PVEng

Pressure Vessel Engineering Ltd.

ASME Calculations - CRN Assistance - Vessel Design - Finite Element Analysis

Design Conditions

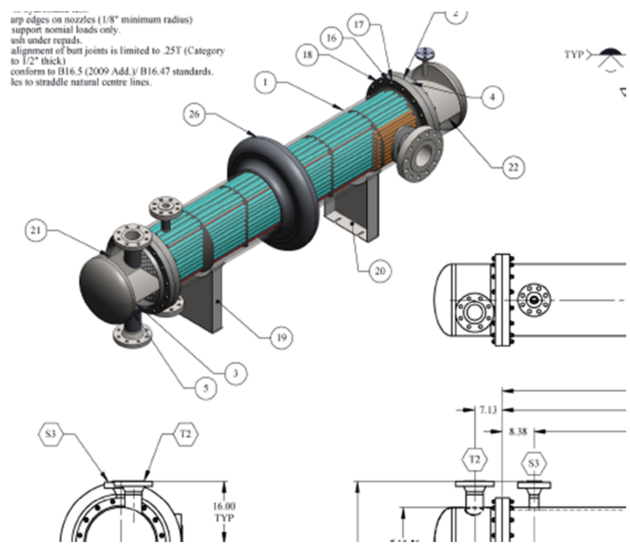
Code:	**ASME VIII-1**	
Year:	**2010**	
Addenda:	**2011**	
MAWP Shell Side:	**1400**	psi
Shell Side Temp:	**650**	°F
MAWP Tube Side:	**150**	psi
Tube Side Temp:	**650**	°F
MDMT:	**-20**	°F
Corrosion All. Shell:	**0.0625**	in
Corrosion All. Tube:	**0.0625**	in
Corrosion All. Tubes:	**0**	in
Hydrotest Shell:	**1820**	psi
Hydrotest Tube:	**195**	psi
Impact Exemption:	**Exempt per UG-20(f)**	
Radiography:	**Full**	

UG-22 Loadings Considered

Internal Press.:	**Yes**
External Press.:	**Yes**
Vessel Weight:	**Yes**
Weight of Attachments:	**Yes**
Attachment of Internals:	**No**
Attachment of Externals:	**No**
Cyclic or Dynamic Reactions:	**No**
Wind Loading:	**No**
Seismic Loading:	**No**
Fluid Impact Shock Reactions:	**No**
Temperature Gradients:	**No**
Differential Thermal Expansion:	**No**
Abnormal Pressures:	**No**
Hydrotest Loads:	**No**

ASME Section VIII-1 Calculations

Cust:	**PVEng, H&C Heat Transfer**
File:	**PVE-4293**
Desc:	**Heat Exchanger Sample**
Dwg:	**PVEdwg-4293-0.0 Heat Exchanger**
Date:	**September 20, 2012**



Author: Jakub Luszczki CET

Reviewer: Laurence Brundrett, P. Eng.

Conclusion: The sample heat exchanger has been analyzed according to ASME Sec VIII-1 and found to be acceptable.

www.pveng.com
info@pveng.com
Phone 519-880-9808

Pressure Vessel Engineering Ltd.
120 Randall Drive, Suite B
Waterloo, Ontario, Canada, N2V 1C6

H&C Heat Transfer Sample
PVE-4293

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H&C Heat Transfer Sample
PVE-4293

DESIGN CALCULATION

In Accordance with ASME Section VIII Division 1

ASME Code Version : 2010 Edition, 2011a Addenda

Analysis Performed by : PRESSURE VESSEL ENGINEERING

Job File : \\PVESERVER\JOBS\4000-4999\4200-4299\4293 H&C HE

Date of Analysis : Sep 18,2012

PV Elite 2012, January 2012

Class From To : Basic Element Checks.
==

Class From To: Check of Additional Element Data
==

There were no geometry errors or warnings.

PV Elite Vessel Analysis Program: Input Data

H&C Heat Transfer Sample
PVE-4293

Exchanger Design Pressures and Temperatures

Shell Side Design Pressure	1400.0	psig
Channel Side Design Pressure	150.00	psig
Shell Side Design Temperature	650	F
Channel Side Design Temperature	650	F

Type of Hydrotest	UG99-b Note [34]	
Hydrotest Position	Horizontal	
Projection of Nozzle from Vessel Top	0.0000	in.
Projection of Nozzle from Vessel Bottom	0.0000	in.
Minimum Design Metal Temperature	-20	F
Type of Construction	Welded	
Special Service	None	
Degree of Radiography	RT 1	
Miscellaneous Weight Percent	0.0	
Use Higher Longitudinal Stresses (Flag)	Y	
Select t for Internal Pressure (Flag)	N	
Select t for External Pressure (Flag)	N	
Select t for Axial Stress (Flag)	N	
Select Location for Stiff. Rings (Flag)	N	
Consider Vortex Shedding	N	
Perform a Corroded Hydrotest	N	
Is this a Heat Exchanger	Yes	
User Defined Hydro. Press. (Used if > 0)	0.0000	psig
User defined MAWP	0.0000	psig
User defined MAPnc	0.0000	psig

Load Case 1	NP+EW+WI+FW+BW
Load Case 2	NP+EW+EE+FS+BS
Load Case 3	NP+OW+WI+FW+BW
Load Case 4	NP+OW+EQ+FS+BS
Load Case 5	NP+HW+HI
Load Case 6	NP+HW+HE
Load Case 7	IP+OW+WI+FW+BW
Load Case 8	IP+OW+EQ+FS+BS
Load Case 9	EP+OW+WI+FW+BW
Load Case 10	EP+OW+EQ+FS+BS
Load Case 11	HP+HW+HI
Load Case 12	HP+HW+HE
Load Case 13	IP+WE+EW
Load Case 14	IP+WF+CW
Load Case 15	IP+VO+OW
Load Case 16	IP+VE+EW
Load Case 17	NP+VO+OW
Load Case 18	FS+BS+IP+OW
Load Case 19	FS+BS+EP+OW

Wind Design Code	No Wind Loads
Seismic Design Code	No Seismic

Design Nozzle for Des. Press. + St. Head	Y
Consider MAP New and Cold in Noz. Design	N
Consider External Loads for Nozzle Des.	Y
Use ASME VIII-1 Appendix 1-9	N
Material Database Year	2009

Configuration Directives:

Do not use Nozzle MDMT Interpretation VIII-1 01-37	No
Use Table G instead of exact equation for "A"	Yes
Shell Head Joints are Tapered	Yes
Compute "K" in corroded condition	Yes
Use Code Case 2286	No
Use the MAWP to compute the MDMT	Yes
Using Metric Material Databases, ASME II D	No

Complete Listing of Vessel Elements and Details:

Element From Node	10	
Element To Node	20	
Element Type	Elliptical	
Description	Left Head	
Distance "FROM" to "TO"	0.08330	ft.
Element Outside Diameter	18.500	in.
Element Thickness	0.1680	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	0.1875	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	150.00	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	0.0000	psig
Design Temperature External Pressure	650	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Allowable Stress, Ambient	20000.	psi
Allowable Stress, Operating	18800.	psi
Allowable Stress, Hydrotest	26000.	psi
Material Density	0.2830	lb./in^3
P Number Thickness	1.2500	in.
Yield Stress, Operating	28200.	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K02700	
Product Form	Plate	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	1.0	
Elliptical Head Factor	2.0	

Element From Node	10	
Detail Type	Liquid	
Detail ID	HEAD	
Dist. from "FROM" Node / Offset dist	0.1600	ft.
Height/Length of Liquid	1.5137	ft.
Liquid Density	62.400	lb./ft^3

Element From Node	20	
Element To Node	30	
Element Type	Cylinder	
Description	Left Channel	
Distance "FROM" to "TO"	0.7290	ft.
Element Outside Diameter	18.500	in.
Element Thickness	0.1875	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	0.1875	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	150.00	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	0.0000	psig
Design Temperature External Pressure	650	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	1.0	

Element From Node	20	
Detail Type	Liquid	
Detail ID	CHANNEL	
Dist. from "FROM" Node / Offset dist	0.8300	ft.
Height/Length of Liquid	1.5104	ft.
Liquid Density	62.400	lb./ft³

Element From Node	20	
Detail Type	Nozzle	
Detail ID	T1/T2	
Dist. from "FROM" Node / Offset dist	0.3600	ft.
Nozzle Diameter	4.0	in.
Nozzle Schedule	40	
Nozzle Class	300	
Layout Angle	110.57	
Blind Flange (Y/N)	N	
Weight of Nozzle (Used if > 0)	0.0000	lb.
Grade of Attached Flange	GR 1.1	
Nozzle Matl	SA-106 B	

Element From Node	30	
Element To Node	40	
Element Type	Flange	
Description	Channel Flange	
Distance "FROM" to "TO"	0.2396	ft.
Flange Inside Diameter	18.125	in.
Element Thickness	1.7500	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	1.7500	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	150.00	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	0.0000	psig
Design Temperature External Pressure	650	F

Effective Diameter Multiplier	1.2	
Material Name	SA-105	
Allowable Stress, Ambient	20000.	psi
Allowable Stress, Operating	17800.	psi
Allowable Stress, Hydrotest	26000.	psi
Material Density	0.2830	lb./in³
P Number Thickness	1.2500	in.
Yield Stress, Operating	26700.	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K03504	
Product Form	Forgings	
Perform Flange Stress Calculation (Y/N)	Y	
Weight of ANSI B16.5/B16.47 Flange	0.0000	lb.
Class of ANSI B16.5/B16.47 Flange		
Grade of ANSI B16.5/B16.47 Flange		

Element From Node	40	
Element To Node	50	
Element Type	Cylinder	
Description	Shell	
Distance "FROM" to "TO"	7.6670	ft.
Element Outside Diameter	18.500	in.
Element Thickness	0.7500	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	0.7500	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	1400.0	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	15.000	psig
Design Temperature External Pressure	650	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Allowable Stress, Ambient	20000.	psi
Allowable Stress, Operating	18800.	psi
Allowable Stress, Hydrotest	26000.	psi
Material Density	0.2830	lb./in³
P Number Thickness	1.2500	in.
Yield Stress, Operating	28200.	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K02700	
Product Form	Plate	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	1.0	

Element From Node	40	
Detail Type	Saddle	
Detail ID	Lft Sdl	
Dist. from "FROM" Node / Offset dist	1.5989	ft.
Width of Saddle	4.0000	in.
Height of Saddle at Bottom	25.000	in.
Saddle Contact Angle	120.0	
Height of Composite Ring Stiffener	0.0000	in.
Width of Wear Plate	5.0000	in.

```
       Thickness of Wear Plate                          0.2500  in.
       Contact Angle, Wear Plate (degrees)               132.0

       Element From Node                                    40
       Detail Type                                      Saddle
       Detail ID                                       Rgt Sdl
       Dist. from "FROM" Node / Offset dist             6.4000  ft.
       Width of Saddle                                  4.0000  in.
       Height of Saddle at Bottom                       25.000  in.
       Saddle Contact Angle                              120.0
       Height of Composite Ring Stiffener               0.0000  in.
       Width of Wear Plate                              5.0000  in.
       Thickness of Wear Plate                          0.2500  in.
       Contact Angle, Wear Plate (degrees)               132.0

       Element From Node                                    40
       Detail Type                                      Liquid
       Detail ID                                         SHELL
       Dist. from "FROM" Node / Offset dist             0.0000  ft.
       Height/Length of Liquid                          1.4427  ft.
       Liquid Density                                   62.400  lb./ft³

       Element From Node                                    40
       Detail Type                                      Nozzle
       Detail ID                                            S2
       Dist. from "FROM" Node / Offset dist             0.5000  ft.
       Nozzle Diameter                                     3.0  in.
       Nozzle Schedule                                     XXS
       Nozzle Class                                        900
       Layout Angle                                      270.0
       Blind Flange (Y/N)                                    N
       Weight of Nozzle ( Used if > 0 )                 0.0000  lb.
       Grade of Attached Flange                         GR 1.1
       Nozzle Matl                                    SA-106 B

       Element From Node                                    40
       Detail Type                                      Nozzle
       Detail ID                                            S1
       Dist. from "FROM" Node / Offset dist             7.2900  ft.
       Nozzle Diameter                                     6.0  in.
       Nozzle Schedule                                     XXS
       Nozzle Class                                        900
       Layout Angle                                      270.0
       Blind Flange (Y/N)                                    N
       Weight of Nozzle ( Used if > 0 )                 0.0000  lb.
       Grade of Attached Flange                         GR 1.1
       Nozzle Matl                                    SA-106 B

       Element From Node                                    40
       Detail Type                                      Nozzle
       Detail ID                                            S3
       Dist. from "FROM" Node / Offset dist             0.5000  ft.
       Nozzle Diameter                                     2.0  in.
       Nozzle Schedule                                     XXS
       Nozzle Class                                        900
       Layout Angle                                       90.0
       Blind Flange (Y/N)                                    N
```

Weight of Nozzle (Used if > 0)	0.0000	lb.
Grade of Attached Flange	GR 1.1	
Nozzle Matl	SA-106 B	

Element From Node	50	
Element To Node	60	
Element Type	Flange	
Description	Channel Flange	
Distance "FROM" to "TO"	0.2396	ft.
Flange Inside Diameter	18.125	in.
Element Thickness	1.7500	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	1.7500	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	150.00	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	0.0000	psig
Design Temperature External Pressure	650	F
Effective Diameter Multiplier	1.2	
Material Name	SA-105	
Allowable Stress, Ambient	20000.	psi
Allowable Stress, Operating	17800.	psi
Allowable Stress, Hydrotest	26000.	psi
Material Density	0.2830	lb./in^3
P Number Thickness	1.2500	in.
Yield Stress, Operating	26700.	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K03504	
Product Form	Forgings	
Perform Flange Stress Calculation (Y/N)	Y	
Weight of ANSI B16.5/B16.47 Flange	0.0000	lb.
Class of ANSI B16.5/B16.47 Flange		
Grade of ANSI B16.5/B16.47 Flange		

Element From Node	60	
Element To Node	70	
Element Type	Cylinder	
Description	Channel	
Distance "FROM" to "TO"	0.7290	ft.
Element Outside Diameter	18.500	in.
Element Thickness	0.1875	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	0.1875	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	150.00	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	0.0000	psig
Design Temperature External Pressure	650	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Allowable Stress, Ambient	20000.	psi
Allowable Stress, Operating	18800.	psi

Allowable Stress, Hydrotest	26000.	psi
Material Density	0.2830	lb./in³
P Number Thickness	1.2500	in.
Yield Stress, Operating	28200.	psi
UCS-66 Chart Curve Designation	B	
External Pressure Chart Name	CS-2	
UNS Number	K02700	
Product Form	Plate	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	1.0	

Element From Node	60	
Detail Type	Liquid	
Detail ID	CHANNEL	
Dist. from "FROM" Node / Offset dist	0.0000	ft.
Height/Length of Liquid	1.5104	ft.
Liquid Density	62.400	lb./ft³

Element From Node	60	
Detail Type	Nozzle	
Detail ID	T3 & T4	
Dist. from "FROM" Node / Offset dist	0.5000	ft.
Nozzle Diameter	1.0	in.
Nozzle Schedule	80	
Nozzle Class	300	
Layout Angle	90.0	
Blind Flange (Y/N)	N	
Weight of Nozzle (Used if > 0)	0.0000	lb.
Grade of Attached Flange	GR 1.1	
Nozzle Matl	SA-106 B	

Element From Node	70	
Element To Node	80	
Element Type	Elliptical	
Description	Right Head	
Distance "FROM" to "TO"	0.08330	ft.
Element Outside Diameter	18.500	in.
Element Thickness	0.1680	in.
Internal Corrosion Allowance	0.06250	in.
Nominal Thickness	0.1875	in.
External Corrosion Allowance	0.0000	in.
Design Internal Pressure	150.00	psig
Design Temperature Internal Pressure	650	F
Design External Pressure	0.0000	psig
Design Temperature External Pressure	650	F
Effective Diameter Multiplier	1.2	
Material Name	SA-516 70	
Efficiency, Longitudinal Seam	1.0	
Efficiency, Circumferential Seam	1.0	
Elliptical Head Factor	2.0	

Element From Node	70	
Detail Type	Liquid	
Detail ID	HEAD	
Dist. from "FROM" Node / Offset dist	0.0000	ft.

Height/Length of Liquid	1.5137	ft.
Liquid Density	62.400	$lb./ft^3$

Flange Input Data Values   Description: Ch. Flange   :

Channel Flange

```
Description of Flange Geometry (Type)          Integral Weld Neck
Design Pressure                            P          150.00  psig
Design Temperature                                       650  F
Internal Corrosion Allowance              ci          0.0625  in.
External Corrosion Allowance              ce          0.0000  in.
Use Corrosion Allowance in Thickness Calcs.               No

Flange Inside Diameter                     B          18.125  in.
Flange Outside Diameter                    A          23.500  in.
Flange Thickness                           t          1.7500  in.
Thickness of Hub at Small End             go          0.1875  in.
Thickness of Hub at Large End             g1          0.5625  in.
Length of Hub                              h          1.1250  in.

Flange Material                                       SA-105
Flange Material UNS number                            K03504
Flange Allowable Stress At Temperature   Sfo        17800.00  psi
Flange Allowable Stress At Ambient       Sfa        20000.00  psi

Bolt Material                                     SA-193 B7
Bolt Allowable Stress At Temperature      Sb        25000.00  psi
Bolt Allowable Stress At Ambient          Sa        25000.00  psi

Diameter of Bolt Circle                    C          21.750  in.
Nominal Bolt Diameter                     dB          0.6250  in.
Type of Threads                            UNC Thread Series
Number of Bolts                                           16

Flange Face Outside Diameter             Fod          19.750  in.
Flange Face Inside Diameter              Fid          18.125  in.
Flange Facing Sketch                       1, Code Sketch 1a

Gasket Outside Diameter                   Go          19.125  in.
Gasket Inside Diameter                    Gi          18.125  in.
Gasket Factor                              m          2.5000
Gasket Design Seating Stress               y         2900.00  psi

Column for Gasket Seating                  2, Code Column II
Gasket Thickness                          tg          0.1250  in.

Length of Partition Gasket                lp         18.1250  in.
Width  of Partition Gasket                tp          0.3130  in.
Partition Gasket Factor                mPart          2.5000
Partition Gasket Design Seating Stress yPart         2900.00  psi
```

ASME Code, Section VIII, Division 1, 2010, 2011a

Hub Small End Required Thickness due to Internal Pressure:

```
 = (P*(D/2+Ca))/(S*E-0.6*P) per UG-27 (c)(1)
 = (150.00*(18.1250/2+0.0625))/(17800.00*1.00-0.6*150.00)+Ca
 = 0.1398 in.
```

Hub Small End Hub MAWP:
 = (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
 = (17800.00 * 1.00 * 0.1250)/(9.1250 + 0.6 * 0.1250)
 = 241.848 psig

Corroded Flange ID,	Bcor = B+2*Fcor	18.250	in.
Corroded Large Hub,	g1Cor = g1-ci	0.500	in.
Corroded Small Hub,	g0Cor = go-ci	0.125	in.
Code R Dimension,	R = ((C-Bcor)/2)-g1cor	1.250	in.

Gasket Contact Width,	N = (Go - Gi) / 2	0.500	in.
Basic Gasket Width,	bo = N / 2	0.250	in.
Effective Gasket Width,	b = bo	0.250	in.
Gasket Reaction Diameter,	G = (Go + Gi) / 2	18.625	in.

Basic Flange and Bolt Loads:

Hydrostatic End Load due to Pressure [H]:
 = 0.785 * G^2 * Peq
 = 0.785 * 18.6250^2 * 150.000
 = 40867.090 lb.
Contact Load on Gasket Surfaces [Hp]:
 = 2 * b * Pi * G * m * P + 2 * lp * bPart * mPart * P
 = 2 * 0.2500 * 3.1416 * 18.6250 * 2.5000 * 150.00
   + 2.0 * 18.1250 * 0.1565 * 2.5000 * 150.0000
 = 13098.453 lb.
Hydrostatic End Load at Flange ID [Hd]:
 = Pi * $Bcor^2$ * P / 4
 = 3.1416 * 18.2500^2 *150.0000/4
 = 39238.004 lb.
Pressure Force on Flange Face [Ht]:
 = H - Hd
 = 40867 - 39238
 = 1629.086 lb.
Operating Bolt Load [Wm1]:
 = max(H + Hp + H'p, 0)
 = max(40867 + 13098 + 0 , 0)
 = 53965.543 lb.
Gasket Seating Bolt Load [Wm2]:
 = y * b * Pi * G + yPart * bPart * lp
 = 2900.00*0.2500*3.141*18.625+2900.00*0.1565*18.12
 = 50647.352 lb.
Required Bolt Area [Am]:
 = Maximum of Wm1/Sb, Wm2/Sa
 = Maximum of 53965/25000 , 50647/25000
 = 2.159 in^2

ASME Maximum Circumferential Spacing between Bolts per App. 2 eq. (3) [Bsmax]:
 = 2a + 6t/(m + 0.5)
 = 2 * 0.625 + 6 * 1.750/(2.50 + 0.5)
 = 4.750 in.

Actual Circumferential Bolt Spacing [Bs]:
 = C * sin(pi / n))
 = 21.750 * sin(3.142/16)
 = 4.243 in.

ASME Moment Multiplier for Bolt Spacing per App. 2 eq. (7) [Bsc]:
```
 = max( sqrt( Bs/( 2a + t )), 1 )
 = max( sqrt( 4.243/( 2 * 0.625 + 1.750 )), 1 )
 = 1.1893
```

Bolting Information for UNC Thread Series (Non Mandatory):

	Minimum	Actual	Maximum
Bolt Area, in²	2.159	3.232	
Radial distance bet. hub and bolts	0.938	1.250	
Radial distance bet. bolts and the edge	0.750	0.875	
Circumferential spacing between bolts	1.500	4.243	4.750

Min. Gasket Contact Width (Brownell Young) [Not an ASME Calc] [Nmin]:
```
 = Ab * Sa/( y * Pi * (Go + Gi) )
 = 3.232 * 25000.00/(2900.00 * 3.14 * (19.125 + 18.12 ) )
 = 0.238 in.
```

Flange Design Bolt Load, Gasket Seating [W]:
```
 = Sa * ( Am + Ab ) / 2
 = 25000.00 * ( 2.1586 + 3.2320 )/2
 = 67382.77 lb.
```
Gasket Load for the Operating Condition [HG]:
```
 = Wm1 - H
 = 53965 - 40867
 = 13098.45 lb.
```

Moment Arm Calculations:
Distance to Gasket Load Reaction [hg]:
```
 = (C - G ) / 2
 = ( 21.7500 - 18.6250 )/2
 = 1.5625 in.
```
Distance to Face Pressure Reaction [ht]:
```
 = ( R + g1 + hg ) / 2
 = ( 1.2500 + 0.5000 + 1.5625 )/2
 = 1.6562 in.
```
Distance to End Pressure Reaction [hd]:
```
 = R + ( g1 / 2 )
 = 1.2500 + ( 0.5000/2.0 )
 = 1.5000 in.
```

Summary of Moments for Internal Pressure:

Loading		Force	Distance	Bolt Corr	Moment	
End Pressure,	Md	39238.	1.5000	1.1893	5833.	ft.lb.
Face Pressure,	Mt	1629.	1.6562	1.1893	267.	ft.lb.
Gasket Load,	Mg	13098.	1.5625	1.1893	2028.	ft.lb.
Gasket Seating,	Matm	67383.	1.5625	1.1893	10435.	ft.lb.

```
Total Moment for Operation,      Mop                    8129. ft.lb.
Total Moment for Gasket seating, Matm                  10435. ft.lb.

Effective Hub Length, ho = sqrt(Bcor*goCor)            1.510  in.
Hub Ratio,           h/h0 = HL / H0                    0.745
Thickness Ratio,   g1/g0 = (g1Cor/goCor)               4.000
```

Flange Factors for Integral Flange:

```
Factor F per 2-7.2                                          0.736
Factor V per 2-7.3                                          0.081
Factor f per 2-7.6                                          2.930
Factors from Figure 2-7.1                         K =       1.288
                    T =      1.803                U =       8.595
                    Y =      7.822                Z =       4.039
                    d =      2.513 in.³           e =     0.4875 in.^-1
Stress Factors                                ALPHA =       1.853
                 BETA =      2.138            GAMMA =       1.028
                DELTA =      2.133            Lamda =       3.161
```

Longitudinal Hub Stress, Operating [SHo]:
 = (f * Mop / Bcor) / (L * g1²)
 = (2.9303*97547/18.2500)/(3.1608*0.5000²)
 = 19821.01 psi

Longitudinal Hub Stress, Seating [SHa]:
 = (f * Matm / Bcor) / (L * g1²)
 = (2.9303*125214/18.2500)/(3.1608*0.5000²)
 = 25442.91 psi

Radial Flange Stress, Operating [SRo]:
 = (Beta * Mop / Bcor) / (L * t²)
 = (2.1376*97547/18.2500)/(3.1608*1.7500²)
 = 1180.33 psi

Radial Flange Stress, Seating [SRa]:
 = (Beta * Matm/Bcor) / (L * t²)
 = (2.1376*125214/18.2500)/(3.1608*1.7500²)
 = 1515.11 psi

Tangential Flange Stress, Operating [STo]:
 = (Y * Mo / (t² * Bcor)) - Z * SRo
 = (7.8217*97547/(1.7500²*18.2500))-4.0391*1180
 = 8883.92 psi

Tangential Flange Stress, Seating [STa]:
 = (y * Matm / (t² * Bcor)) - Z * SRa
 = (7.8217*125214/(1.7500²*18.2500))-4.0391*1515
 = 11403.70 psi

Average Flange Stress, Operating [SAo]:
 = (SHo + max(SRo, STo)) / 2
 = (19821+max(1180,8883))/2
 = 14352.46 psi

Average Flange Stress, Seating [SAa]:
 = (SHa + max(SRa, STa)) / 2
 = (25442+max(1515,11403))/2
 = 18423.30 psi

Bolt Stress, Operating [BSo]:
 = (Wm1 / Ab)
 = (53965/3.2320)
 = 16697.26 psi

Bolt Stress, Seating [BSa]:
 = (Wm2 / Ab)
 = (50647/3.2320)
 = 15670.59 psi

Stress Computation Results:

	Operating Actual	Operating Allowed	Gasket Seating Actual	Gasket Seating Allowed	
Longitudinal Hub	19821.	26700.	25443.	30000.	psi
Radial Flange	1180.	17800.	1515.	20000.	psi
Tangential Flange	8884.	17800.	11404.	20000.	psi
Maximum Average	14352.	17800.	18423.	20000.	psi
Bolting	16697.	25000.	15671.	25000.	psi

Minimum Required Flange Thickness	1.684	in.
Estimated M.A.W.P. (Operating)	186.0	psig
Estimated Finished Weight of Flange at given Thk.	94.0	lbm
Estimated Unfinished Weight of Forging at given Thk	143.0	lbm

Flange Rigidity Based on Required Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
```
 = 52.14 * Ma / Bsc * Cnv_fac * V / ( Lambda * Eamb * go^(2) * ho * Ki )
 = 52.14 * 10434.6/1.2026 * 12.000 * 0.081/( 2.908 * 29400000 *
   0.125^(2) * 1.510 * 0.300 )
 = 0.724  (should be <= 1)
```

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
```
 = 52.14 * Mo / Bsc * Cnv_fac * V / ( Lambda * Eop * goc^(2) * ho * Ki )
 = 52.14 * 8128.9/1.2026 * 12.000 * 0.081/( 2.908 * 26000000
   * 0.125^(2) * 1.510 * 0.300 )
 = 0.638  (should be <= 1)
```

Flange Rigidity Based on Given Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
```
 = 52.14 * Ma / Bsc * Cnv_fac * V / ( Lambda * Eamb * go^(2) * ho * Ki )
 = 52.14 * 10434.6/1.1893 * 12.000 * 0.081/( 3.161 * 29400000 *
   0.125^(2) * 1.510 * 0.300 )
 = 0.674  (should be <= 1)
```

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
```
 = 52.14 * Mo / Bsc * Cnv_fac * V / ( Lambda * Eop * goc^(2) * ho * Ki )
 = 52.14 * 8128.9/1.1893 * 12.000 * 0.081/( 3.161 * 26000000
   * 0.125^(2) * 1.510 * 0.300 )
 = 0.593  (should be <= 1)
```

Minimum Design Metal Temperature Results:
Stress Ratio = 0.775 , Temperature Reduction per Fig. UCS 66.1 = 23 F

Min Metal Temp. w/o impact per UCS-66	-20 F
Min Metal Temp. at Required thickness (UCS 66.1)	-43 F

Flange Input Data Values **Description: Ch. Flange :**

Channel Flange

```
Description of Flange Geometry (Type)          Integral Weld Neck
Design Pressure                             P           150.00  psig
Design Temperature                                         650  F
Internal Corrosion Allowance               ci           0.0625  in.
External Corrosion Allowance               ce           0.0000  in.
Use Corrosion Allowance in Thickness Calcs.                 No

Flange Inside Diameter                      B           18.125  in.
Flange Outside Diameter                     A           23.500  in.
Flange Thickness                            t           1.7500  in.
Thickness of Hub at Small End              go           0.1875  in.
Thickness of Hub at Large End              g1           0.5625  in.
Length of Hub                               h           1.1250  in.

Flange Material                                         SA-105
Flange Material UNS number                              K03504
Flange Allowable Stress At Temperature    Sfo         17800.00  psi
Flange Allowable Stress At Ambient        Sfa         20000.00  psi

Bolt Material                                       SA-193 B7
Bolt Allowable Stress At Temperature       Sb         25000.00  psi
Bolt Allowable Stress At Ambient           Sa         25000.00  psi

Diameter of Bolt Circle                     C           21.750  in.
Nominal Bolt Diameter                      dB           0.6250  in.
Type of Threads                             UNC Thread Series
Number of Bolts                                             16

Flange Face Outside Diameter              Fod           19.750  in.
Flange Face Inside Diameter               Fid           18.125  in.
Flange Facing Sketch                        1, Code Sketch 1a

Gasket Outside Diameter                    Go           19.125  in.
Gasket Inside Diameter                     Gi           18.125  in.
Gasket Factor                               m           2.5000
Gasket Design Seating Stress                y          2900.00  psi

Column for Gasket Seating                   2, Code Column II
Gasket Thickness                           tg           0.1250  in.

Length of Partition Gasket                 lp          18.1250  in.
Width  of Partition Gasket                 tp           0.3130  in.
Partition Gasket Factor                 mPart           2.5000
Partition Gasket Design Seating Stress  yPart          2900.00  psi
```

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Hub Small End Required Thickness due to Internal Pressure:

```
 = (P*(D/2+Ca))/(S*E-0.6*P) per UG-27 (c)(1)
 = (150.00*(18.1250/2+0.0625))/(17800.00*1.00-0.6*150.00)+Ca
 = 0.1398 in.
```

Hub Small End Hub MAWP:
 = (S*E*t)/(R+0.6*t) per UG-27 (c)(1)
 = (17800.00 * 1.00 * 0.1250)/(9.1250 + 0.6 * 0.1250)
 = 241.848 psig

Corroded Flange ID,	Bcor = B+2*Fcor	18.250	in.
Corroded Large Hub,	g1Cor = g1-ci	0.500	in.
Corroded Small Hub,	g0Cor = go-ci	0.125	in.
Code R Dimension,	R = ((C-Bcor)/2)-g1cor	1.250	in.
Gasket Contact Width,	N = (Go - Gi) / 2	0.500	in.
Basic Gasket Width,	bo = N / 2	0.250	in.
Effective Gasket Width,	b = bo	0.250	in.
Gasket Reaction Diameter,	G = (Go + Gi) / 2	18.625	in.

