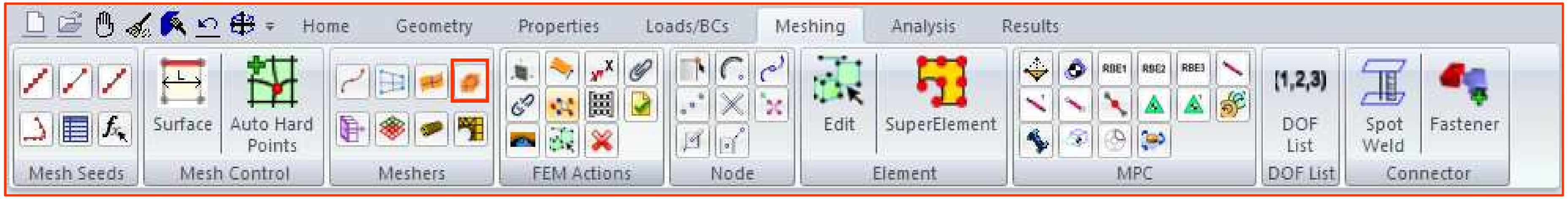






Delete the upper quarter of the tank

SCUBA TANK



Let's create a coarse mesh.

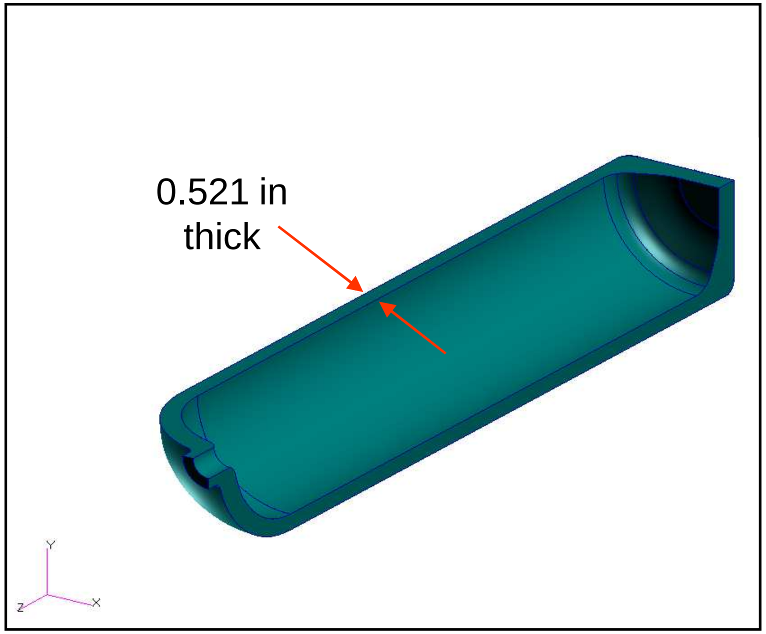
Select Tet10 elements.

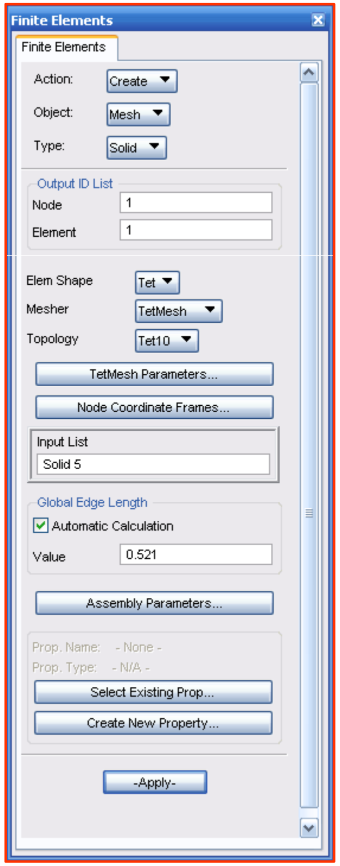
Select TetMesh Parameters and deselect curvature check.

Select the solid.

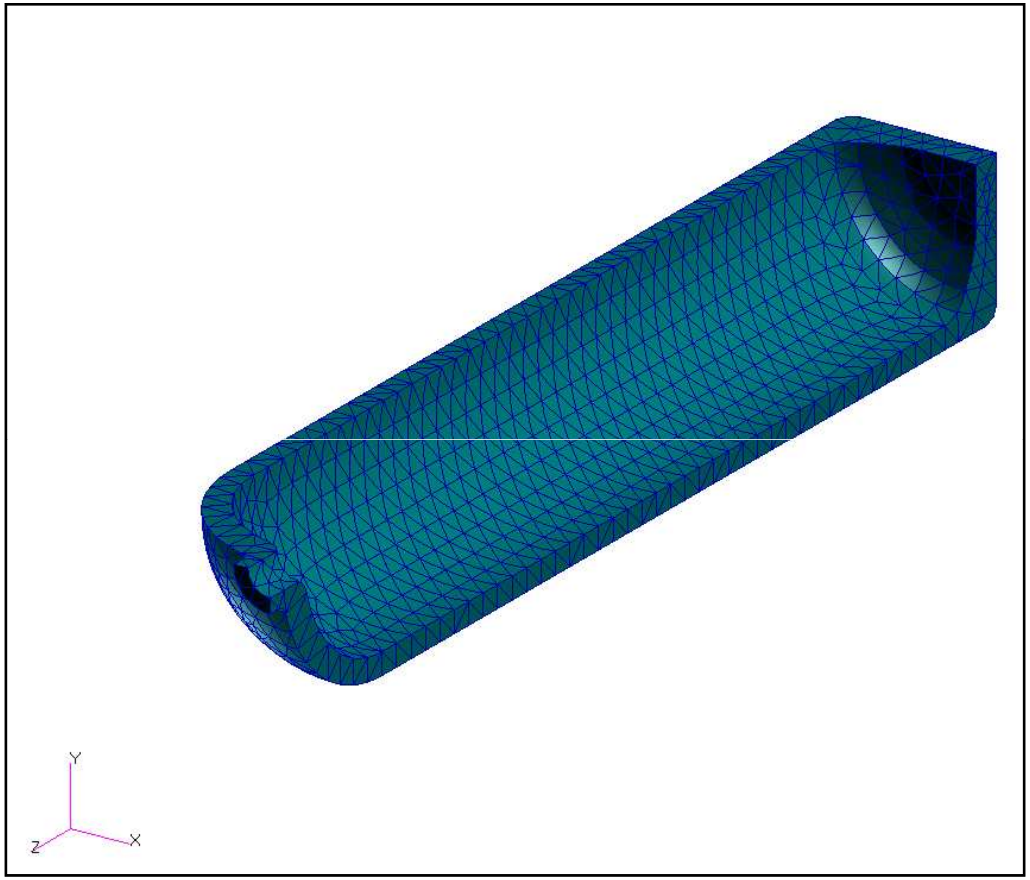
Use a global edge length of 0.521 to create one element through the thickness.

Click Apply.





SCUBA TANK



A relatively coarse mesh is created

SCUBA TANK

- Create Boundary Conditions
  - Since the scuba tank is axisymmetric, we need to create a cylindrical coordinate system to define the symmetry boundary conditions.

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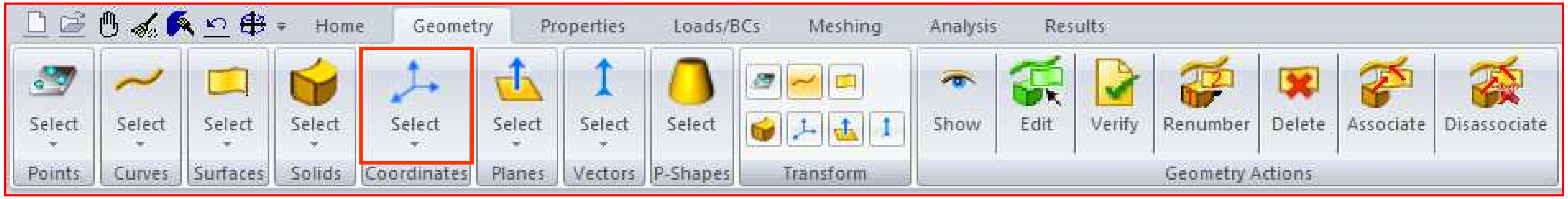

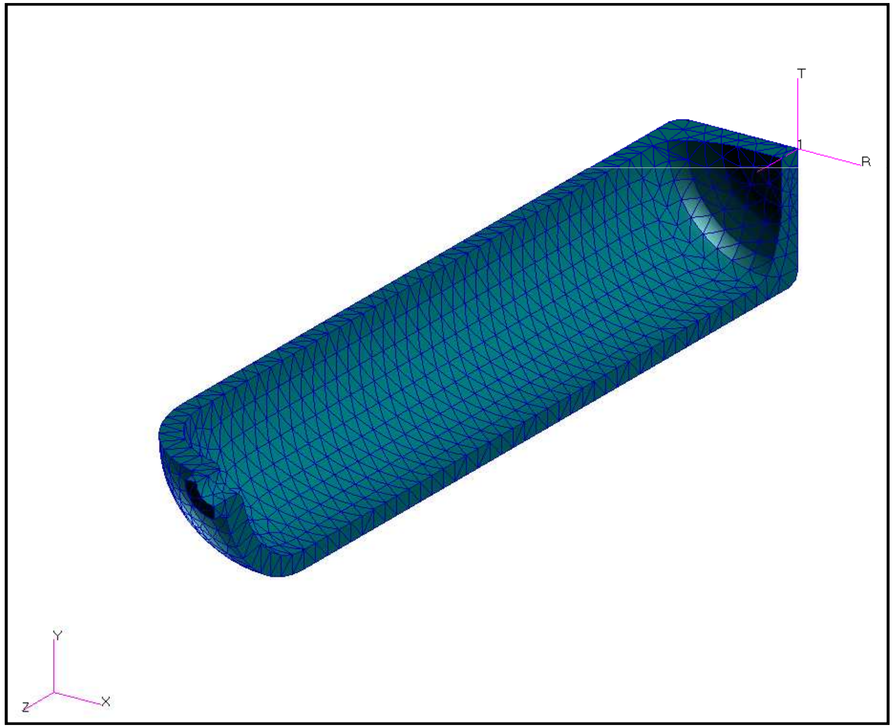

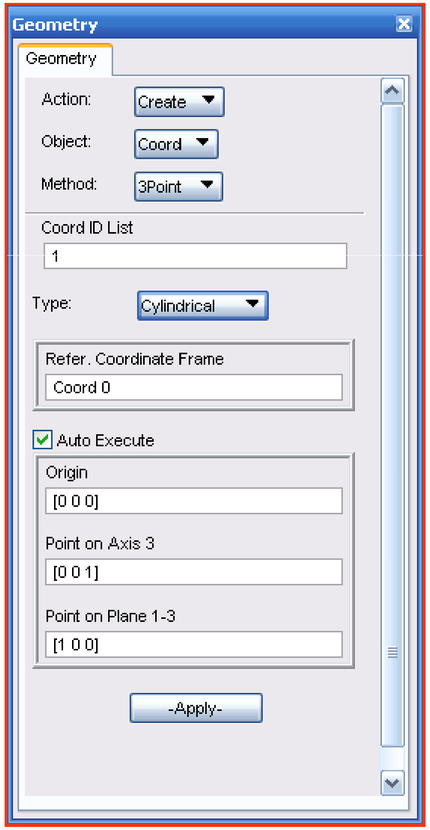

Create a cylindrical coordinate system

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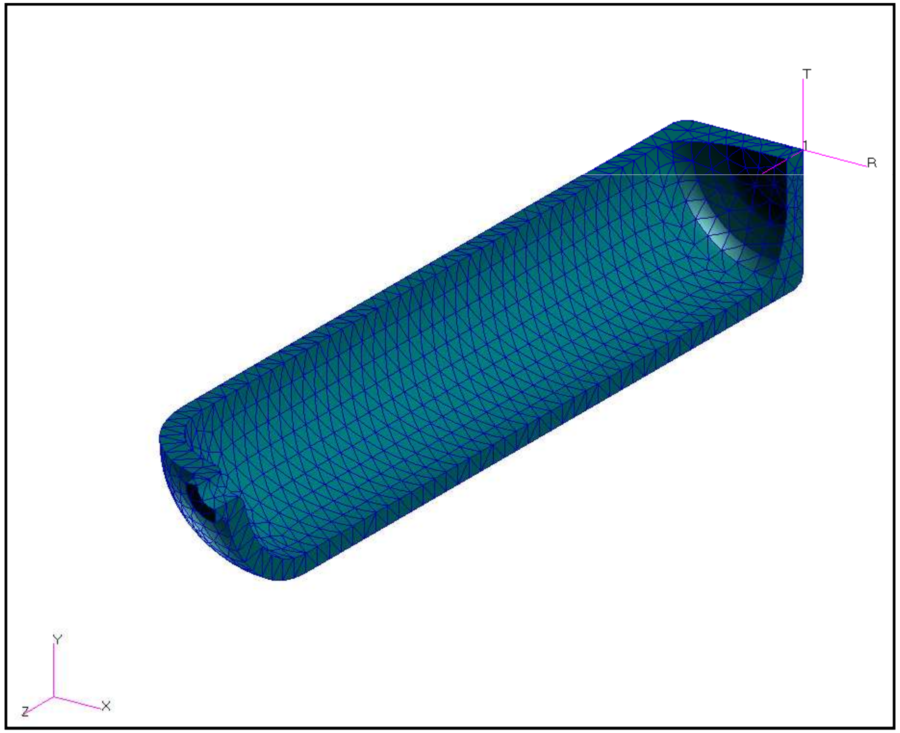
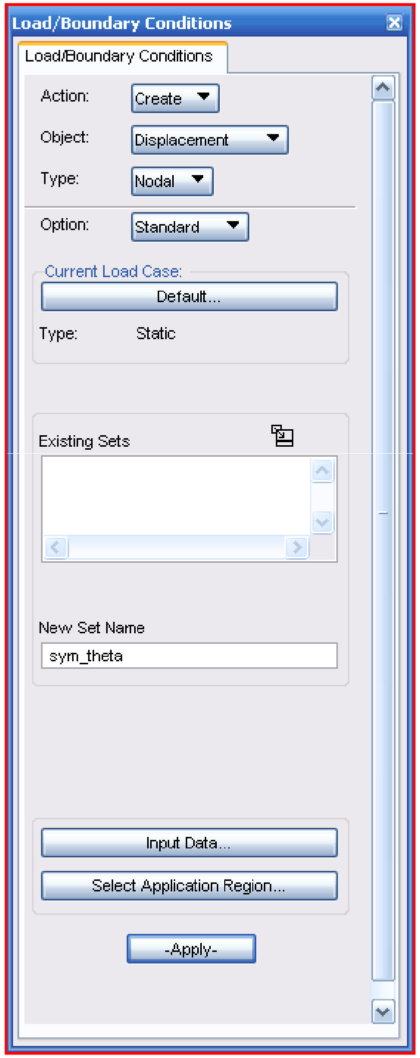
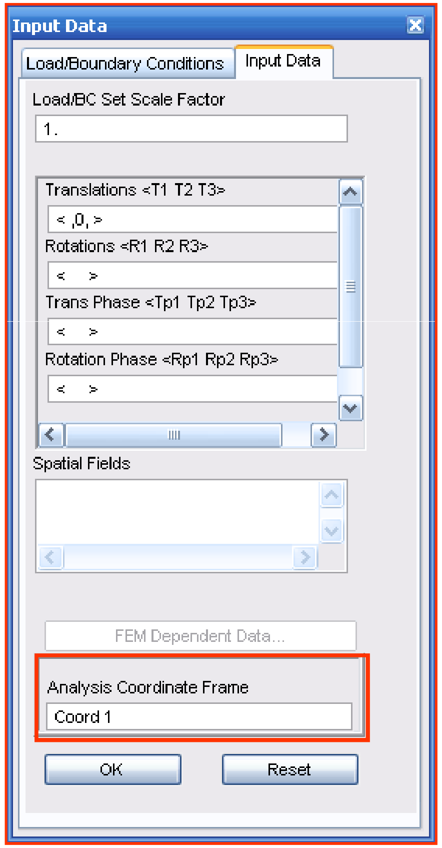


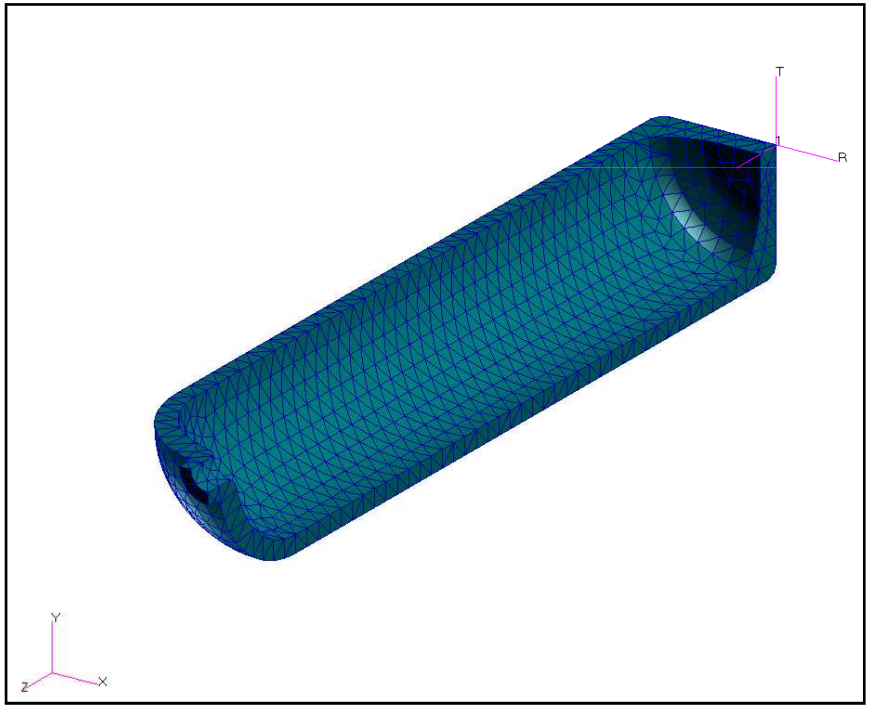


Create a symmetric constraint in the tangential (theta) direction

SCUBA TANK



Constrain translation in the theta direction and select coordinate system 1 as the analysis coordinate system



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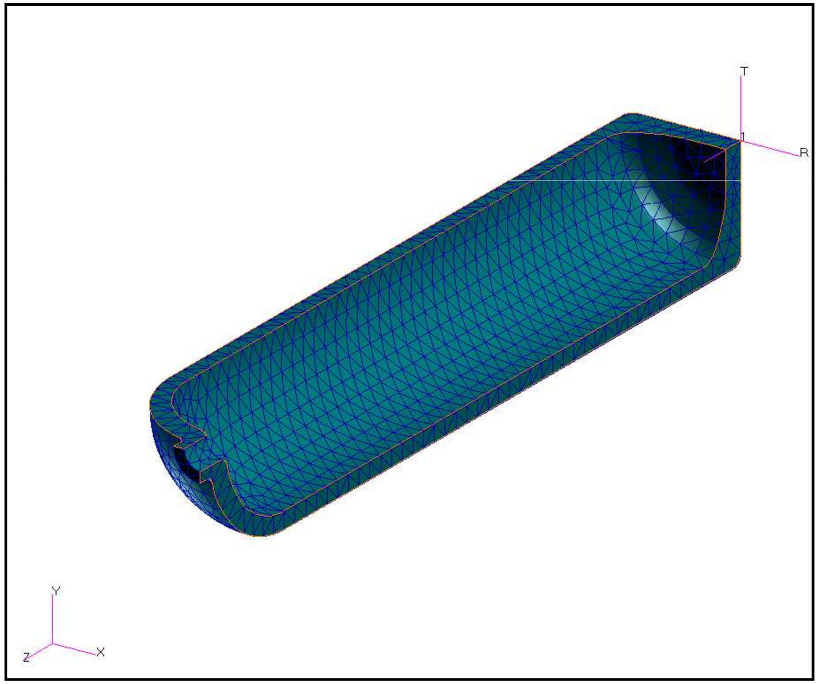
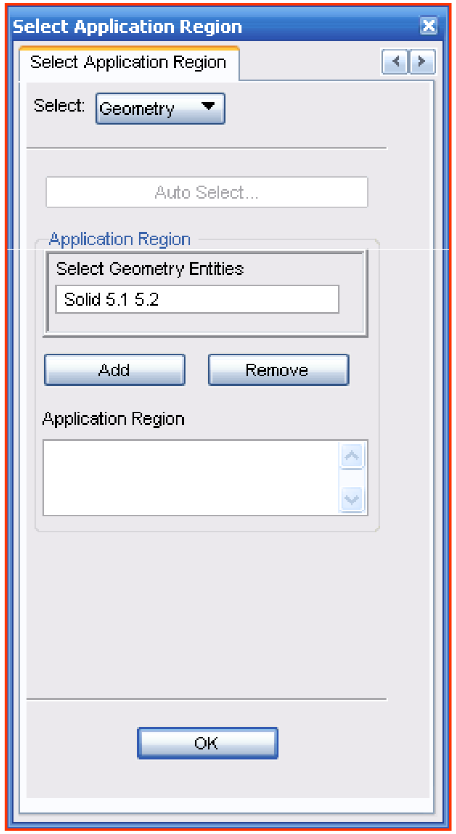
Select the two surfaces located on the planes of symmetry





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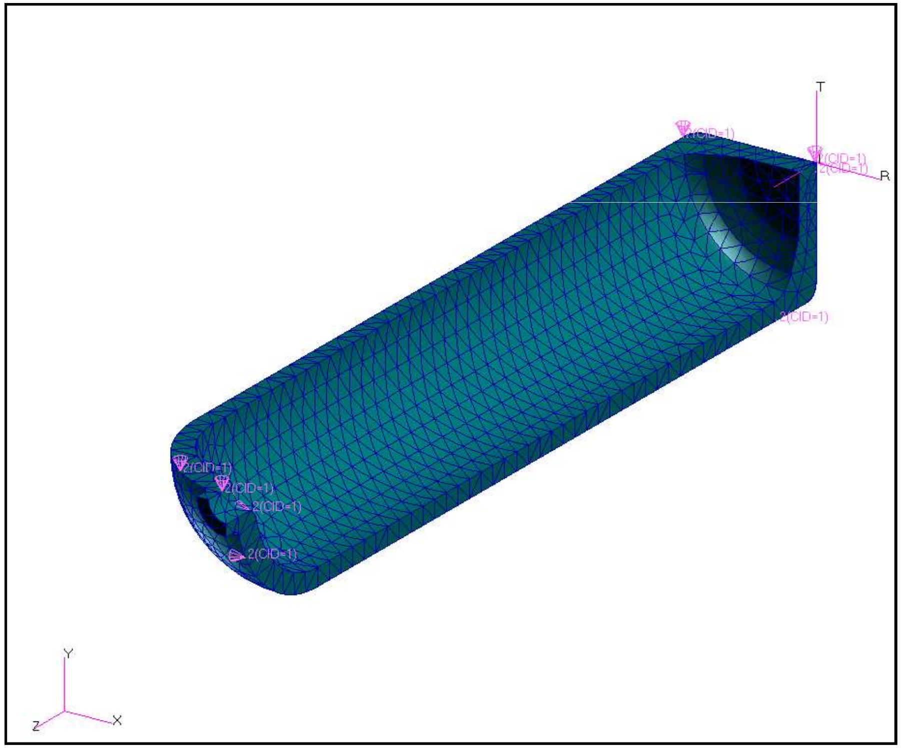
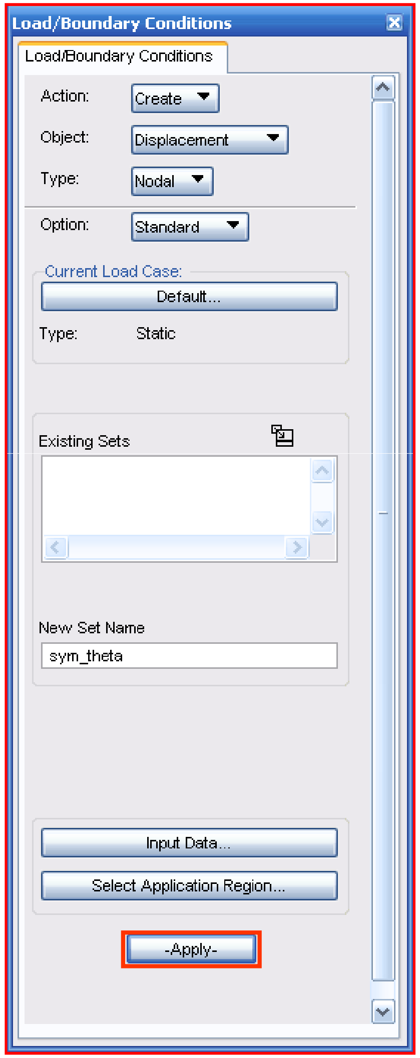
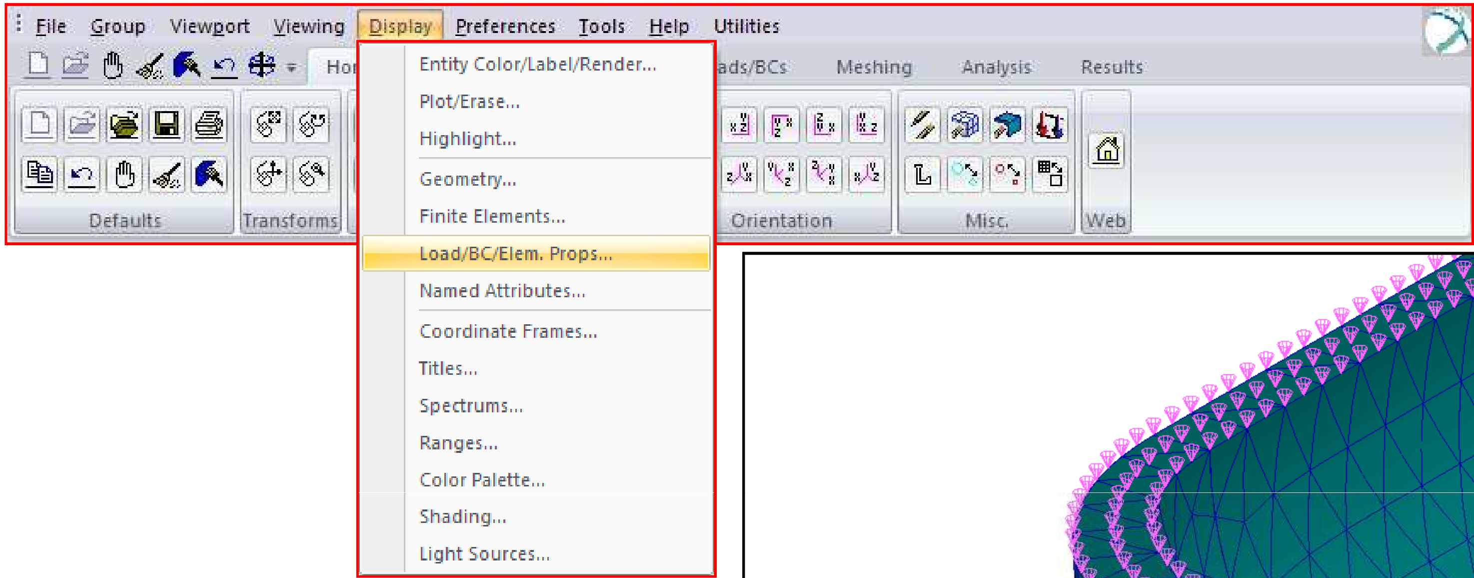
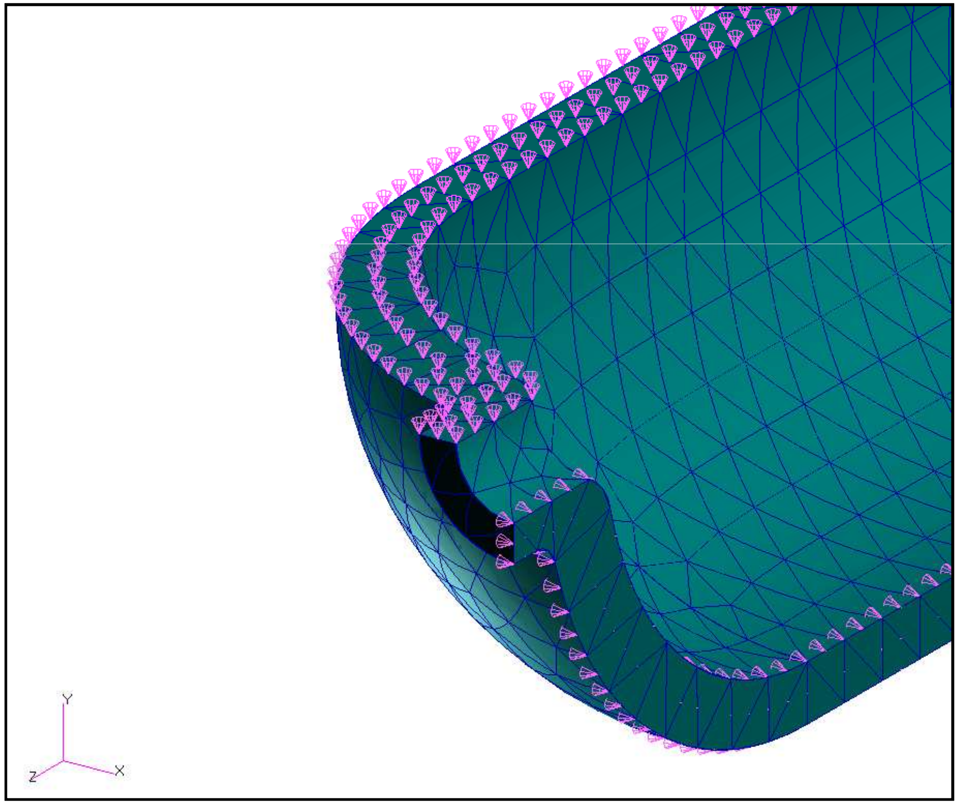
Finish creating the theta symmetry boundary condition





SCUBA TANK

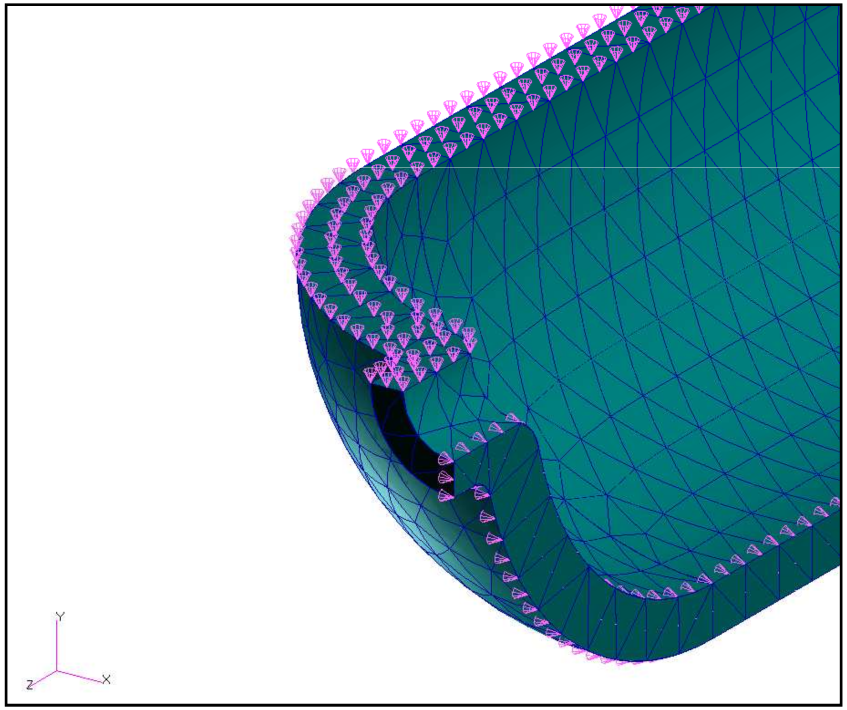


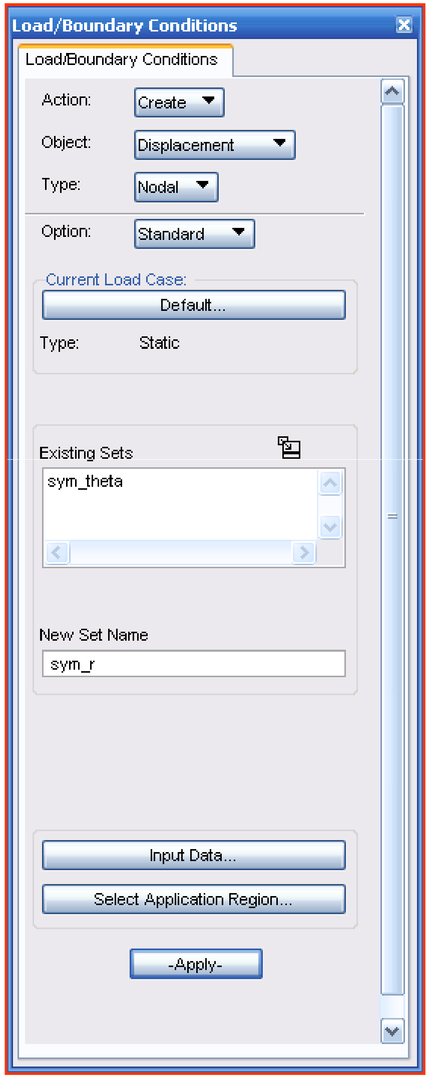


Select Display - **Load/BC/Elem. Props** to change the display to show on FEM only. Also turn off LBC/Prop values to simplify the display.

