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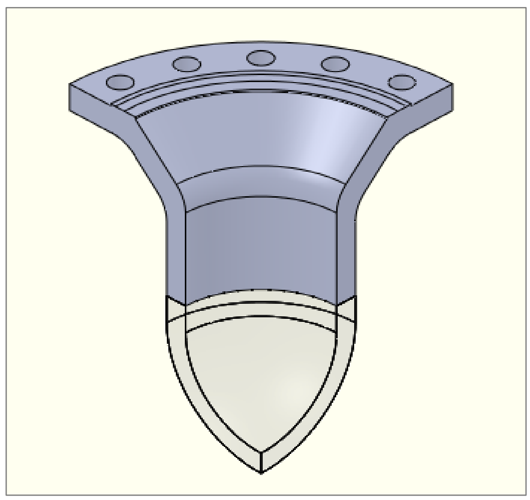
Finite Element Analysis (FEA) Report

Sample Job #22

Flange Analysis

123-456-ABC

May 21, 2009



PVE-3429 Rev.0

Ben Vanderloo
Laurence Brundrett P. Eng.

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Revision(s)

Rev	Description	Date	By
0	Release	05/20/09	BV
1			
2			

Executive Summary ver 4.00

Project Information:

Sample Job #22	Customer
Flange Analysis	Vessel / Component(s)
123-456-ABC	Part Number
PVE-3429 Rev.0	Job
SolidWorks CosmosWorks 2008	FEA Program Used
21-May-2009	Date

Max Pressure (psi) 300	@Temperature (F) 200	Maximum Allowed Working Pressure
Max Operating Temp (F) 200	@ Pressure (psi) 300	Maximum Design Metal Temperature

Goal:

The flange, PVE-3429, will be used under ASME VIII-1 service. This flange cannot be calculated to ASME VIII-1 code rules due to the complexity of its geometry. The rules of VIII-2 are used with VIII-1 allowed stresses to determine the acceptability of the flange.

Summary Conclusions:

Materials

Material strength properties used in this report are obtained from ASME IID, Table 1A and Table 3. Stress classification limits are calculated to VIII-2 rules using ASME IID allowables for VIII-1. Properties are shown for the SA-105 carbon steel flange and the SA-197 B7 bolts.

Model Information

The model used in this report represents 1/4 of the flange. A 2nd order, tetrahedral solid mesh has been refined to 0.25" to reduce the reported error to less than 5% for general areas.

Restraints & Loads

All cut plane surfaces are restrained using symmetry. Bolts are simulated using the COSMOS connector utility. These bolts hold the flange in the seated position. Flange loads are calculated and applied to the effective gasket area. The flange is internally pressurized to 300 psi. The model is restrained in all directions and rigid body motion is prevented.

Results

Through the FEA we found a 0.0014" maximum displacement. All general membrane stresses are below the 20,000 psi general allowable. All local membrane stresses have been proven acceptable after linearization. All stresses are below their respective membrane allowables. The flange design is acceptable.

Analysis Conclusion:

The flange meets ASME VIII-2 design rules using VIII-1 allowed stresses. The flange design is acceptable.

Material Stress Limits ver 4.00 ASME VIII-2 Fig 4-130.1

Material:

SA-105	**Material**
Flange	**Application**

Strength Properties:

ASME VIII-IID, 2007 Table 1A	**Source** of strength properties
200	**T** [ºF] temperature
20,000	**Sm** [psi] basic allowable stress at temperature T
	Sy [psi] yield stress at temperature T (optional)
1.0	**k** [] - stress intensity k factor
1.00	**E1** [] - weld efficiency factor
1.00	**E2** [] - casting efficiency factor

FEA Properties:

ASME VIII-IID, 2007 Table 1A	**Source** of FEA properties
28,800,000	**E** [psi] - modulus of elasticity (at temperature)
0.31	**v** [] - Poison's ratio

Stress Limits:

Pm = k*E1*E2*Sm   general primary membrane stress intensity limit

1*1*1*20000 = **20,000**

Pl = 1.5*k*E1*E2*Sm   local membrane stress intensity limit

1.5*1*1*1*20000 = **30,000**

Pl+Pb = 1.5*k*E1*E2*Sm   primary membrane + primary bending stress intensity limit

1.5*1*1*1*20000 = **30,000**

Pl+Pb+Q = Max(3*E1*E2*Sm,2*E1*E2*Sy)   primary + secondary stress intensity

MAX(3*1*1*20000,2*1*1*0) = **60,000**

Pl+Pb+Q+F = Use fatigue curves   peak stress intensity limit

Comments:

(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) Refer to VIII-2 Table AD-150.1 for k values
(3) The thermal expansion coeficient is only required for studies including thermal stresses
(4) Refer to VIII-2 App 4-130 and following for the Pm, Pl, Q and F stress limits
(5) Refer to VIII-2 App 4-130 Table 4-120.1 for the correct application of the calculated stress limits
(6) Use IID tables 2A and 2B for Sm for VIII-2 studies
(7) Use IID tables 1A and 2A for Sm values (S) for VIII-1 studies
(8) Use B31.1 Table A for Sm values for B31.1 studies
(9) Use B31.3 Table A for Sm values for B31.3 studies

Bolt Stress Limits ver 4.00 ASME VIII-2 4-140

Material:

SA-193 B7	**Material**
Flange Bolts	**Application**

Strength Properties:

ASME VIII-IID, 2007 Table 3	**Source** of strength properties
200	**T** [ºF] temperature
25,000	**Sm** [psi] basic allowable stress at temperature T

FEA Properties:

ASME VIII-IID, 2007 Table 3	**Source** of FEA properties
29,000,000	**E** [psi] - modulus of elasticity (at temperature)
0.30	**v** [] - Poison's ratio

Service Stress Limits for Seating + Operating Loads: 4-140

Pm = 2*Sm membrane stress intensity limit at location without stress concentration

2*25000 = **50,000**

Pm+Pb = 3*Sm membrane + bending stress limit at at location without stress concentration

3*25000 = **75,000**

Pl+Pb+Q+F = Use fatigue curves peak stress intensity limit

Comments:

(1) The thermal expansion coeficient is only required for studies including thermal stresses
(2) Use IID table3 for Sm for VIII-2 studies
(3) Use IID table 3 for Sm values (S) for VIII-1 studies
(4) Use B31.1 Table A for Sm values for B31.1 studies
(5) Use B31.3 Table A for Sm values for B31.3 studies

Model, Mesh and Error Ver 4.06

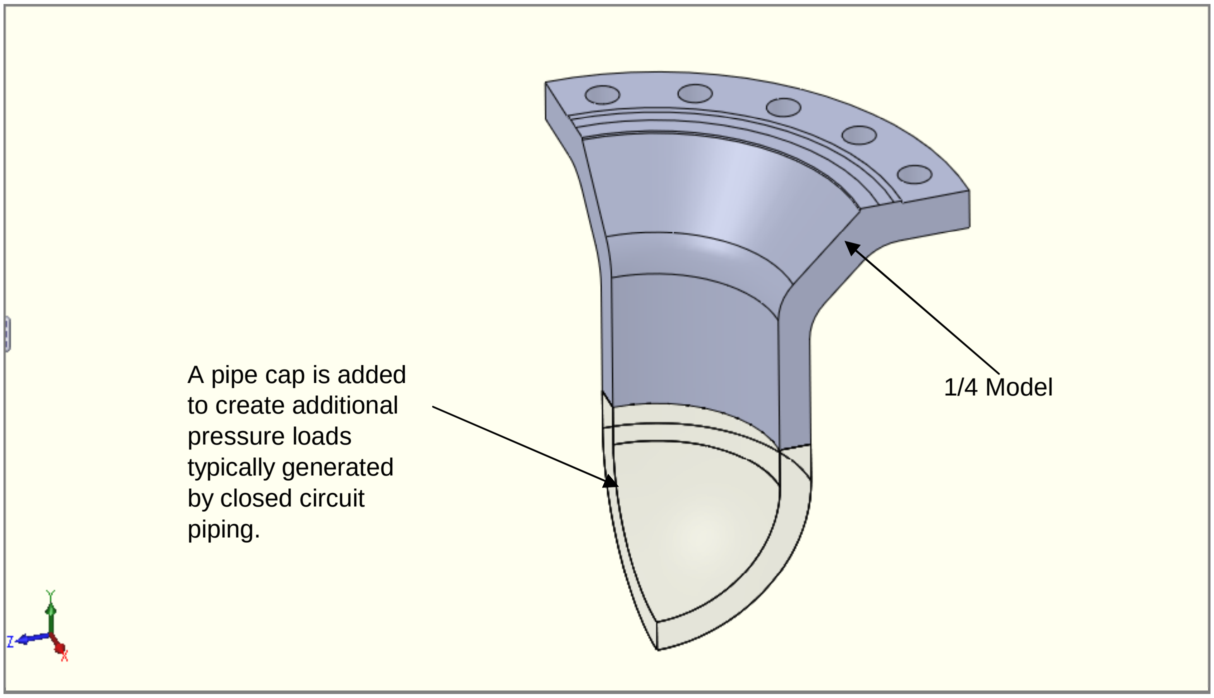


Fig-A A view of the flange as cut from the complete model. An 1/4 solid model was used to simplify the analysis. The resulting stresses in the pipe cap will not be analyzed. This component is for setup purposes only. Refer to drawing PVE-3429 for more details.

