Mech-4200
Weld Neck Flange design
Spring 2021

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Professor Duva,

Enclosed is our report regarding the “Weld Neck Flange” with specifications for group 9. The report documents the selection process of the assembly's gasket and bolting based on API standards as well as the FEA tests necessary to prove that the proposed assembly meets the design requirements [1]. The design process began with preliminary research into standards related to the project. The material researched included the API specs sheet for type 6A flanges which provided us with the gasket size and bolt count of our size flange [1]. These parts were the basis of our CAD models that which would undergo FEA testing of the preload, rated and proof pressure to ensure that neither part failure nor leakage would occur.

In retrospect, the homework assignments leading up to the completion of this report contained inaccuracies caused by misinformed assumptions. Our team had originally assumed that the flange components would be made of plain Carbon Steel as is recommended by WoodCo, however we now understand that for this underwater application, 347 Annealed Steel is required to prevent damage to the assembly and have corrected our documents and drawings for this report [3]. We were also unsure whether the coefficient of static friction of which the bolt torque is dependent on until we were informed that the bolts would be well lubricated to which API assigns a coefficient of .13 [1]. Through corrections of our prior false assumptions our team has ensured the design to be optimal and accurately reflects the recommendations of API [1].

The FEA tests of the preload, rated and proof pressures indicate that only the gasket will yield and there is no evidence of leakage. You will find the details of these tests, as well our discoveries relating to important stress concentrations and reaction forces in the following report.

We look forward to your review of the report.

Sincerely,
Nicolas Deguglielmo,

Weld Neck Flange

Simulation Based Design Final Project

Professor Anthony Duva– Spring 2021

WENTWORTH
INSTITUTE OF TECHNOLOGY

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Introduction

This case study documents the design process of a 5000 psi rated weld neck flange under American Petroleum Industry (API) guidelines[1]. This flange will be designed to connect a piping system in a petroleum plant and will be submerged in water. The configuration assigned to our team has a size of 2-9/16”. For a weld neck flange of this size and rated pressure, there exists standards regarding proof pressure as well as bolt size, quantity, and preload that the design must adhere to. With the design requirements selected, factor of safety testing must be conducted to ensure that the flange will be capable of withstanding the preload, rated pressure, and proof pressure with negligible risk of failure or oil leakage.

Design Requirements

Codes & Standards

The following API 6A standards were obtained from the ASTM Compass website: [1]

- API 5.1.3: Bodies, Bonnets, and Other End Connectors
- API 7.3: Pressure-containing Fabrication Welds
  - API 7.3.6: Welding Requirements
- API 8: Bolting
  - API 8.2: Closure Bolting for Flanged and Studded End and Outlet Connectors
    - API 8.2.3.2: Exposed Bolting
- API 10.4.5: Ring Gaskets and Nonintegral Metal Seals
  - API 10.4.5.5.2: Test Method and Acceptance Criteria
  - API 10.4.5.6: Surface Finish
- API 11.2: Hydrostatic Testing
- API 14.2: Ring Gaskets
- Annex H: Recommended Assembly of Closure Bolting
- Annex J: Weld-neck Flanges
- Table D.3 – Type 6B Flanges for 34.5 MPa
- Table D.8 – Type R Ring Grooves
- Table D.9 – Type R Ting Gaskets
- Table E.3 – Type 6B Flanges for 5000 psi

Bolts & Preload

The flange assembly consists of a flange and a cap abridged by a ring gasket and fastened together by a collection of bolts. For a 5000 psi flange of size 2-9/16", API recommends 1” diameter bolts for our flange size [1].

Table 1. Bolt Sizes & Flange Size [2]

Nominal Size of Flange [a]	Diameter of Bolt Circle	Number of Bolts	Bolt Size and TPI	Bolt Holes		Hub Length, Threaded Flange			Ring Groove
						Line Pipe Flange	Casing Flange	Tubing Flange	
in.	*BC*	*N*	in.	*BH*		L_L	L_C	L_T	
Tolerance>	See figure for GDT		(Ref.)	Diameter	Tolerance	min.	min.	min.	
$2^1/_{16}$	165.1	8	$^7/_8$-9	26	+2/−0.5	65.0	—	65.0	R 24
$2^9/_{16}$	190.5	8	1-8	29	+2/−0.5	71.4	—	71.4	R 27
$3^1/_8$	203.2	8	$1^1/_8$-8	32	+2/−0.5	81.0	—	81.0	R 35
$4^1/_{16}$	241.3	8	$1^1/_4$-8	35	+2/−0.5	98.6	98.6	98.6	R 39
$5^1/_8$	292.1	8	$1^1/_2$-8	42	+2.5/−0.5	112.8	112.8	—	R 44
$7^1/_{16}$	317.5	12	$1^3/_8$-8	39	+2/−0.5	128.5	128.5	—	R 46
9	393.7	12	$1^5/_8$-8	45	+2.5/−0.5	153.9	153.9	—	R 50
11	482.6	12	$1^7/_8$-8	51	+2.5/−0.5	169.9	169.9	—	R 54

FOOTNOTE

[a] For flange sizes $13^5/_8$ in., $16^3/_4$ in., $18^3/_4$ in., and $21^1/_4$ in., see Table D.7.

Table 1 indicates that a R 27 gasket fits the groove of the API flange of the group's assigned size which has a pitch diameter of 107.95 mm. The dimensions of the gasket can be seen in Figure 1 and Table 2 below.