SCUBA TANK

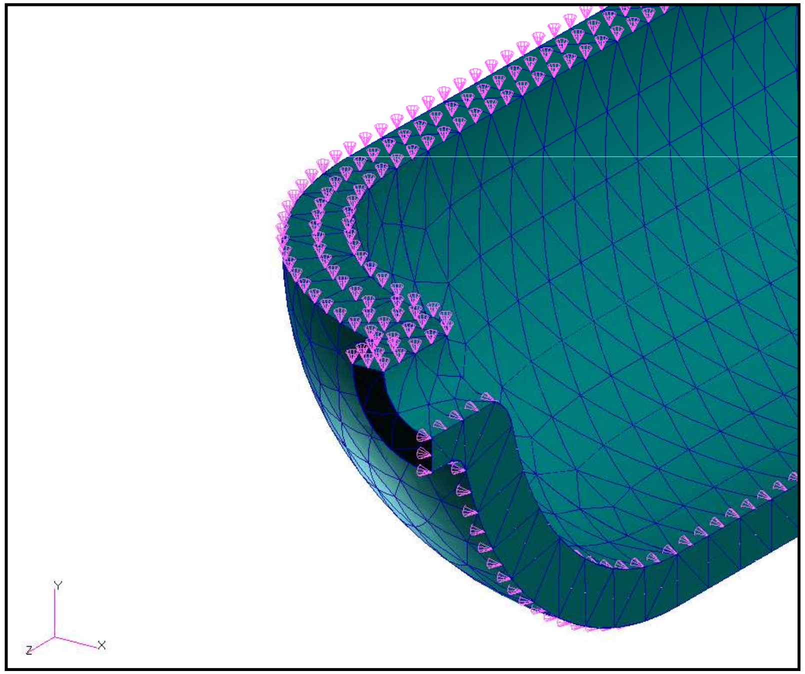
Next, create a symmetry constraint in the radial direction.

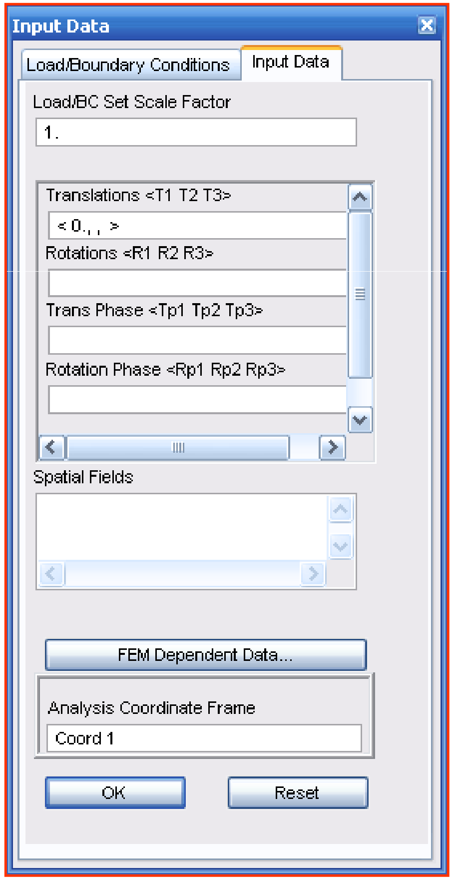




SCUBA TANK

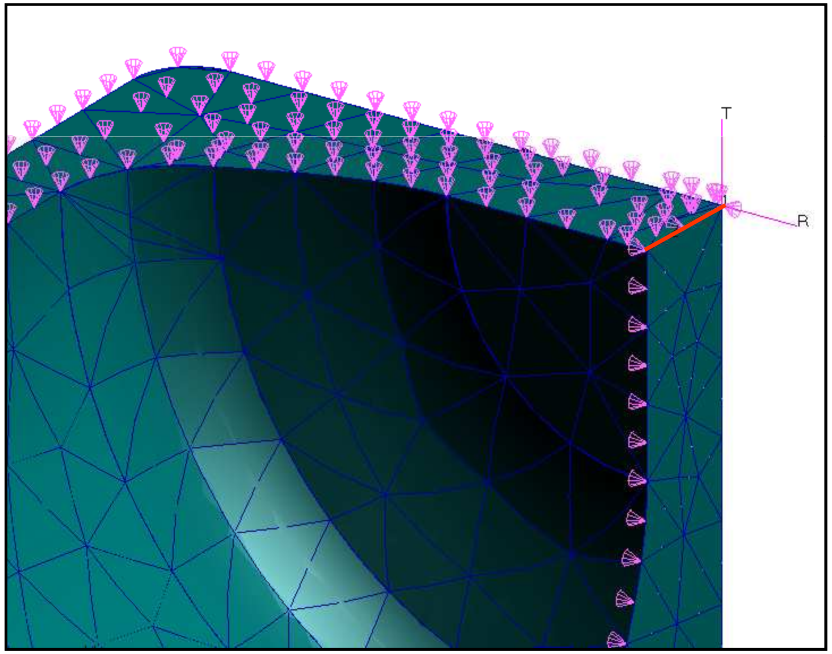
Constrain the radial translation

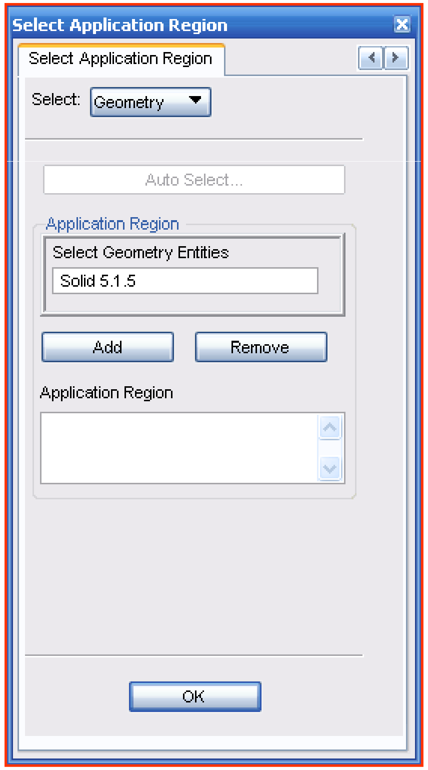




SCUBA TANK

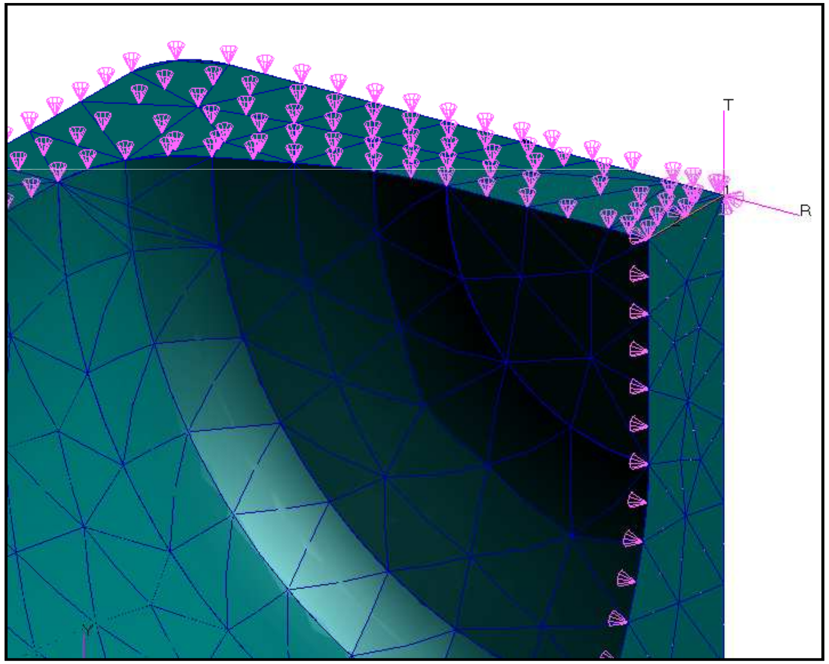
Select the edge along the tank centerline.

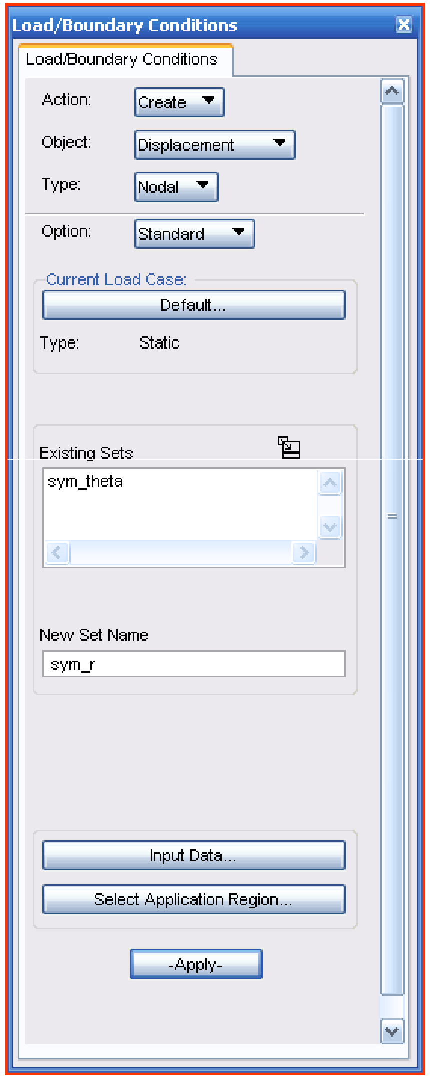




SCUBA TANK

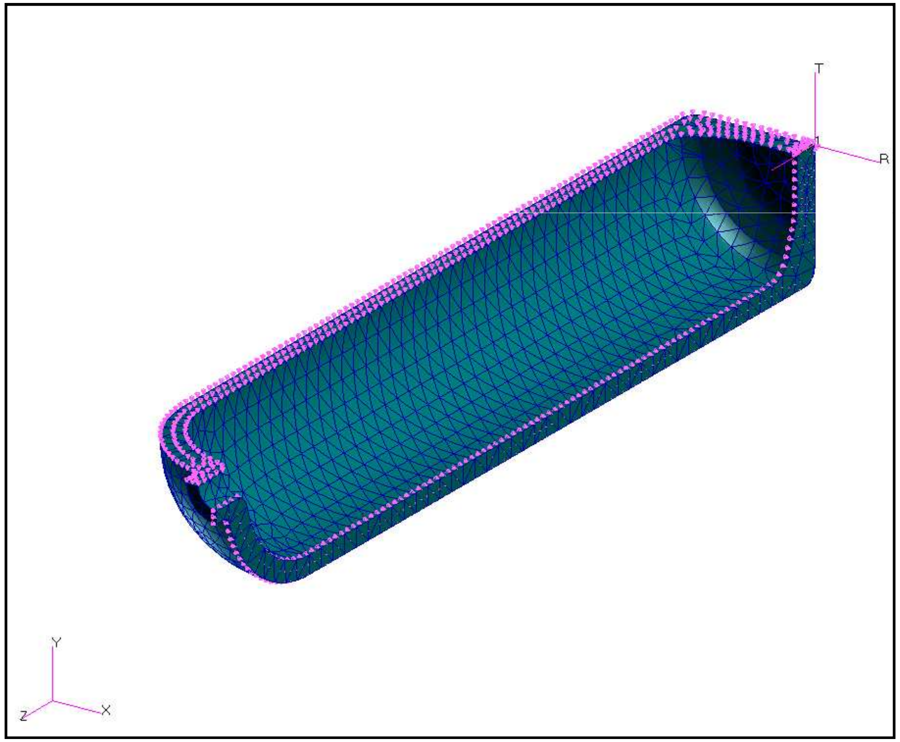
Finish creating the radial constraint.

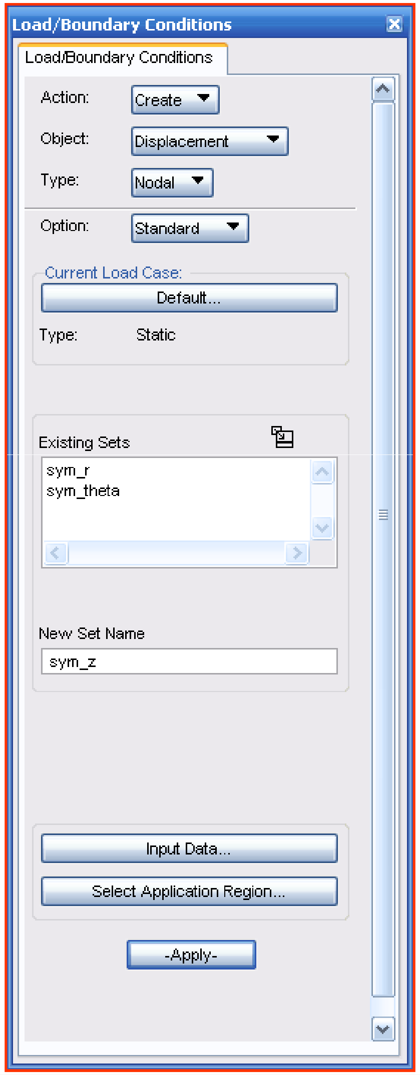




SCUBA TANK

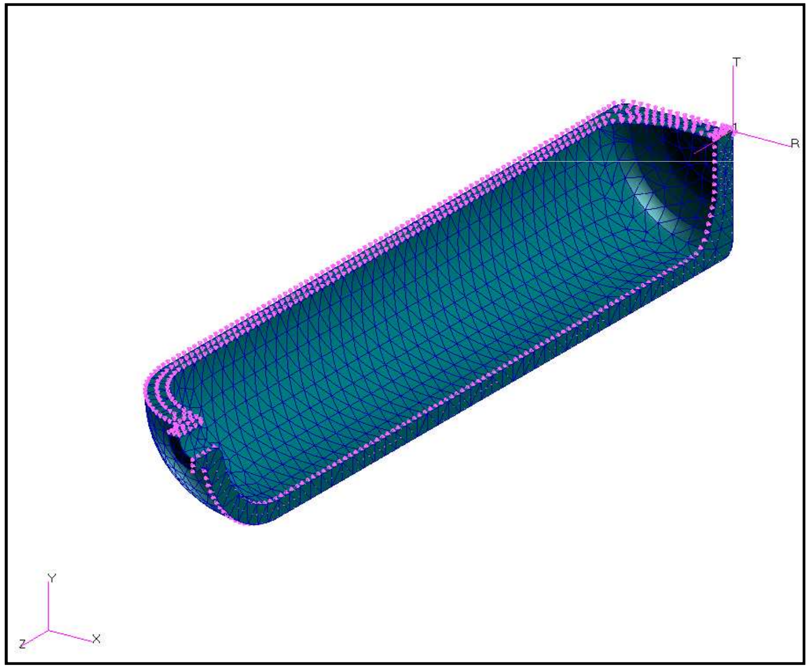
Create a final constraint in the Z direction.

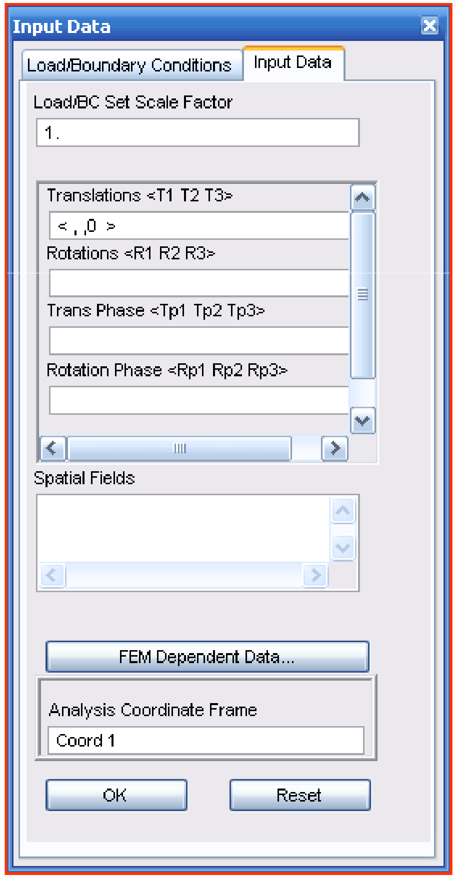




SCUBA TANK

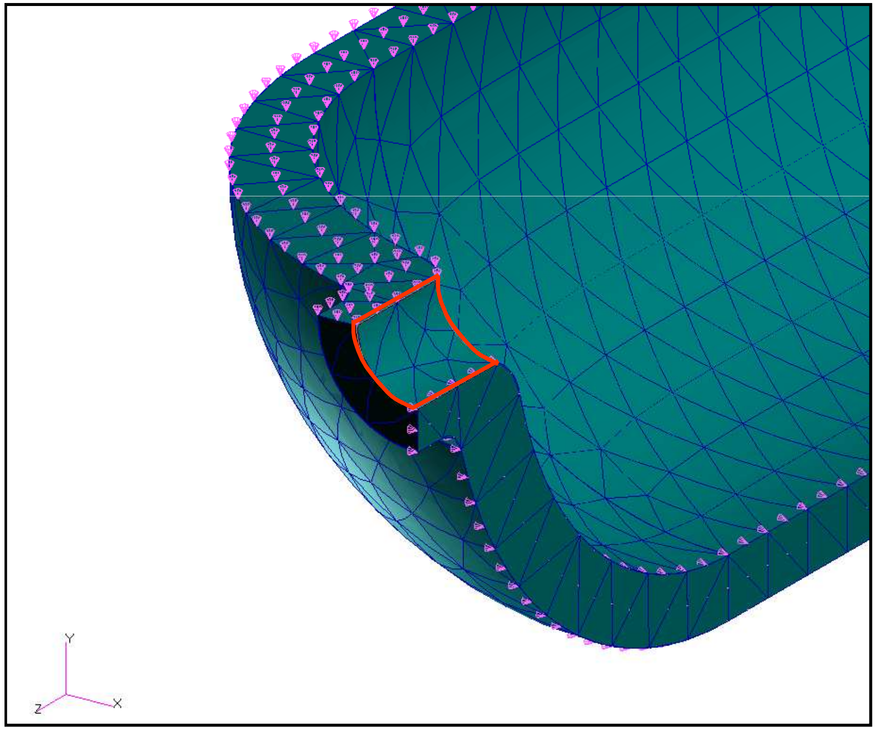
Constrain the z translation

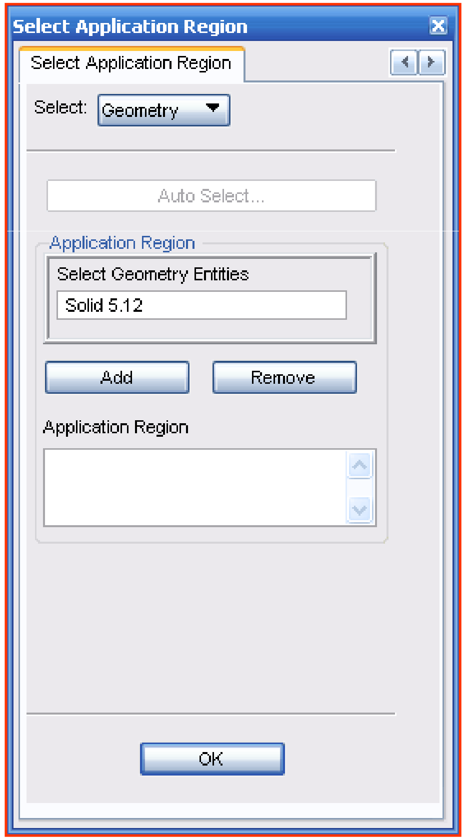




SCUBA TANK

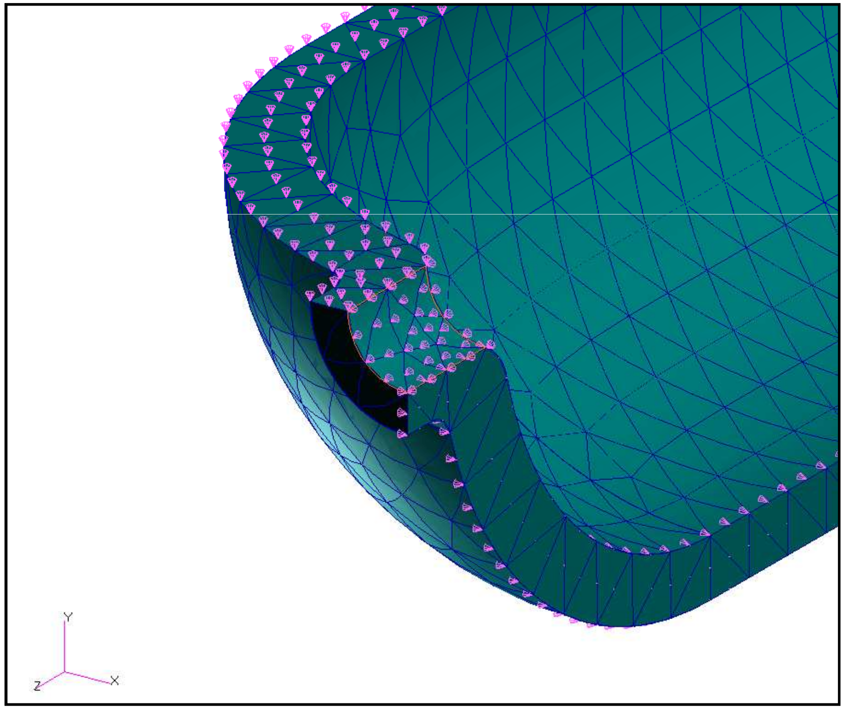
Select the cylindrical surface at the valve interface.

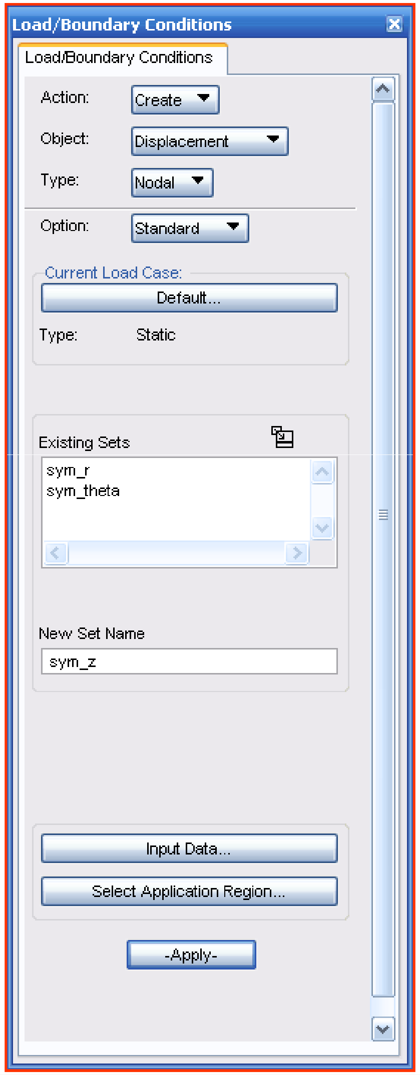




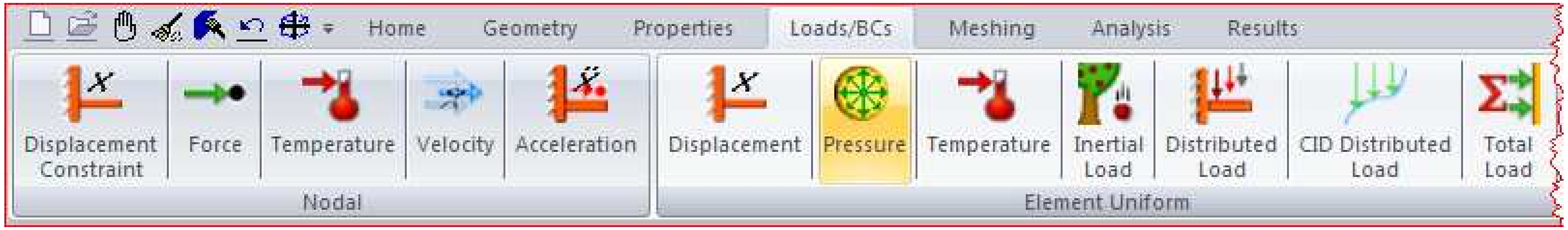
SCUBA TANK

Finish creating the z constraint.

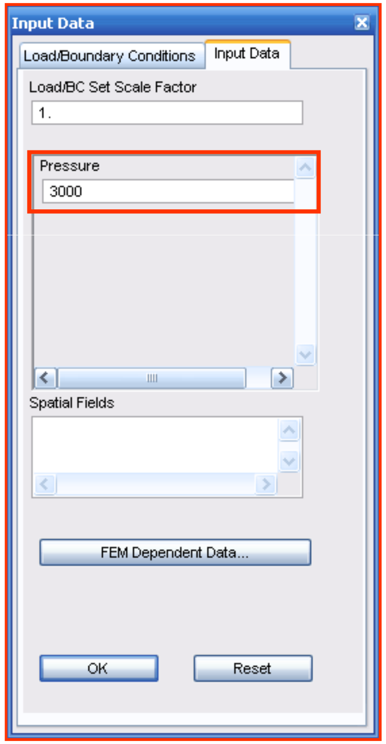


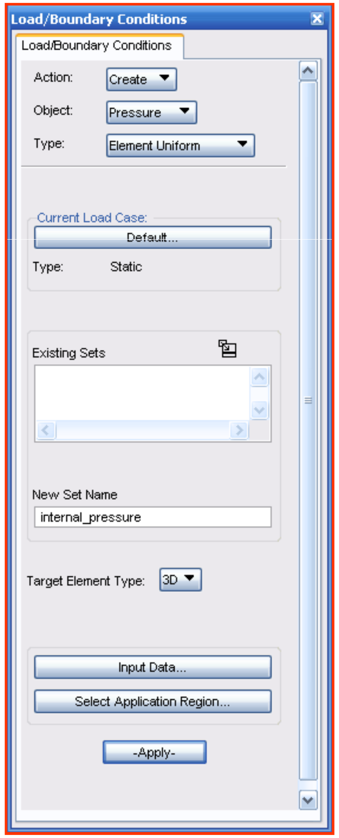


SCUBA TANK

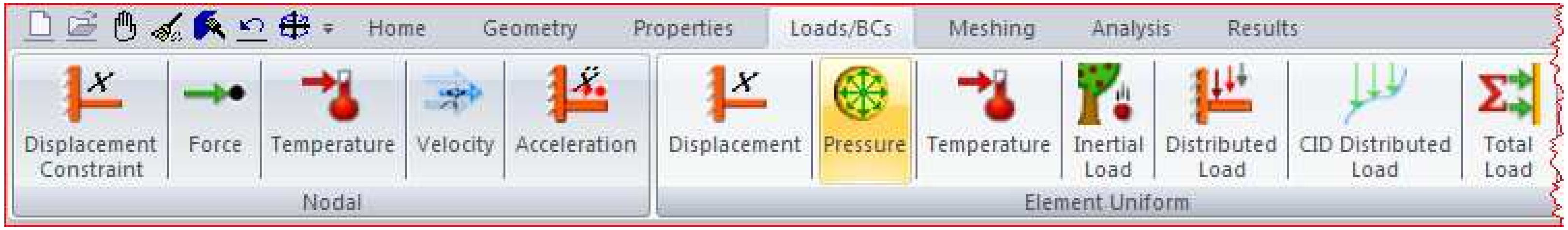


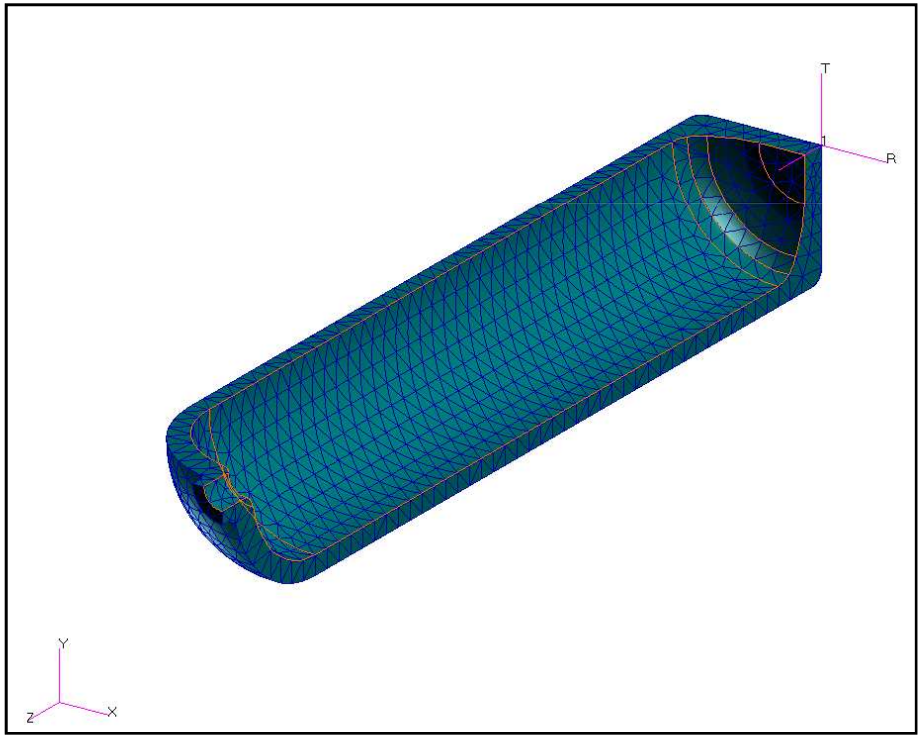
Create a pressure load.

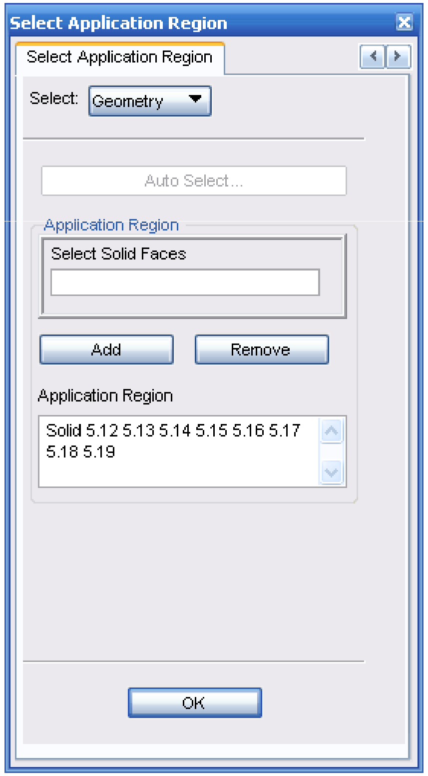




SCUBA TANK

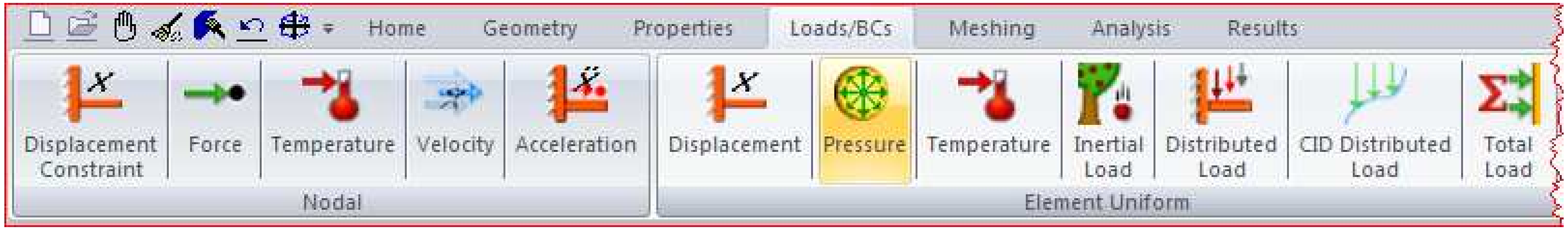




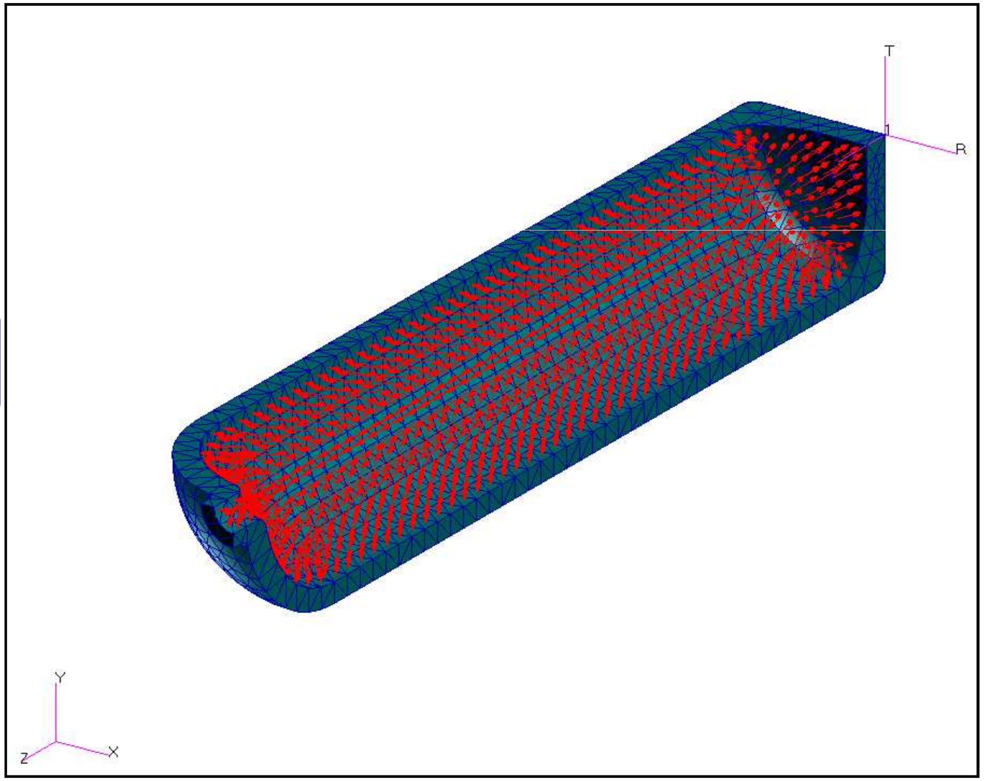


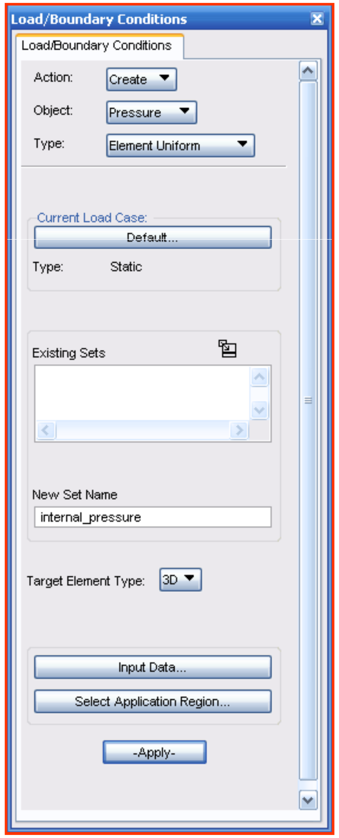
Select all the internal wetted surfaces.

