Thin Walled Pressure Vessel

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Submitted to:
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Letter of Transmittal

Dr. Seyedreza Djeddi
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Dear Dr. Djeddi:

In this packet I am submitting a formal lab report for the thin walled pressure vessel experiment, conducted under your supervision. This experiment studied the relationship between stress and strain using a thin walled pressure vessel. Based on theoretical equations, the hoop and axial stress can be determined knowing the pressure vessel radius, wall thickness, and internal pressure. Experimentally, one can determine the internal stresses using strain transformations, principal strains, and Hooke's law. The acquired strain data allowed us to determine that Rosettes A and B were the least accurate, and Rosettes C and D were highly accurate in measuring principal stresses. The data analysis involved comparing measured normalized strain relationships, measured principal stresses to theoretical principal stresses, and measured hoop stress to measured axial stress. Most of the data followed a linear trend, so the inconsistencies in Rosettes A and B were precise but not accurate.

Sincerely,
Henry V. Gilbert.

Enclosed: Thin-walled pressure vessel report.

Executive Summary

The goal of this laboratory experiment was to understand the process of measuring stress. Unfortunately, stress gages do not exist. To counter this lack of direct measurement, experimentally measuring stress is accomplished through the stress-strain relationship found in Hooke's law. Hooke's law states that stress is related to strain through the material properties E, Young's Modulus of Elasticity, and ν, Poisson's ratio.

Using a thin walled pressure vessel, this procedure enabled not only the measurement of stress, but also the ability to check the accuracy of these measurements. Based on the thin wall pressure vessel theory, axial and hoop stresses can be calculated using the thin-walled cylinder approximation. These equations, $\sigma_{hoop} = \frac{pr}{t}$ and $\sigma_{long} = \frac{pr}{2t}$, relate applied internal pressure to principal stresses. Based on this, the strains (and therefore stresses) experienced from direct control of internal pressure can be validated from the cylinder pressure vessel theory.

For the stress measurements, a unitless resemblance ratio, R*, was approximated by $\frac{measured}{theoretical}$. Here, a 1.00 resemblance would mean perfectly identical data, while anything higher than 1.0 would show that measured data was higher than theoretical, and lower than 1.0 means measured was lower than theoretical. The calculations showed that rosettes C and D were the most accurate. Rosette C had an average of R*=0.93 to theoretical axial stress, and Rosette D had an average R* = 1.06 to theoretical axial stress and an average R*=1.03 to theoretical hoop stress. Rosette A had an average R*= 0.69 axial, and R*=0.75 hoop. Rosette B had a R*=0.59 and R*= 0.73 similarity to theoretical axial and hoop stress, respectively. The experiment validated the cylinder stress thin-wall approximation, as well as the strain-to-stress data reduction process.

Recall that the cylindrical stress equations are only theoretical. In this case, the data received from rosette D most closely represented the true stresses. The theoretical cylindrical stresses rely on the assumption that internal pressures are perfectly uniformly distributed. Also one must consider the age of the equipment and the effect of fatigue on the pressure vessel. With the hand pump, the pressure 50 psig, 100 psig, etc. represented the *internal* pressure. In a thin walled vessel, the maximum stress will occur at the inside of the wall, and decrease to its minimum on the outside of the wall. This means that our strain rosettes were measuring only the *lowest* value of the stress state.

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Symbol	Description	Unit
μ	Shorthand for strain	(in*e-6/in)
θ	Angle	degrees
ε	Normal & principal strain	μ
ɣ	Shear Strain	radian
ν	Poisson's Ratio	(unitless)
σ	Stress	$\frac{lbf}{in^2}$
psig	Gage Pressure	$\frac{lbf}{in^2}$
L	Length	meter
F	Force	lbf
p	Pressure	$\frac{lbf}{in^2}$
r	radius	in
t	thickness	in
E	Young's Modulus	$\frac{lbf}{in^2}$
in	inches	in

3 Introduction

3.0.0.1 Background Pressure vessels find themselves in modern engineering applications across various fields. These engineering feats help astronauts, and supply scuba divers with the precious breath of life during underwater missions. Anyone who loves cooking with propane and propane accessories understands the vital need of a pressured container for the precious gas. With pressure vessels, trapping the ever-expanding gaseous molecules is a thing of ease.

Strain, ϵ, is a measure of deformity in an object. It is defined as

$$\epsilon = \frac{\Delta L}{L_0}$$

The value of the resultant strain applied to an object is a function of its material properties, mainly Young's Modulus of Elasticity, E. This property defines a materials elasticity, and is the ratio of the applied stress to its deformation, given in the equation $\frac{F}{\epsilon} = E$. However, these equations are only relevant during tensile testing. In two and three dimensional states of applied stress, a more complex derivation occurs to give the equations :
This experiment explores the effect of applied pressure to a thin walled pressure vessel. A pressure vessel is defined as "thin" if the ratio of its total diameter to wall thickness is greater than 20. Here, assuming that the internal stresses are constant and uniform, [1].

3.0.0.2 Objectives The primary objective in this experiment was to relate the theoretical stress calculations in a cylindrical pressure vessel from the equation $\sigma_{hoop} = \frac{pr}{t}$ and $\sigma_{long} = \frac{pr}{2t}$, to the process of obtaining stresses from strain measurements. Once the measured strain values were converted to principal stresses, data analysis was used to check the validity of the data. Among these calculations was comparing the measured stresses to the theoretical values.

4 Methodology

4.0.0.1 General Overview With the pressure vessel apparatus, strain rosettes were attached to various locations along the vessel. Once the strain values were measured, principal stresses were calculated using Hooke's law. The principal stresses obtained from Hooke's law were graphed and compared to theoretical values. Checks were put in place to determine the validity of the strain gage readings. Note: All configuration figures are derived from reference [2].

