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Pressure Vessel Engineering Ltd. provides: ASME Vessel Code Calculations - Finite Element Analysis (FEA) - Solid Modeling / Drafting - Canadian Registration Number (CRN) Assistance

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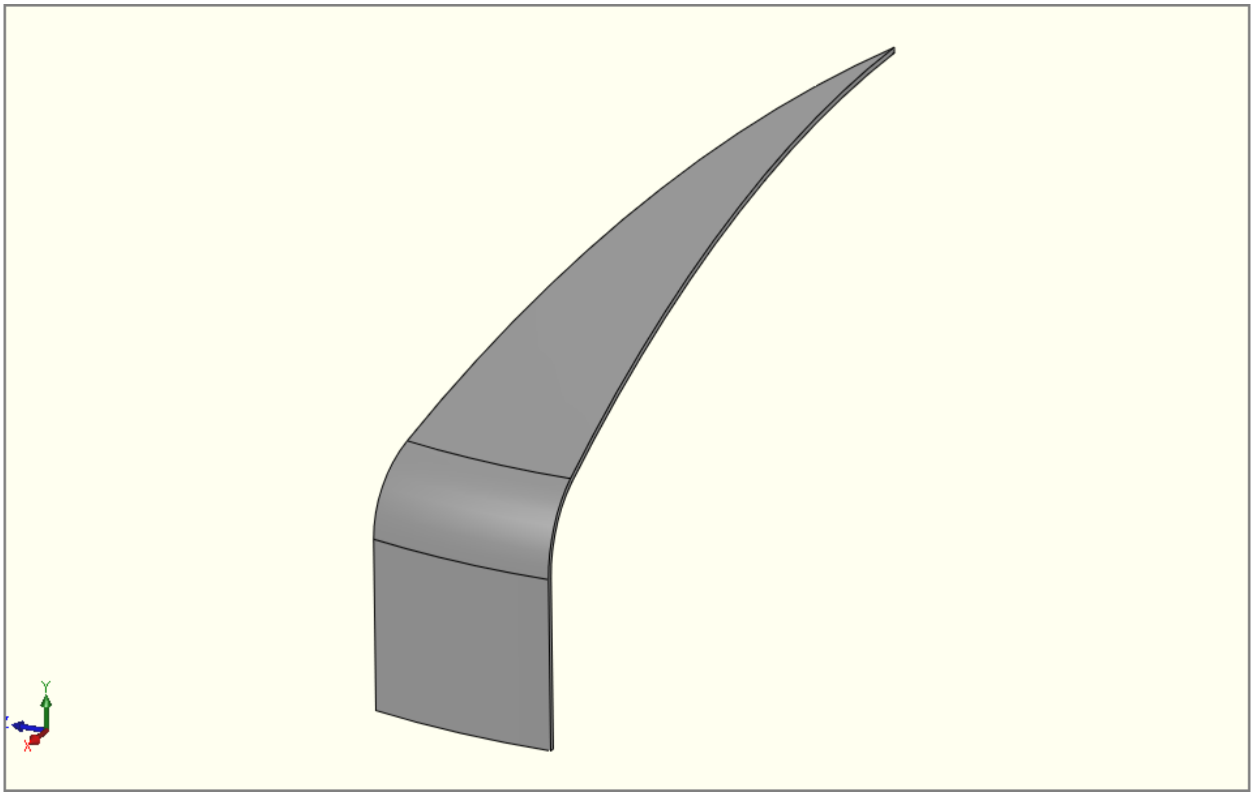
Finite Element Analysis Reaction Forces

Summary

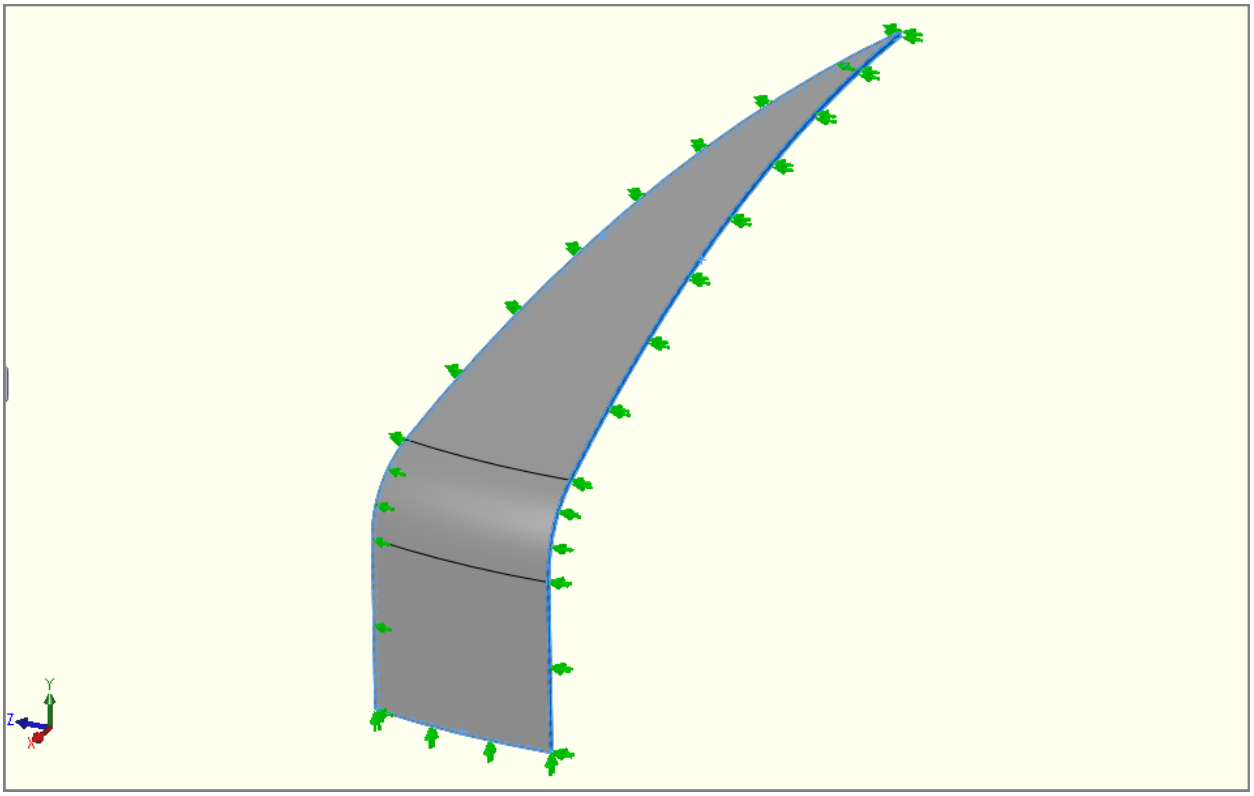
Reaction forces are the resulting loads seen at the restraints of a model being analyzed. They can be used to ensure an analysis is restrained from rigid body motion, and is static or in balance. The reaction forces are equal and opposite to the sum of the applied loads.

This report shows typical methods used for restraining models and compares the resulting displacement and stresses of identical models both in balance and out of balance.

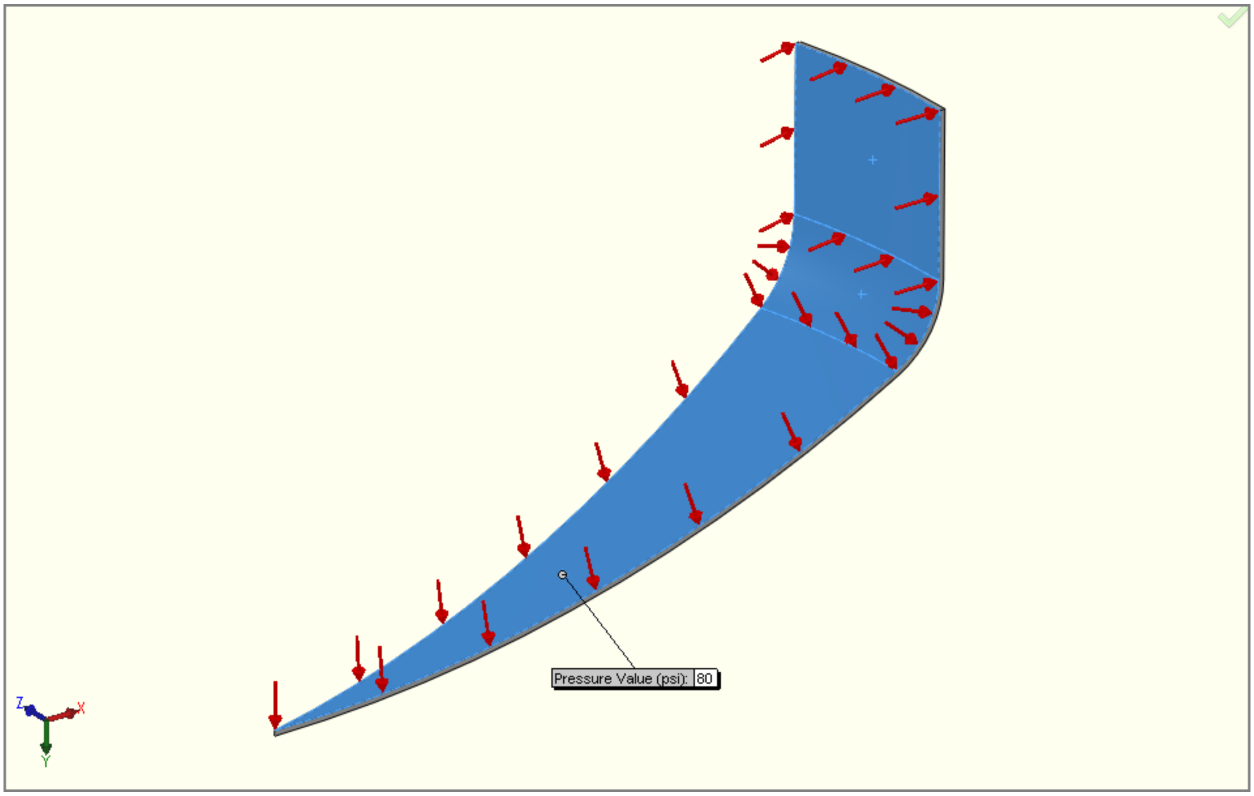
Example #1: F&D Head - 15 Degree Swept Model (Checking Static Condition)



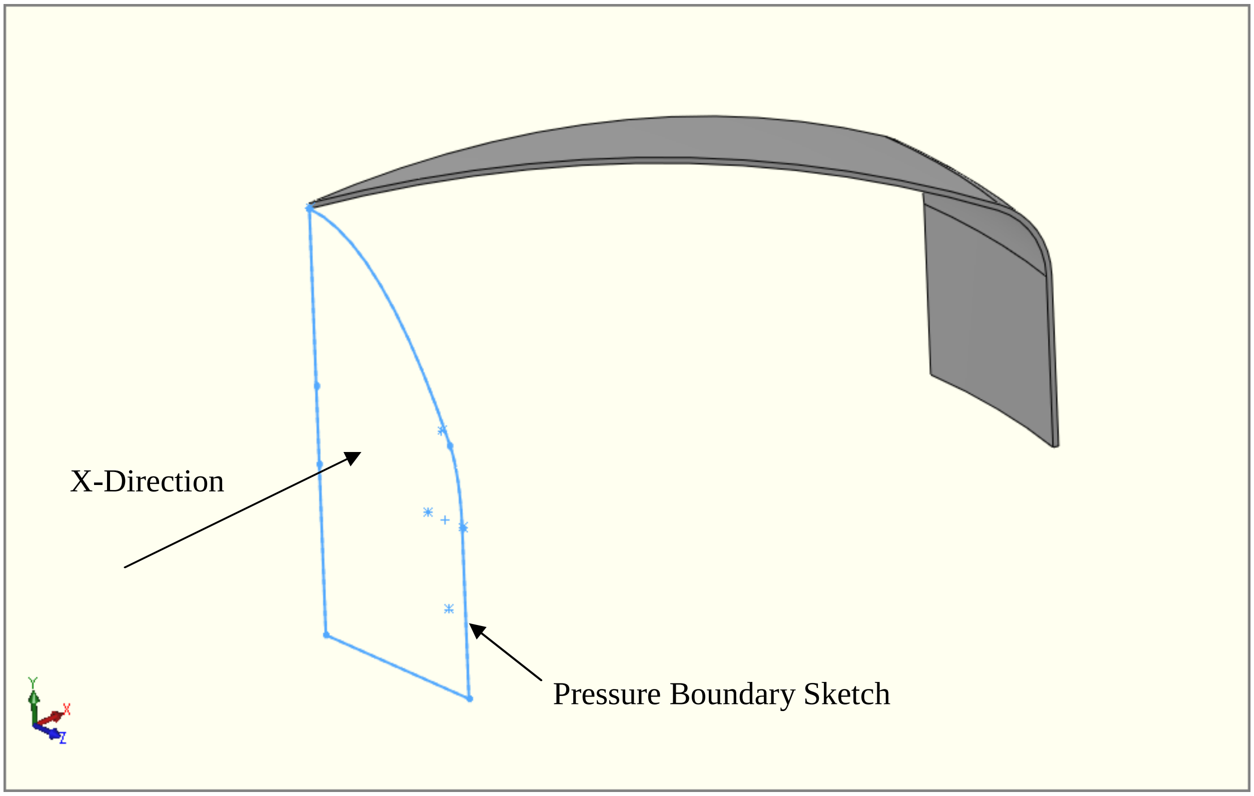
A 15 degree sweep of a F&D head is used in this example to demonstrate the method used for checking that a model is static or in balance.