SCUBA TANK



Finish creating the pressure load

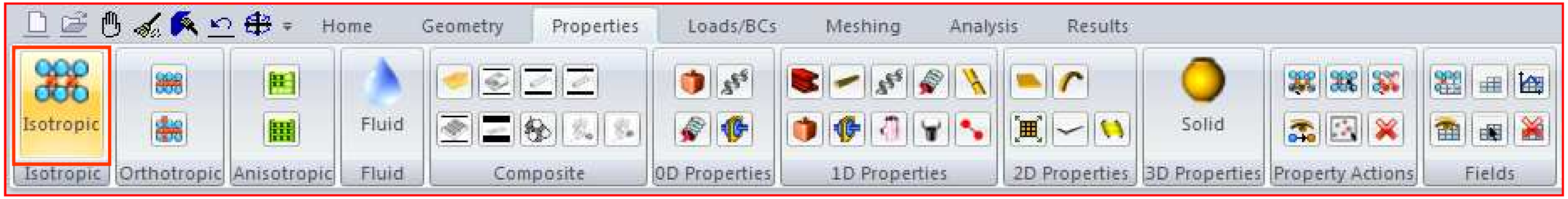




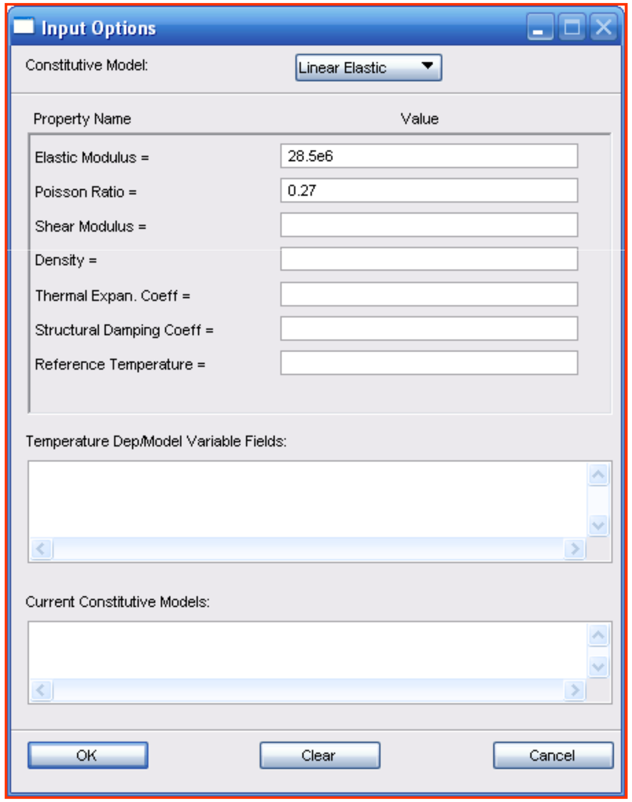
SCUBA TANK

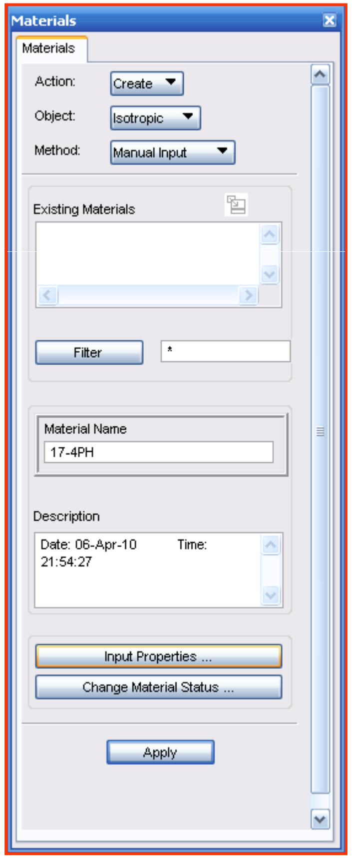
- Create the scuba tank material properties
  - The tank is made from 17-4 PH stainless steel forging, heat treated to the H1025 condition.
    - $E = 28.5 \times 10^6$ psi
    - $\nu = 0.27$
    - Ultimate strength = 155 ksi
    - Yield strength = 145 ksi

SCUBA TANK

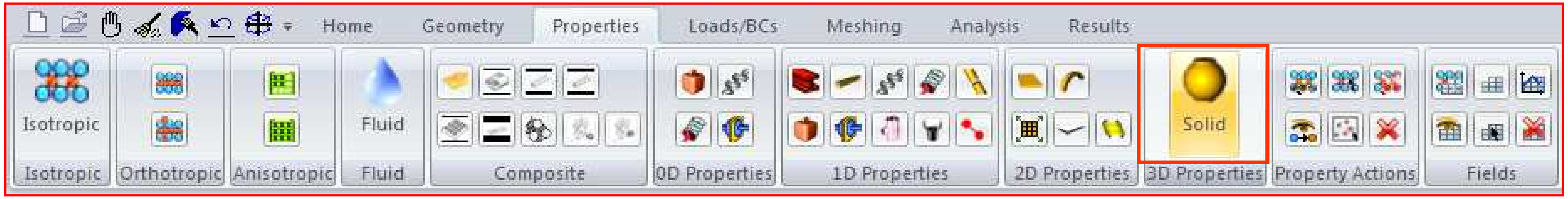


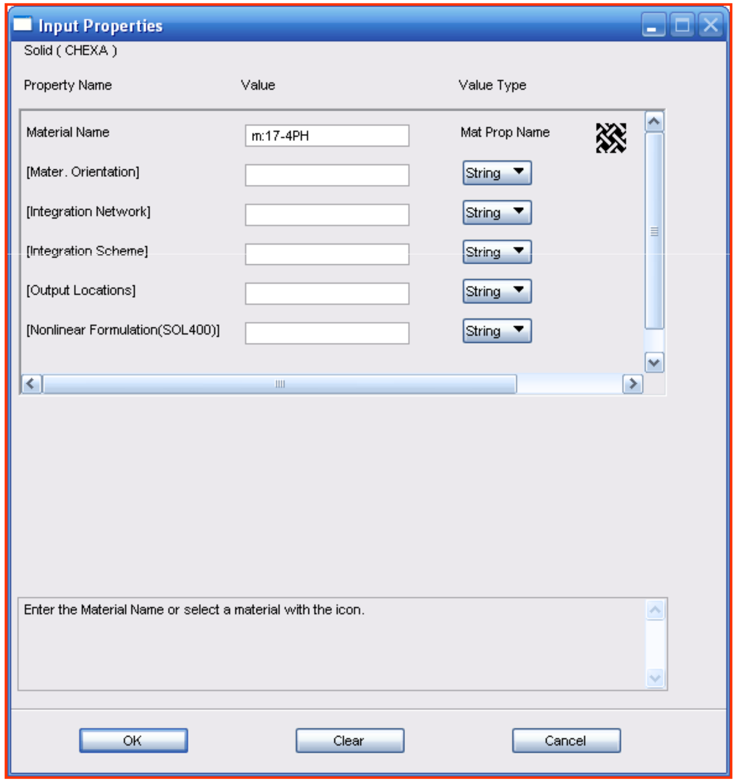
Create an isotropic material named 17-4PH.

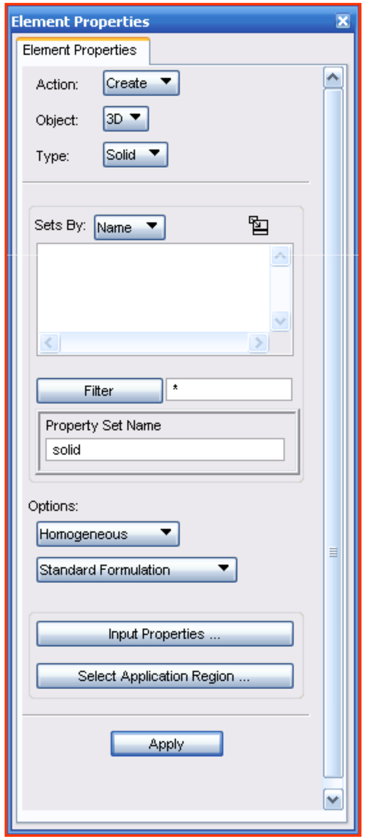




SCUBA TANK

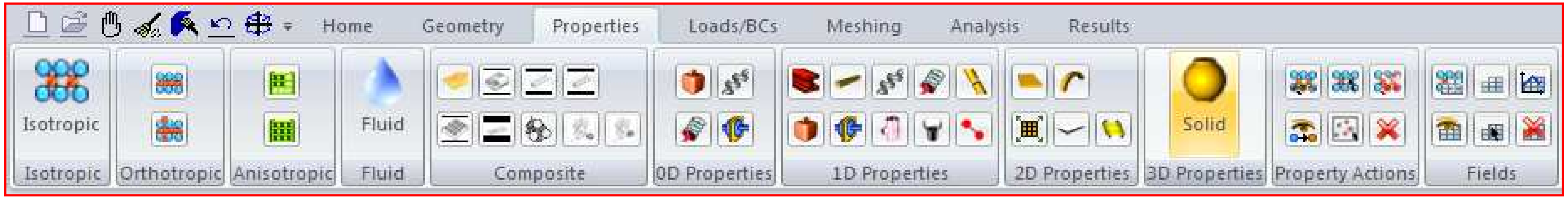




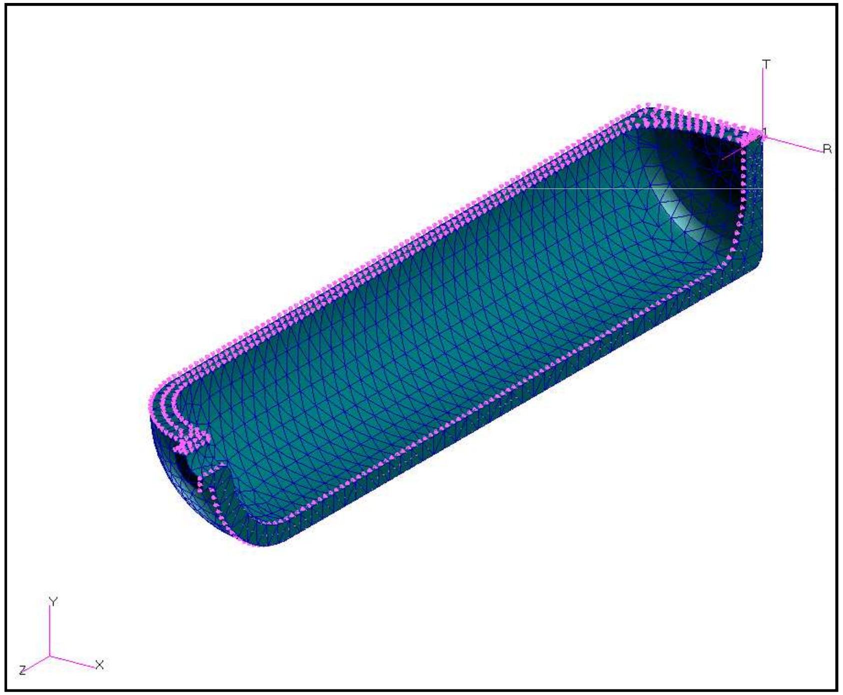


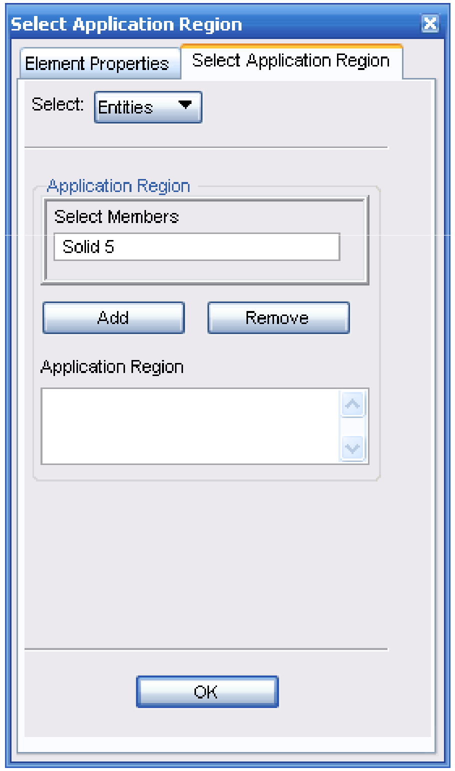
Create a 3D solid physical property set for the tank.

SCUBA TANK

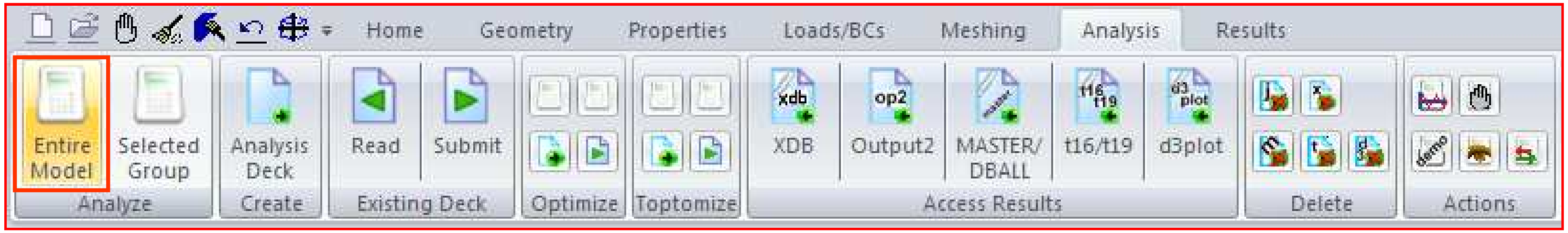


Select the solid and apply.

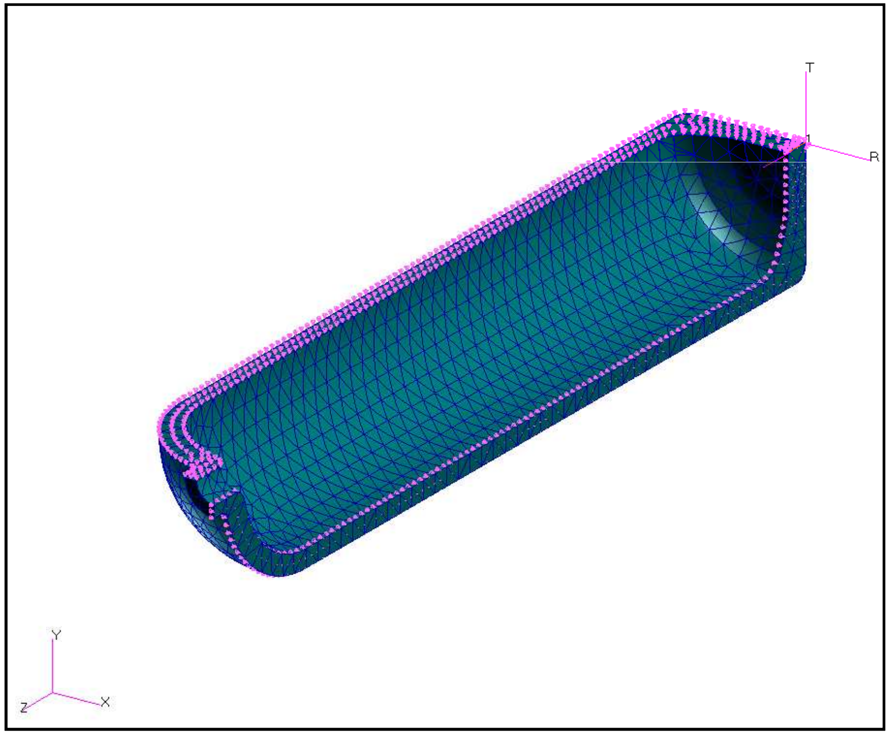


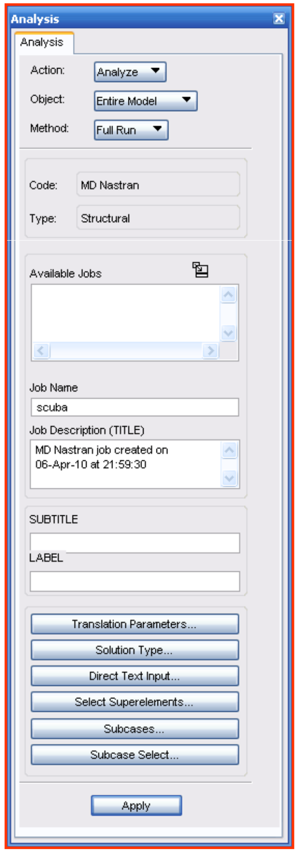


SCUBA TANK

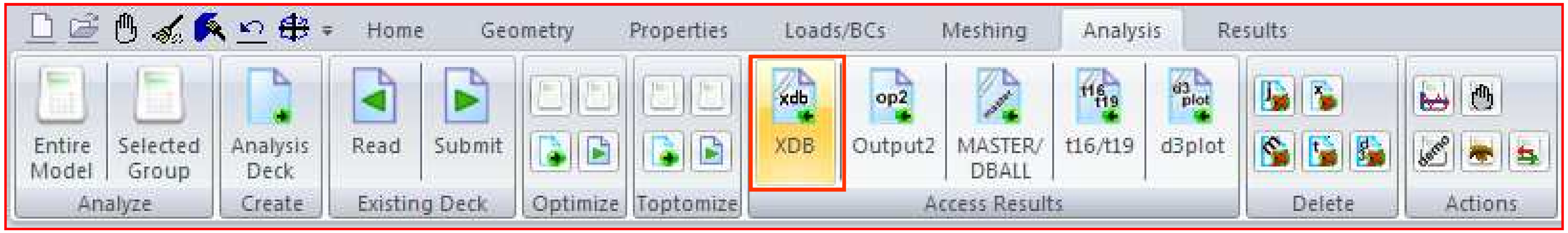


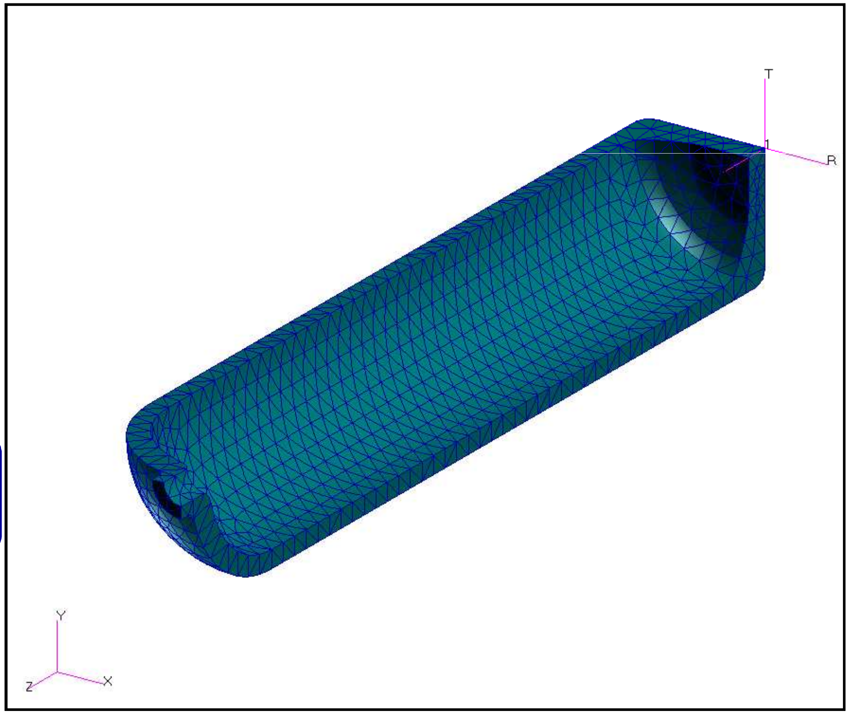
Submit the model to MD NASTRAN for a static analysis.

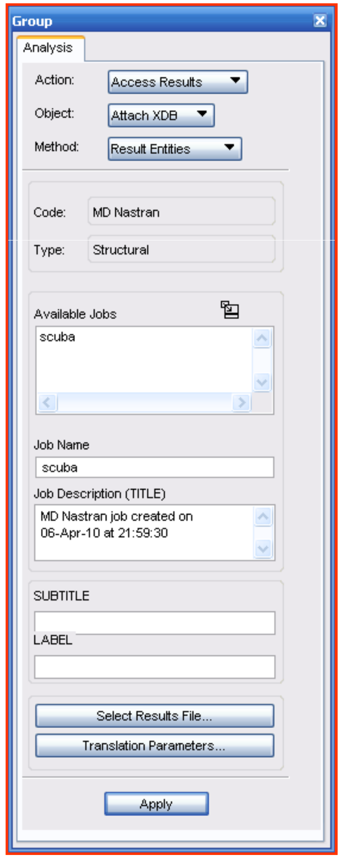




SCUBA TANK

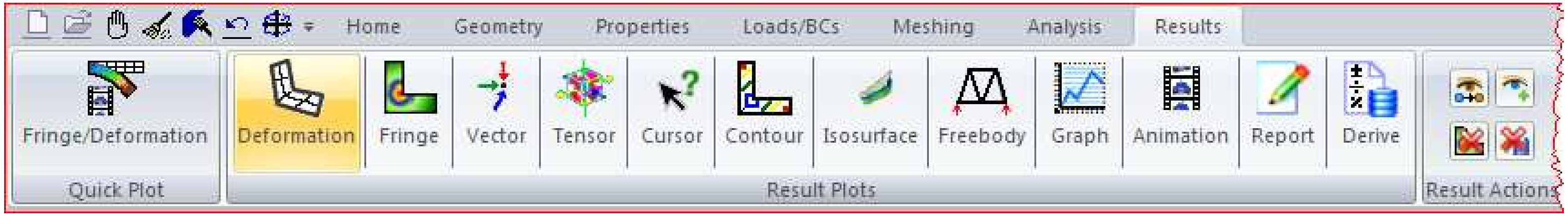






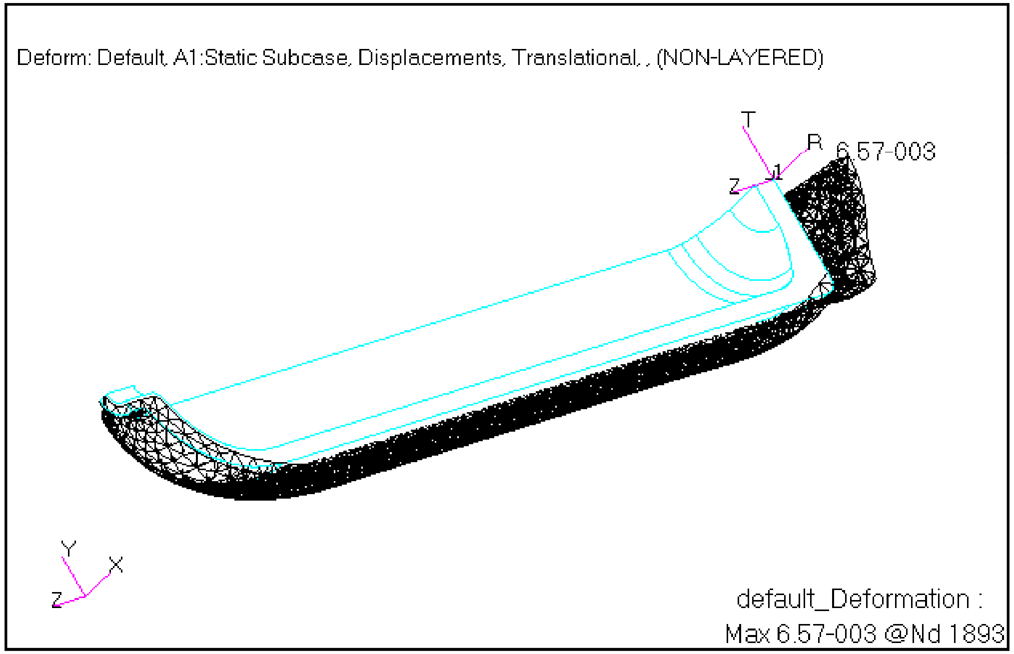
Attach the analysis results into Patran

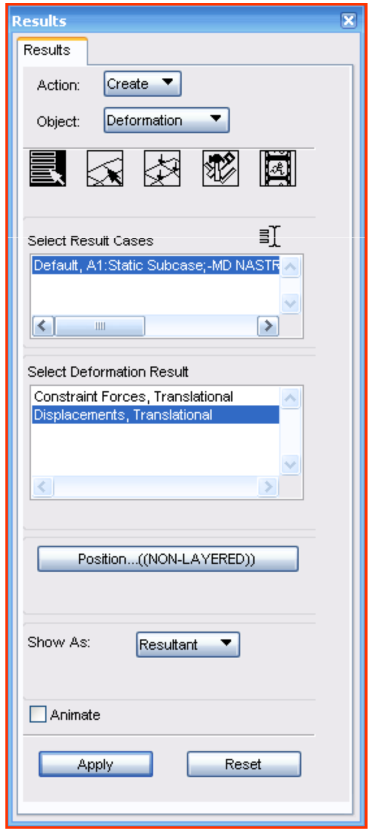
SCUBA TANK



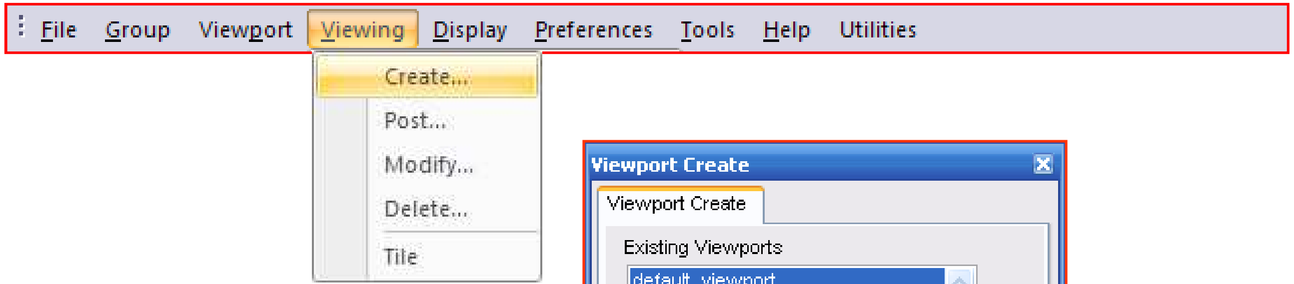
Create the deformation plot.

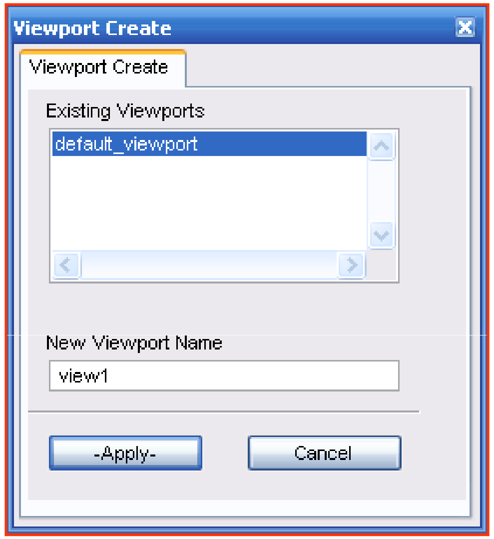
The maximum deformation is 0.0065 in, which is reasonable.



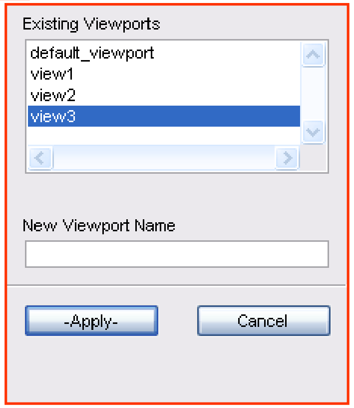


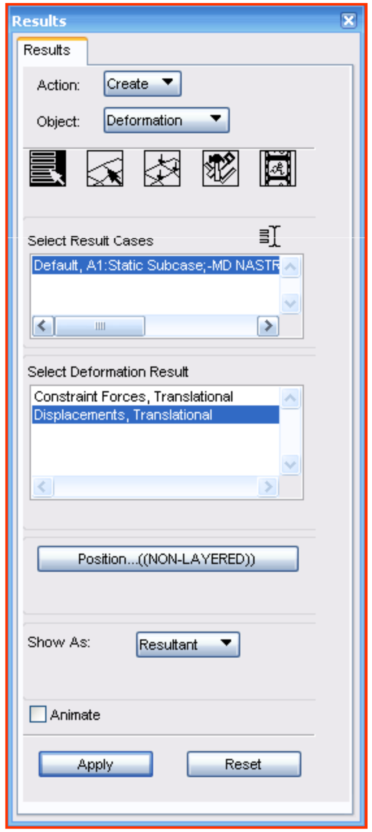
SCUBA TANK



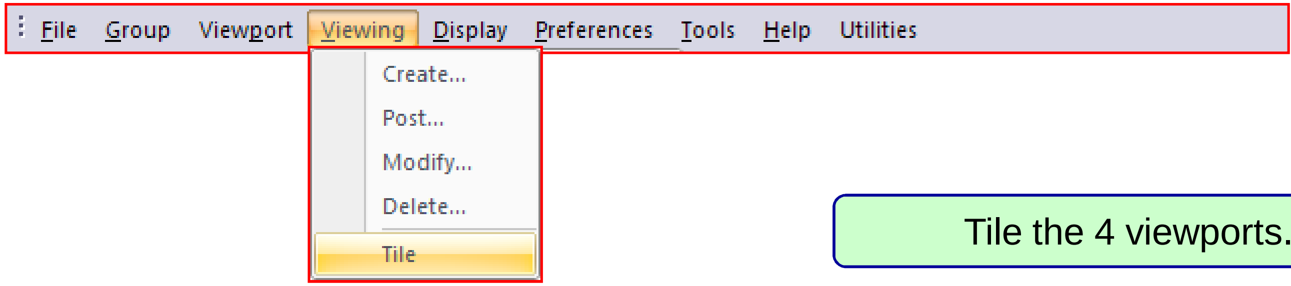


Create 3 additional viewports to display the results.

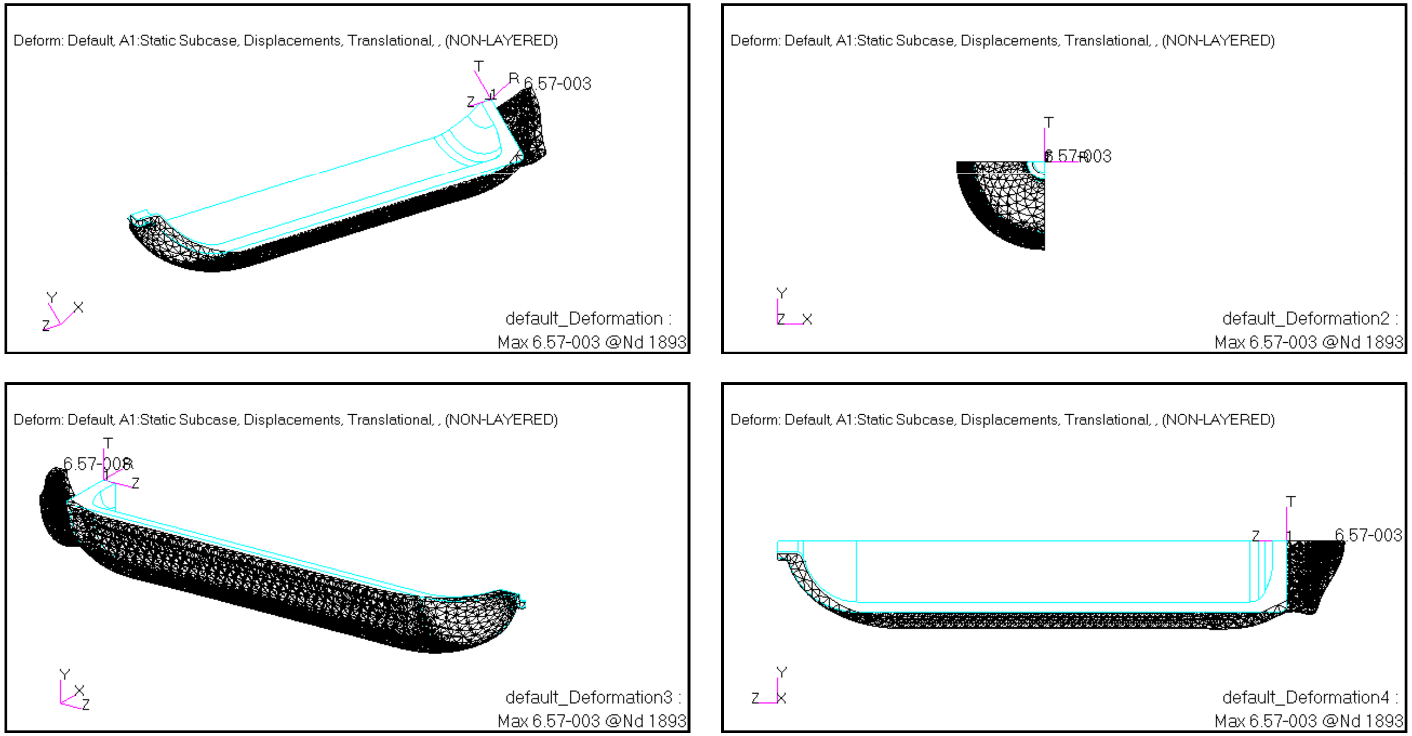




SCUBA TANK



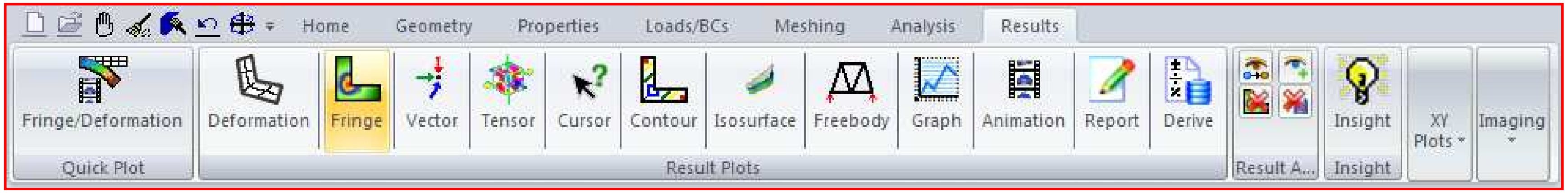
Tile the 4 viewports.