Basic Flange and Bolt Loads:

Hydrostatic End Load due to Pressure [H]:
 = 0.785 * G² * Peq
 = 0.785 * 18.6250² * 150.000
 = 40867.090 lb.

Contact Load on Gasket Surfaces [Hp]:
 = 2 * b * Pi * G * m * P + 2 * lp * bPart * mPart * P
 = 2 * 0.2500 * 3.1416 * 18.6250 * 2.5000 * 150.00
   + 2.0 * 18.1250 * 0.1565 * 2.5000 * 150.0000
 = 13098.453 lb.

Hydrostatic End Load at Flange ID [Hd]:
 = Pi * Bcor² * P / 4
 = 3.1416 * 18.2500² *150.0000/4
 = 39238.004 lb.

Pressure Force on Flange Face [Ht]:
 = H - Hd
 = 40867 - 39238
 = 1629.086 lb.

Operating Bolt Load [Wm1]:
 = max(H + Hp + H'p, 0)
 = max(40867 + 13098 + 0 , 0)
 = 53965.543 lb.

Gasket Seating Bolt Load [Wm2]:
 = y * b * Pi * G + yPart * bPart * lp
 = 2900.00*0.2500*3.141*18.625+2900.00*0.1565*18.12
 = 50647.352 lb.

Required Bolt Area [Am]:
 = Maximum of Wm1/Sb, Wm2/Sa
 = Maximum of 53965/25000 , 50647/25000
 = 2.159 in²

ASME Maximum Circumferential Spacing between Bolts per App. 2 eq. (3) [Bsmax]:
 = 2a + 6t/(m + 0.5)
 = 2 * 0.625 + 6 * 1.750/(2.50 + 0.5)
 = 4.750 in.

Actual Circumferential Bolt Spacing [Bs]:
 = C * sin(pi / n))
 = 21.750 * sin(3.142/16)
 = 4.243 in.

ASME Moment Multiplier for Bolt Spacing per App. 2 eq. (7) [Bsc]:
 = max(sqrt(Bs/(2a + t)), 1)
 = max(sqrt(4.243/(2 * 0.625 + 1.750)), 1)
 = 1.1893

Bolting Information for UNC Thread Series (Non Mandatory):

	Minimum	Actual	Maximum
Bolt Area, in^2	2.159	3.232	
Radial distance bet. hub and bolts	0.938	1.250	
Radial distance bet. bolts and the edge	0.750	0.875	
Circumferential spacing between bolts	1.500	4.243	4.750

Min. Gasket Contact Width (Brownell Young) [Not an ASME Calc] [Nmin]:
 = Ab * Sa/(y * Pi * (Go + Gi))
 = 3.232 * 25000.00/(2900.00 * 3.14 * (19.125 + 18.12))
 = 0.238 in.

Flange Design Bolt Load, Gasket Seating [W]:
 = Sa * (Am + Ab) / 2
 = 25000.00 * (2.1586 + 3.2320)/2
 = 67382.77 lb.
Gasket Load for the Operating Condition [HG]:
 = Wm1 - H
 = 53965 - 40867
 = 13098.45 lb.

Moment Arm Calculations:
Distance to Gasket Load Reaction [hg]:
 = (C - G) / 2
 = (21.7500 - 18.6250)/2
 = 1.5625 in.
Distance to Face Pressure Reaction [ht]:
 = (R + g1 + hg) / 2
 = (1.2500 + 0.5000 + 1.5625)/2
 = 1.6562 in.
Distance to End Pressure Reaction [hd]:
 = R + (g1 / 2)
 = 1.2500 + (0.5000/2.0)
 = 1.5000 in.

Summary of Moments for Internal Pressure:

Loading		Force	Distance	Bolt Corr	Moment	
End Pressure,	Md	39238.	1.5000	1.1893	5833.	ft.lb.
Face Pressure,	Mt	1629.	1.6562	1.1893	267.	ft.lb.
Gasket Load,	Mg	13098.	1.5625	1.1893	2028.	ft.lb.
Gasket Seating,	Matm	67383.	1.5625	1.1893	10435.	ft.lb.

Total Moment for Operation,	Mop	8129.	ft.lb.
Total Moment for Gasket seating,	Matm	10435.	ft.lb.

Effective Hub Length,	ho = sqrt(Bcor*goCor)	1.510	in.
Hub Ratio,	h/h0 = HL / H0	0.745	
Thickness Ratio,	g1/g0 = (g1Cor/goCor)	4.000	

Flange Factors for Integral Flange:

Factor F per 2-7.2				0.736
Factor V per 2-7.3				0.081
Factor f per 2-7.6				2.930
Factors from Figure 2-7.1			K =	1.288
	T =	1.803	U =	8.595
	Y =	7.822	Z =	4.039
	d =	2.513 $in.^3$	e =	0.4875 in.^-1
Stress Factors			ALPHA =	1.853
	BETA =	2.138	GAMMA =	1.028
	DELTA =	2.133	Lamda =	3.161

Longitudinal Hub Stress, Operating [SHo]:
= (f * Mop / Bcor) / (L * $g1^2$)
= (2.9303*97547/18.2500)/(3.1608*0.5000^2)
= 19821.01 psi
Longitudinal Hub Stress, Seating [SHa]:
= (f * Matm / Bcor) / (L * $g1^2$)
= (2.9303*125214/18.2500)/(3.1608*0.5000^2)
= 25442.91 psi

Radial Flange Stress, Operating [SRo]:
= (Beta * Mop / Bcor) / (L * t^2)
= (2.1376*97547/18.2500)/(3.1608*1.7500^2)
= 1180.33 psi
Radial Flange Stress, Seating [SRa]:
= (Beta * Matm/Bcor) / (L * t^2)
= (2.1376*125214/18.2500)/(3.1608*1.7500^2)
= 1515.11 psi

Tangential Flange Stress, Operating [STo]:
= (Y * Mo / (t^2 * Bcor)) - Z * SRo
= (7.8217*97547/(1.7500^2*18.2500))-4.0391*1180
= 8883.92 psi
Tangential Flange Stress, Seating [STa]:
= (y * Matm / (t^2 * Bcor)) - Z * SRa
= (7.8217*125214/(1.7500^2*18.2500))-4.0391*1515
= 11403.70 psi

Average Flange Stress, Operating [SAo]:
= (SHo + max(SRo, STo)) / 2
= (19821+max(1180,8883))/2
= 14352.46 psi
Average Flange Stress, Seating [SAa]:
= (SHa + max(SRa, STa)) / 2
= (25442+max(1515,11403))/2
= 18423.30 psi

Bolt Stress, Operating [BSo]:
= (Wm1 / Ab)
= (53965/3.2320)
= 16697.26 psi
Bolt Stress, Seating [BSa]:
= (Wm2 / Ab)
= (50647/3.2320)
= 15670.59 psi

Stress Computation Results:

	Operating Actual	Operating Allowed	Gasket Seating Actual	Gasket Seating Allowed	
Longitudinal Hub	19821.	26700.	25443.	30000.	psi
Radial Flange	1180.	17800.	1515.	20000.	psi
Tangential Flange	8884.	17800.	11404.	20000.	psi
Maximum Average	14352.	17800.	18423.	20000.	psi
Bolting	16697.	25000.	15671.	25000.	psi

```
Minimum Required Flange Thickness                         1.684  in.
Estimated M.A.W.P. ( Operating )                          186.0  psig
Estimated Finished Weight of Flange at given Thk.          94.0  lbm
Estimated Unfinished Weight of Forging at given Thk      143.0  lbm
```

Flange Rigidity Based on Required Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
```
 = 52.14 * Ma / Bsc * Cnv_fac * V / ( Lambda * Eamb * go^(2) * ho * Ki )
 = 52.14 * 10434.6/1.2026 * 12.000 * 0.081/( 2.908 * 29400000 *
   0.125^(2) * 1.510 * 0.300 )
 = 0.724  (should be <= 1)
```

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
```
 = 52.14 * Mo / Bsc * Cnv_fac * V / ( Lambda * Eop * goc^(2) * ho * Ki )
 = 52.14 * 8128.9/1.2026 * 12.000 * 0.081/( 2.908 * 26000000
   * 0.125^(2) * 1.510 * 0.300 )
 = 0.638  (should be <= 1)
```

Flange Rigidity Based on Given Thickness [ASME]:

Flange Rigidity Index, Seating (rotation check) per APP. 2 [Js]:
```
 = 52.14 * Ma / Bsc * Cnv_fac * V / ( Lambda * Eamb * go^(2) * ho * Ki )
 = 52.14 * 10434.6/1.1893 * 12.000 * 0.081/( 3.161 * 29400000 *
   0.125^(2) * 1.510 * 0.300 )
 = 0.674  (should be <= 1)
```

Flange Rigidity Index Operating (rotation check) per APP. 2 [J]:
```
 = 52.14 * Mo / Bsc * Cnv_fac * V / ( Lambda * Eop * goc^(2) * ho * Ki )
 = 52.14 * 8128.9/1.1893 * 12.000 * 0.081/( 3.161 * 26000000
   * 0.125^(2) * 1.510 * 0.300 )
 = 0.593  (should be <= 1)
```

Minimum Design Metal Temperature Results:
Stress Ratio = 0.775 , Temperature Reduction per Fig. UCS 66.1 = 23 F

```
Min Metal Temp. w/o impact per UCS-66                       -20 F
Min Metal Temp. at Required thickness (UCS 66.1)            -43 F
```

Element Thickness, Pressure, Diameter and Allowable Stress :

From | To	Int. Press + Liq. Hd psig	Nominal Thickness in.	Total Corr Allowance in.	Element Diameter in.	Allowable Stress(SE) psi
Left Head	150.658	0.18750	0.062500	18.5000	18800.0
Left Chann	150.657	0.18750	0.062500	18.5000	18800.0
Channel Fl	150.000	1.75000	0.062500	18.1250	17800.0
Shell	1400.63	0.75000	0.062500	18.5000	18800.0
Channel Fl	150.000	1.75000	0.062500	18.1250	17800.0
Channel	150.657	0.18750	0.062500	18.5000	18800.0
Right Head	150.658	0.18750	0.062500	18.5000	18800.0

Element Required Thickness and MAWP :

From | To	Design Pressure psig	M.A.W.P. Corroded psig	M.A.P. New & Cold psig	Minimum Thickness in.	Required Thickness in.
Left Head	150.000	217.957	369.279	0.16800	0.13544
Left Chann	150.000	254.778	408.719	0.18750	0.13639
Channel Fl	150.000	161.970	194.220	1.75000	1.68400
Shell	1400.00	1439.48	1675.98	0.75000	0.73170
Channel Fl	150.000	161.970	194.220	1.75000	1.68400
Channel	150.000	254.778	408.719	0.18750	0.13639
Right Head	150.000	217.957	369.279	0.16800	0.13544

Summary of Heat Exchanger Maximum Allowable Working Pressures :

Note: For ASME UHX designs, the following values include MAWPs that consider the tubesheet, tubes, tube/tubesheet joint etc. These values were determined by iteration. Review the tubesheet analysis report for more information.

```
Shell Side MAWP      =   1439.484 psig
Shell Side MAPnc     =   1675.978 psig
Channel Side  MAWP  =    161.970 psig
Channel Side  MAPnc =    194.220 psig
```

Internal Pressure Calculation Results :

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Elliptical Head From 10 To 20 SA-516 70 , UCS-66 Crv. B at 650 F

Left Head

Material UNS Number: K02700

Required Thickness due to Internal Pressure [tr]:

```
 = (P*Do*Kcor)/(2*S*E+2*P*(Kcor-0.1)) per Appendix 1-4 (c)
 = (150.658*18.5000*0.991)/(2*18800.00*1.00+2*150.658*(0.99-0.1))
 = 0.0729 + 0.0625 = 0.1354 in.
```

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:

Less Operating Hydrostatic Head Pressure of 0.658 psig
 = (2*S*E*t)/(Kcor*Do-2*t*(Kcor-0.1)) per Appendix 1-4 (c)
 = (2*18800.00*1.00*0.1055)/(0.991*18.5000-2*0.1055*(0.99-0.1))
 = 218.615 - 0.658 = 217.957 psig

Maximum Allowable Pressure, New and Cold [MAPNC]:
 = (2*S*E*t)/(K*Do-2*t*(K-0.1)) per Appendix 1-4 (c)
 = (2*20000.00*1.00*0.1680)/(1.000*18.5000-2*0.1680*(1.000-0.1))
 = 369.279 psig

Actual stress at given pressure and thickness, corroded [Sact]:
 = (P*(Kcor*Do-2*t*(Kcor-0.1)))/(2*E*t)
 = (150.658*(0.991*18.5000-2*0.1055*(0.991-0.1)))/(2*1.00*0.1055)
 = 12955.980 psi

Straight Flange Required Thickness:
 = (P*Ro)/(S*E+0.4*P) + c   per Appendix 1-1 (a)(1)
 = (150.658*9.2500)/(18800.00*1.00+0.4*150.658)+0.063
 = 0.136 in.

Straight Flange Maximum Allowable Working Pressure:
Less Operating Hydrostatic Head Pressure of 0.658 psig
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (18800.00 * 1.00 * 0.1250)/(9.2500 - 0.4 * 0.1250)
 = 255.435 - 0.658 = 254.777 psig

Factor K, corroded condition [Kcor]:
 = (2 + (Inside Diameter/(2 * Inside Head Depth))^(2))/6
 = (2 + (18.289/(2 * 4.603))^(2))/6
 = 0.990980

Percent Elong. per UCS-79, VIII-1-01-57 (75*tnom/Rf)*(1-Rf/Ro) 4.429 %

MDMT Calculations in the Knuckle Portion:

Govrn. thk, tg = 0.168 , tr = 0.074 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.699 , Temp. Reduction = 30 F

Min Metal Temp. w/o impact per UCS-66   -20 F
Min Metal Temp. at Required thickness (UCS 66.1)   -50 F

MDMT Calculations in the Head Straight Flange:

Govrn. thk, tg = 0.188 , tr = 0.075 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.597 , Temp. Reduction = 41 F

Min Metal Temp. w/o impact per UCS-66   -20 F
Min Metal Temp. at Required thickness (UCS 66.1)   -55 F

Cylindrical Shell From 20 To 30 SA-516 70 , UCS-66 Crv. B at 650 F

Left Channel

Material UNS Number: K02700

Required Thickness due to Internal Pressure [tr]:
 = (P*Ro) / (S*E+0.4*P) per Appendix 1-1 (a)(1)

```
 = (150.657*9.2500)/(18800.00*1.00+0.4*150.657)
 = 0.0739 + 0.0625 = 0.1364 in.
```

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
Less Operating Hydrostatic Head Pressure of 0.657 psig

```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (18800.00*1.00*0.1250)/(9.2500-0.4*0.1250)
 = 255.435 - 0.657 = 254.778  psig
```

Maximum Allowable Pressure, New and Cold [MAPNC]:

```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (20000.00*1.00*0.1875)/(9.2500-0.4*0.1875)
 = 408.719 psig
```

Actual stress at given pressure and thickness, corroded [Sact]:

```
 = (P*(Ro-0.4*t))/(E*t)
 = (150.657*((9.2500-0.4*0.1250))/(1.00*0.1250)
 = 11088.338 psi
```

```
Percent Elongation per UCS-79  (50*tnom/Rf)*(1-Rf/Ro)  1.024 %
```

Minimum Design Metal Temperature Results:

Govrn. thk, tg = 0.188 , tr = 0.075 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.597 , Temp. Reduction = 41 F

```
Min Metal Temp. w/o impact per UCS-66                      -20 F
Min Metal Temp. at Required thickness (UCS 66.1)           -55 F
```

Cylindrical Shell From 40 To 50 SA-516 70 , UCS-66 Crv. B at 650 F

Shell

Material UNS Number: K02700

Required Thickness due to Internal Pressure [tr]:

```
 = (P*Ro) / (S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (1400.627*9.2500)/(18800.00*1.00+0.4*1400.627)
 = 0.6692 + 0.0625 = 0.7317 in.
```

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
Less Operating Hydrostatic Head Pressure of 0.627 psig

```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (18800.00*1.00*0.6875)/(9.2500-0.4*0.6875)
 = 1440.111 - 0.627 = 1439.484  psig
```

Maximum Allowable Pressure, New and Cold [MAPNC]:

```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (20000.00*1.00*0.7500)/(9.2500-0.4*0.7500)
 = 1675.978 psig
```

Actual stress at given pressure and thickness, corroded [Sact]:

```
 = (P*(Ro-0.4*t))/(E*t)
 = (1400.627*((9.2500-0.4*0.6875))/(1.00*0.6875)
 = 18284.555 psi
```

```
Percent Elongation per UCS-79  (50*tnom/Rf)*(1-Rf/Ro)  4.225 %
```

Minimum Design Metal Temperature Results:

Govrn. thk, tg = 0.750 , tr = 0.647 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.941 , Temp. Reduction = 6 F

```
Min Metal Temp. w/o impact per UCS-66                        16 F
Min Metal Temp. at Required thickness (UCS 66.1)             10 F
Min Metal Temp. w/o impact per UG-20(f)                     -20 F
```

Cylindrical Shell From 60 To 70 SA-516 70 , UCS-66 Crv. B at 650 F

Channel

Material UNS Number: K02700

Required Thickness due to Internal Pressure [tr]:
```
 = (P*Ro) / (S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (150.657*9.2500)/(18800.00*1.00+0.4*150.657)
 = 0.0739 + 0.0625 = 0.1364 in.
```

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
Less Operating Hydrostatic Head Pressure of 0.657 psig
```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (18800.00*1.00*0.1250)/(9.2500-0.4*0.1250)
 = 255.435 - 0.657 = 254.778  psig
```

Maximum Allowable Pressure, New and Cold [MAPNC]:
```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (20000.00*1.00*0.1875)/(9.2500-0.4*0.1875)
 = 408.719 psig
```

Actual stress at given pressure and thickness, corroded [Sact]:
```
 = (P*(Ro-0.4*t))/(E*t)
 = (150.657*((9.2500-0.4*0.1250))/(1.00*0.1250)
 = 11088.338 psi
```

```
Percent Elongation per UCS-79  (50*tnom/Rf)*(1-Rf/Ro)  1.024 %
```

Minimum Design Metal Temperature Results:

Govrn. thk, tg = 0.188 , tr = 0.075 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.597 , Temp. Reduction = 41 F

```
Min Metal Temp. w/o impact per UCS-66                       -20 F
Min Metal Temp. at Required thickness (UCS 66.1)            -55 F
```

Elliptical Head From 70 To 80 SA-516 70 , UCS-66 Crv. B at 650 F

Right Head

Material UNS Number: K02700

Required Thickness due to Internal Pressure [tr]:
```
 = (P*Do*Kcor)/(2*S*E+2*P*(Kcor-0.1)) per Appendix 1-4 (c)
 = (150.658*18.5000*0.991)/(2*18800.00*1.00+2*150.658*(0.99-0.1))
 = 0.0729 + 0.0625 = 0.1354 in.
```

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
Less Operating Hydrostatic Head Pressure of 0.658 psig

```
 = (2*S*E*t)/(Kcor*Do-2*t*(Kcor-0.1)) per Appendix 1-4 (c)
 = (2*18800.00*1.00*0.1055)/(0.991*18.5000-2*0.1055*(0.99-0.1))
 = 218.615 - 0.658 = 217.957  psig
```

Maximum Allowable Pressure, New and Cold [MAPNC]:

```
 = (2*S*E*t)/(K*Do-2*t*(K-0.1)) per Appendix 1-4 (c)
 = (2*20000.00*1.00*0.1680)/(1.000*18.5000-2*0.1680*(1.000-0.1))
 = 369.279 psig
```

Actual stress at given pressure and thickness, corroded [Sact]:

```
 = (P*(Kcor*Do-2*t*(Kcor-0.1)))/(2*E*t)
 = (150.658*(0.991*18.5000-2*0.1055*(0.991-0.1)))/(2*1.00*0.1055)
 = 12955.980 psi
```

Straight Flange Required Thickness:

```
 = (P*Ro)/(S*E+0.4*P) + c   per Appendix 1-1 (a)(1)
 = (150.658*9.2500)/(18800.00*1.00+0.4*150.658)+0.062
 = 0.136 in.
```

Straight Flange Maximum Allowable Working Pressure:
Less Operating Hydrostatic Head Pressure of 0.658 psig

```
 = (S*E*t)/(Ro-0.4*t) per Appendix 1-1 (a)(1)
 = (18800.00 * 1.00 * 0.1250 )/(9.2500 - 0.4 * 0.1250 )
 = 255.435 - 0.658 = 254.777  psig
```

Factor K, corroded condition [Kcor]:

```
 = ( 2 + ( Inside Diameter/( 2 * Inside Head Depth ))^(2))/6
 = ( 2 + ( 18.289/( 2 * 4.603 ))^(2))/6
 = 0.990980
```

Percent Elong. per UCS-79, VIII-1-01-57 (75*tnom/Rf)*(1-Rf/Ro) 4.429 %

MDMT Calculations in the Knuckle Portion:

Govrn. thk, tg = 0.168 , tr = 0.074 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.699 , Temp. Reduction = 30 F

Min Metal Temp. w/o impact per UCS-66	-20 F
Min Metal Temp. at Required thickness (UCS 66.1)	-50 F

MDMT Calculations in the Head Straight Flange:

Govrn. thk, tg = 0.188 , tr = 0.075 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.597 , Temp. Reduction = 41 F

Min Metal Temp. w/o impact per UCS-66	-20 F
Min Metal Temp. at Required thickness (UCS 66.1)	-55 F

Note: Heads and Shells Exempted to -20F (-29C) by paragraph UG-20F

Hydrostatic Test Pressure Results:

Exchanger Shell Side Hydrostatic Test Pressures:

```
Pressure per UG99b     = 1.3 * M.A.W.P. * Sa/S       1871.329  psig
Pressure per UG99b[34] = 1.3 * Design Pres * Sa/S    1820.000  psig
Pressure per UG99c     = 1.3 * M.A.P. - Head(Hyd)    2178.771  psig
Pressure per UG100     = 1.1 * M.A.W.P. * Sa/S       1583.432  psig
Pressure per PED       = 1.43 * MAWP                 2058.462  psig
```

Exchanger Channel Side Hydrostatic Test Pressures:

```
Pressure per UG99b     = 1.3 * M.A.W.P. * Sa/S        210.561  psig
Pressure per UG99b[34] = 1.3 * Design Pres * Sa/S     195.000  psig
Pressure per UG99c     = 1.3 * M.A.P. - Head(Hyd)     252.486  psig
Pressure per UG100     = 1.1 * M.A.W.P. * Sa/S        178.167  psig
Pressure per PED       = 1.43 * MAWP                  231.617  psig
```

UG-99(b) Note 34, Test Pressure Calculation [Shell Side]:

```
 = Test Factor * Design Pressure * Stress Ratio
 = 1.3 * 1400.000 * 1.000
 = 1820.000 psig
```

UG-99(b) Note 34, Test Pressure Calculation [Channel Side]:

```
 = Test Factor * Design Pressure * Stress Ratio
 = 1.3 * 150.000 * 1.000
 = 195.000 psig
```

Horizontal Test performed per: UG-99b (Note 34)

Please note that Nozzle, Shell, Head, Flange, etc MAWPs are all considered when determining the hydrotest pressure for those test types that are based on the MAWP of the vessel.

Stresses on Elements due to Hydrostatic Test Pressure:

From To	Stress	Allowable	Ratio	Pressure
Left Head	10597.3	26000.0	0.408	195.67
Left Channel	9574.7	26000.0	0.368	195.67
Shell	21726.6	26000.0	0.836	1820.67
Channel	9574.7	26000.0	0.368	195.67
Right Head	10597.3	26000.0	0.408	195.67

Elements Suitable for Internal Pressure.