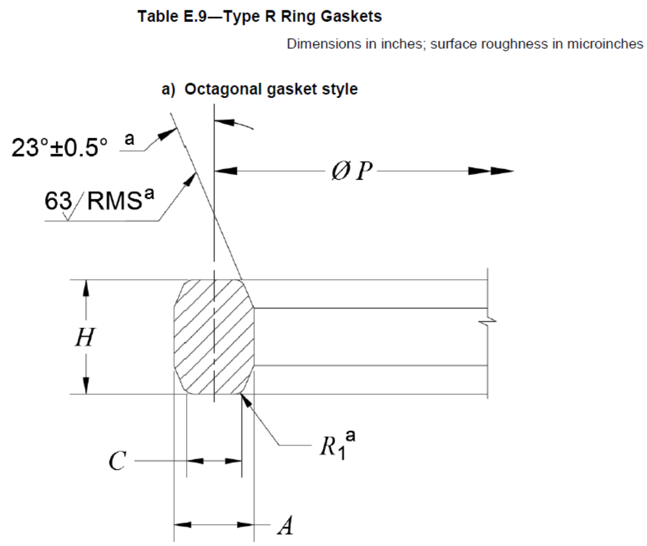

Fig 1. R 27 Gasket Dimensions [1]

Table 2. Gasket Dimensions [2]

Table D.9—Type R Ring Gaskets *(continued)*

Dimensions in millimeters unless noted otherwise

Gasket Number	Pitch Diameter *P*	Width of Ring *A*	Height of Oval Ring *B*	Height of Octagonal Ring *H*	Width of Flat on Octagonal Ring *C*	Radius on Octagonal Ring *R*1	Distance between Flanges *S*
Tolerance>	± 0.18	± 0.20	± 0.5	± 0.5	± 0.20	± 0.5	(Approx.)
R 23	82.55	11.13	17.5	15.9	7.75	1.5	4.8
R 24	95.25	11.13	17.5	15.9	7.75	1.5	4.8
R 26	101.6	11.13	17.5	15.9	7.75	1.5	4.8
R 27	107.95	11.13	17.5	15.9	7.75	1.5	4.8

Using Table 3, and assuming the bolts are to be lubricated, the torque required for the preload is estimated to be 488 N-m.

Table 3. Torques for Flange Bolting [2]

Table H.1—Recommended Torques for Flange Bolting (S

Stud Diameter	Threads per in.	Studs with S_y = 550 MPa Bolt Stress Equal to 275 MPa			Studs with S_y = 720 MPa Bolt Stress Equal to 360 MPa		
		Tension	Torque	Torque	Tension	Torque	Torque
D	N	F	f = 0.07	f = 0.13	F	f = 0.07	f = 0.13
in.	1/in.	kN	N-m	N-m	kN	N-m	N-m
0.500	13	25	36	61	33	48	80
0.625	11	40	70	118	52	92	155
0.750	10	59	122	206	78	160	270
0.875	9	82	193	328	107	253	429
1.000	8	107	288	488	141	376	639

Pre-Processing

Pre-load Only

Knowing the torque and nut factor, the total preload on the assembly was calculated.

T=Torque on Bolt

D=Diameter of Stud

K= Bolt Conditions (Zinc-Plated)

$$T = 0.20 * 31{,}802 * 1 = \boldsymbol{6360.4\ lbf * in}$$

Rated Pressure

The reaction load due to the given rated pressure of 5 KSI can be found by multiplying the pressure by the surface area affected.

P_o = Operational Pressure d=bore diameter F_o= reaction load due to operational pressure

$P_o = 5000\,psi = 7500psi$

$d = 65.8mm = 2.59in$

$$A = \frac{\pi * d^2}{4} = \frac{\pi * 2.59^2}{4} 5.27in^2$$

$$F = AP_o = 5.27in^2 * 5000\ psi = \mathbf{26,363\ lb_f}$$

Proof Pressure

The same surface area used to calculate the reaction due to the rated pressure can be multiplied by the proof pressure to find the reaction due to the maximum pressure that the flange can withstand.

P_p = Proof Pressure d=bore diameter F_P= reaction load due to proof pressure

$P_p = 7.5ksi = 7500psi$

$d = 65.8mm = 2.59in$

$$A = \frac{\pi * d^2}{4} = \frac{\pi * 2.59^2}{4} 5.27in^2$$

$$F_f = A * P_p = 5.27in^2 * 7500psi = \mathbf{39,525lb_f}$$

Analysis

Boundary Conditions

Using the assigned configuration of a 2-9/16" flange and the data collected for the bolts and gasket, the team then performed simulation analysis on the assembly. The welded neck of the flange was fixed, while a 5000 psi pressure force was to be applied to the inside of the (as seen to the right in Figure 2). In addition, a 6360.4 psi preload was applied by each bolt, creating a clamping force on the flange, cap, and gasket. The full assembly and setup can also be seen in Figure 2.

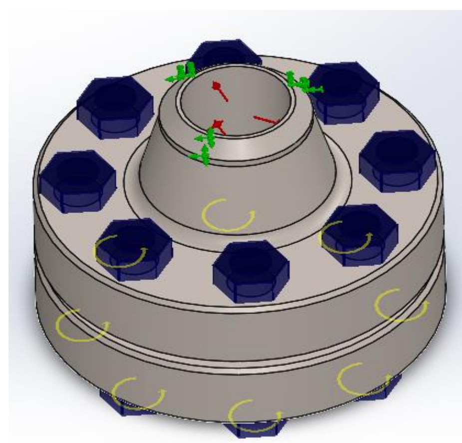

Fig 2. Flange Assembly

A bill of materials used in the assembly can be found in Table 4.

Table 4 Bill of Materials (Ali)

ITEM NO.	PART NUMBER	PRICE	manual explode/QTY.	COST
1	flange		1	
2	gasket (2)		1	
3	cap 1		1	

FEA analysis

Pre-Load

To simulate the preload, bolt connections were used to connect the flange. This was completed by adjusting the Bolt Connectors settings in Solidworks (Figure 3). Using each bolt's known strength and applied torque, a Factor of Safety plot (Figure 4) was created to check that the bolts were installed properly.