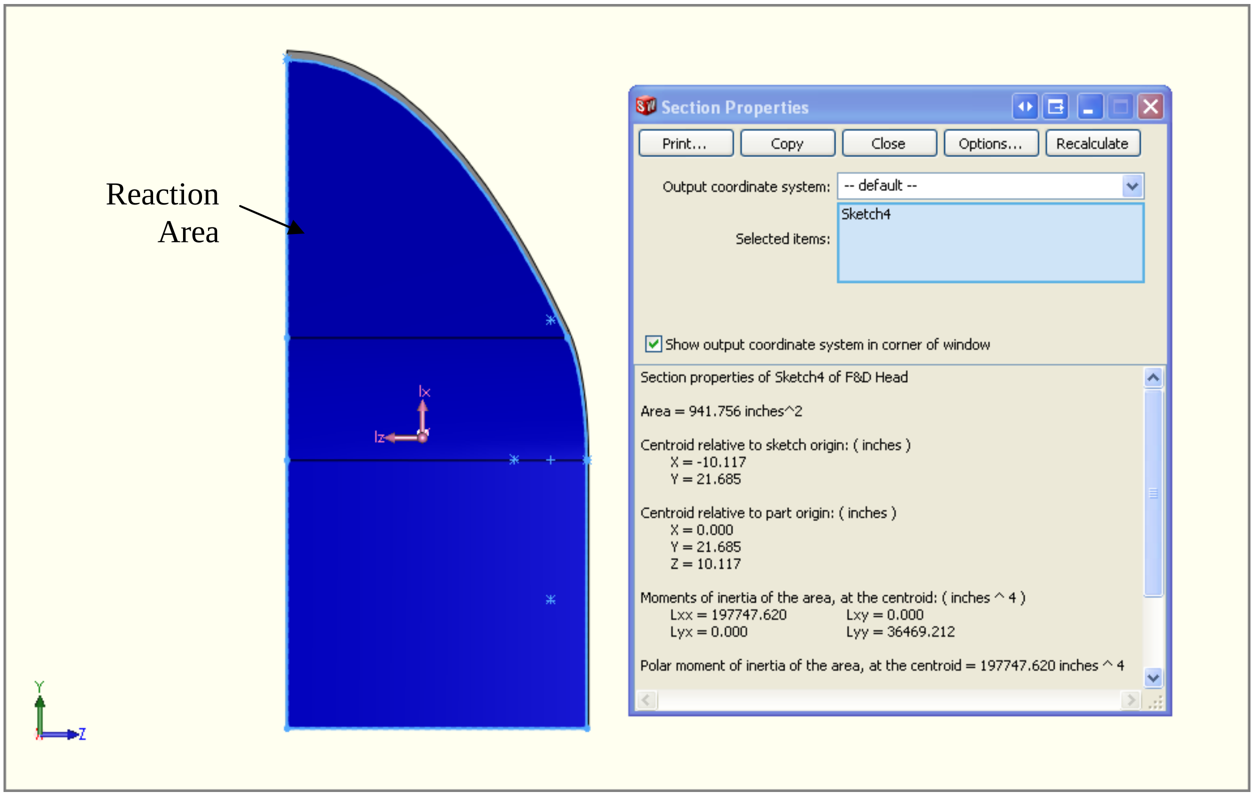
The head is restrained using symmetry on all cut plane surfaces. These restraints allow the model to be held in model space while still being able to deform due to applied loads. The restraints must be applied in each of the three primary directions to avoid rigid body motion.


Pressure Value (psi): 80

An 80 psi pressure is applied normal to on all internal surfaces. The reaction resultant is calculated for each primary direction.



The X component of the reaction resultant can be found by looking at the model along the x-axis or normal to the YZ plane. The pressure boundary sketch outlines the area of applied pressure.



Output coordinate system: -- default --

Selected items: Sketch4

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```
Section properties of Sketch4 of F&D Head

Area = 941.756 inches^2

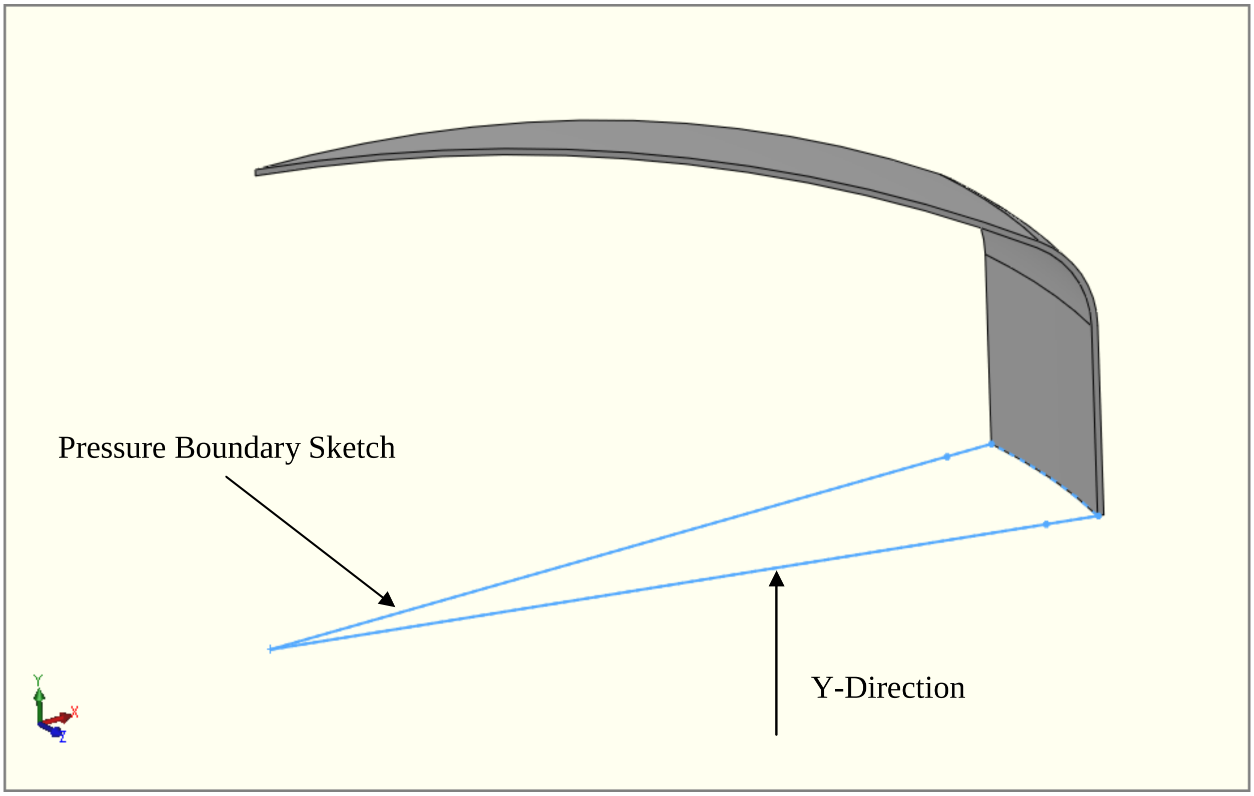
Centroid relative to sketch origin: ( inches )
      X = -10.117
      Y = 21.685

Centroid relative to part origin: ( inches )
      X = 0.000
      Y = 21.685
      Z = 10.117

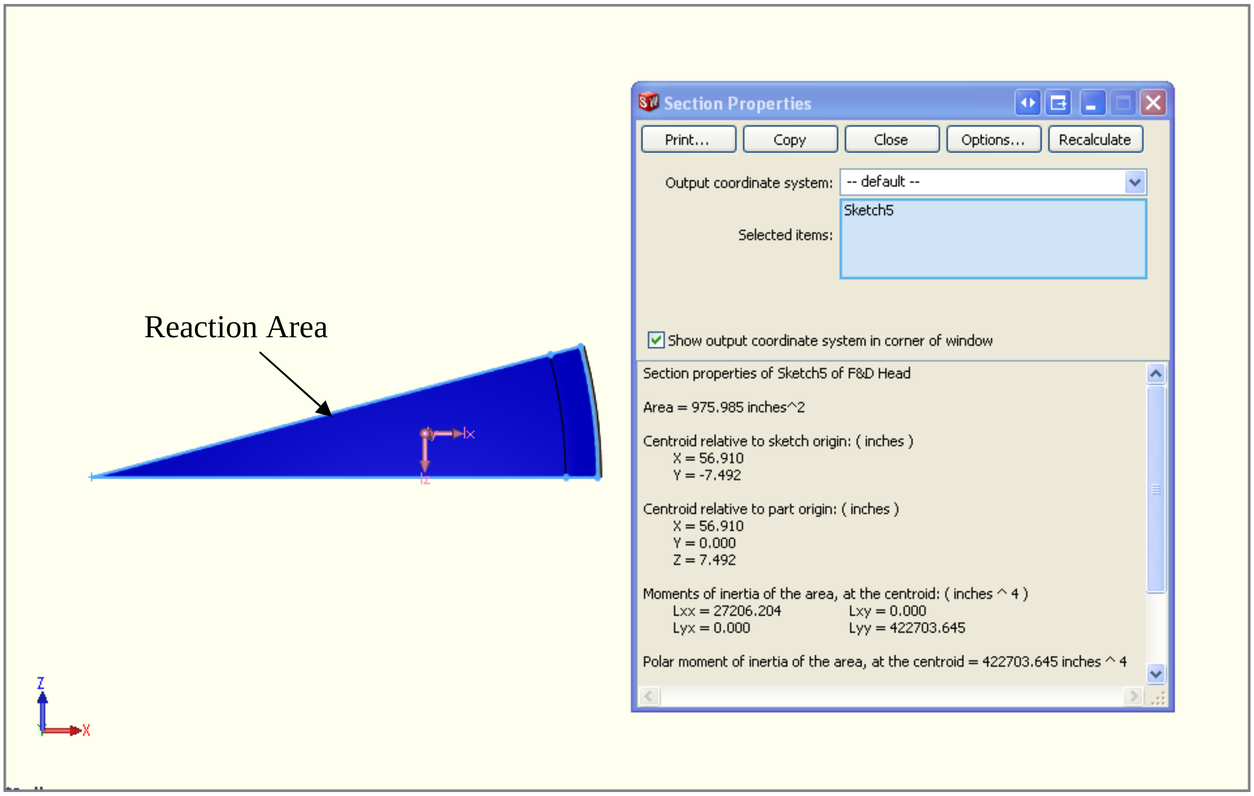
Moments of inertia of the area, at the centroid: ( inches ^ 4 )
      Lxx = 197747.620          Lxy = 0.000
      Lyx = 0.000               Lyy = 36469.212