External Pressure Calculation Results :

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Elliptical Head From 10 to 20 Ext. Chart: CS-2 at 650 F

Left Head

Elastic Modulus from Chart: CS-2 at 650 F :   0.251E+08 psi

Results for Maximum Allowable External Pressure (MAEP):
```
    Tca          OD        D/t     Factor A            B
  0.105       18.50     175.36    0.0007920     8040.84
EMAP = B/(K0*D/t) = 8040.8364/(0.9000 *175.3555 ) = 50.9494 psig
```

*Check the requirements of UG-33(a)(1) using P = 1.67 * External Design pressure for this head.*

Material UNS Number: K02700

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:
```
 = ((2*S*E*t)/(Kcor*Do-2*t*(Kcor-0.1)))/1.67   per Appendix 1-4 (c)
 = ((2*18800.00*1.00*0.1055)/(0.991*18.5000-2*0.1055*(0.99-0.1)))/1.67
 = 130.907 psig
```

Maximum Allowable External Pressure [MAEP]:
```
 = min( MAEP, MAWP )
 = min( 50.95 , 130.9073 )
 = 50.949 psig
```

Cylindrical Shell From 20 to 30 Ext. Chart: CS-2 at 650 F

Left Channel

Elastic Modulus from Chart: CS-2 at 650 F :   0.251E+08 psi

Results for Maximum Allowable External Pressure (MAEP):
```
    Tca          OD       SLEN        D/t        L/D    Factor A         B
  0.125       18.50      11.26     148.00     0.6087  0.0012594  8959.65
EMAP = (4*B)/(3*(D/t)) = (4*8959.6514 )/(3*148.0000 ) = 80.7176 psig
```

Results for Maximum Stiffened Length (Slen):
```
    Tca          OD       SLEN        D/t        L/D    Factor A         B
  0.125       18.50      11.26     148.00     0.6087  0.0012594  8959.65
EMAP = (4*B)/(3*(D/t)) = (4*8959.6514 )/(3*148.0000 ) = 80.7176 psig
```

Cylindrical Shell From 40 to 50 Ext. Chart: CS-2 at 650 F

Shell

Elastic Modulus from Chart: CS-2 at 650 F :   0.251E+08 psi

Results for Maximum Allowable External Pressure (MAEP):
```
    Tca          OD       SLEN        D/t        L/D    Factor A         B
```

```
  0.688       18.50      92.00      26.91     4.9732  0.0018108  9670.06
EMAP = (4*B)/(3*(D/t)) = (4*9670.0586 )/(3*26.9091 ) = 479.1471 psig
```

Results for Required Thickness (Tca):

```
    Tca          OD       SLEN        D/t        L/D   Factor A         B
  0.124       18.50      92.00     149.23     4.9732  0.0001336  1678.88
EMAP = (4*B)/(3*(D/t)) = (4*1678.8820 )/(3*149.2293 ) = 15.0005 psig
```

Results for Maximum Stiffened Length (Slen):

```
    Tca          OD       SLEN        D/t        L/D   Factor A         B
  0.688       18.50    2890.10      26.91    50.0000  0.0015359  9348.96
EMAP = (4*B)/(3*(D/t)) = (4*9348.9580 )/(3*26.9091 ) = 463.2367 psig
```

Cylindrical Shell From 60 to 70 Ext. Chart: CS-2 at 650 F

Channel

Elastic Modulus from Chart: CS-2 at 650 F :   0.251E+08 psi

Results for Maximum Allowable External Pressure (MAEP):

```
    Tca          OD       SLEN        D/t        L/D   Factor A         B
  0.125       18.50      11.26     148.00     0.6087  0.0012594  8959.65
EMAP = (4*B)/(3*(D/t)) = (4*8959.6514 )/(3*148.0000 ) = 80.7176 psig
```

Results for Maximum Stiffened Length (Slen):

```
    Tca          OD       SLEN        D/t        L/D   Factor A         B
  0.125       18.50      11.26     148.00     0.6087  0.0012594  8959.65
EMAP = (4*B)/(3*(D/t)) = (4*8959.6514 )/(3*148.0000 ) = 80.7176 psig
```

Elliptical Head From 70 to 80 Ext. Chart: CS-2 at 650 F

Right Head

Elastic Modulus from Chart: CS-2 at 650 F :   0.251E+08 psi

Results for Maximum Allowable External Pressure (MAEP):

```
    Tca          OD        D/t     Factor A            B
  0.105       18.50     175.36    0.0007920     8040.84
EMAP = B/(K0*D/t) = 8040.8364/(0.9000 *175.3555 ) = 50.9494 psig
```

*Check the requirements of UG-33(a)(1) using P = 1.67 * External Design pressure for this head.*

Material UNS Number: K02700

Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:

```
 = ((2*S*E*t)/(Kcor*Do-2*t*(Kcor-0.1)))/1.67   per Appendix 1-4 (c)
 = ((2*18800.00*1.00*0.1055)/(0.991*18.5000-2*0.1055*(0.99-0.1)))/1.67
 = 130.907 psig
```

Maximum Allowable External Pressure [MAEP]:

```
 = min( MAEP, MAWP )
 = min( 50.95 , 130.9073 )
 = 50.949 psig
```

External Pressure Calculations

From	To	Section Length ft.	Outside Diameter in.	Corroded Thickness in.	Factor A	Factor B psi
10	20	No Calc	18.5000	0.10550	0.00079204	8040.84
20	30	0.93844	18.5000	0.12500	0.0012594	8959.65
30	40	No Calc	...	1.68750	No Calc	No Calc
40	50	7.66700	18.5000	0.68750	0.0018108	9670.06
50	60	No Calc	...	1.68750	No Calc	No Calc
60	70	0.93844	18.5000	0.12500	0.0012594	8959.65
70	80	No Calc	18.5000	0.10550	0.00079204	8040.84

External Pressure Calculations

From	To	External Actual T. in.	External Required T. in.	External Des. Press. psig	External M.A.W.P. psig
10	20	0.16800	0.12500	...	50.9494
20	30	0.18750	No Calc	...	80.7176
30	40	1.75000	1.66400	...	No Calc
40	50	0.75000	0.18647	15.0000	479.147
50	60	1.75000	1.66400	...	No Calc
60	70	0.18750	No Calc	...	80.7176
70	80	0.16800	0.12500	...	50.9494
Minimum					50.949

External Pressure Calculations

From	To	Actual Len. Bet. Stiff. ft.	Allow. Len. Bet. Stiff. ft.	Ring Inertia Required in**4	Ring Inertia Available in**4
10	20	No Calc	No Calc	No Calc	No Calc
20	30	0.93844	No Calc	No Calc	No Calc
30	40	No Calc	No Calc	No Calc	No Calc
40	50	7.66700	240.842	No Calc	No Calc
50	60	No Calc	No Calc	No Calc	No Calc
60	70	0.93844	No Calc	No Calc	No Calc
70	80	No Calc	No Calc	No Calc	No Calc

Elements Suitable for External Pressure.

Element and Detail Weights

From	To	Element Metal Wgt. lb.	Element ID Volume in³	Corroded Metal Wgt. lb.	Corroded ID Volume in³	Extra due Misc % lb.
10	20	24.4461	1043.49	16.2974	1063.37	...
20	30	26.7051	2257.12	17.8642	2288.36	...
30	40	93.9645	748.044	91.0590	752.062	...
40	50	1088.94	13368.1	1001.71	13676.3	...
50	60	93.9645	748.044	91.0590	752.062	...
60	70	26.7051	2257.12	17.8642	2288.36	...
70	80	24.4461	1043.49	16.2974	1063.37	...
Total		1379	21465	1252	21883	0

For elements specified as shell side elements, the volume(s) shown above for those elements, reflects the displacement of the tubes.

Weight of Details

From	Type	Weight of Detail lb.	X Offset, Dtl. Cent. ft.	Y Offset, Dtl. Cent. ft.	Description
10	Liqd	37.6815	-0.12614	...	HEAD
20	Liqd	81.5071	0.77950	...	CHANNEL
20	Nozl	29.8733	0.36000	0.94271	T1/T2
40	Sadl	56.7760	1.59890	1.35417	Lft Sdl
40	Sadl	56.7760	6.40000	1.35417	Rgt Sdl
40	Liqd	482.735	3.83350	-0.013002	SHELL
40	Nozl	47.5039	0.50000	0.85417	S2
40	Nozl	140.290	7.29000	0.98438	S1
40	Nozl	29.1602	0.50000	0.80729	S3
60	Liqd	81.5071	0.36450	...	CHANNEL
60	Nozl	4.59655	0.50000	0.81000	T3 & T4
70	Liqd	37.6815	0.20944	...	HEAD
30	FTsh	199.263	0.32292	...	Tubesheet
30	Tube	862.075	4.23958	...	
30	RTsh	199.263	8.15625	...	

Total Weight of Each Detail Type

Total Weight of Saddles	113.6
Total Weight of Liquid	721.1
Total Weight of Nozzles	251.4
Total Weight of Exchanger Components	1260.6
Total Weight of Liquid in Tubes	173.2
Sum of the Detail Weights	2519.8 lb.

Weight Summation

Fabricated	Shop Test	Shipping	Erected	Empty	Operating

1379.2	3004.7	1379.2	3004.7	1379.2	3004.7
113.6	775.1	113.6	...	113.6	721.1
251.4	...	251.4	...	...	...
...	173.2	...	...	...	...
...	...	...	...	...	...
...	...	...	...	...	...
...	...	...	...	251.4	173.2
1260.6	...	1260.6	...	...	...
...	...	...	...	1260.6	...
3004.7	3953.0	3004.7	3004.7	3004.7	3899.0 lb.

Note: The shipping total has been modified because some items have been specified as being installed in the shop.

Weight Summary

Fabricated Wt.	- Bare Weight W/O Removable Internals	3004.7 lb.
Shop Test Wt.	- Fabricated Weight + Water (Full)	3953.0 lb.
Shipping Wt.	- Fab. Wt + Rem. Intls.+ Shipping App.	3004.7 lb.
Erected Wt.	- Fab. Wt + Rem. Intls.+ Insul. (etc)	3004.7 lb.
Ope. Wt. no Liq	- Fab. Wt + Intls. + Details + Wghts.	3004.7 lb.
Operating Wt.	- Empty Wt + Operating Liq. Uncorroded	3899.0 lb.
Oper. Wt. + CA	- Corr Wt. + Operating Liquid	3772.0 lb.
Field Test Wt.	- Empty Weight + Water (Full)	3953.0 lb.

Exchanger Tube Data

Volume of Exchanger tubes :	4795.2 in^3
Weight of Ope Liq in tubes :	173.2 lb.
Weight of Water in tubes :	173.2 lb.

Note: The Corroded Weight and thickness are used in the Horizontal Vessel Analysis (Ope Case) and Earthquake Load Calculations.

Outside Surface Areas of Elements

From	To	Surface Area in^2
10	20	430.779
20	30	508.429
30	40	372.954
40	50	5347.22
50	60	372.954
60	70	508.429
70	80	430.779

Total 7971.545 in^2 [55.4 Square Feet]

Nozzle Flange MAWP Results :

Nozzle Description	----- Flange Rating Operating psig	Ambient psig	Temperature F	Class	Grade|Group
T1/T2	550.0	740.0	650	300	GR 1.1
S2	1650.0	2220.0	650	900	GR 1.1
S1	1650.0	2220.0	650	900	GR 1.1
S3	1650.0	2220.0	650	900	GR 1.1
T3 & T4	550.0	740.0	650	300	GR 1.1

Shellside Flange Rating

Lowest Flange Pressure Rating was (Ope)[ShellSide]: 1650.000 psig
Lowest Flange Pressure Rating was (Amb)[ShellSide]: 2220.000 psig

Channelside Flange Rating

Lowest Flange Pressure Rating was (Ope)[TubeSide]: 550.000 psig
Lowest Flange Pressure Rating was (Amb)[TubeSide]: 740.000 psig

Note: ANSI Ratings are per ANSI/ASME B16.5 2009 Edition

Shop/Field Installation Options :

Note : The CG is computed from the first Element From Node

Center of Gravity of Saddles	5.218 ft.
Center of Gravity of Liquid	5.099 ft.
Center of Gravity of Nozzles	5.503 ft.
Center of Gravity of Tubesheet(s)	5.052 ft.
Center of Gravity of Tubes	5.052 ft.
Center of Gravity of Bare Shell New and Cold	5.052 ft.
Center of Gravity of Bare Shell Corroded	5.052 ft.
Vessel CG in the Operating Condition	5.098 ft.
Vessel CG in the Fabricated (Shop/Empty) Condition	5.096 ft.

ASME Horizontal Vessel Analysis: Stresses for the Left Saddle
(per ASME Sec. VIII Div. 2 based on the Zick method.)

Horizontal Vessel Stress Calculations : Operating Case

Note: Wear Pad Width (5.00) is less than 1.56*sqrt(rm*t)
and less than 2a. The wear plate will be ignored.

Minimum Wear Plate Width to be considered in analysis [b1]:
```
 = min( b + 1.56*sqrt( Rm * t ), 2a )
 = min( 4.000 + 1.56*sqrt( 8.9062 * 0.6875 ), 2 * 6.625 )
 = 7.8602 in.
```

Input and Calculated Values:

```
Vessel Mean Radius                             Rm        8.91  in.
Stiffened Vessel Length per 4.15.6              L        7.67  ft.
Distance from Saddle to Vessel tangent          a        6.62  in.

Saddle Width                                    b        4.00  in.
Saddle Bearing Angle                        theta      120.00  degrees

Shell Allowable Stress used in Calculation           18800.00  psi
Head Allowable Stress used in Calculation            17800.00  psi
Circumferential Efficiency in Plane of Saddle            1.00
Circumferential Efficiency at Mid-Span                   1.00

Saddle Force Q, Operating Case                        1696.94  lb.
```

Horizontal Vessel Analysis Results: Actual   Allowable

```
-------------------------------------------------------------------
Long. Stress at Top    of Midspan       8903.77     18800.00  psi
Long. Stress at Bottom of Midspan       9236.72     18800.00  psi
Long. Stress at Top    of Saddles       9074.51     18800.00  psi
Long. Stress at Bottom of Saddles       9067.88     18800.00  psi

Tangential Shear in Shell                277.72     15040.00  psi
Circ. Stress at Horn of Saddle           253.77     23500.00  psi
Circ. Compressive Stress in Shell         23.87     18800.00  psi
```

Load Combination Results for Q + Wind or Seismic [Q]:
```
 = Saddle Load + Max( Fwl, Fwt, Fsl, Fst )
 = 1696 + Max( 0 , 0 , 0 , 0 )
 = 1696.9 lb.
```

Summary of Loads at the base of this Saddle:
```
Vertical Load (including saddle weight)               1753.71  lb.
Transverse Shear Load Saddle                             0.00  lb.
Longitudinal Shear Load Saddle                           0.00  lb.
```

Formulas and Substitutions for Horizontal Vessel Analysis:

Note: Wear Plate is Welded to the Shell, k = 0.1

The Computed K values from Table 4.15.1:
```
K1  = 0.1066     K2  = 1.1707     K3  = 0.8799     K4  = 0.4011
```

```
K5  = 0.7603     K6  = 0.0529     K7  = 0.0325     K8  = 0.3405
K9  = 0.2711     K10 = 0.0581     K1* = 0.1923
```

Note: Dimension a is greater than or equal to Rm / 2.

Moment per Equation 4.15.3 [M1]:
```
 = -Q*a [1 - (1- a/L + (R²-h2²)/(2a*L))/(1+(4h2)/3L)]
 = -1696*0.55[1-(1-0.55/7.67+(0.742²-0.000²)/
   (2*0.55*7.67))/(1+(4*0.00)/(3*7.67))]
 = -6.5 ft.lb.
```

Moment per Equation 4.15.4 [M2]:
```
 = Q*L/4(1+2(R²-h2²)/(L²))/(1+(4h2)/( 3L))-4a/L
 = 1696*7.7/4(1+2(0.742²-0.000²)/(7.67²))/(1+(4*0.000)/
   (3*7.667))-4*0.55/7.67
 = 2376.7 ft.lb.
```

Longitudinal Stress at Top of Shell (4.15.6) [Sigma1]:
```
 = P * Rm/(2t) - M2/(pi*Rm²t)
 = 1400.32 * 8.906/(2*0.688 ) - 28520.5/(pi*8.9²*0.688 )
 = 8903.77 psi
```

Longitudinal Stress at Bottom of Shell (4.15.7) [Sigma2]:
```
 = P * Rm/(2t) + M2/(pi * Rm² * t)
 = 1400.32 * 8.906/(2 * 0.688 ) + 28520.5/(pi * 8.9² * 0.688 )
 = 9236.72 psi
```

Longitudinal Stress at Top of Shell at Support (4.15.10) [Sigma*3]:
```
 = P * Rm/(2t) - M1/(K1*pi*Rm²t)
 = 1400.32*8.906/(2*0.688)--78.0/(0.1066*pi*8.9²*0.688)
 = 9074.51 psi
```

Longitudinal Stress at Bottom of Shell at Support (4.15.11) [Sigma*4]:
```
 = P * Rm/(2t) + M1/(K1* * pi * Rm² * t)
 = 1400.32*8.906/(2*0.688)+-78.0/(0.1923*pi*8.9²*0.688)
 = 9067.88 psi
```

Maximum Shear Force in the Saddle (4.15.5) [T]:
```
 = Q(L-2a)/(L+(4*h2/3))
 = 1696 ( 7.67 - 2 * 0.55 )/(7.67 + ( 4 * 0.00/3))
 = 1452.6 lb.
```

Shear Stress in the shell no rings, not stiffened (4.15.14) [tau2]:
```
 = K2 * T / ( Rm * t )
 = 1.1707 * 1452.55/( 8.9062 * 0.6875 )
 = 277.72 psi
```

Decay Length (4.15.22) [x1,x2]:
```
 = 0.78 * sqrt( Rm * t )
 = 0.78 * sqrt( 8.906 * 0.688 )
 = 1.930 in.
```

Circumferential Stress in shell, no rings (4.15.23) [sigma6]:
```
 = -K5 * Q * k / ( t * ( b + X1 + X2 ) )
 = -0.7603 * 1696 * 0.1/( 0.688 * ( 4.00 + 1.93 + 1.93 ) )
 = -23.87 psi
```

Circ. Comp. Stress at Horn of Saddle, L>=8Rm (4.15.24)   [sigma7]:

```
 = -Q/(4*t*(b+X1+X2)) - 3*K7*Q/(2*t²)
 = -1696/(4*0.688 *(4.000 +1.930 +1.930 )) -
    3*0.0325 *1696/(2*0.688²)
 = -253.77 psi
```

Effective reinforcing plate width (4.15.1)   [B1]:

```
 = min( b + 1.56 * sqrt( Rm * t ), 2a  )
 = min( 4.00 + 1.56 * sqrt( 8.906 * 0.688 ), 2 * 6.625 )
 = 7.86 in.
```

Free Un-Restrained Thermal Expansion between the Saddles [Exp]:

```
 = Alpha * Ls * ( Design Temperature - Ambient Temperature )
 = 0.750E-05 * 57.613 * ( 650.0 - 70.0 )
 = 0.251 in.
```

Results for Vessel Ribs, Web and Base:

Baseplate Length	Bplen	16.4000	in.
Baseplate Thickness	Bpthk	0.2500	in.
Baseplate Width	Bpwid	4.0000	in.
Number of Ribs (inc. outside ribs)	Nribs	2	
Rib Thickness	Ribtk	0.2500	in.
Web Thickness	Webtk	0.2500	in.
Web Location	Webloc	Side	

Moment of Inertia of Saddle - Lateral Direction

	Y	A	AY	Io
Shell	0.3438	6.0397	2.0761	0.9516
Wearplate	0.8125	1.2500	1.0156	0.8317
Web	12.3438	5.7031	70.3979	1116.3051
BasePlate	23.8750	1.0000	23.8750	570.0208
Totals	37.3750	13.9928	97.3647	1688.1091

```
Value  C1 = Sumof(Ay)/Sumof(A)              =       6.9582  in.
Value   I = Sumof(Io) - C1*Sumof(Ay)        =    1010.6252  in**4
Value  As = Sumof(A) - Ashell               =       7.9531  in²

K1 = (1+Cos(beta)-.5*Sin(beta)² )/(pi-beta+Sin(beta)*Cos(beta)) =   0.2035

Fh = K1 * Q = 0.2035 * 1696.937 = 345.3636 lb.

Tension Stress, St = ( Fh/As )       =         43.4249  psi
Allowed Stress, Sa = 0.6 * Yield Str =      21600.0000  psi

d  = B - R*Sin(theta) / theta        =         25.4814  in.
Bending Moment, M  = Fh * d          =        733.3613  ft.lb.

Bending Stress, Sb = ( M * C1 / I  ) =         60.5908  psi
Allowed Stress, Sa = 2/3 * Yield Str =      24000.0000  psi
```

Minimum Thickness of Baseplate per Moss :

```
 = ( 3 * ( Q + Saddle_Wt ) * BasePlateWidth / ( 2 * BasePlateLength *
   AllStress ))½
 = ( 3 * (1696 + 56 ) * 4.00/( 2 * 16.400 * 24000.000 ))½
 = 0.164 in.
```

Calculation of Axial Load, Intermediate Values and Compressive Stress

Effective Baseplate Length [e]:
 = (Bplen - Clearance) / (Nribs - 1)
 = (16.4000 - 1.0)/(2 - 1) = 15.4000 in.

Baseplate Pressure Area [Ap]:
 = e * Bpwid / 2
 = 15.4000 * 4.0000/2 = 30.8000 in^2

Axial Load [P]:
 = Ap * Bp
 = 30.8 * 25.87 = 796.7 lb.

Area of the Rib and Web [Ar]:
 = (Bpwid - Clearance - Webtk) * Ribtk + e/2 * Webtk
 = (4.000 - 1.0 - 0.250) * 0.250 + 15.4000/2 * 0.250
 = 2.612 in^2

Compressive Stress [Sc]:
 = P/Ar
 = 796.7/2.6125 = 304.9695 psi

Check of Outside Ribs:

Inertia of Saddle, Outer Ribs - Longitudinal Direction

	Y	A	AY	Ay^2	Io
Rib	1.6250	0.8125	1.3203	0.9040	0.8932
Web	0.1250	1.9250	0.2406	0.3816	0.0201
Values	0.5702	2.7375	1.5609	1.2855	0.9133

Bending Moment [Rm]:
 = Fl /(2 * Bplen) * e * rl / 2
 = 0.0/(2 * 16.40) * 15.400 * 27.94/2
 = 0.000 ft.lb.

KL/R < Cc (30.4524 < 126.0993) per AISC E2-1
Sca = $(1-(Klr)^2/(2*Cc^2))*Fy/(5/3+3*(Klr)/(8*Cc)-(Klr^3)/(8*Cc^3)$
Sca = $(1-(30.45)^2/(2 * 126.10^2)) * 36000/$
      $(5/3+3*(30.45)/(8* 126.10)-(30.45^3)/(8*126.10^3)$
Sca = 19909.37 psi

AISC Unity Check on Outside Ribs (must be <= 1.0)
Check = Sc/Sca + (Rm/Z)/Sba
Check = 304.97/19909.37 + (0.00/0.905)/24000.00
Check = 0.02

ASME Horizontal Vessel Analysis: Stresses for the Right Saddle
(per ASME Sec. VIII Div. 2 based on the Zick method.)

Note: Wear Pad Width (5.00) is less than 1.56*sqrt(rm*t)
and less than 2a. The wear plate will be ignored.

Minimum Wear Plate Width to be considered in analysis [b1]:
 = min(b + 1.56*sqrt(Rm * t), 2a)
 = min(4.000 + 1.56*sqrt(8.9062 * 0.6875), 2 * 6.625)
 = 7.8602 in.

Input and Calculated Values:

Vessel Mean Radius	Rm	8.91	in.
Stiffened Vessel Length per 4.15.6	L	7.67	ft.
Distance from Saddle to Vessel tangent	a	6.62	in.
Saddle Width	b	4.00	in.
Saddle Bearing Angle	theta	120.00	degrees
Shell Allowable Stress used in Calculation		18800.00	psi
Head Allowable Stress used in Calculation		17800.00	psi
Circumferential Efficiency in Plane of Saddle		1.00	
Circumferential Efficiency at Mid-Span		1.00	
Saddle Force Q, Operating Case		1961.51	lb.

Horizontal Vessel Analysis Results:	**Actual**	**Allowable**	
Long. Stress at Top of Midspan	8877.81	18800.00	psi
Long. Stress at Bottom of Midspan	9262.67	18800.00	psi
Long. Stress at Top of Saddles	9075.18	18800.00	psi
Long. Stress at Bottom of Saddles	9067.51	18800.00	psi
Tangential Shear in Shell	321.02	15040.00	psi
Circ. Stress at Horn of Saddle	293.34	23500.00	psi
Circ. Compressive Stress in Shell	27.60	18800.00	psi

Load Combination Results for Q + Wind or Seismic [Q]:
```
 = Saddle Load + Max( Fwl, Fwt, Fsl, Fst )
 = 1961 + Max( 0 , 0 , 0 , 0 )
 = 1961.5 lb.
```

Summary of Loads at the base of this Saddle:

Vertical Load (including saddle weight)	2018.29	lb.
Transverse Shear Load Saddle	0.00	lb.
Longitudinal Shear Load Saddle	0.00	lb.

Formulas and Substitutions for Horizontal Vessel Analysis:

Note: Wear Plate is Welded to the Shell, k = 0.1

The Computed K values from Table 4.15.1:

K1 = 0.1066	K2 = 1.1707	K3 = 0.8799	K4 = 0.4011
K5 = 0.7603	K6 = 0.0529	K7 = 0.0325	K8 = 0.3405
K9 = 0.2711	K10 = 0.0581	K1* = 0.1923	

Note: Dimension a is greater than or equal to Rm / 2.

Moment per Equation 4.15.3 [M1]:
```
 = -Q*a [1 - (1- a/L + (R²-h2²)/(2a*L))/(1+(4h2)/3L)]
 = -1961*0.55[1-(1-0.55/7.67+(0.742²-0.000²)/
   (2*0.55*7.67))/(1+(4*0.00)/(3*7.67))]
 = -7.5 ft.lb.
```

Moment per Equation 4.15.4 [M2]:
```
 = Q*L/4(1+2(R²-h2²)/(L²))/(1+(4h2)/( 3L))-4a/L
```

```
 = 1961*7.7/4(1+2(0.742²-0.000²)/(7.67²))/(1+(4*0.000)/
   (3*7.667))-4*0.55/7.67
 = 2747.3 ft.lb.
```

Longitudinal Stress at Top of Shell (4.15.6)   [Sigma1]:

```
 = P * Rm/(2t) - M2/(pi*Rm²t)
 = 1400.32 * 8.906/(2*0.688 ) - 32967.2/(pi*8.9²*0.688 )
 = 8877.81 psi
```

Longitudinal Stress at Bottom of Shell (4.15.7)   [Sigma2]:

```
 = P * Rm/(2t) + M2/(pi * Rm² * t)
 = 1400.32 * 8.906/(2 * 0.688 ) + 32967.2/(pi * 8.9² * 0.688 )
 = 9262.67 psi
```

Longitudinal Stress at Top of Shell at Support (4.15.10)   [Sigma*3]:

```
 = P * Rm/(2t) - M1/(K1*pi*Rm²t)
 = 1400.32*8.906/(2*0.688)--90.2/(0.1066*pi*8.9²*0.688)
 = 9075.18 psi
```

Longitudinal Stress at Bottom of Shell at Support (4.15.11)   [Sigma*4]:

```
 = P * Rm/(2t) + M1/(K1* * pi * Rm² * t)
 = 1400.32*8.906/(2*0.688)+-90.2/(0.1923*pi*8.9²*0.688)
 = 9067.51 psi
```

Maximum Shear Force in the Saddle (4.15.5)   [T]:

```
 = Q(L-2a)/(L+(4*h2/3))
 = 1961 ( 7.67 - 2 * 0.55 )/(7.67 + ( 4 * 0.00/3))
 = 1679.0 lb.
```

Shear Stress in the shell no rings, not stiffened (4.15.14)   [tau2]:

```
 = K2 * T / ( Rm * t )
 = 1.1707 * 1679.02/( 8.9062 * 0.6875 )
 = 321.02 psi
```

Decay Length (4.15.22)   [x1,x2]:

```
 = 0.78 * sqrt( Rm * t )
 = 0.78 * sqrt( 8.906 * 0.688 )
 = 1.930 in.
```

Circumferential Stress in shell, no rings (4.15.23)   [sigma6]:

```
 = -K5 * Q * k / ( t * ( b + X1 + X2 ) )
 = -0.7603 * 1961 * 0.1/( 0.688 * ( 4.00 + 1.93 + 1.93 ) )
 = -27.60 psi
```

Circ. Comp. Stress at Horn of Saddle, L>=8Rm (4.15.24)   [sigma7]:

```
 = -Q/(4*t*(b+X1+X2)) - 3*K7*Q/(2*t²)
 = -1961/(4*0.688 *(4.000 +1.930 +1.930 )) -
    3*0.0325 *1961/(2*0.688²)
 = -293.34 psi
```

Effective reinforcing plate width (4.15.1)   [B1]:

```
 = min( b + 1.56 * sqrt( Rm * t ), 2a  )
 = min( 4.00 + 1.56 * sqrt( 8.906 * 0.688 ), 2 * 6.625 )
 = 7.86 in.
```

Results for Vessel Ribs, Web and Base

Baseplate Length	Bplen	16.4000	in.
Baseplate Thickness	Bpthk	0.2500	in.
Baseplate Width	Bpwid	4.0000	in.
Number of Ribs (inc. outside ribs)	Nribs	2	
Rib Thickness	Ribtk	0.2500	in.
Web Thickness	Webtk	0.2500	in.
Web Location	Webloc	Side	

Moment of Inertia of Saddle - Lateral Direction

	Y	A	AY	Io
Shell	0.3438	6.0397	2.0761	0.9516
Wearplate	0.8125	1.2500	1.0156	0.8317
Web	12.3438	5.7031	70.3979	1116.3051
BasePlate	23.8750	1.0000	23.8750	570.0208
Totals	37.3750	13.9928	97.3647	1688.1091

```
Value  C1 = Sumof(Ay)/Sumof(A)              =       6.9582  in.
Value   I = Sumof(Io) - C1*Sumof(Ay)        =    1010.6252  in**4
Value  As = Sumof(A) - Ashell               =       7.9531  in²

K1 = (1+Cos(beta)-.5*Sin(beta)² )/(pi-beta+Sin(beta)*Cos(beta)) =   0.2035

Fh = K1 * Q = 0.2035 * 1961.509 = 399.2097 lb.

Tension Stress, St = ( Fh/As )       =         50.1953  psi
Allowed Stress, Sa = 0.6 * Yield Str =      21600.0000  psi

d  = B - R*Sin(theta) / theta        =         25.4814  in.
Bending Moment, M  = Fh * d          =        847.7009  ft.lb.

Bending Stress, Sb = ( M * C1 / I  ) =         70.0376  psi
Allowed Stress, Sa = 2/3 * Yield Str =      24000.0000  psi
```

Minimum Thickness of Baseplate per Moss :

= (3 * (Q + Saddle_Wt) * BasePlateWidth / (2 * BasePlateLength * AllStress))½
= (3 * (1961 + 56) * 4.00/(2 * 16.400 * 24000.000))½
= 0.175 in.