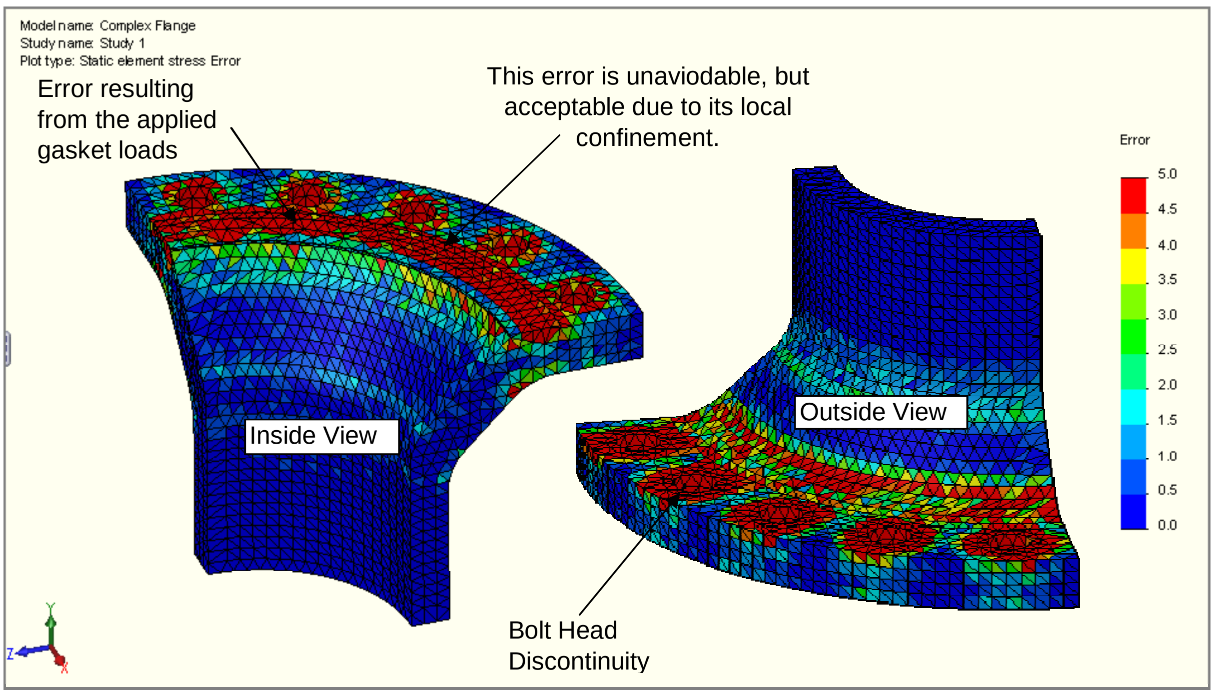
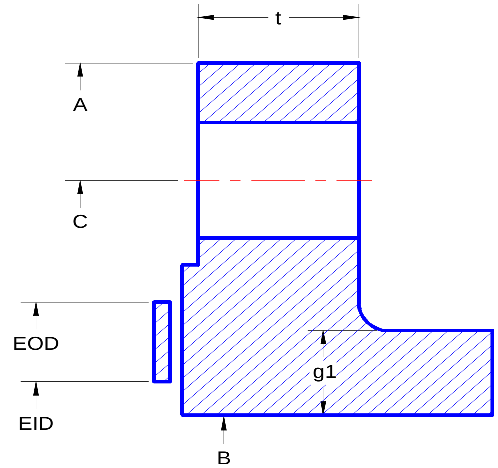


Fig-B A view of the error plot capped at 5% with the mesh overlaid. A global mesh size of 0.25" was used for the entire model. Error exceeding the 5% is located at bolt heads, areas of applied loads and areas of discontinuity. The error is acceptable and the model may be used for results.

Flange Loads <- Description



Dimensions and Conditions:

10.000	<- B - ID, uncorroded
1.000	<- g1 - hub thickness
0.000	<- Corr - corrosion allowance
300.0	<- P, internal operating pressure
12.000	<- GOD - gasket OD
10.000	<- GID - gasket ID
1.00	<- m - gasket factor
200	<- gy - gasket factor y
13.500	<- varC - bolt circle dia
0.750	<- BoltOD, bolt size
20.0	<- Nbolt, number of bolts

Material Properties:

SA-193 B7	<- Bolting Material
25,000	<- Sb - allowable bolt stress at DESIGN temp
25,000	<- Sba - allowable bolt stress at ASSEMBLY temp

Calculated Dimensions:

gOne =	g1 - corr	= 1-0		gOne =	***1.000***
B =	B+2*corr	= 10+2*0	*Corroded ID*	B =	***10.000***
varR =	(varC-B)/2 - gOne	= (13.5-10)/2 - 1		varR =	***0.750***
varN =	(GOD-GID)/2	= (12-10)/2	*Gasket Width in Contact*	varN =	***1.000***
b0 =	varN / 2	= 1 / 2	*gasket seating width*	b0 =	***0.500***
varb =	min(Sqrt(b0)/2,b0)	= min(Sqrt(0.5)/2,0.5)	*eff seating width*	varb =	***0.354***
varG =	max(GOD-2*varb,(GOD-GID)/2 + GID)		*gasket load reaction diameter*	varG =	***11.293***
=	max(12-2*0.354,(12-10)/2 + 10)				

Flange Loads (VIII App 2-5):

H =	0.785*varG^2*P	= 0.785*11.293^2*300	*end load*	H =	***30,048***
HP =	2*varb*3.14*varG*m*P	= 2*0.354*3.14*11.293*1*300	*contact load*	HP =	***7,522***
HD =	pi/4 * B^2 * P	= pi/4 * 10^2 * 300	*end load*	HD =	***23,562***
HT =	H - HD	= 30048 - 23562	*face load*	HT =	***6,486***
Wm1 =	H + HP	= 30048 + 7522	*bolt load*	Wm1 =	***37,571***
Wm2 =	pi*varb*varG*gy	= pi*0.354*11.293*200	*seating load*	Wm2 =	***2,509***
Am =	max(Wm1/Sb, Wm2/Sba)	= max(37571/25000, 2509/25000)	*req bolt area*	Am =	***1.503***
Ab =	Root*Nbolt	= 0.31*20 ***3/4-10 UNC 2A***		Ab =	***6.200***

Total Bolt Loads - lbs - (app 2-5):

W =	(Am + Ab)*Sba/2	= (1.503 + 6.2)*25000/2	*seating conditions*	W =	***96,285***
HG =	Wm1 - H	= 37571 - 30048	*operating conditions*	HG =	***7,522***

Flange Moment Arms - inch - (Table App 2-6 - Integral flanges):

mhD =	varR+0.5*gOne	= 0.75+0.5*1	*end pressure*	mhD =	***1.2500***
mhT =	(varR+gOne+mhG)/2	= (0.75+1+1.104)/2	*face pressure*	mhT =	***1.4268***
mhG =	(varC-varG)/2	= (13.5-11.293)/2	*gasket load*	mhG =	***1.1036***
Mavg =	(HT*mhT+(HG+W)*mhG)/(HT+HG+W)		*average gasket moment arm*	Mavg =	***1.1226***
=	(6486*1.427+(7522+96285)*1.104)/(6486+7522+96285)				

Summary of Load Conditions

EOD =	varC-2*Mavg+varb	= 13.5-2*1.123+0.354	*eff gasket OD*	EOD =	***11.6084***
EID =	varC-2*Mavg-varb	= 13.5-2*1.123-0.354	*eff gasket ID*	EID =	***10.9013***
TG =	HT+HG+W	= 6486+7522+96285	*total gasket load*	TG =	***110,294***
HD =	HD		*flange end load*	HD =	***23,562***

Apply TG to the gasket face surface between EOD and EID in the model

Omit end load HD if a closed pipe end is modeled and pressurized

TG and HD are for a complete 360° flange model. Reduce if symmetry is used.

Restraints and Loads Ver 4.06

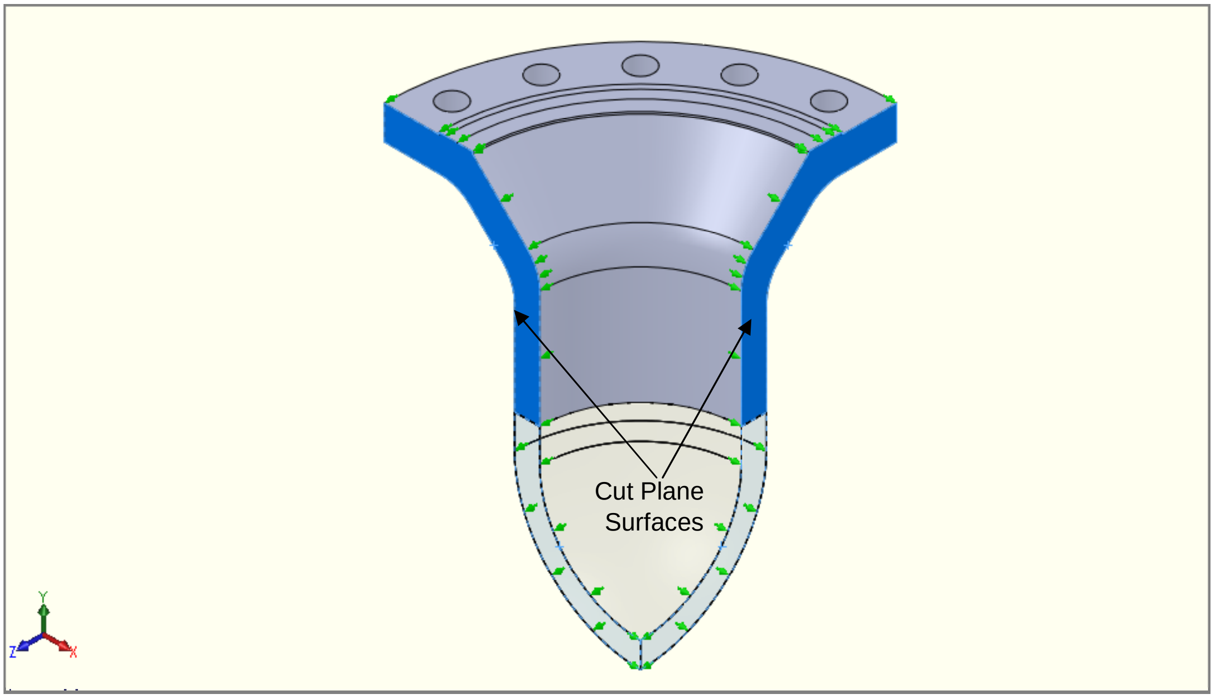


Fig-A A view of the symmetry restraints applied to all cut plane surfaces. The symmetry restraint provides results identical to that of a full model.