Polar moment of inertia of the area, at the centroid = 197747.620 inches ^ 4
```

The above image shows the X reaction area normal to the YZ plane. The X reaction force is calculated by multiplying the reaction area in the x-direction by the applied pressure.
X Reaction = (941.76 in^2) * (80 lb/in^2) = 75,340.8 lb



The Y component of the reaction resultant can be found by looking at the model along the y-axis or normal to the XZ plane.



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Output coordinate system: -- default --
Selected items: Sketch5

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Section properties of Sketch5 of F&D Head

Area = 975.985 inches^2

Centroid relative to sketch origin: ( inches )
     X = 56.910
     Y = -7.492

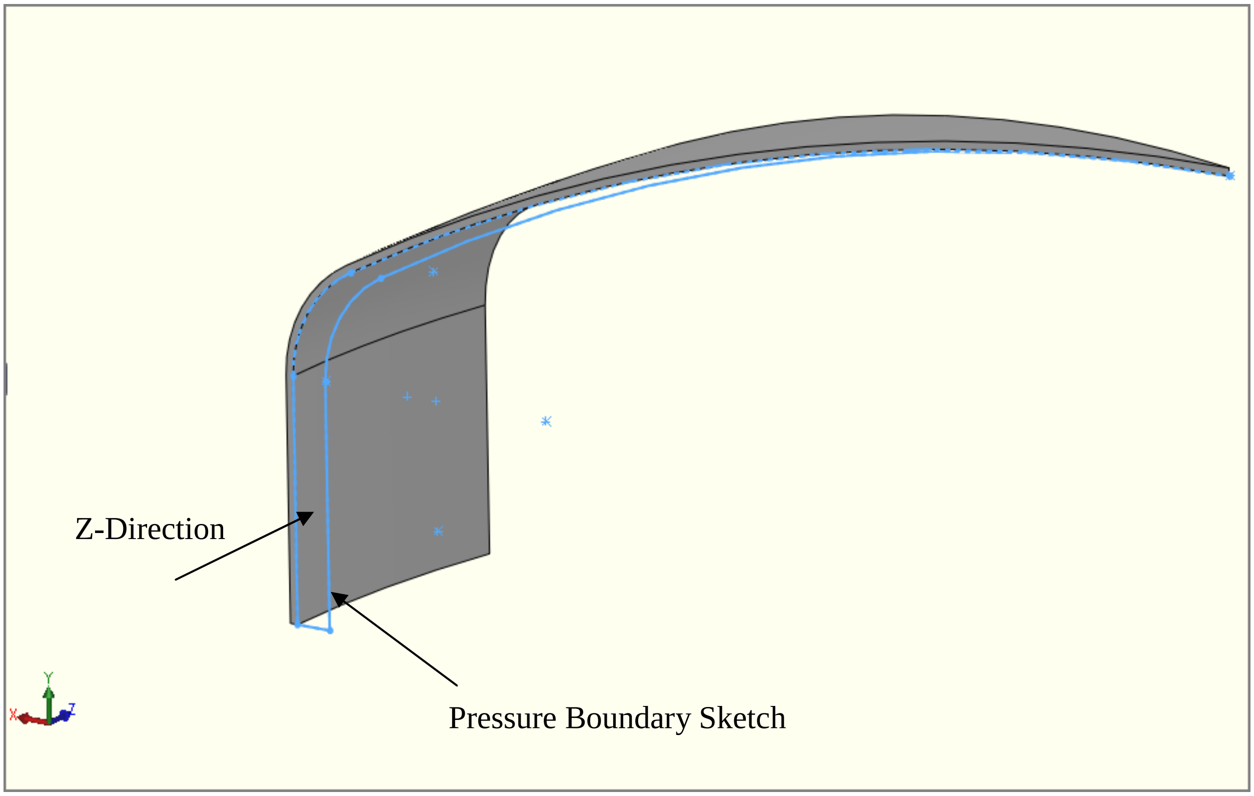
Centroid relative to part origin: ( inches )
     X = 56.910
     Y = 0.000
     Z = 7.492

Moments of inertia of the area, at the centroid: ( inches ^ 4 )
     Lxx = 27206.204            Lxy = 0.000
     Lyx = 0.000                Lyy = 422703.645

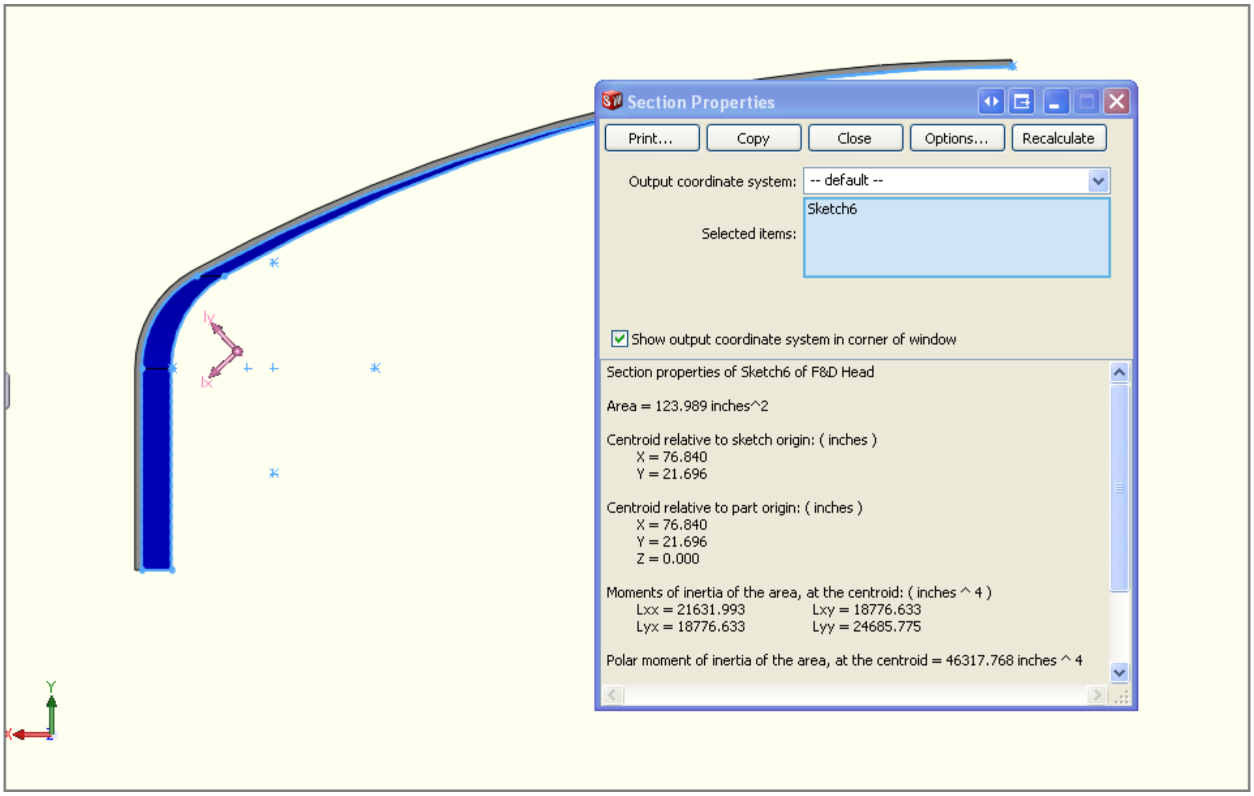
Polar moment of inertia of the area, at the centroid = 422703.645 inches ^ 4
```

The above image shows the Y reaction area normal to the XZ plane. The Y reaction force is calculated by multiplying the reaction area in the y-direction by the applied pressure.

Y Reaction = (975.99 in^2) * (80 lb/in^2) = 78,079.2 lb



The Z component of the reaction resultant can be found by looking at the model along the z-axis or normal to the XY plane.



Output coordinate system: -- default --

Selected items: Sketch6

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```
Section properties of Sketch6 of F&D Head

Area = 123.989 inches^2

Centroid relative to sketch origin: ( inches )
      X = 76.840
      Y = 21.696

Centroid relative to part origin: ( inches )
      X = 76.840
      Y = 21.696
      Z = 0.000

Moments of inertia of the area, at the centroid: ( inches ^ 4 )
      Lxx = 21631.993          Lxy = 18776.633
      Lyx = 18776.633          Lyy = 24685.775