Calculation of Axial Load, Intermediate Values and Compressive Stress

Effective Baseplate Length [e]:
= (Bplen - Clearance) / (Nribs - 1)
= (16.4000 - 1.0)/(2 - 1) = 15.4000 in.

Baseplate Pressure Area [Ap]:
= e * Bpwid / 2
= 15.4000 * 4.0000/2 = 30.8000 in²

Axial Load [P]:
= Ap * Bp
= 30.8 * 29.90 = 921.0 lb.

Area of the Rib and Web [Ar]:
= (Bpwid - Clearance - Webtk) * Ribtk + e/2 * Webtk
= (4.000 - 1.0 - 0.250) * 0.250 + 15.4000/2 * 0.250

= 2.612 in^2

Compressive Stress [Sc]:
= P/Ar
= 921.0/2.6125 = 352.5177 psi

Check of Outside Ribs:
Inertia of Saddle, Outer Ribs - Longitudinal Direction

	Y	A	AY	Ay^2	Io
Rib	1.6250	0.8125	1.3203	0.9040	0.8932
Web	0.1250	1.9250	0.2406	0.3816	0.0201
Values	0.5702	2.7375	1.5609	1.2855	0.9133

Bending Moment [Rm]:
= Fl /(2 * Bplen) * e * rl / 2
= 0.0/(2 * 16.40) * 15.400 * 27.94/2
= 0.000 ft.lb.

KL/R < Cc (30.4524 < 126.0993) per AISC E2-1
$Sca = (1-(Klr)^2/(2*Cc^2))*Fy/(5/3+3*(Klr)/(8*Cc)-(Klr^3)/(8*Cc^3)$
$Sca = (1-(30.45)^2/(2 * 126.10^2)) * 36000/$
$(5/3+3*(30.45)/(8* 126.10)-(30.45^3)/(8*126.10^3)$
Sca = 19909.37 psi

AISC Unity Check on Outside Ribs (must be <= 1.0)
Check = Sc/Sca + (Rm/Z)/Sba
Check = 352.52/19909.37 + (0.00/0.905)/24000.00
Check = 0.02

ASME Horizontal Vessel Analysis: Stresses for the Left Saddle
(per ASME Sec. VIII Div. 2 based on the Zick method.)

Horizontal Vessel Stress Calculations : Test Case

Note: Wear Pad Width (5.00) is less than 1.56*sqrt(rm*t)
and less than 2a. The wear plate will be ignored.

Minimum Wear Plate Width to be considered in analysis [b1]:
```
 = min( b + 1.56*sqrt( Rm * t ), 2a )
 = min( 4.000 + 1.56*sqrt( 8.8750 * 0.7500 ), 2 * 6.625 )
 = 8.0248 in.
```

Input and Calculated Values:

Vessel Mean Radius	Rm	8.88	in.
Stiffened Vessel Length per 4.15.6	L	7.67	ft.
Distance from Saddle to Vessel tangent	a	6.62	in.
Saddle Width	b	4.00	in.
Saddle Bearing Angle	theta	120.00	degrees
Shell Allowable Stress used in Calculation		20000.00	psi
Head Allowable Stress used in Calculation		20000.00	psi
Circumferential Efficiency in Plane of Saddle		1.00	
Circumferential Efficiency at Mid-Span		1.00	
Saddle Force Q, Test Case, no Ext. Forces		1800.76	lb.

Horizontal Vessel Analysis Results:	**Actual**	**Allowable**	
Long. Stress at Top of Midspan	10607.18	20000.00	psi
Long. Stress at Bottom of Midspan	10933.28	20000.00	psi
Long. Stress at Top of Saddles	10774.69	20000.00	psi
Long. Stress at Bottom of Saddles	10767.76	20000.00	psi
Tangential Shear in Shell	271.10	16000.00	psi
Circ. Stress at Horn of Saddle	232.08	25000.00	psi
Circ. Compressive Stress in Shell	22.75	20000.00	psi

Load Combination Results for Q + Wind or Seismic [Q]:
```
 = Saddle Load + Max( Fwl, Fwt, Fsl, Fst )
 = 1800 + Max( 0 , 0 , 0 , 0 )
 = 1800.8 lb.
```

Summary of Loads at the base of this Saddle:

Vertical Load (including saddle weight)	1857.54	lb.
Transverse Shear Load Saddle	0.00	lb.
Longitudinal Shear Load Saddle	0.00	lb.

Hydrostatic Test Pressure at center of Vessel: 1820.320 psig

Formulas and Substitutions for Horizontal Vessel Analysis:

Note: Wear Plate is Welded to the Shell, k = 0.1

The Computed K values from Table 4.15.1:

```
K1  = 0.1066     K2  = 1.1707     K3  = 0.8799     K4  = 0.4011
K5  = 0.7603     K6  = 0.0529     K7  = 0.0328     K8  = 0.3405
K9  = 0.2711     K10 = 0.0581     K1* = 0.1923
```

Note: Dimension a is greater than or equal to Rm / 2.

Moment per Equation 4.15.3   [M1]:

```
 = -Q*a [1 - (1- a/L + (R²-h2²)/(2a*L))/(1+(4h2)/3L)]
 = -1800*0.55[1-(1-0.55/7.67+(0.740²-0.000²)/
   (2*0.55*7.67))/(1+(4*0.00)/(3*7.67))]
 = -7.4 ft.lb.
```

Moment per Equation 4.15.4   [M2]:

```
 = Q*L/4(1+2(R²-h2²)/(L²))/(1+(4h2)/( 3L))-4a/L
 = 1800*7.7/4(1+2(0.740²-0.000²)/(7.67²))/(1+(4*0.000)/
   (3*7.667))-4*0.55/7.67
 = 2521.7 ft.lb.
```

Longitudinal Stress at Top of Shell (4.15.6)   [Sigma1]:

```
 = P * Rm/(2t) - M2/(pi*Rm²t)
 = 1820.32 * 8.875/(2*0.750 ) - 30260.1/(pi*8.9²*0.750 )
 = 10607.18 psi
```

Longitudinal Stress at Bottom of Shell (4.15.7)   [Sigma2]:

```
 = P * Rm/(2t) + M2/(pi * Rm² * t)
 = 1820.32 * 8.875/(2 * 0.750 ) + 30260.1/(pi * 8.9² * 0.750 )
 = 10933.28 psi
```

Longitudinal Stress at Top of Shell at Support (4.15.10)   [Sigma*3]:

```
 = P * Rm/(2t) - M1/(K1*pi*Rm²t)
 = 1820.32*8.875/(2*0.750)--88.2/(0.1066*pi*8.9²*0.750)
 = 10774.69 psi
```

Longitudinal Stress at Bottom of Shell at Support (4.15.11)   [Sigma*4]:

```
 = P * Rm/(2t) + M1/(K1* * pi * Rm² * t)
 = 1820.32*8.875/(2*0.750)+-88.2/(0.1923*pi*8.9²*0.750)
 = 10767.76 psi
```

Maximum Shear Force in the Saddle (4.15.5)   [T]:

```
 = Q(L-2a)/(L+(4*h2/3))
 = 1800 ( 7.67 - 2 * 0.55 )/(7.67 + ( 4 * 0.00/3))
 = 1541.4 lb.
```

Shear Stress in the shell no rings, not stiffened (4.15.14)   [tau2]:

```
 = K2 * T / ( Rm * t )
 = 1.1707 * 1541.43/( 8.8750 * 0.7500 )
 = 271.10 psi
```

Decay Length (4.15.22)   [x1,x2]:

```
 = 0.78 * sqrt( Rm * t )
 = 0.78 * sqrt( 8.875 * 0.750 )
 = 2.012 in.
```

Circumferential Stress in shell, no rings (4.15.23)   [sigma6]:

```
 = -K5 * Q * k / ( t * ( b + X1 + X2 ) )
 = -0.7603 * 1800 * 0.1/( 0.750 * ( 4.00 + 2.01 + 2.01 ) )
```

 = -22.75 psi

Circ. Comp. Stress at Horn of Saddle, L>=8Rm (4.15.24)   [sigma7]:

```
 = -Q/(4*t*(b+X1+X2)) - 3*K7*Q/(2*t²)
 = -1800/(4*0.750 *(4.000 +2.012 +2.012 )) -
    3*0.0328 *1800/(2*0.750²)
 = -232.08 psi
```

Effective reinforcing plate width (4.15.1)   [B1]:

```
 = min( b + 1.56 * sqrt( Rm * t ), 2a  )
 = min( 4.00 + 1.56 * sqrt( 8.875 * 0.750 ), 2 * 6.625 )
 = 8.02 in.
```

Results for Vessel Ribs, Web and Base:

Baseplate Length	Bplen	16.4000	in.
Baseplate Thickness	Bpthk	0.2500	in.
Baseplate Width	Bpwid	4.0000	in.
Number of Ribs (inc. outside ribs)	Nribs	2	
Rib Thickness	Ribtk	0.2500	in.
Web Thickness	Webtk	0.2500	in.
Web Location	Webloc	Side	

Moment of Inertia of Saddle - Lateral Direction

	Y	A	AY	Io
Shell	0.3750	6.7041	2.5140	1.2570
Wearplate	0.8750	1.2500	1.0938	0.9635
Web	12.3750	5.6875	70.3828	1116.2904
BasePlate	23.8750	1.0000	23.8750	570.0208
Totals	37.5000	14.6416	97.8656	1688.5317

```
Value  C1 = Sumof(Ay)/Sumof(A)             =       6.6841  in.
Value   I = Sumof(Io) - C1*Sumof(Ay)       =    1034.3906  in**4
Value  As = Sumof(A) - Ashell              =       7.9375  in²

K1 = (1+Cos(beta)-.5*Sin(beta)² )/(pi-beta+Sin(beta)*Cos(beta)) =   0.2035

Fh = K1 * Q = 0.2035 * 1800.763 = 366.4943 lb.

Tension Stress, St = ( Fh/As )       =         46.1725  psi
Allowed Stress, Sa = 0.6 * Yield Str =      21600.0000  psi

d  = B - R*Sin(theta) / theta        =         25.4706  in.
Bending Moment, M  = Fh * d          =        777.9012  ft.lb.

Bending Stress, Sb = ( M * C1 / I  ) =         60.3202  psi
Allowed Stress, Sa = 2/3 * Yield Str =      24000.0000  psi
```

Minimum Thickness of Baseplate per Moss :

```
 = ( 3 * ( Q + Saddle_Wt ) * BasePlateWidth / ( 2 * BasePlateLength *
   AllStress ))½
 = ( 3 * (1800 + 56 ) * 4.00/( 2 * 16.400 * 24000.000 ))½
 = 0.168 in.
```

Calculation of Axial Load, Intermediate Values and Compressive Stress

Effective Baseplate Length [e]:

```
 = ( Bplen - Clearance ) / ( Nribs - 1)
 = ( 16.4000 - 1.0 )/( 2 - 1 ) = 15.4000 in.
```

Baseplate Pressure Area [Ap]:

```
 = e * Bpwid / 2
 = 15.4000 * 4.0000/2 = 30.8000 in²
```

Axial Load [P]:

```
 = Ap * Bp
 = 30.8 * 27.45 = 845.5 lb.
```

Area of the Rib and Web [Ar]:

```
 = ( Bpwid - Clearance - Webtk ) * Ribtk + e/2 * Webtk
 = ( 4.000 - 1.0 - 0.250 ) * 0.250 + 15.4000/2 * 0.250
 = 2.612 in²
```

Compressive Stress [Sc]:

```
 = P/Ar
 = 845.5/2.6125 = 323.6288 psi
```

Check of Outside Ribs:

Inertia of Saddle, Outer Ribs - Longitudinal Direction

	Y	A	AY	Ay²	Io
Rib	1.6250	0.8125	1.3203	0.9040	0.8932
Web	0.1250	1.9250	0.2406	0.3816	0.0201
Values	0.5702	2.7375	1.5609	1.2855	0.9133

Bending Moment [Rm]:

```
 = Fl /( 2 * Bplen ) * e * rl / 2
 = 0.0/( 2 * 16.40 ) * 15.400 * 27.88/2
 = 0.000 ft.lb.
```

```
KL/R < Cc ( 30.3843 < 126.0993 ) per AISC E2-1
Sca = (1-(Klr)²/(2*Cc²))*Fy/(5/3+3*(Klr)/(8*Cc)-(Klr³)/(8*Cc³)
Sca = ( 1-( 30.38 )²/(2 * 126.10² )) * 36000/
      ( 5/3+3*(30.38 )/(8* 126.10 )-( 30.38³)/(8*126.10³)
Sca = 19914.21 psi
```

AISC Unity Check on Outside Ribs (must be <= 1.0)

```
Check = Sc/Sca + (Rm/Z)/Sba
Check = 323.63/19914.21 + (0.00/0.905 )/24000.00
Check = 0.02
```

ASME Horizontal Vessel Analysis: Stresses for the Right Saddle

(per ASME Sec. VIII Div. 2 based on the Zick method.)

Note: Wear Pad Width (5.00) is less than 1.56*sqrt(rm*t)
and less than 2a. The wear plate will be ignored.

Minimum Wear Plate Width to be considered in analysis [b1]:

```
 = min( b + 1.56*sqrt( Rm * t ), 2a )
 = min( 4.000 + 1.56*sqrt( 8.8750 * 0.7500 ), 2 * 6.625 )
 = 8.0248 in.
```

Input and Calculated Values:

Vessel Mean Radius	Rm	8.88	in.
Stiffened Vessel Length per 4.15.6	L	7.67	ft.
Distance from Saddle to Vessel tangent	a	6.62	in.
Saddle Width	b	4.00	in.
Saddle Bearing Angle	theta	120.00	degrees
Shell Allowable Stress used in Calculation		20000.00	psi
Head Allowable Stress used in Calculation		20000.00	psi
Circumferential Efficiency in Plane of Saddle		1.00	
Circumferential Efficiency at Mid-Span		1.00	
Saddle Force Q, Test Case, no Ext. Forces		2038.73	lb.

Horizontal Vessel Analysis Results:	**Actual**	**Allowable**	
Long. Stress at Top of Midspan	10585.63	20000.00	psi
Long. Stress at Bottom of Midspan	10954.83	20000.00	psi
Long. Stress at Top of Saddles	10775.28	20000.00	psi
Long. Stress at Bottom of Saddles	10767.43	20000.00	psi
Tangential Shear in Shell	306.93	16000.00	psi
Circ. Stress at Horn of Saddle	262.75	25000.00	psi
Circ. Compressive Stress in Shell	25.75	20000.00	psi

Load Combination Results for Q + Wind or Seismic [Q]:

```
 = Saddle Load + Max( Fwl, Fwt, Fsl, Fst )
 = 2038 + Max( 0 , 0 , 0 , 0 )
 = 2038.7 lb.
```

Summary of Loads at the base of this Saddle:

Vertical Load (including saddle weight)	2095.50	lb.
Transverse Shear Load Saddle	0.00	lb.
Longitudinal Shear Load Saddle	0.00	lb.

Hydrostatic Test Pressure at center of Vessel: 1820.320 psig

Formulas and Substitutions for Horizontal Vessel Analysis:

Note: Wear Plate is Welded to the Shell, k = 0.1

The Computed K values from Table 4.15.1:

```
K1  = 0.1066     K2  = 1.1707     K3  = 0.8799     K4  = 0.4011
K5  = 0.7603     K6  = 0.0529     K7  = 0.0328     K8  = 0.3405
K9  = 0.2711     K10 = 0.0581     K1* = 0.1923
```

Note: Dimension a is greater than or equal to Rm / 2.

Moment per Equation 4.15.3 [M1]:

```
 = -Q*a [1 - (1- a/L + (R²-h2²)/(2a*L))/(1+(4h2)/3L)]
 = -2038*0.55[1-(1-0.55/7.67+(0.740²-0.000²)/
   (2*0.55*7.67))/(1+(4*0.00)/(3*7.67))]
 = -8.3 ft.lb.
```

Moment per Equation 4.15.4 [M2]:

```
 = Q*L/4(1+2(R²-h2²)/(L²))/(1+(4h2)/( 3L))-4a/L
 = 2038*7.7/4(1+2(0.740²-0.000²)/(7.67²))/(1+(4*0.000)/
```

```
   (3*7.667))-4*0.55/7.67
 = 2854.9 ft.lb.
```

Longitudinal Stress at Top of Shell (4.15.6) [Sigma1]:

```
 = P * Rm/(2t) - M2/(pi*Rm²t)
 = 1820.32 * 8.875/(2*0.750 ) - 34258.9/(pi*8.9²*0.750 )
 = 10585.63 psi
```

Longitudinal Stress at Bottom of Shell (4.15.7) [Sigma2]:

```
 = P * Rm/(2t) + M2/(pi * Rm² * t)
 = 1820.32 * 8.875/(2 * 0.750 ) + 34258.9/(pi * 8.9² * 0.750 )
 = 10954.83 psi
```

Longitudinal Stress at Top of Shell at Support (4.15.10) [Sigma*3]:

```
 = P * Rm/(2t) - M1/(K1*pi*Rm²t)
 = 1820.32*8.875/(2*0.750)--99.9/(0.1066*pi*8.9²*0.750)
 = 10775.28 psi
```

Longitudinal Stress at Bottom of Shell at Support (4.15.11) [Sigma*4]:

```
 = P * Rm/(2t) + M1/(K1* * pi * Rm² * t)
 = 1820.32*8.875/(2*0.750)+-99.9/(0.1923*pi*8.9²*0.750)
 = 10767.43 psi
```

Maximum Shear Force in the Saddle (4.15.5) [T]:

```
 = Q(L-2a)/(L+(4*h2/3))
 = 2038 ( 7.67 - 2 * 0.55 )/(7.67 + ( 4 * 0.00/3))
 = 1745.1 lb.
```

Shear Stress in the shell no rings, not stiffened (4.15.14) [tau2]:

```
 = K2 * T / ( Rm * t )
 = 1.1707 * 1745.12/( 8.8750 * 0.7500 )
 = 306.93 psi
```

Decay Length (4.15.22) [x1,x2]:

```
 = 0.78 * sqrt( Rm * t )
 = 0.78 * sqrt( 8.875 * 0.750 )
 = 2.012 in.
```

Circumferential Stress in shell, no rings (4.15.23) [sigma6]:

```
 = -K5 * Q * k / ( t * ( b + X1 + X2 ) )
 = -0.7603 * 2038 * 0.1/( 0.750 * ( 4.00 + 2.01 + 2.01 ) )
 = -25.75 psi
```

Circ. Comp. Stress at Horn of Saddle, L>=8Rm (4.15.24) [sigma7]:

```
 = -Q/(4*t*(b+X1+X2)) - 3*K7*Q/(2*t²)
 = -2038/(4*0.750 *(4.000 +2.012 +2.012 )) -
    3*0.0328 *2038/(2*0.750²)
 = -262.75 psi
```

Effective reinforcing plate width (4.15.1) [B1]:

```
 = min( b + 1.56 * sqrt( Rm * t ), 2a  )
 = min( 4.00 + 1.56 * sqrt( 8.875 * 0.750 ), 2 * 6.625 )
 = 8.02 in.
```

Results for Vessel Ribs, Web and Base

```
Baseplate Length                        Bplen           16.4000  in.
```

Baseplate Thickness	Bpthk	0.2500	in.
Baseplate Width	Bpwid	4.0000	in.
Number of Ribs (inc. outside ribs)	Nribs	2	
Rib Thickness	Ribtk	0.2500	in.
Web Thickness	Webtk	0.2500	in.
Web Location	Webloc	Side	

Moment of Inertia of Saddle - Lateral Direction

	Y	A	AY	Io
Shell	0.3750	6.7041	2.5140	1.2570
Wearplate	0.8750	1.2500	1.0938	0.9635
Web	12.3750	5.6875	70.3828	1116.2904
BasePlate	23.8750	1.0000	23.8750	570.0208
Totals	37.5000	14.6416	97.8656	1688.5317

```
Value  C1 = Sumof(Ay)/Sumof(A)              =       6.6841  in.
Value   I = Sumof(Io) - C1*Sumof(Ay)        =    1034.3906  in**4
Value  As = Sumof(A) - Ashell               =       7.9375  in²

K1 = (1+Cos(beta)-.5*Sin(beta)² )/(pi-beta+Sin(beta)*Cos(beta)) =   0.2035

Fh = K1 * Q = 0.2035 * 2038.728 = 414.9255 lb.

Tension Stress, St = ( Fh/As )       =        52.2741  psi
Allowed Stress, Sa = 0.6 * Yield Str =     21600.0000  psi

d  = B - R*Sin(theta) / theta        =        25.4706  in.
Bending Moment, M  = Fh * d          =       880.6987  ft.lb.

Bending Stress, Sb = ( M * C1 / I  ) =        68.2913  psi
Allowed Stress, Sa = 2/3 * Yield Str =     24000.0000  psi
```

Minimum Thickness of Baseplate per Moss :

```
 = ( 3 * ( Q + Saddle_Wt ) * BasePlateWidth / ( 2 * BasePlateLength *
   AllStress ))½
 = ( 3 * (2038 + 56 ) * 4.00/( 2 * 16.400 * 24000.000 ))½
 = 0.179 in.
```

Calculation of Axial Load, Intermediate Values and Compressive Stress

Effective Baseplate Length [e]:

```
 = ( Bplen - Clearance ) / ( Nribs - 1)
 = ( 16.4000 - 1.0 )/( 2 - 1 ) = 15.4000 in.
```

Baseplate Pressure Area [Ap]:

```
 = e * Bpwid / 2
 = 15.4000 * 4.0000/2 = 30.8000 in²
```

Axial Load [P]:

```
 = Ap * Bp
 = 30.8 * 31.08 = 957.2 lb.
```

Area of the Rib and Web [Ar]:

```
 = ( Bpwid - Clearance - Webtk ) * Ribtk + e/2 * Webtk
 = ( 4.000 - 1.0 - 0.250 ) * 0.250 + 15.4000/2 * 0.250
 = 2.612 in²
```

Compressive Stress [Sc]:
 = P/Ar
 = 957.2/2.6125 = 366.3954 psi

Check of Outside Ribs:

Inertia of Saddle, Outer Ribs - Longitudinal Direction

	Y	A	AY	Ay²	Io
Rib	1.6250	0.8125	1.3203	0.9040	0.8932
Web	0.1250	1.9250	0.2406	0.3816	0.0201
Values	0.5702	2.7375	1.5609	1.2855	0.9133

Bending Moment [Rm]:
 = Fl /(2 * Bplen) * e * rl / 2
 = 0.0/(2 * 16.40) * 15.400 * 27.88/2
 = 0.000 ft.lb.

KL/R < Cc (30.3843 < 126.0993) per AISC E2-1
Sca = (1-(Klr)²/(2*Cc²))*Fy/(5/3+3*(Klr)/(8*Cc)-(Klr³)/(8*Cc³)
Sca = (1-(30.38)²/(2 * 126.10²)) * 36000/
      (5/3+3*(30.38)/(8* 126.10)-(30.38³)/(8*126.10³)
Sca = 19914.21 psi

AISC Unity Check on Outside Ribs (must be <= 1.0)
Check = Sc/Sca + (Rm/Z)/Sba
Check = 366.40/19914.21 + (0.00/0.905)/24000.00
Check = 0.02

INPUT VALUES, Nozzle Description: T1/T2   From : 20

Pressure for Reinforcement Calculations	P	150.021	psig
Temperature for Internal Pressure	Temp	650	F
Shell Material		SA-516 70	
Shell Allowable Stress at Temperature	S	18800.00	psi
Shell Allowable Stress At Ambient	Sa	20000.00	psi
Inside Diameter of Cylindrical Shell	D	18.1250	in.
Shell Finished (Minimum) Thickness	t	0.1875	in.
Shell Internal Corrosion Allowance	c	0.0625	in.
Shell External Corrosion Allowance	co	0.0000	in.
Distance from Cylinder/Cone Centerline	L1	3.2500	in.
Distance from Bottom/Left Tangent		0.4433	ft.
User Entered Minimum Design Metal Temperature		-20.00	F

Type of Element Connected to the Shell : Nozzle

Material		SA-106 B	
Material UNS Number		K03006	
Material Specification/Type		Smls. pipe	
Allowable Stress at Temperature	Sn	17100.00	psi
Allowable Stress At Ambient	Sna	17100.00	psi
Diameter Basis (for tr calc only)		OD	
Layout Angle		110.57	deg
Diameter		4.0000	in.
Size and Thickness Basis		Nominal	
Nominal Thickness	tn	40	
Flange Material		SA-105	
Flange Type		Weld Neck Flange	
Corrosion Allowance	can	0.0625	in.
Joint Efficiency of Shell Seam at Nozzle	E1	1.00	
Joint Efficiency of Nozzle Neck	En	1.00	
Outside Projection	ho	7.3400	in.
Weld leg size between Nozzle and Pad/Shell	Wo	0.2500	in.
Groove weld depth between Nozzle and Vessel	Wgnv	0.1875	in.
Inside Projection	h	0.0000	in.
Weld leg size, Inside Element to Shell	Wi	0.0000	in.
ASME Code Weld Type per UW-16		None	
Class of attached Flange		300	
Grade of attached Flange		GR 1.1	

The Pressure Design option was Design Pressure + static head.

Nozzle Sketch (may not represent actual weld type/configuration)

```
             |  |
             |  |
             |  |
             |  |
 ___________/|  |
|         \  |  |
|          \ |  |
|___________\|__|
```

Insert Nozzle No Pad, no Inside projection

Note : Checking Nozzle 90 degrees to the Longitudinal axis.

Reinforcement CALCULATION, Description: T1/T2

ASME Code, Section VIII, Division 1, 2010, 2011a, UG-37 to UG-45

Actual Outside Diameter Used in Calculation	4.500	in.
Actual Thickness Used in Calculation	0.237	in.

Nozzle input data check completed without errors.

Reqd thk per UG-37(a)of Cylindrical Shell, Tr [Int. Press]
 = (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
 = (150.02*9.1250)/(18800*1.00-0.6*150.02)
 = 0.0732 in.

Reqd thk per UG-37(a)of Nozzle Wall, Trn [Int. Press]
 = (P*Ro)/(S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (150.02*2.2500)/(17100*1.00+0.4*150.02)
 = 0.0197 in.

UG-40, Limits of Reinforcement : [Internal Pressure]

Parallel to Vessel Wall (Diameter Limit)	Dl	9.0105	in.
Parallel to Vessel Wall, opening length	d	4.5053	in.
Normal to Vessel Wall (Thickness Limit), no pad	Tlnp	0.3125	in.

Results of Nozzle Reinforcement Area Calculations:

AREA AVAILABLE, A1 to A5		Design	External	Mapnc	
Area Required	Ar	0.166	NA	NA	in^2
Area in Shell	A1	0.396	NA	NA	in^2
Area in Nozzle Wall	A2	0.089	NA	NA	in^2
Area in Inward Nozzle	A3	0.000	NA	NA	in^2
Area in Welds	A41+A42+A43	0.057	NA	NA	in^2
Area in Element	A5	0.000	NA	NA	in^2
TOTAL AREA AVAILABLE	Atot	0.541	NA	NA	in^2

The Internal Pressure Case Governs the Analysis.