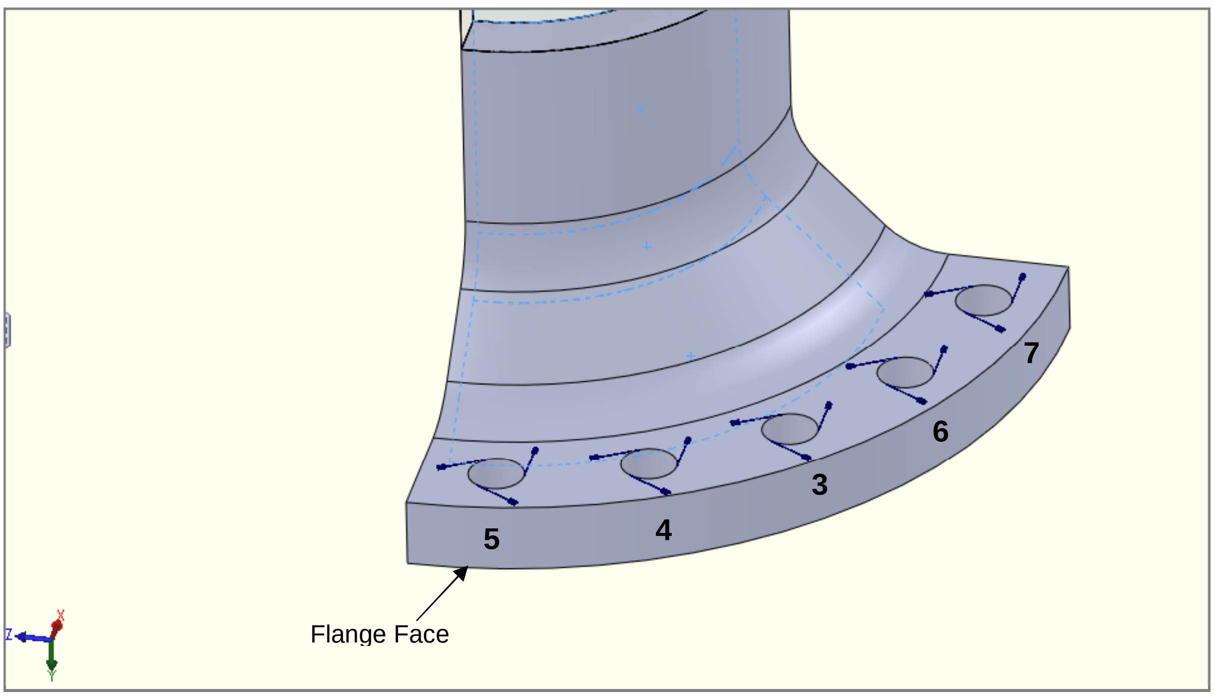


Fig-B A view of the COSMOS simulated bolts applied to the flange. These bolts hold the flange in the seated position. The bolt connector numbers have been indicated to match results shown on the bolt loadings and the bolt stresses page.

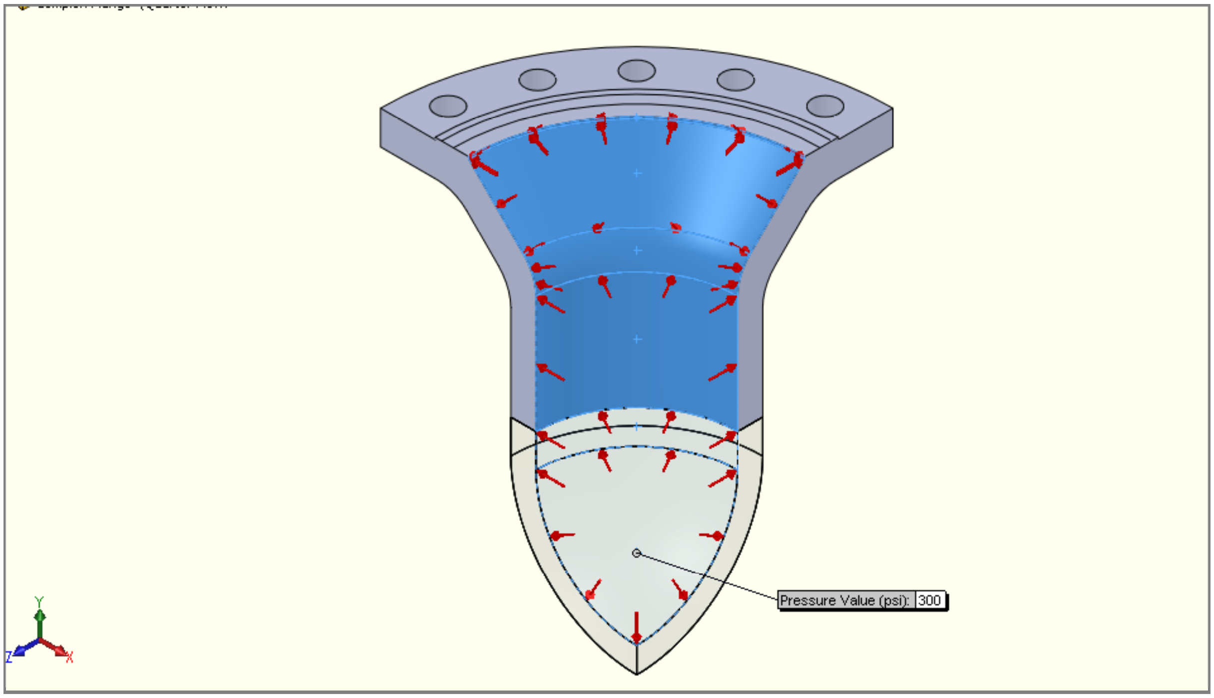


Fig-A A view of the 300 psi internal pressure applied to the inside surfaces.

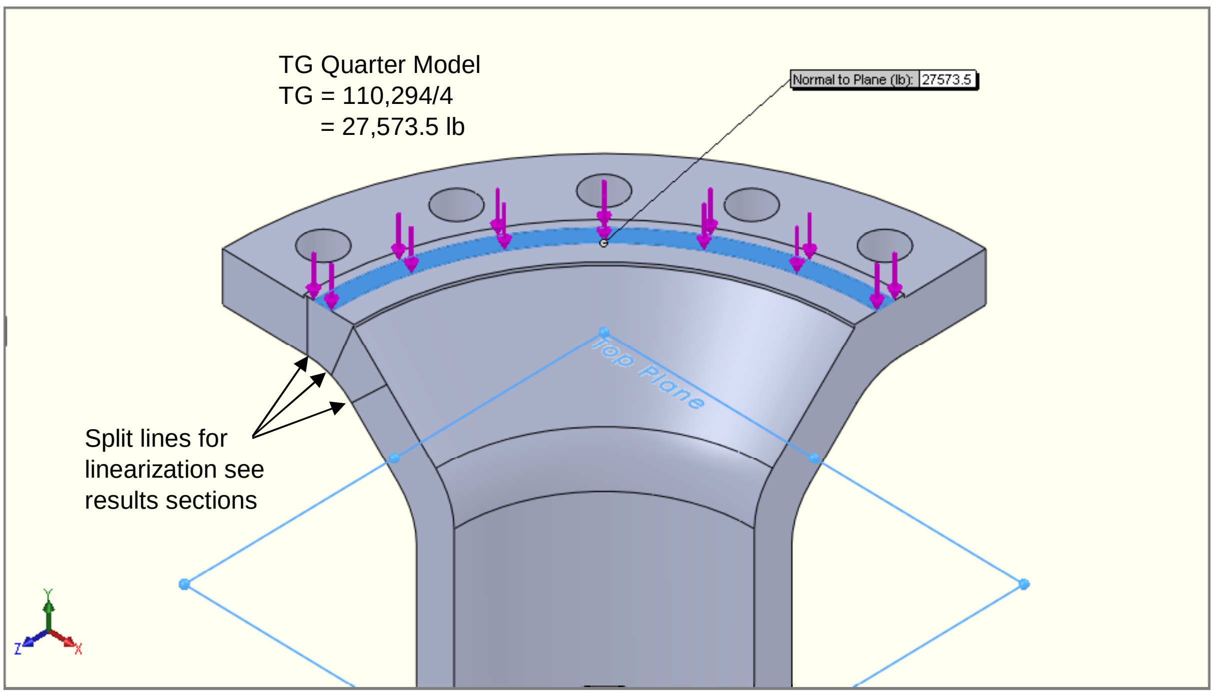


Fig-B A view of the TG gasket load applied to the flange (value found on page 7). Refer to drawing PVE-3429 for details on the effective gasket area.

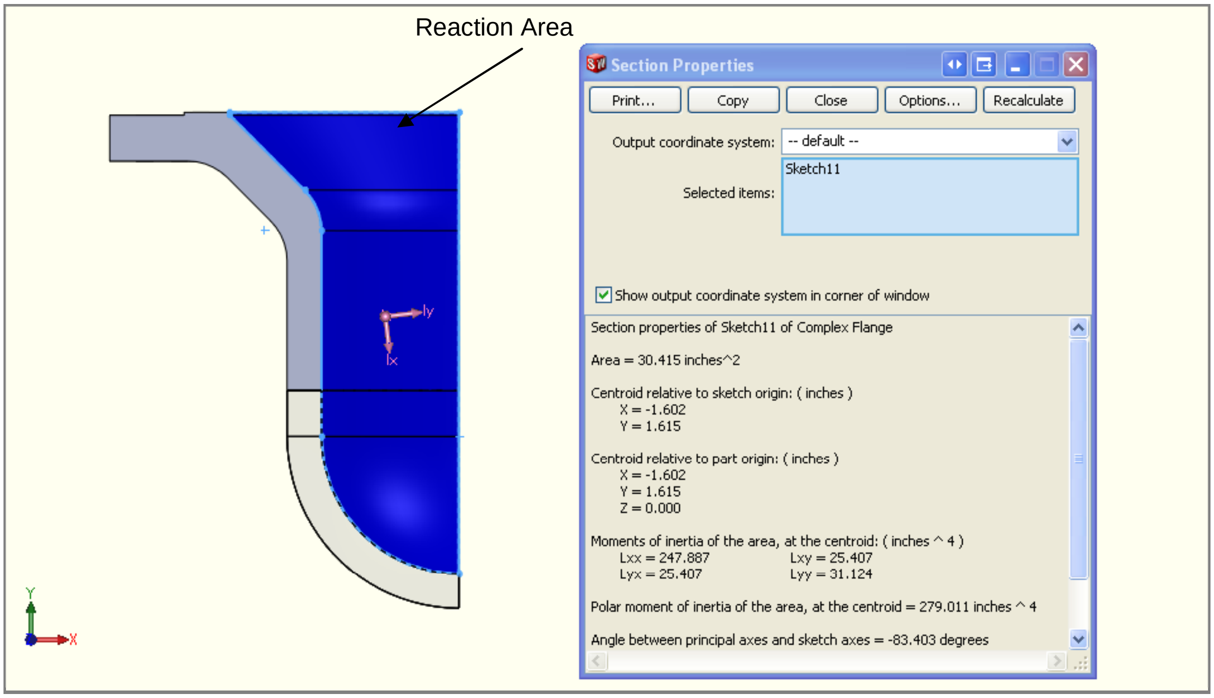


Fig-A A view normal to the XY plane.
Reaction Area = 30.415 in^2 (in the "Z" direction).
Expected Reaction Force = (30.415 in^2) * (300 psi) = 9124.5 lb (in the "Z" direction)