Polar moment of inertia of the area, at the centroid = 46317.768 inches ^ 4
```

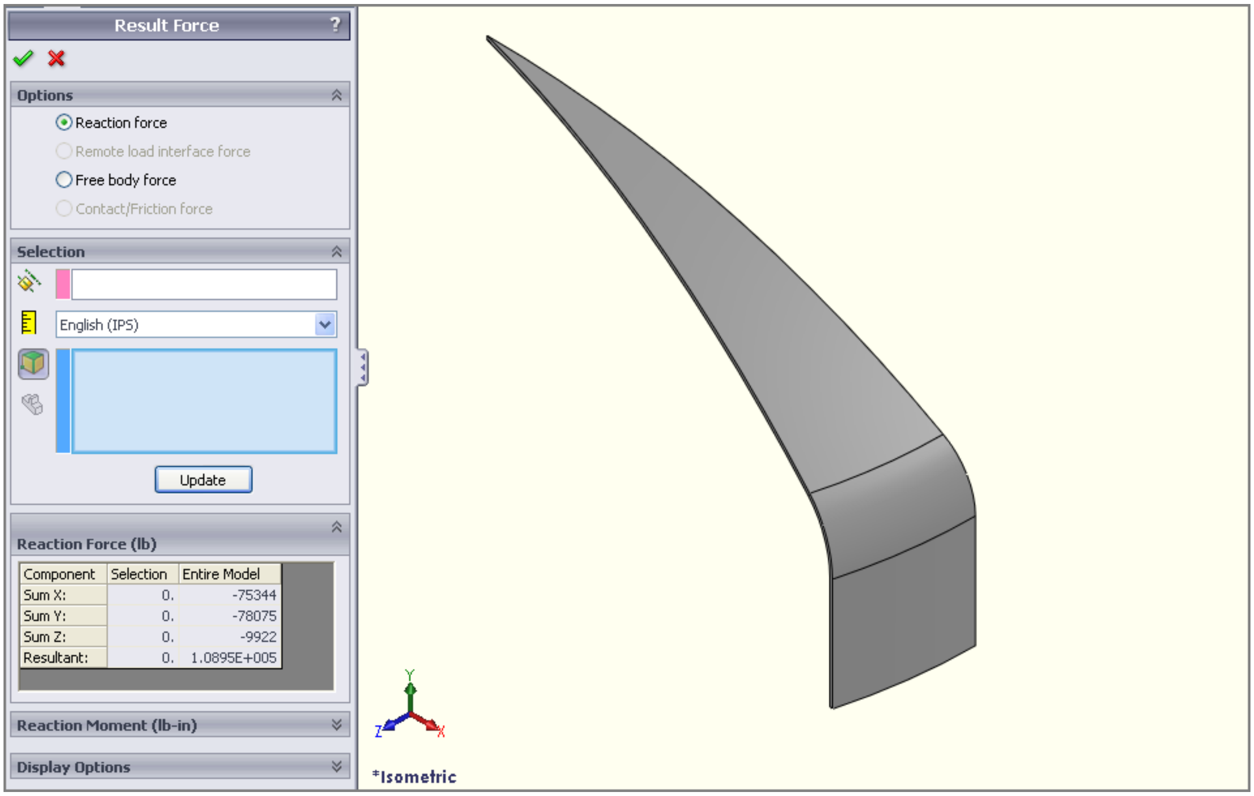
The above image shows the Z reaction area normal to the XY plane. The Z reaction force is calculated by multiplying the reaction area in the z-direction by the applied pressure.

Z Reaction = (123.99 in^2) * (80 lb/in^2) = 9,919.2 lb

Theoretical Reaction Force Components:
X Reaction = -75,340.8 lb
Y Reaction = -78,079.2 lb
Z Reaction = -9,919.2 lb

Note: Component directions are generated by inspection of the pressure

Theoretical Resultant = SQRT ((-75,340.8 lb)^2 + (-78,079.2 lb)^2 + (-9,919.2 lb)^2)
Theoretical Resultant = 108,954 lb



● Reaction force
○ Remote load interface force
○ Free body force
○ Contact/Friction force

English (IPS)

Reaction Force (lb)

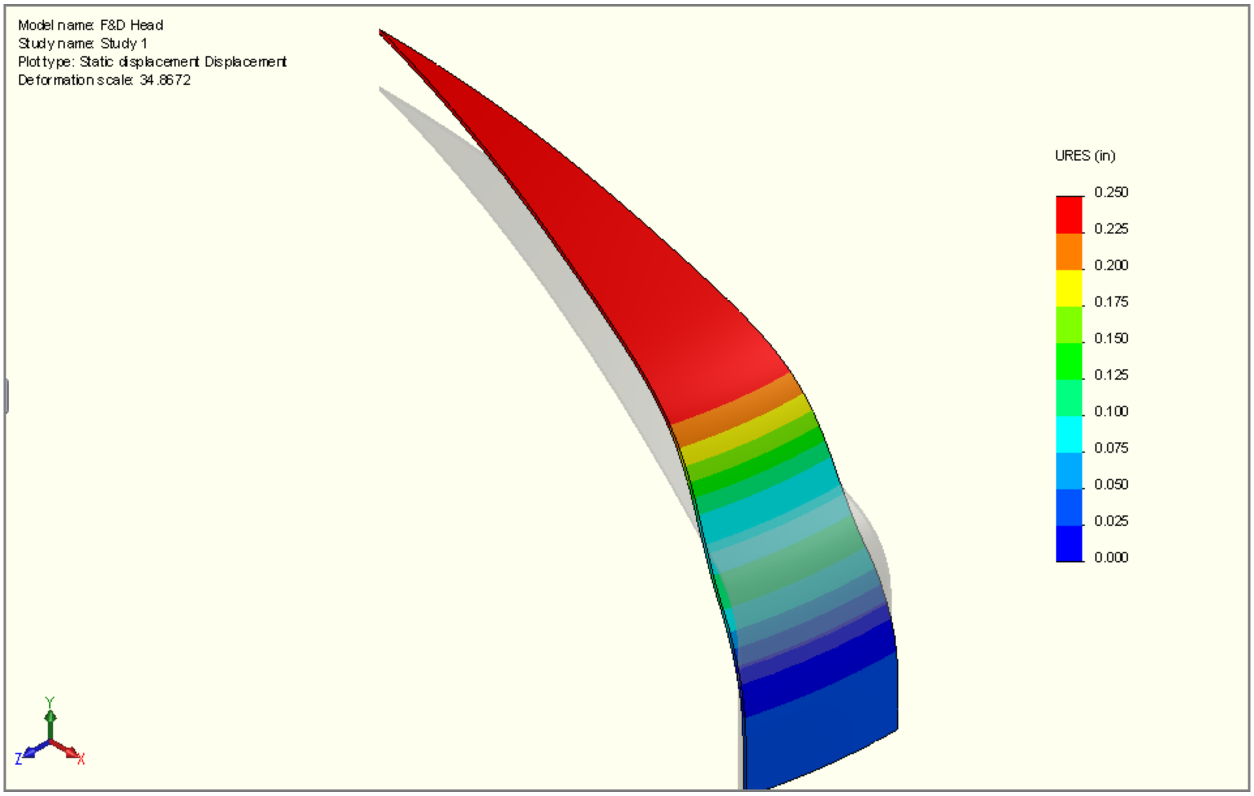
Component	Selection	Entire Model
Sum X:	0.	-75344
Sum Y:	0.	-78075
Sum Z:	0.	-9922
Resultant:	0.	1.0895E+005

The reaction components can be reported from COSMOS and measured against the theoretical values.

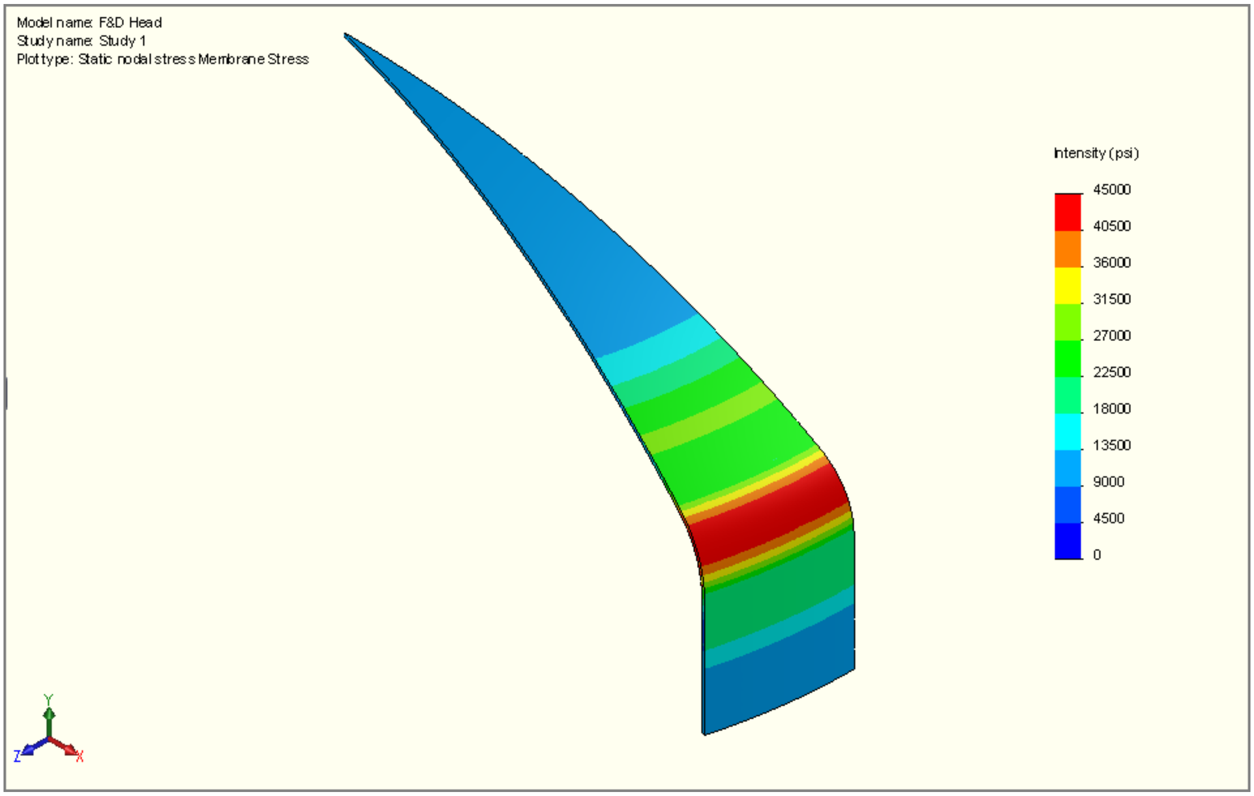
Actual Reaction Force Components:
X Reaction = -75,344 lb
Y Reaction = -78,075 lb
Z Reaction = -9,922 lb
Actual Resultant = SQRT ((-75,344 lb)^2 + (-78,075 lb)^2 + (-9,922 lb)^2)
Actual Resultant = 108,950 lb

Error Calculation:
Error = ((Resultant Theoretical – Resultant Actual) / Resultant Actual) * 100%
Error = ((108,954 lb – 108,950 lb) / 108,950 lb) * 100%
Error = 0.00 %

From the error calculation we can see that the actual results fall within 2% of the theoretical results. This criteria determines if a model is acceptable for analysis of stresses and displacements.

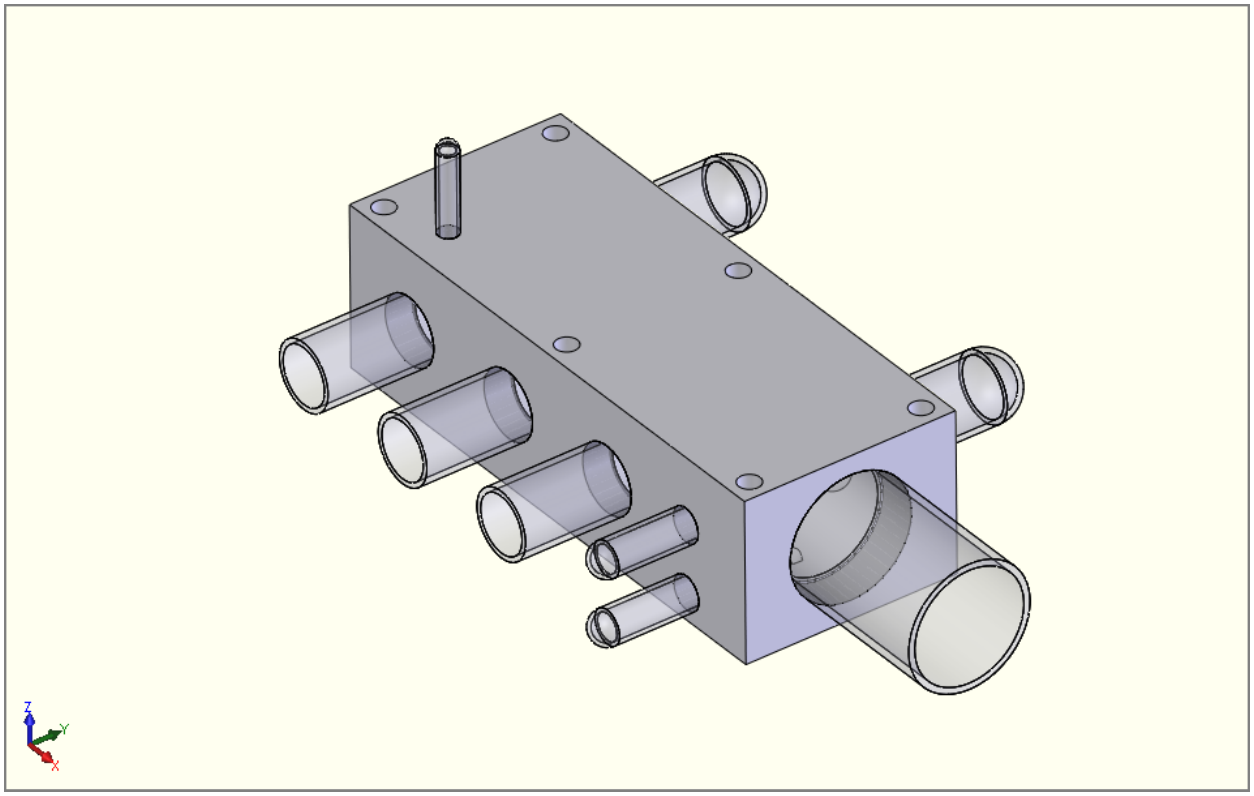


The model is in balance and the stresses and displacements can be analyzed to prove the acceptability of the design. The above view shows the displacement of the F&D head. This displacement is typical for F&D heads.

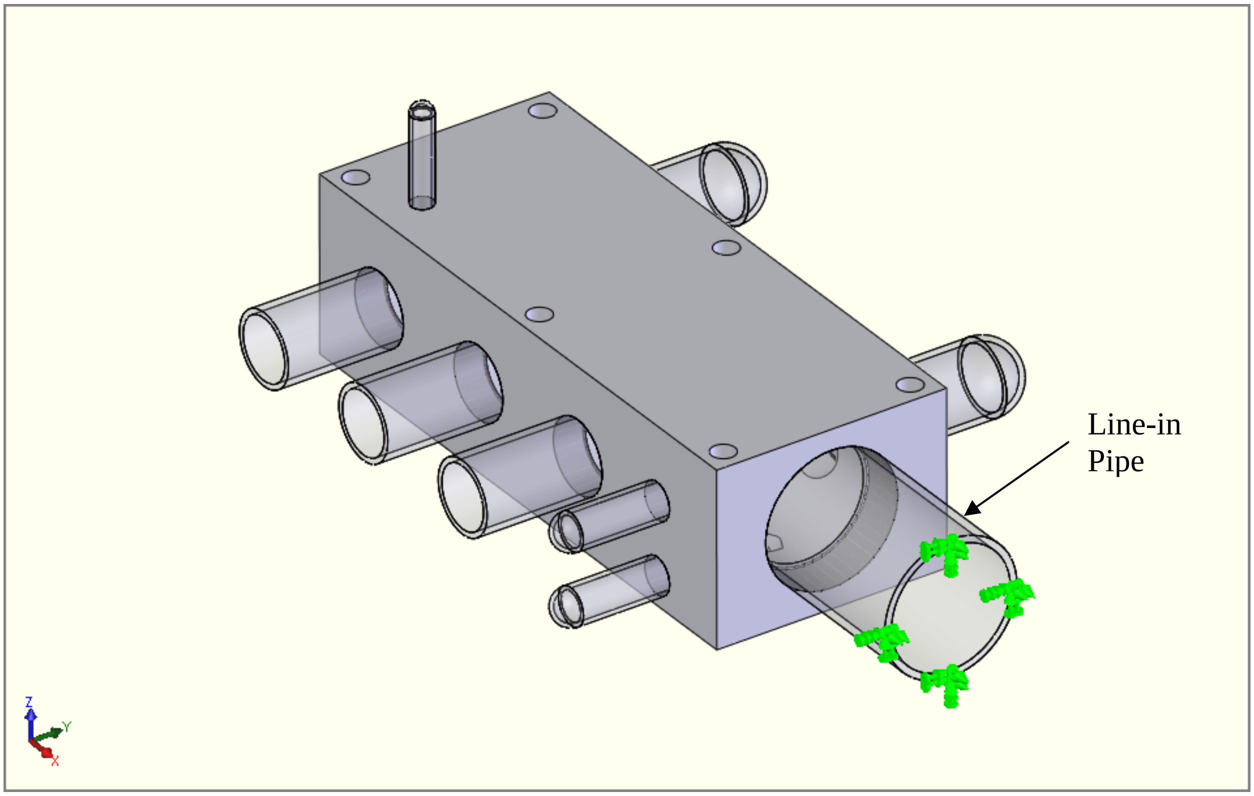


The above view shows the stress in the head. The head stresses are radial which indicates the model is reacting correctly to the applied pressure.

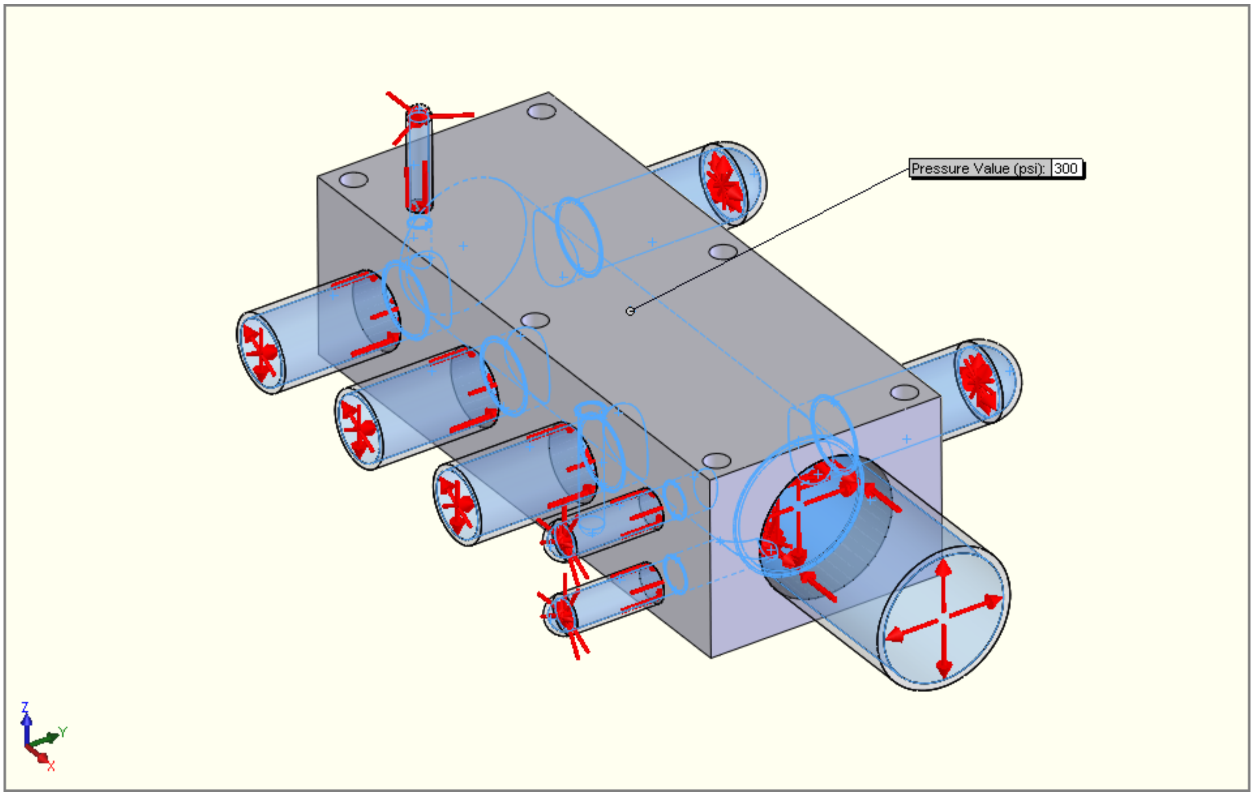
Example #2: Hydraulic Manifold Block



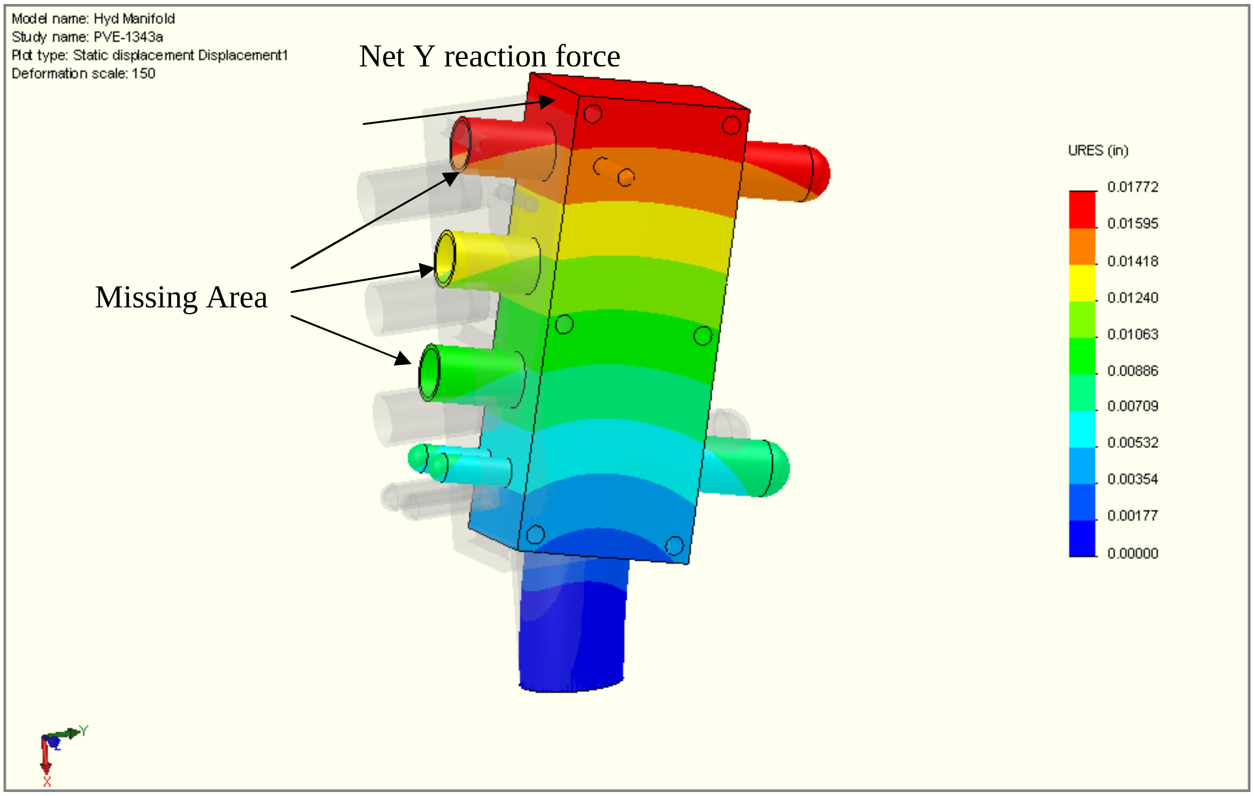
A complete hydraulic manifold block is used in this example to demonstrate how an out of balance model affects model displacement and stress results. Pipes and pipe caps have been added to simulate loads applied at the port locations.



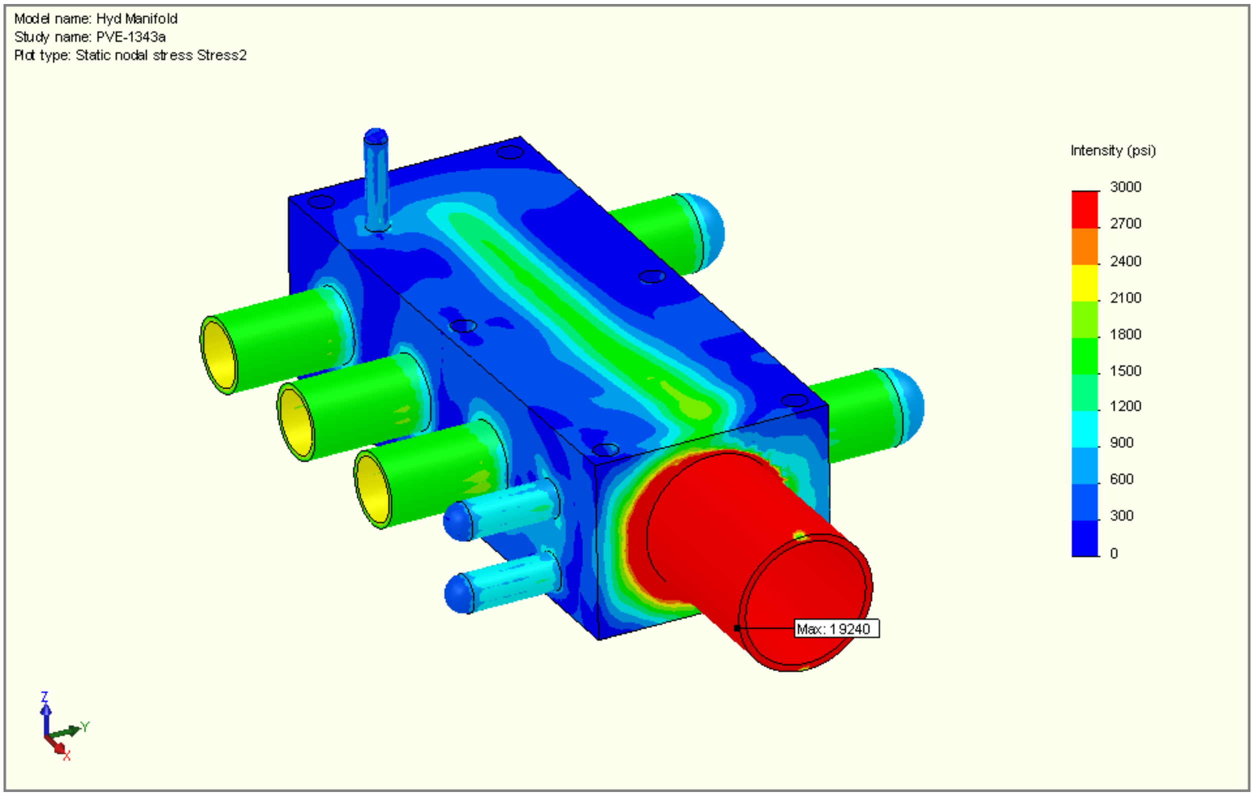