Nozzle Angle Used in Area Calculations   67.13 Degs.

The area available without a pad is Sufficient.

Area Required [A]:
 = (d * tr*F + 2 * tn * tr*F * (1-fr1)) UG-37(c)
 = (4.5053*0.0732*0.5+2*0.1745*0.0732*0.5*(1-0.91))
 = 0.166 in^2

Reinforcement Areas per Figure UG-37.1

Area Available in Shell [A1]:
```
 = d( E1*t - F*tr ) - 2 * tn( E1*t - F*tr ) * ( 1 - fr1 )
 = 4.505 ( 1.00 * 0.1250 - 0.5 * 0.073 ) - 2 * 0.175
   ( 1.00 * 0.1250 - 0.5 * 0.0732 ) * ( 1 - 0.910 )
 = 0.396 in²
```

Area Available in Nozzle Projecting Outward [A2]:
```
 = ( 2 * tlnp ) * ( tn - trn ) * fr2/sin( alpha3 )
 = ( 2 * 0.312 ) * ( 0.1745 - 0.0197 ) * 0.9096/sin( 83.4 )
 = 0.089 in²
```

Note: See Appendix L, L-7.7.7(b) for more information.

Area Available in Inward Weld + Outward Weld [A41 + A43]:
```
 = Wo² * fr2 + ( Wi-can/0.707 )² * fr2
 = 0.2500² * 0.9096 + ( 0.0000 )² * 0.9096
 = 0.057 in²
```

Nozzle Junction Minimum Design Metal Temperature (MDMT) Calculations:

MDMT of the Nozzle Neck to Flange Weld,   Curve: B

Govrn. thk, tg = 0.207 , tr = 0.020 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.136 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                          -20 F
Min Metal Temp. at Required thickness (UCS 66.1)              -155 F
```

MDMT of Nozzle-Shell/Head Weld for the Nozzle (UCS-66(a)1(b)), Curve: B

Govrn. thk, tg = 0.188 , tr = 0.069 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.550 , Temp. Reduction = 50 F

```
Min Metal Temp. w/o impact per UCS-66                          -20 F
Min Metal Temp. at Required thickness (UCS 66.1)               -55 F

Governing MDMT of all the sub-joints of this Junction  :   -55 F
```

ANSI Flange MDMT including Temperature reduction per UCS-66.1:

```
Unadjusted MDMT of ANSI B16.5/47 flanges per UCS-66(c)     -20 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(b)       -155 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(c)       -155 F
```

Where the Stress Reduction Ratio per UCS-66(b)(1)(b) is :
```
 Design Pressure/Ambient Rating = 150.02/740.00 = 0.203
```

Note: Using the minimum value from (b)(1)(b) and (b)(1)(c) above
as the calculated nozzle flange MDMT.

Weld Size Calculations, Description: T1/T2

```
Intermediate Calc. for nozzle/shell Welds   Tmin      0.1250  in.
```

Results Per UW-16.1:

```
                      Required Thickness    Actual Thickness
Nozzle Weld          0.0875 = 0.7 * tmin.  0.1768 = 0.7 * Wo in.
```

Weld Strength and Weld Loads per UG-41.1, Sketch (a) or (b)

Weld Load [W]:

```
 = (A-A1+2*tn*fr1*(E1*t-tr))*Sv
 = (0.1660 - 0.3956 + 2 * 0.1745 * 0.9096 *
   (1.00 * 0.1250 - 0.0366 ) ) * 18800
 = 0.00 lb.
```

Note: F is always set to 1.0 throughout the calculation.

Weld Load [W1]:

```
 = (A2+A5+A4-(Wi-Can/.707)²*fr2)*Sv
 = ( 0.0886 + 0.0000 + 0.0568 - 0.0000 * 0.91 ) * 18800
 = 2734.52 lb.
```

Weld Load [W2]:

```
 = (A2 + A3 + A4 + (2 * tn * t * fr1)) * Sv
 = ( 0.0886 + 0.0000 + 0.0568 + ( 0.0397 ) ) * 18800
 = 3480.50 lb.
```

Weld Load [W3]:

```
 = (A2+A3+A4+A5+(2*tn*t*fr1))*S
 = ( 0.0886 + 0.0000 + 0.0568 + 0.0000 + ( 0.0397 ) ) * 18800
 = 3480.50 lb.
```

Strength of Connection Elements for Failure Path Analysis

Shear, Outward Nozzle Weld [Sonw]:

```
 = (pi/2) * Dlo * Wo * 0.49 * Snw
 = ( 3.1416/2.0 ) * 4.8840 * 0.2500 * 0.49 * 17100
 = 16071. lb.
```

Shear, Nozzle Wall [Snw]:

```
 = (pi *( Dlr + Dlo )/4 ) * ( Thk - Can ) * 0.7 * Sn
 = (3.1416 * 2.3473 ) * ( 0.2370 - 0.0625 ) * 0.7 * 17100
 = 15403. lb.
```

Tension, Shell Groove Weld [Tngw]:

```
 = (pi/2) * Dlo * (Wgnvi-Cas) * 0.74 * Sng
 = ( 3.1416/2.0 ) * 4.8840 * ( 0.1875 - 0.0625 ) * 0.74 * 18800
 = 13341. lb.
```

Strength of Failure Paths:

```
 PATH11 = ( SONW + SNW ) = ( 16070 + 15403 ) = 31473 lb.
 PATH22 = ( Sonw + Tpgw + Tngw + Sinw )
        = ( 16070 + 0 + 13341 + 0 ) = 29411 lb.
 PATH33 = ( Sonw + Tngw + Sinw )
        = ( 16070 + 13341 + 0 ) = 29411 lb.
```

Summary of Failure Path Calculations:

```
Path 1-1 = 31473 lb., must exceed W = 0 lb. or W1 = 2734 lb.
Path 2-2 = 29411 lb., must exceed W = 0 lb. or W2 = 3480 lb.
```

Path 3-3 = 29411 lb., must exceed W = 0 lb. or W3 = 3480 lb.

Maximum Allowable Pressure for this Nozzle at this Location:
Converged Max. Allow. Pressure in Operating case   254.799 psig

Note: The MAWP of this junction was limited by the parent Shell/Head.

Note : Checking Nozzle in plane parallel to the vessel axis.

Reinforcement CALCULATION, Description: T1/T2

ASME Code, Section VIII, Division 1, 2010, 2011a, UG-37 to UG-45

Actual Outside Diameter Used in Calculation	4.500	in.
Actual Thickness Used in Calculation	0.237	in.

Nozzle input data check completed without errors.

Reqd thk per UG-37(a)of Cylindrical Shell, Tr [Int. Press]
= (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
= (150.02*9.1250)/(18800*1.00-0.6*150.02)
= 0.0732 in.

Reqd thk per UG-37(a)of Nozzle Wall, Trn [Int. Press]
= (P*Ro)/(S*E+0.4*P) per Appendix 1-1 (a)(1)
= (150.02*2.2500)/(17100*1.00+0.4*150.02)
= 0.0197 in.

UG-40, Limits of Reinforcement : [Internal Pressure]

Parallel to Vessel Wall (Diameter Limit)	Dl	8.3020	in.
Parallel to Vessel Wall, opening length	d	4.1510	in.
Normal to Vessel Wall (Thickness Limit), no pad	Tlnp	0.3125	in.

Results of Nozzle Reinforcement Area Calculations:

AREA AVAILABLE, A1 to A5		Design	External	Mapnc	
Area Required	Ar	0.306	NA	NA	in^2
Area in Shell	A1	0.214	NA	NA	in^2
Area in Nozzle Wall	A2	0.088	NA	NA	in^2
Area in Inward Nozzle	A3	0.000	NA	NA	in^2
Area in Welds	A41+A42+A43	0.057	NA	NA	in^2
Area in Element	A5	0.000	NA	NA	in^2
TOTAL AREA AVAILABLE	Atot	0.358	NA	NA	in^2

The Internal Pressure Case Governs the Analysis.

Nozzle Angle Used in Area Calculations   90.00 Degs.

The area available without a pad is Sufficient.

Area Required [A]:
= (d * tr*F + 2 * tn * tr*F * (1-fr1)) UG-37(c)
= (4.1510*0.0732*1.0+2*0.1745*0.0732*1.0*(1-0.91))
= 0.306 in^2

Reinforcement Areas per Figure UG-37.1

Area Available in Shell [A1]:

```
 = d( E1*t - F*tr ) - 2 * tn( E1*t - F*tr ) * ( 1 - fr1 )
 = 4.151 ( 1.00 * 0.1250 - 1.0 * 0.073 ) - 2 * 0.175
   ( 1.00 * 0.1250 - 1.0 * 0.0732 ) * ( 1 - 0.910 )
 = 0.214 in²
```

Area Available in Nozzle Projecting Outward [A2]:

```
 = ( 2 * tlnp ) * ( tn - trn ) * fr2
 = ( 2 * 0.312 ) * ( 0.1745 - 0.0197 ) * 0.9096
 = 0.088 in²
```

Area Available in Inward Weld + Outward Weld [A41 + A43]:

```
 = Wo² * fr2 + ( Wi-can/0.707 )² * fr2
 = 0.2500² * 0.9096 + ( 0.0000 )² * 0.9096
 = 0.057 in²
```

UG-45 Minimum Nozzle Neck Thickness Requirement: [Int. Press.]

```
Wall Thickness for Internal/External pressures      ta = 0.0822 in.
Wall Thickness per UG16(b),                       tr16b = 0.1250 in.
Wall Thickness, shell/head, internal pressure      trb1 = 0.1357 in.
Wall Thickness                  tb1 = max(trb1, tr16b) = 0.1357 in.
Wall Thickness                  tb2 = max(trb2, tr16b) = 0.1250 in.
Wall Thickness per table UG-45                      tb3 = 0.2695 in.
```

Determine Nozzle Thickness candidate [tb]:

```
 = min[ tb3, max( tb1,tb2) ]
 = min[ 0.270 , max( 0.136 , 0.125 ) ]
 = 0.1357 in.
```

Minimum Wall Thickness of Nozzle Necks [tUG-45]:

```
 = max( ta, tb )
 = max( 0.0822 , 0.1357 )
 = 0.1357 in.
```

Available Nozzle Neck Thickness = 0.875 * 0.237 = 0.207 in. --> OK

Weld Size Calculations, Description: T1/T2

```
Intermediate Calc. for nozzle/shell Welds   Tmin      0.1250  in.
```

Results Per UW-16.1:

```
                      Required Thickness    Actual Thickness
Nozzle Weld          0.0875 = 0.7 * tmin.  0.1768 = 0.7 * Wo in.
```

Weld Strength and Weld Loads per UG-41.1, Sketch (a) or (b)

Weld Load [W]:

```
 = (A-A1+2*tn*fr1*(E1*t-tr))*Sv
 = (0.3060 - 0.2135 + 2 * 0.1745 * 0.9096 *
   (1.00 * 0.1250 - 0.0732 ) ) * 18800
 = 2048.27 lb.
```

Note: F is always set to 1.0 throughout the calculation.

Weld Load [W1]:

```
 = (A2+A5+A4-(Wi-Can/.707)²*fr2)*Sv
 = ( 0.0880 + 0.0000 + 0.0568 - 0.0000 * 0.91 ) * 18800
 = 2723.49 lb.
```

Weld Load [W2]:
```
 = (A2 + A3 + A4 + (2 * tn * t * fr1)) * Sv
 = ( 0.0880 + 0.0000 + 0.0568 + ( 0.0397 ) ) * 18800
 = 3469.48 lb.
```

Weld Load [W3]:
```
 = (A2+A3+A4+A5+(2*tn*t*fr1))*S
 = ( 0.0880 + 0.0000 + 0.0568 + 0.0000 + ( 0.0397 ) ) * 18800
 = 3469.48 lb.
```

Strength of Connection Elements for Failure Path Analysis

Shear, Outward Nozzle Weld [Sonw]:
```
 = (pi/2) * Dlo * Wo * 0.49 * Snw
 = ( 3.1416/2.0 ) * 4.5000 * 0.2500 * 0.49 * 17100
 = 14807. lb.
```

Shear, Nozzle Wall [Snw]:
```
 = (pi *( Dlr + Dlo )/4 ) * ( Thk - Can ) * 0.7 * Sn
 = (3.1416 * 2.1628 ) * ( 0.2370 - 0.0625 ) * 0.7 * 17100
 = 14192. lb.
```

Tension, Shell Groove Weld [Tngw]:
```
 = (pi/2) * Dlo * (Wgnvi-Cas) * 0.74 * Sng
 = ( 3.1416/2.0 ) * 4.5000 * ( 0.1875 - 0.0625 ) * 0.74 * 18800
 = 12292. lb.
```

Strength of Failure Paths:

```
 PATH11 = ( SONW + SNW ) = ( 14806 + 14192 ) = 28998 lb.
 PATH22 = ( Sonw + Tpgw + Tngw + Sinw )
        = ( 14806 + 0 + 12292 + 0 ) = 27099 lb.
 PATH33 = ( Sonw + Tngw + Sinw )
        = ( 14806 + 12292 + 0 ) = 27099 lb.
```

Summary of Failure Path Calculations:
```
Path 1-1 = 28998 lb., must exceed W = 2048 lb. or W1 = 2723 lb.
Path 2-2 = 27099 lb., must exceed W = 2048 lb. or W2 = 3469 lb.
Path 3-3 = 27099 lb., must exceed W = 2048 lb. or W3 = 3469 lb.
```

Maximum Allowable Pressure for this Nozzle at this Location:
```
Converged Max. Allow. Pressure in Operating case      162.656  psig
```

The Drop for this Nozzle is : 1.2570 in.
The Cut Length for this Nozzle is, Drop + Ho + H + T : 8.7976 in.

INPUT VALUES, Nozzle Description: S2   From : 40

```
Pressure for Reinforcement Calculations        P    1400.625  psig
Temperature for Internal Pressure           Temp         650  F
Design External Pressure                    Pext       15.00  psig
Temperature for External Pressure         Tempex         650  F

Shell Material                                      SA-516 70
Shell Allowable Stress at Temperature          S    18800.00  psi
Shell Allowable Stress At Ambient             Sa    20000.00  psi

Inside Diameter of Cylindrical Shell           D     17.0000  in.
Design Length of Section                       L     92.0040  in.
Shell Finished (Minimum) Thickness             t      0.7500  in.
Shell Internal Corrosion Allowance             c      0.0625  in.
Shell External Corrosion Allowance            co      0.0000  in.

Distance from Bottom/Left Tangent                     1.5519  ft.

User Entered Minimum Design Metal Temperature         -20.00  F
```

Type of Element Connected to the Shell : Nozzle

```
Material                                             SA-106 B
Material UNS Number                                   K03006
Material Specification/Type                       Smls. pipe
Allowable Stress at Temperature               Sn    17100.00  psi
Allowable Stress At Ambient                  Sna    17100.00  psi

Diameter Basis (for tr calc only)                         OD
Layout Angle                                          270.00  deg
Diameter                                              3.0000  in.

Size and Thickness Basis                                Nominal
Nominal Thickness                             tn        XXS

Flange Material                                       SA-105
Flange Type                                  Weld Neck Flange

Corrosion Allowance                          can      0.0625  in.
Joint Efficiency of Shell Seam at Nozzle      E1        1.00
Joint Efficiency of Nozzle Neck               En        1.00

Outside Projection                            ho      7.7500  in.
Weld leg size between Nozzle and Pad/Shell    Wo      0.3750  in.
Groove weld depth between Nozzle and Vessel Wgnv      0.7500  in.
Inside Projection                              h      0.0000  in.
Weld leg size, Inside Element to Shell        Wi      0.0000  in.

Pad Material                                        SA-516 70
Pad Allowable Stress at Temperature           Sp    18800.00  psi
Pad Allowable Stress At Ambient              Spa    20000.00  psi
Diameter of Pad along vessel surface          Dp      8.0000  in.
Thickness of Pad                              te      0.6250  in.
Weld leg size between Pad and Shell           Wp      0.5000  in.
Groove weld depth between Pad and Nozzle    Wgpn      0.6250  in.
```

```
Reinforcing Pad Width                                   2.2500  in.
ASME Code Weld Type per UW-16                             None

Class of attached Flange                              900
Grade of attached Flange                              GR 1.1
```

The Pressure Design option was Design Pressure + static head.

Nozzle Sketch (may not represent actual weld type/configuration)

```
                  |  |
                  |  |
                  |  |
                  |  |
      __________/|  |
 ____/|__________\|  |
|            \   |  |
|             \  |  |
|_______________\|__|
```

Insert Nozzle With Pad, no Inside projection

Reinforcement CALCULATION, Description: S2

ASME Code, Section VIII, Division 1, 2010, 2011a, UG-37 to UG-45

```
Actual Outside Diameter Used in Calculation              3.500  in.
Actual Thickness Used in Calculation                     0.600  in.
```

Nozzle input data check completed without errors.

Reqd thk per UG-37(a)of Cylindrical Shell, Tr [Int. Press]
```
 = (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
 = (1400.63*8.5625)/(18800*1.00-0.6*1400.63)
 = 0.6678 in.
```

Reqd thk per UG-37(a)of Nozzle Wall, Trn [Int. Press]
```
 = (P*Ro)/(S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (1400.63*1.7500)/(17100*1.00+0.4*1400.63)
 = 0.1388 in.
```

Required Nozzle thickness under External Pressure per UG-28 : 0.0166 in.

UG-40, Limits of Reinforcement : [Internal Pressure]
```
Parallel to Vessel Wall (Diameter Limit)            Dl     4.8750  in.
Parallel to Vessel Wall                        Rn+tn+t     2.4375  in.
Normal to Vessel Wall (Thickness Limit), pad side Tlwp     1.7188  in.
```

Note : The Pad diameter is greater than the Diameter Limit, the
excess will not be considered .

Weld Strength Reduction Factor [fr1]:
```
 = min( 1, Sn/S )
 = min( 1, 17100.0/18800.0 )
 = 0.910
```

Weld Strength Reduction Factor [fr2]:
```
 = min( 1, Sn/S )
```

```
 = min( 1, 17100.0/18800.0 )
 = 0.910
```

Weld Strength Reduction Factor [fr4]:

```
 = min( 1, Sp/S )
 = min( 1, 18800.0/18800.0 )
 = 1.000
```

Weld Strength Reduction Factor [fr3]:

```
 = min( fr2, fr4 )
 = min( 0.9 , 1.0 )
 = 0.910
```

Results of Nozzle Reinforcement Area Calculations:

AREA AVAILABLE, A1 to A5		Design	External	Mapnc	
Area Required	Ar	1.684	0.156	NA	in^2
Area in Shell	A1	0.046	1.326	NA	in^2
Area in Nozzle Wall	A2	1.247	1.629	NA	in^2
Area in Inward Nozzle	A3	0.000	0.000	NA	in^2
Area in Welds	A41+A42+A43	0.128	0.128	NA	in^2
Area in Element	A5	0.859	0.859	NA	in^2
TOTAL AREA AVAILABLE	Atot	2.280	3.942	NA	in^2

The Internal Pressure Case Governs the Analysis.

```
Nozzle Angle Used in Area Calculations                   90.00  Degs.
```

The area available without a pad is Insufficient.
The area available with the given pad is Sufficient.

SELECTION OF POSSIBLE REINFORCING PADS:	Diameter	Thickness	
Based on given Pad Thickness:	3.9375	0.6250	in.
Based on given Pad Diameter:	8.0000	0.2500	in.
Based on Shell or Nozzle Thickness:	3.9375	0.6250	in.

Area Required [A]:

```
 = ( d * tr*F + 2 * tn * tr*F * (1-fr1) ) UG-37(c)
 = (2.4250*0.6678*1.0+2*0.5375*0.6678*1.0*(1-0.91))
 = 1.684 in^2
```

Reinforcement Areas per Figure UG-37.1

Area Available in Shell [A1]:

```
 = d( E1*t - F*tr ) - 2 * tn( E1*t - F*tr ) * ( 1 - fr1 )
 = 2.450 ( 1.00 * 0.6875 - 1.0 * 0.668 ) - 2 * 0.538
   ( 1.00 * 0.6875 - 1.0 * 0.6678 ) * ( 1 - 0.910 )
 = 0.046 in^2
```

Area Available in Nozzle Wall Projecting Outward [A2]:

```
 = ( 2 * Tlwp ) * ( tn - trn ) * fr2
 = ( 2 * 1.719 ) * ( 0.5375 - 0.1388 ) * 0.9096
 = 1.247 in^2
```

Area Available in Welds [A41 + A42 + A43]:

```
 = Wo^2*fr3+(Wi-can/0.707)^2*fr2+Wp^2*fr4
 = 0.3750^2 *0.91 + (0.0000 )^2 *0.91 + 0.0000^2 * 1.00
 = 0.128 in^2
```

Area Available in Element [A5]:

```
 = (min(Dp,DL)-(Nozzle OD))*(min(tp,Tlwp,te))*fr4
 = ( 4.8750 - 3.5000 ) * 0.6250 * 1.0000
 = 0.859 in²
```

UG-45 Minimum Nozzle Neck Thickness Requirement: [Int. Press.]

```
Wall Thickness for Internal/External pressures      ta = 0.2013 in.
Wall Thickness per UG16(b),                       tr16b = 0.1250 in.
Wall Thickness, shell/head, internal pressure     trb1 = 0.7303 in.
Wall Thickness                  tb1 = max(trb1, tr16b) = 0.7303 in.
Wall Thickness                  tb2 = max(trb2, tr16b) = 0.1250 in.
Wall Thickness per table UG-45                     tb3 = 0.2515 in.
```

Determine Nozzle Thickness candidate [tb]:

```
 = min[ tb3, max( tb1,tb2) ]
 = min[ 0.251 , max( 0.730 , 0.125 ) ]
 = 0.2515 in.
```

Minimum Wall Thickness of Nozzle Necks [tUG-45]:

```
 = max( ta, tb )
 = max( 0.2013 , 0.2515 )
 = 0.2515 in.
```

Available Nozzle Neck Thickness = 0.875 * 0.600 = 0.525 in. --> OK

Nozzle Junction Minimum Design Metal Temperature (MDMT) Calculations:

MDMT of the Nozzle Neck to Flange Weld,   Curve: B

Govrn. thk, tg = 0.525 , tr = 0.139 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.300 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                         -4 F
Min Metal Temp. at Required thickness (UCS 66.1)            -144 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F
```

MDMT of Nozzle Neck to Pad Weld for the Nozzle,   Curve: B

Govrn. thk, tg = 0.525 , tr = 0.139 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.300 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                         -4 F
Min Metal Temp. at Required thickness (UCS 66.1)            -144 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F
```

MDMT of Nozzle Neck to Pad Weld for Reinforcement pad,   Curve: B

Govrn. thk, tg = 0.525 , tr = 0.139 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.300 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                         -4 F
Min Metal Temp. at Required thickness (UCS 66.1)            -144 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F
```

MDMT of Shell to Pad Weld at Pad OD for pad,   Curve: B

Govrn. thk, tg = 0.625 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.910 , Temp. Reduction = 9 F
Pad governing, Conservatively assuming Pad stress = Shell stress(Div. 1 L-9.3)

```
Min Metal Temp. w/o impact per UCS-66                          6 F
Min Metal Temp. at Required thickness (UCS 66.1)              -3 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F
```

MDMT of Nozzle-Shell/Head Weld for the Nozzle (UCS-66(a)1(b)), Curve: B

Govrn. thk, tg = 0.525 , tr = 0.139 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.300 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                         -4 F
Min Metal Temp. at Required thickness (UCS 66.1)            -144 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F

Governing MDMT of the Nozzle                           :  -144 F
Governing MDMT of the Reinforcement Pad                :   -20 F
Governing MDMT of all the sub-joints of this Junction  :   -20 F
```

ANSI Flange MDMT including Temperature reduction per UCS-66.1:

```
Unadjusted MDMT of ANSI B16.5/47 flanges per UCS-66(c)     -20 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(b)        -55 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(c)       -155 F
```

Where the Stress Reduction Ratio per UCS-66(b)(1)(b) is :
```
 Design Pressure/Ambient Rating = 1400.63/2220.00 = 0.631
```

Note: Using the minimum value from (b)(1)(b) and (b)(1)(c) above
as the calculated nozzle flange MDMT.

Weld Size Calculations, Description: S2

```
Intermediate Calc. for nozzle/shell Welds   Tmin      0.5375  in.
Intermediate Calc. for pad/shell Welds   TminPad      0.6250  in.
```

Results Per UW-16.1:

```
                      Required Thickness    Actual Thickness
Nozzle Weld          0.2500 = Min per Code 0.2651 = 0.7 * Wo in.
Pad Weld             0.3125 = 0.5*TminPad  0.3535 = 0.7 * Wp in.
```

Weld Strength and Weld Loads per UG-41.1, Sketch (a) or (b)
Weld Load [W]:
```
 = (A-A1+2*tn*fr1*(E1*t-tr))*Sv
 = (1.6842 - 0.0464 + 2 * 0.5375 * 0.9096 *
   (1.00 * 0.6875 - 0.6678 ) ) * 18800
 = 31153.78 lb.
```

Note: F is always set to 1.0 throughout the calculation.

Weld Load [W1]:
```
 = (A2+A5+A4-(Wi-Can/.707)²*fr2)*Sv
 = ( 1.2466 + 0.8594 + 0.1279 - 0.0000 * 0.91 ) * 18800
 = 41997.52 lb.
```

Weld Load [W2]:
```
 = (A2 + A3 + A4 + (2 * tn * t * fr1)) * Sv
 = ( 1.2466 + 0.0000 + 0.1279 + ( 0.6722 ) ) * 18800
 = 38479.24 lb.
```

Weld Load [W3]:
```
 = (A2+A3+A4+A5+(2*tn*t*fr1))*S
 = ( 1.2466 + 0.0000 + 0.1279 + 0.8594 + ( 0.6722 ) ) * 18800
 = 54635.49 lb.
```

Strength of Connection Elements for Failure Path Analysis

Shear, Outward Nozzle Weld [Sonw]:
```
 = (pi/2) * Dlo * Wo * 0.49 * Snw
 = ( 3.1416/2.0 ) * 3.5000 * 0.3750 * 0.49 * 17100
 = 17275. lb.
```

Shear, Pad Element Weld [Spew]:
```
 = (pi/2) * DP * WP * 0.49 * SEW
 = ( 3.1416/2.0 ) * 8.0000 * 0.5000 * 0.49 * 18800
 = 57881. lb.
```

Shear, Nozzle Wall [Snw]:
```
 = (pi *( Dlr + Dlo )/4 ) * ( Thk - Can ) * 0.7 * Sn
 = (3.1416 * 1.4813 ) * ( 0.6000 - 0.0625 ) * 0.7 * 17100
 = 29940. lb.
```

Tension, Pad Groove Weld [Tpgw]:
```
 = ( pi/2) * Dlo * Wgpn * 0.74 * Seg
 =  (3.1416/2 ) * 3.5000 * 0.6250 * 0.74 * 18800
 = 47803. lb.
```

Tension, Shell Groove Weld [Tngw]:
```
 = (pi/2) * Dlo * (Wgnvi-Cas) * 0.74 * Sng
 = ( 3.1416/2.0 ) * 3.5000 * ( 0.7500 - 0.0625 ) * 0.74 * 18800
 = 52584. lb.
```

Strength of Failure Paths:

```
 PATH11 = ( SPEW + SNW ) = ( 57880 + 29939 ) = 87820 lb.
 PATH22 = ( Sonw + Tpgw + Tngw + Sinw )
        = ( 17274 + 47803 + 52583 + 0 ) = 117661 lb.
 PATH33 = ( Spew + Tngw + Sinw )
        = ( 57880 + 52583 + 0 ) = 110464 lb.
```

Summary of Failure Path Calculations:
```
Path 1-1 = 87820 lb., must exceed W = 31153 lb. or W1 = 41997 lb.
Path 2-2 = 117661 lb., must exceed W = 31153 lb. or W2 = 38479 lb.
Path 3-3 = 110464 lb., must exceed W = 31153 lb. or W3 = 54635 lb.
```

Maximum Allowable Pressure for this Nozzle at this Location:
```
Converged Max. Allow. Pressure in Operating case     1440.109  psig
```

Note: The MAWP of this junction was limited by the parent Shell/Head.