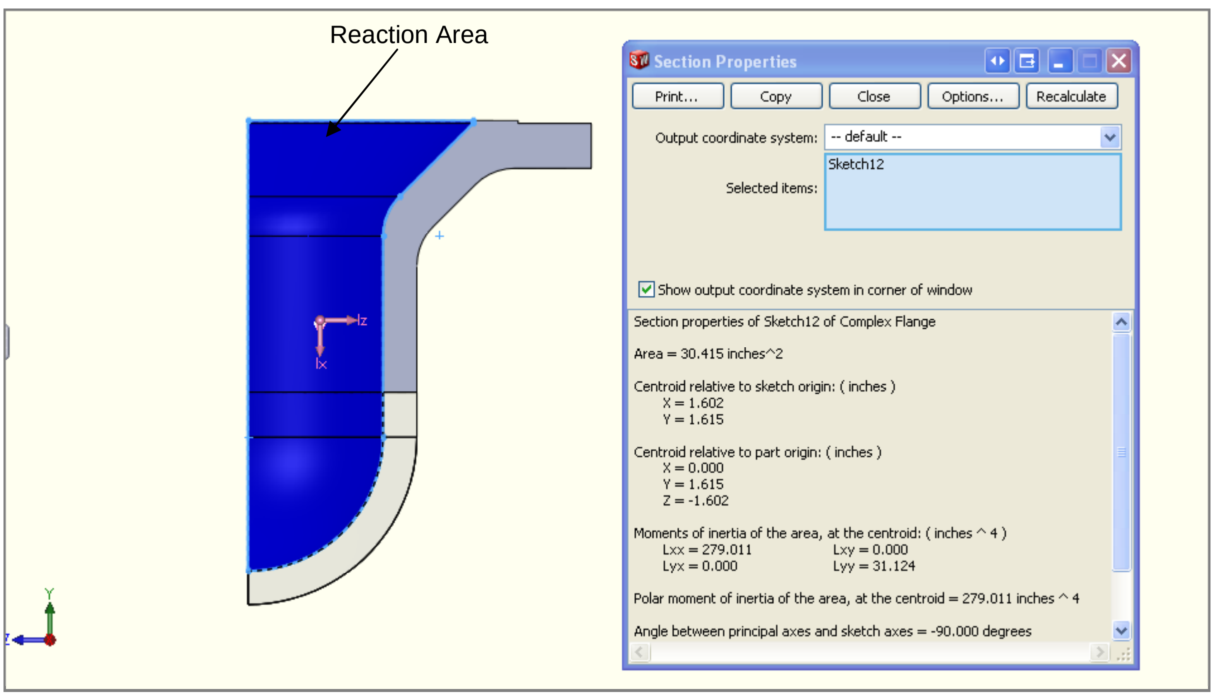
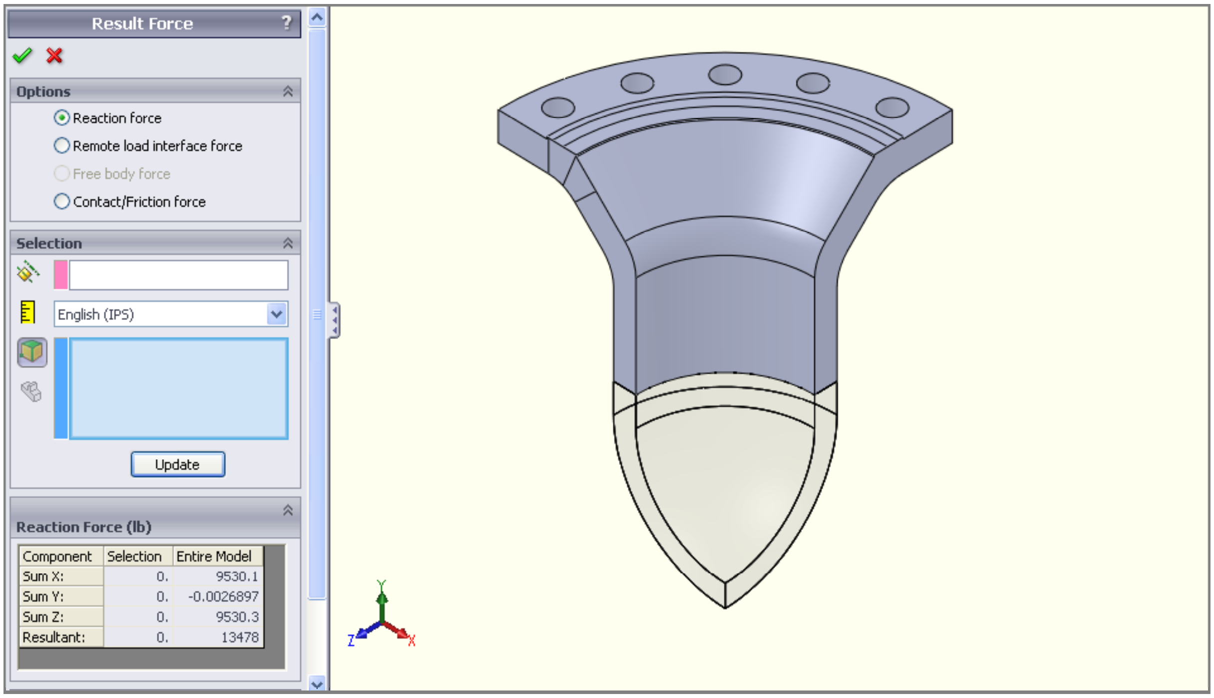


Fig-B A view normal to the YZ plane.
Reaction Area = 30.415 in^2 (in the "X" direction).
Expected Reaction Force = (30.415 in^2) * (300 psi) = 9124.5 lb (in the "X" direction)

Reaction Forces ver 4.08



View showing global reaction forces from analysis "X" = 9530.1 lb, "Y" = -0.003 lb, "Z" = 9530.3 lb
Calculated Reaction Forces = Analysis Reaction Forces within 0.0%
Model is balanced, results are valid.

X Axis: reaction forces on the YZ plane caused by loads in the X direction

30.42	**XArea** [in2] - Pressurized area on YZ plane
300	**P** [psi] - Pressure
406	**XForce** [lbs] - Added force in the X direction (see next page)
9,530.1	**XReaction** [lbs] - Reaction force in X direction reported by FEA program

TReactionX [lbs] = XArea*P+XForce — Theoretical X reaction force — 30.42*300+406 = **9,530**

Y Axis: reaction forces on the XZ plane caused by loads in the Y direction

0.00	**YArea** [in2] - Pressurized area on XZ plane
0	**YForce** [lbs] - Added force in the Y direction (see next page)
-0.003	**YReaction** [lbs] - Reaction force in Y direction reported by FEA program

TReactionY [lbs] = YArea*P+YForce — Theoretical Y reaction force — 0*300+0 = **0**

Z Axis: reaction forces on the XY plane caused by loads in the Z direction

30.42	**ZArea** [in2] - Pressurized area on XY plane
406	**ZForce** [lbs] - Added force in the Z direction (see next page)
9,530.3	**ZReaction** [lbs] - Reaction force in Z direction reported by FEA program

TReactionZ [lbs] = ZArea*P+ZForce — Theoretical Z reaction force — 30.42*300+406 = **9,530**

Resultant of reaction forces in X, Y and Z:

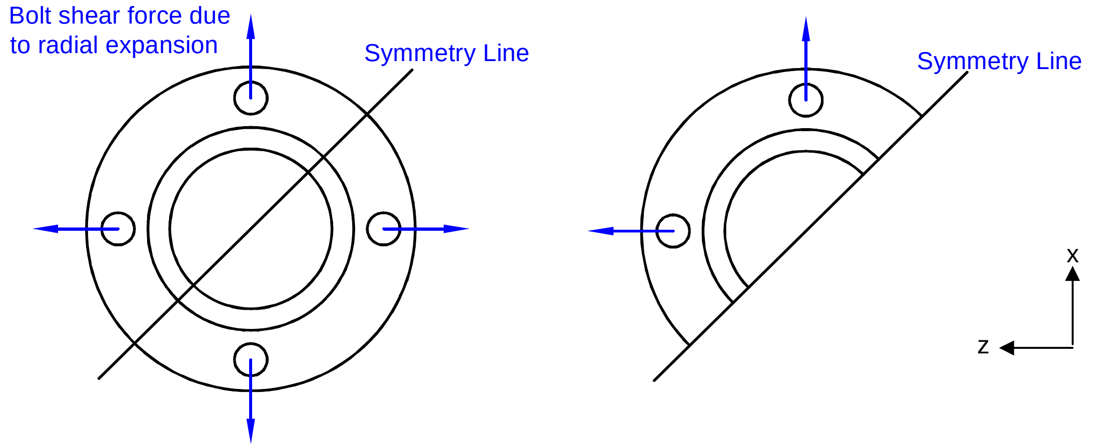
TResultant [lbs] = sqrt(TReactionX^2+TReactionY^2+TReactionZ^2) — Theoretical resultant
SQRT(9530^2+0^2+9530^2) = **13,478**

Resultant [lbs] = sqrt(XReaction^2+YReaction^2+ZReaction^2) — Actual resultant
SQRT(9530.1^2+-0.003^2+9530.3^2) = **13,478**

Error [%] = 100*(TResultant-Resultant)/Resultant — 100*(13478-13478)/13478 = **0.0**

CheckError = abs(Error)<2 — Error should be less than 2% — ABS(0)<2 = **Acceptable**

Bolt Loadings:



Forces in Equilibrium

Forces not in Equilibrium

Bolt shear forces do not cancel each other out since only a section of the flange is modeled. This issue can be corrected by adding the sum of the shear forces on each bolt to the calculated reaction forces. This must be completed for each shear force direction (x and z)