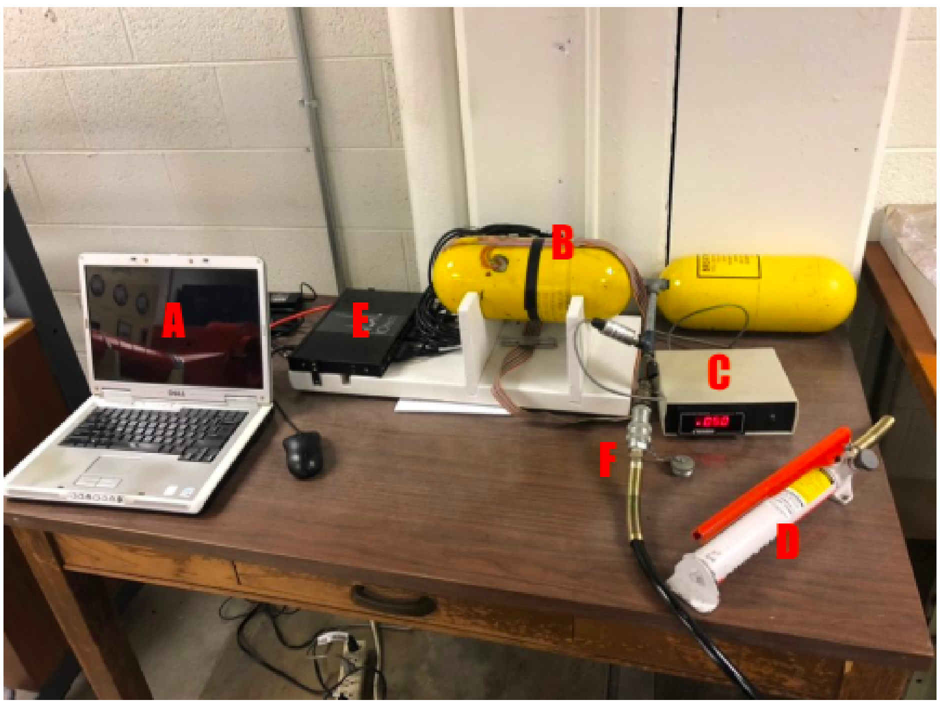

Figure 1: **Overhead view of the experiment configuration**

4.0.0.2 Apparatus Figure 1 shows the full setup for the pressure vessel experiment, with red letters "A-F" to label individual components. Letter A represents the Dell Latitude data acquisition machine. The Excel program was used here to store the measured data. "B" is the MIT-C-5435 oxygen tank, with strain rosettes configured on it as shown in **Figure 2**. "C" is the OMEGA DP-350 pressure indicator, which retrieves data from "E", the

IOtech-6224 strain gage input module, attached to "F", the OMEGA PX302-500GV pressure transducer. Label D corresponds to the hydraulic hand pump that was manually used to control the oxygen tank's internal pressure.

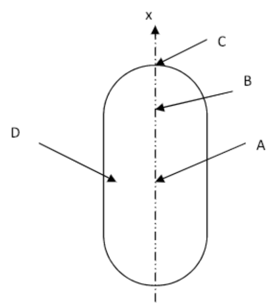

Figure 2: **Overview of the pressure vessel rosette configuration**

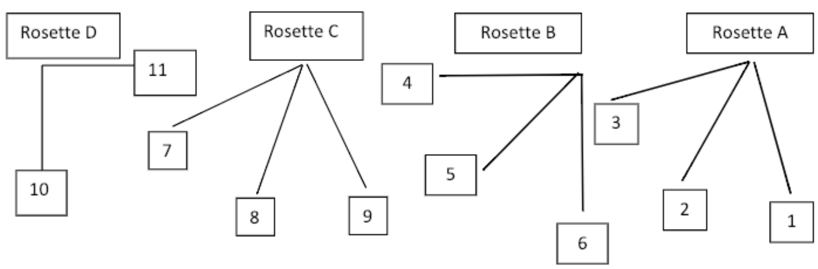

Figure 3: **Strain Rosette Configurations**

Shown in **Figure 3** is the configuration of each strain rosette, and **Figure 4** shows the angle values which belong to each strain gage. These angles are measured counterclockwise from the x axis.

Based on the configuration above, the gage pairs (4 & 11) and (6 & 10) will detect the same strain value. Therefore,

$$\epsilon_4 = \epsilon_{11} \tag{1}$$

$$\epsilon_6 = \epsilon_{10} \tag{2}$$

Rosette D's average value of strain should be equal to the strain read on gage 5, shown in

$$2 \times \epsilon_5 = \epsilon_{10} + \epsilon_{11} \tag{3}$$

Due to rosette C's placement on the axial end, there will be only a one dimensional state of strain recorded. Therefore, the values detected in all gages should be equal.

$$\epsilon_7 = \epsilon_8 = \epsilon_9 \tag{4}$$

	Rosette A			Rosette B			Rosette C			Rosette D	
Gage	1	2	3	4	5	6	7	8	9	10	11
Angle	105	60	15	0	45	90	20	65	110	90	180

Figure 4: **Strain Rosette Angles**

4.0.0.3 Test Procedure Starting at 0 psig, a hand pump was used to increase the pressure by 50 psig increments. Once the pressure was set, a mean strain gage was shot selected in the data acquisition program, capturing an instantaneous state of mean strain. At 0 psig, theoretically, there should be zero stress and strain in the vessel. However, strain gages work by measuring micro displacements, and some minor effects of gravity, age, and physical configuration can cause the voltage at 0 psig to give a value of strain. To compensate this linear offset, a "normalized" set of data was used, in which every set of data was subtracted from the zero offset measurement. For example, instead of the strain reading at 100 psig being the raw values pulled from the data acquisition system, the strain value from 100 psig would be captured, then the difference between the baseline value at 0 psig would be subtracted from 100 psig, and the resulting value would be the normalized value. For example, at 100 psig, $\epsilon_{100} = \epsilon_{100measured} - \epsilon_0$. *All calculations used the normalized strain measurements at each pressure increment.* This process was repeated for each strain measurement up to 400 psig. After the ascending measurements were taken, the hand pump had its pressure released, and the strain values from 400 psig to 0 psig were taken, in 50 psig decrements, to determine the descending sets of data.