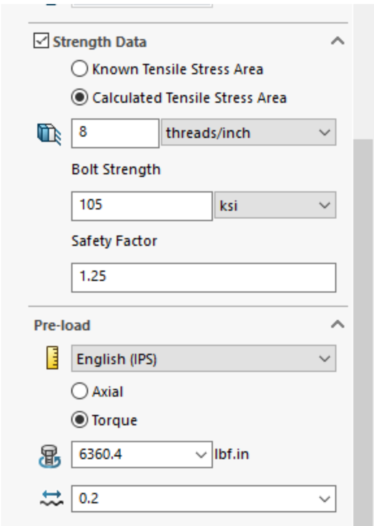

Fig 3. Bolt Connector Settings

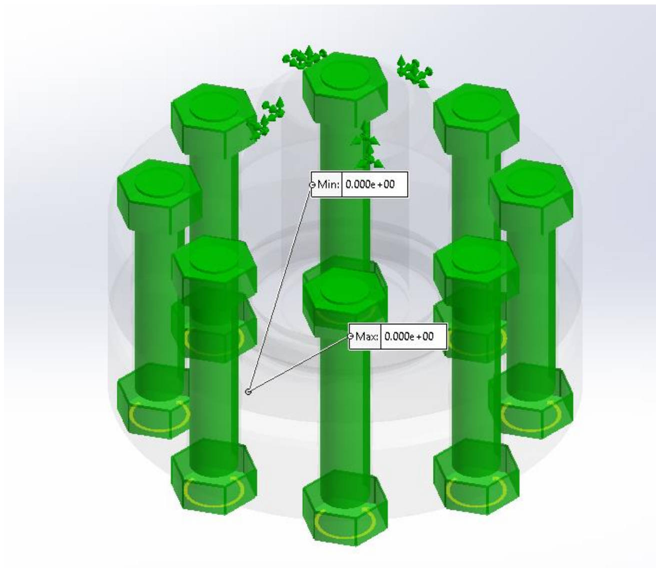

Fig 4. Pin Bolt Check

Table 5 shows the bolt preload (found in the bolt check) through the simulation. Due to how the model was created, this load occurs in the Y direction.

Table 5. Axial Force on Bolt Preload

Type	X-Component	Y-Component	Z-Component	Resultant	Connector
Shear Force (lbf)	-1,420.2	0	588.72	1,537.4	Bolt 1
Axial Force (lbf)	0	-31,803	0	31,803	Bolt 1
Bending moment (lbf.in)	-297.09	0	724.51	783.06	Bolt 1
Shear Force (lbf)	-1,228.5	0	1,087.1	1,640.4	Bolt 2
Axial Force (lbf)	0	-31,802	0	31,802	Bolt 2
Bending moment (lbf.in)	171.43	0	598.05	622.13	Bolt 2

After comparing the results of the simulation to that of the hand calculations, it was found that the percent error was less than 0.1% (as seen in Table 6), validating the simulation setup.

Table 6. Hand Calculations vs. Simulation

Simulated Pre-Load	
Hand calculation:	31,802
Simulated	31,803
% Error	0.003

Figure 5 depicts the Factor of Safety plot for the gasket. Under these conditions, the gasket's factor of safety is below 1, therefore the gasket yields and disforms when the pre-load is applied. In this instance the gasket should yield since it will create a tight seal when pressure forces are applied to the assembly. This is vital for fixtures like this because if there is not a tight seal, the flange would leak and cause catastrophic problems.

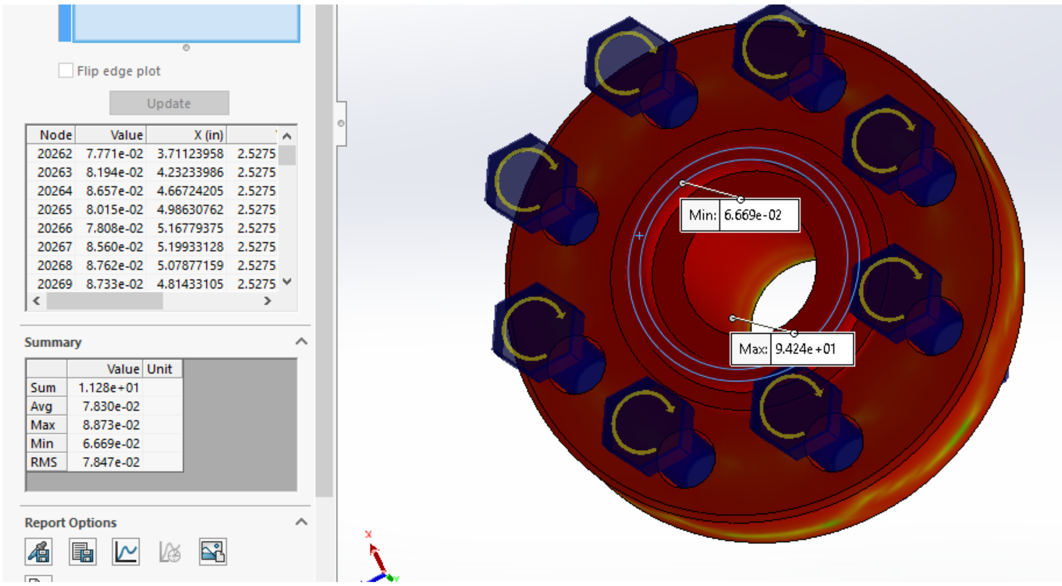

Fig 5. Gasket Factor of Safety Plot

After completing this process, it was determined that the assembly was design properly. Simulations were then created for the rated and proof pressures.

Rated Pressure:

Using the rated pressure (5000 psi) the flange assembly can be seen below in Figure 6. The Von-Mises maximum and minimum stresses can be seen below in the figure.

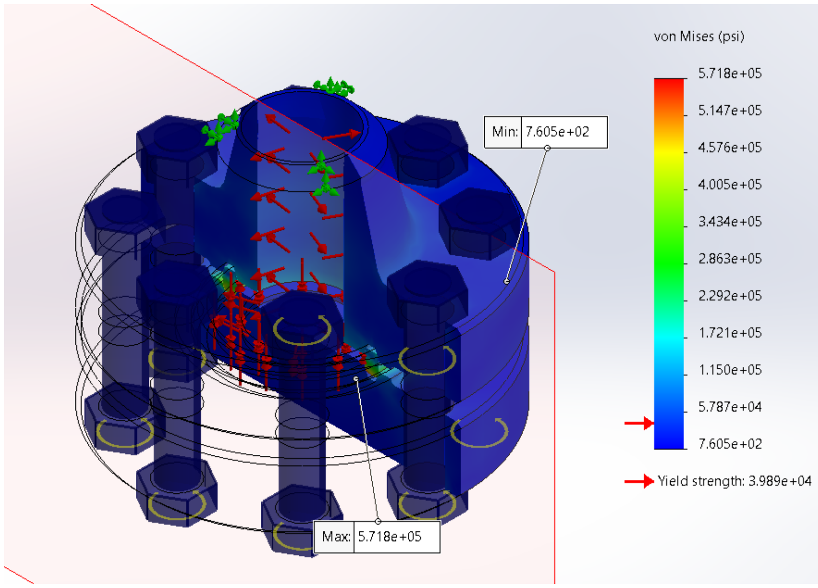

Fig 6. Von Mises Stress of Flange Assembly at Rated Pressure

Since the gasket yields during preloading, it is vital that the assembly can withstand the added pressure forces and not leak. As seen in Tables 7 & 8, the maximum pressure of the top and bottom inner diameter of the gasket exceeds the rated pressure, thus there is no leakage of the system.