SCUBA TANK

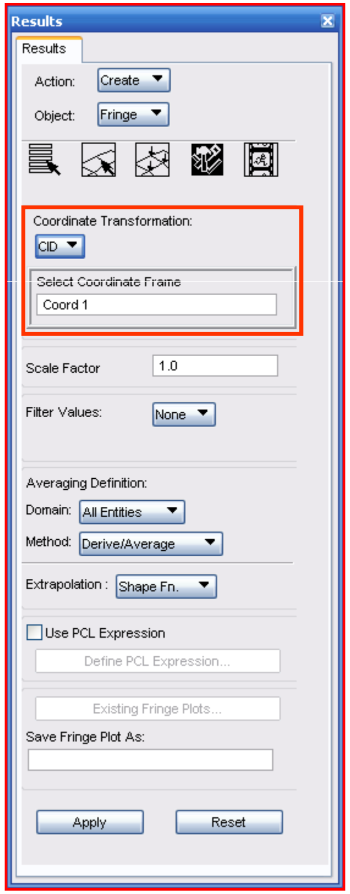
- Next, let's plot the stresses
  - By default, the solid element stresses are computed in the basic coordinate system.
  - For the scuba tank, we are interested in the radial, hoop, and axial stresses which are defined in a cylindrical system. We need to transform the stresses from the basic coordinate system to the cylindrical coordinate system no. 1.

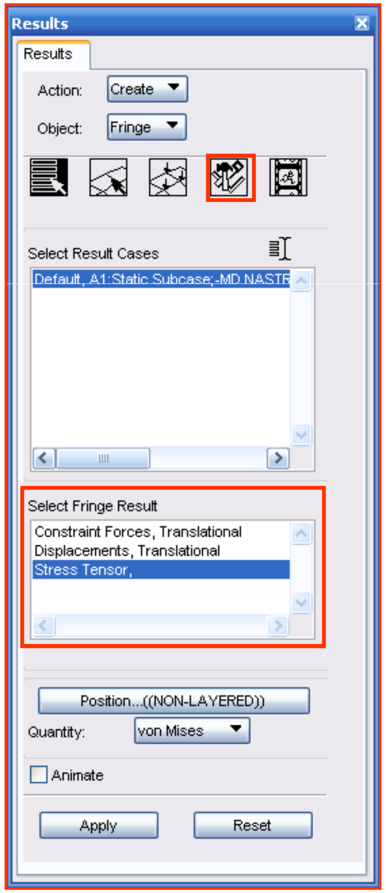
SCUBA TANK



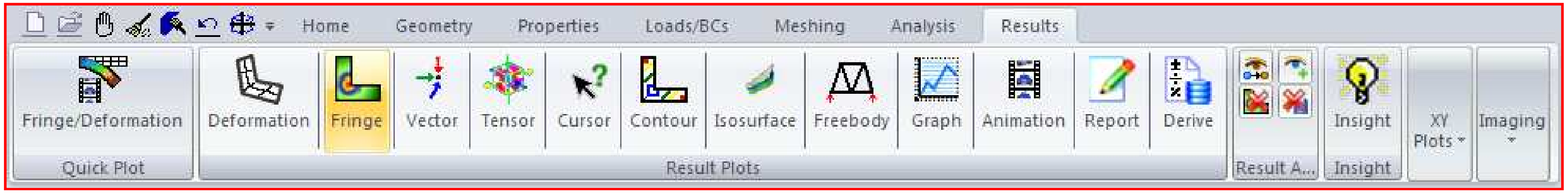
Click the Plot Options icon.

Select CID and coordinate system no. 1. This transforms the stresses into coordinate system 1.

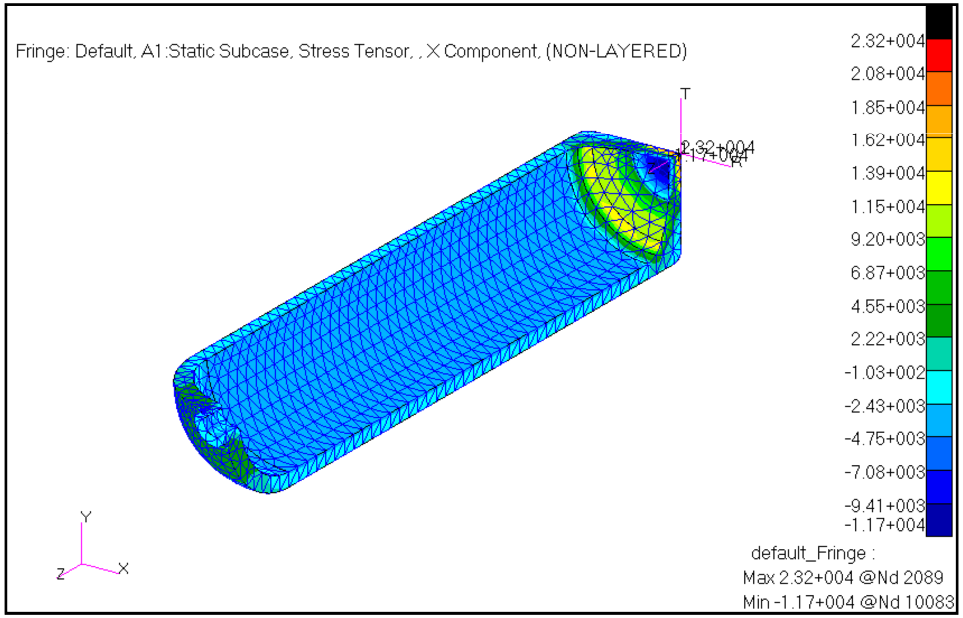


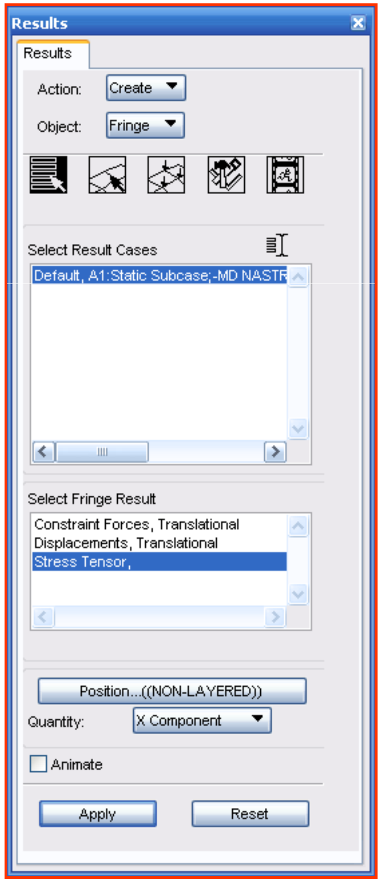


SCUBA TANK

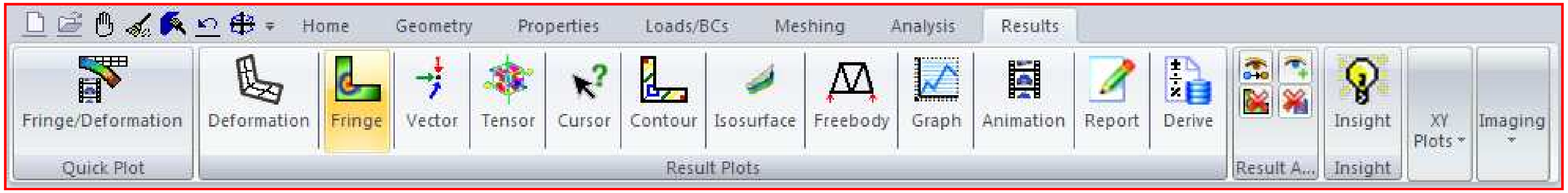


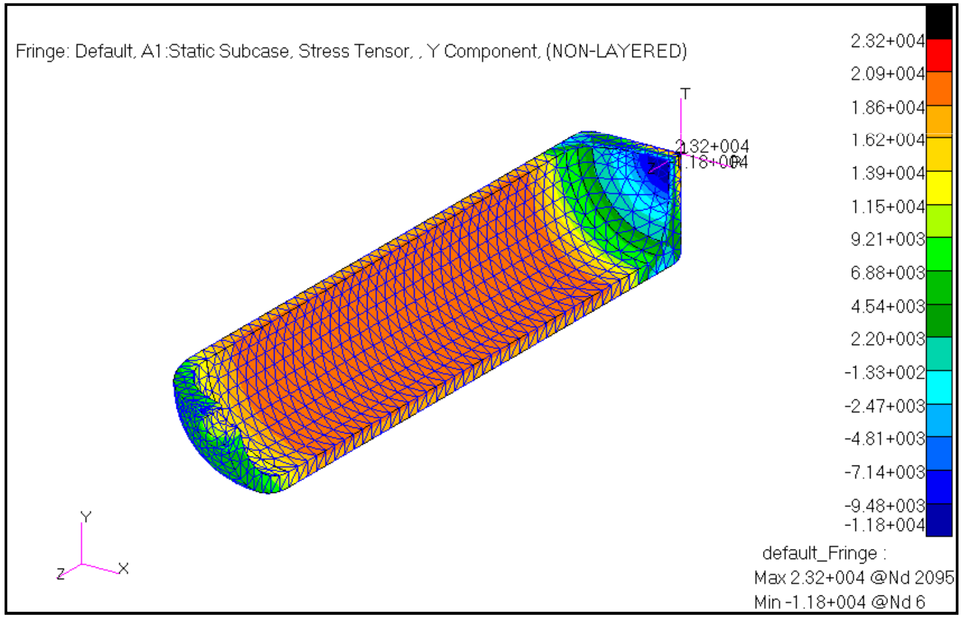
Plot the radial (x component) stress.

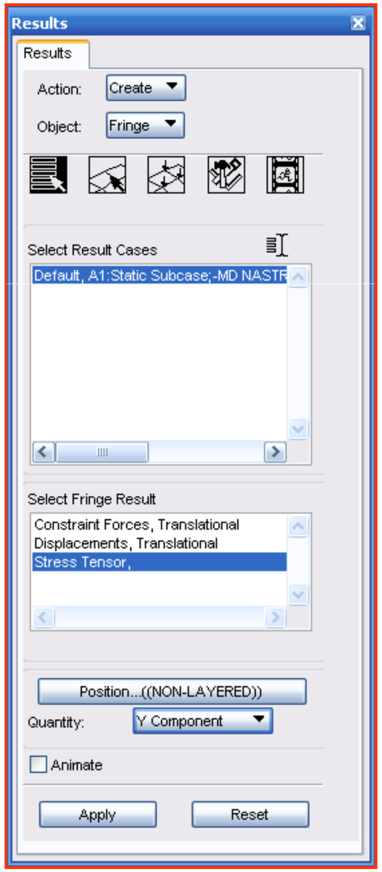




SCUBA TANK

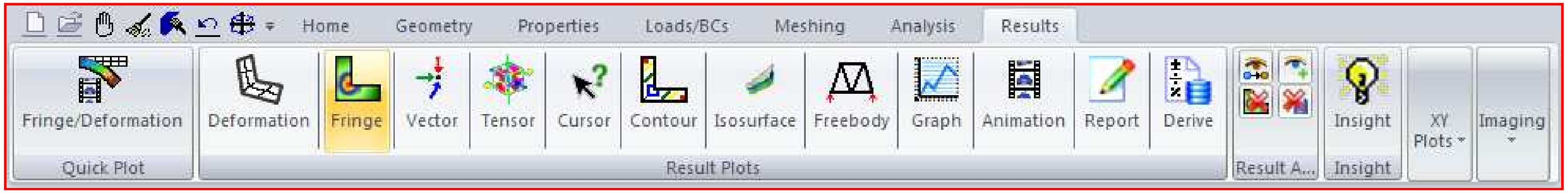


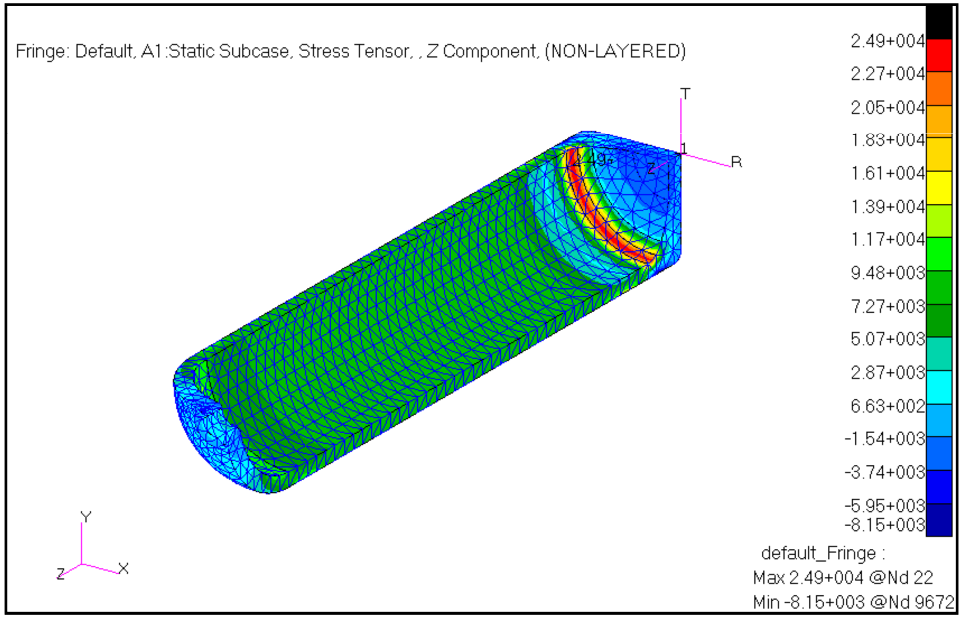


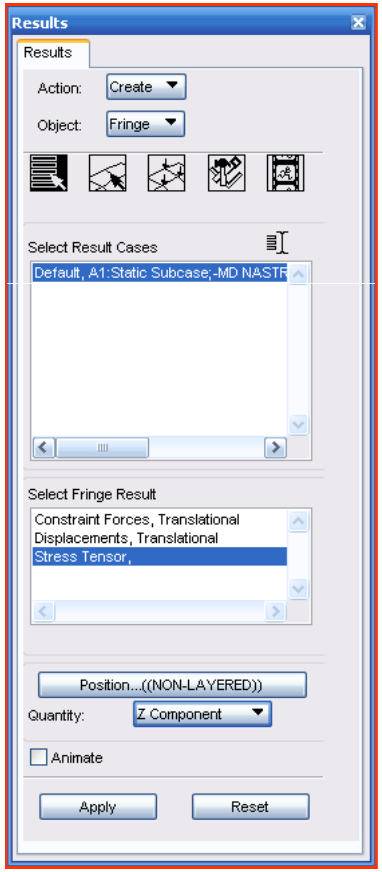


Plot the hoop (y component) stress.

SCUBA TANK

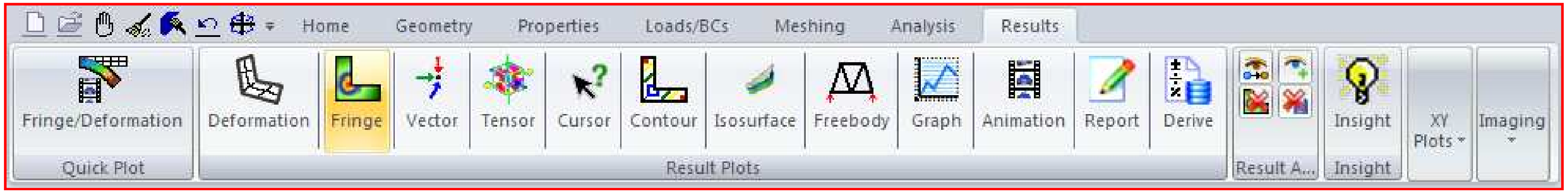




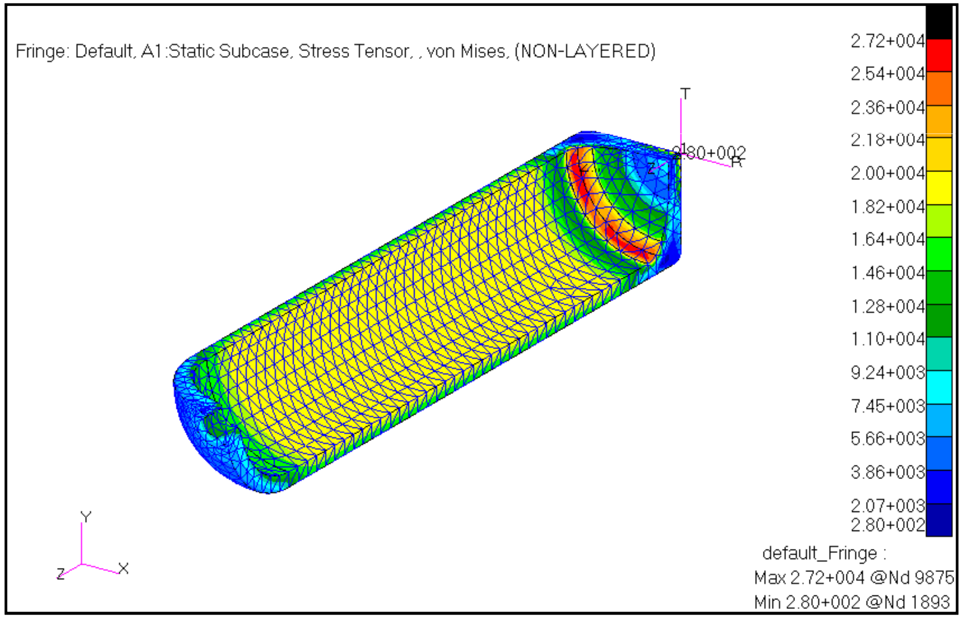


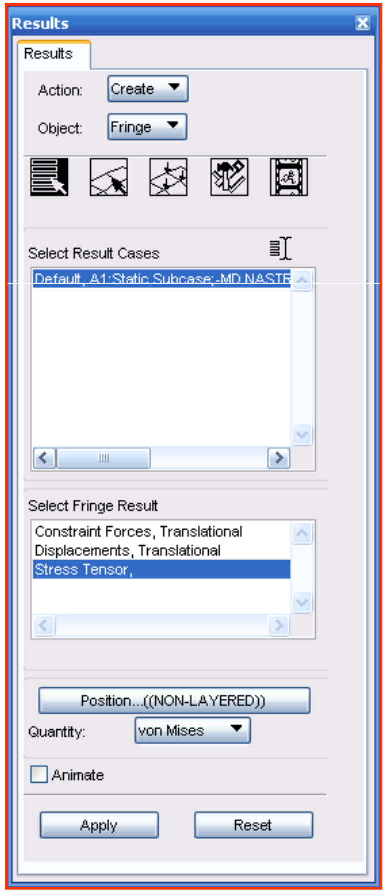
Plot the axial (z component) stress

SCUBA TANK

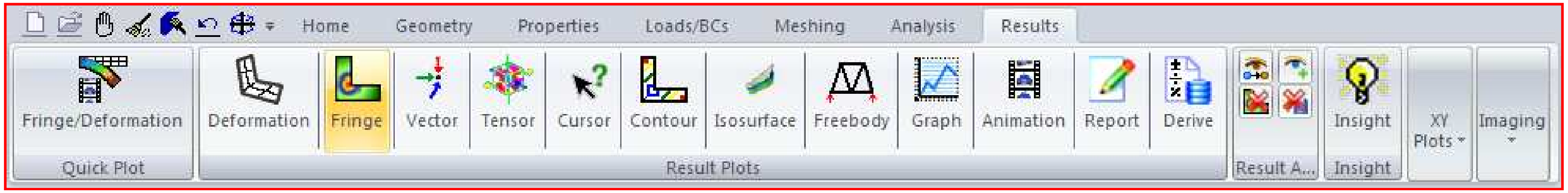


Plot the Von Mises stress



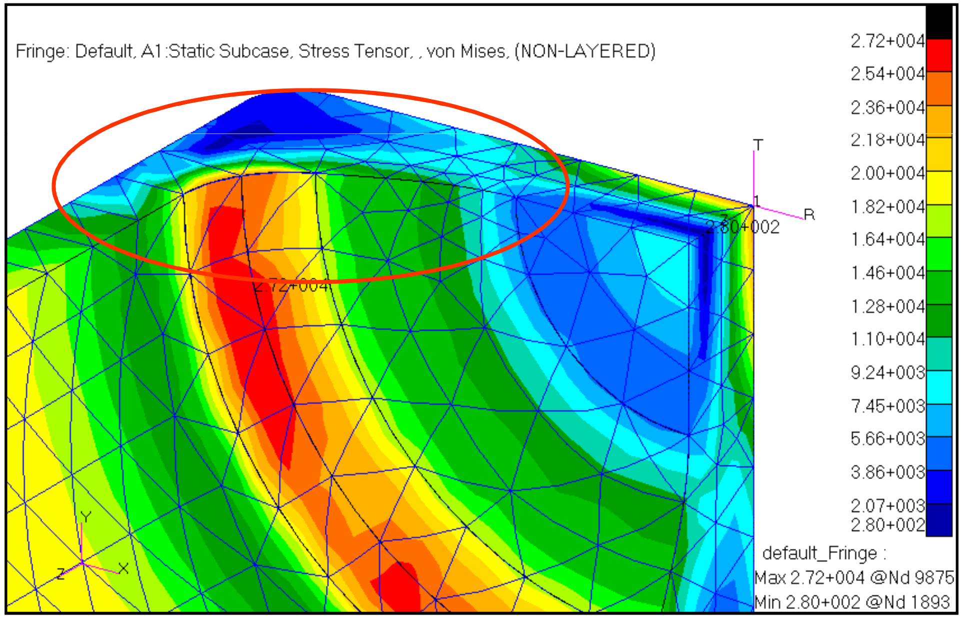


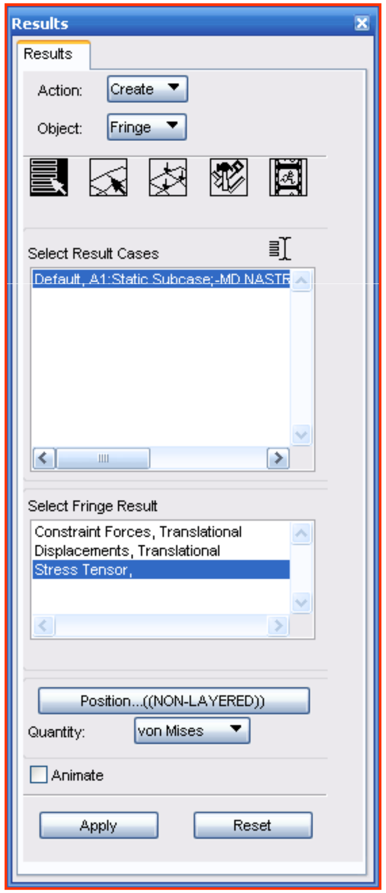
SCUBA TANK



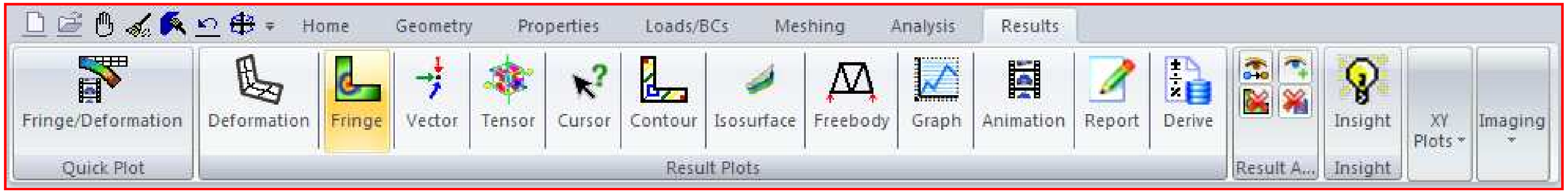
Zoom in to the critical area near the base of the tank.

Notice that the stress gradient is high through the thickness of the tank.



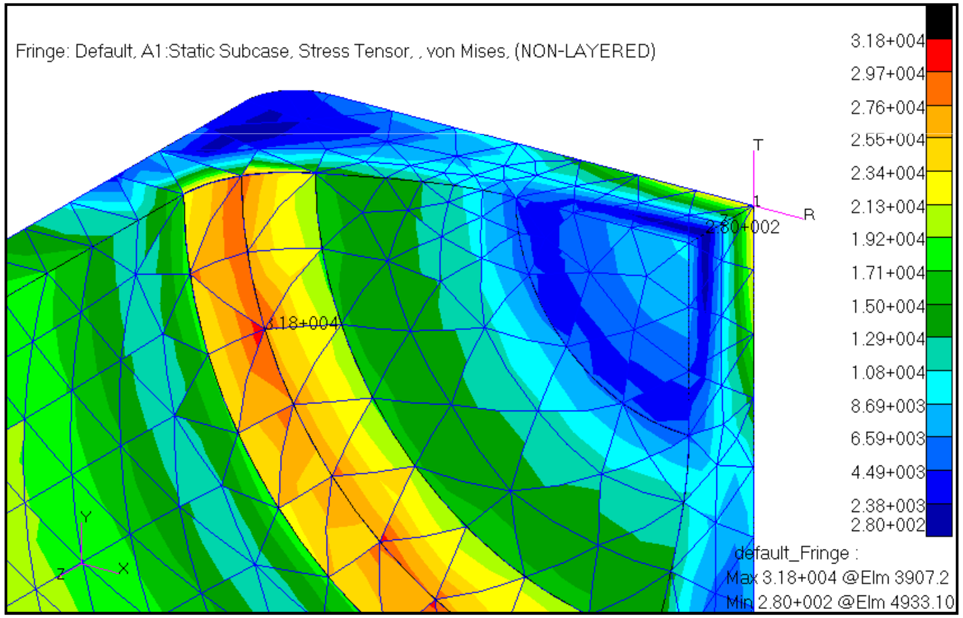


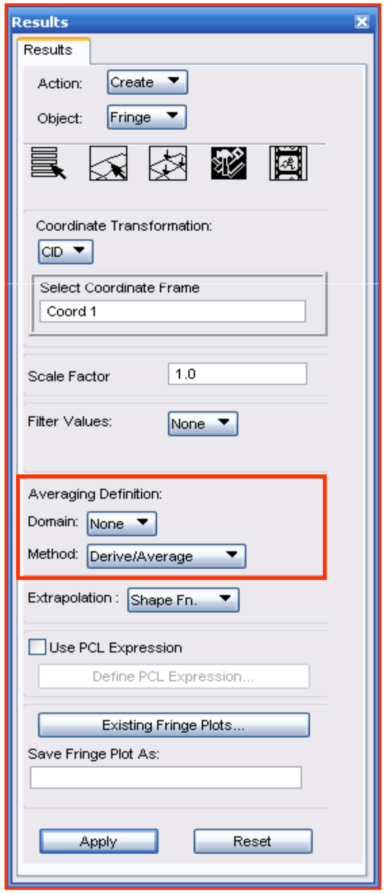
SCUBA TANK



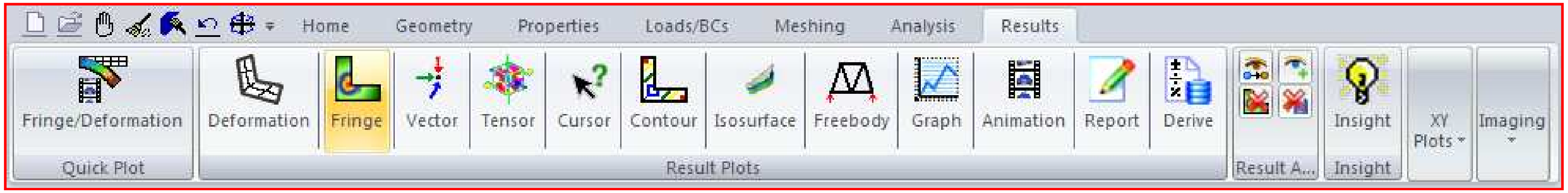
Turn off stress averaging.

Notice that the stress fringes are “jagged”.



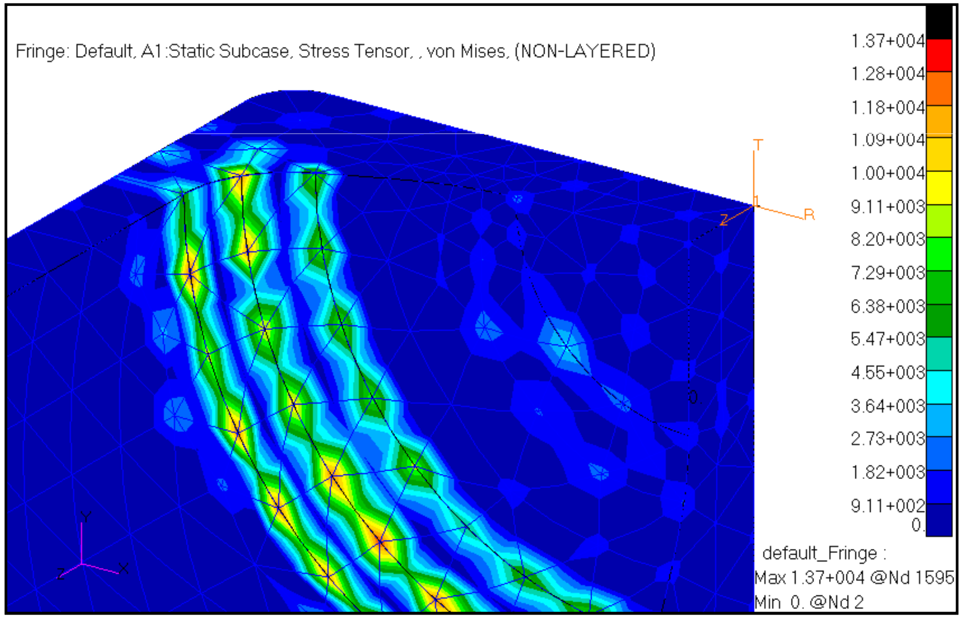


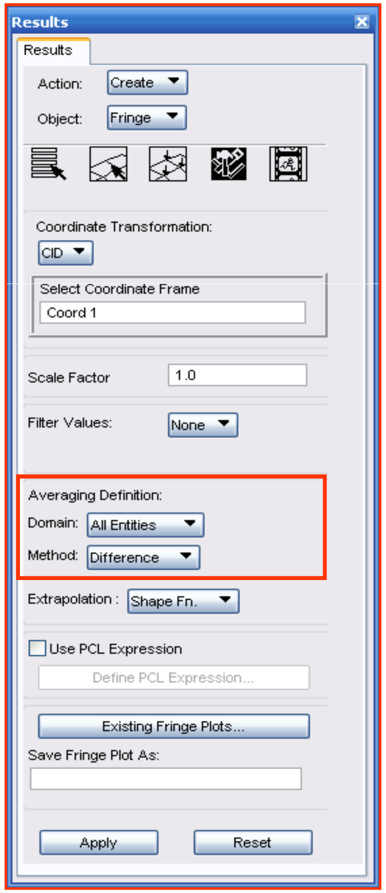
SCUBA TANK



Plot the stress jumps at each node.

The difference between the maximum stress and the minimum stress at each node is plotted.

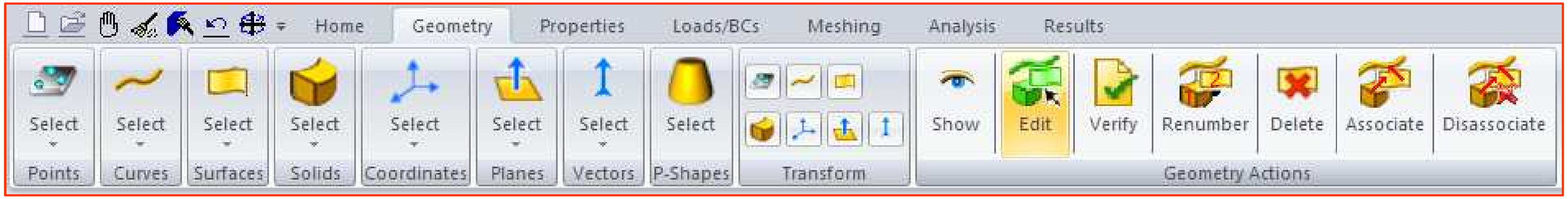




SCUBA TANK

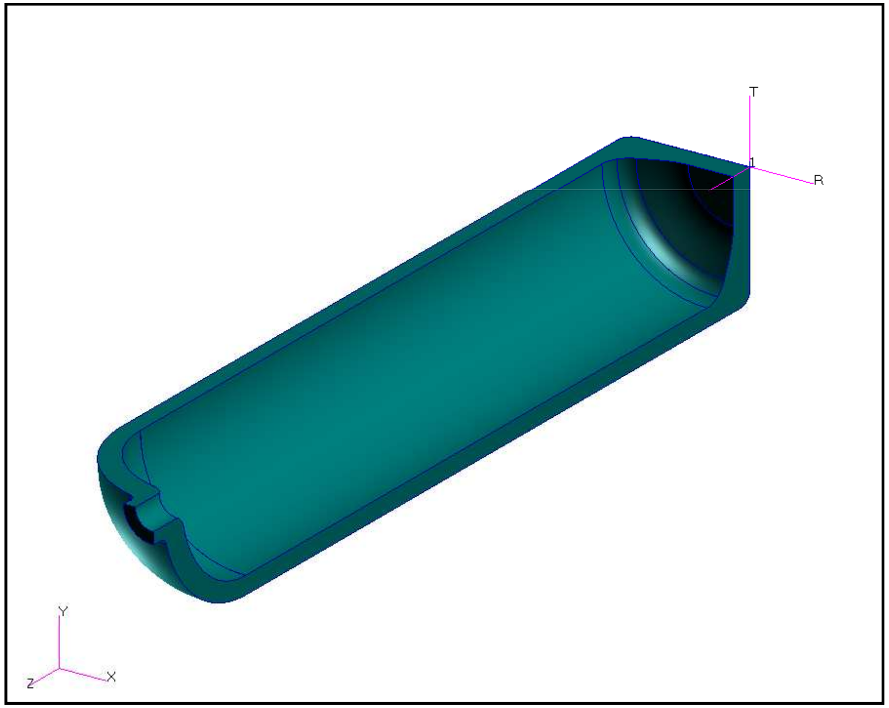
- Scuba tank coarse-mesh model analysis summary:
  - The maximum Von Mises stress is 31,800 psi at the base of the tank near the fillet radius.
  - The stress gradient through the tank wall thickness is high. It ranges from 31,800 psi on the inside wall to about 5,000 psi on the outside wall. This stress gradient is captured by a single tet10 element through the thickness.
  - The un-averaged stress fringe plot is jagged, an indication that the mesh is too coarse.
  - The stress difference plot shows a maximum stress jump of 13,700 psi. This suggests that the mesh is too coarse in this area.
- This first scuba tank model was relatively coarse. It helped us identify the critical area in the tank. We will now create a second model with a finer mesh in the critical area.