4.0.0.4 Data Reduction Procedure

The overall flow of data starts at nominal strains, transformed to plane strains, converted to principal strains, and finally, through Hooke's law, converted to principal stresses. Once the measured principal stresses were obtained, they are classified as either hoop or axial stresses. For rosettes A, B, and D, the hoop stress is the larger value, and the axial stress is the smaller value.The corresponding θ_i values for each gage come from **Figure 4**.

Starting with nominal strains, the strain transformation theory is applied to three measured strains, shown in the set of equations

$$\epsilon_1 = \epsilon_x \cos^2\theta_1 + \epsilon_y \sin^2\theta_1 + \gamma_{xy}\cos\theta_1 \sin\theta_1 \tag{5}$$
$$\epsilon_2 = \epsilon_x \cos^2\theta_2 + \epsilon_y \sin^2\theta_2 + \gamma_{xy}\cos\theta_2 \sin\theta_2 \tag{6}$$
$$\epsilon_3 = \epsilon_x \cos^2\theta_3 + \epsilon_y \sin^2\theta_3 + \gamma_{xy}\cos\theta_3 \sin\theta_3 \tag{7}$$

These three equations are solved using the matrix multiplication:

$$\begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} \cos^2\theta_1 & \sin^2\theta_1 & \cos\theta_1\sin\theta_1 \\ \cos^2\theta_2 & \sin^2\theta_2 & \cos\theta_2\sin\theta_2 \\ \cos^2\theta_3 & \sin^2\theta_3 & \cos\theta_3\sin\theta_3 \end{bmatrix}^{-1} \times \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \end{bmatrix} \tag{8}$$

Once the plane strain values ϵ_x, ϵ_x, and γ_{xy} are solved, the principal strains are produced by the equations :

$$\epsilon_{p1}, \epsilon_{p2} = \frac{\epsilon_x + \epsilon_y}{2} \pm \frac{1}{2}\sqrt{\frac{\epsilon_x - \epsilon_y}{2}^2 + \gamma_{xy}^2} \tag{9}$$

Principal strains lead directly to the principal stresses via Hooke's law. Given the material properties of the vessel,

$$\sigma_{p1} = \frac{E}{1-\nu^2}\left[\epsilon_{p1} + \nu\epsilon_{p2}\right] \tag{10}$$
$$\sigma_{p2} = \frac{E}{1-\nu^2}\left[\epsilon_{p2} + \nu\epsilon_{p1}\right] \tag{11}$$

Material properties for the oxygen tank were as follows:

$$thickness = t = 0.04in$$

$$radius = r = 2.773in$$

$$Young's Modulus = E = 30 \times 10^6 psi$$

$$Poisson's Ratio : \nu = 0.29$$

4.0.0.5 Data Validity Checking

To offer a validity check to the strain gages, ratios were compared once the normalized data was taken. From the rosette configurations, if the data were perfect, the values of equations (1), (2), (3), and (4) would hold perfectly true, i.e., equal 1.

4.0.0.6 Theoretical Measurements

Based on the thin walled pressure vessel theory, the cylinder stresses are calculated by

$$\sigma_{Hoop} = \frac{p \times r}{t} \tag{12}$$

$$\sigma_{Axial} = \frac{p \times r}{2t} \tag{13}$$

Thin walled pressure vessel theory only holds true if $\frac{D}{t} > 20$, For the vessel in this experiment, $\frac{D}{t} = \frac{5.545in}{0.04in} = 138$, thus, the assumption holds true.

4.0.0.7 Data Analysis

After all the measurements were taken, three analysis methods were conducted, all involving "resemblance ratios" R*= $\frac{\sigma_{measured}}{\sigma_{theory}}$. Here, a value of 1.0 would signify the measured data is exactly the theoretical data. Any number higher than 1.0 states that the measured value was higher than the theoretical value, and any number lower than 1.0 states that the measured value was lower than the theoretical value. For rosettes A, B, and D, where both axial and hoop stresses are present, a separate ratio was created as R* = $\frac{\sigma_{Hoop}}{\sigma_{Axial}}$. A value of 2.0 is expected, since by definition, hoop stress is twice the value of axial stress. The three stress measurements that were analyzed were *axial vs hoop*, *hoop vs theoretical hoop*, and *axial vs theoretical axial.*

5 Results and Discussion

5.0.0.1 Results Below are tables and figures representing the reduced and analyzed data from the strain rosettes and the calculated hoop and axial stresses. An important consideration is that the word "accurate" refers to closeness to the theoretical calculation, which served as the main reference state for strain measurement accuracy.

Table 1: **Normalized Strain data**

Normalized Strain	0	50	100	150	200	250	300	350	400	psig
Gage 1	0	71.7	141	214	285	357	431	504	578	µin/in
Gage 2	0	58.1	114	175	234	295	358	421	484	µin/in
Gage 3	0	17.4	34.0	53.7	73.3	93.2	114	135	156	µin/in
Gage 4	0	21.1	40.8	62.3	84.0	106	128	150	172	µin/in
Gage 5	0	65.3	129	198	264	333	402	473	543	µin/in
Gage 6	0	62.9	122	187	251	317	385	454	522	µin/in
Gage 7	0	36.5	71.4	110	148	187	227	267	307	µin/in
Gage 8	0	37.7	73.6	113	152	192	232	273	313	µin/in
Gage 9	0	38.9	76.7	116	156	195	236	276	316	µin/in
Gage 10	0	109.0	211	311	406	499	591	681	768	µin/in
Gage 11	0	28.5	54.3	81.4	107	133	158	183	207	µin/in

Table 1 shows the normalized strain data for each rosette, at each pressure value. These values comes from the method of subtracting the nominal value form the zeroed value, $\epsilon_n = \epsilon_{measured} - \epsilon_0$. The values were measured in microstrain, $\frac{\mu in}{in}$. Recall that the rosette configurations held the following gages: Rosette A (1,2,3), Rosette B(4,5,6), Rosette C(7,8,9) and Rosette D(10,11).