```
Nozzle is O.K. for the External Pressure              15.000  psig
```

The Drop for this Nozzle is : 0.1821 in.
The Cut Length for this Nozzle is, Drop + Ho + H + T : 8.6821 in.

INPUT VALUES, Nozzle Description: S1   From : 40

```
Pressure for Reinforcement Calculations        P    1400.625  psig
Temperature for Internal Pressure           Temp         650  F
Design External Pressure                    Pext       15.00  psig
Temperature for External Pressure         Tempex         650  F

Shell Material                                      SA-516 70
Shell Allowable Stress at Temperature          S    18800.00  psi
Shell Allowable Stress At Ambient             Sa    20000.00  psi

Inside Diameter of Cylindrical Shell           D     17.0000  in.
Design Length of Section                       L     92.0040  in.
Shell Finished (Minimum) Thickness             t      0.7500  in.
Shell Internal Corrosion Allowance             c      0.0625  in.
Shell External Corrosion Allowance            co      0.0000  in.

Distance from Bottom/Left Tangent                     8.3419  ft.

User Entered Minimum Design Metal Temperature         -20.00  F
```

Type of Element Connected to the Shell : Nozzle

```
Material                                              SA-106 B
Material UNS Number                                     K03006
Material Specification/Type                         Smls. pipe
Allowable Stress at Temperature               Sn    17100.00  psi
Allowable Stress At Ambient                  Sna    17100.00  psi

Diameter Basis (for tr calc only)                         OD
Layout Angle                                          270.00  deg
Diameter                                              6.0000  in.

Size and Thickness Basis                                 Nominal
Nominal Thickness                             tn         XXS

Flange Material                                         SA-105
Flange Type                                  Weld Neck Flange

Corrosion Allowance                          can      0.0625  in.
Joint Efficiency of Shell Seam at Nozzle      E1        1.00
Joint Efficiency of Nozzle Neck               En        1.00

Outside Projection                            ho      7.7500  in.
Weld leg size between Nozzle and Pad/Shell    Wo      0.3750  in.
Groove weld depth between Nozzle and Vessel Wgnv      0.7500  in.
Inside Projection                              h      0.0000  in.
Weld leg size, Inside Element to Shell        Wi      0.0000  in.

Pad Material                                        SA-516 70
Pad Allowable Stress at Temperature           Sp    18800.00  psi
Pad Allowable Stress At Ambient              Spa    20000.00  psi
Diameter of Pad along vessel surface          Dp     10.1250  in.
Thickness of Pad                              te      0.6250  in.
Weld leg size between Pad and Shell           Wp      0.5000  in.
Groove weld depth between Pad and Nozzle    Wgpn      0.6250  in.
```

```
Reinforcing Pad Width                                  1.7500  in.
ASME Code Weld Type per UW-16                            None

Class of attached Flange                             900
Grade of attached Flange                             GR 1.1
```

The Pressure Design option was Design Pressure + static head.

Nozzle Sketch (may not represent actual weld type/configuration)

```
                 |  |
                 |  |
                 |  |
                 |  |
      __________/|  |
 ____/|__________\|  |
|            \   |  |
|             \  |  |
|_______________\|__|
```

Insert Nozzle With Pad, no Inside projection

Reinforcement CALCULATION, Description: S1

ASME Code, Section VIII, Division 1, 2010, 2011a, UG-37 to UG-45

```
Actual Outside Diameter Used in Calculation            6.625  in.
Actual Thickness Used in Calculation                   0.864  in.
```

Nozzle input data check completed without errors.

Reqd thk per UG-37(a)of Cylindrical Shell, Tr [Int. Press]
 = (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
 = (1400.63*8.5625)/(18800*1.00-0.6*1400.63)
 = 0.6678 in.

Reqd thk per UG-37(a)of Nozzle Wall, Trn [Int. Press]
 = (P*Ro)/(S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (1400.63*3.3125)/(17100*1.00+0.4*1400.63)
 = 0.2627 in.

Required Nozzle thickness under External Pressure per UG-28 : 0.0240 in.

UG-40, Limits of Reinforcement : [Internal Pressure]

```
Parallel to Vessel Wall (Diameter Limit)            Dl    10.0440  in.
Parallel to Vessel Wall, opening length              d     5.0220  in.
Normal to Vessel Wall (Thickness Limit), pad side Tlwp     1.7188  in.
```

Note : The Pad diameter is greater than the Diameter Limit, the
excess will not be considered .

Weld Strength Reduction Factor [fr1]:
 = min(1, Sn/S)
 = min(1, 17100.0/18800.0)
 = 0.910

Weld Strength Reduction Factor [fr2]:
 = min(1, Sn/S)

```
 = min( 1, 17100.0/18800.0 )
 = 0.910
```

Weld Strength Reduction Factor [fr4]:

```
 = min( 1, Sp/S )
 = min( 1, 18800.0/18800.0 )
 = 1.000
```

Weld Strength Reduction Factor [fr3]:

```
 = min( fr2, fr4 )
 = min( 0.9 , 1.0 )
 = 0.910
```

Results of Nozzle Reinforcement Area Calculations:

AREA AVAILABLE, A1 to A5		Design	External	Mapnc	
Area Required	Ar	3.450	0.320	NA	in^2
Area in Shell	A1	0.096	2.748	NA	in^2
Area in Nozzle Wall	A2	1.685	2.431	NA	in^2
Area in Inward Nozzle	A3	0.000	0.000	NA	in^2
Area in Welds	A41+A42+A43	0.128	0.128	NA	in^2
Area in Element	A5	2.137	2.137	NA	in^2
TOTAL AREA AVAILABLE	Atot	4.046	7.444	NA	in^2

The Internal Pressure Case Governs the Analysis.

Nozzle Angle Used in Area Calculations 90.00 Degs.

The area available without a pad is Insufficient.
The area available with the given pad is Sufficient.

SELECTION OF POSSIBLE REINFORCING PADS:	Diameter	Thickness	
Based on given Pad Thickness:	9.1250	0.6250	in.
Based on given Pad Diameter:	10.1250	0.5000	in.
Based on Shell or Nozzle Thickness:	8.6875	0.7500	in.

Area Required [A]:

```
 = ( d * tr*F + 2 * tn * tr*F * (1-fr1) ) UG-37(c)
 = (5.0220*0.6678*1.0+2*0.8015*0.6678*1.0*(1-0.91))
 = 3.450 in²
```

Reinforcement Areas per Figure UG-37.1

Area Available in Shell [A1]:

```
 = d( E1*t - F*tr ) - 2 * tn( E1*t - F*tr ) * ( 1 - fr1 )
 = 5.022 ( 1.00 * 0.6875 - 1.0 * 0.668 ) - 2 * 0.802
   ( 1.00 * 0.6875 - 1.0 * 0.6678 ) * ( 1 - 0.910 )
 = 0.096 in²
```

Area Available in Nozzle Wall Projecting Outward [A2]:

```
 = ( 2 * Tlwp ) * ( tn - trn ) * fr2
 = ( 2 * 1.719 ) * ( 0.8015 - 0.2627 ) * 0.9096
 = 1.685 in²
```

Area Available in Welds [A41 + A42 + A43]:

```
 = Wo²*fr3+(Wi-can/0.707)²*fr2+Wp²*fr4
 = 0.3750² *0.91 + (0.0000 )² *0.91 + 0.0000² * 1.00
 = 0.128 in²
```

Area Available in Element [A5]:
```
 = (min(Dp,DL)-(Nozzle OD))*(min(tp,Tlwp,te))*fr4
 = ( 10.0440 - 6.6250 ) * 0.6250 * 1.0000
 = 2.137 in²
```

UG-45 Minimum Nozzle Neck Thickness Requirement: [Int. Press.]
```
Wall Thickness for Internal/External pressures      ta = 0.3252 in.
Wall Thickness per UG16(b),                       tr16b = 0.1250 in.
Wall Thickness, shell/head, internal pressure     trb1 = 0.7303 in.
Wall Thickness                  tb1 = max(trb1, tr16b) = 0.7303 in.
Wall Thickness                  tb2 = max(trb2, tr16b) = 0.1250 in.
Wall Thickness per table UG-45                     tb3 = 0.3074 in.
```

Determine Nozzle Thickness candidate [tb]:
```
 = min[ tb3, max( tb1,tb2) ]
 = min[ 0.307 , max( 0.730 , 0.125 ) ]
 = 0.3074 in.
```

Minimum Wall Thickness of Nozzle Necks [tUG-45]:
```
 = max( ta, tb )
 = max( 0.3252 , 0.3074 )
 = 0.3252 in.
```

Available Nozzle Neck Thickness = 0.875 * 0.864 = 0.756 in. --> OK

Nozzle Junction Minimum Design Metal Temperature (MDMT) Calculations:

MDMT of the Nozzle Neck to Flange Weld,   Curve: B

Govrn. thk, tg = 0.756 , tr = 0.263 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.379 , Temp. Reduction = 118 F

```
Min Metal Temp. w/o impact per UCS-66                          17 F
Min Metal Temp. at Required thickness (UCS 66.1)              -55 F
Min Metal Temp. w/o impact per UG-20(f)                       -20 F
```

MDMT of Nozzle Neck to Pad Weld for the Nozzle,   Curve: B

Govrn. thk, tg = 0.625 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.910 , Temp. Reduction = 9 F
Pad governing, Conservatively assuming Pad stress = Shell stress(Div. 1 L-9.3)

```
Min Metal Temp. w/o impact per UCS-66                           6 F
Min Metal Temp. at Required thickness (UCS 66.1)               -3 F
Min Metal Temp. w/o impact per UG-20(f)                       -20 F
```

MDMT of Nozzle Neck to Pad Weld for Reinforcement pad,   Curve: B

Govrn. thk, tg = 0.625 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.910 , Temp. Reduction = 9 F
Pad governing, Conservatively assuming Pad stress = Shell stress(Div. 1 L-9.3)

```
Min Metal Temp. w/o impact per UCS-66                           6 F
Min Metal Temp. at Required thickness (UCS 66.1)               -3 F
Min Metal Temp. w/o impact per UG-20(f)                       -20 F
```

MDMT of Shell to Pad Weld at Pad OD for pad, Curve: B

Govrn. thk, tg = 0.625 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.910 , Temp. Reduction = 9 F
Pad governing, Conservatively assuming Pad stress = Shell stress(Div. 1 L-9.3)

```
Min Metal Temp. w/o impact per UCS-66                          6 F
Min Metal Temp. at Required thickness (UCS 66.1)              -3 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F
```

MDMT of Nozzle-Shell/Head Weld for the Nozzle (UCS-66(a)1(b)), Curve: B

Govrn. thk, tg = 0.750 , tr = 0.626 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.910 , Temp. Reduction = 9 F

```
Min Metal Temp. w/o impact per UCS-66                         16 F
Min Metal Temp. at Required thickness (UCS 66.1)               7 F
Min Metal Temp. w/o impact per UG-20(f)                      -20 F

Governing MDMT of the Nozzle                           :     -20 F
Governing MDMT of the Reinforcement Pad                :     -20 F
Governing MDMT of all the sub-joints of this Junction  :     -20 F
```

ANSI Flange MDMT including Temperature reduction per UCS-66.1:

```
Unadjusted MDMT of ANSI B16.5/47 flanges per UCS-66(c)       -20 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(b)          -55 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(c)          -55 F
```

Where the Stress Reduction Ratio per UCS-66(b)(1)(b) is :
 Design Pressure/Ambient Rating = 1400.63/2220.00 = 0.631

Note: Using the minimum value from (b)(1)(b) and (b)(1)(c) above
as the calculated nozzle flange MDMT.

Weld Size Calculations, Description: S1

```
Intermediate Calc. for nozzle/shell Welds    Tmin      0.6250  in.
Intermediate Calc. for pad/shell Welds    TminPad      0.6250  in.
```

Results Per UW-16.1:

```
                      Required Thickness    Actual Thickness
Nozzle Weld          0.2500 = Min per Code 0.2651 = 0.7 * Wo in.
Pad Weld             0.3125 = 0.5*TminPad  0.3535 = 0.7 * Wp in.
```

Weld Strength and Weld Loads per UG-41.1, Sketch (a) or (b)
Weld Load [W]:

```
 = (A-A1+2*tn*fr1*(E1*t-tr))*Sv
 = (3.4503 - 0.0962 + 2 * 0.8015 * 0.9096 *
   (1.00 * 0.6875 - 0.6678 ) ) * 18800
 = 63597.71 lb.
```

Note: F is always set to 1.0 throughout the calculation.

Weld Load [W1]:

```
 = (A2+A5+A4-(Wi-Can/.707)²*fr2)*Sv
```

```
 = ( 1.6846 + 2.1369 + 0.1279 - 0.0000 * 0.91 ) * 18800
 = 74248.52 lb.
```

Weld Load [W2]:
```
 = (A2 + A3 + A4 + (2 * tn * t * fr1)) * Sv
 = ( 1.6846 + 0.0000 + 0.1279 + ( 1.0024 ) ) * 18800
 = 52920.55 lb.
```

Weld Load [W3]:
```
 = (A2+A3+A4+A5+(2*tn*t*fr1))*S
 = ( 1.6846 + 0.0000 + 0.1279 + 2.1369 + ( 1.0024 ) ) * 18800
 = 93093.80 lb.
```

Strength of Connection Elements for Failure Path Analysis

Shear, Outward Nozzle Weld [Sonw]:
```
 = (pi/2) * Dlo * Wo * 0.49 * Snw
 = ( 3.1416/2.0 ) * 6.6250 * 0.3750 * 0.49 * 17100
 = 32699. lb.
```

Shear, Pad Element Weld [Spew]:
```
 = (pi/2) * DP * WP * 0.49 * SEW
 = ( 3.1416/2.0 ) * 10.1250 * 0.5000 * 0.49 * 18800
 = 73255. lb.
```

Shear, Nozzle Wall [Snw]:
```
 = (pi *( Dlr + Dlo )/4 ) * ( Thk - Can ) * 0.7 * Sn
 = (3.1416 * 2.9117 ) * ( 0.8640 - 0.0625 ) * 0.7 * 17100
 = 87761. lb.
```

Tension, Pad Groove Weld [Tpgw]:
```
 = ( pi/2) * Dlo * Wgpn * 0.74 * Seg
 =  (3.1416/2 ) * 6.6250 * 0.6250 * 0.74 * 18800
 = 90485. lb.
```

Tension, Shell Groove Weld [Tngw]:
```
 = (pi/2) * Dlo * (Wgnvi-Cas) * 0.74 * Sng
 = ( 3.1416/2.0 ) * 6.6250 * ( 0.7500 - 0.0625 ) * 0.74 * 18800
 = 99533. lb.
```

Strength of Failure Paths:

```
 PATH11 = ( SPEW + SNW ) = ( 73255 + 87761 ) = 161016 lb.
 PATH22 = ( Sonw + Tpgw + Tngw + Sinw )
        = ( 32698 + 90484 + 99533 + 0 ) = 222716 lb.
 PATH33 = ( Spew + Tngw + Sinw )
        = ( 73255 + 99533 + 0 ) = 172788 lb.
```

Summary of Failure Path Calculations:
```
Path 1-1 = 161016 lb., must exceed W = 63597 lb. or W1 = 74248 lb.
Path 2-2 = 222716 lb., must exceed W = 63597 lb. or W2 = 52920 lb.
Path 3-3 = 172788 lb., must exceed W = 63597 lb. or W3 = 93093 lb.
```

Maximum Allowable Pressure for this Nozzle at this Location:
```
Converged Max. Allow. Pressure in Operating case     1440.109  psig
```

Note: The MAWP of this junction was limited by the parent Shell/Head.

```
Nozzle is O.K. for the External Pressure               15.000  psig
```

The Drop for this Nozzle is : 0.6720 in.
The Cut Length for this Nozzle is, Drop + Ho + H + T : 9.1720 in.

INPUT VALUES, Nozzle Description: S3   From : 40

Pressure for Reinforcement Calculations	P	1400.011	psig
Temperature for Internal Pressure	Temp	650	F
Design External Pressure	Pext	15.00	psig
Temperature for External Pressure	Tempex	650	F
Shell Material		SA-516 70	
Shell Allowable Stress at Temperature	S	18800.00	psi
Shell Allowable Stress At Ambient	Sa	20000.00	psi
Inside Diameter of Cylindrical Shell	D	17.0000	in.
Design Length of Section	L	92.0040	in.
Shell Finished (Minimum) Thickness	t	0.7500	in.
Shell Internal Corrosion Allowance	c	0.0625	in.
Shell External Corrosion Allowance	co	0.0000	in.
Distance from Bottom/Left Tangent		1.5519	ft.
User Entered Minimum Design Metal Temperature		-20.00	F

Type of Element Connected to the Shell : Nozzle

Material		SA-106 B	
Material UNS Number		K03006	
Material Specification/Type		Smls. pipe	
Allowable Stress at Temperature	Sn	17100.00	psi
Allowable Stress At Ambient	Sna	17100.00	psi
Diameter Basis (for tr calc only)		OD	
Layout Angle		90.00	deg
Diameter		2.0000	in.
Size and Thickness Basis		Nominal	
Nominal Thickness	tn	XXS	
Flange Material		SA-105	
Flange Type		Weld Neck Flange	
Corrosion Allowance	can	0.0625	in.
Joint Efficiency of Shell Seam at Nozzle	E1	1.00	
Joint Efficiency of Nozzle Neck	En	1.00	
Outside Projection	ho	7.7500	in.
Weld leg size between Nozzle and Pad/Shell	Wo	0.3750	in.
Groove weld depth between Nozzle and Vessel	Wgnv	0.7500	in.
Inside Projection	h	0.0000	in.
Weld leg size, Inside Element to Shell	Wi	0.0000	in.
ASME Code Weld Type per UW-16		None	
Class of attached Flange		900	
Grade of attached Flange		GR 1.1	

The Pressure Design option was Design Pressure + static head.

Nozzle Sketch (may not represent actual weld type/configuration)

```
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```

Insert Nozzle No Pad, no Inside projection

Reinforcement CALCULATION, Description: S3

ASME Code, Section VIII, Division 1, 2010, 2011a, UG-37 to UG-45

```
Actual Outside Diameter Used in Calculation            2.375  in.
Actual Thickness Used in Calculation                   0.436  in.
```

Nozzle input data check completed without errors.

Reqd thk per UG-37(a)of Cylindrical Shell, Tr [Int. Press]

```
 = (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
 = (1400.01*8.5625)/(18800*1.00-0.6*1400.01)
 = 0.6675 in.
```

Reqd thk per UG-37(a)of Nozzle Wall, Trn [Int. Press]

```
 = (P*Ro)/(S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (1400.01*1.1875)/(17100*1.00+0.4*1400.01)
 = 0.0941 in.
```

Required Nozzle thickness under External Pressure per UG-28 : 0.0132 in.

UG-40, Limits of Reinforcement : [Internal Pressure]

```
Parallel to Vessel Wall (Diameter Limit)            Dl     3.7500  in.
Parallel to Vessel Wall                        Rn+tn+t     1.8750  in.
Normal to Vessel Wall (Thickness Limit), no pad   Tlnp     0.9337  in.
```

Note:

Taking a UG-36(c)(3)(a) exemption for nozzle: S3.
This calculation is valid for nozzles that meet all the requirements of paragraph UG-36. Please check the Code carefully, especially for nozzles that are not isolated or do not meet Code spacing requirements. To force the computation of areas for small nozzles go to Tools->Configuration and check the box to force the UG-37 area or App 1-10 computation.

UG-45 Minimum Nozzle Neck Thickness Requirement: [Int. Press.]

```
Wall Thickness for Internal/External pressures      ta = 0.1566 in.
Wall Thickness per UG16(b),                      tr16b = 0.1250 in.
Wall Thickness, shell/head, internal pressure     trb1 = 0.7300 in.
Wall Thickness                tb1 = max(trb1, tr16b) = 0.7300 in.
Wall Thickness                tb2 = max(trb2, tr16b) = 0.1250 in.
Wall Thickness per table UG-45                     tb3 = 0.1971 in.
```

Determine Nozzle Thickness candidate [tb]:

```
 = min[ tb3, max( tb1,tb2) ]
```

```
 = min[ 0.197 , max( 0.730 , 0.125 ) ]
 = 0.1971 in.
```

Minimum Wall Thickness of Nozzle Necks [tUG-45]:

```
 = max( ta, tb )
 = max( 0.1566 , 0.1971 )
 = 0.1971 in.
```

Available Nozzle Neck Thickness = 0.875 * 0.436 = 0.382 in. --> OK

Nozzle Junction Minimum Design Metal Temperature (MDMT) Calculations:

MDMT of the Nozzle Neck to Flange Weld,   Curve: B

Govrn. thk, tg = 0.382 , tr = 0.094 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.295 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                         -20 F
Min Metal Temp. at Required thickness (UCS 66.1)             -155 F
```

MDMT of Nozzle-Shell/Head Weld for the Nozzle (UCS-66(a)1(b)), Curve: B

Govrn. thk, tg = 0.382 , tr = 0.094 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.295 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                         -20 F
Min Metal Temp. at Required thickness (UCS 66.1)             -155 F

Governing MDMT of all the sub-joints of this Junction  :     -155 F
```

ANSI Flange MDMT including Temperature reduction per UCS-66.1:

```
Unadjusted MDMT of ANSI B16.5/47 flanges per UCS-66(c)        -20 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(b)           -55 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(c)          -155 F
```

Where the Stress Reduction Ratio per UCS-66(b)(1)(b) is :

```
 Design Pressure/Ambient Rating = 1400.01/2220.00 = 0.631
```

*Note: Using the minimum value from (b)(1)(b) and (b)(1)(c) above
as the calculated nozzle flange MDMT.*

Weld Size Calculations, Description: S3

```
Intermediate Calc. for nozzle/shell Welds   Tmin      0.3735  in.
```

Results Per UW-16.1:

```
                      Required Thickness    Actual Thickness
Nozzle Weld          0.2500 = Min per Code 0.2651 = 0.7 * Wo in.
```

NOTE : Skipping the nozzle attachment weld strength calculations.
Per UW-15(b)(2) the nozzles exempted by UG-36(c)(3)(a)
(small nozzles) do not require a weld strength check.

Maximum Allowable Pressure for this Nozzle at this Location:

```
Converged Max. Allow. Pressure in Operating case     1439.495  psig
```

Note: The MAWP of this junction was limited by the parent Shell/Head.

The Drop for this Nozzle is : 0.0834 in.
The Cut Length for this Nozzle is, Drop + Ho + H + T : 8.5834 in.

INPUT VALUES, Nozzle Description: T3 & T4 From : 60

Pressure for Reinforcement Calculations	P	150.000	psig
Temperature for Internal Pressure	Temp	650	F
Shell Material		SA-516 70	
Shell Allowable Stress at Temperature	S	18800.00	psi
Shell Allowable Stress At Ambient	Sa	20000.00	psi
Inside Diameter of Cylindrical Shell	D	18.1250	in.
Shell Finished (Minimum) Thickness	t	0.1875	in.
Shell Internal Corrosion Allowance	c	0.0625	in.
Shell External Corrosion Allowance	co	0.0000	in.
Distance from Bottom/Left Tangent		9.7918	ft.
User Entered Minimum Design Metal Temperature		-20.00	F

Type of Element Connected to the Shell : Nozzle

Material		SA-106 B	
Material UNS Number		K03006	
Material Specification/Type		Smls. pipe	
Allowable Stress at Temperature	Sn	17100.00	psi
Allowable Stress At Ambient	Sna	17100.00	psi
Diameter Basis (for tr calc only)		OD	
Layout Angle		90.00	deg
Diameter		1.0000	in.
Size and Thickness Basis		Nominal	
Nominal Thickness	tn	80	
Flange Material		SA-105	
Flange Type		Weld Neck Flange	
Corrosion Allowance	can	0.0625	in.
Joint Efficiency of Shell Seam at Nozzle	E1	1.00	
Joint Efficiency of Nozzle Neck	En	1.00	
Outside Projection	ho	6.0000	in.
Weld leg size between Nozzle and Pad/Shell	Wo	0.1875	in.
Groove weld depth between Nozzle and Vessel	Wgnv	0.1875	in.
Inside Projection	h	0.0000	in.
Weld leg size, Inside Element to Shell	Wi	0.0000	in.
ASME Code Weld Type per UW-16		None	
Class of attached Flange		300	
Grade of attached Flange		GR 1.1	

The Pressure Design option was Design Pressure + static head.

Nozzle Sketch (may not represent actual weld type/configuration)

```
             |  |
             |  |
```

```
             |  |
             |  |
 ___________/|  |
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|___________\|__|
```

Insert Nozzle No Pad, no Inside projection

Reinforcement CALCULATION, Description: T3 & T4

ASME Code, Section VIII, Division 1, 2010, 2011a, UG-37 to UG-45

```
Actual Outside Diameter Used in Calculation            1.315  in.
Actual Thickness Used in Calculation                   0.179  in.
```

Nozzle input data check completed without errors.

Reqd thk per UG-37(a)of Cylindrical Shell, Tr [Int. Press]

```
 = (P*R)/(S*E-0.6*P) per UG-27 (c)(1)
 = (150.00*9.1250)/(18800*1.00-0.6*150.00)
 = 0.0732 in.
```

Reqd thk per UG-37(a)of Nozzle Wall, Trn [Int. Press]

```
 = (P*Ro)/(S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (150.00*0.6575)/(17100*1.00+0.4*150.00)
 = 0.0057 in.
```

UG-40, Limits of Reinforcement : [Internal Pressure]

```
Parallel to Vessel Wall (Diameter Limit)            Dl     2.1640  in.
Parallel to Vessel Wall, opening length              d     1.0820  in.
Normal to Vessel Wall (Thickness Limit), no pad   Tlnp     0.2913  in.
```

Note:

Taking a UG-36(c)(3)(a) exemption for nozzle: T3 & T4.
This calculation is valid for nozzles that meet all the requirements of paragraph UG-36. Please check the Code carefully, especially for nozzles that are not isolated or do not meet Code spacing requirements. To force the computation of areas for small nozzles go to Tools->Configuration and check the box to force the UG-37 area or App 1-10 computation.