Table 7. Forces of Top I.D. of Gasket

	Value	Unit
Sum	1.232e+07	psi
Avg	9.334e+04	psi
Max	2.215e+05	psi
Min	2.297e+04	psi
RMS	9.892e+04	psi

Table 8. Forces of Bottom I.D. of Gasket

	Value	Unit
Sum	6.801e+07	psi
Avg	5.152e+05	psi
Max	5.718e+05	psi
Min	4.781e+05	psi
RMS	5.156e+05	psi

The reaction force (23,300 lb_f) due to the rated pressure can be seen in Figure 7.

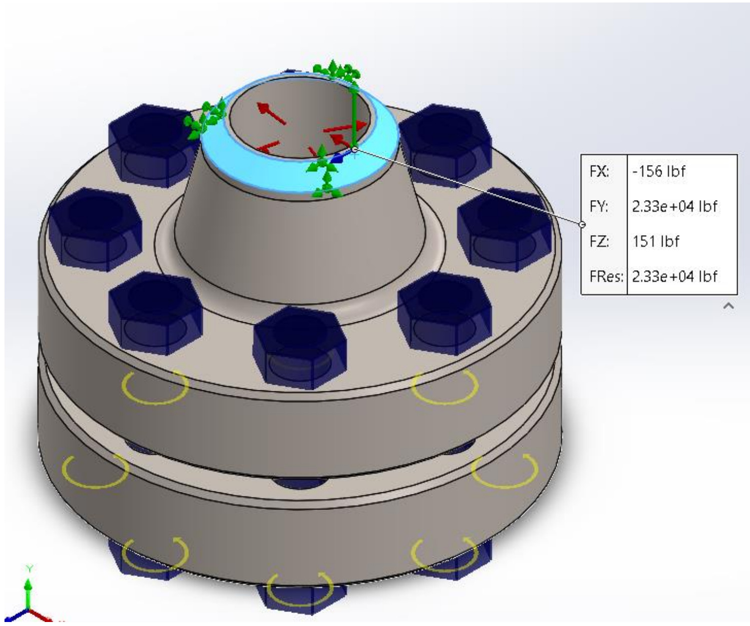

Fig 7. Reaction Force Due to Rated Pressure

Table 9 depicts the hand calculated value for the reaction force (26,363 $_{lbf}$) along with the simulated value (23,300 lb_f). It was found that the percent error of the two was 11.6%. This can be due to updates in the assembly, specifically in the way the bolts were set up.

Table 9 Reaction Forces Due to Rated Pressure

Simulated Pre-Load	
Hand calculation :	26,363 lb_f
Simulated	23,300 lb_f
% Error	11.6%

Proof pressure:

The flange assembly underwent a simulation of the 7500 psi proof pressure.

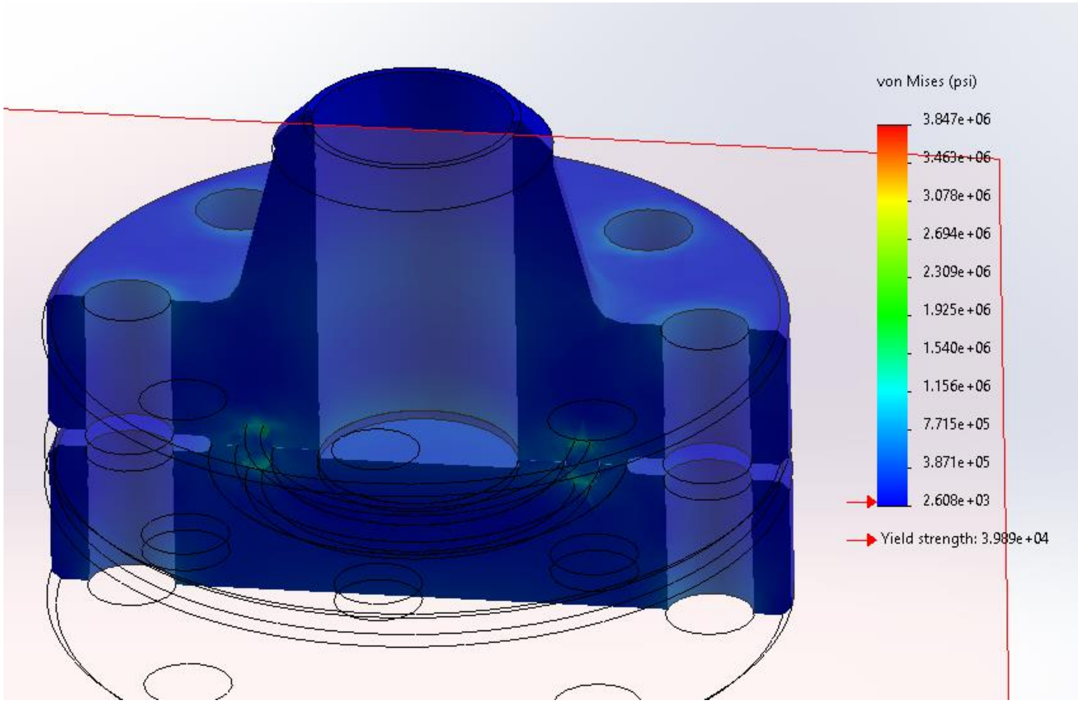

Fig 8. Von Mises stress plot of the flange under proof pressure

To achieve an effective seal, the stress on the contact areas of the gasket must be greater than the pressure inside the flange as to prevent leakage. The top right and bottom right contact points of the gasket were probed to evaluate this criterion.