Table 2: **Calculated Hoop and Axial Stresses**

Measurement	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	psig
Rosette A Hoop	0.0	2590	5090	7740	10400	13000	15700	18400	21100	psi
Rosette A Axial	0.0	1180	2300	3560	4800	6040	7320	8590	9880	psi
Rosette B Hoop	0.0	2500	4900	7490	10000	12700	15300	18100	20800	psi
Rosette B Axial	0.0	1050	1990	3030	4110	5200	6310	7440	8570	psi
Rosette C Axial	0.0	1590	3120	4780	6420	8090	9790	11500	13200	psi
Rosette D Hoop	0.0	3830	7430	11000	14300	17600	20800	24000	27100	psi
Rosette D Axial	0.0	1960	3780	5620	7370	9080	10800	12500	14100	psi
Hoop Theoretical	0.0	3470	6930	10400	13900	17300	20800	24300	27700	psi
Axial Theoretical	0.0	1730	3470	5200	6930	8660	10400	12100	13900	psi

Table 2 shows the calculated hoop and axial stresses for each rosette. The bottom two rows are the theoretical values calculated from equations (12) and (13) at each pressure level.

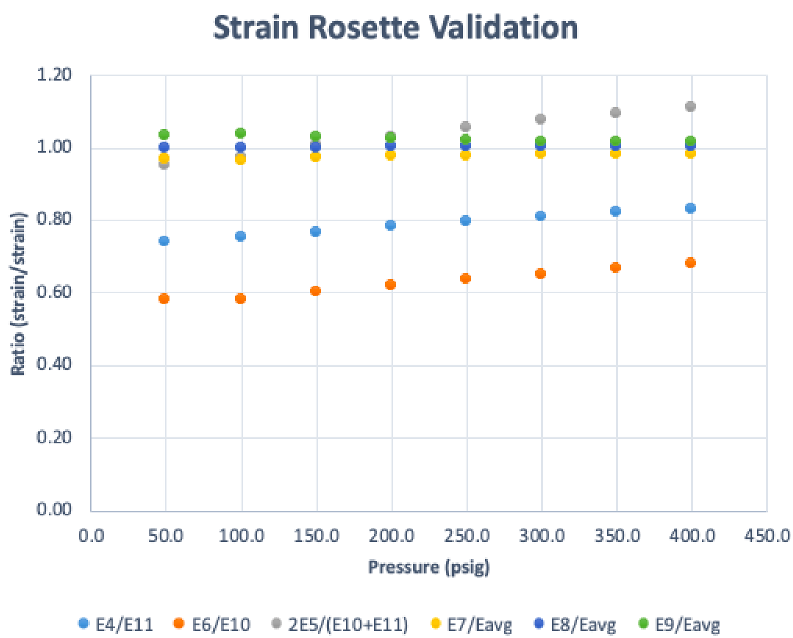

Figure 5: **Rosette Validation Checks**

Figure 5 displays the results from equations (1-4). These values determine how different gages within the rosettes are detecting strains which, based on configuration, should be equal. From **Table 3**, the most accurate data is colored green, and the inaccurate data colored red.

Table 3: **Strain Rosette Validation Data**

Rosette Validation	50	100	150	200	250	300	350	400
E4/E11	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83
E6/E10	0.58	0.58	0.60	0.62	0.64	0.65	0.67	0.68
(2*E5)/(E10+E11)	0.95	0.97	1.01	1.03	1.05	1.07	1.09	1.11
Avg Strain on C [Ec]	37.7	73.9	113.1	152.1	191.4	231.6	271.9	312.1
E7/Ec	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98
E8/Ec	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
E9/Ec	1.03	1.04	1.03	1.02	1.02	1.02	1.02	1.01

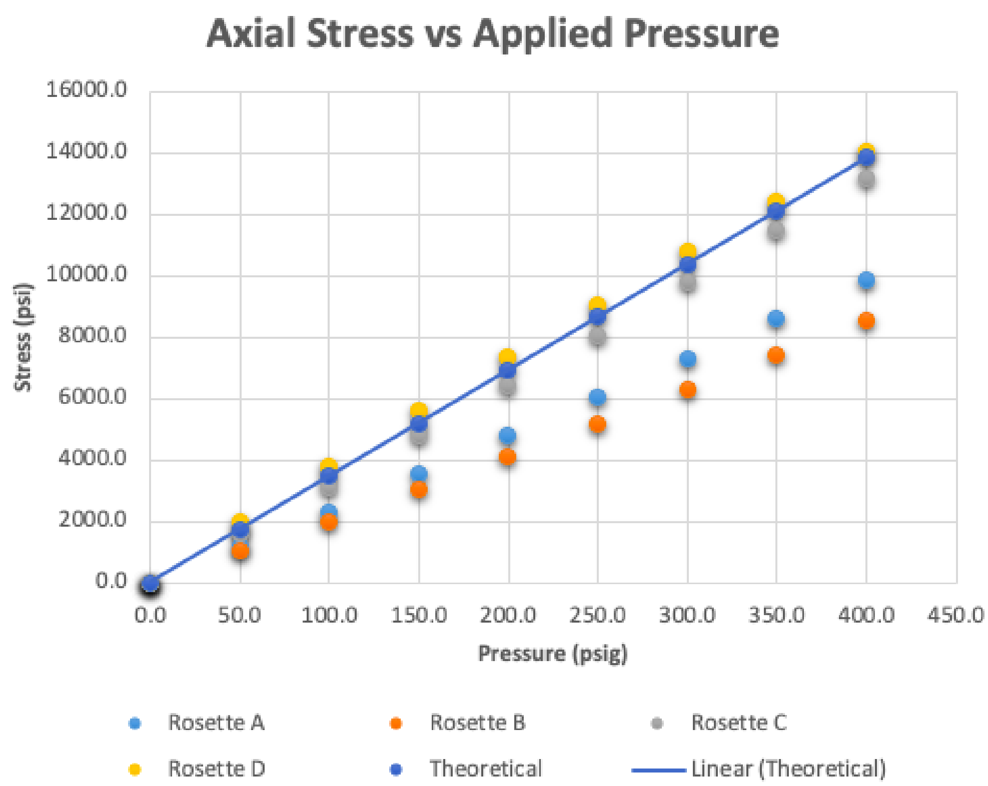

Figure 6: **Calculated Axial stress vs Pressure**

Figure 6 shows the calculated axial stress per pressure. The blue line demonstrates the theoretical values. Thus, data closer to the trend line represents more accurate data relative to the theoretical values. Rosettes C and D displayed the closest resemblance, Rosettes A and B, while linear, were not accurate. This is supported by the fact that from Figure 5 and Table 3, the gages on Rosettes A and B tended to be the least accurate.