SCUBA TANK

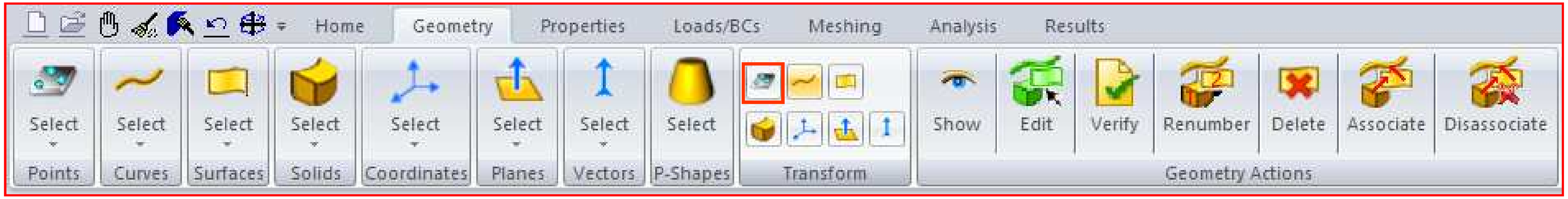


Create a new database and import the tank geometry.

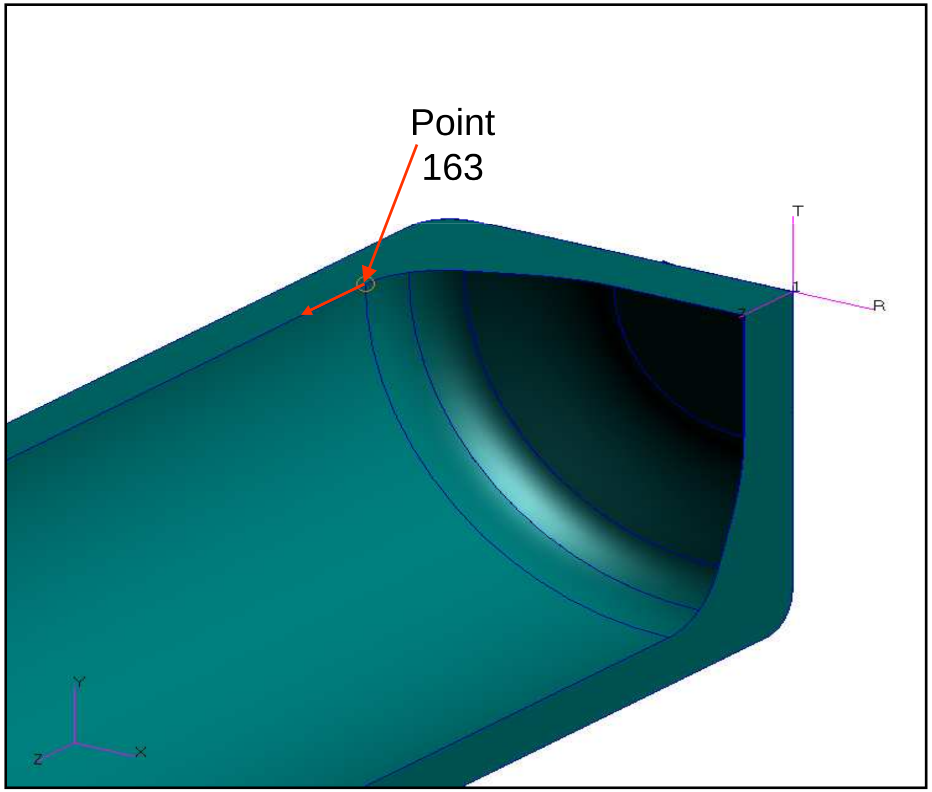
Break the solid into 90-degree sectors as before and create a cylindrical coordinate system.

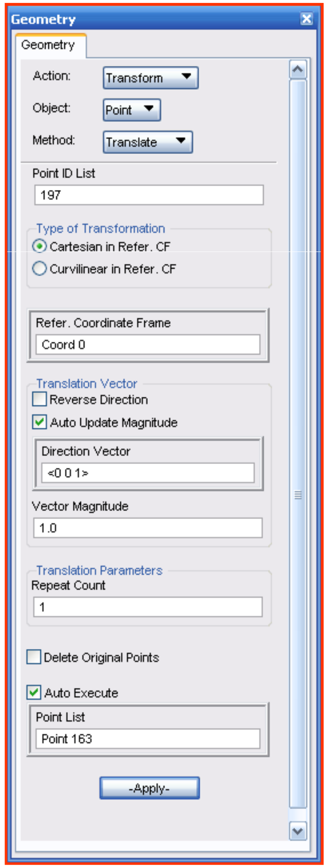


SCUBA TANK

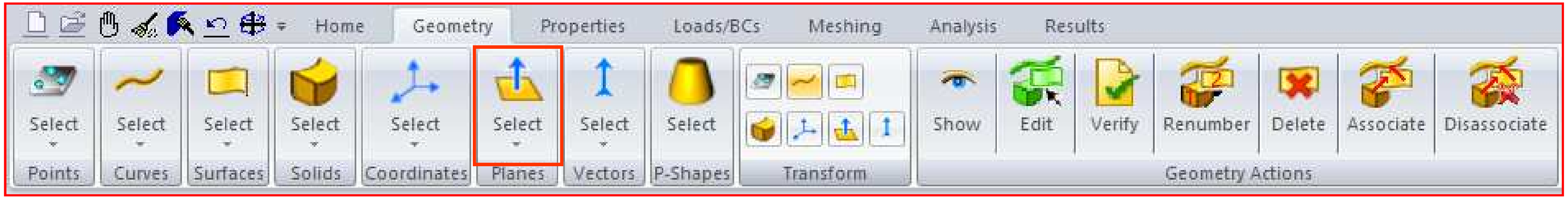


Create a point 1” away from the fillet radius.

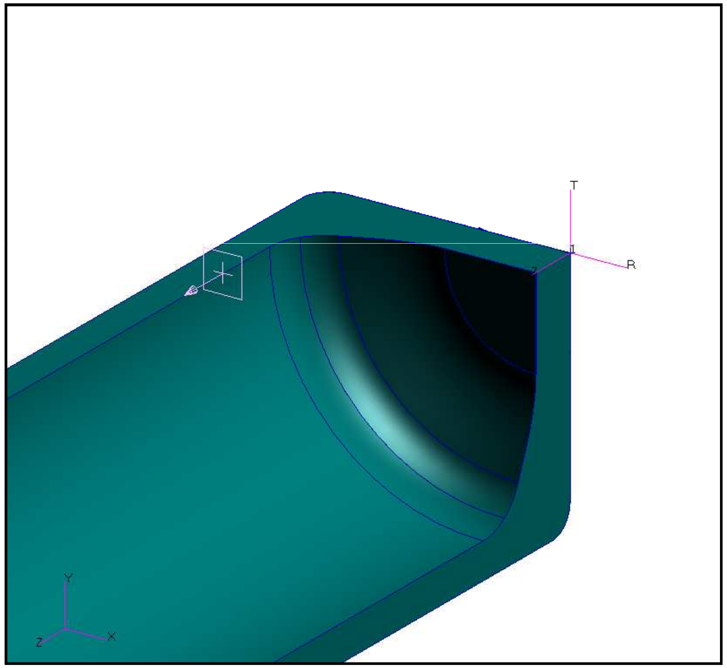


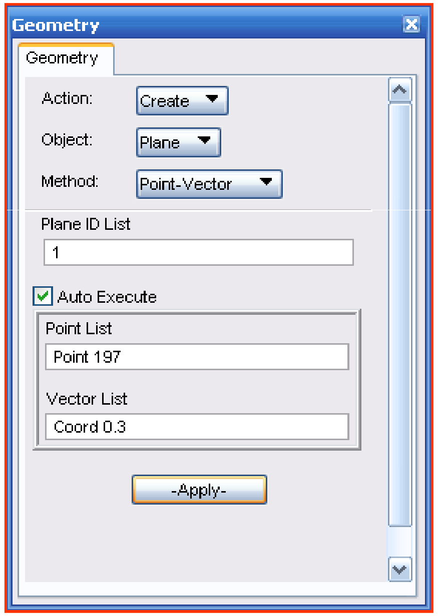


SCUBA TANK

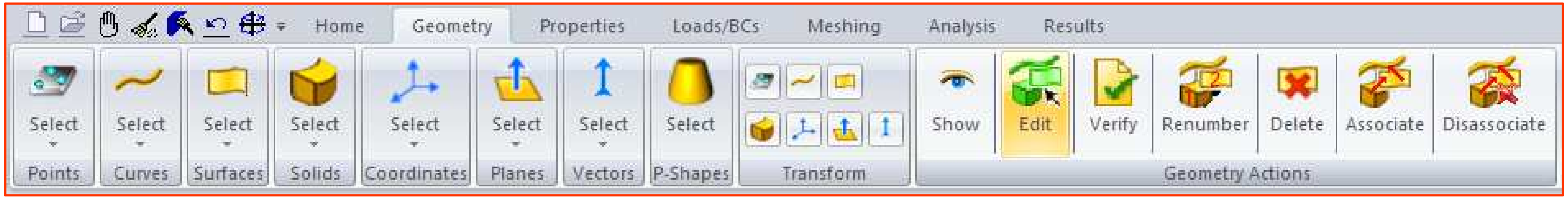


Create a plane at this new point.

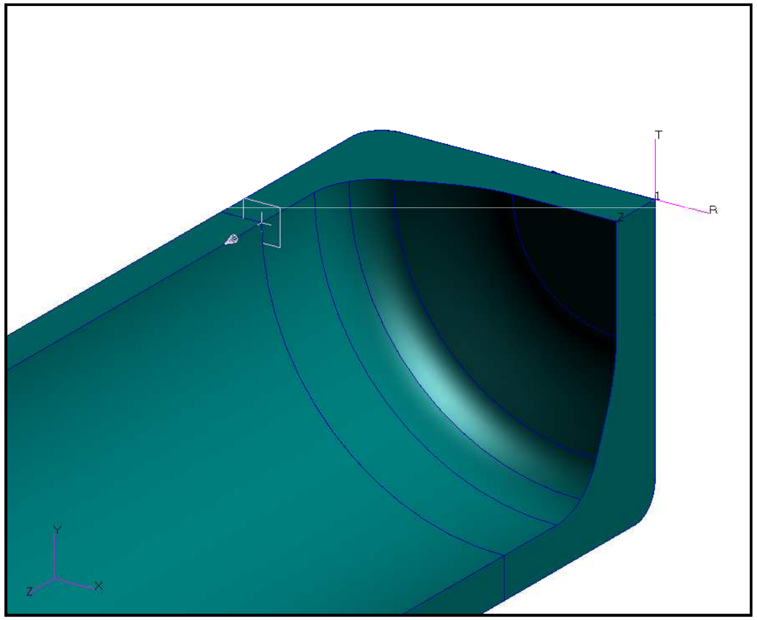


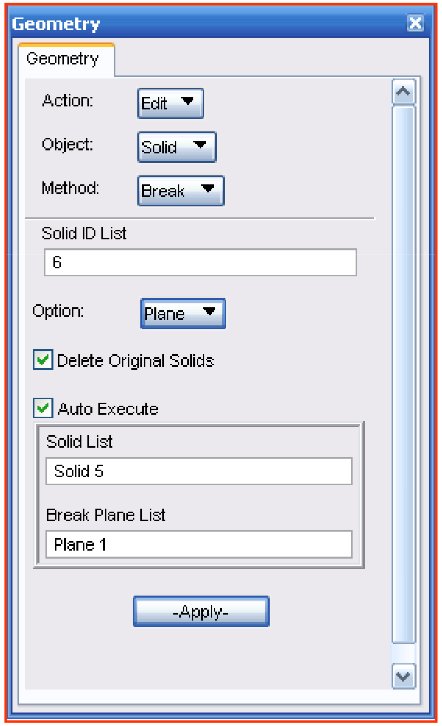


SCUBA TANK

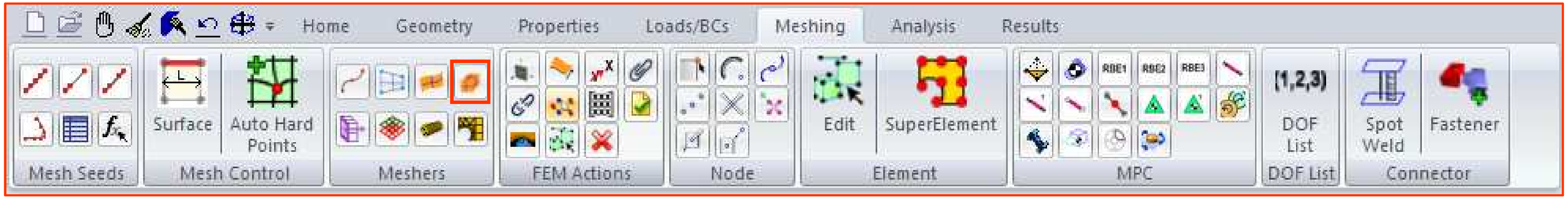


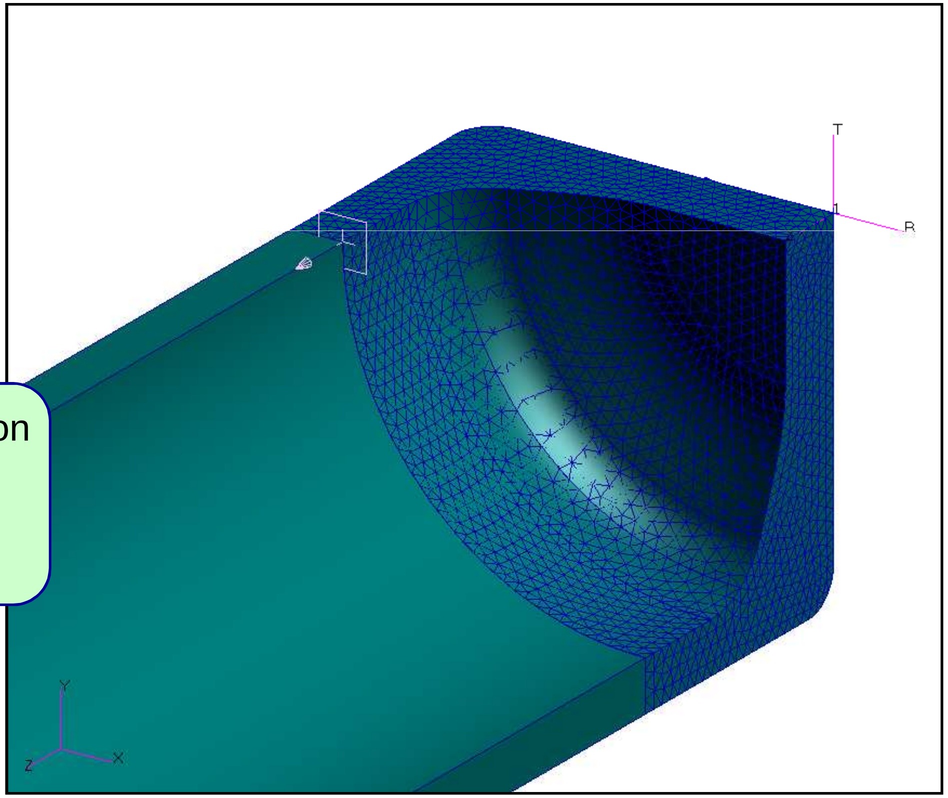
Use the plane to break the solid.

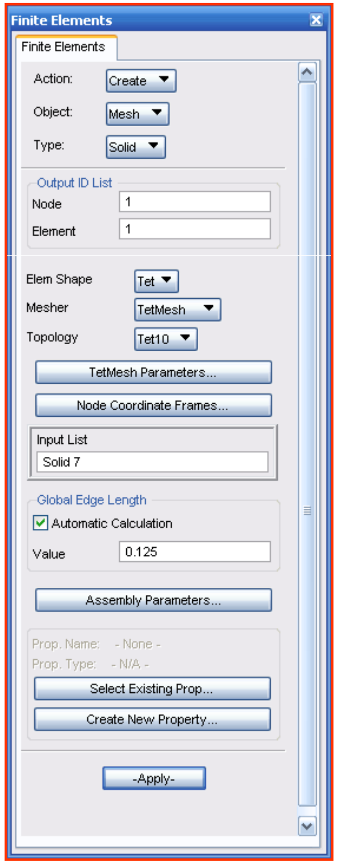




SCUBA TANK

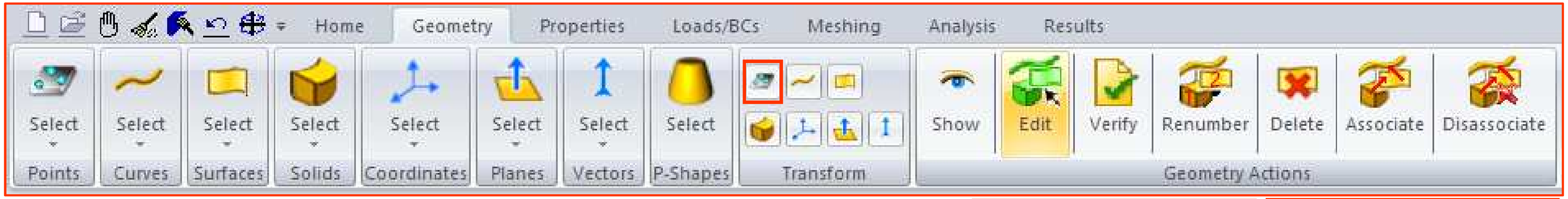






Mesh the bottom portion of the tank with an element size of 0.125 inch.

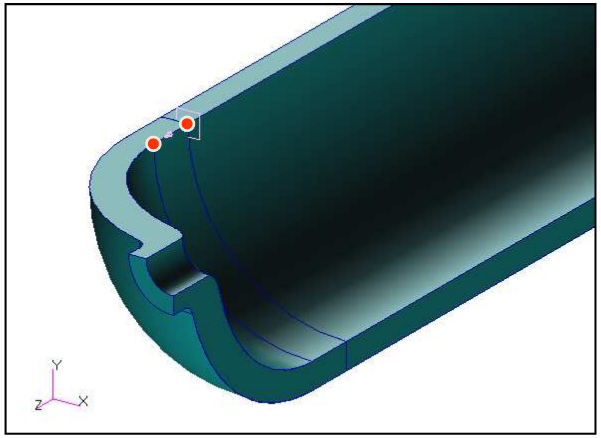
SCUBA TANK

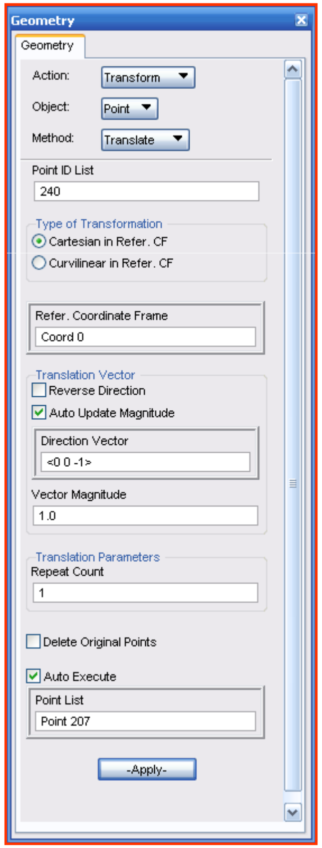


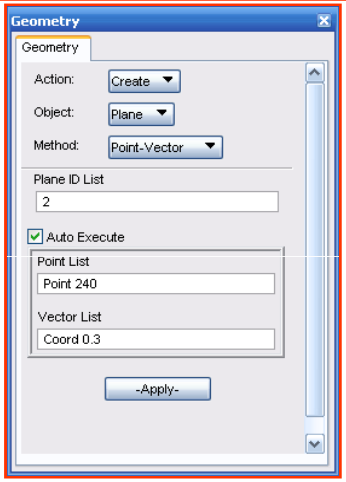
Move to the other end of the tank.

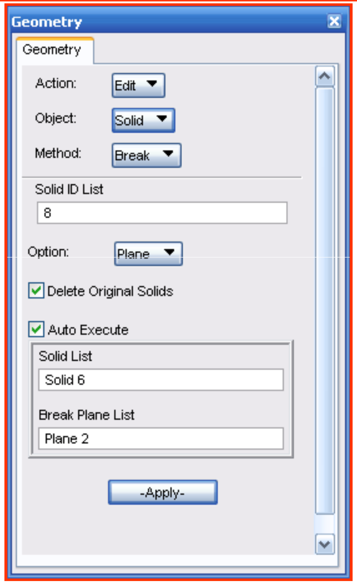
Create a point 1" away from the dome/cylinder transition point and create a plane there.

Break the solid using this plane.









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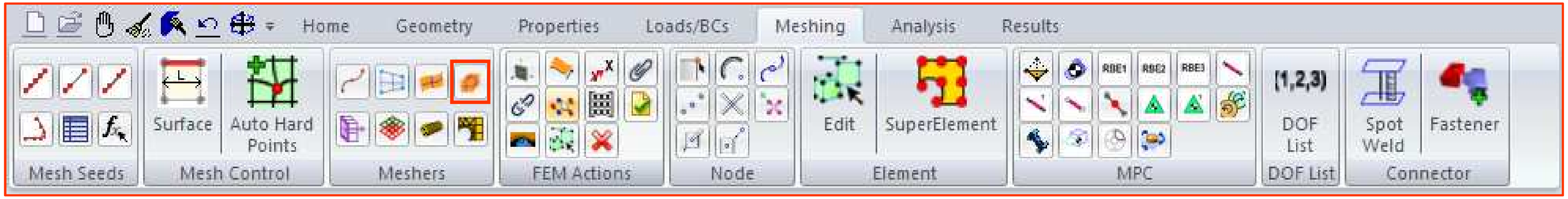
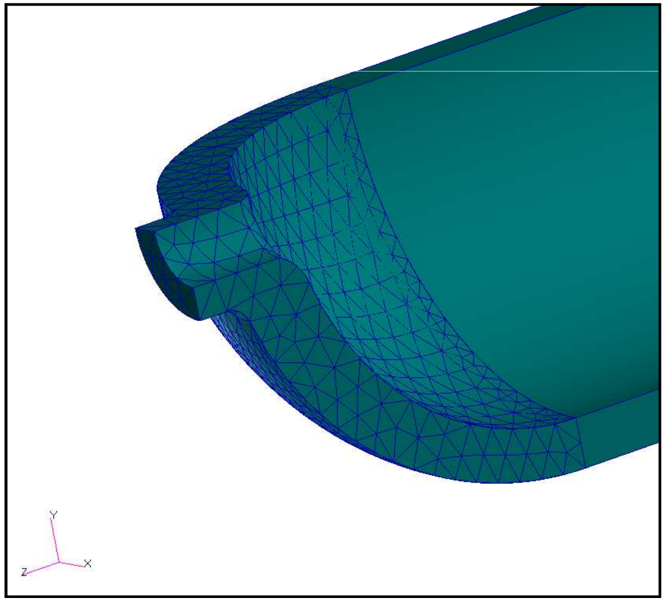
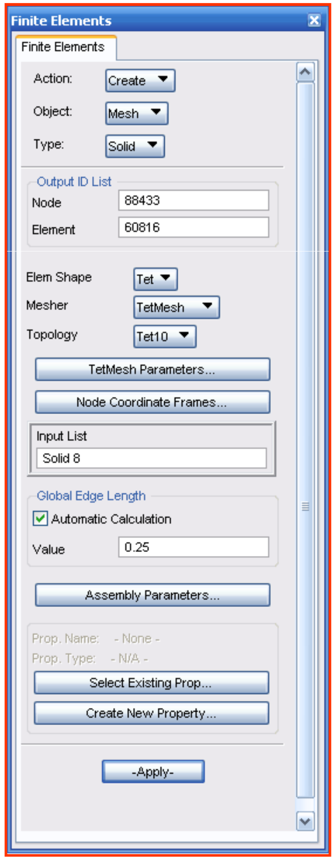
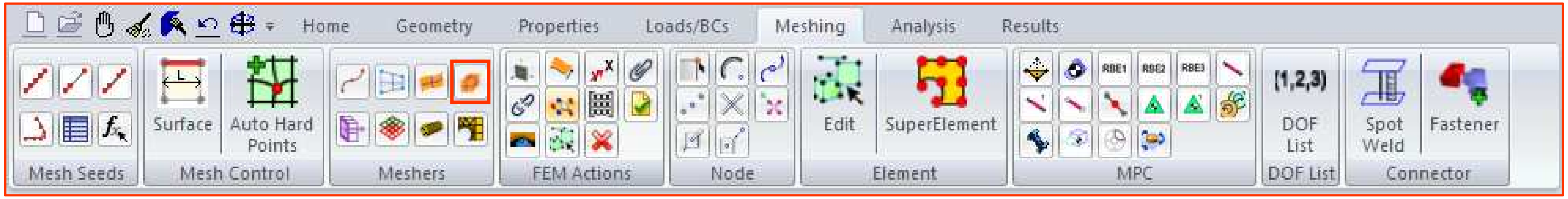


Mesh the dome portion of the tank with an element size of 0.25 inch.



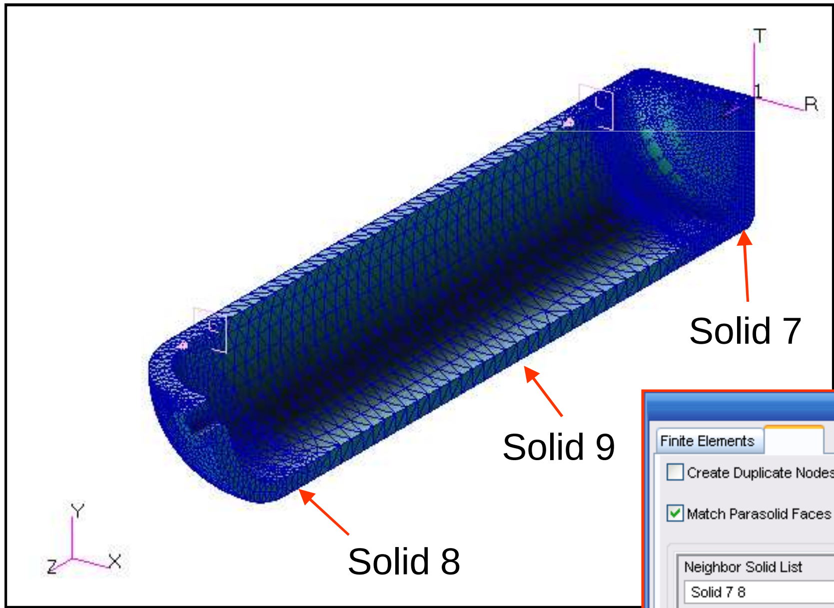


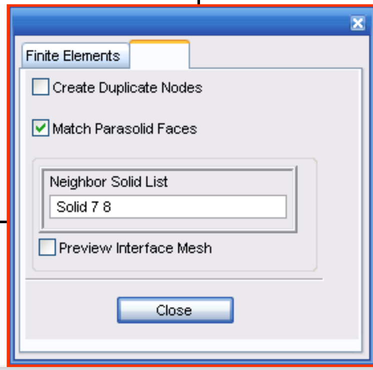
SCUBA TANK

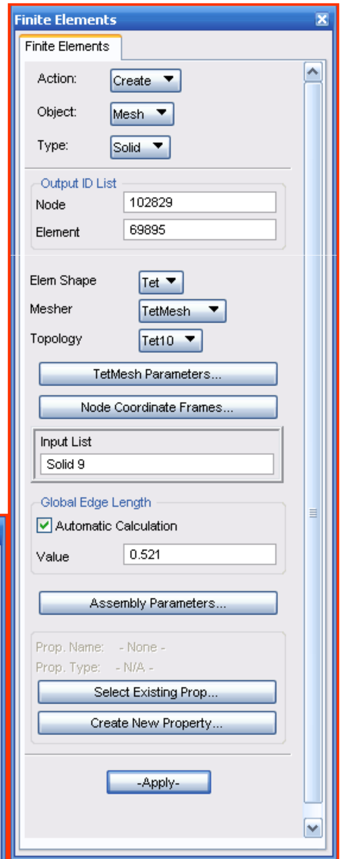


Finally, mesh the cylindrical portion with an element size of 0.521 inch.

Under assembly parameters, turn on Match Parasolid Faces to match the mesh on two neighboring solids.







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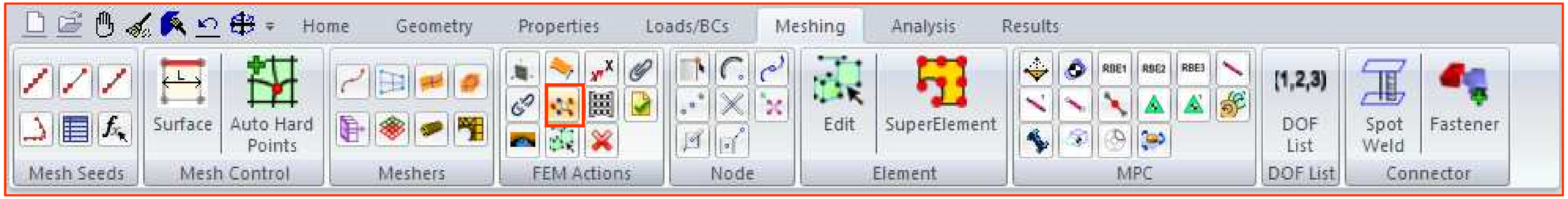
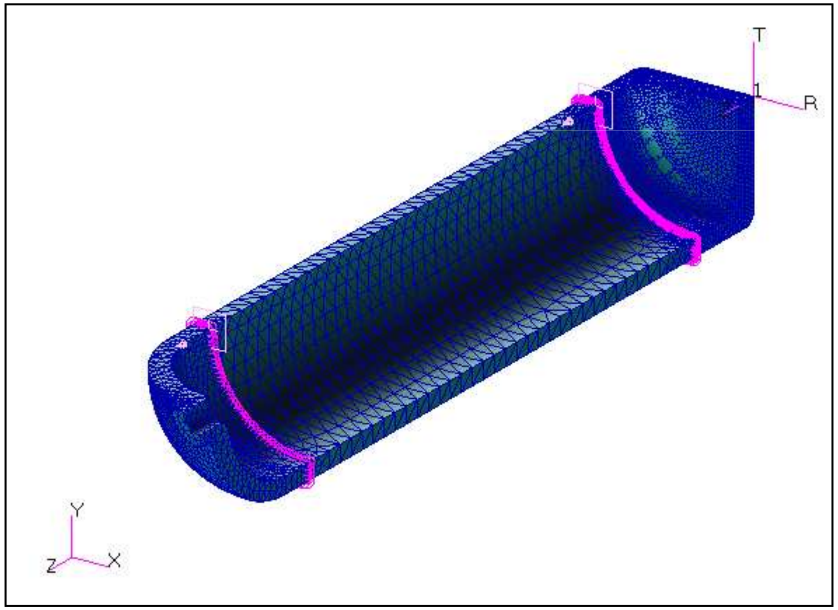
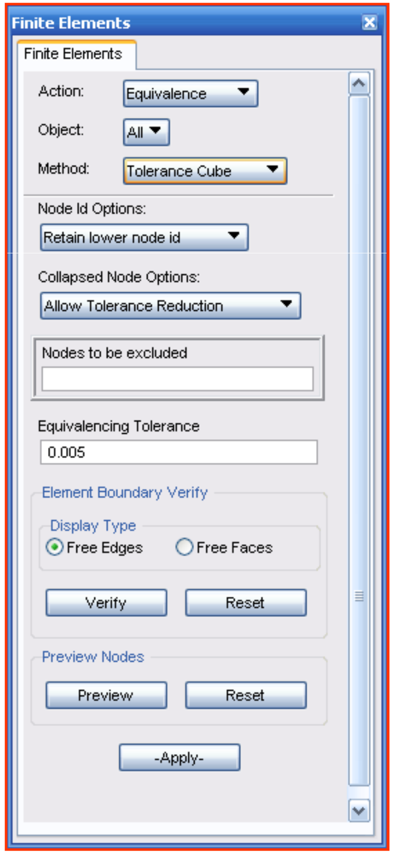
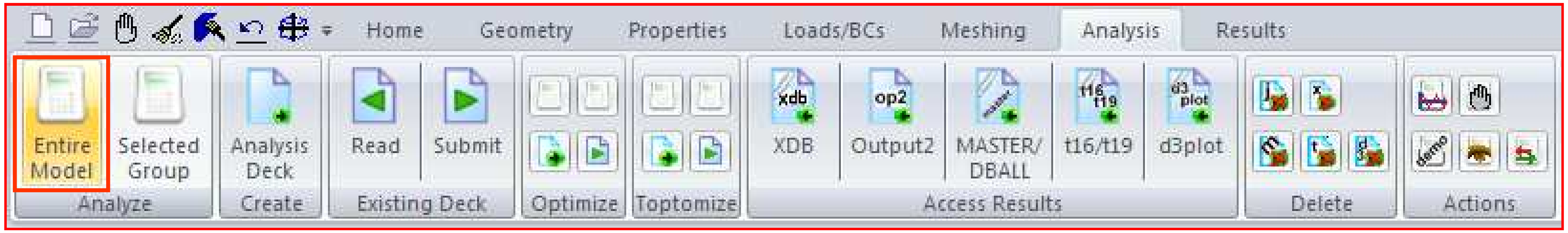


Equivalence the model



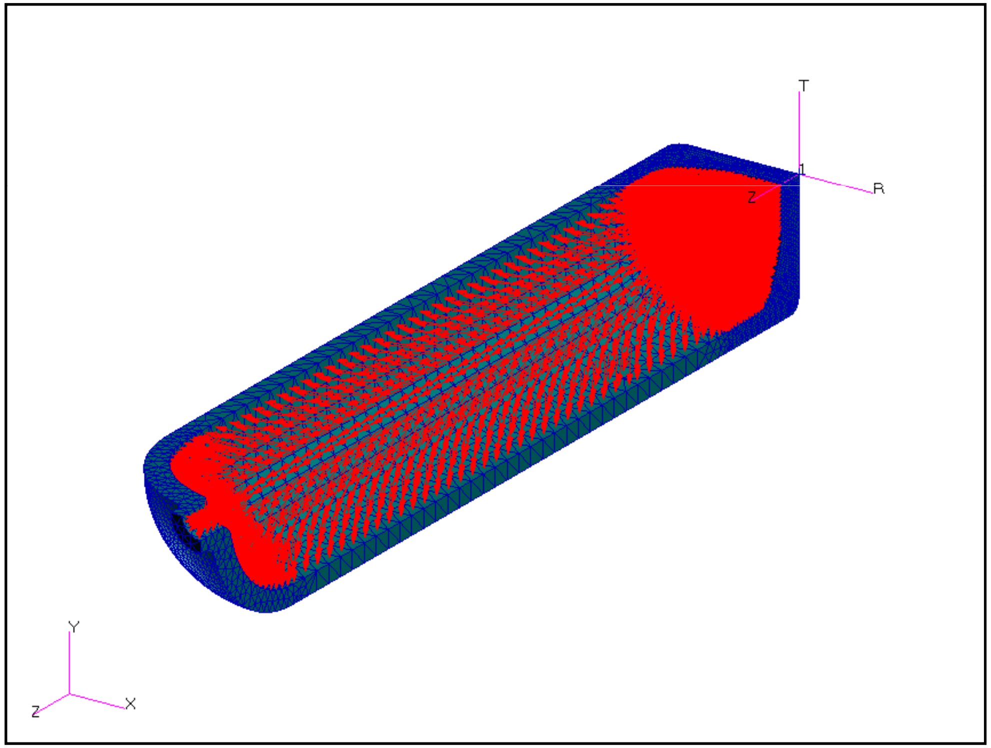


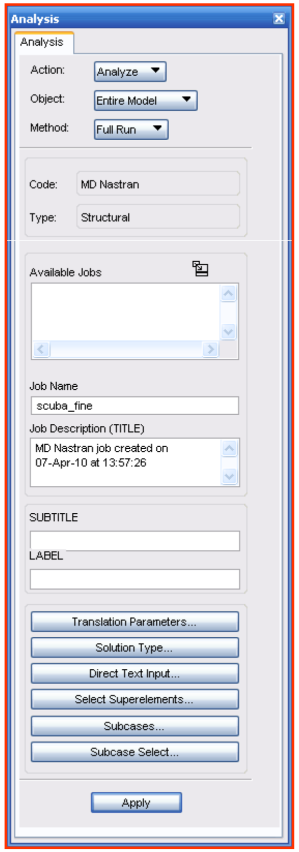
SCUBA TANK



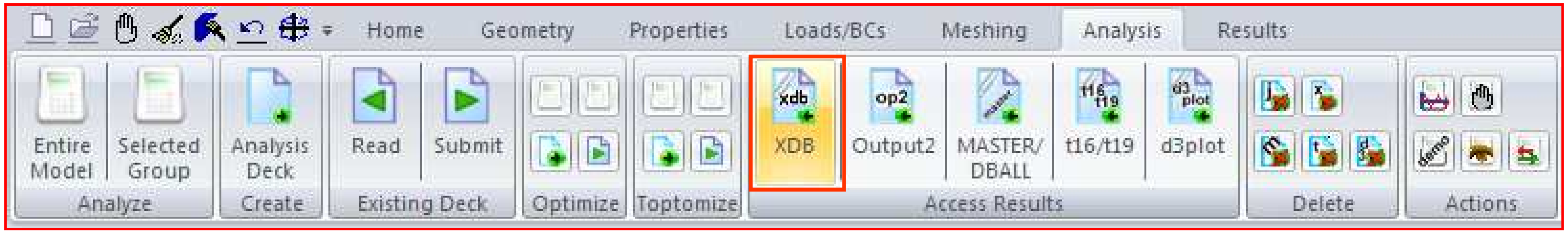
Finish creating loads, boundary conditions, material properties, and element properties.