A fixed restraint is placed on the end face of the in-line pipe. Applying this restraint to the pipe end allows the hydraulic manifold block to deform without any undue restraints.


Pressure Value (psi): 300

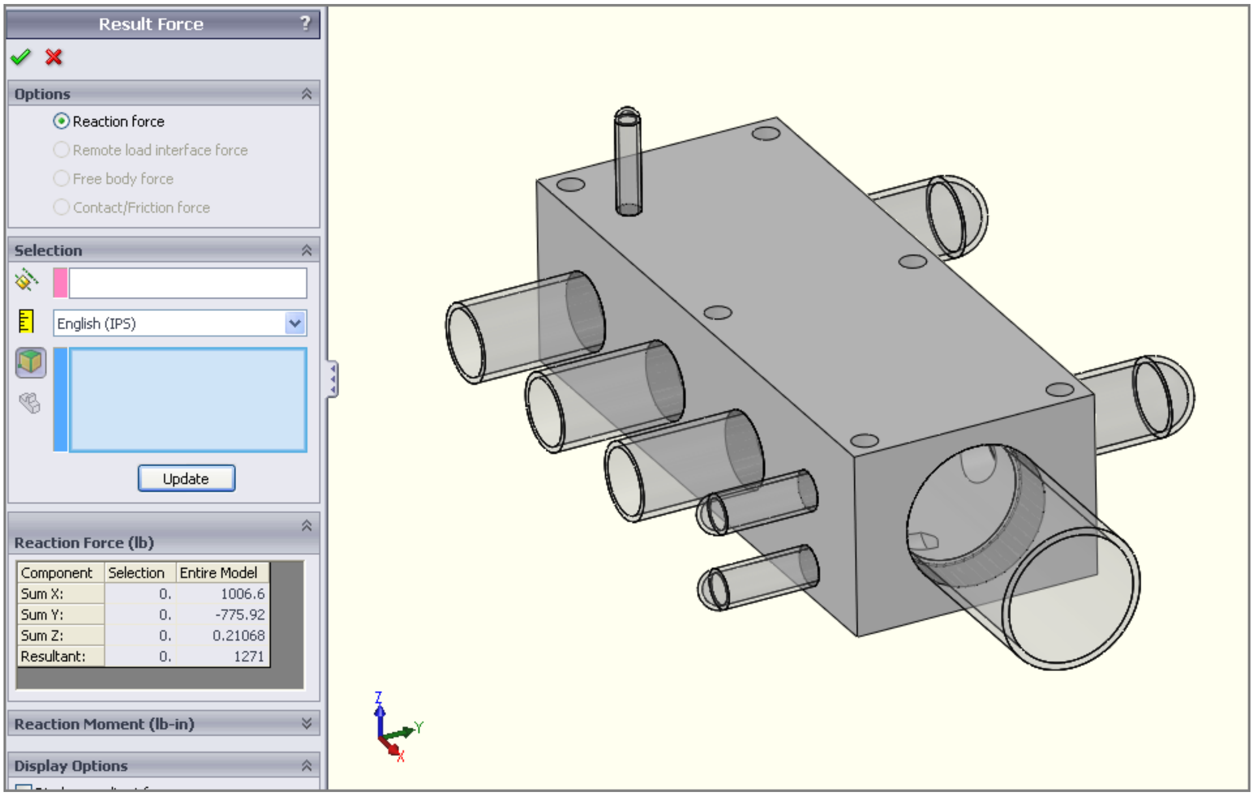
All internal cavity surfaces are pressurized to 300 psi. In this example the model is not sectioned using symmetry or other means. This requires the model to be closely examined for missing areas. Missing areas will unbalance the internal forces due to the pressure.



Without observing the reaction forces it is evident that the deformation is not as expected. The entire block begins to rotate about its fixed restraint. The missing area on the left side of the model results in greater forces (due to pressure) in the positive y direction than the negative y.



Large stresses are generated in the line-in pipe due to the resulting moment shown in the previous figure. These results indicate that the model is out of balance.



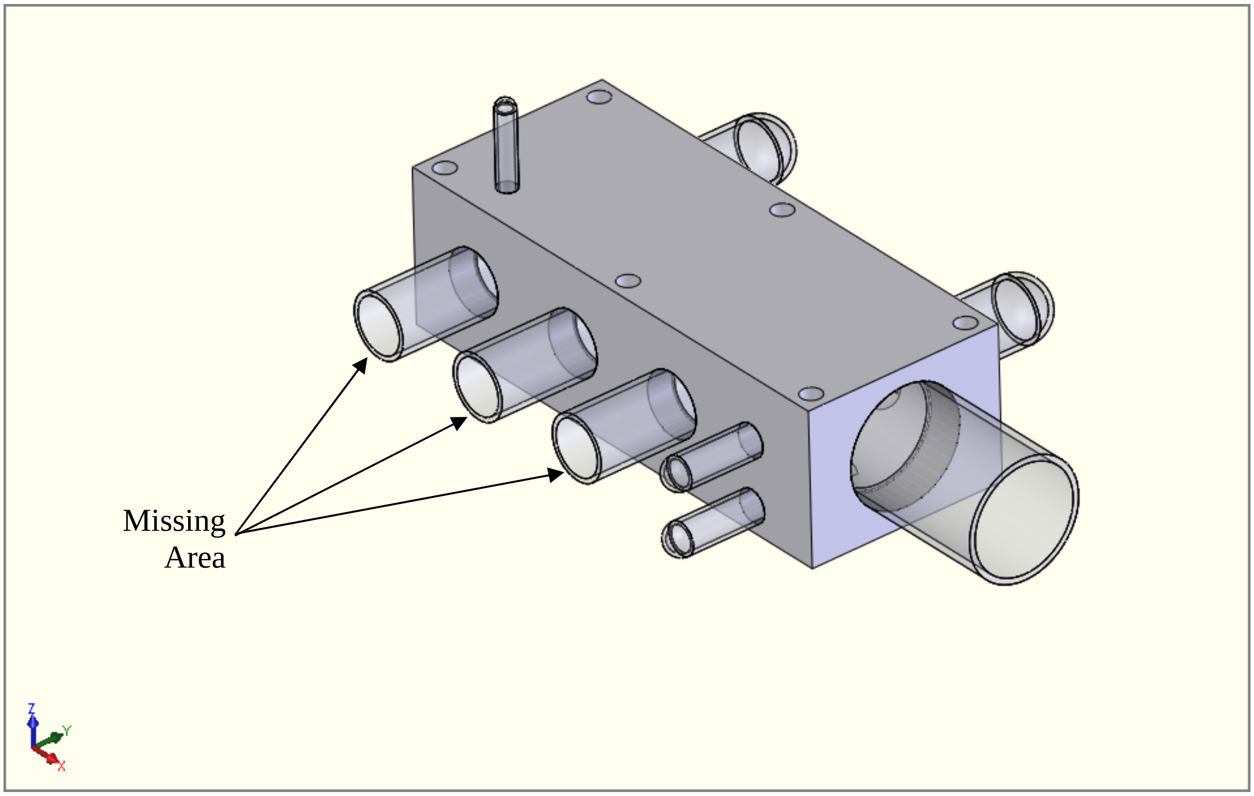
● Reaction force
○ Remote load interface force
○ Free body force
○ Contact/Friction force

English (IPS)

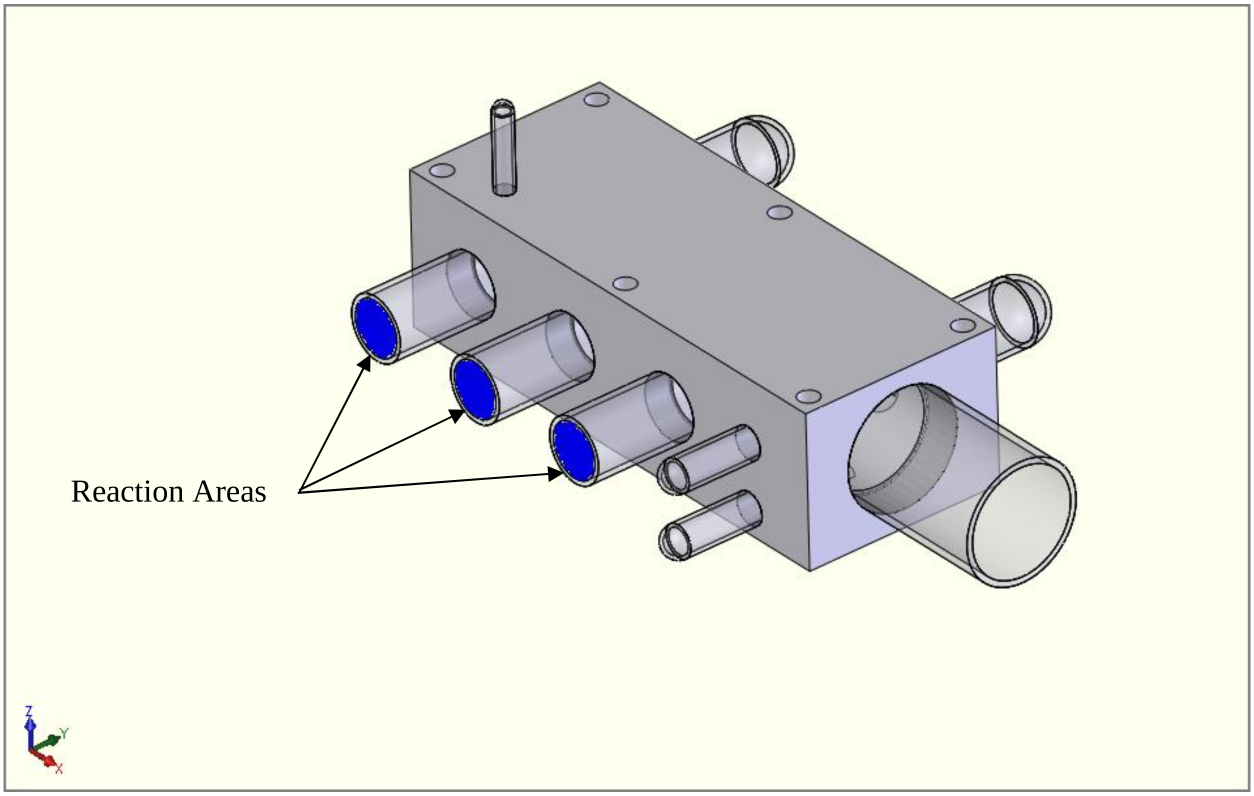
Reaction Force (lb)

Component	Selection	Entire Model
Sum X:	0.	1006.6
Sum Y:	0.	-775.92
Sum Z:	0.	0.21068
Resultant:	0.	1271

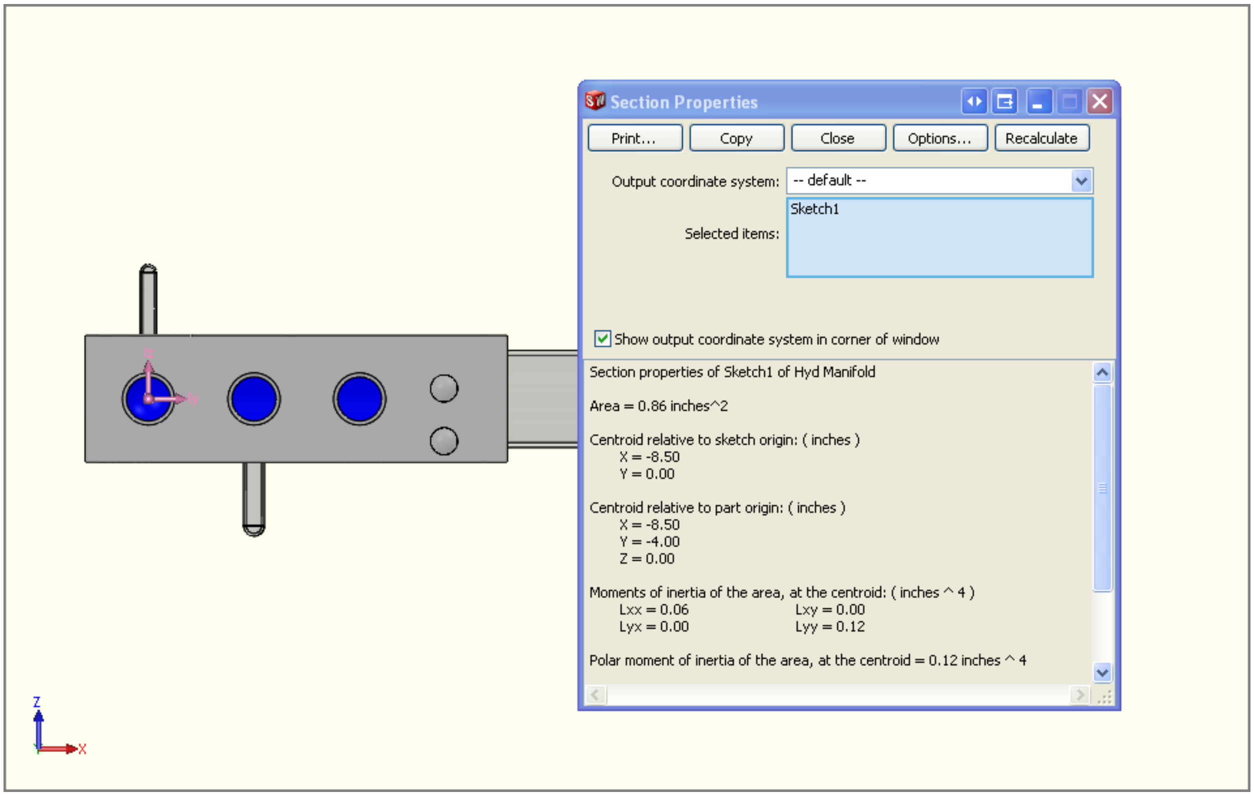
The reported reactions forces from COSMOS for this example are non-zero values in the X and Y directions. The model is not balanced and the displacement and stress results are not valid.



The reaction forces unaccounted for are generated by unbalanced internal areas. The area on the right of the model is greater than that of the left. When forces are calculated by multiplying these areas by the internal pressure it is evident that the net reaction force will not be zero.



The reaction force in the y-direction is equal to the sum of all 3 areas multiplied by the internal pressure.



Output coordinate system: -- default --

Selected items: Sketch1

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```
Section properties of Sketch1 of Hyd Manifold

Area = 0.86 inches^2

Centroid relative to sketch origin: ( inches )
     X = -8.50
     Y = 0.00

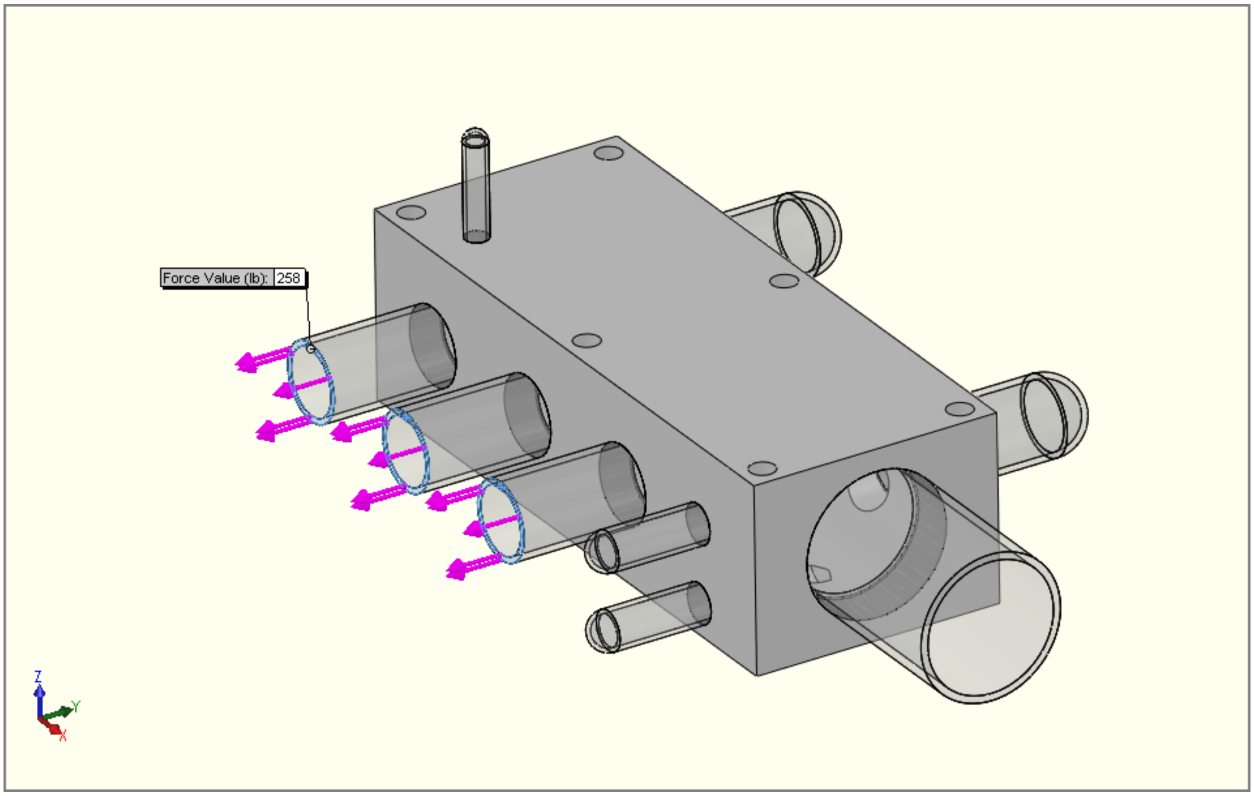
Centroid relative to part origin: ( inches )
     X = -8.50
     Y = -4.00
     Z = 0.00

Moments of inertia of the area, at the centroid: ( inches ^ 4 )
     Lxx = 0.06                    Lxy = 0.00
     Lyx = 0.00                    Lyy = 0.12

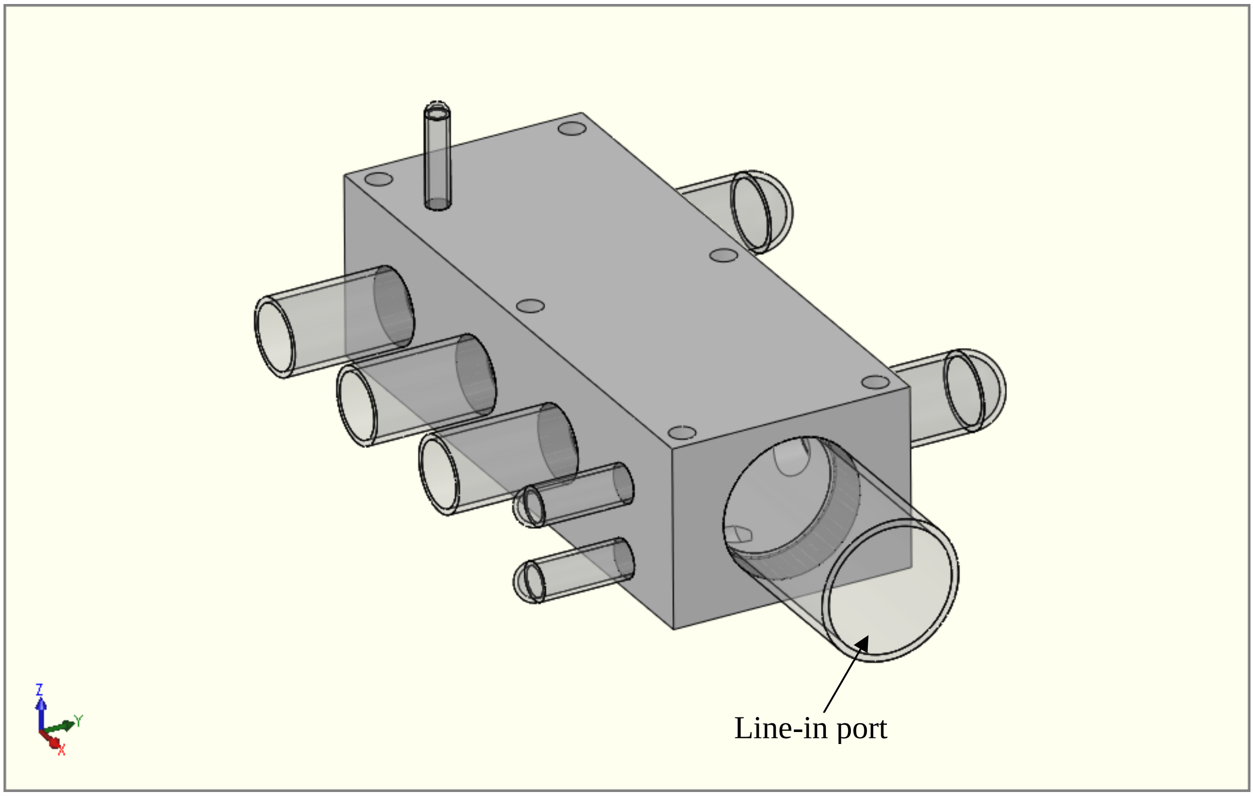
Polar moment of inertia of the area, at the centroid = 0.12 inches ^ 4
```