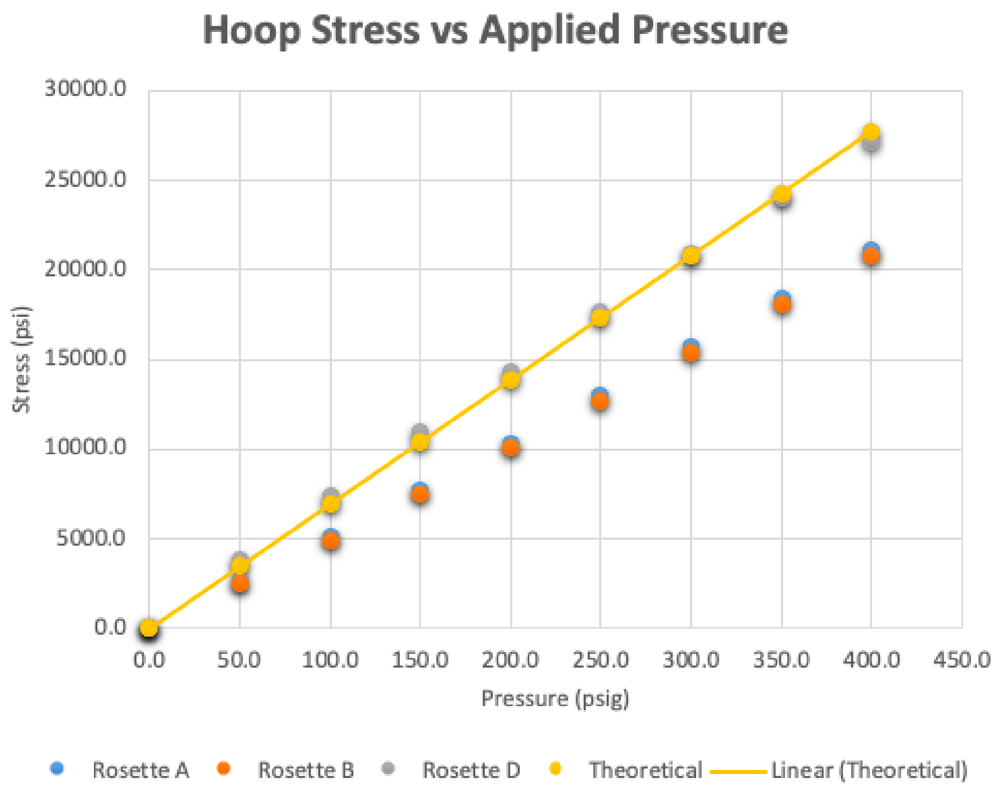

Figure 7: **Calculated Hoop Stress vs Pressure**

Figure 7 displays the calculated hoop stress for each rosette, with the theoretical values displayed on the yellow trend line. Thus, data closer to the line represents more accurate data, relative to the theoretical values. Recall that Rosette C, based on the position, has no hoop stress. Once again, similar to the axial stress calculations, Rosettes A and B displayed linear but inaccurate data. The values collected from Rosette D almost mirrored the theoretical data.

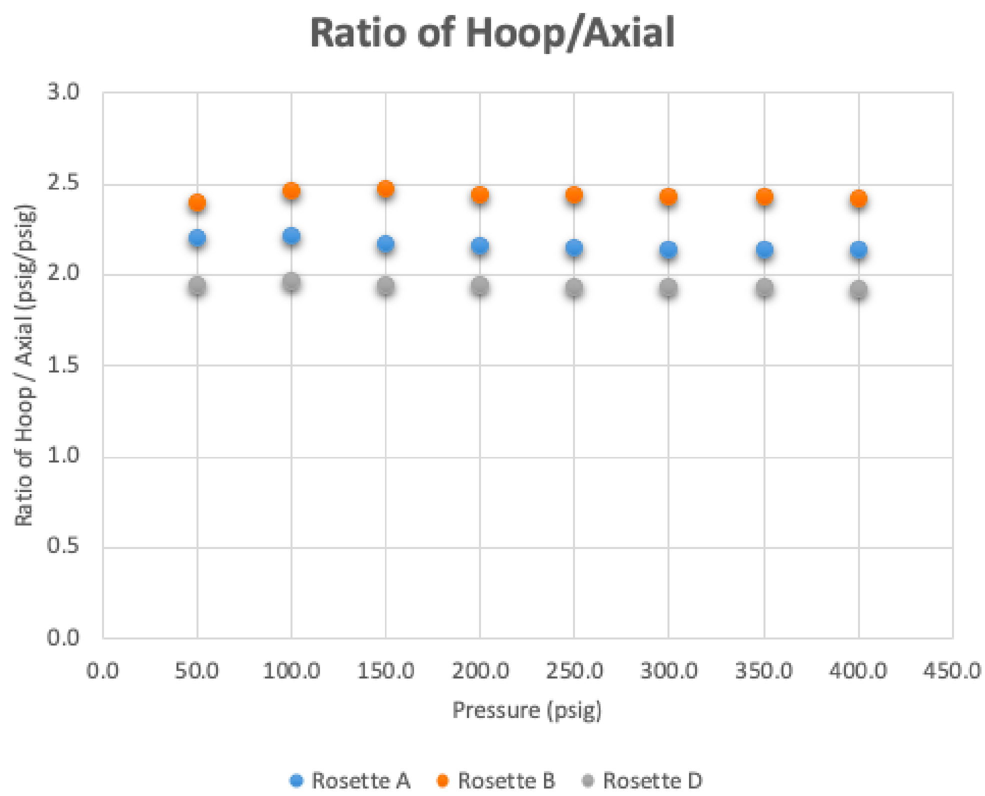

Figure 8: **Measured Hoop vs Measured Axial**

Based on equations (12) and (13), σ_{Hoop} should be twice the value of σ_{Axial}. Thus, the ratio of the measured hoop stress vs measured axial stress should be 2.0. Rosette D displayed the closest resemblance to 2.0, while rosettes A and B showed values higher than 2.0. Rosette B consistently averaged a value of around 2.45, making it the least accurate value in this measurement series.