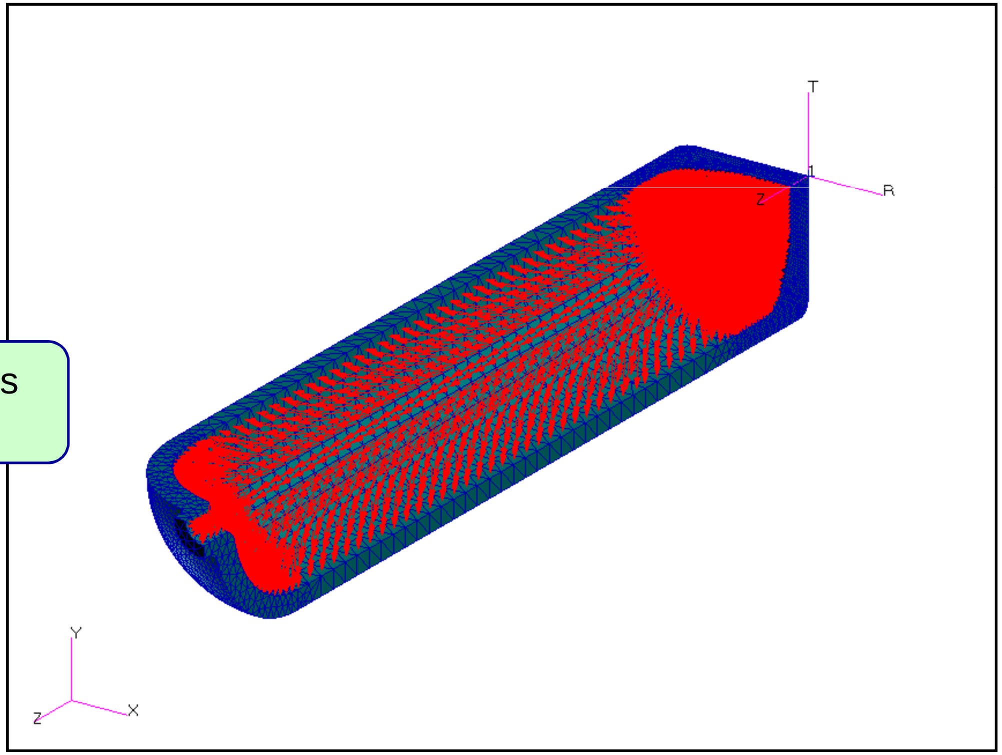
Submit the model to NASTRAN for static analysis.



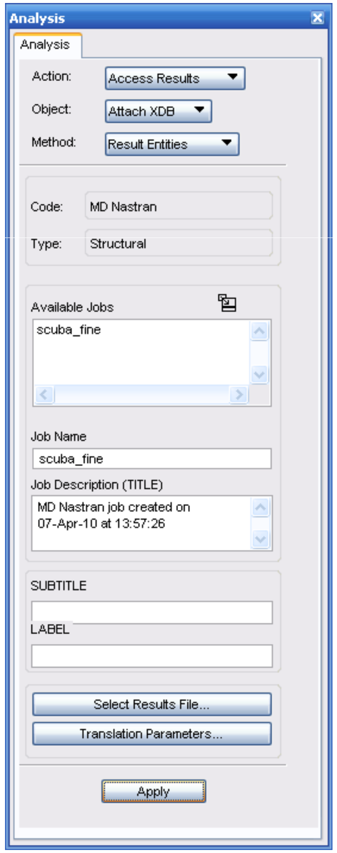


SCUBA TANK





Attach the analysis results into Patran



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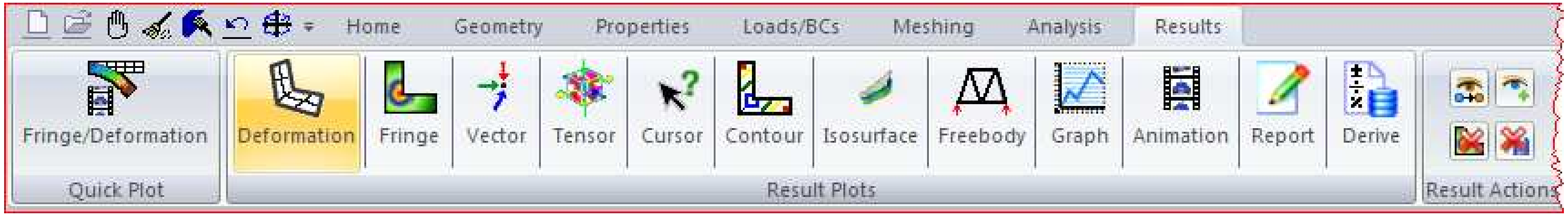
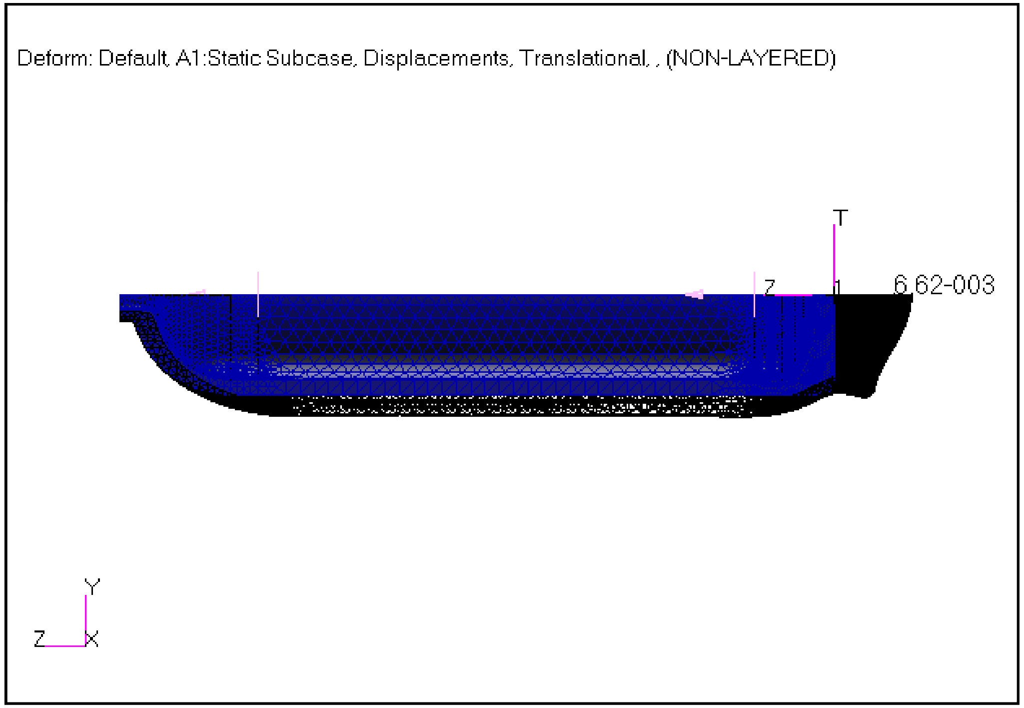
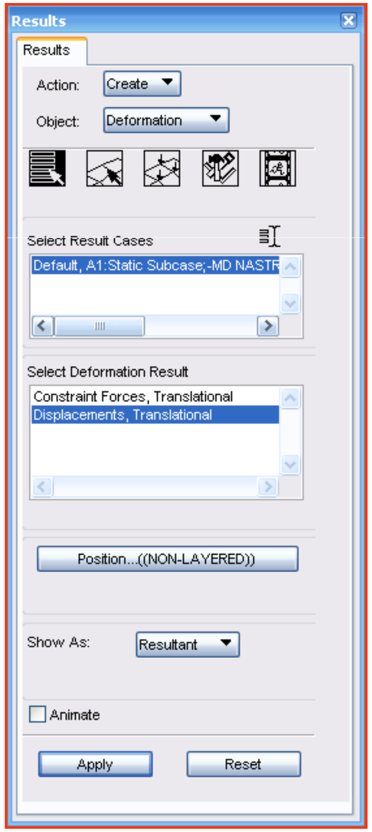


Create the deformation plot.

The maximum deformation of 0.007 inch agrees with the coarse model.





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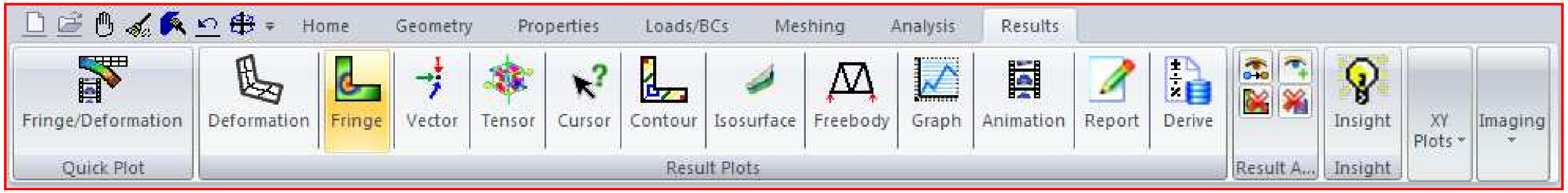
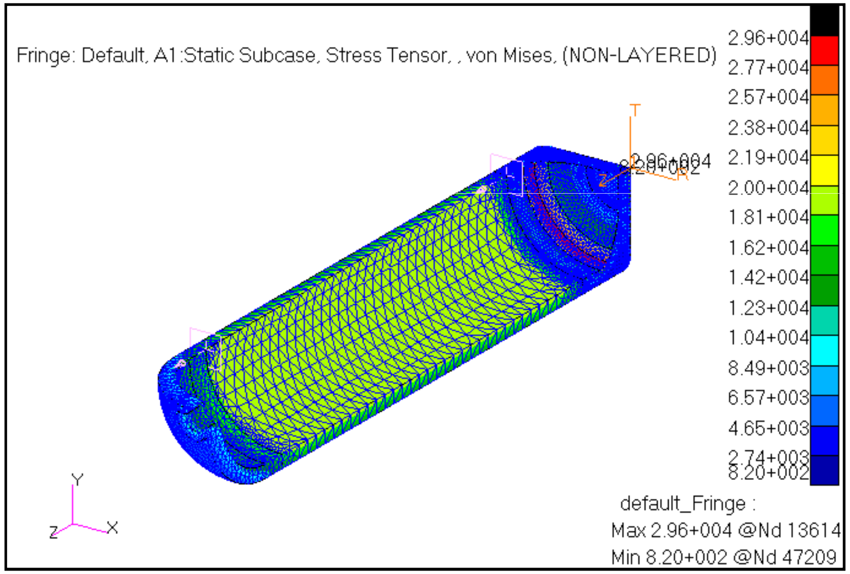
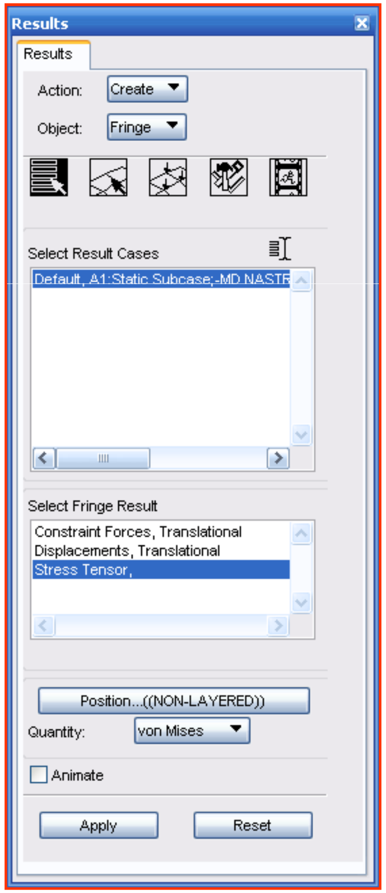
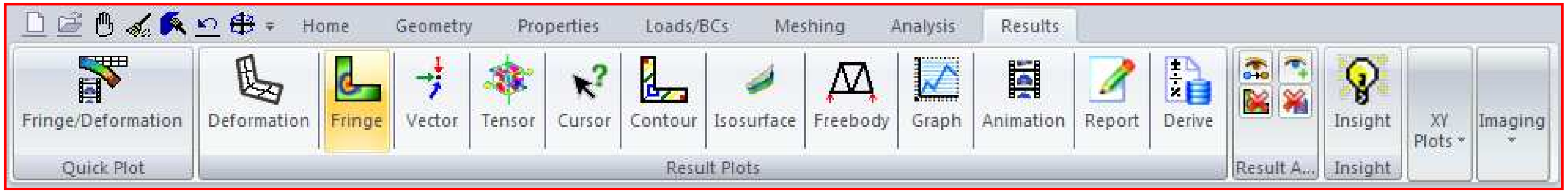


Plot the Von Mises stress





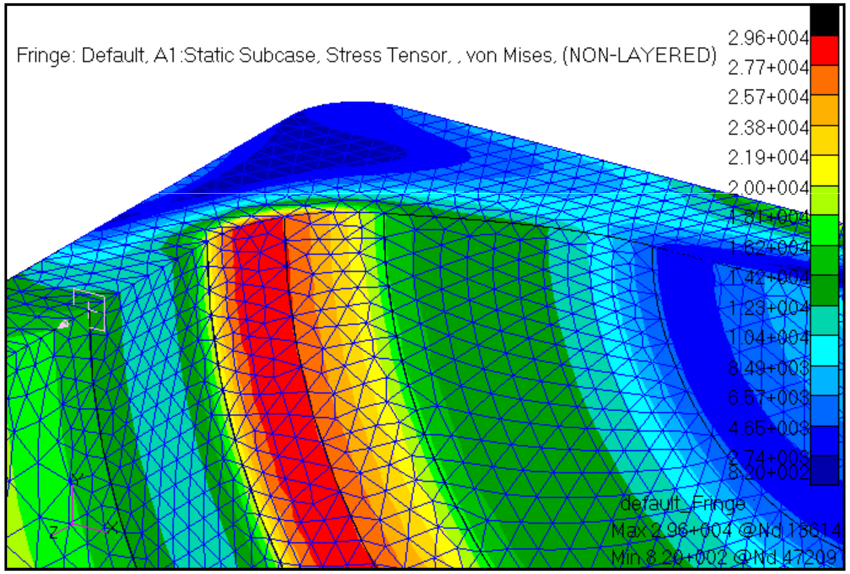
SCUBA TANK

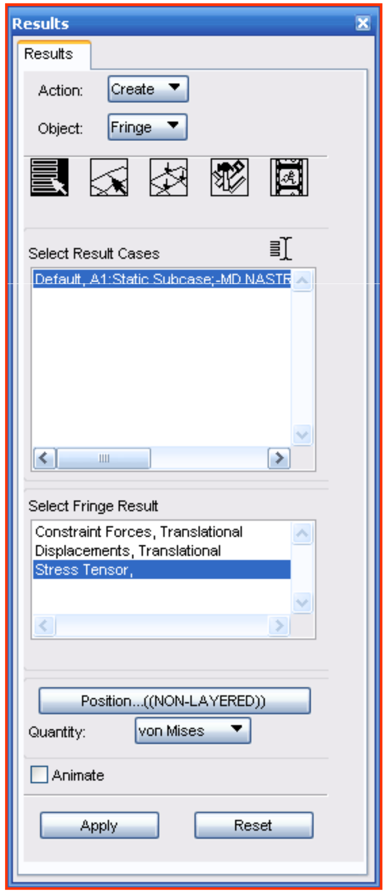


Zoom into the critical area.

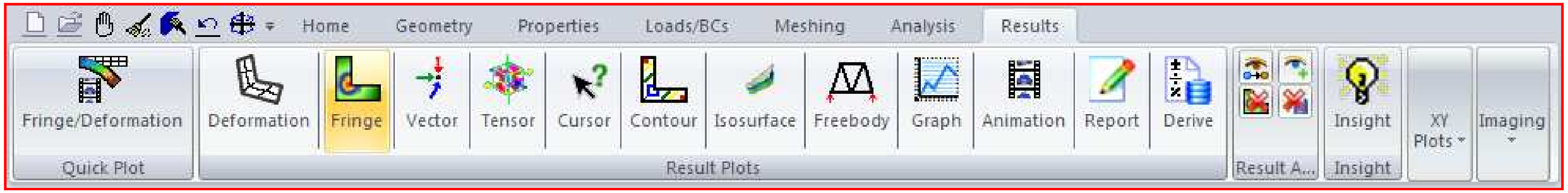
The maximum Von Mises stress is 29,500 psi.

Notice that there are 5 elements through the thickness in the critical area.



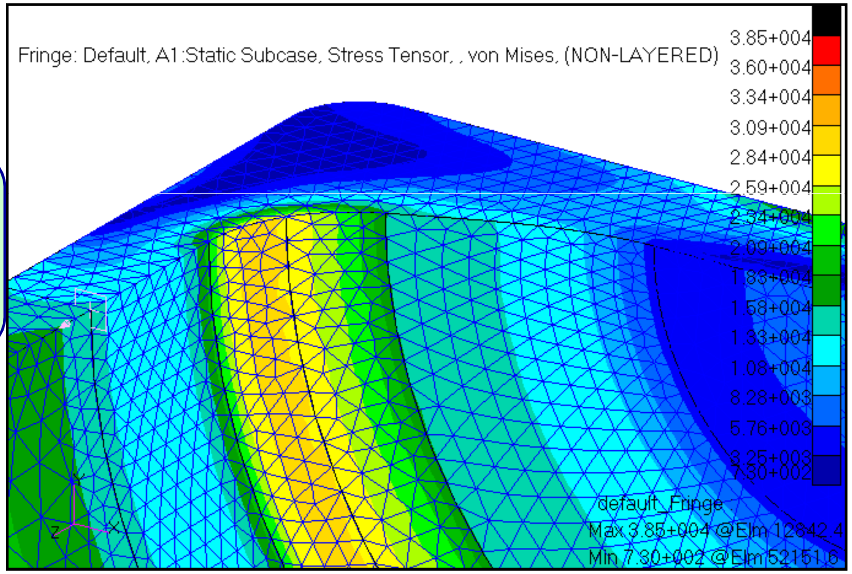


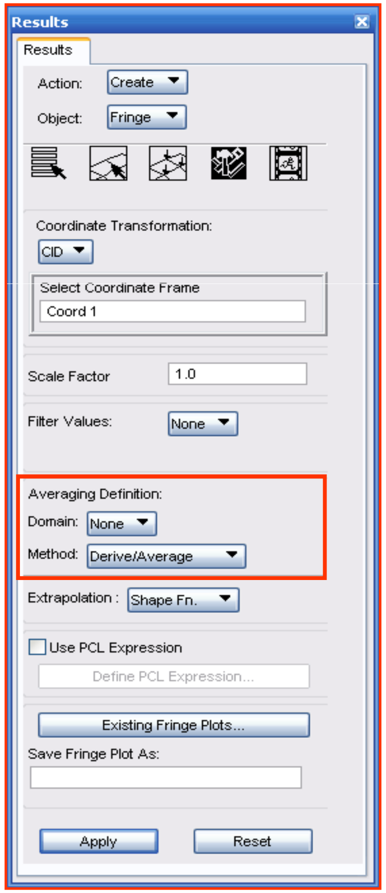
SCUBA TANK



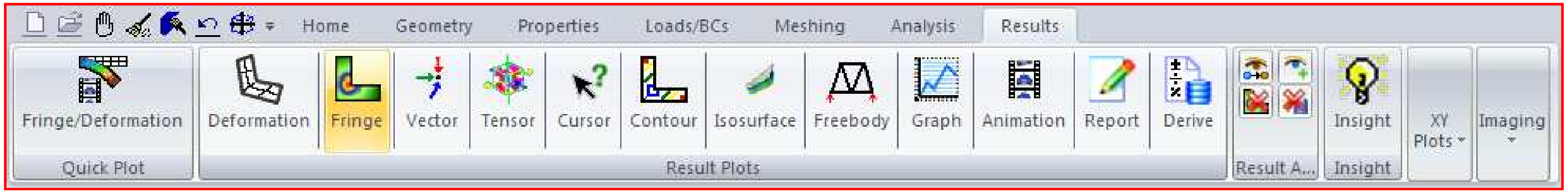
Turn off stress averaging.

The maximum Von Mises stress is 38,500 psi

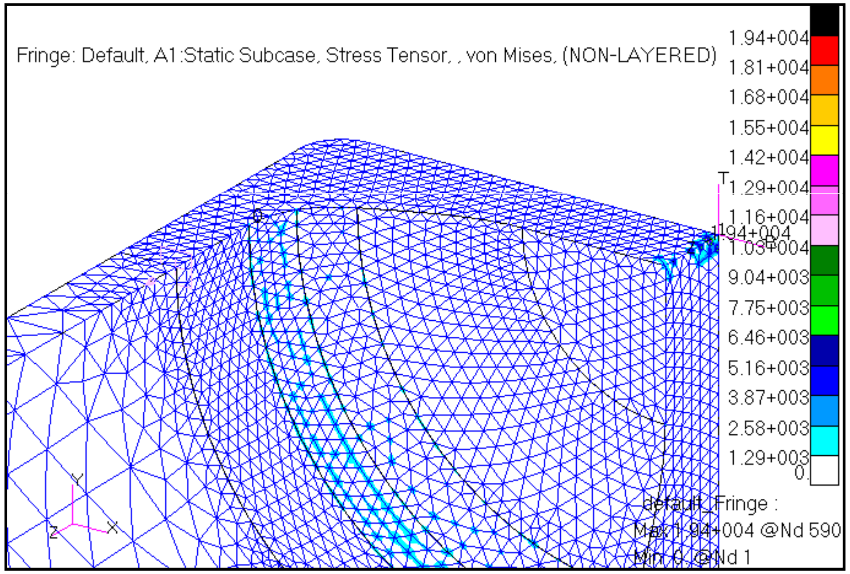


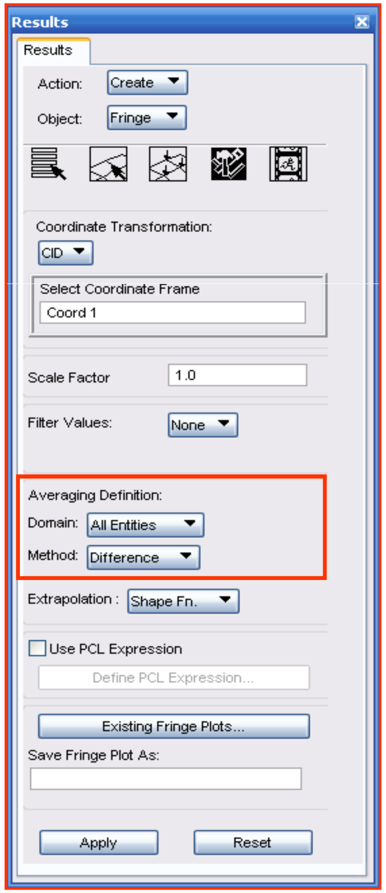


SCUBA TANK



Plot the stress jumps across nodes.





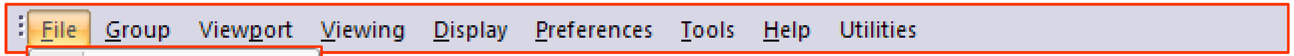
SCUBA TANK

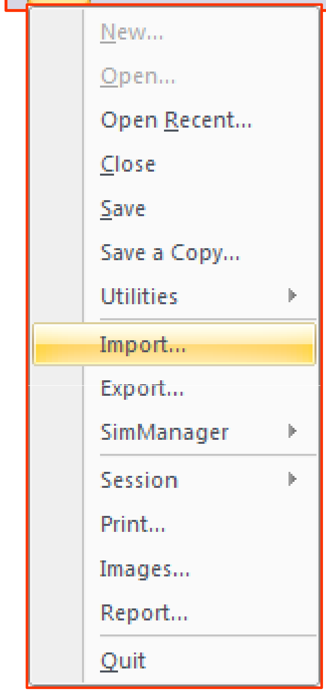
- Scuba tank fine-mesh model analysis summary:
  - The maximum Von Mises stress is 30,300 psi at the base of the tank near the fillet radius.
  - There are 5 elements through the thickness in this critical area. The stress gradient is represented reasonably well through the thickness.
  - The un-averaged stress fringe plot is relatively smooth, indicating that the re-meshing effort paid off.
  - The stress difference plot shows a maximum stress jump of 4300 psi. Is further mesh refinement necessary?
  - A total of 98,830 nodes and 66,504 elements were used to model this problem.
- Let's analyze the tank again using 2D axisymmetric elements.

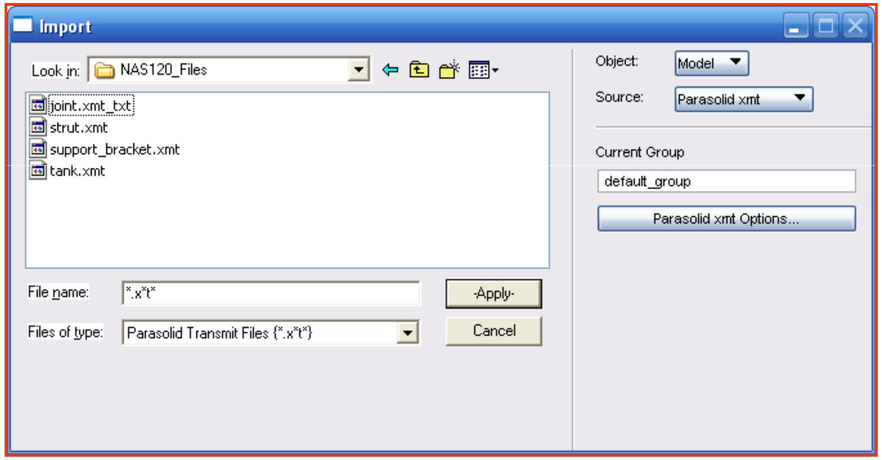
SCUBA TANK

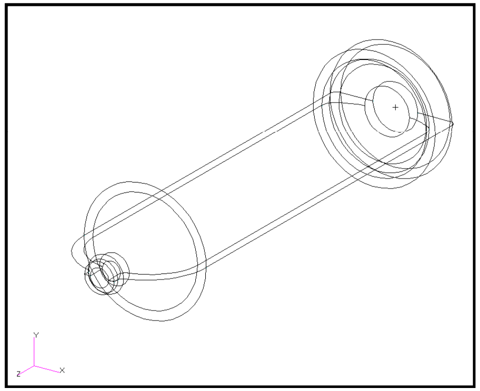
- Using 2D Axisymmetric Elements
  - This converts a 3D problem into a planar problem by using 2D elements.
  - Only half of the tank cross section is modeled.
  - Geometry, boundary condition, and loads must all be axisymmetric.
  - A much finer mesh can be used to solve this problem.

SCUBA TANK



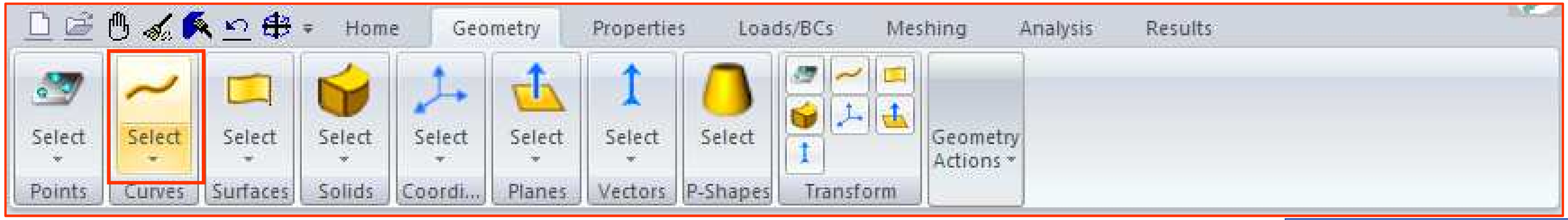




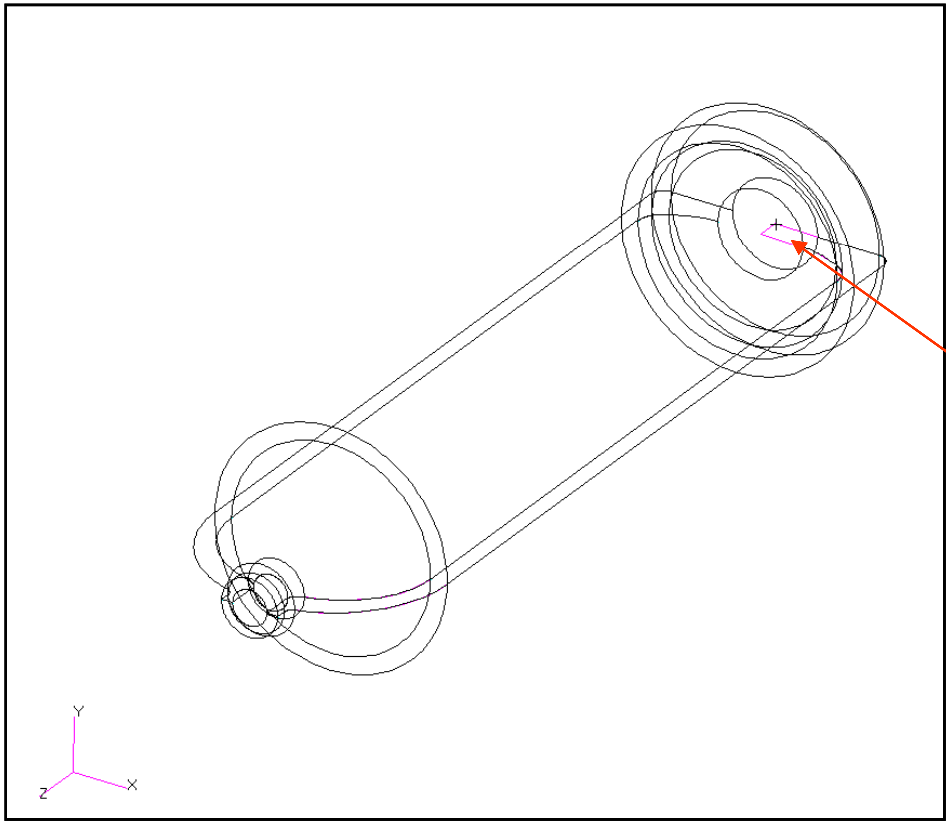


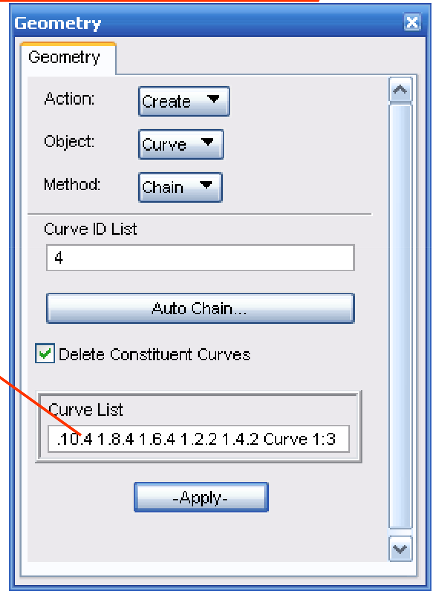
Open a new PATRAN database and import the scuba tank parasolid model.