The unbalanced force due to the missing area of each port can be calculated by multiplying the area by the internal pressure.

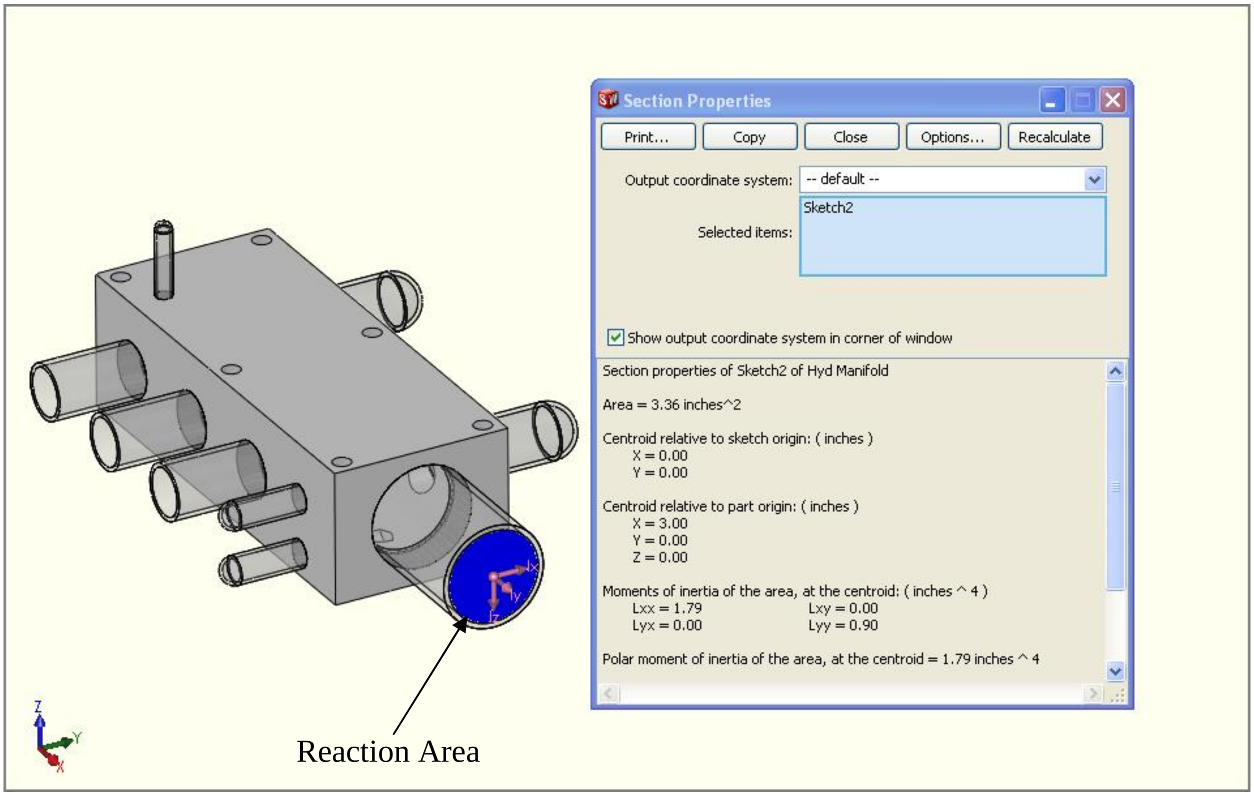
Reaction per Port = (0.864 in^2) * (300 lb/in^2) = 259.276 lb