Table 4: **Table of Hoop vs Axial stress per rosette**

Hoop/Axial Ratio	50	100	150	200	250	300	350	400
Rosette A	2.2	2.2	2.2	2.2	2.2	2.1	2.1	2.1
Rosette B	2.4	2.5	2.5	2.4	2.4	2.4	2.4	2.4
Rosette D	1.9	2.0	1.9	1.9	1.9	1.9	1.9	1.9

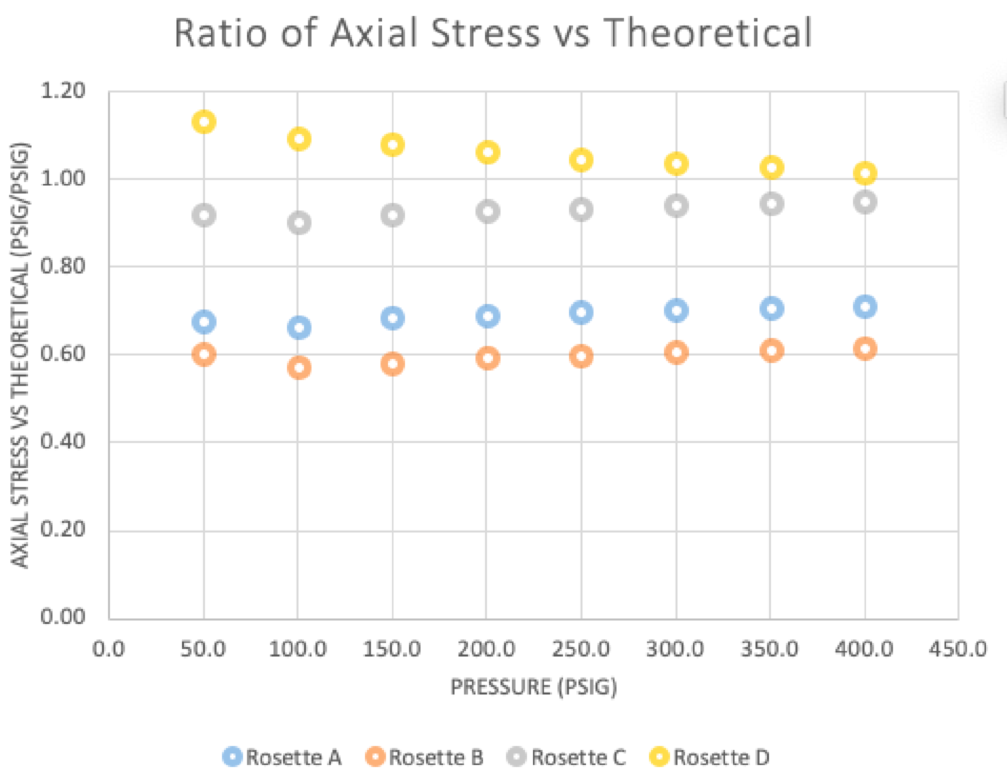

Figure 9: **Ratio of Measured Axial vs Theoretical Stress**

In Figure 9, measured axial stress is analyzed. The acquired axial stress from the data reduction procedure is compared to the theoretical axial stress.

Table 5: **Axial stress ratio of measured vs theoretical**

Axial vs Theoretical	50	100	150	200	250	300	350	400
Rosette A	0.68	0.66	0.68	0.69	0.70	0.70	0.71	0.71
Rosette B	0.60	0.57	0.58	0.59	0.60	0.61	0.61	0.62
Rosette C	0.92	0.90	0.92	0.93	0.93	0.94	0.95	0.95
Rosette D	1.13	1.09	1.08	1.06	1.05	1.04	1.03	1.02

Table 5 shows the data from Figure 9. Red text signifies less accurate data, while green text signifies accurate data.