Type	Comp X	Comp Y	Comp Z	Result	Connector
Shear Force (lb)	**89.79**	0	**89.81**	127	Bolt Connector-3
Axial Force (lb)	0	-6692.9	0	6692.9	Bolt Connector-3
Bending moment (lb-in)	97.352	0	-97.345	137.67	Bolt Connector-3
Shear Force (lb)	**112.94**	0	**57.694**	126.83	Bolt Connector-4
Axial Force (lb)	0	-6692.5	0	6692.5	Bolt Connector-4
Bending moment (lb-in)	62.521	0	-122.51	137.54	Bolt Connector-4
Shear Force (lb)	**125.51**	0	**19.888**	127.08	Bolt Connector-5
Axial Force (lb)	0	-6692.7	0	6692.7	Bolt Connector-5
Bending moment (lb-in)	21.563	0	-136.04	137.73	Bolt Connector-5
Shear Force (lb)	**57.653**	0	**113.09**	126.94	Bolt Connector-6
Axial Force (lb)	0	-6693.1	0	6693.1	Bolt Connector-6
Bending moment (lb-in)	122.61	0	-62.478	137.61	Bolt Connector-6
Shear Force (lb)	**19.787**	**0**	**125.42**	126.97	Bolt Connector-7
Axial Force (lb)	0	-6692.9	0	6692.9	Bolt Connector-7
Bending moment (lb-in)	135.97	0	-21.469	137.65	Bolt Connector-7

Sum of Shear	**405.7**	**0.0**	**405.9**	< Add force to the respective direction above
	XForce	**YForce**	**ZForce**	

The flange is modeled as being anchored to a large manifold block. As the flange radially expands the bolts remain fixed in the manifold block. This expansion creates shear loads in the bolts. All y-direction reaction forces are contained in the bolt connectors as an axial force.

Bolt Stress ver 4.00

Highest Stressed Bolt #5 **Description**

Inputs:

UNC	**Bolt** Type
3/4	**Dia** [in] Nominal Bolt Size (UNC)
25,000	**Sm** [psi] Allowable Bolt Stress
J:\3400-3499\PVE-3429 Complex Flange FEA\bolt data.csv	**File** Location

Type	X	Y	Z	Resultant	Connector	
SF (lb)	125.51	0.00	19.89	127.08	Bolt Connector-5	**Shear Force**
AF (lb)	0.00	-6693	0.00	6692.70		**Axial Force**
BM (lb-in)	21.56	0.00	-136.04	137.73		**Bend Moment**

RDia [in] = PVELookup("BoltDia","Lookup","Root Dia",Dia) Root Diameter **0.627**

HDia [in] = PVELookup("BoltDia","Lookup","AF",Dia) Head Diameter **1.125**

A [in^2] = (π*RDia^2)/4 cross sectional area (3.142*0.627^2)/4 = **0.309**

C [in] = RDia/2 moment arm length 0.627/2 = **0.314**

I [in^4] = (π*(RDia/2)^4)/4 moment of inertia (3.142*(0.627/2)^4)/4 = **0.007586**

PL [lb] = 0.9*Sm*A bolt preload force 0.9*25000*0.309 = **6947**

Shear Stress:

SSx [psi] = SFx/A 125.51/0.309 = **406**

SSy [psi] = SFy/A 0/0.309 = **0**

SSz [psi] = SFz/A 19.89/0.309 = **64**

Axial Stress:

SAx [psi] = AFx/A 0/0.309 = **0**

SAy [psi] = AFy/A -6692.7/0.309 = **-21,676**

SAz [psi] = AFz/A 0/0.309 = **0**

Von Mises:

σ [psi] = SQRT(((SAx-SAy)^2+(SAy-SAz)^2+(SAz-SAx)^2+6*(SSx^2+SSy^2+SSz^2))/2)

SQRT(((0--21676)^2+(-21676-0)^2+(0-0)^2+6*(406^2+0^2+64^2))/2) = **21,688**

Checkσ = σ<= 2*Sm 21688<= 2*25000 = **Acceptable**

Bending Stress:

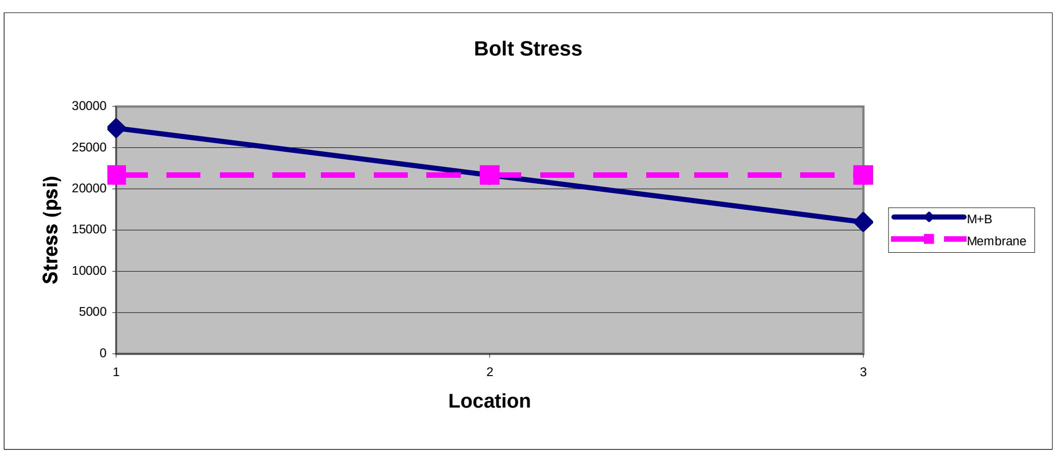
M [lb-in] = 137.73 = **138**

SB [psi] = M*C/I 138*0.314/0.007586 = **5,691**

PmPb [psi] = Max(abs(σ+SB),abs(σ-SB))

MAX(ABS(21688+5691),ABS(21688-5691)) = **27379**

CheckPmPb = PmPb<= 3*Sm 27379<= 3*25000 = **Acceptable**



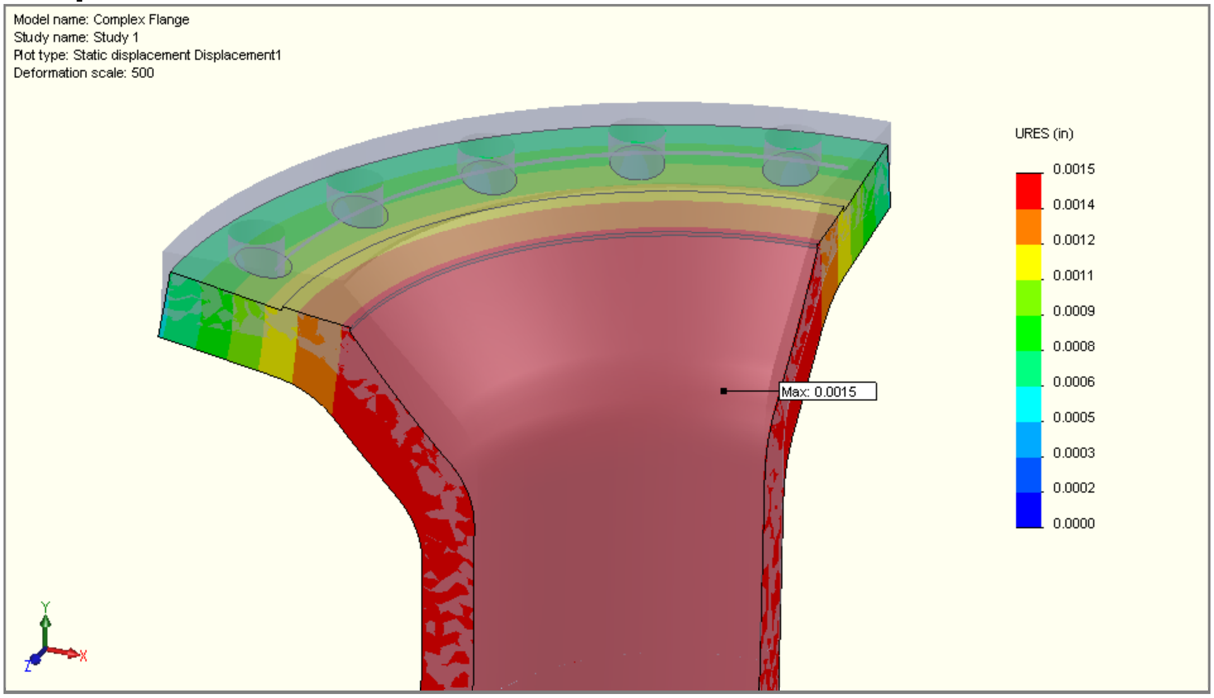


Fig-A A view of the displacement plot with superimposed original geometry. Results are magnified 500X. The flange pulls away from the seating position.

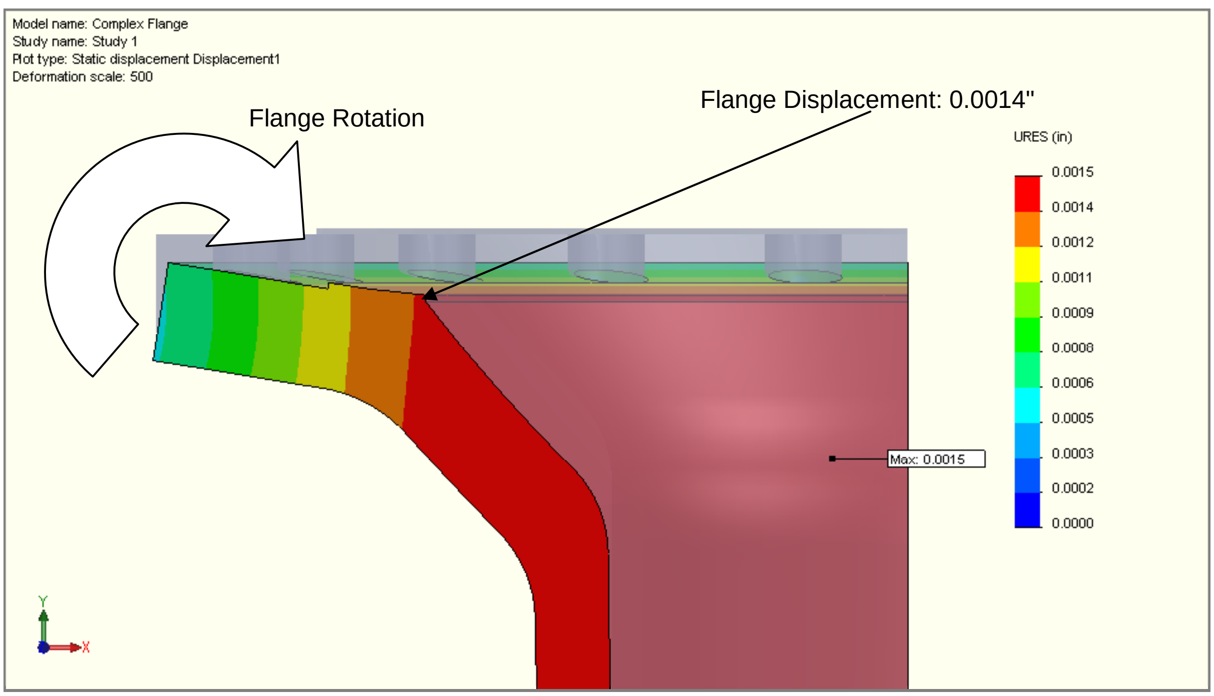


Fig-B An alternate view of Fig-A showing flange rotation. Maximum flange face displacement is 0.0014".