A force is added to each port to balance the model in the y-direction. These forces account for the missing areas of applied pressure and place the model in balance.



The x-direction of the model has a reaction force due to the uncapped line-in port of the manifold. The reaction areas in the x-direction are unbalanced due to the void at the line-in port.



Output coordinate system: -- default --

Selected items: Sketch2

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```
Section properties of Sketch2 of Hyd Manifold

Area = 3.36 inches^2

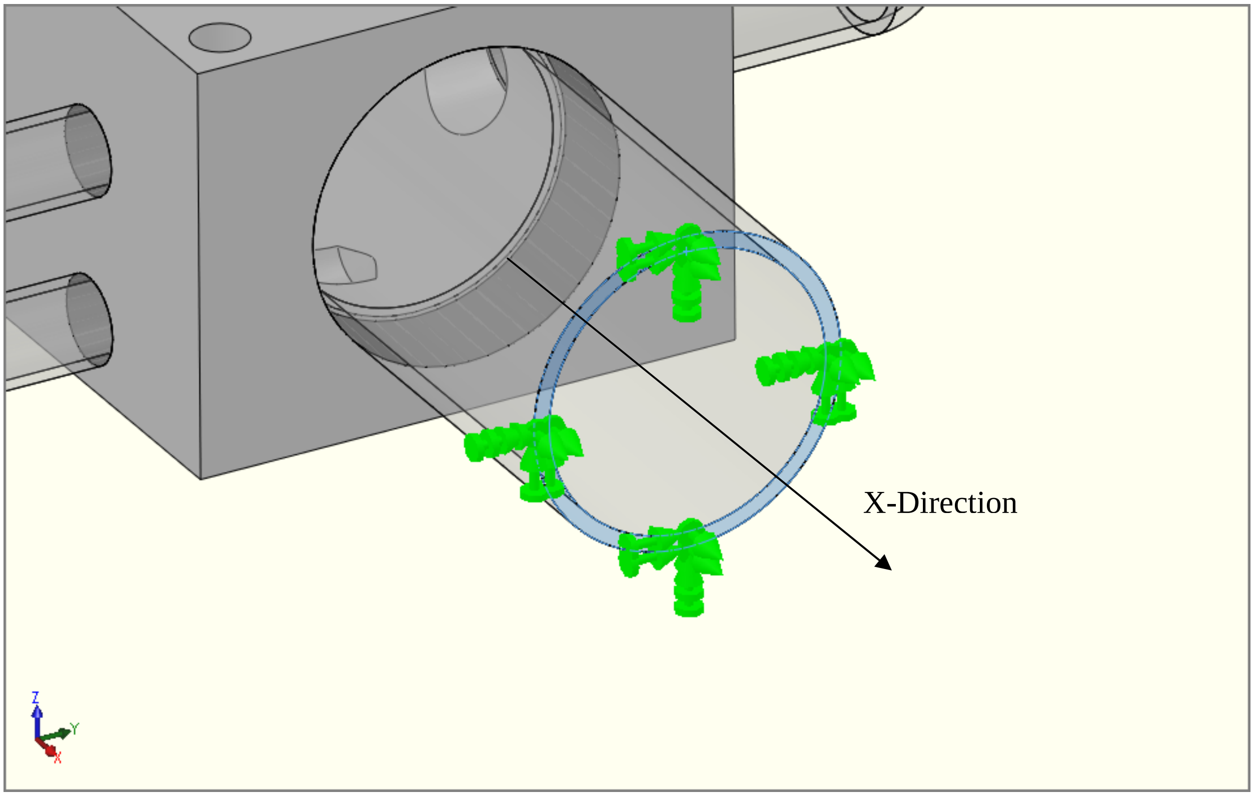
Centroid relative to sketch origin: ( inches )
     X = 0.00
     Y = 0.00