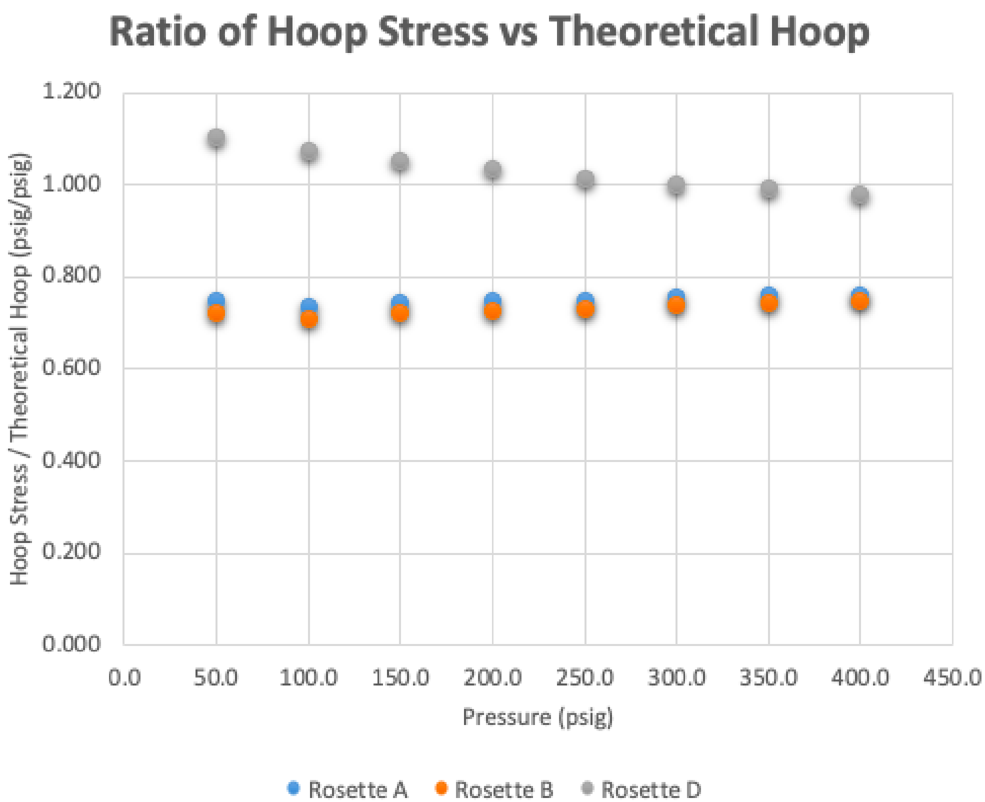

Figure 10: **Hoop Stress Ratio: Measured vs Theoretical**

Figure 10 shows the ratio of calculated hoop stress vs theoretical hoop stress. This table shows that Rosettes A and B were consistently and linearly well below the theoretical values, meaning that these rosettes were measuring a lower value than expected. Rosette D started out giving a value of 1.1, but ended up approaching the value of 1.0 as pressures increased.

Table 6: **Rosettes A, B, and D: Hoop vs Theoretical Stress**

Hoop vs Theoretical	50	100	150	200	250	300	350	400
Rosette A	0.75	0.73	0.74	0.75	0.75	0.75	0.76	0.76
Rosette B	0.72	0.71	0.72	0.72	0.73	0.74	0.74	0.75
Rosette D	1.10	1.07	1.05	1.03	1.02	1.00	0.99	0.98

Table 7: **Average R* ratios of all pressures per measurement.**

Hoop/Axial Ratio	Table
Rosette A	2.16
Rosette B	2.44
Rosette D	1.94

Axial vs Theoretical	Table
Rosette A	0.693
Rosette B	0.599
Rosette C	0.930
Rosette D	1.06

Hoop vs Theoretical	Table
Rosette A	0.750
Rosette B	0.730
Rosette D	1.03

Table 7 explains the average between every psig increment per ratio classification. This table gives a more compact summary of the other tables and figures. Here, the average differences and similarities between rosettes are more clearly and concisely conveyed. For the $\frac{\sigma_{Hoop}}{\sigma_{Axial}}$ ratio, the closer the values approach 2, the more accurate the data within the rosette. The same applies to the ratio $\frac{\sigma_{AxialMeasured}}{\sigma_{AxialTheoretical}}$. The closer to 1 these two ratios approach, the more accurate. Lower than 1 signifies a smaller than expected measured value, and a higher than 1 value shows the measured stress was larger than expected. These values came exactly from the tables above, but are simple averages of all the numbers.

5.0.0.2 Discussion Based on the results, Rosettes A and B were not accurate, and Rosettes C and D gave the most accurate data for both hoop and axial stresses. Not only were rosettes C and D close to the theoretical values, but all of the strain gages in these rosettes had values close to 1 in the validation equations and had an average of 2.164 and 1.942 hoop/axial ratio, respectively. Rosettes A and B had the least accuracy. This mainly comes from two factors: location and mechanical imperfections. From **Figure 2**, rosette B was placed at a location away from the center, where as rosettes A, C, and D were placed at discrete locations. The thin wall approximation assumes that all internal stresses are uniformly distributed, and this placement likely explains these differences between calculated and theoretical. Rosette B tended to give consistent data, however. All of its trends were linear as expected, and tended to, despite being inaccurate, consistently reproduce the same results. This trend of precise and inaccurate data is likely due to mechanical wear on the rosettes, age, and or tolerance issues.

Rosette A gave consistent stress values for its own hoop and axial stresses. The ratio between hoop and axial for A was 2.164, while B had a value of 2.437. This shows that not only was rosette B inaccurate in terms of theoretical values, but it was also inaccurate at producing a value of $2\sigma_{Axial} = \sigma_{Hoop}$. As pressure increased, all rosettes tended to increase in accuracy, shown in figures 8, 9, and 10.

6 Conclusions and Recommendations

6.0.0.1 Interpretations All measurements tended to be more accurate as pressure increased. Likely, at lower pressures, the internal pressure was not distributed as evenly as it would be during higher pressures. Rosettes A and B were not reliable, but C and D were. For demonstrative/laboratory purposes, rosette B is an effective way to showcase how placements of gages can affect stress measurements. However, for industrial or research problems, the configuration of rosette B would not be effective. Also, the data supports the assumption that rosette B likely had internal mechanical issues, meaning that it could due for replacement. To measure pure axial stress, rosette C had the best location, while overall rosette D had the most accurate data set for both hoop and axial stress. Placing multiple rosettes on a single pressure vessel is an efficient way to test how accurate a set of rosettes is, and could be an effective way of determining which rosettes need replacement.

6.0.0.2 Reliability Just as any other piece of mechanical equipment can begin to lose accuracy over time, strain gages are no different. Rosettes A and B tended to yield the least accurate results. Age, wear and tear, and repeated usage of the rosettes could have led to deteriorated accuracy over time. When conducting an experiment for research or more "serious" matters, check the fatigue data and general life cycle of equipment before relying on the data it receives.

6.0.0.3 Placement While not only the age and wear of rosette B could have contributed to the bad accuracy, the physical placement of the strain gage on the rosette could have made a considerable difference. Rosette D was placed dead center on the vessel, while rosette C was place at the axial end. These symmetrical placements of the rosettes played a critical role in the stress accuracy.

7 What I learned

This experiment tested our ability to not only work in teams, but to use the methods and skills we have learned through years of class and apply them to an actual experiment. With the pressure vessel experiment, we bridged the knowledge gap between theoretical engineering and hands-on experimentation. Not only were we exposed to modern engineering instrumentation, we learned highly valuable skills in collaboration, communication, and writing proper documentation for reports.