UG-45 Minimum Nozzle Neck Thickness Requirement: [Int. Press.]

```
Wall Thickness for Internal/External pressures       ta = 0.0682 in.
Wall Thickness per UG16(b),                       tr16b = 0.1250 in.
Wall Thickness, shell/head, internal pressure      trb1 = 0.1357 in.
Wall Thickness                tb1 = max(trb1, tr16b) = 0.1357 in.
Wall Thickness                tb2 = max(trb2, tr16b) = 0.1250 in.
Wall Thickness per table UG-45                      tb3 = 0.1785 in.
```

Determine Nozzle Thickness candidate [tb]:

```
 = min[ tb3, max( tb1,tb2) ]
 = min[ 0.178 , max( 0.136 , 0.125 ) ]
 = 0.1357 in.
```

Minimum Wall Thickness of Nozzle Necks [tUG-45]:

```
 = max( ta, tb )
```

```
 = max( 0.0682 , 0.1357 )
 = 0.1357 in.
```

Available Nozzle Neck Thickness = 0.875 * 0.179 = 0.157 in. --> OK

Nozzle Junction Minimum Design Metal Temperature (MDMT) Calculations:

MDMT of the Nozzle Neck to Flange Weld,   Curve: B

Govrn. thk, tg = 0.157 , tr = 0.006 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.061 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                       -20 F
Min Metal Temp. at Required thickness (UCS 66.1)           -155 F
```

MDMT of Nozzle-Shell/Head Weld for the Nozzle (UCS-66(a)1(b)), Curve: B

Govrn. thk, tg = 0.157 , tr = 0.006 , c = 0.0625 in. , E* = 1.00
Stress Ratio = tr * (E*)/(tg - c) = 0.061 , Temp. Reduction = 140 F

```
Min Metal Temp. w/o impact per UCS-66                       -20 F
Min Metal Temp. at Required thickness (UCS 66.1)           -155 F

Governing MDMT of all the sub-joints of this Junction  :  -155 F
```

ANSI Flange MDMT including Temperature reduction per UCS-66.1:

```
Unadjusted MDMT of ANSI B16.5/47 flanges per UCS-66(c)      -20 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(b)        -155 F
Flange MDMT with Temp reduction per UCS-66(b)(1)(c)        -155 F
```

Where the Stress Reduction Ratio per UCS-66(b)(1)(b) is :
 Design Pressure/Ambient Rating = 150.00/740.00 = 0.203

Note: Using the minimum value from (b)(1)(b) and (b)(1)(c) above
    as the calculated nozzle flange MDMT.

Weld Size Calculations, Description: T3 & T4

```
Intermediate Calc. for nozzle/shell Welds   Tmin      0.1165  in.
```

Results Per UW-16.1:

```
                      Required Thickness    Actual Thickness
Nozzle Weld          0.0816 = 0.7 * tmin.  0.1326 = 0.7 * Wo in.
```

NOTE : Skipping the nozzle attachment weld strength calculations.
    Per UW-15(b)(2) the nozzles exempted by UG-36(c)(3)(a)
    (small nozzles) do not require a weld strength check.

Maximum Allowable Pressure for this Nozzle at this Location:

```
Converged Max. Allow. Pressure in Operating case      192.729  psig
```

The Drop for this Nozzle is : 0.0239 in.
The Cut Length for this Nozzle is, Drop + Ho + H + T : 6.2114 in.

Nozzle Schedule:

Description	Nominal Size in.	Flange Sch/Type Cls		Noz. O/Dia in.	Wall Thk in.	Re-Pad ODia in.	Re-Pad Thick in.	Cut Length in.
T3 & T4	1.000	80	WNF	1.315	0.179	-	-	6.21
S3	2.000	XXS	WNF	2.375	0.436	-	-	8.58
S2	3.000	XXS	WNF	3.500	0.600	8.00	0.625	8.68
T1/T2	4.000	40	WNF	4.500	0.237	-	-	8.80
S1	6.000	XXS	WNF	6.625	0.864	10.12	0.625	9.17

General Notes for the above table:

The Cut Length is the Outside Projection + Inside Projection + Drop +
In Plane Shell Thickness. This value does not include weld gaps,
nor does it account for shrinkage.

In the case of Oblique Nozzles, the Outside Diameter must
be increased. The Re-Pad WIDTH around the nozzle is calculated as follows:
Width of Pad = (Pad Outside Dia. (per above) - Nozzle Outside Dia.)/2

For hub nozzles, the thickness and diameter shown are those of the smaller
and thinner section.

Nozzle Material and Weld Fillet Leg Size Details:

Nozzle	Material	Shl Grve Weld in.	Noz Shl/Pad Weld in.	Pad OD Weld in.	Pad Grve Weld in.	Inside Weld in.
T3 & T4	SA-106 B	0.188	0.188	-	-	-
S3	SA-106 B	0.750	0.375	-	-	-
S2	SA-106 B	0.750	0.375	0.500	0.625	-
T1/T2	SA-106 B	0.188	0.250	-	-	-
S1	SA-106 B	0.750	0.375	0.500	0.625	-

Note: The Outside projections below do not include the flange thickness.

Nozzle Miscellaneous Data:

Nozzle	Elevation/Distance From Datum ft.	Layout Angle deg.	Projection Outside in.	Projection Inside in.	Installed In Component
T3 & T4	9.792	90.00	6.00	0.00	Channel
S3	1.719	90.00	7.75	0.00	Shell
S2	1.719	270.00	7.75	0.00	Shell
T1/T2	0.443	110.57	7.34	0.00	Left Channel
S1	8.509	270.00	7.75	0.00	Shell

Nozzle Calculation Summary:

Description	MAWP psig	Ext	MAPNC psig	UG45 [tr]	Weld Path	Areas or Stresses
T1/T2	254.78	...	...	OK 0.136	OK	Passed
T1/T2	162.64	...	...	OK 0.136	OK	Passed
S2	1439.48	OK	...	OK 0.251	OK	Passed
S1	1439.48	OK	...	OK 0.325	OK	Passed
S3	1439.48	...	...	OK 0.197	OK	NoCalc[*]
T3 & T4	192.73	...	...	OK 0.136	OK	NoCalc[*]

Min. - Nozzles   162.64 T1/T2

[*] - This was a small opening and the areas were not computed or
the MAWP of this connection could not be computed because
the longitudinal bending stress was greater than the hoop stress.

Note: MAWPs (Internal Case) shown above are at the High Point.

Check the Spatial Relationship between the Nozzles

From Node	Nozzle Description	X Coordinate,	Layout Angle,	Dia. Limit
20	T1/T2	5.320	110.570	8.302
40	S2	18.623	270.000	4.875
40	S1	100.103	270.000	10.044
40	S3	18.623	90.000	3.750
60	T3 & T4	117.502	90.000	2.164

The nozzle spacing is computed by the following:

= Sqrt($ll^2 + lc^2$) where
ll - Arc length along the inside vessel surface in the long. direction.
lc - Arc length along the inside vessel surface in the circ. direction

If any interferences/violations are found, they will be noted below.
No interference violations have been detected !

Minimum Design Metal Temperature Results Summary :

Description	Notes	Curve	Basic MDMT F	Reduced MDMT F	UG-20(f) MDMT F	Thickness ratio	Gov Thk in.	E*
Channel Flang	[11]	B	-20	-43	-20	0.775	0.188	1.000
Channel Flang	[11]	B	-20	-43	-20	0.775	0.188	1.000
Left Head	[10]	B	-20	-50	-20	0.699	0.168	1.000
Left Head	[7]	B	-20	-55	-20	0.597	0.188	1.000
Left Channel	[8]	B	-20	-55	-20	0.597	0.188	1.000
Shell	[8]	B	16	10	-20	0.941	0.750	1.000
Channel	[8]	B	-20	-55	-20	0.597	0.188	1.000
Right Head	[10]	B	-20	-50	-20	0.699	0.168	1.000
Right Head	[7]	B	-20	-55	-20	0.597	0.188	1.000
T1/T2	[1]	B	-20	-55		0.550	0.188	1.000
Nozzle Flg	[4]		-20	-155		0.136		
S2	[1]	B	6	-20	-20	0.910	0.625	1.000
Nozzle Flg	[4]		-20	-155		0.300		
S1	[1]	B	6	-20	-20	0.910	0.625	1.000
Nozzle Flg	[4]		-20	-55		0.379		
S3	[1]	B	-20	-155		0.295	0.382	1.000
Nozzle Flg	[4]		-20	-155		0.295		
T3 & T4	[1]	B	-20	-155		0.061	0.157	1.000
Nozzle Flg	[4]		-20	-155		0.061		

Required Minimum Design Metal Temperature -20 F
Warmest Computed Minimum Design Metal Temperature -20 F

Notes:
[!] - This was an impact tested material.
[1] - Governing Nozzle Weld.
[4] - ANSI Flange MDMT Calcs; Thickness ratio per UCS-66(b)(1)(c).
[5] - ANSI Flange MDMT Calcs; Thickness ratio per UCS-66(b)(1)(b).
[6] - MDMT Calculations at the Shell/Head Joint.
[7] - MDMT Calculations for the Straight Flange.
[8] - Cylinder/Cone/Flange Junction MDMT.
[9] - Calculations in the Spherical Portion of the Head.
[10] - Calculations in the Knuckle Portion of the Head.
[11] - Calculated (Body Flange) Flange MDMT.
[12] - Calculated Flat Head MDMT per UCS-66(3)

UG-84(b)(2) was not considered.
UCS-66(g) was not considered.
UCS-66(i) was not considered.

Notes:
Impact test temps were not entered in and not considered in the analysis.
UCS-66(i) applies to impact tested materials not by specification and
UCS-66(g) applies to materials impact tested per UG-84.1 General Note (c).
The Basic MDMT includes the (30F) PWHT credit if applicable.

Input Echo, Tubesheet Number 1, Description: Tubesheet

Shell Data:

Main Shell Description: Shell

Shell Design Pressure	Ps	1400.00	psig
Shell Thickness	ts	0.7500	in.
Shell Corrosion Allowance	cas	0.0625	in.
Inside Diameter of Shell	Ds	17.000	in.
Shell Circumferential Joint Efficiency	Esw	1.000	
Shell Temperature for Internal Pressure	Ts	650.00	F
Shell Material		SA-516 70	

*Note: Using 2 * Yield for Discontinuity Stress Allowable (UG-23(e)), Sps.*
Make sure that material properties at this temperature are not
time-dependent for Material: SA-516 70

Shell Material UNS Number		K02700	
Shell Allowable Stress at Temperature	Ss	18800.00	psi
Shell Allowable Stress at Ambient		20000.00	psi

Channel Description: Left Channel

Channel Type:		Cylinder	
Channel Design Pressure	Pt	150.00	psig
Channel Thickness	tc	0.1875	in.
Channel Corrosion Allowance	cac	0.0625	in.
Inside Diameter of Channel	Dc	18.125	in.
Channel Design Temperature	TEMPC	650.00	F
Channel Material		SA-516 70	

*Note: Using 2 * Yield for Discontinuity Stress Allowable (UG-23(e)), Sps.*
Make sure that material properties at this temperature are not
time-dependent for Material: SA-516 70

Channel Material UNS Number		K02700	
Channel Allowable Stress at Temperature	Sc	18800.00	psi
Channel Allowable Stress at Ambient		20000.00	psi

Tube Data:

Number of Tube Holes	Nt	104	
Tube Wall Thickness	et	0.1090	in.
Tube Outside Diameter	D	1.0000	in.
Total Straight Tube Length	Lt	96.00	in.
Straight Tube Length (bet. inner tubsht faces)	L	92.00	in.
Design Temperature of the Tubes		650.00	F
Tube Material		SA-178 C	
Tube Material UNS Number		K03503	
Is this a Welded Tube		No	
Tube Material Specification used		Wld. tube	
Tube Allowable Stress at Temperature		14600.00	psi
Tube Allowable Stress At Ambient		14600.00	psi
Tube Yield Stress At design Temperature	Syt	27400.00	psi
Tube Pitch (Center to Center Spacing)	P	1.2500	in.
Tube Layout Pattern		Triangular	

Fillet Weld Leg	af	0.0000	in.
Groove Weld Leg	ag	0.1090	in.

```
Tube-Tubesheet Joint Weld Type                            Full Strength
Method for Tube-Tubesheet Jt. Allow.                         UW-20
Tube-Tubesheet Joint Classification                             b-1

Radius to Outermost Tube Hole Center           ro       8.005  in.
Largest Center-to-Center Tube Distance         Ul      1.7500  in.
Length of Expanded Portion of Tube            ltx      0.0000  in.
Tube-side pass partition groove depth          hg      0.0000  in.
```

Tubesheet Data:

Tubesheet TYPE: Fixed Tubesheet Exchanger, Conf B

```
Tubesheet Design Metal Temperature              T      650.00  F
Tubesheet Material Specification              SA-516 70
```

*Note: Using 2 * Yield for Discontinuity Stress Allowable (UG-23(e)), Sps.*
Make sure that material properties at this temperature are not
time-dependent for Material: SA-516 70

```
Tubesheet Material UNS Number                              K02700
Tubesheet Allowable Stress at Temperature       S    18800.00  psi
Tubesheet Allowable Stress at Ambient          Tt    20000.00  psi
Thickness of Tubesheet                          h      2.0000  in.
Tubesheet Corr. Allowance (Shell side)       Cats      0.0625  in.
Tubesheet Corr. Allowance (Channel side)     Catc      0.0625  in.
Tubesheet Outside Diameter                      A      23.500  in.
Area of the Untubed Lanes                      AL      31.718  in²
```

Additional Data for Fixed/Floating Tubesheet Exchangers:

```
Unsupported Tube Span under consideration       l      15.500  in.
Tube End condition corresponding to Span (l)    k        1.00
Tubesheet Metal Temp. at Rim                   T'      500.00  F
Shell Metal Temp. at Tubesheet                T'S      571.00  F
Channel Metal Temp. at Tubesheet              T'C      429.00  F
Perform Differential Pressure Design                        N
Run Multiple Load Cases                                   YES
Shell Side Vacuum Pressure                  Pexts     15.0000  psig

Mean Shell Metal Temp. along Shell len.       Tsm      572.59  F
Mean Tube Metal Temp. along Tube length       Ttm      475.00  F

Expansion Joint Type                        Thick Flanged/Flued type
User Exp. Joint Spring Rate  (Corroded)      Kjc  2149840.00  lb./in.
User Exp. Joint Spring Rate  (Uncorroded)   Kjnc  2149840.00  lb./in.
Expansion Joint Inside Diameter                Dj      17.000  in.
Outside Diameter of Expansion Joint          RODE      31.000  in.
Expansion Joint Corrosion Allowance           Caj      0.0625  in.
Junction Stress Reduction option           Perform Plastic Calculation
```

Additional Data for Gasketed Tubesheets:

```
Tubesheet Gasket on which Side                           Channel
Flange Outside Diameter                         A      23.500  in.
Flange Inside Diameter                          B      18.125  in.
Flange Face Outside Diameter                  Fod      19.750  in.
Flange Face Inside Diameter                   Fid      18.125  in.
Gasket Outside Diameter                        Go      19.125  in.
```

Gasket Inside Diameter	Gi	18.125	in.
Small end Hub thk.	g0	0.1875	in.
Large end Hub thk.	g1	0.5625	in.
Gasket Factor,	m	2.50	
Gasket Design Seating Stress	y	2900.00	psi
Flange Facing Sketch	Code Sketch 1a		
Column for Gasket Seating	Code Column II		
Gasket Thickness	tg	0.1250	in.
Full face Gasket Flange Option	Program Selects		
Length of Partition Gasket	lp	18.125	in.
Width of Partition Gasket	wp	0.3130	in.
Partition Gasket Factor,	mPart	2.5000	
Partition Gasket Design Seating Stress	yPart	2900.00	psi
Partition Gasket Facing Sketch	Code Sketch 1a		
Partition Gasket Column for Gasket Seating	Code Column II		

Bolting Information:

Diameter of Bolt Circle	C	21.750	in.
Nominal Bolt Diameter	dB	0.6250	in.
Type of Thread Series	UNC Thread Series		
Number of Bolts	n	16	
Bolt Material		SA-193 B7	
Bolt Allowable Stress At Temperature	Sb	25000.00	psi
Bolt Allowable Stress At Ambient	Sa	25000.00	psi
Weld between Flange and Shell/Channel		0.0000	in.

Tubesheet Integral with		Shell	
Tubesheet Extended as Flange		Yes	
Thickness of Extended Portion of Tubesheet	Tf	2.0000	in.
Is Bolt Load Transferred to the Tubesheet		Yes	

Is Exchanger in Creep range (skip EP, Use 3S for Sps) NO

ASME TubeSheet Results per Part UHX, 2010, 2011a

Elasticity/Expansion Material Properties:

Shell - TE-1 Carbon & Low Alloy Steels, Group 1
Shell - TM-1 Carbon Steels with C<= 0.3%

Th. Exp. Coeff. Metal Temp. along Len	572.6 F	0.0000073452	/F
Elastic Mod. at Design Temperature	650.0 F	0.26000E+08	psi
Th. Exp. Coeff. Metal Temp. at Tubsht	571.0 F	0.0000073420	/F
Elastic Mod. at Metal Temp. along Len	572.6 F	0.26719E+08	psi
Elastic Mod. at Ambient Temperature	70.0 F	0.29400E+08	psi

Channel - TE-1 Carbon & Low Alloy Steels, Group 1
Channel - TM-1 Carbon Steels with C<= 0.3%

Th. Exp. Coeff. Metal Temp. at Tubsht	429.0 F	0.0000071580	/F
Elastic Mod. at Design Temperature	650.0 F	0.26000E+08	psi
Elastic Mod. at Ambient Temperature	70.0 F	0.29400E+08	psi

Tubes - TE-1 Carbon & Low Alloy Steels, Group 1
Tubes - TM-1 Carbon Steels with C<= 0.3%

```
Th. Exp. Coeff. Metal Temp. along Len   475.0 F  0.0000072500 /F
Elastic Mod. at Design Temperature      650.0 F   0.26000E+08 psi
Elastic Mod. at Metal Temp. along Len   475.0 F   0.27450E+08 psi
Elastic Mod. at Tubsht. Design Temp.    650.0 F   0.26000E+08 psi
Elastic Mod. at Ambient Temperature      70.0 F   0.29400E+08 psi
```

TubeSheet - TE-1 Carbon & Low Alloy Steels, Group 1
TubeSheet - TM-1 Carbon Steels with C<= 0.3%

```
-----------------------------------------------------------------
Th. Exp. Coeff. Metal Temp. at Rim      500.0 F  0.0000073000 /F
Elastic Mod. at Design Temperature      650.0 F   0.26000E+08 psi
Elastic Mod. at Metal Temp. at Rim      500.0 F   0.27300E+08 psi
Elastic Mod. at Ambient Temperature      70.0 F   0.29400E+08 psi
```

Note:
The Elasticity and Alpha values are taken from Tables in ASME II D.
Please insure these properties are consistent with the
type of Material for the tubes, shell, channel etc.

Tube Required Thickness under Internal Pressure (Tubeside pressure) :

Thickness Due to Internal Pressure:

```
 = (P*(D/2-CAE)) / (S*E+0.4*P) per Appendix 1-1 (a)(1)
 = (165.00*(1.0000/2-0.000)/(14600.00*1.00+0.4*165.00)
 = 0.0056 + 0.0000 = 0.0056 in.
```

Tube Required Thickness under External Pressure (Shellside pressure) :

```
External Pressure Chart     CS-2             at        650.00  F
Elastic Modulus for Material                        25125000.00  psi
```

Results for Max. Allowable External Pressure (Emawp):

```
    TCA        ODCA      SLEN       D/T       L/D    Factor A        B
  0.1090       1.00     92.00      9.17   50.0000   0.0130691      13399.55
EMAWP = (2.167/(D/T)-0.0833)*B = 2048.8315 psig
```

Results for Reqd Thickness for Ext. Pressure (Tca):

```
    TCA        ODCA      SLEN       D/T       L/D    Factor A        B
  0.0843       1.00     92.00     11.86   50.0000   0.0078218      12453.27
EMAWP = (4*B)/(3*(D/T)) = ( 4 *12453.2715 )/( 3 *11.8589 ) = 1400.1616 psig
```

Summary of Tube Required Thickness Results:

```
Total Required Thickness including Corrosion all.           0.0843  in.
Allowable Internal Pressure at Corroded thickness         3486.85  psig
Required Internal Design Pressure                          165.00  psig
Allowable External Pressure at Corroded thickness         2048.83  psig
Required External Design Pressure                         1400.00  psig
Required Thickness due to Shell Side pressure               0.0843  in.
```

Detailed Results for load Case 3 un-corr. (Ps + Pt - Th)

Intermediate Calculations For Tubesheets Extended As Flanges:

ASME Code, Section VIII, Div. 1, 2010, 2011a

```
Gasket Contact Width,       N = (Goc-Gic) / 2             0.500  in.
Basic Gasket Width,        b0 = N / 2.0                   0.250  in.
Effective Gasket Width,     b = b0                        0.250  in.
Gasket Reaction Diameter,   G = (Go+Gi) / 2.0            18.625  in.
```

ASME Maximum Circumferential Spacing between Bolts per App. 2 eq. (3) [Bsmax]:

```
 = 2a + 6t/(m + 0.5)
 = 2 * 0.625 + 6 * 2.000 /(2.50 + 0.5)
 = 5.250 in.
```

Actual Circumferential Bolt Spacing [Bs]:

```
 = C * sin( pi / n ) )
 = 21.750 * sin( 3.142 / 16 )
 = 4.243 in.
```

ASME Moment Multiplier for Bolt Spacing per App. 2 eq. (7) [Bsc]:

```
 = max( sqrt( Bs/( 2a + t )), 1 )
 = max( sqrt( 4.243 /( 2 * 0.625 + 2.000 )), 1 )
 = 1.1426
```

Bolting Information for UNC Thread Series (Non Mandatory):

```
Distance Across Corners for Nuts                           1.175  in.
Circular Wrench End Diameter                         a     1.750  in.
```

	Minimum	Actual	Maximum
Bolt Area, in^2	2.159	3.232	
Radial distance bet. hub and bolts	0.750	1.625	
Radial distance bet. bolts and the edge	0.750	0.875	
Circumferential spacing between bolts	1.500	4.243	5.250

```
Flange Design Bolt Load, Seating Condition    W  :    67382.77  lb.
Flange Design Bolt Load, Operating Condition  Wm1:    53965.54  lb.
```

Results for ASME Fixed Tubesheet Calculations for Configuration b,

Results for Tubesheet Calculations Original Thickness :

UHX-13.5.1 Step 1:

Compute the Tube Expansion Depth Ratio [rho]:

```
 = ltx / h  ( modified for corrosion if present )
 = 0.0000 / 2.0000 = 0.0000 ( must be 0 <= rho <= 1 )
```

Compute the Effective Tube Hole Diameter [d*]:

```
 = Max( dt - 2tt*( Et/E )( St/S )( rho ), dt - 2tt)
 = Max( 1.0000 -2*0.1090 *(26000000 /26000000 )*
   ( 14600 /18800 )*(0.000 ), 1.0000 -2*0.1090 )
 = 1.0000 in.
```

Compute the Equivalent Outer Tube Limit Circle Diameter [Do]:

```
 = 2 * ro + dt = 2 * 8.005 + 1.000 = 17.010 in.
```

Determine the Basic Ligament Efficiency for Shear [mu]:
```
 = (p - dt)/p = (1.2500 - 1.0000 )/1.2500 = 0.2000
```

Compute the Equivalent Outer Tube Limit Radius [ao]:
```
 = Do / 2 = 17.0100 / 2 = 8.5050 in.
```

Compute the Effective Tube Pitch [p*]:
```
 = p / sqrt( 1 - 4 * min( AL * CNV_factor, 4*Do*p)/(Pi * Do^2) )
 = 1.2500 / sqrt( 1 - 4 * min( 31.72 *1.000 , 4*17.010 *1.250 )
   / ( 3.141 * 17.010^2) )
 = 1.3476 in.
```

Compute the Effective Ligament Efficiency for Bending [mu*]:
```
 = (p* - d*) / p* = (1.3476 - 1.0000 ) / 1.3476 = 0.2579
```

Compute the Ratio [Rhos]:
```
 = as / ao = 8.5000 / 8.5050 = 0.999412
```

Compute the Ratio [Rhoc]:
```
 = ac / ao = 9.3125 / 8.5050 = 1.094944
```

Compute Parameter [xt]:
```
 = 1 - Nt * (( dt - 2 * tt )/( 2 * ao ))^(2)
 = 1 - 104 * ((1.0000 - 2 * 0.1090 )/(2 * 8.5050 ))^(2) = 0.7802
```

Determine Parameter [xs]:
```
 = 1 - Nt*( dt/(2*ao) )^(2)
 = 1 - 104 *( 1.0000 /(2*8.5050 ) )^(2) = 0.6406
```

Determine the Value [h'g]:
```
 = Max(( hg - CATC ), 0 )  (For pressure only cases)
 = Max(( 0.000 - 0.000 ), 0 ) = 0.000 in.
```

UHX-13.5.2 Step 2:

Determine the Axial Shell Stiffness [Ks]:
```
 = pi * ts( Ds + ts )Es/L
 = 3.1416 * 0.7500 ( 17.0000 + 0.7500 )26000000 /92.000
 = 11819389.0000 psi * in.
```

Determine the Axial Tube Stiffness [Kt]:
```
 = pi * tt( Dt - tt )Et/L
 = 3.1416 * 0.1090 ( 1.0000 - 0.1090 )26000000 /92.000
 = 86226.2734 psi * in.
```

Compute the Stiffness Factor [Kst]:
```
 = Ks / ( Nt * Kt ) = 11819389 / ( 104 * 86226.273 ) = 1.31802
```

Compute Factor [J]:
```
 = 1 / ( 1 + Ks/Kj )
 = 1/(1 + 11819389 /2149840 ) = 0.1538983 (= 1 if No Exp. Jt.)
```

Compute Shell Coefficient [betas]:
```
 = (( 12 * (1-nus^2))^(0.25) )/((Ds + ts) * ts )^(0.5)
 = (( 12 * (1 - 0.30^2) )^(0.25) ) / (( 17.0000 + 0.7500 ) * 0.7500 )^(0.5)
 = 0.4982 1/in.
```

Determine Shell Coefficient [ks]:
```
 = betas * Es * ts³ / ( 6 * (1 - nus²) )
 = 0.498 * 26000000 * 0.750 ^(3) / ( 6 * (1 - 0.300²) )
 = 1000899.1875 psig*in.²
```

Determine Shell Coefficient [Lambdas]:
```
 = (6*Ds*ks)/(h³) * (1 + h*betas + 0.5*(h*betas)²)
 = 6*17.000 *1000899 /(2.000³) * ( 1 + 2.000 *0.498 + 0.496 )
 = 31813154.0000 psig
```

Determine Shell Coefficient [deltaS]:
```
 = Ds^(2)/(4 * Es * Ts) * ( 1 - nus/2 )
 = 17.000 ^(2)/( 4 * 26000000 * 0.750 ) * ( 1 - 0.3 /2 )
 = 0.0000031494 in./psi
```

Intermediate parameters for Tubesheet Gasketed on the Channel Side:
betac, kc, deltaC, Lambdac = 0

UHX-13.5.3 Step 3:

E*/E and nu* for Triangular pattern from Fig. UHX-11.3.
```
  h/p =   1.600000 ;  mu* =   0.257927
 E*/E =   0.240335 ;  nu* =   0.371831 ;  E* = 6248720. psi
```

Compute the Tube Bundle Stiffness Factor [Xa]:
```
 = ((24 *(1 - nu*^(2))*Nt * Et* tt* (dt - tt)* ao²) /
   ( E* * L * H^(3) ) )^(0.25)
 = ((24 *(1 - 0.372 ^(2))*104 *26000000 *0.1090 *
   (1.0000 - 0.1090 )*8.5050 ^(2))/( 6248720 *
   92.00 * 2.000 ^(3) ))^(0.25)
 = 3.0401
```

Values from Table UHX-13.1
```
 Zd =       0.052796 ;  Zv =       0.103117 ;  Zm =       0.491601
 Za =   0.226483E+01 ;  Zw =       0.103117
```

UHX-13.5.4 Step 4:

Compute the Diameter Ratio [K]:
```
 = A / Do = 23.5000 / 17.0100 = 1.3815
```

Compute Coefficient [F]:
```
 = (1 - nu*) / (E*) * ( Lambdas + Lambdac + E * ln(K) )
 = (1 - 0.37 ) / (6248720 ) * ( 31813154 + 0.00 +
   26000000 * ln(1.38 ) )
 = 4.0429
```

Compute Parameter [Phi]:
```
 = (1 + nu*) * F = (1 + 0.3718 ) * 4.0429 = 5.5461
```

Compute Parameter [Q1]:
```
 = (Rhos - 1 - Phi * Zv)/(1 + Phi * Zm)
 = (0.9994 - 1 - 5.5461 *0.1031 )/(1 + 5.5461 *0.4916 )
 = -0.153626248
```

Compute Parameter [Qz1]:
```
 = (Zd + Q1*Zw)/2 *Xa^(4)
```

```
 = (0.05280 + -0.15363 *0.10312 )/2 *3.04015 ^(4) = 1.5784
```

Compute Parameter [Qz2]:

```
 = (Zv + Q1*Zm)/2 *Xa^(4)
 = (0.10312 + -0.15363 *0.49160 )/2 *3.04015 ^(4) = 1.1786
```

Compute Parameter [U]:

```
 = (Zw + (Rhos - 1)*Zm)*Xa^(4) / (1 + Phi*Zm)
 = (0.1031 + (0.9994 - 1)*0.4916 )*3.04015 ^(4)/ (1 + 5.5461 *0.4916 )
 = 2.3572
```

UHX-13.5.5 Step 5:

Determine factor [gamab]:

```
 = ( Gc - C ) / Do (config b)
 = (18.6250 - 21.7500 ) / 17.0100 = -0.18372
```

Compute Parameter [gamma]:

```
 = 0.000 in. (For Pressure only cases)
```

Calculate Parameter [OmegaS]:

```
 = rhos * ks * Betas * deltaS( 1 + h * Betas )
 = 0.9994 * 1000899 * 0.4982 * 0.000003 ( 1 + 2.0000 * 0.4982 )
 = 3.1336 in.²
```

Calculate Parameter [Omega*S]:

```
 = Ao² * ( Rhos² - 1 ) * ( Rhos - 1 ) / 4 - OmegaS
 = 8.505² * ( 0.999² - 1 ) * ( 0.999 - 1 ) / 4 - 3.134
 = -3.1336 in.²
```

Calculate Parameter [OmegaC]:

```
 = rhoc * kc * Betac * deltaC( 1 + h * Betac )
 = 1.0949 * 0.00 * 0.0000 * 0.000000 ( 1 + 2.0000 * 0.0000 )
 = 0.0000 in.²
```

Calculate Parameter [Omega*C]:

```
 = ao²[( Rhoc²+1 )*( Rhoc-1 )/4 -(Rhos-1)/2]- OmegaC
 = 8.50500²[( 1.09494²+1 )*( 1.09494 -1 )/4 -(0.99941 -1)/2]- 0.00000
 = 3.7967 in.²
```

Compute the Pressure [P*S]:
 = 0 For Pressure only cases or Configurations d,e,f,A,B,C,D

Compute the Pressure [P*C]:
 = 0 For Pressure only cases or Configurations b,c,d,B,C,D

UHX-13.5.6 Step 6:

Compute the Pressure [P's]:

```
 = Ps * {xs + 2( 1 - xs )nut + [2/Kst(Ds/Do)²]nus -
   [(rhos²-1)/(J*Kst)]-[(1-J)/(2J*Kst)][(Dj²-(Ds)²)/Do²]}
 = 1400.000 * {0.641 + 2( 1 - 0.641 ) 0.300 +
   [2/1.318 (17.000 /17.010 )²]0.300 -
   [(0.999²-1)/( 0.154 * 1.318 )] -
   [(1 - 0.154 )/(2 * 0.154 * 1.318 )][(17.000²-(17.000 )²)/17.010²]}
 = 1843.3975 psig
```

Compute the Pressure [P't]:
```
 = [ xt + 2(1 - xt)nut + 1/(J * Kst) ]*Pt
 = [ 0.780 + 2(1 - 0.780 )0.300 +
   1/(0.15390 * 1.318 ) ]* 150.000
 = 876.3071 psig
```

Compute the Pressure [Pgama]:
```
 = Nt * Kt * gama / ( pi * ao² )
 = 104 * 86226.273 * 0.000 / (3.142 * 8.505²) = 0.000 psig
```

Compute the Pressure [Pw]:
```
 = -gamab * U * W* / (2 * pi * ao²)
 = --0.184 * 2.357 * 53965.54 / (2 * 3.142 * 8.505²)
 = 51.4191 psig
```

Calculate the Pressure [Prim]:
```
 = -( U/ao²)(Omega*S * Ps - Omega*C * Pt )
 = -( 2.357 / 8.505²)(-3.134 * 1400.000 - 3.797 * 150.000 )
 = 161.5167 psig
```

Calculate the Pressure [POmega]:
```
 = U/ao²(OmegaS * P*s - OmegaC * P*c )
 = 2.357 /8.5050²( 3.1336 * 0.0000 - 0.0000 * 0.0000 )
 = 0.0000 psig
```

Determine the Effective Pressure [Pe]:
```
 = J * Kst / (1 + J * Kst *(Qz1 + (Rhos - 1) * Qz2)) *
   (P's - P't + Pgama + Pw + Prim )
 = 0.1539E+00 * 1.318 / (1 + 0.154 * 1.318 *(1.578 + (0.999 -
   1) * 1.179 )) * (1843.397 - 876.307 + 0.000 + 51.419 + 161.517 )
 = 181.3287 psig
```

UHX-13.5.7 Step 7:

Determine Factor [Q2]:
```
 = [((Omega*S*Ps - Omega*C*Pt) - (Omegas*P*s - Omegac P*c))CNV_FAC +
   W* * gamab/(2*pi)]/(1 + Phi*Zm)
 = [( ( -3.134 * 1400.000 - 3.797 * 150.000 ) -
   ( 3.134 * 0.000 - 0.000 * 0.000 )) * 1.000 +
   53965.5 * -0.184 /(2*3.141)]/(1 + 5.54611 * 0.49160 )
 = -1753.511718750 lb.
```

Calculate Factor [Q3]:
```
 = Q1 + 2 * Q2 / ( Pe * ao^(2)
 = -0.154 + 2 * -1753.512 / ( 181.329 * 8.505 ^(2) = -0.421003
```

Fm Value from Table UHX-13.1 = 0.210501

The Tubesheet Bending Stress - Original Thickness [Sigma]:
```
 = (1.5 * Fm / mu* ) * (2 * ao/(H - h'g)^(2) * Pe
 = (1.5 * 0.2105 /0.2579 ) * (2 * 8.5050 /(2.000 - 0.000 ))^(2) * 181.33
 = 16057.0020 psi
```

The Allowable Tubesheet Bending Stress [Sigma allowed]:
```
 = 1.5 * S = 1.5 * 18800.00 = 28200.00 psi
```

The Tubesheet Bending Stress - Final Thickness [Sigmaf]:

```
 = (1.5 * Fm/mu*) * (2 * ao/( h - h'g)² * Pe
 = (1.5 * 0.1440 /0.2579 ) * (2 * 8.5050 /(1.238 - 0.000 ))² * 178.50
 = 28199.3555 psi
```

Reqd Tubesheet Thickness, for Bending Stress (Including CA) [HReqB]:

```
 = h + Cats + Catc = 1.2383 + 0.0000 + 0.0000 = 1.2383 in.
```

UHX-13.5.8 Step 8:

Shear Stress check [Tau_limit]:

```
 = 3.2 * S * MU * h / Do
 = 3.2 * 18800.00 * 0.200 * 2.000 / 17.01 = 1414.70 psig
```

The Tubesheet Average Shear Stress - Original Thickness [Tau]:

```
 = ( 1 / ( 2*mu ) ) * ( ao/h ) * Pe
 = ( 1 / (2*0.200 ) ) * ( 8.5050 /2.000 ) * 181.329
 = 1927.7510 psi
```

The Allowable Tubesheet Shear Stress [Tau allowed]:

```
 = 0.8 * S = 0.8 * 18800.00 = 15040.00 psi
```

```
Note: Tubesheet Shear Stress is probably low, use the following req. thk:
 Tubesheet thickness (Incl. Corr.)= 0.1500 in.
 Tubesheet Shear Stress           = 12768.5088 psi
```

Reqd Tubesheet Thickness for Given Loadings (Including CA) [Hreqd] :

```
 = Max( HreqB, HreqS ) = Max( 1.2383 , 0.1500 ) = 1.2383 in.
```

UHX-13.5.9 Step 9:

The Ftmin and Ftmax Coefficients from Table UHX-13.2:

```
 Ftmin = 0.4008 , Ftmax = 1.2041
```

First Extreme Tube Axial Stress from among all the tubes [Sigmat1]:

```
 = ( (Ps * xs - Pt * xt) - Pe * Ftmin ) / ( Xt - Xs )
 = ( (1400.00 * 0.6406 - 150.00 * 0.7802 ) - (181.329 ) * 0.401 ) /
   (0.7802 - 0.6406 ) )
 = 5063.8682 psi
```

Second Extreme value of Tube Axial Stress from among all the tubes [Sigmat2]:

```
 = ( (Ps * xs - Pt * xt) - Pe * Ftmax ) / ( Xt - Xs )
 = ( (1400.00 * 0.6406 - 150.00 * 0.7802 ) - (181.329 ) * 1.204 ) /
   (0.7802 - 0.6406 ) )
 = 4020.6965 psi
```

Maximum Tube Axial Stress [Sigmat,max]:

```
 = MAX( |Sigmat1|, |Sigmat2| ) = 5063.868 psi
```

The Allowable Tube Stress, [SigmatA]

```
 = Sot = 14600.0000 psi
```

The Largest tube-to-tubesheet Joint Load [Wt]:

```
 = Sigmat,max * Tube Area = 5063.87 * 0.3051 = 1545.03 lb.
```

Tube Weld Size Results per UW-20:

Tube Strength [Ft]:

```
 = 3.1415 * t * ( do - t ) * Sa
 = 3.1415 * 0.109 * ( 1.000 - 0.109 ) * 14600.00 = 4454.582 lb.
```

Fillet Weld Strength, Ff = 0.0

Groove Weld Strength [Fg]:

```
 = .85 * 3.1415 * ag * (do + 0.67*ag) * Sw (but not > Ft)
 = .85 * 3.1415 * 0.109 * (1.000 + 0.67*0.109 ) * 14600.00
 = 4454.5815  lb.
```

```
Max. Allow. Tube-Tubesheet Joint load, Lmax
 = Ft = 4454.5815 lb.
```

Design Strength Ratio [fd]:

```
 = 1.0000
```

Weld Strength Factor [fw]:

```
 = Sot / ( Min(Sot, S) ) = 1.0000
```

Min Weld Length [ar]:

```
 = ( (0.75 * do)² + 1.76*t*(do - t)* fw * fd ) )½ - .75 * do
 = 0.1064  in.
```

```
Minimum Required Groove Weld Leg             agr      0.1090  in.

Tube-Tubesheet Jt allowable, 4454.58 is >= tube strength 4454.58 lb.
```

Note: This tube-tubesheet joint is a Full Strength joint

UHX-13.5.10 Step 10:

Shell Axial Membrane Allowable Stress:

```
 = Ss * Esw = 18800.00 * 1.00 = 18800.00 psi
```

Axial Membrane Stress in Shell [Sigmasm_ax]:

```
 = ao²/((Ds+ts)*ts)* [Pe + (Rhos²-1)(Ps-Pt)]+ as²*Pt/((Ds+ts)*ts)
 = 8.505²/((17.000 +0.7500 )*0.7500 )* [181.33 + (0.999²-1)
   (1400.00 -150.00 )] + 8.500²*150.00 /((17.00 +0.7500 )
   * 0.75 )
 = 1791.3718 psi
```

UHX-13.5.11 Step 11:

Note: For a given Shell thickness of: 0.750 in.
Min. Shell len. adjacent to the tubesheet should be: 6.427 in.

The Shell Membrane Stress due to Joint Interaction [Sigmasm]:

```
 = ao²/((Ds+ts)*ts)[Pe + (Rhos²-1)(Ps-Pt)]+ as²*Pt/((Ds+ts)*ts)
 = 8.505²/((17.000 +0.7500 )*0.7500 )[181.33 + (0.999²-1)
   (1400.00 -150.00 )] + 8.500²*150.00 /((17.00 +0.7500 )
   * 0.75 )
 = 1791.3718 psi
```

The Shell Bending Stress due to Joint Interaction [Sigmasb]

```
 = 6*ks/ts² {betas[deltaS*Ps + as²*PstarS/(Es*ts)] +
   6(1 - nu*²)/(E*)(ao/h)³(1 + h*betas/2)[Pe(Zv + Zm*Q1) +
   2/ao² * Zm * Q2 ]}
```

```
 = 6 * 1000899 /0.7500² {0.498 [ 0.000 * 1400.000 + 8.5000²
   * 0.0000 /(19500000 ) ] +
   6(1 - 0.37²)/(6248720 )(8.51 /2.00 )³(1 + 2.00 *
   0.50 /2)[ 181.3 ( 0.103 + 0.492 * -0.154 ) +
   2/8.51² * 0.492 * -1753.512 ] }
 = 4286.6968 psi
```

Shell Stress Summation vs. Allowable

```
 |Sigmasm| + |Sigmasb| =< 1.5 * Ss
 |1791.4 | + |4286.7 | =< 28200.00 psi
 6078.07 must be < or = 28200.00 psi
```

Computations Completed for ASME Tubesheet Configuration b

Stress/Force summary for loadcase 3 un-corr. (Ps + Pt - Th):

Stress Description	Actual		Allowable	Pass/Fail
Tubesheet Bend. Stress	16057.0	<=	28200.0 psi	Ok
Tubesheet Shear Stress	1927.8	<=	15040.0 psi	Ok
Maximum Tube Stress	5063.9	<=	14600.0 psi	Ok
Maximum Force on any one Tube	1545.0	<=	4454.6 lb.	Ok
Axial Membrane Stress in Shell	1791.4	<=	18800.0 psi	Ok
Shell Stress (jt. inter.)	6078.1	<=	28200.0 psi	Ok

Thickness results for loadcase 3 un-corr. (Ps + Pt - Th):

Thickness (in.)	Required	Actual	P/F
Tubesheet Thickness :	1.2383	2.0000	Ok
Tube-Tubesheet Groove Weld Leg :	0.1090	0.1090	Ok

Fixed Tubesheet results per ASME UHX-13 2010, 2011a

Results for 16 Load Cases:

	--Reqd. Thk. + CA		-------- Tubesheet	Stresses			Case	Pass/
Case#	Tbsht	Extnsn	Bend	Allwd	Shear	Allwd	Type	Fail
1uc	0.376	0.733	4332	28200	1352	15040	Fvs+Pt-Th	Ok
2uc	1.332	...	16709	28200	3245	15040	Ps+Fvt-Th	Ok
3uc	1.238	...	16057	28200	1928	15040	Ps+Pt-Th	Ok
4uc	0.644	...	11814	56400	4353	15040	Fvs+Fvt+Th	Ok
5uc	0.789	...	15457	56400	5754	15040	Fvs+Pt+Th	Ok
6uc	0.174	...	10320	56400	1073	15040	Ps+Fvt+Th	Ok
7uc	0.340	...	11915	56400	2474	15040	Ps+Pt+Th	Ok
8uc	0.299	...	2539	28200	49	15040	Fvs+Fvt-Th	Ok
1c	0.473	0.733	4661	28200	1397	15040	Fvs+Pt-Th-Ca	Ok
2c	1.433	...	17802	28200	3344	15040	Ps+Fvt-Th-Ca	Ok
3c	1.393	...	17637	28200	1983	15040	Ps+Pt-Th-Ca	Ok
4c	0.732	...	11831	56400	4499	15040	Fvs+Fvt+Th-Ca	Ok
5c	0.868	...	15463	56400	5967	15040	Fvs+Pt+Th-Ca	Ok
6c	0.288	...	11659	56400	1119	15040	Ps+Fvt+Th-Ca	Ok
7c	0.443	...	13189	56400	2587	15040	Ps+Pt+Th-Ca	Ok

8c	0.333	...	3111	28200	72	15040	Fvs+Fvt-Th-Ca	Ok
Max:	1.4330	0.733 in.		0.631		0.397	(Str. Ratio)	

Load Case Definitions:
Fvs,Fvt - User-defined Shell-side and Tube-side vacuum pressures or 0.0.
Ps, Pt - Shell-side and Tube-side Design Pressures.
(+-)Th - With or Without Thermal Expansion.
Ca - With or Without Corrosion Allowance.

Shell Axial Membrane Stress Summary:

	----- Shell Stresses ------				----- Shell Band Stress ---				Pass
Case#	Ten	Allwd	Cmp	Allwd	Ten	Allwd	Cmp	Allwd	Fail
1uc	124	18800	...	...	...	...	...	...	Ok
2uc	1650	18800	...	...	...	...	...	...	Ok
3uc	1791	18800	...	...	...	...	...	...	Ok
4uc	2224	56400	-2224	-12932	...	...	...	...	Ok
5uc	2126	56400	-2126	-12932	...	...	...	...	Ok
6uc	557	56400	-557	-12932	...	...	...	...	Ok
7uc	458	56400	-458	-12932	...	...	...	...	Ok
8uc	25	18800	...	...	...	...	...	...	Ok
1c	157	18800	...	...	...	...	...	...	Ok
2c	1854	18800	...	...	...	...	...	...	Ok
3c	2031	18800	...	...	...	...	...	...	Ok
4c	2345	56400	-2345	-12784	...	...	...	...	Ok
5c	2223	56400	-2223	-12784	...	...	...	...	Ok
6c	471	56400	-471	-12784	...	...	...	...	Ok
7c	349	56400	-349	-12784	...	...	...	...	Ok
8c	36	18800	...	...	...	...	...	...	Ok
Max RATIO		0.108		0.183		...		...	

Tube, Shell and Channel Stress Summary:

	--------- Tube Stresses				Tube Loads		Shell Stress		Channel Stress		Pass
Case#	Ten	Allwd	Cmp	Allwd	Ld	Allwd	Stress	Allwd	Stress	Allwd	Fail
1uc	1096	14600	-1096	-11255	334	4454	11745	28200	...	...	Ok
2uc	5213	14600	...	...	1590	4454	17388	28200	...	...	Ok
3uc	5064	14600	...	...	1545	4454	6078	28200	...	...	Ok
4uc	5261	29200	-14	-11255	1605	4454	18338	56400	...	...	Ok
5uc	6046	29200	-764	-11255	1845	4454	24055	56400	...	...	Ok
6uc	9303	29200	...	...	2838	4454	763	56400	...	...	Ok
7uc	10088	29200	...	...	3078	4454	6480	56400	...	...	Ok
8uc	345	14600	-345	-11255	105	4454	5830	28200	...	...	Ok
1c	1232	14600	-1232	-11255	376	4454	13347	28200	...	...	Ok
2c	5416	14600	...	...	1652	4454	19998	28200	...	...	Ok
3c	5197	14600	...	...	1586	4454	7180	28200	...	...	Ok
4c	5476	29200	-358	-11255	1671	4454	21008	56400	...	...	Ok
5c	6338	29200	-1212	-11255	1934	4454	27410	56400	...	...	Ok
6c	9529	29200	...	...	2907	4454	795	56400	...	...	Ok
7c	10391	29200	...	...	3170	4454	7197	56400	...	...	Ok
8c	378	14600	-378	-11255	115	4454	6703	28200	...	...	Ok
Max RATIO		0.371		0.109		0.712		0.709		...	

Summary of Thickness Comparisons for 16 Load Cases:

Thickness (in.)	Required	Actual	P/F
Tubesheet Thickness :	1.4330	2.0000	Ok
Tubesheet Thickness Flanged Extension :	0.7328	2.0000	Ok
Tube Thickness :	0.0843	0.1090	Ok
Tube-Tubesheet Groove Weld Leg :	0.1090	0.1090	Ok

Min Shell length of thk,   (0.750) adj. to tubesheet: 6.427 in.

Note: This is a full strength Tube to Tubesheet Joint.

Summary of Axial Differential Expansion bet. Shell and Tubes :

Due to Thermal Expansion   Exp. Jt. Compresses by : -0.070 in.
Due to Pressure   Exp. Jt. Extends by   : +0.0302 in.
Due to Pressure + Thermal Exp. Jt. Compresses by : -0.070 in.

Tubesheet MAWP used to Compute Hydrotest Pressure:

Stress / Force Condition	Tubeside (0 shellside) MAWP	Stress Rat.	Shellside (0 tubeside) MAWP	Stress Rat.
Tubesheet Bending Stress	910.98	1.000	2215.76	1.000
Tubesheet Shear Stress	1115.96	1.000	6296.51	1.000
Tube Tensile Stress	1846.01	1.000	3773.98	1.000
Tube Compressive Stress	1115.96	0.683	----	----
Tube-Tubesheet Joint load	1354.01	1.000	3173.88	1.000
Shell Stress (Axial, Junc)	605.83	1.000	2048.82	0.519
Tube Pressure Stress	3486.84	1.000	2048.82	1.000
Tubesheet Extension Stress	224.58	0.000	----	----
Minimum MAWP	224.58		2048.82	

Tubesheet MAPnc used to Compute Hydrotest Pressure:

Stress / Force Condition	Tubeside (0 shellside) MAPnc	Stress Rat.	Shellside (0 tubeside) MAPnc	Stress Rat.
Tubesheet Bending Stress	1036.92	1.000	2633.09	1.000
Tubesheet Shear Stress	1792.75	1.000	7478.11	1.000
Tube Tensile Stress	2013.14	1.000	3896.03	1.000
Tube Compressive Stress	2111.44	1.000	----	----
Tube-Tubesheet Joint load	2013.14	1.000	3896.03	1.000
Shell Stress (Axial, Junc)	916.20	0.999	2633.09	0.411
Tube Pressure Stress	3486.84	1.000	2721.66	1.000
Tubesheet Extension Stress	224.58	0.000	----	----
Minimum MAPnc	224.58		2633.09	

Design Code: ASME Code Section VIII Division 1, 2010, 2011a

Diameter Spec : 18.500 in. OD		
Vessel Design Length, Tangent to Tangent	10.10	ft.
Specified Datum Line Distance	0.00	ft.
Shell Material Specification	SA-516 70	
Nozzle Material Specification	SA-106 B	
Re-Pad Material Specification	SA-516 70	
Shell Side Design Temperature	650	F
Channel Side Design Temperature	650	F
Shell Side Design Pressure	1400.000	psig
Channel Side Design Pressure	150.000	psig
Shell Side Hydrostatic Test Pressure	1820.000	psig
Channel Side Hydrostatic Test Pressure	195.000	psig
Required Minimum Design Metal Temperature	-20	F
Warmest Computed Minimum Design Metal Temperature	-20	F
Wind Design Code	No Wind Loads	
Earthquake Design Code	No Seismic	

Element Pressures and MAWP: psig

Element Desc	Design Pres. + Stat. head	External Pressure	M.A.W.P	Corrosion Allowance
Left Head	150.658	0.000	217.957	0.0625
Left Channel	150.657	0.000	254.778	0.0625
Channel Flange	150.000	0.000	161.970	0.0625
Shell	1400.627	15.000	1439.484	0.0625
Channel Flange	150.000	0.000	161.970	0.0625
Channel	150.657	0.000	254.778	0.0625
Right Head	150.658	0.000	217.957	0.0625

Liquid Level: 1.51 ft. Dens.: 62.400 lb./ft^3 Sp. Gr.: 1.000

Element Type	"To" Elev ft.	Length ft.	Element Thk in.	Reqd Thk Int.	Reqd Thk Ext.	Joint Eff Long	Joint Eff Circ
Ellipse	0.08	0.083	0.188	0.135	0.125	1.00	1.00
Cylinder	0.81	0.729	0.188	0.136	No Calc	1.00	1.00
Body Flg	1.05	0.240	1.750	1.684	1.664	1.00	1.00
Cylinder	8.89	7.667	0.750	0.732	0.186	1.00	1.00
Body Flg	9.29	0.240	1.750	1.684	1.664	1.00	1.00
Cylinder	10.02	0.729	0.188	0.136	No Calc	1.00	1.00
Ellipse	10.10	0.083	0.188	0.135	0.125	1.00	1.00

Element thicknesses are shown as Nominal if specified, otherwise are Minimum

Saddle Parameters:

Saddle Width	4.000	in.
Saddle Bearing Angle	120.000	deg.

Centerline Dimension	25.000	in.
Wear Pad Width	5.000	in.
Wear Pad Thickness	0.250	in.
Wear Pad Bearing Angle	132.000	deg.
Distance from Saddle to Tangent	6.625	in.
Baseplate Length	16.400	in.
Baseplate Thickness	0.250	in.
Baseplate Width	4.000	in.
Number of Ribs (including outside ribs)	2	
Rib Thickness	0.250	in.
Web Thickness	0.250	in.
Height of Center Web	24.000	in.

Summary of Maximum Saddle Loads, Operating Case :

Maximum Vertical Saddle Load	2018.29	lb.
Maximum Transverse Saddle Shear Load	0.00	lb.
Maximum Longitudinal Saddle Shear Load	0.00	lb.

Summary of Maximum Saddle Loads, Hydrotest Case :

Maximum Vertical Saddle Load	2095.50	lb.
Maximum Transverse Saddle Shear Load	0.00	lb.
Maximum Longitudinal Saddle Shear Load	0.00	lb.

Weights:

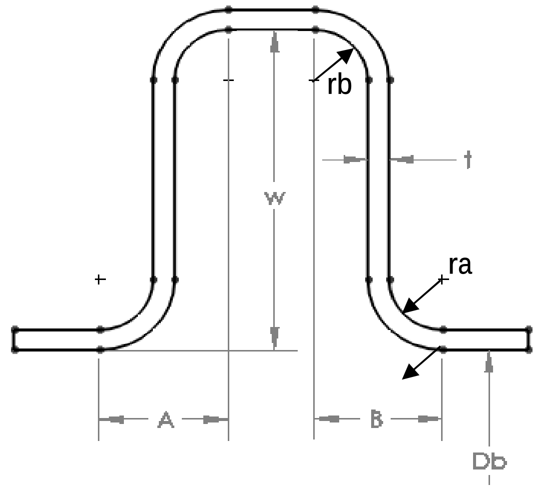
Fabricated	- Bare W/O Removable Internals	3004.7	lbm
Shop Test	- Fabricated + Water (Full)	3953.0	lbm
Shipping	- Fab. + Rem. Intls.+ Shipping App.	3004.7	lbm
Erected	- Fab. + Rem. Intls.+ Insul. (etc)	3004.7	lbm
Empty	- Fab. + Intls. + Details + Wghts.	3004.7	lbm
Operating	- Empty + Operating Liquid (No CA)	3899.0	lbm
Field Test	- Empty Weight + Water (Full)	3953.0	lbm

VIII-1-Flanged and Flued EJ ver 4.01

EJMA 1998, A2000 and ASME VIII-1 App 5 and App 26

Shell Expansion Joint (Corroded State) **Description**

Materials and Conditions:



SA-299 B **Bellows** material

26,000,000 **Eb** [psi] - bellows modulus

22,900 **Sab** [psi] - allowed stress - bellows

3.00 **Cm** - material factor (1.5 Ann, 3 - cf)

1400.0 **P** [psi] - operating pressure

Dimensions:

17.000 **Db** - inside diameter of bellows

6.500 **w** - convolution height

10.500 **q** - Convolution Pitch (A+B)

0.750 **t** - bellows thickness

2.250 **ra** - outside bellows radius

2.250 **rb** - inside bellows radius

Motion:

0.070 **xc** - axial compression - inch

0.000 **xe** - axial extension - inch

Constants: (per EJMA A-2, Cp, Cd, and Cf come from Fig C-24)

e = xc+xe 0.07+0 = **0.070**

Dm = Db+w+t 17+6.5+0.75 = **24.250**

Kr = 2*(q+xe)/(2*q) 2*(10.5+0)/(2*10.5) = **1.000**

fv = q/(2.2*sqrt(Dm*t)) 10.5/(2.2*SQRT(24.25*0.75)) = **1.119**

fh = q/(2*w) 10.5/(2*6.5) = **0.808**

Cp = PVELookup("CpTable","Int2DLin",fh,fv) **0.505**

Cf = PVELookup("CfTable","Int2DLin",fh,fv) **1.205**

Cd = PVELookup("CdTable","Int2DLin",fh,fv) **2.424**

Checkr = Min(ra,rb) >= (3*t) MIN(2.25,2.25) >= (3*0.75) = **Acceptable**

Pressure and Deflection Stresses: (per EJMA A-2 Same as ASME VIII-1 App26-6 except Nc and Fi)

S2 [psi] = (P*Dm/(2*t))*(Kr/(0.571+2*w/q)) Circ. Stress from pressure (C-22)

(1400*24.25/(2*0.75))*(1/(0.571+2*6.5/10.5)) = **12,511**

S3 [psi] = (P*w)/(2*t) Meridional membrane from pressure (C-23)

(1400*6.5)/(2*0.75) = **6,067**

S4 [psi] = (P/2)*(w/t)^2*Cp Meridional bending from pressure (C-24)

(1400/2)*(6.5/0.75)^2*0.505 = **26,541**

S5 [psi] = (Eb*t^2*e)/(2*w^3*Cf) Meridional membrane from deflection (C-25)

(26000000*0.75^2*0.07)/(2*6.5^3*1.205) = **1,547**

S6 [psi] = (5*Eb*t*e)/(3*w^2*Cd) Meridional bending from deflection (C-26)

(5*26000000*0.75*0.07)/(3*6.5^2*2.424) = **22,215**

St [psi] = 0.7*(S3+S4)+(S5+S6) Combined total stress

0.7*(6067+26541)+(1547+22215) = **46,587**

Nc = IF(St>54000,(1860000/(St-54000))^3.4,100000000) EJMA predicted cycle life (C-27)

IF(46587>54000,(1860000/(46587-54000))^3.4,100000000) = **100,000,000**

Fi [lb/in] = 1.7*(Dm*Eb*t^3)/(w^3*Cf) Bellows axial spring rate (lb/in) (C-29)

1.7*(24.25*26000000*0.75^3)/(6.5^3*1.205) = **1,366,173**

Stress Evaluation:

CheckS2a = S2 <= Sab EJMA C-24 12511 <= 22900 = **Acceptable**

CheckS3S4 = S3 + S4 <= Cm*Sab EJMA C-24 6067 + 26541 <= 3*22900 = **Acceptable**

CheckS2b = S2 <= 1.5*Sab ASME Appendix 5-3(b) 12511 <= 1.5*22900 = **Acceptable**

CheckS3 = S3 <= 1.5*Sab ASME Appendix 5-3(b) 6067 <= 1.5*22900 = **Acceptable**

CheckS4 = S4 <= 1.5*Sab ASME Appendix 5-3(b) 26541 <= 1.5*22900 = **Acceptable**

CheckS4S5 = S4 + S5 <= 3*Sab ASME Appendix 5-3(b) 26541 + 1547 <= 3*22900 = **Acceptable**

CheckNc = Nc >= 100 ASME Appendix 5-3(b) 100000000 >= 100 = **Acceptable**