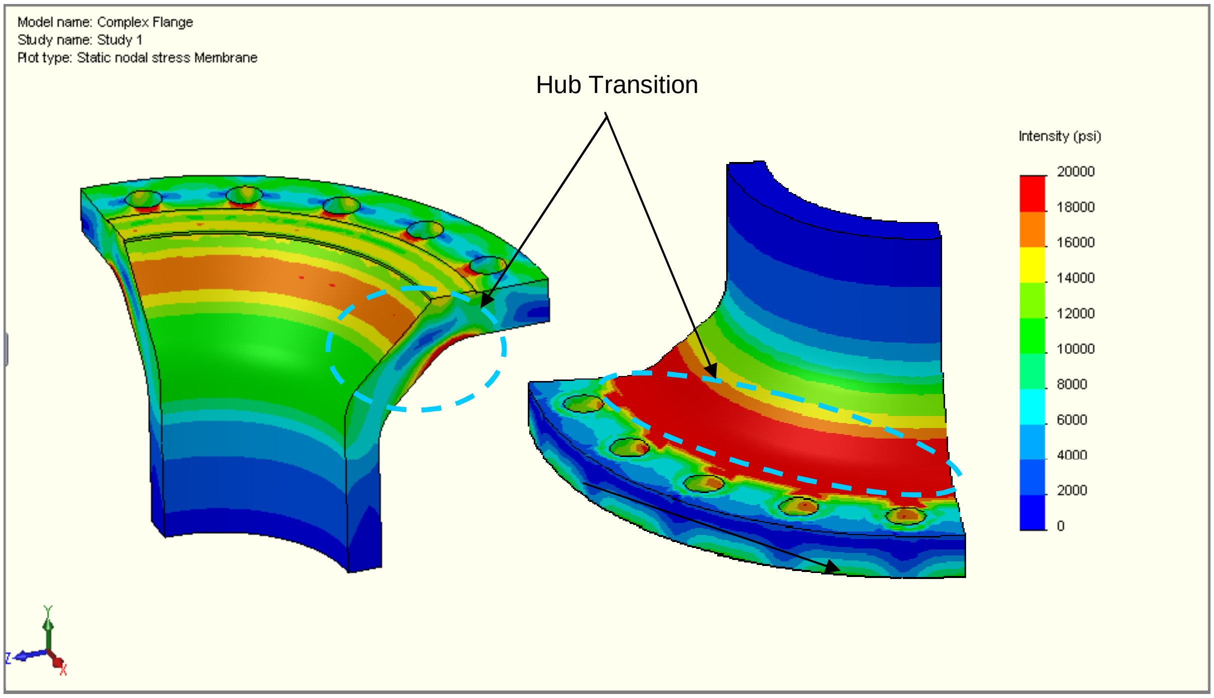


Fig-A A view of the membrane stress plot (Intensity) capped at the general membrane allowable of 20,000 psi. Maximum stresses are at the hub transition. These areas are considered to be local and will be further analyzed.

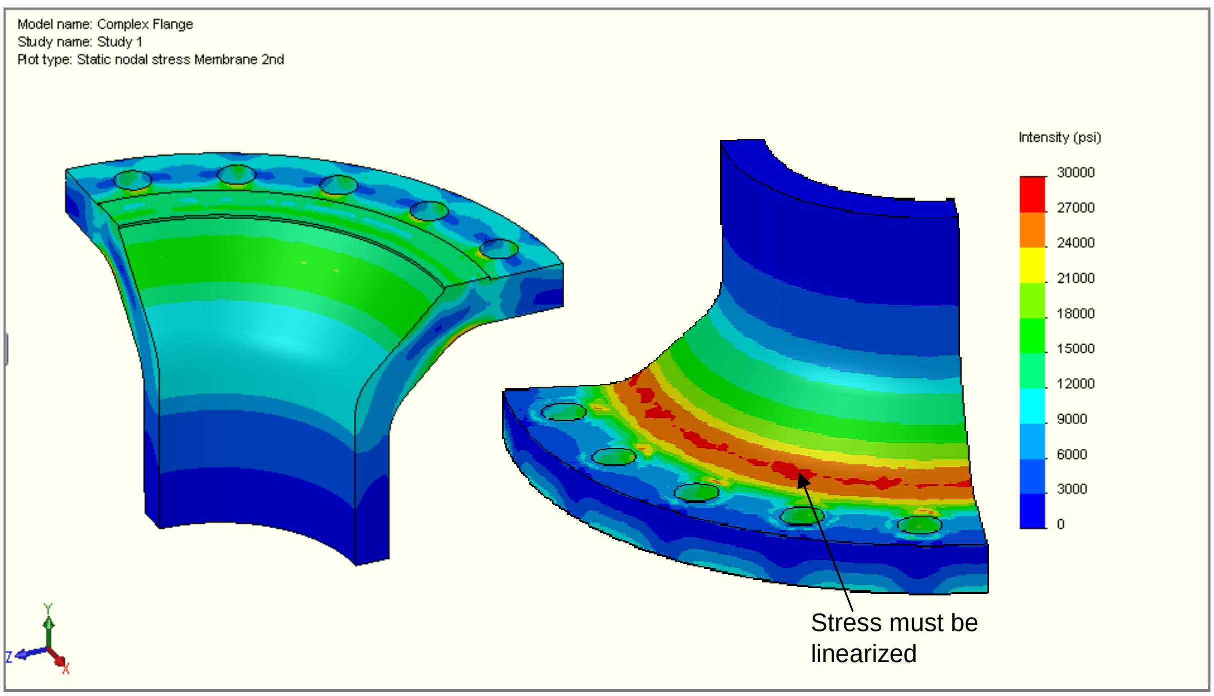
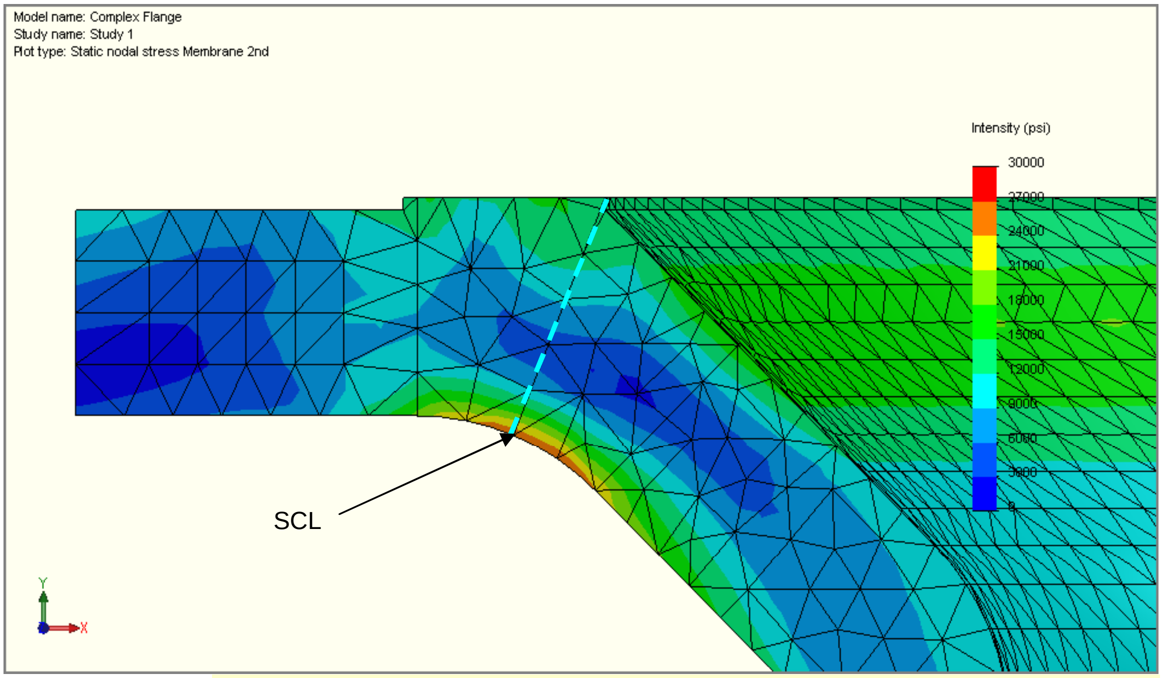
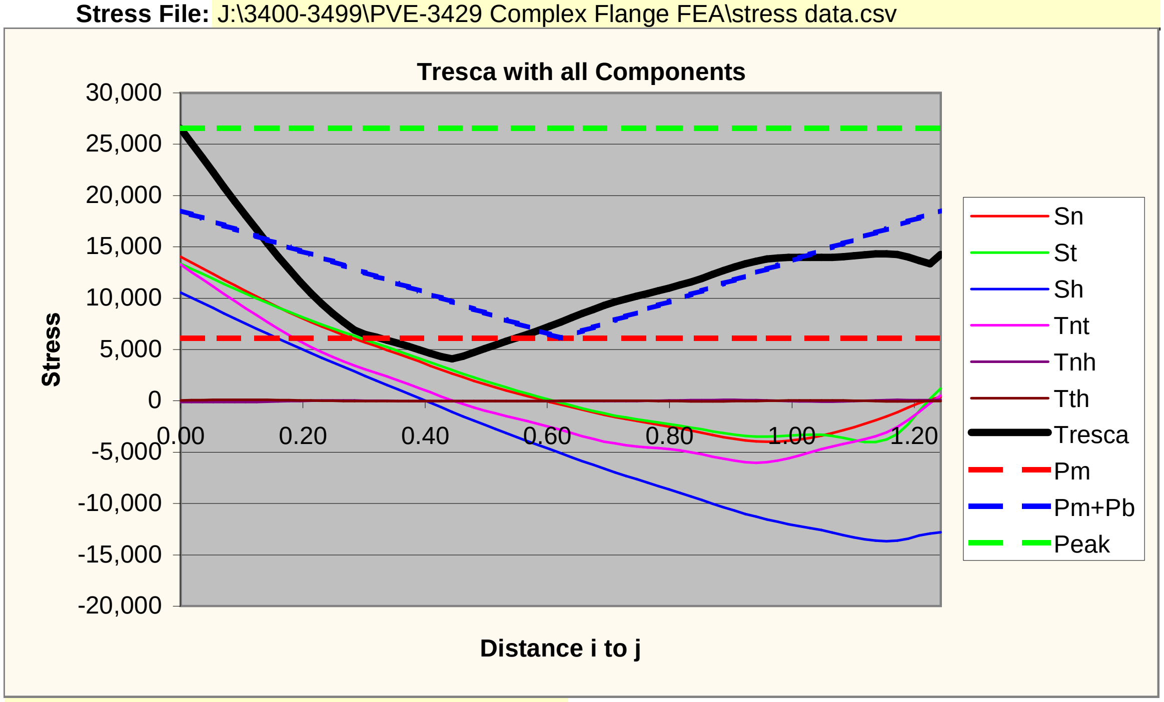