I testify that I have read this report and edited it as I had seen fit before submission

8 References

[1] Beitz, W., Kuttner, K., Davies, B., and Shields, M. (1994). Dubbel: Handbook of Mechanical Engineering. London: Springer-Verlag) B-42.

[2] Djeddi, Reza. (2019).Pressure Vessel Slides [pdf file]. (The University of Tennessee Knoxville). Retreived: Canvas

9 Appendices

9.0.0.1 Raw Strain Data Appendix 1

Raw Strain Data, Ascending

Rosette	**0.00**	50.00	100.00	150.00	200.00	250.00	300.00	350.00	400.00	psig
1	**9104.33**	9176.05	9245.31	9318.01	9389.67	9461.56	9535.20	9608.76	9682.32	μ
2	**9185.56**	9243.69	9300.05	9360.22	9419.90	9480.79	9543.43	9606.60	9669.64	μ
3	**1883.45**	1900.87	1917.42	1937.13	1956.72	1976.68	1997.37	2018.01	2039.13	μ
4	**835.69**	856.77	876.48	898.03	919.64	941.40	963.47	985.69	1007.87	μ
5	**899.25**	964.57	1028.40	1096.78	1163.29	1231.84	1301.22	1371.77	1441.87	μ
6	**5688.48**	5751.38	5810.75	5875.25	5939.61	6005.69	6073.23	6142.10	6210.80	μ
7	**2064.38**	2100.90	2135.77	2174.39	2212.67	2251.53	2291.41	2331.30	2371.20	μ
8	**2142.88**	2180.62	2216.52	2256.07	2295.09	2334.69	2375.18	2415.59	2456.04	μ
9	**2140.73**	2179.63	2217.42	2256.97	2296.39	2335.88	2376.28	2416.73	2457.09	μ
10	**1495.28**	1603.86	1706.34	1806.29	1901.58	1994.26	2086.00	2175.84	2263.48	μ
11	**1747.80**	1776.29	1802.14	1829.24	1854.89	1880.32	1905.59	1930.62	1955.05	μ
Initial	RB	MD	JG	JJG	DD	EMD	H.G.	CC	RB	

Raw Strain Data, Descending

	400.00	350.00	300.00	250.00	200.00	150.00	100.00	50.00	psig
1	9682.32	9611.02	9539.11	9466.95	9393.70	9321.42	9245.11	9170.39	μ
2	9669.64	9607.87	9546.02	9484.37	9422.56	9361.83	9298.22	9236.90	μ
3	2039.13	2018.47	1997.53	1977.03	1956.37	1936.40	1915.57	1895.61	μ
4	1007.87	983.50	960.66	938.59	917.56	894.77	873.48	851.20	μ
5	1441.87	1373.04	1303.06	1233.87	1161.37	1096.84	1020.31	954.92	μ
6	6210.80	6140.12	6071.42	6004.34	5939.14	5872.15	5804.42	5738.07	μ
7	2371.20	2331.11	2290.83	2250.88	2211.12	2171.92	2131.90	2092.64	μ
8	2456.04	2415.35	2374.39	2333.83	2293.27	2253.44	2212.50	2172.35	μ
9	2457.09	2416.66	2375.91	2335.52	2295.24	2255.46	2214.75	2174.41	μ
10	2263.48	2176.37	2086.95	1995.78	1902.37	1807.00	1705.34	1600.31	μ
11	1955.05	1930.51	1905.24	1879.80	1853.55	1827.09	1798.64	1769.44	μ
	RB	JG	MD	DD	JJG	H.G.	CC	RB	

9.0.0.2 Lab Procedure Appendix 2

Lab Procedure

1. Turn on the Laptop, DAQ, and Pressure Monitor.
2. Open Excel and the Pressure Vessel Program.
3. Pressurize the pump by turning the valve clockwise.
4. Make sure the display shows zero. If there is a minus sign, pump a little until it is gone.
5. If the display is steady at zero, press "single shot" in the pressure vessel program. Readings from all the rosettes appear. Press single shot a few times and make sure the numbers aren't fluctuating by large amounts.
6. Once the numbers are steady find the data, which should be called "Mean Strain" on the left side of the program, and right click it. Then click "export to", then "clipboard".
7. The data can then be pasted into Excel. Take the relevant data and move it under the correct pressure column.
8. The pressure can then be moved up to 50 psi by pumping the handle.
9. When at 50 wait a bit and make sure that it is steady at 50. The number may fluctuate some and can take a minute or so to become steady.
10. If you pass 50 psi, some pressure can be released by very slightly turning the pressure valve counterclockwise and back. If the valve is turned too much or not brought back quickly enough too much air may be released.
11. Same as before, run multiple single shots and make sure the numbers aren't fluctuating greatly.
12. Copy and paste the data as before and then repeat this process all the way up to 400 psi then back down to 50 psi. (Don't let the pressure go above 400 psi)

9.0.0.3 Equipment Specifications Appendix 3

1. Strain Gage Input Module, IOtech-6224
    - 12 Channel input
    - Internal Full and Half Bridge Configuration
    - Analog to Digital Conversion Resolution: 24 bits
    - Nominal Full Scale Range: ± 25 mV/V
2. Quarter Bride Completion Adapters, IOtech-CN-269
    - Resistor Value: 120 Ω
    - Resistance Drift: 0.012 Ω/°C
    - Resistor Tolerance (25 °C): 0.1%max
3. Hydraulic Hand Pump, Power Team P-12
    - 10,000 psi (max)
    - 0.069 in^3 per stroke
4. Pressure Indicator, OMEGA DP-350
    - Model Obsolete – No Specs Found
5. Pressure Transducer, OMEGA PX302-500GV
    - Operating Range: 0-500 psig
    - Accuracy: 0.25% BFSL (linearity, hysteresis, repeatability)
6. Shut-off Valve, VALPRES ¼″ ball valve
7. Pressure Tank, Converted Oxygen Tank
    - 280 in^3
    - Spec: MIT-C-5435
8. Strain Gages
    - 4 Rosettes
    - 45° Apart
9. Computer, Dell Latitude: Not registered with the University (No I.D. Sticker)

9.0.0.4 Hand Sample Calculations