Centroid relative to part origin: ( inches )
     X = 3.00
     Y = 0.00
     Z = 0.00

Moments of inertia of the area, at the centroid: ( inches ^ 4 )
     Lxx = 1.79                    Lxy = 0.00
     Lyx = 0.00                    Lyy = 0.90

Polar moment of inertia of the area, at the centroid = 1.79 inches ^ 4
```

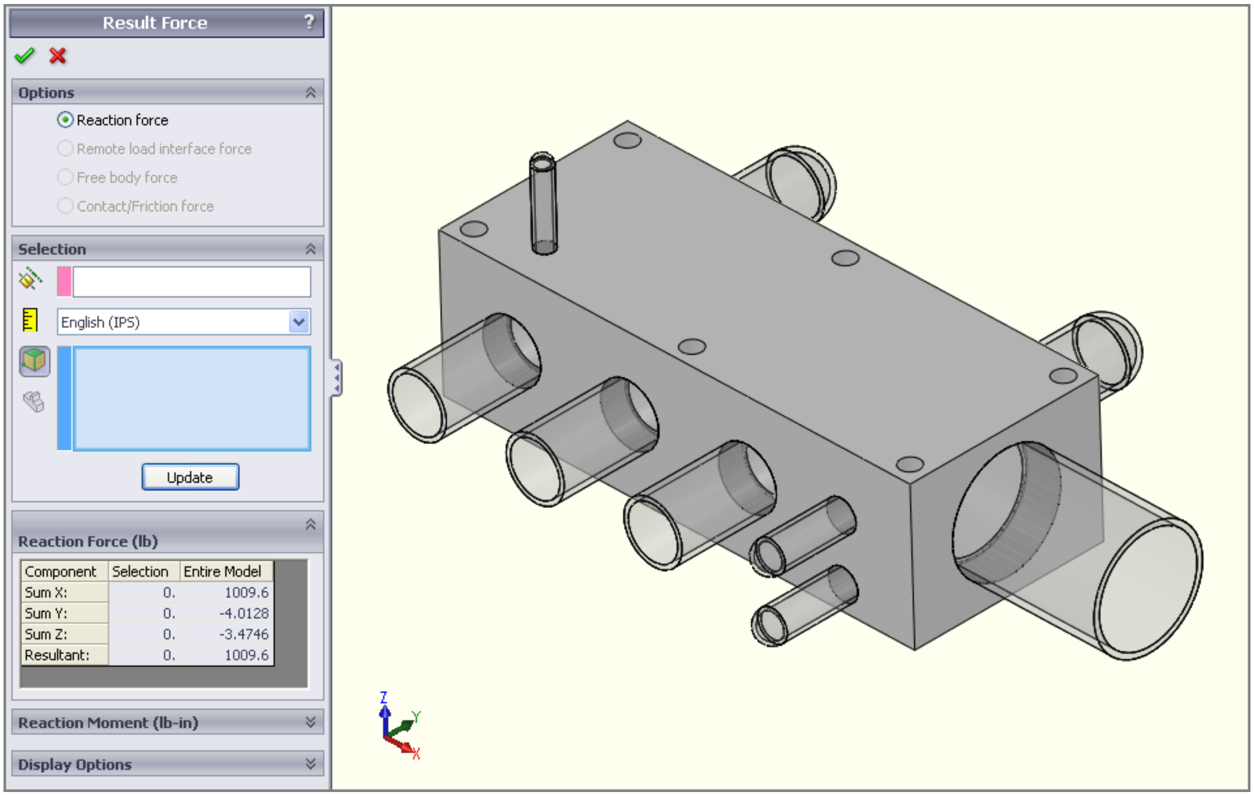
The reaction force at this port can be calculated by multiplying the reaction area by the pressure. Reaction X = (3.36 in^2) * (300 lb/in^2) = 1008 lb



The model is not in balance in the x-direction. The restraint needs to provide a force to prevent motion in the x-direction. The restraint provided an equal and opposite force to the pressure multiplied by the line-in area.

Theoretical Reaction Summary:

Reaction X = 1008 lb
Reaction Y = Force Applied – Force Due to Exit Pressure
Reaction Y = 3 Ports * (259 lb -259 lb)
Reaction Y = 0
Reaction Z = 0
Theoretical Resultant = SQRT ((1008 lb)^2 + (0 lb)^2 + (0 lb)^2)
Theoretical Resultant = 1008 lb



● Reaction force
○ Remote load interface force
○ Free body force
○ Contact/Friction force

English (IPS)

Reaction Force (lb)

Component	Selection	Entire Model
Sum X:	0.	1009.6
Sum Y:	0.	-4.0128
Sum Z:	0.	-3.4746
Resultant:	0.	1009.6

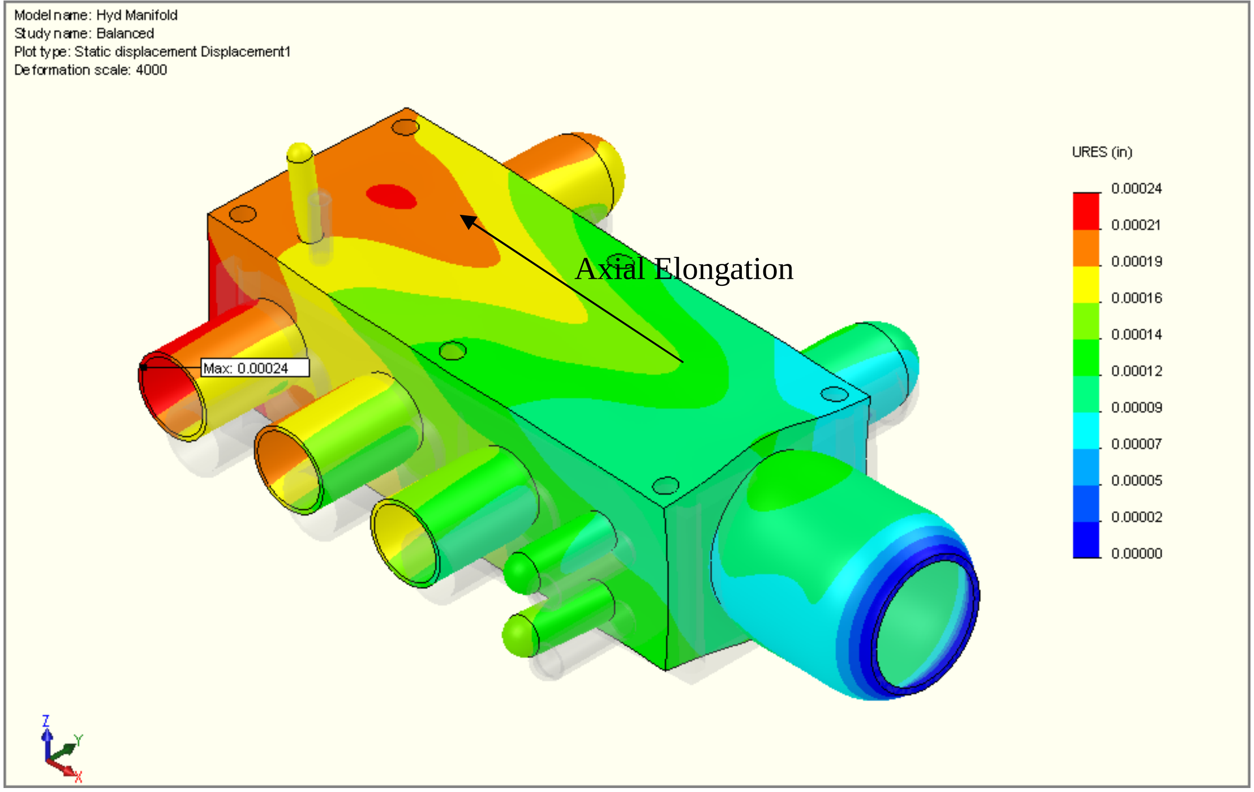
The final reaction components can be reported from COSMOS and measured against the theoretical values.

Actual Reaction Force Components:
X Reaction = 1009.6 lb
Y Reaction = -4.03 lb
Z Reaction = -3.47 lb
Actual Resultant = SQRT ((1009.6 lb)^2 + (-4.03 lb)^2 + (-3.47 lb)^2)
Actual Resultant = 1009.6 lb

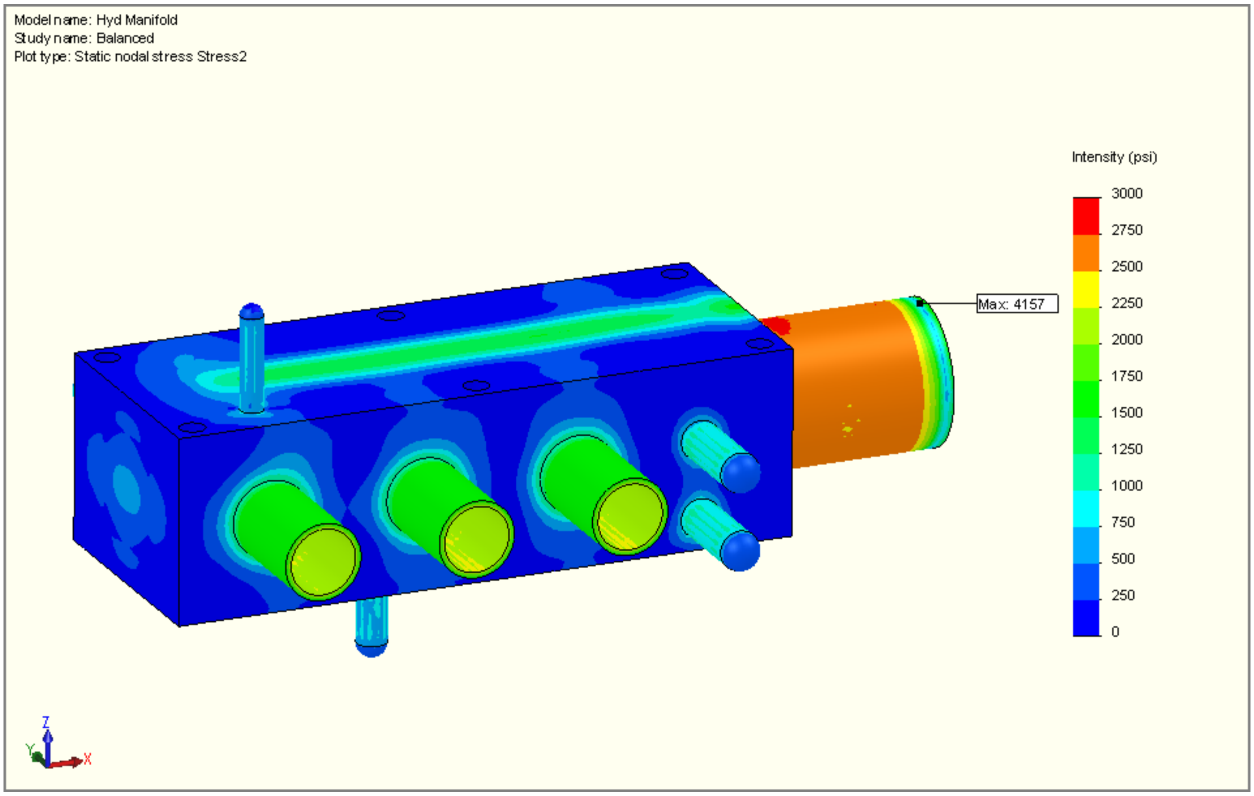
Error Calculation:
Error = ((Resultant Theoretical – Resultant Actual) / Resultant Actual) * 100%
Error = ((1008 lb – 1009.6 lb) / 1009.6 lb) * 100%
Error = -0.16 %

From the error calculation we can see that the actual results fall within 2% of the theoretical results. This model is in balance.

negative.



The displacement is as expected with the model in balance. The model displaces outward and elongates axially due to the internal pressure.



Stress concentrations are no longer exaggerated at the line-in pipe. The balanced model provides realistic displacements and valid stress results that can be analyzed against material allowables.

Checking the model balance is an important step for verifying that all loads are acting upon restraints correctly. An out of balanced model provides invalid result that cannot be used.

Ben Vanderloo
January 22, 2009
Balancing Reaction Forces PVE-3179
Rev.0