Fig-B A view of the local membrane stress plot (Intensity) capped at the local membrane allowable of 30,000 psi. The stresses in excess of the local allowable require further analysis.



Description:	**Flange hub stress linearization 1**
Probe File:	J:\3400-3499\PVE-3429 Complex Flange FEA\probe.csv
Stress File:	J:\3400-3499\PVE-3429 Complex Flange FEA\stress data.csv



Tresca with all Components **Graph** - settings

Allowable Stresses:

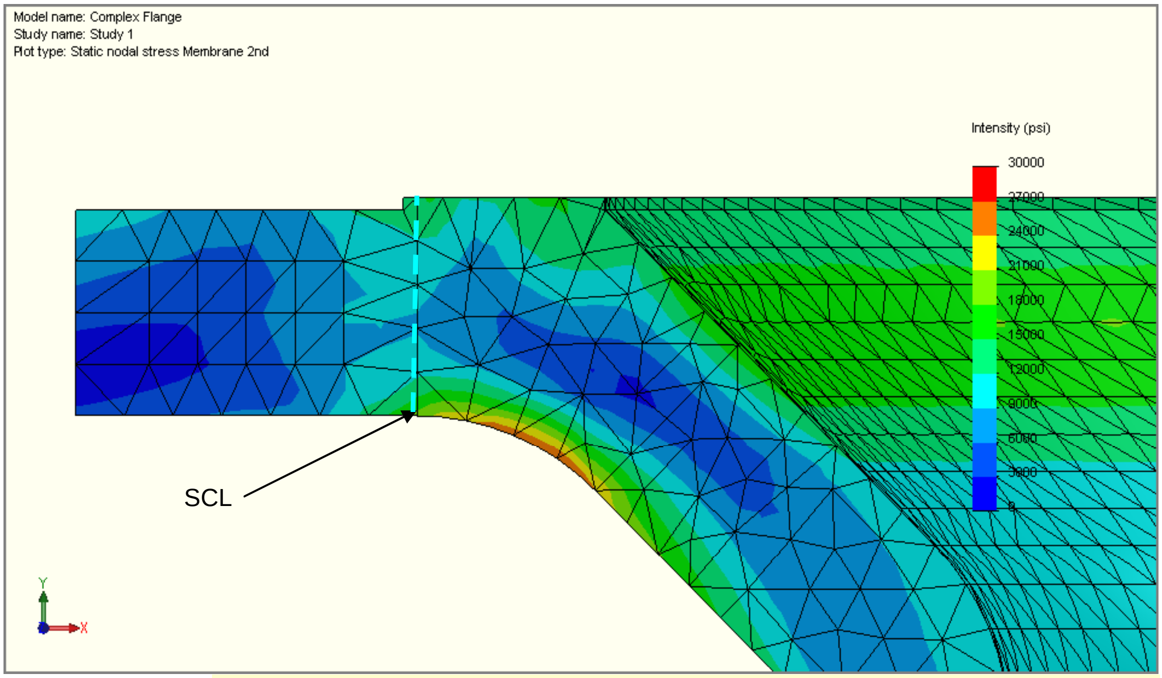
30,000	**M** - Membrane Allowable (Max Pm for global or Pl for local stresses)
60,000	**MB** - Membrane+Bending Allowable (Max Pl+Pb for Global or Pl+Pb+Q for Local)

Actual Tresca Stresses:

Membrane	**6,107**	**Acceptable**
Bending	**12,700**	
Membrane + Bending	**18,522**	**Acceptable**
Peak	**26,535**	

13 nodes found on the stress classification line 1.2434 units long - cubic spline interpolated to 71 equally spaced nodes.

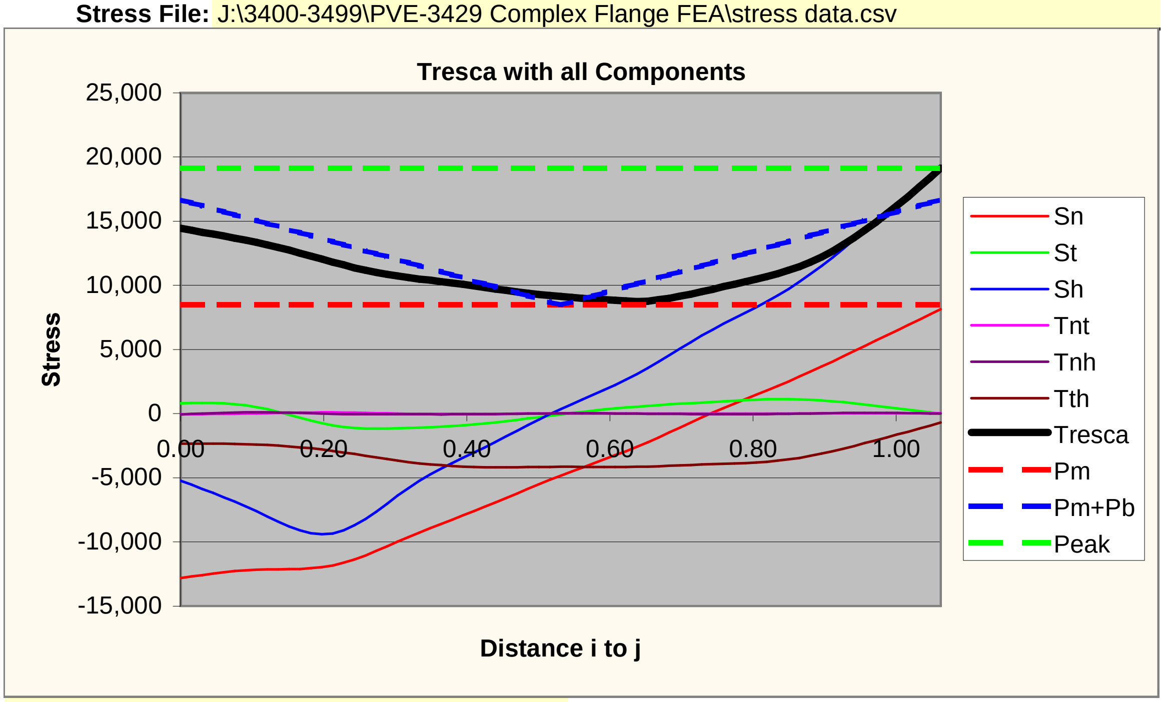
Stress Linearization ver 2.34



Description: **Flange hub stress linearization 2**

Probe File: J:\3400-3499\PVE-3429 Complex Flange FEA\probe1.csv

Stress File: J:\3400-3499\PVE-3429 Complex Flange FEA\stress data.csv



Tresca with all Components **Graph** - settings

Allowable Stresses:

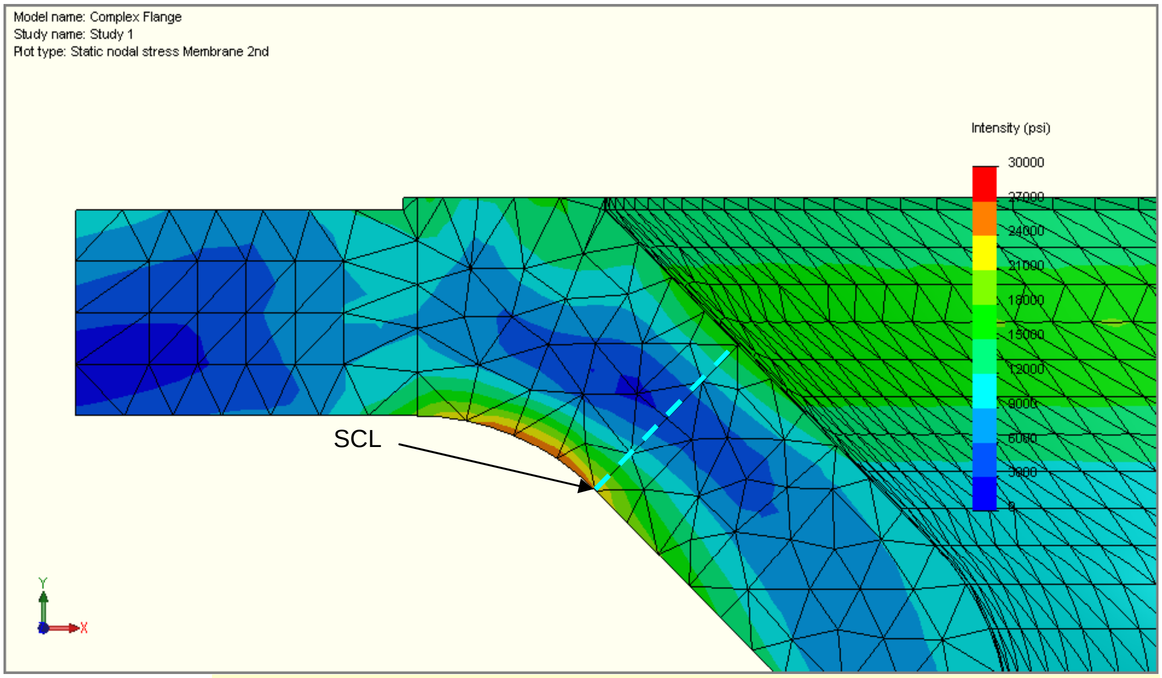
30,000 **M** - Membrane Allowable (Max Pm for global or Pl for local stresses)