SCUBA TANK

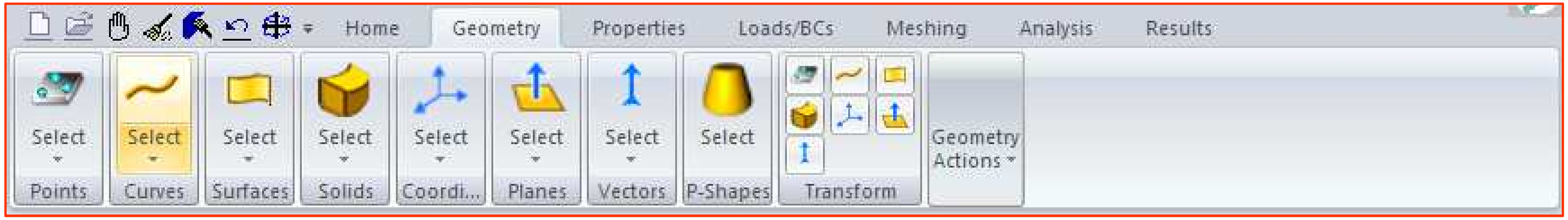


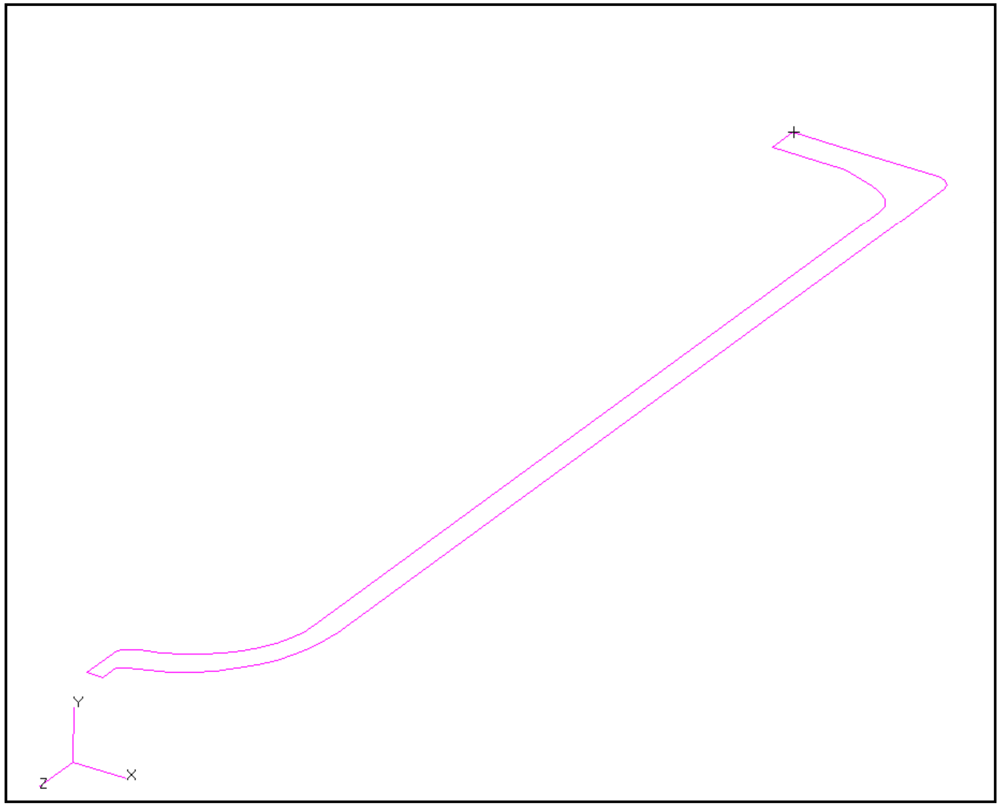
Use the existing solid edges and 3 new curves to create an outline for the tank cross section.





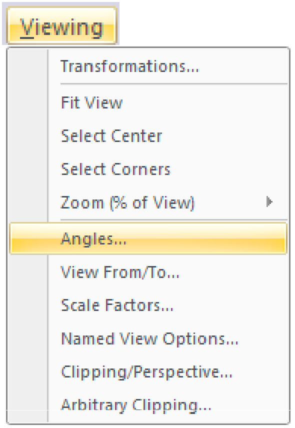
SCUBA TANK

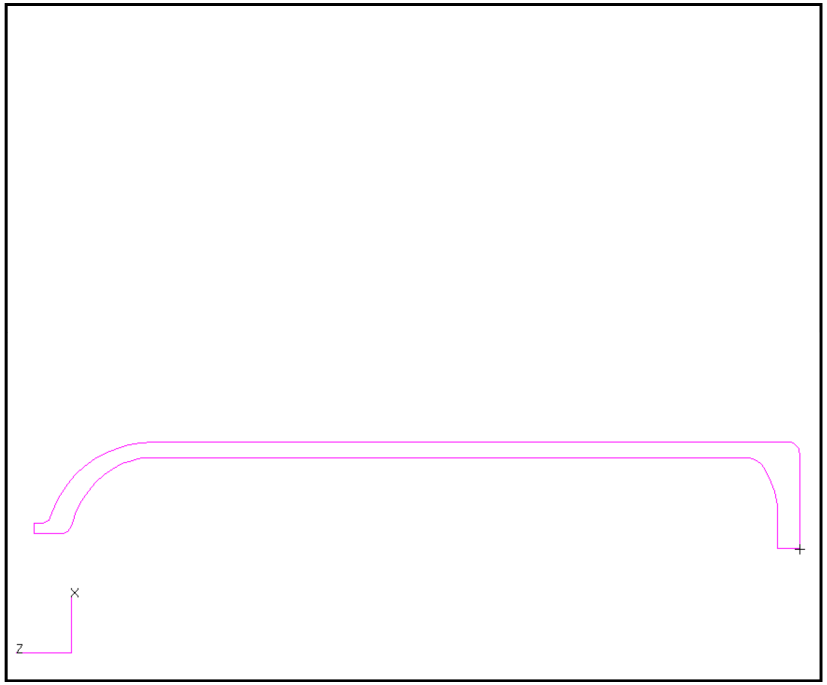


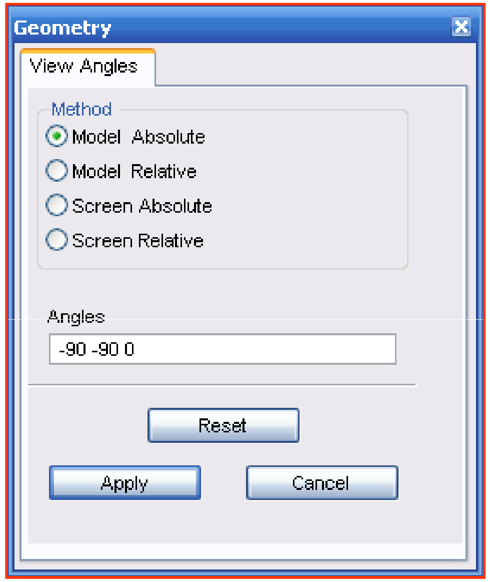


Erase all geometry except the chained curve.

SCUBA TANK

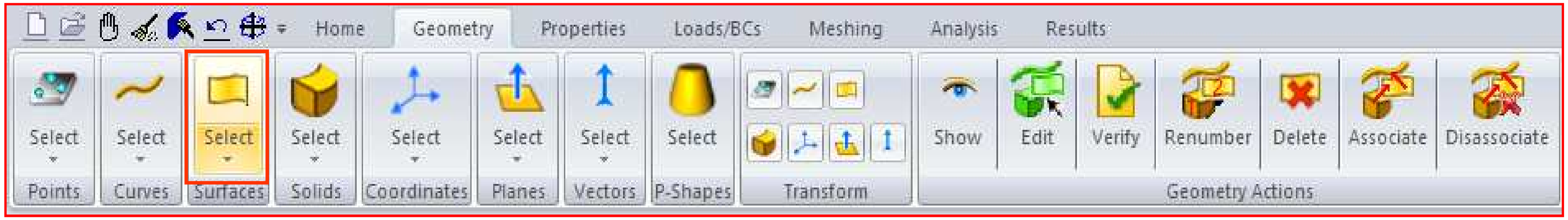




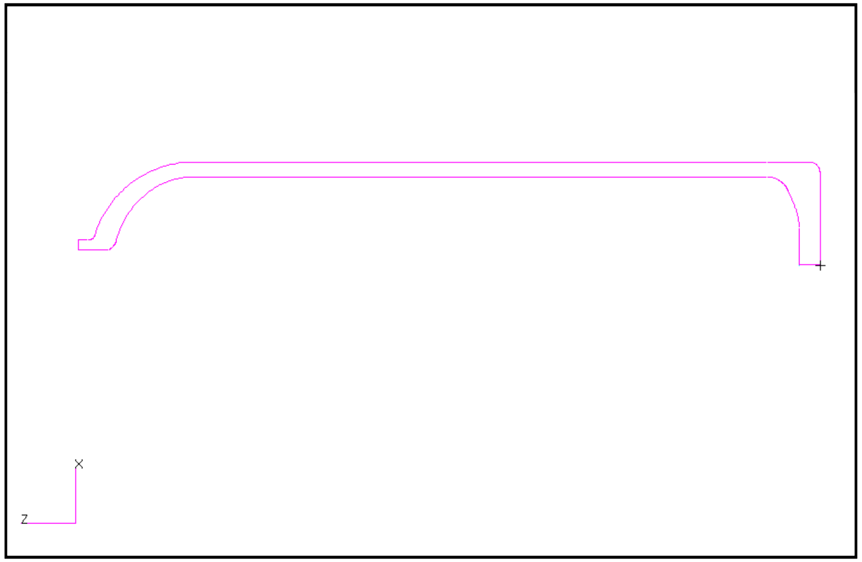


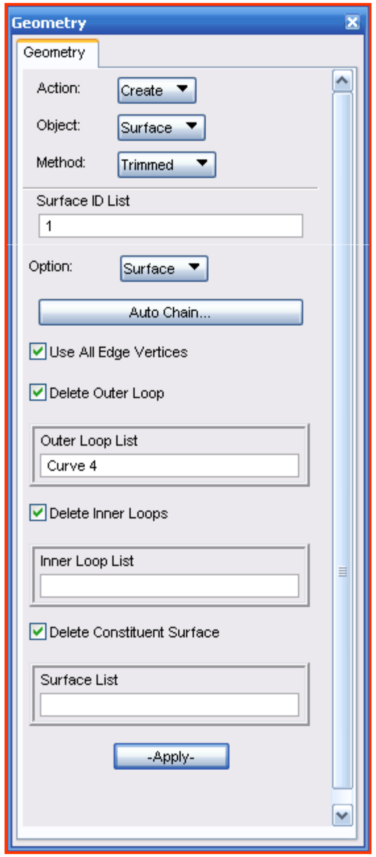
Change the view by using Viewing Angles.

SCUBA TANK

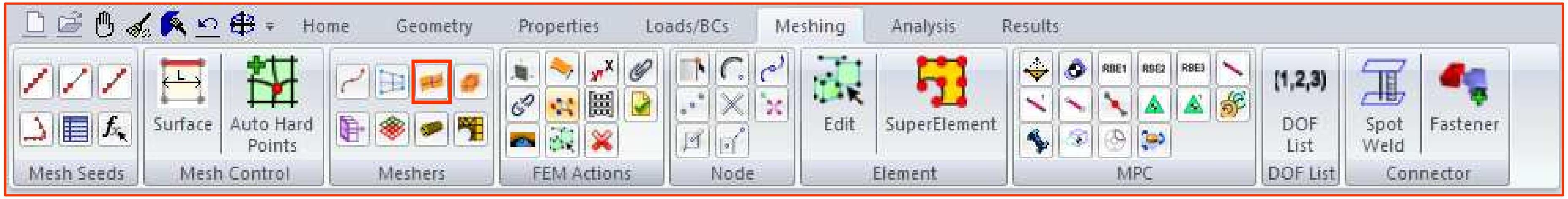


Create a trimmed surface from the chained curve.



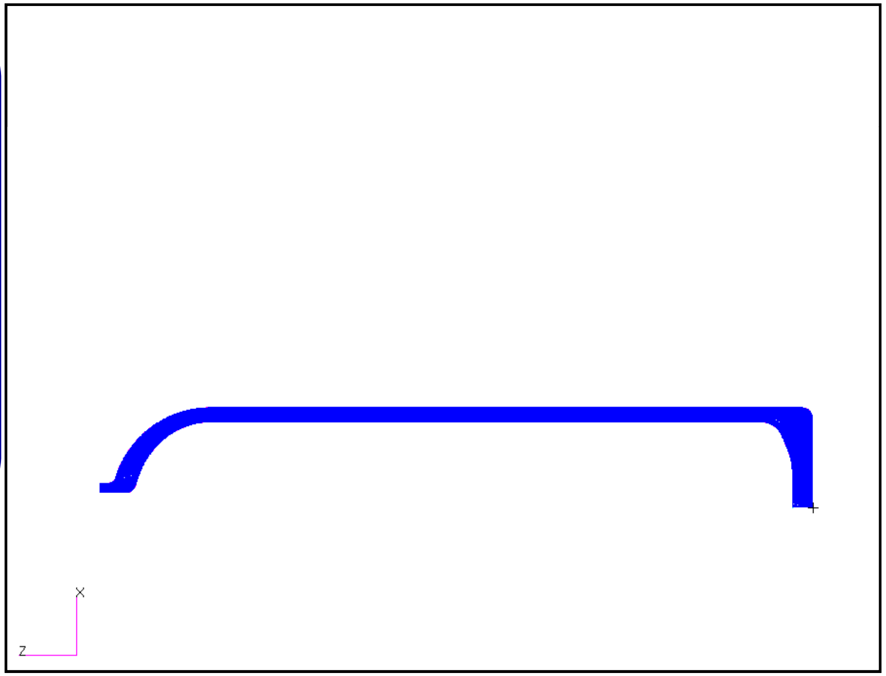


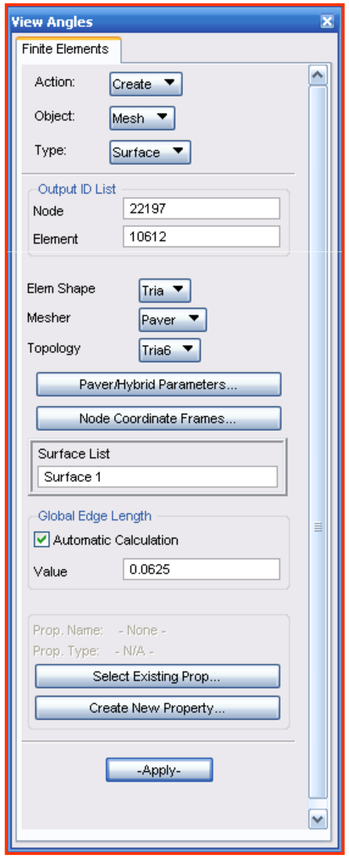
SCUBA TANK



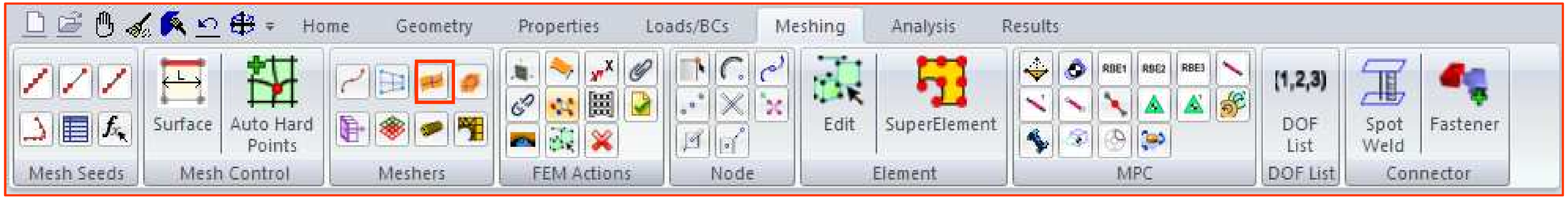
Mesh the surface to generate triangular elements with a global edge length of 0.0625 inch.

The axisymmetric elements must lie in the positive x half of the x-z plane of the basic coordinate system with the z axis as the centerline.



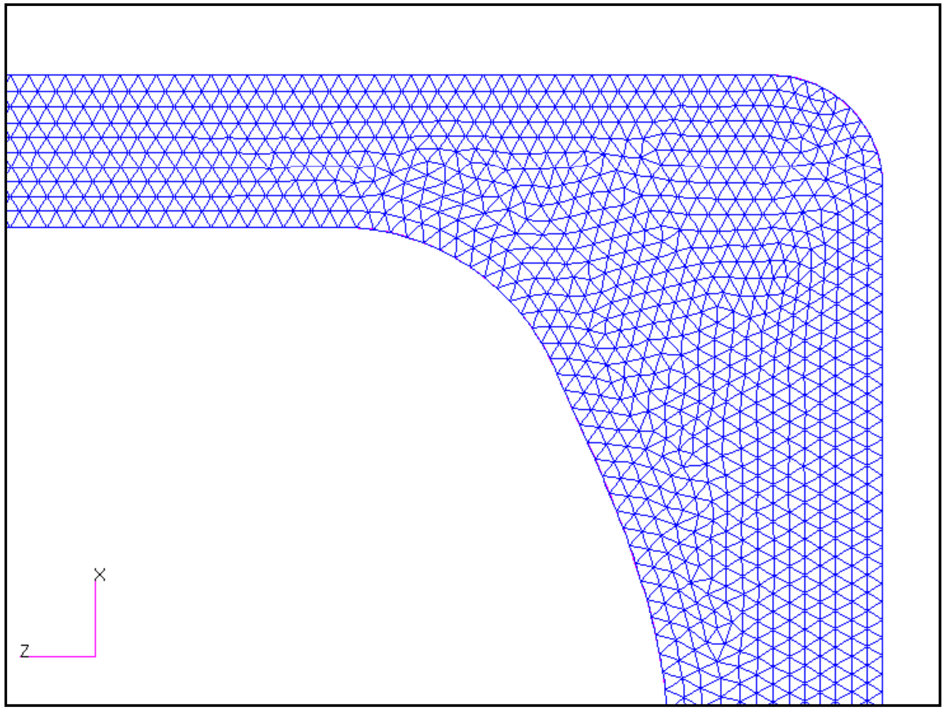


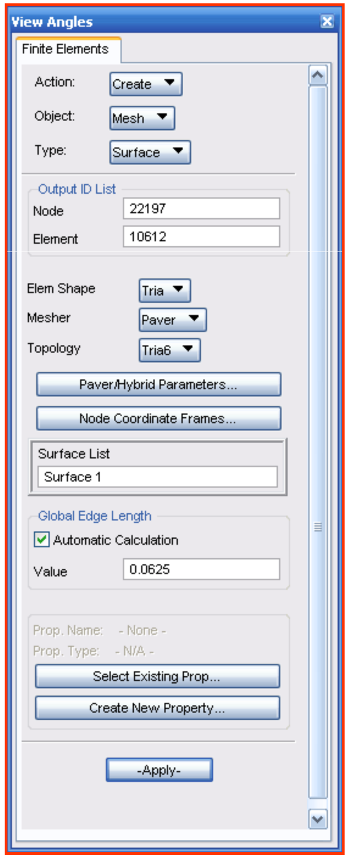
SCUBA TANK



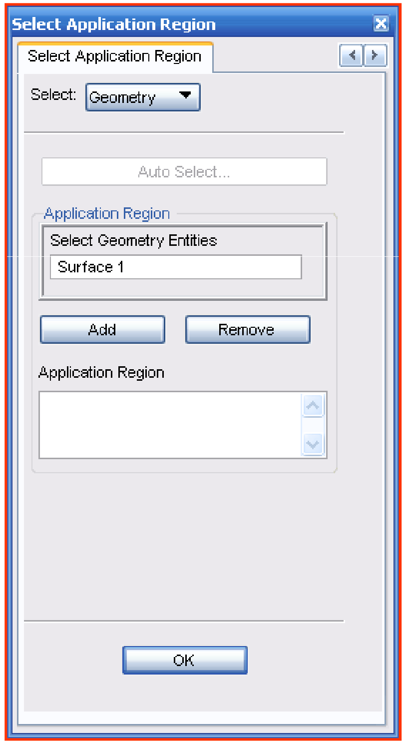
The use of planar elements allowed us to use a much finer mesh.

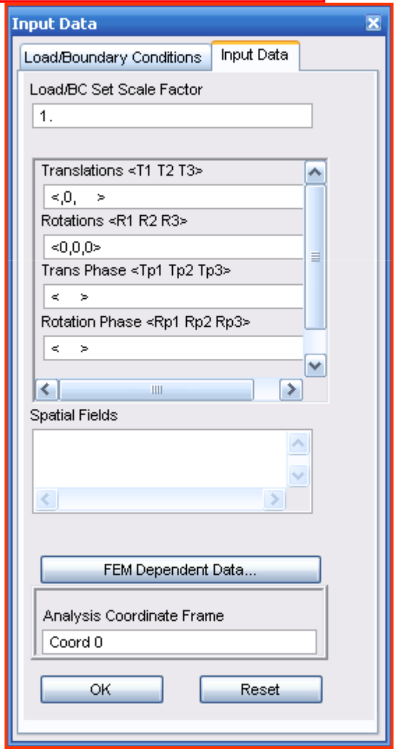
There are now 10 elements through the thickness in the critical area.

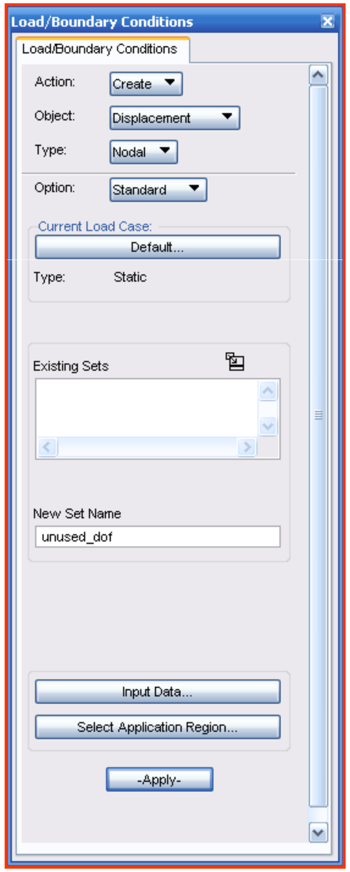




SCUBA TANK



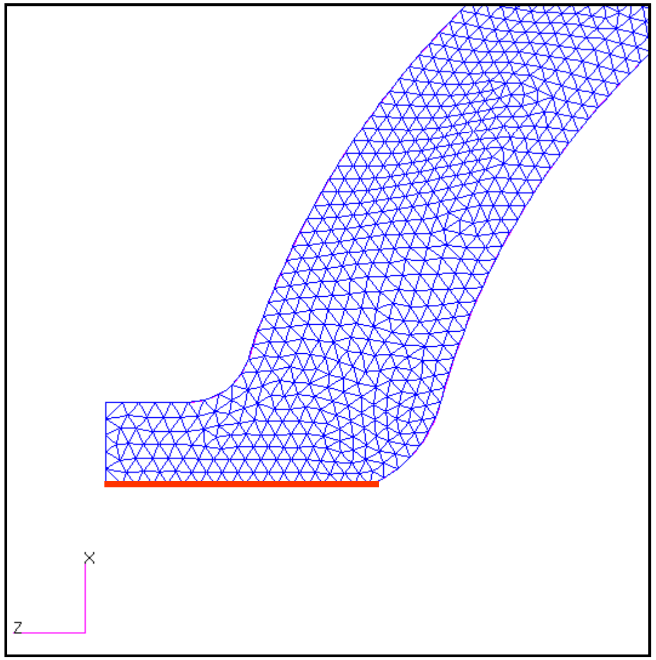


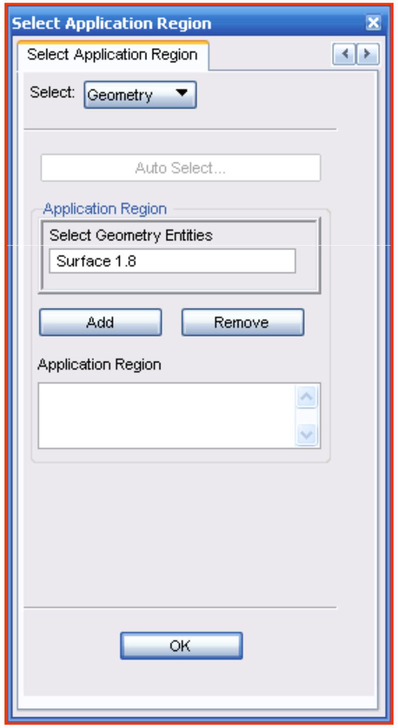


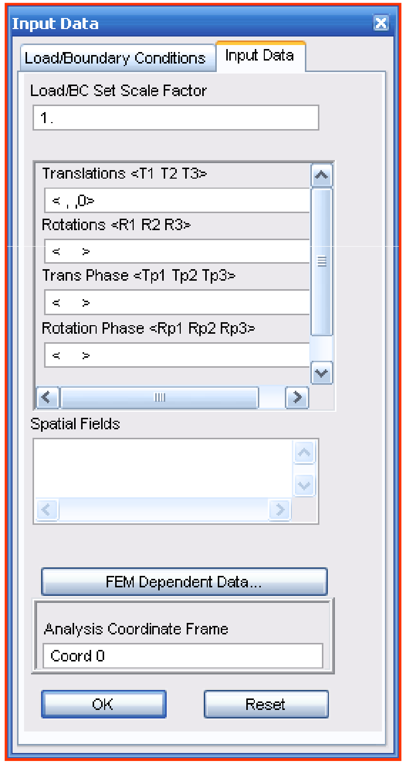
The T2, R1, R2, and R3 degrees of freedom are not used in this axisymmetric problem. Constrain these unused degrees of freedom.

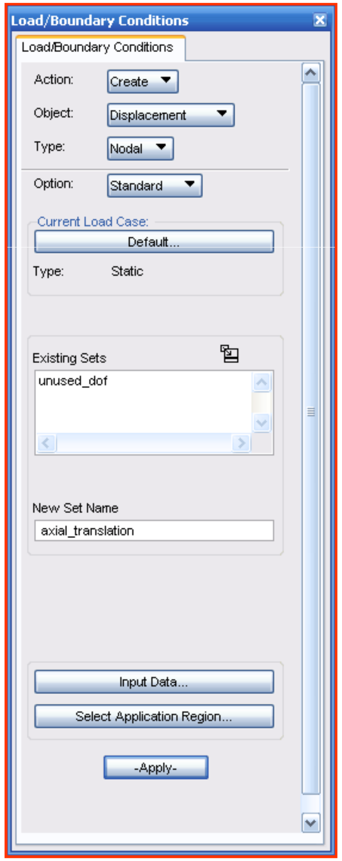
SCUBA TANK

Constrain the model in the z direction.

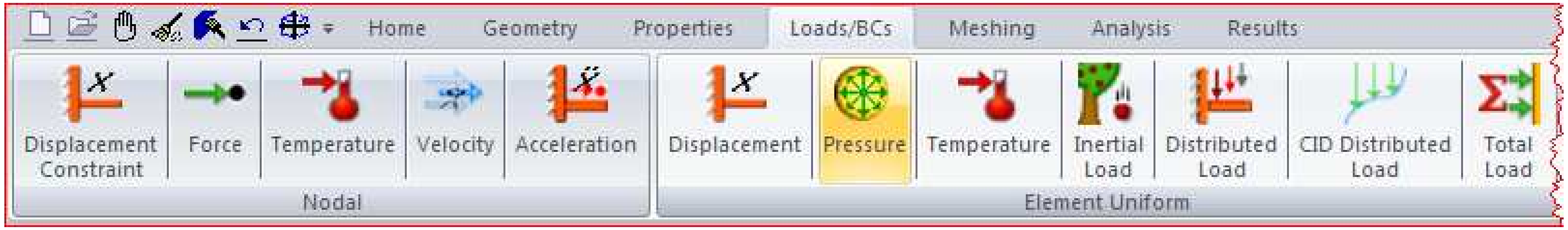




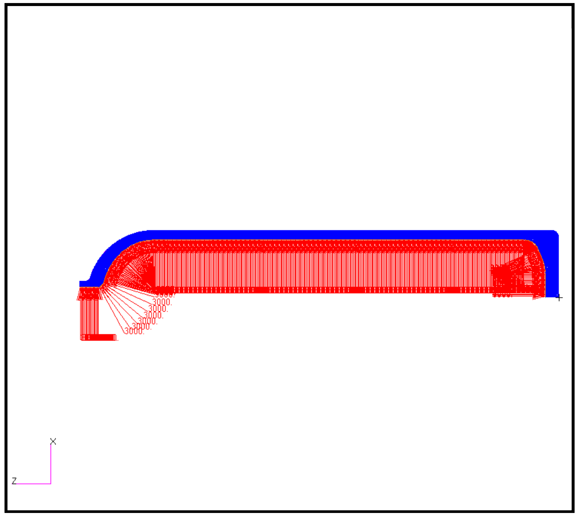


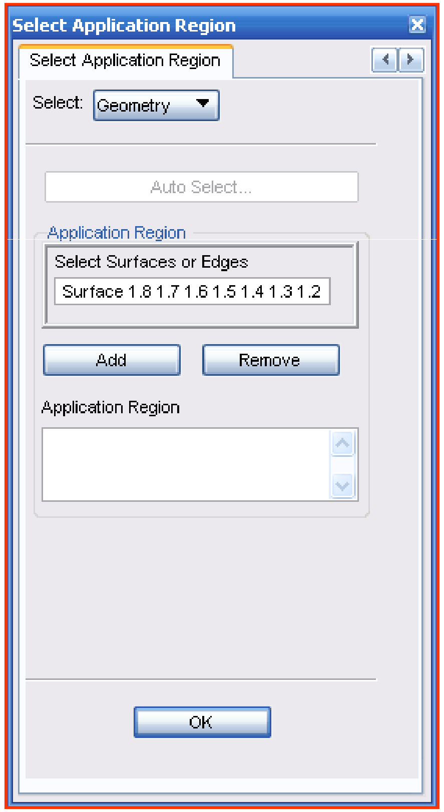


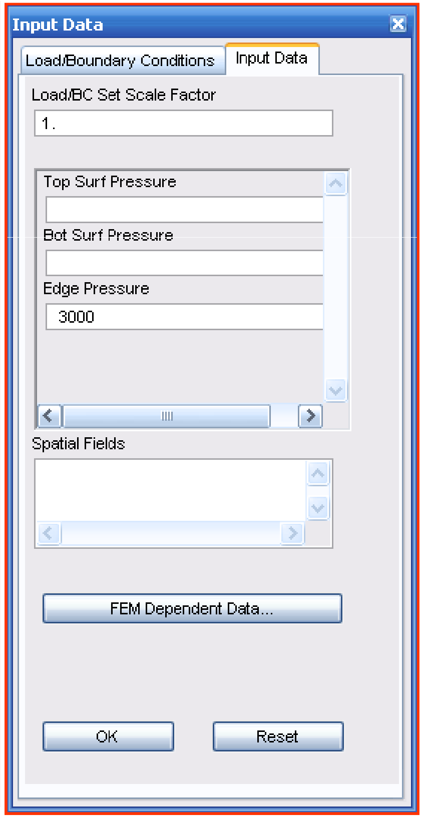
SCUBA TANK

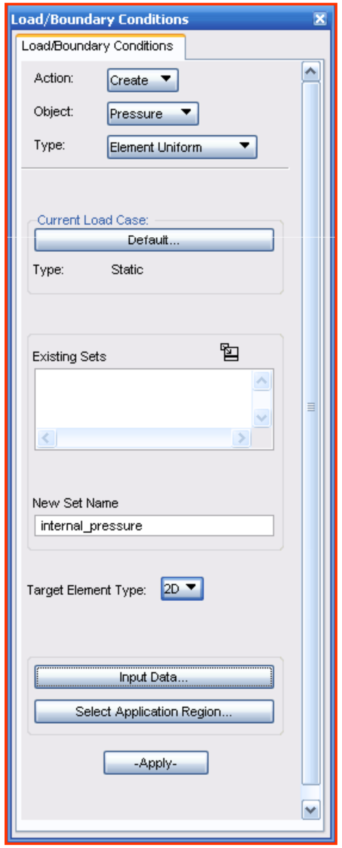


Apply the pressure to all the internal curves.