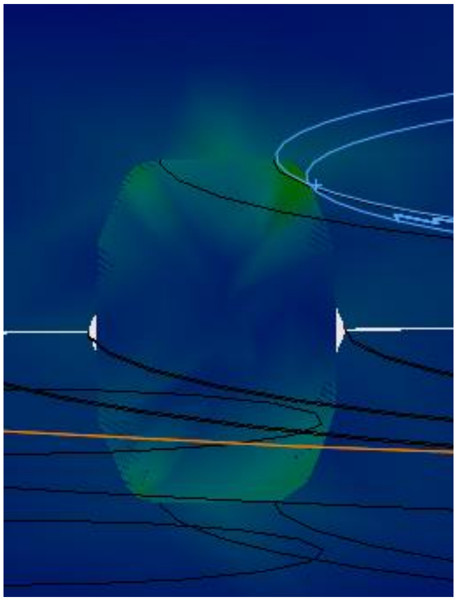

Fig 9. Cross section Von Mises plot of gasket in contact with the flange and cap.

Tables 10 (left) & 11 (right) Stress at the gasket-flange (left) and gasket-cap (right) contact surface due to Proof Pressure.

	Value	Unit
Sum	2.332e+08	psi
Avg	1.766e+06	psi
Max	3.847e+06	psi
Min	8.472e+05	psi
RMS	1.829e+06	psi

	Value	Unit
Sum	2.174e+08	psi
Avg	1.647e+06	psi
Max	3.505e+06	psi
Min	6.556e+05	psi
RMS	1.722e+06	psi

Both minimum stresses exceed the 7500 psi pressure, therefore, the fluid inside will not leak. The reaction force on the edge of the flange's tube was probed for its reaction force to verify our calculations.

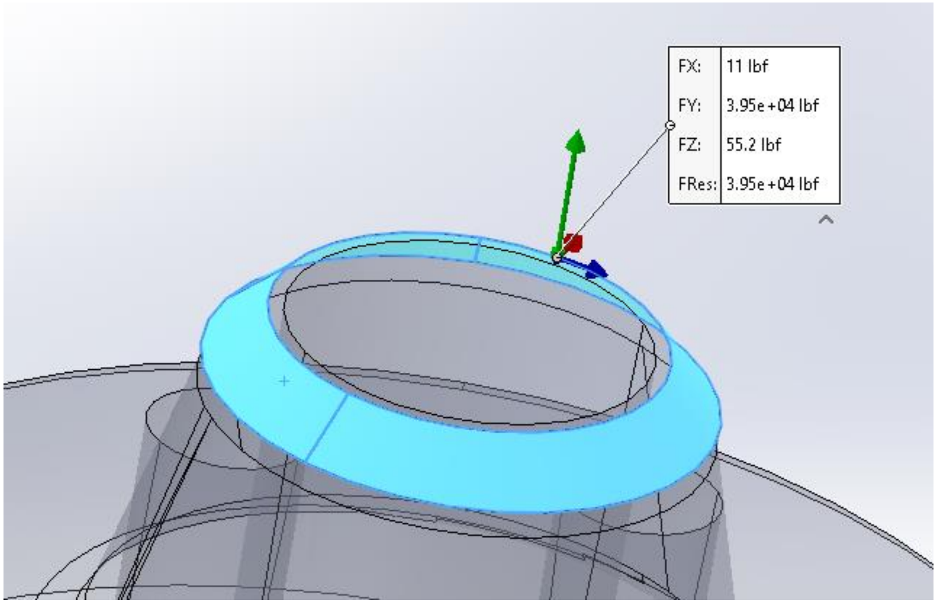

Fig 10. Resultant force probe of the fixed edge of the flange tube.