60,000 **MB** - Membrane+Bending Allowable (Max Pl+Pb for Global or Pl+Pb+Q for Local)

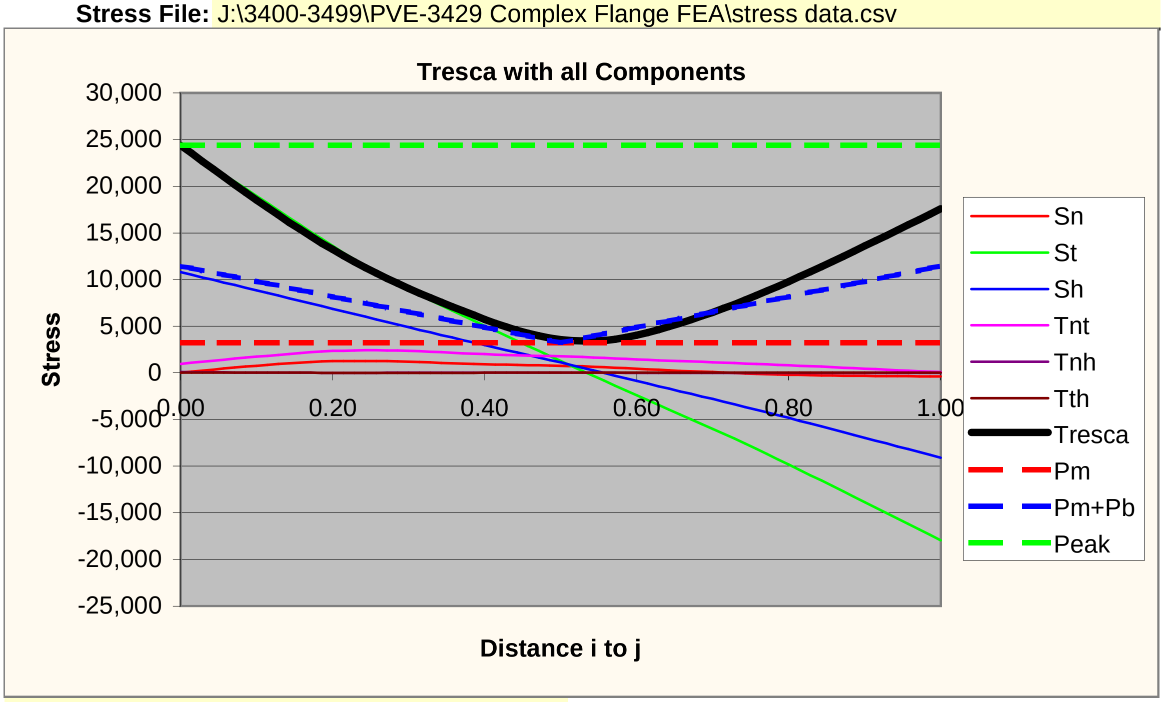
Actual Tresca Stresses:

Membrane	**8,478**	**Acceptable**
Bending	**13,959**	
Membrane + Bending	**16,675**	**Acceptable**
Peak	**19,135**	

11 nodes found on the stress classification line 1.0625 units long - cubic spline interpolated to 71 equally spaced nodes.



Description: Flange hub stress linearization 3
Probe File: J:\3400-3499\PVE-3429 Complex Flange FEA\probe2.csv
Stress File: J:\3400-3499\PVE-3429 Complex Flange FEA\stress data.csv



Tresca with all Components **Graph** - settings

Allowable Stresses:

30,000	**M** - Membrane Allowable (Max Pm for global or Pl for local stresses)
60,000	**MB** - Membrane+Bending Allowable (Max Pl+Pb for Global or Pl+Pb+Q for Local)

Actual Tresca Stresses:

Membrane	**3,237**	**Acceptable**
Bending	**9,835**	
Membrane + Bending	**11,442**	**Acceptable**
Peak	**24,398**	

9 nodes found on the stress classification line 1 units long - cubic spline interpolated to 71 equally spaced nodes.

Reference List:

Please refer to the following links for additional information;

Including reference components in an FEA to provide appropriate boundary and load conditions.
http://www.pveng.com/documents/content_80.pdf

The use and effects of 2nd order integration elements.
http://www.pveng.com/documents/content_151.pdf

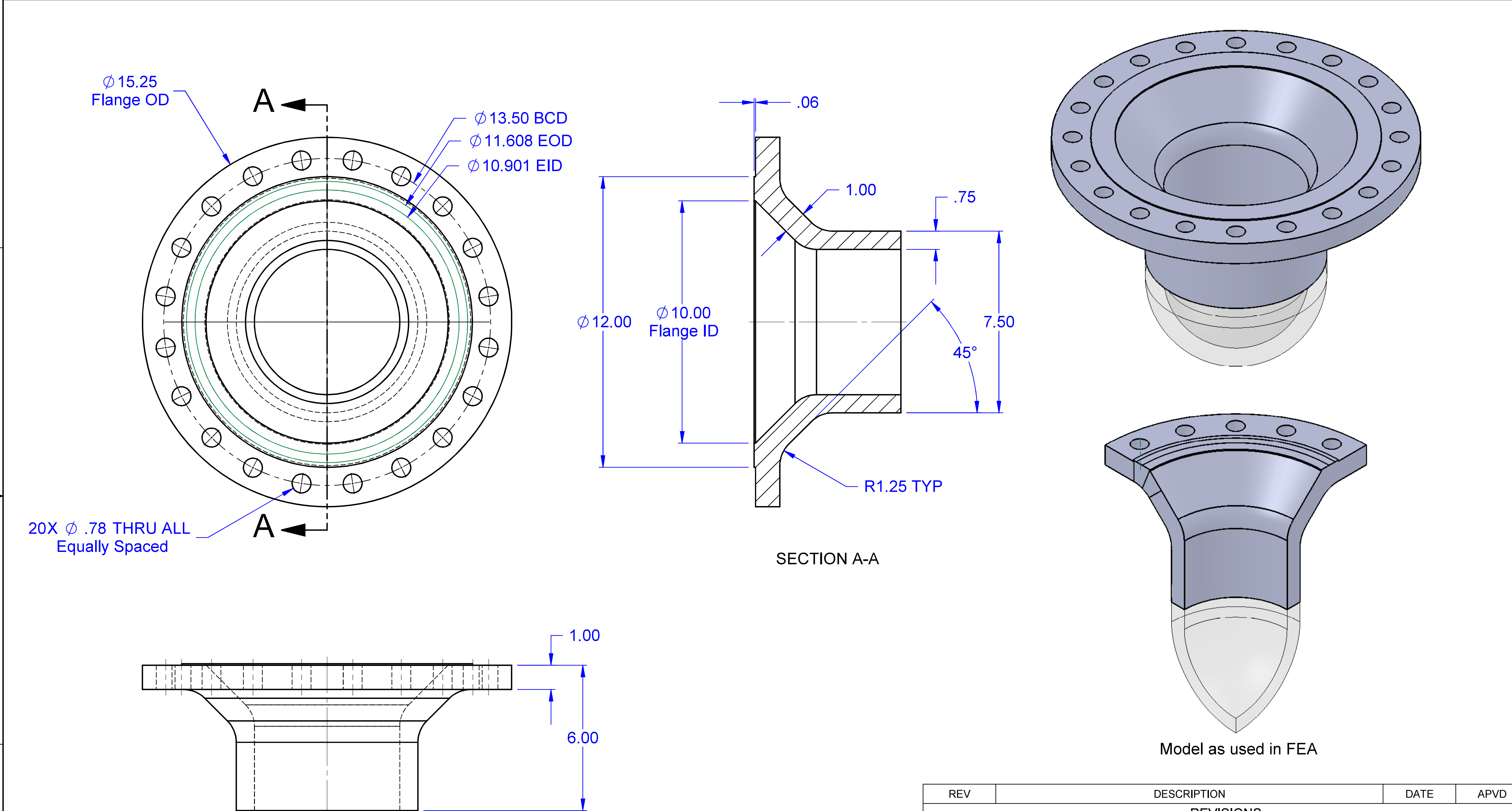
Mesh Refinement Using the Error Function Results for Areas at Discontinuities.
http://www.pveng.com/documents/content_250.pdf

Mesh Refinement Using the Error Function Results for Areas near Discontinuities.
http://www.pveng.com/documents/content_251.pdf

Error Plots for Bolt Heads and Surface to Surface Contacts Areas.
http://www.pveng.com/documents/content_248.pdf

FEA Software Validation - A comparison to theoretical results.
http://www.pveng.com/documents/content_249.pdf

COSMOSWorks Validation Examples.
http://www.pveng.com/documents/content_247.pdf



REV	DESCRIPTION	DATE	APVD

REVISIONS

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES

INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

TOLERANCES APPLY AS SHOWN BELOW

0 PL DEC	± 0.2
1 PL DEC	± 0.1
2 PL DEC	± 0.01
3 PL DEC	± 0.005
ANGLES	± .1°
SURFACE ROUGHNESS	32 μ in

THIRD ANGLE PROJECTION

MATERIAL: SA-105 @200°F

FINISH:

SolidWorks MAINTAINED DATA
CHANGES SHALL BE INCORPORATED
ELECTRONICALLY BY THE DESIGN ACTIVITY

CUSTOMER: Pressure Vessel Engineering

PROJECT: PVE-3429

DRAWN BY: BTV	DATE: 03/20/09
CHECKED BY:	DATE:
APPROVED:	DATE:

PVEng Pressure Vessel Engineering
120 Randall Drive, Suite B Waterloo, Ontario N2V 1C6
P: 519-880-9808 F: 519-880-9810
http://www.pveng.com info@pveng.com

TITLE: **Flange**

SIZE: **B** DRAWING NO: **PVE-3429** REVISION: **0**

SCALE: 1:4 WEIGHT: 2.610 lbs SHEET 1 OF 1