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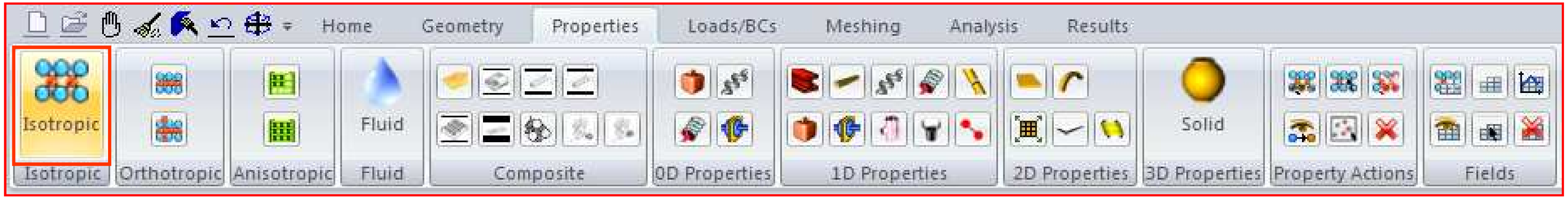
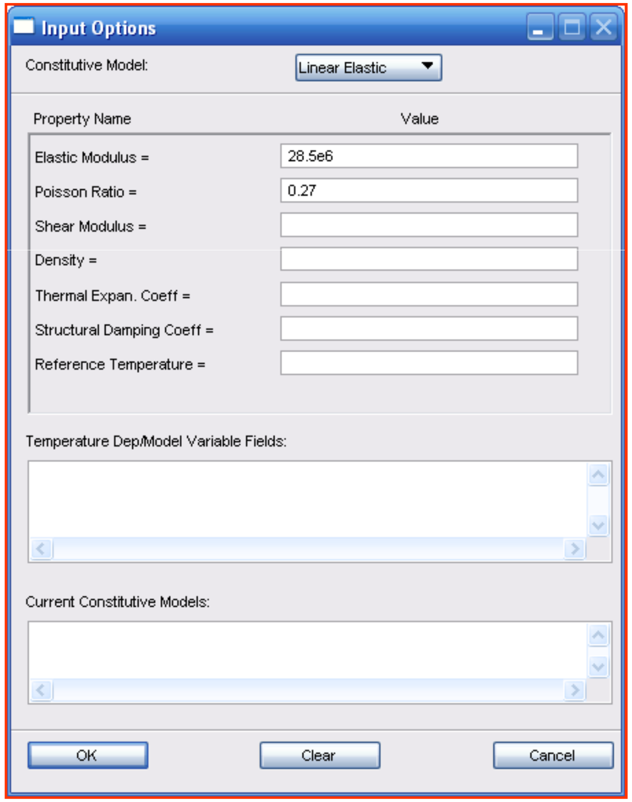
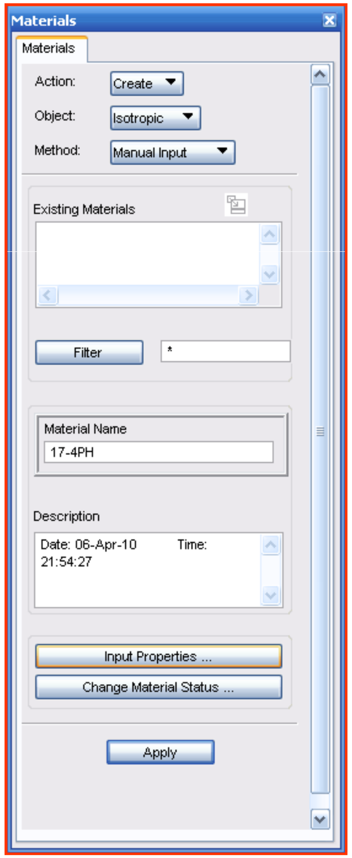


Create an isotropic material named 17-4PH.





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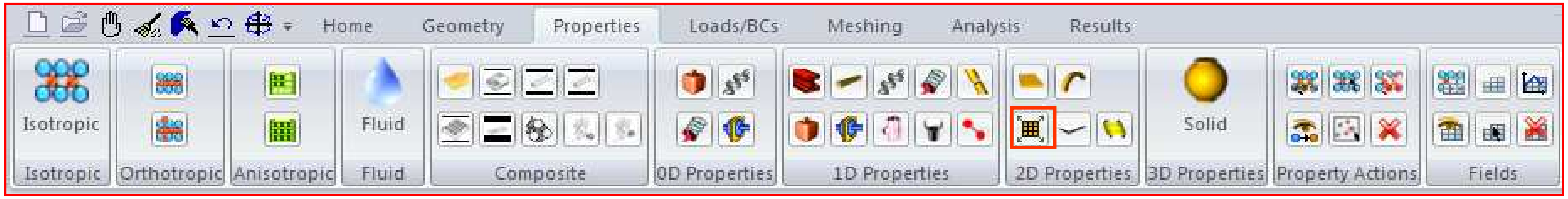

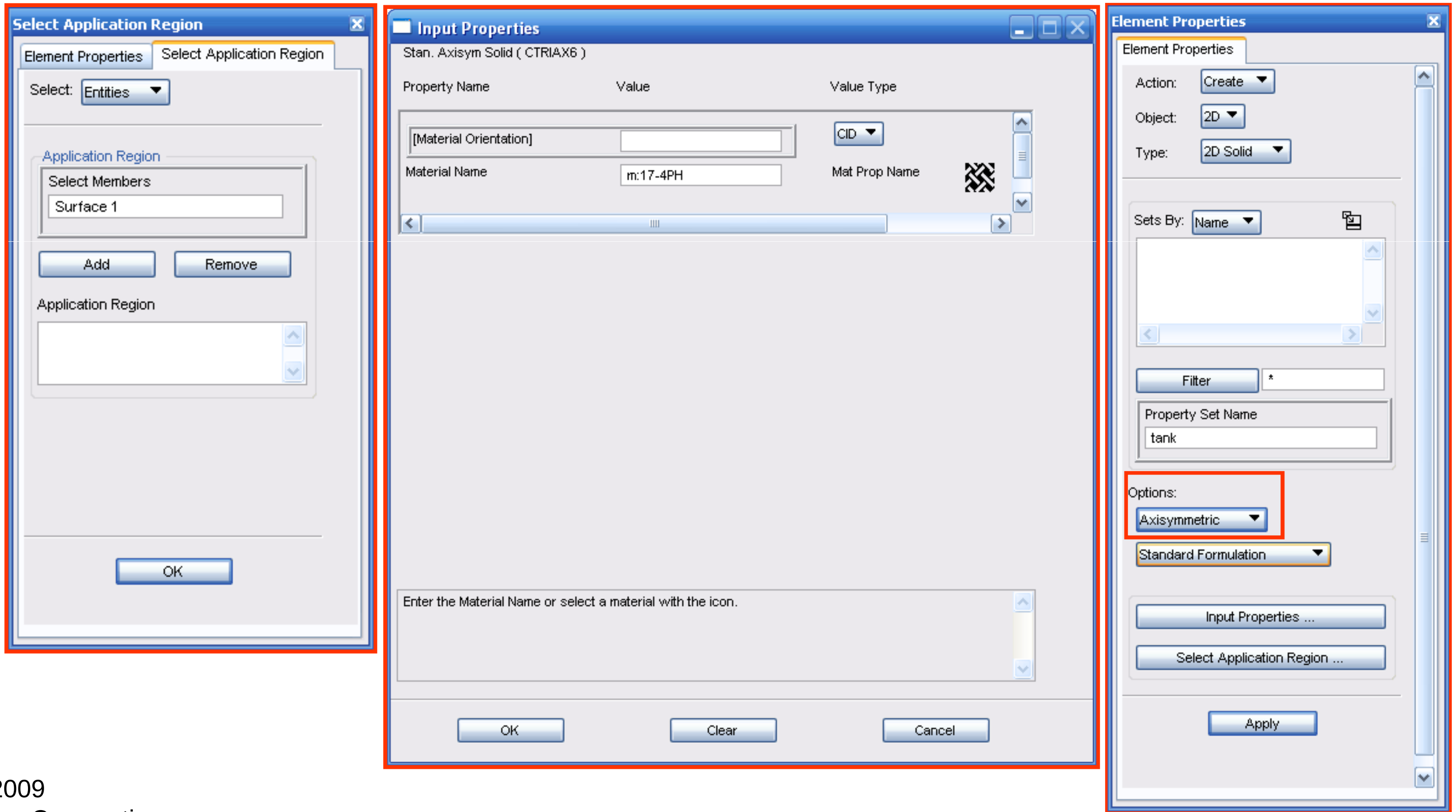

Create the axisymmetric element properties

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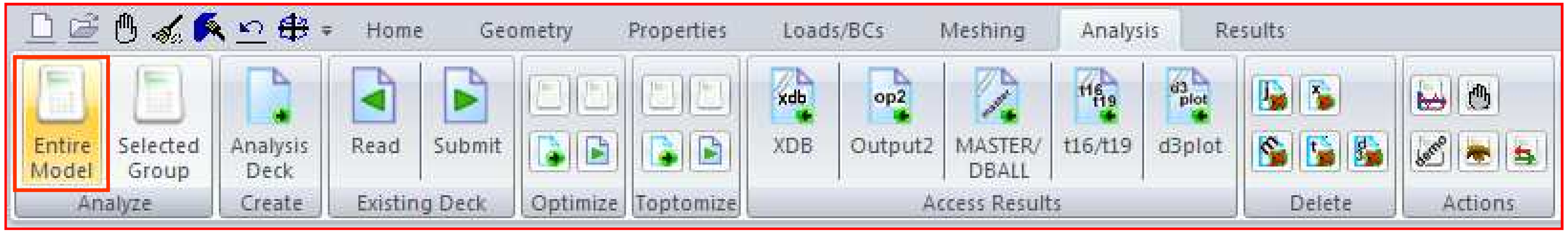
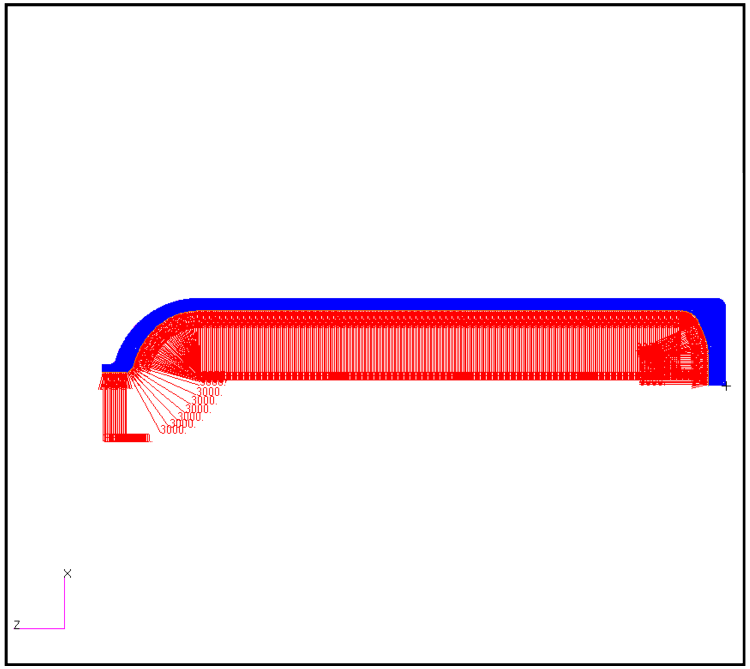
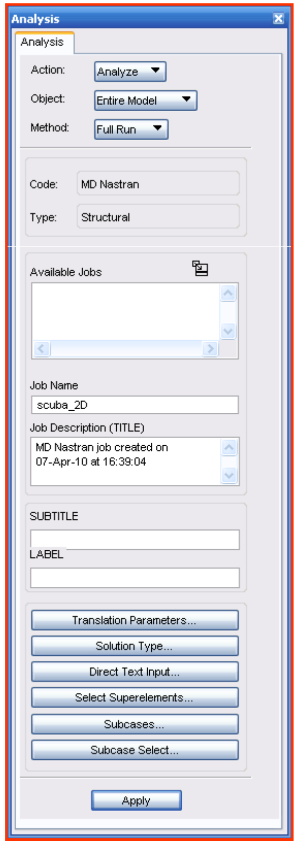


Run the static analysis.





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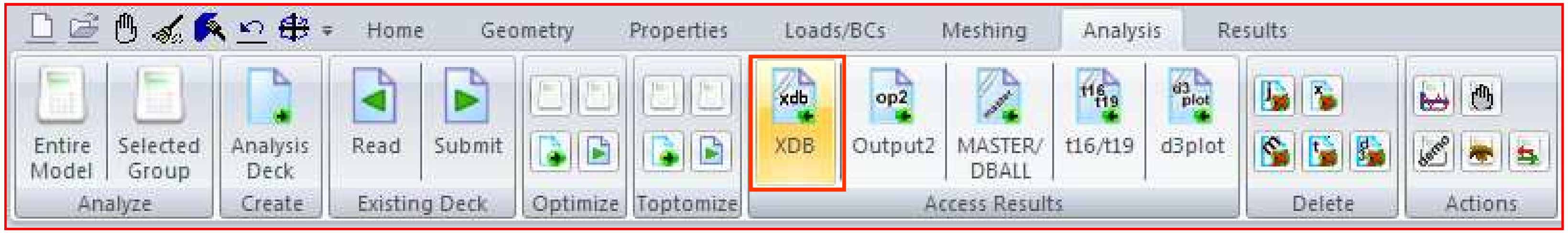
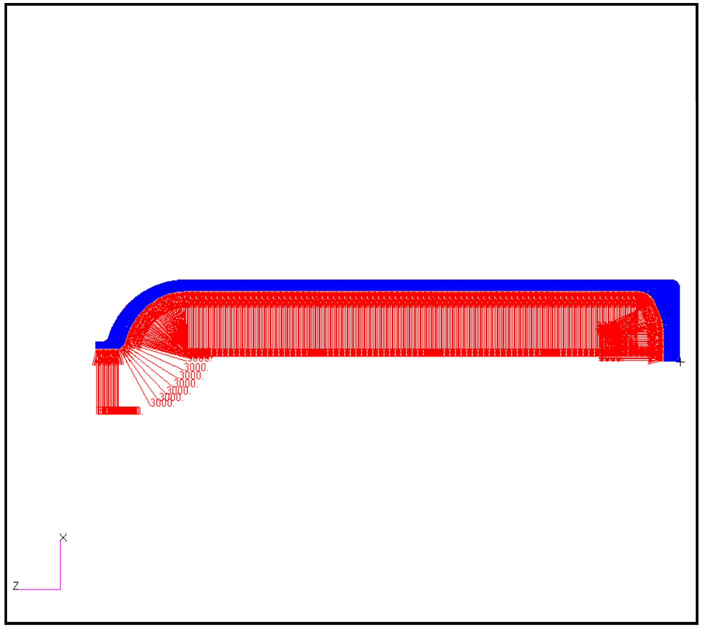
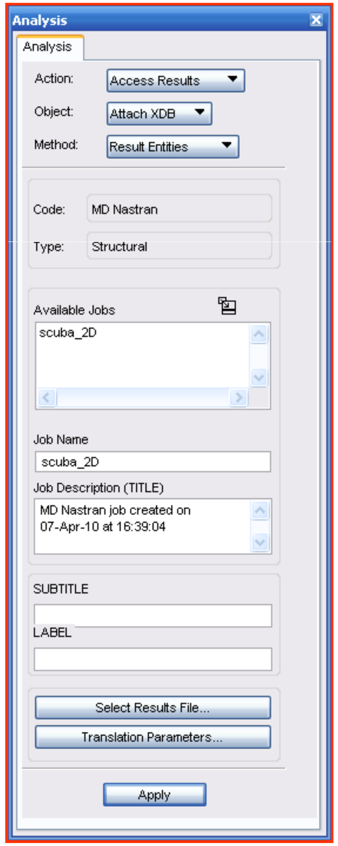


Attach the analysis results into Patran





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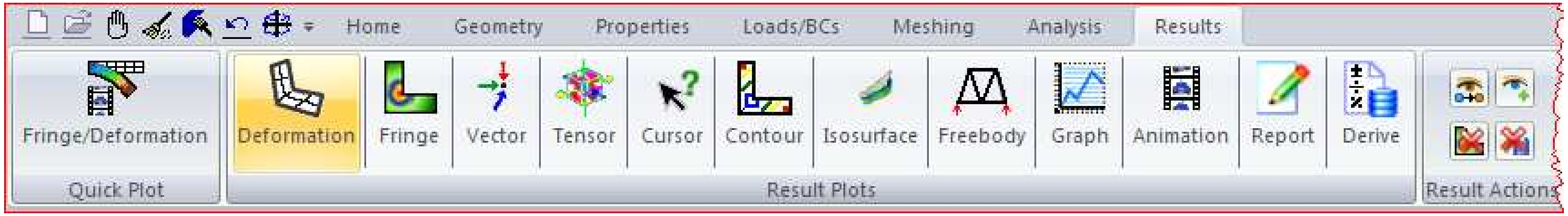
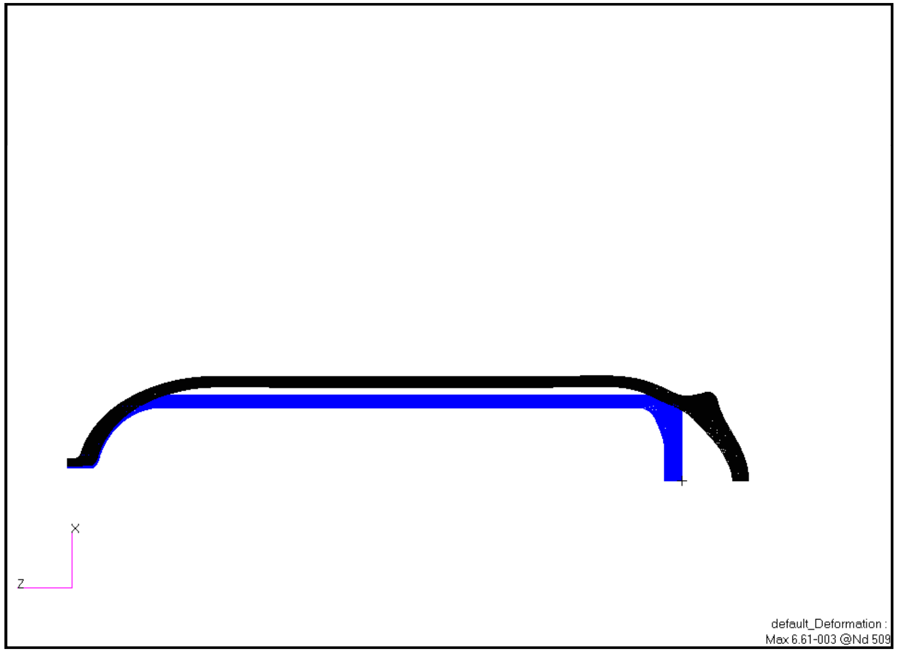
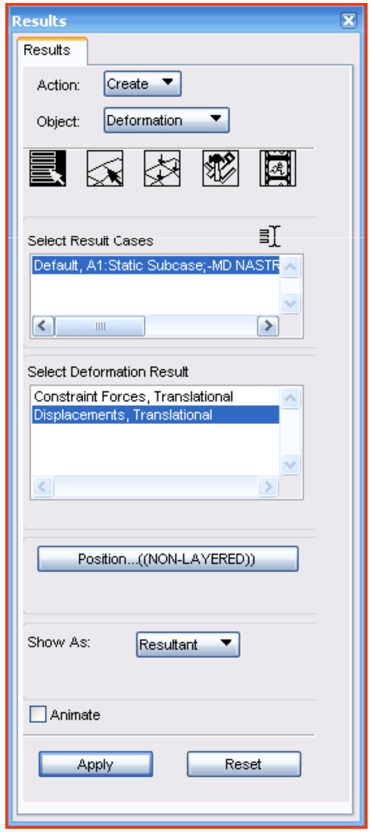


Create the deformation plot.

Maximum deformation is 0.007 inch which agrees with the previous two models.





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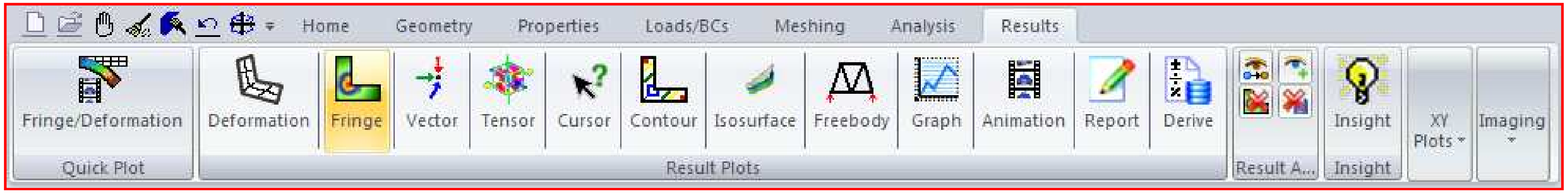
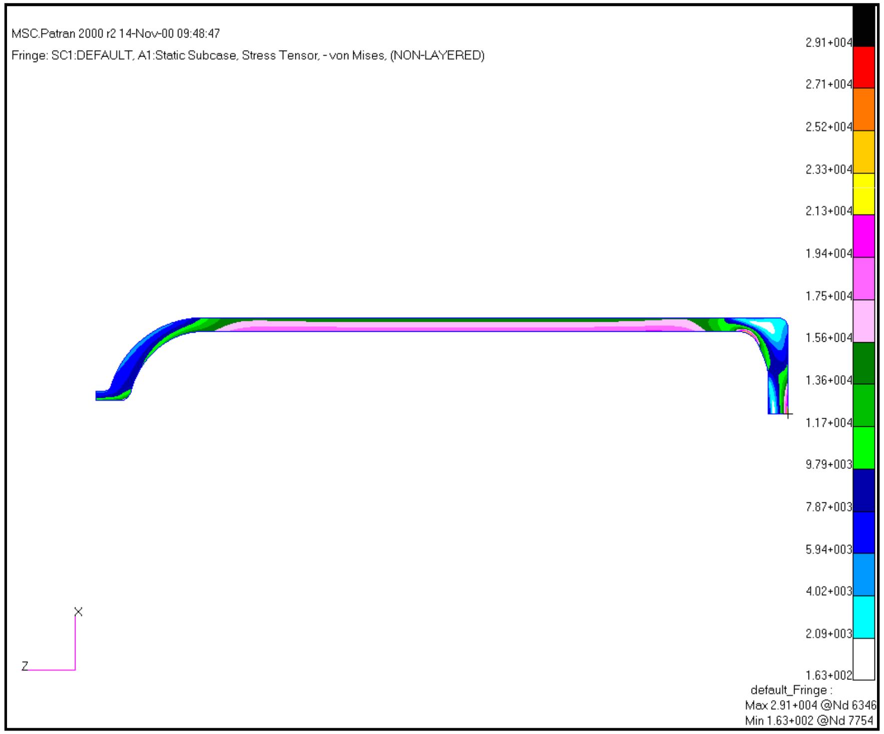
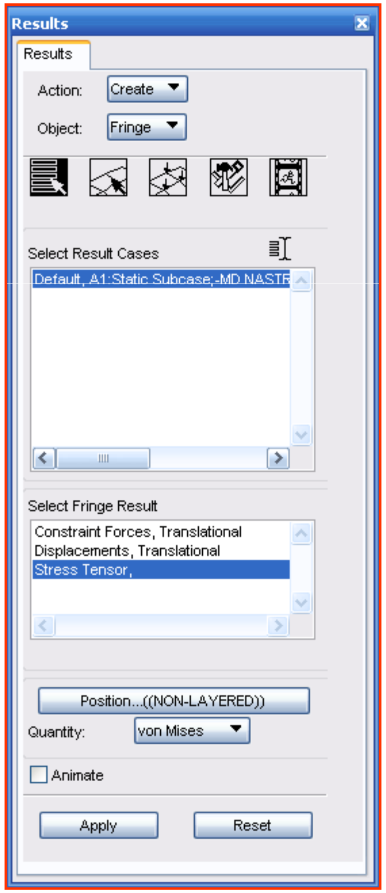


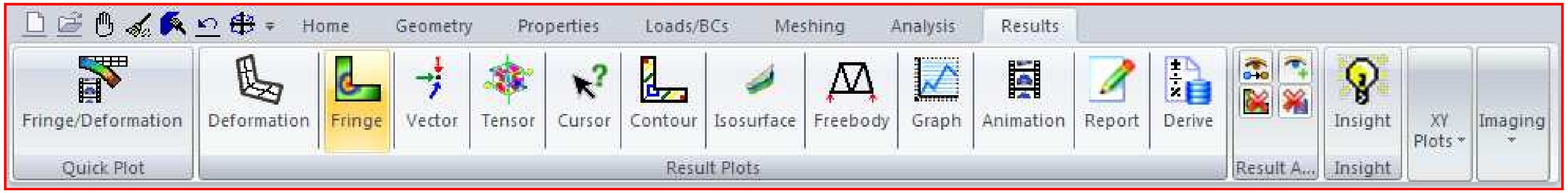
Plot the Von Mises stress.

The maximum Von Mises Stress is 29,100 psi



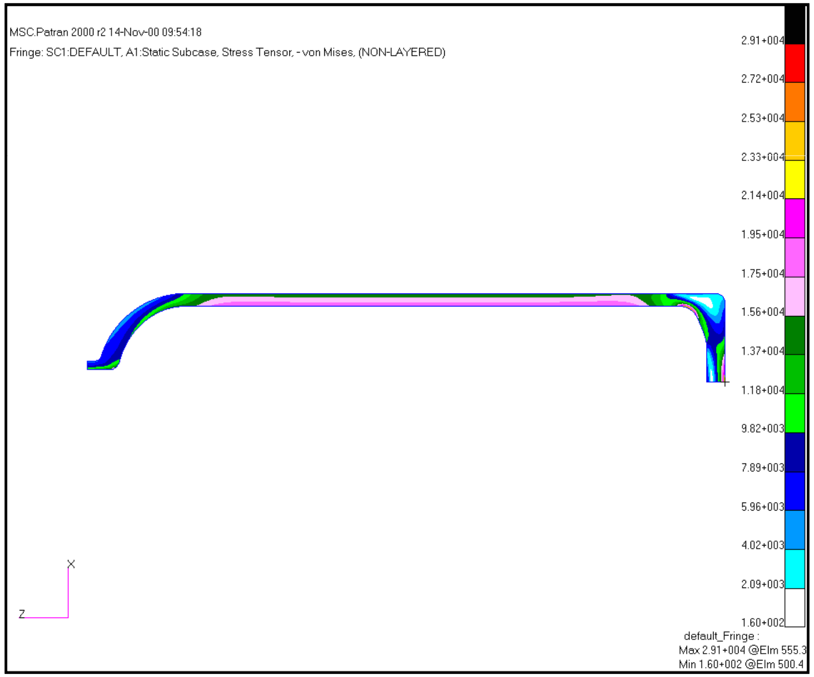


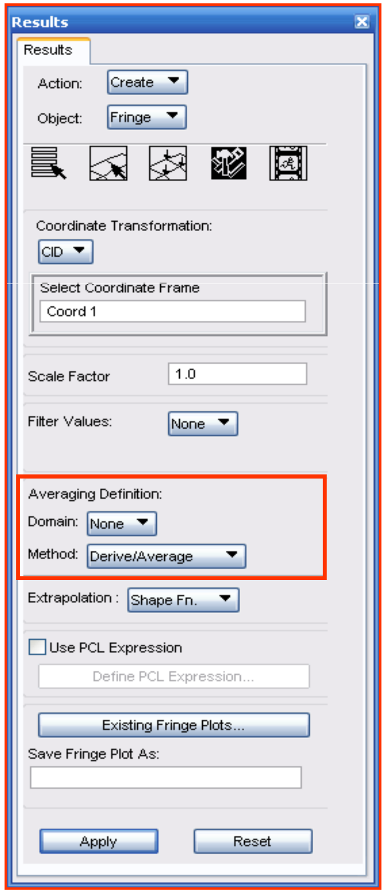
SCUBA TANK



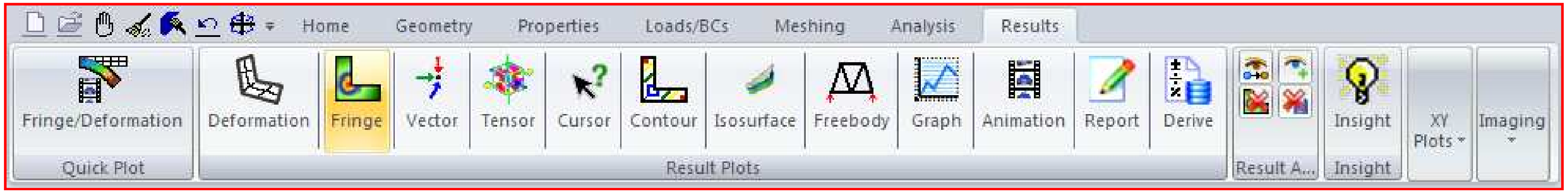
Turn off stress averaging.

The maximum Von Mises stress remains at 29,100 psi



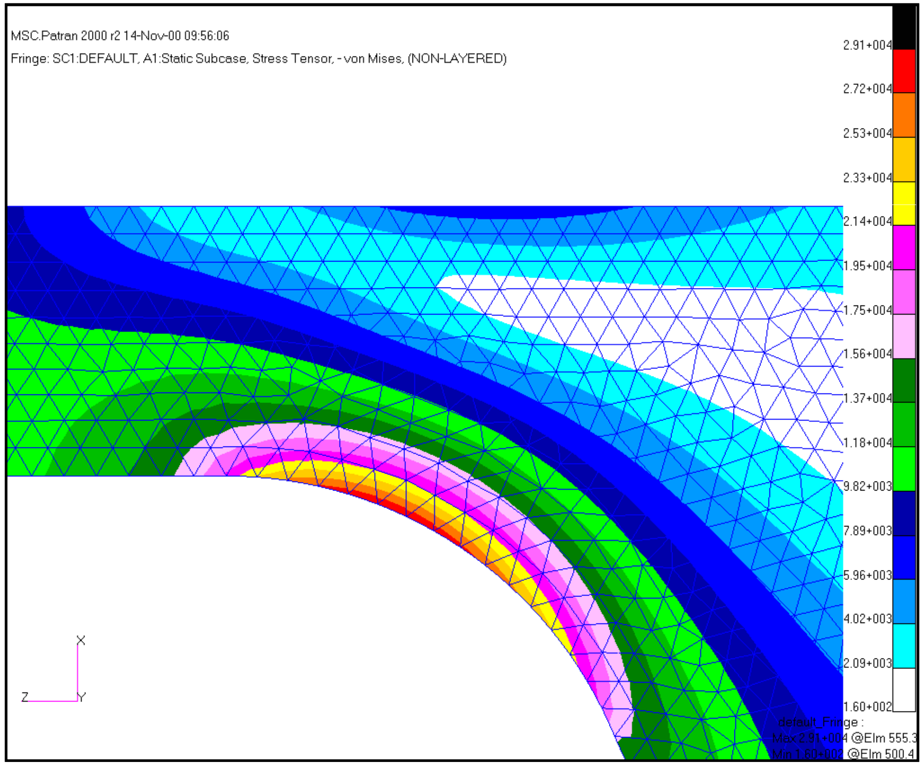


SCUBA TANK



Zoom in on the critical area.

Note that the un-averaged stress fringes are relatively smooth.



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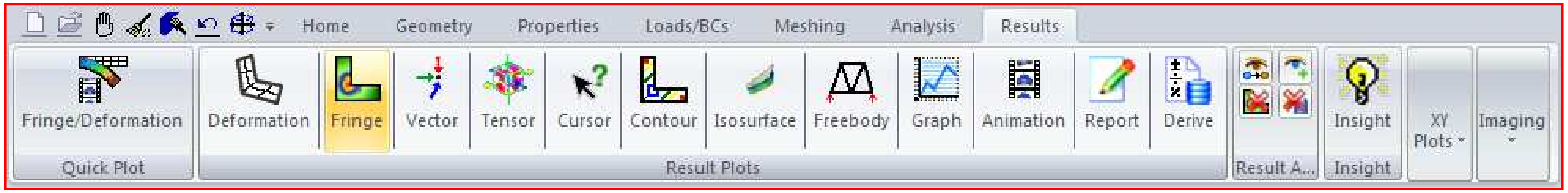
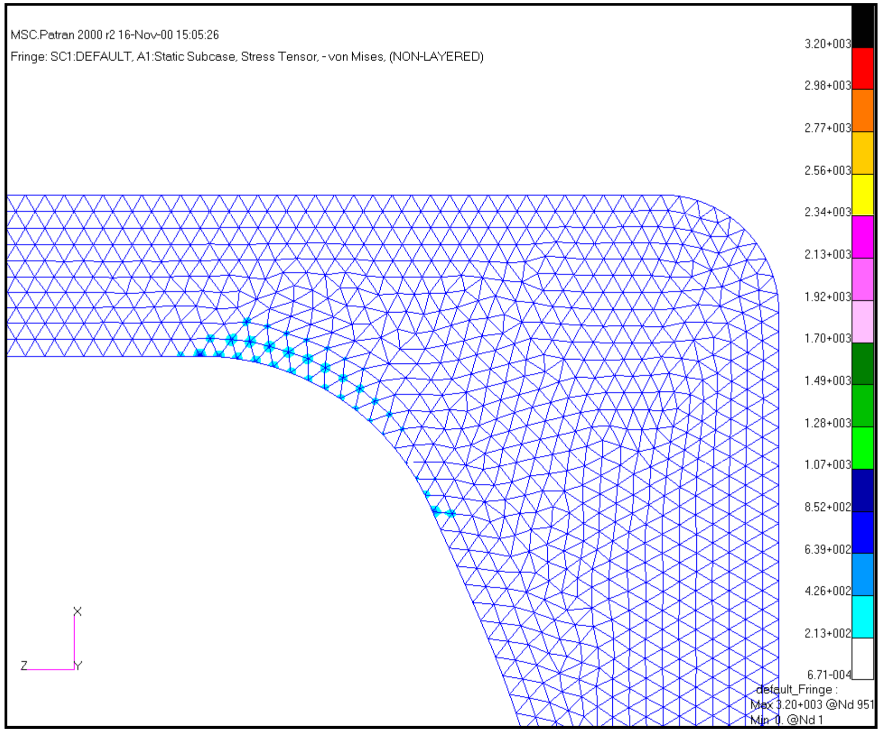
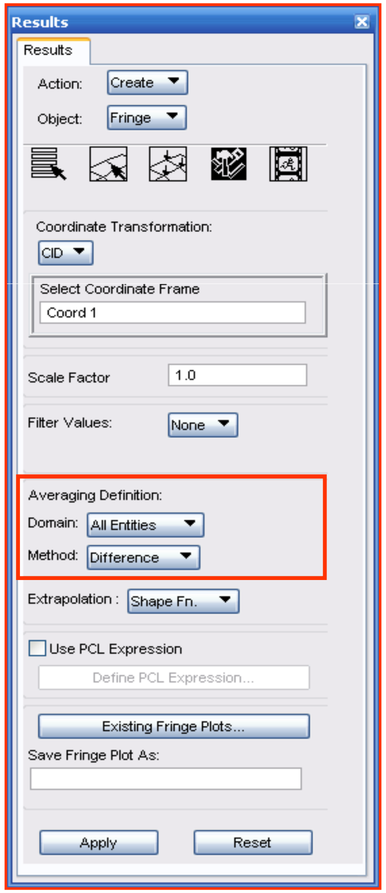


Plot the stress jumps across nodes.

The maximum stress difference in the critical area is near zero.





SCUBA TANK

- Scuba tank 2D axisymmetric analysis summary
  - The maximum Von Mises stress is 29,100 psi at the base of the tank near the fillet radius.
  - There are 10 elements through the thickness in this critical area. The stress gradient is represented reasonably well through the thickness.
  - The un-averaged stress fringe plot is very smooth, indicating that the mesh density is adequate.
  - The stress difference plot shows near zero values.
  - Using a 2D representation of the scuba tank, we were able to create a smaller model with a finer mesh compared to the 3D model.

EXERCISE

- Perform Workshop 9 “Support Bracket” in your exercise workbook.
- Optional:
  - Analyze the Scuba Tank covered in this section.