Drawings

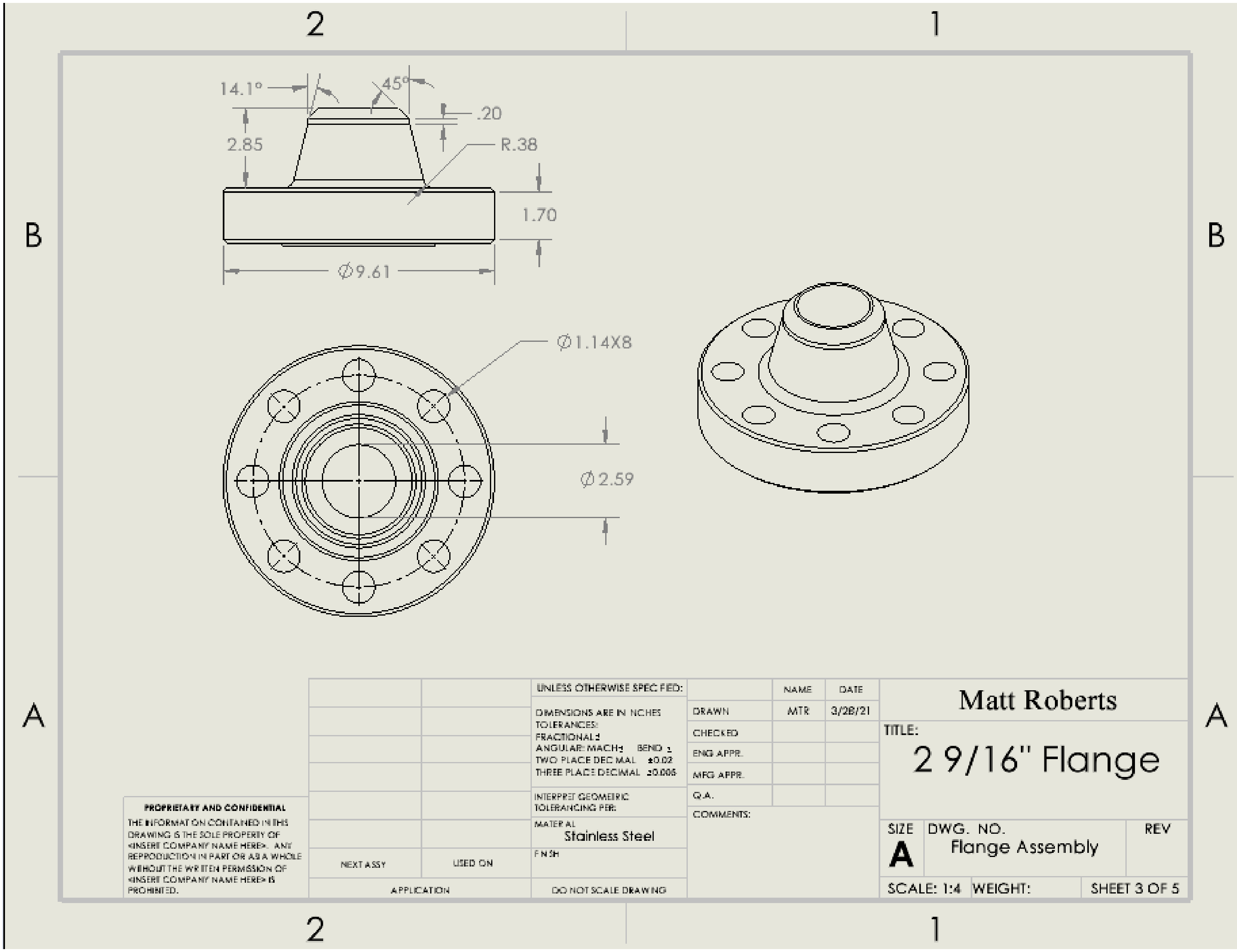

Fig 11. Flange Drawing

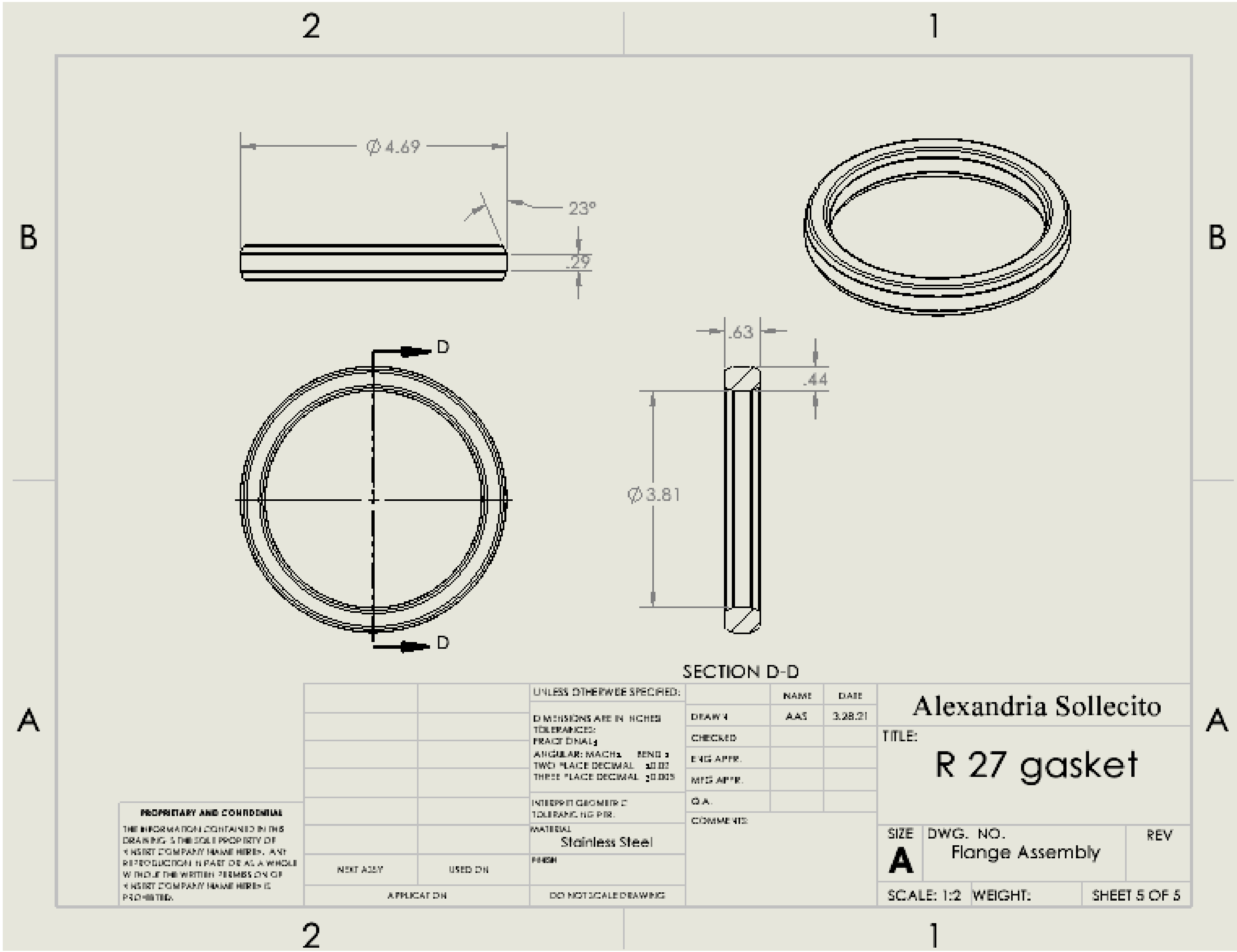

Fig 12. Gasket Drawing

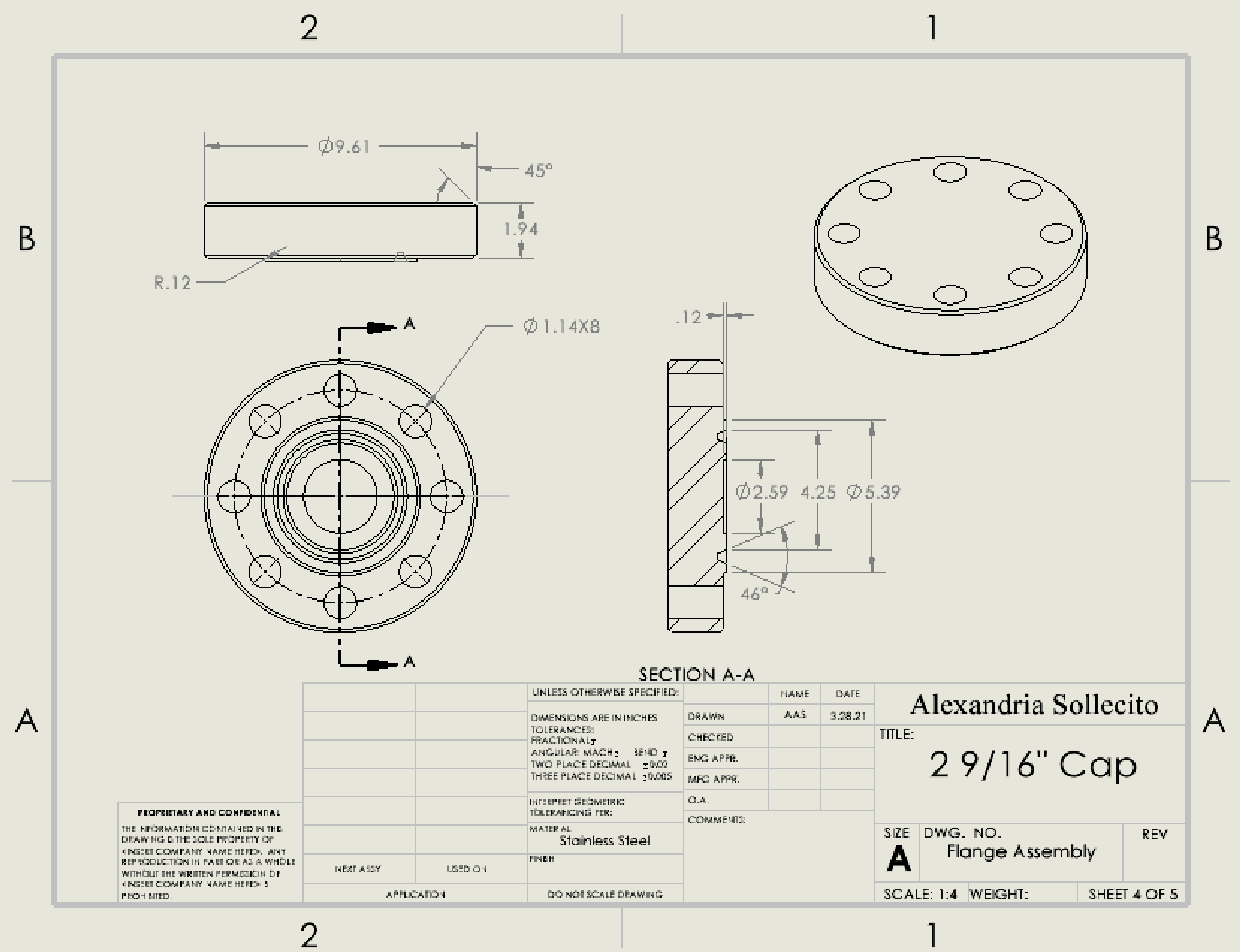

Fig 13. Cap Drawing

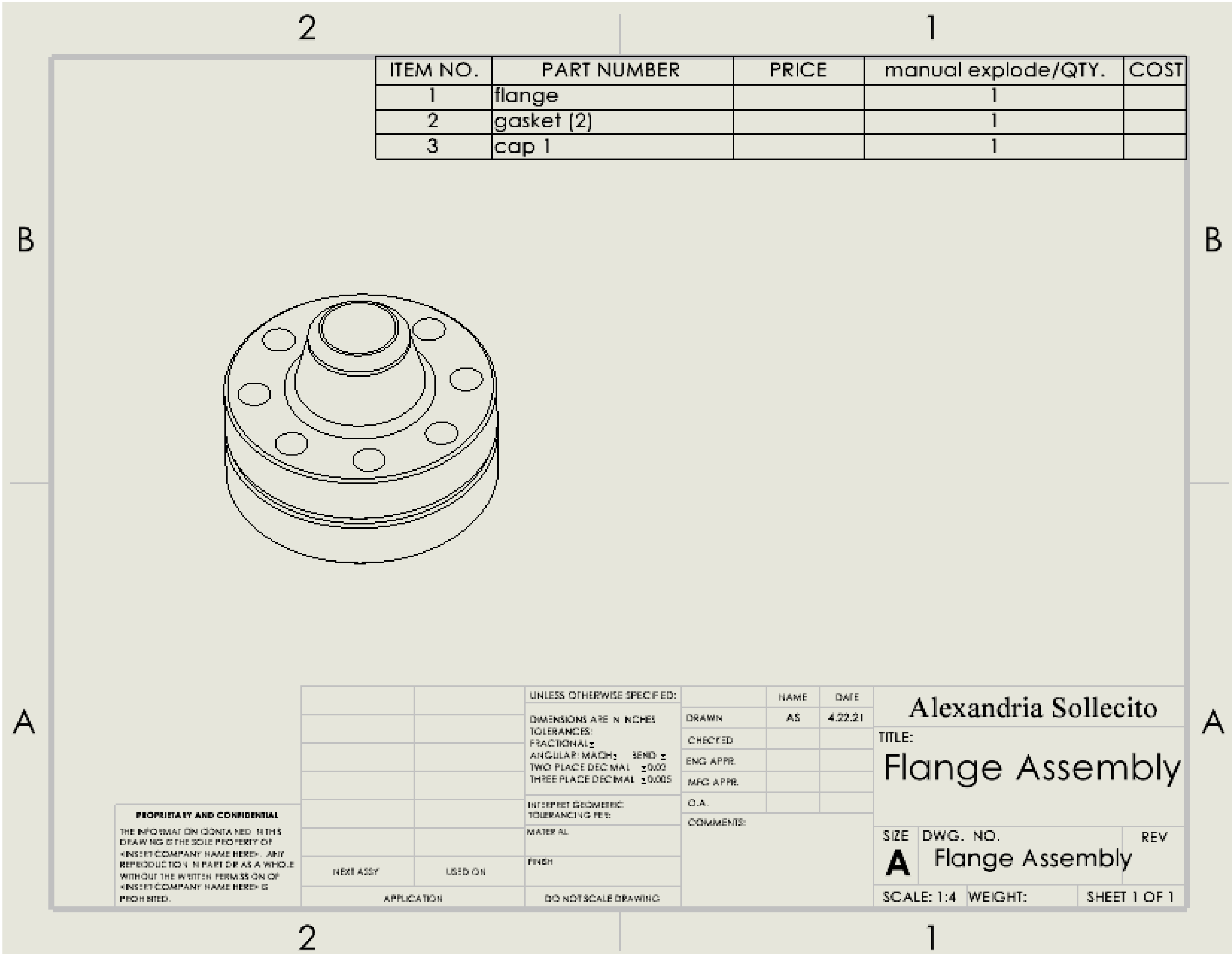

Fig 14. Flange Assembly Drawing

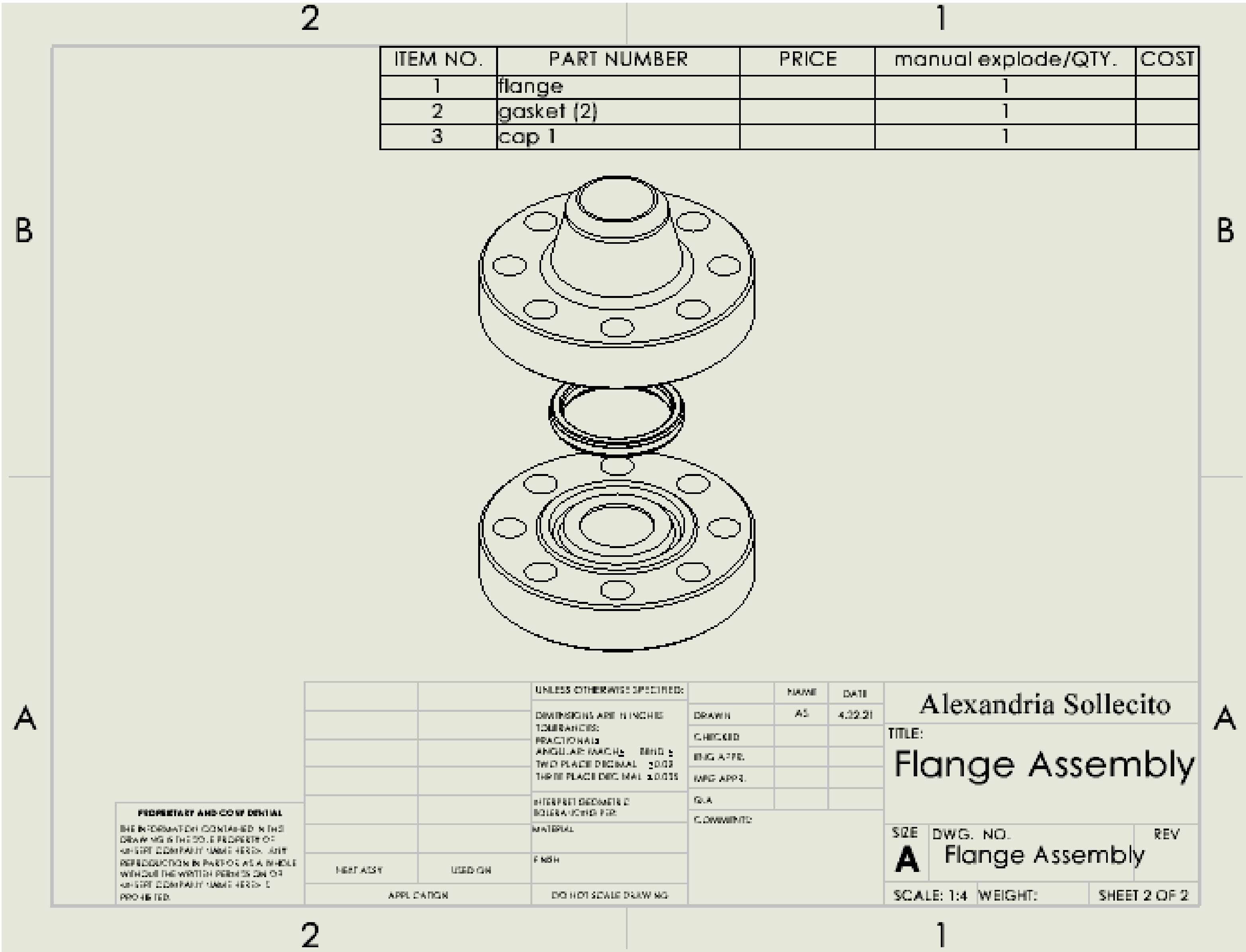

Fig 15. Flange Assembly Drawing: Exploded View

Conclusions/Recommendations

Based on the research, hand calculations and FEA tests conducted in this case study, it is conclusive that the design requirements are met by the selected parts. The AISI 347 flange, cap and 8 bolts fastening them together will withstand the 5000 psi rated pressure as well as the 7500 psi proof pressure without leakage [1]. The flange will sustain the bolt preload while yielding the gasket to seal the gap between the flange and the cap. The client should note that API asserts that gaskets may not be reused as they are coined in a sealing relationship with the flange [1]. Portland Bolt advises against bolt reuse when inelastic elongation of the bolt is a possibility [6]. The client can however be assured that the flange assembly designed in this case study is suitable for the intended service.

References

[1] "API 6A Spec Flange Bolt & Ring Chart." *Whitliejo Specialty*, www.whitliejospecialty.com/_literature_89815/API_Flange_Bolt_Ring_Chart.

[2] *Specification for Wellhead and Christmas Tree Equipment*. American Petroleum Institute, 2021.

[3] *API Weld Neck Flange Dimensions, Recommended Pipe Schedule, Butt Weld Dimensions*, www.woodcousa.com/flange/weldneck-edge.htm.

[4] *Weld Neck Flange Dimensions*, 2021, www.piping-world.com/flange-dimensions/weld-neck-flange-dimensions.

[5] "API 6A Type 6B 5000 PSI Weld Neck & Blind Flanges." *Dynamic Forge & Fittings (I) P. Limited Main Page*, www.dynamicforgefittings.com/api-6a-type-6b-5000-psi-weld-neck-blind-flanges/.

[6] says:, H., says:, D. M. K., says:, S. M., says:, B. D., says:, S., says:, J. C., … says:, A. H. (2016, September 9). *Can a bolt be reused? If so, what grades and in what scenarios?* Portland Bolt Rules for Reusing Bolts Comments. https://www.portlandbolt.com/technical/faqs/rules-for-reusing-bolts/.