Structures I Lab III

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This experiment aimed to study the bending behavior of an aluminum Hollow Shaft using a strain gauge rosette and to compare the experimental strain and stress distributions to calculated values based on bending theory. Data was collected using strain gauge rosettes and processed through a LabView data acquisition system, enabling precise measurement of strain at various locations along the beam. The determined stress distribution was then compared to theoretically calculated values, giving information on the accuracy of such models. The experiment also examined potential sources of discrepancies between experimental and theoretical results, whether that be human error or otherwise.

Nomenclature

E	=	Youngs Modulus
G	=	Shear Modulus
ε	=	Normal Strain
γ	=	Shear Strain
υ	=	Possions Ratio
σ	=	Normal Stress
τ	=	Shear Stress
t	=	Thickness of beam
T	=	Torque Applied
d	=	Diameter of beam
J	=	Polar moment of inertia
θ	=	Angle of twist
l	=	tube length

I. Introduction

In aerospace engineering, shear stress is important because it influences the structural integrity of aircraft components subjected to torsional loads. For example, the fuselage experiences torsion loading due to aerodynamic forces acting on the vertical stabilizer, causing it to twist around its longitudinal axis. This torsional stress must be analyzed, as excessive shear stress can lead to deformation or failure of necessary components. To simulate these conditions, in this experiment we utilize a hollow shaft made of aluminum to simulate the torsional behavior found in aircraft structures like the fuselage. Torsion occurs when an object twists as a result of applied torque, generating shear stress within the material. The material's resistance to this twisting is quantified by its shear modulus (G), a property that defines its stiffness under shear stress. Understanding these behaviors is essential in aerospace design to ensure the strength and safety of structural components.

II. Methodology

The experiment involved an aluminum Hollow shaft equipped with strain gauges positioned at several locations along the beam to collect shear strain data during the bending process. These strain gauges were linked to a National Instruments Data Acquisition (NI DAQ) system, while LabVIEW software facilitated the recording of strain values as different loads were applied.

To complete the lab, we followed the following procedure:

1. The Hollow Shaft was mounted to the testing apparatus, and strain gauges were installed at key locations (gages 1, 2, 3, 5, 6, and 7) to measure shear strain at the sides of the beam.
2. Standard weights were added to the tip of the beam to apply a bending moment.

3. Strain readings were recorded through LabVIEW for each weight applied. The strain values were used to calculate normal and shear stresses using equations derived from beam theory.

Variable	Value
E (psi)	10,000,000
G (psi)	3,800,000
υ	.33

Table 1

The properties of the aluminum I-beam, including Young's modulus and shear modulus, were used for the theoretical calculations (Table 1). MATLAB was used to generate plots and calculate the shear stress from both experimental and theoretical models. All of this is outlined in the experimental Flow Diagram (figure 1).

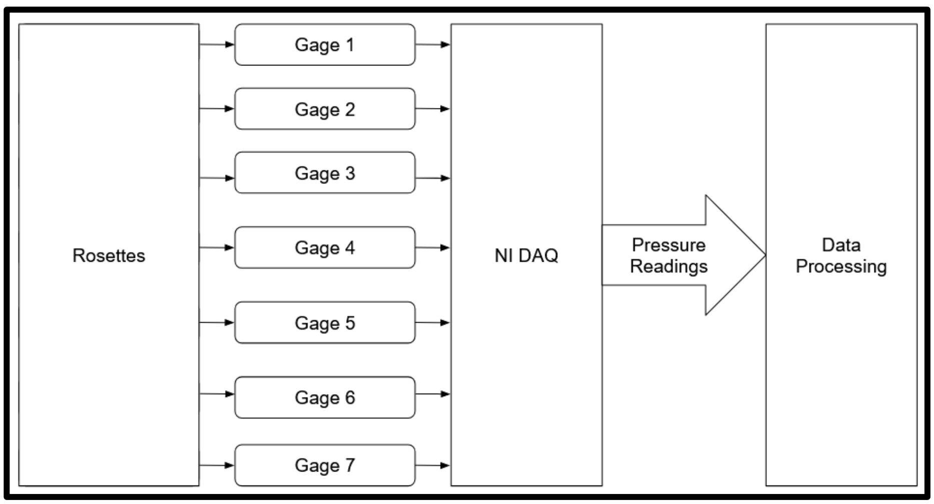

Figure 1

III. Results and Discussion

In this analysis, MATLAB was used to process strain gauge data and calculate stresses in the Shaft. The Polar moment of inertia J was calculated using J = (pi/32)*(d_o^4 - *(d_o – 2* t)^4), based on the shaft's dimensions. Experimental Shear Stress was calculated using $\tau = G*\gamma_{xy}$ and Theoretical Shear Stress was Calculated using τ = (T * 2)/(d_o * J). Angle of twist θ was calculated using θ = (T * l) / (G * J).

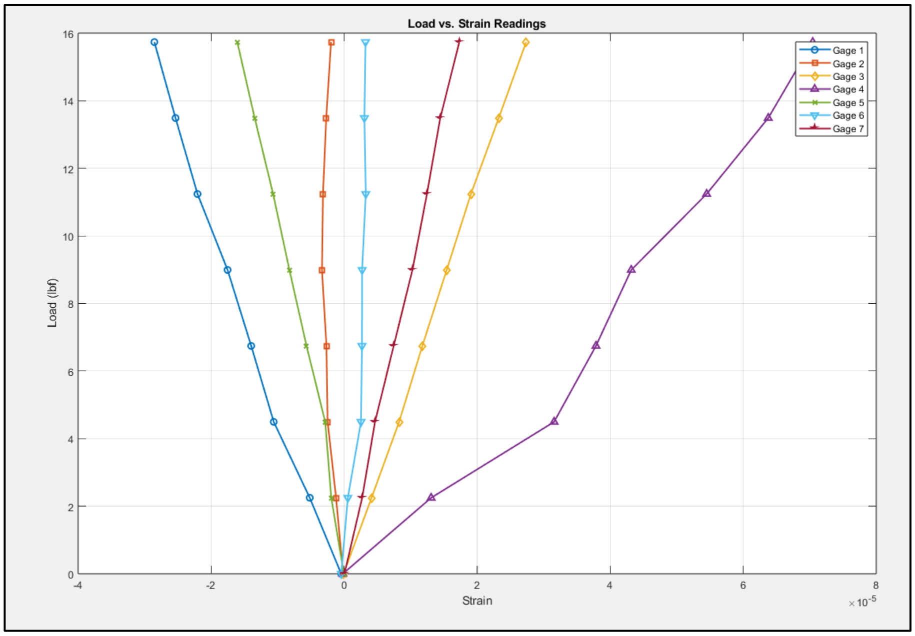

Figure 2

The data in figure 2 illustrates the correlation between the applied load and the strain readings from all strain gauges. As expected, the strain shows a proportional increase with the load applied, with gauges located farther from the neutral axis registering greater strain values. This observation aligns with theoretical predictions, indicating that strain should vary linearly with the distance from the neutral axis. There is some slight deviation, likely due to human error.

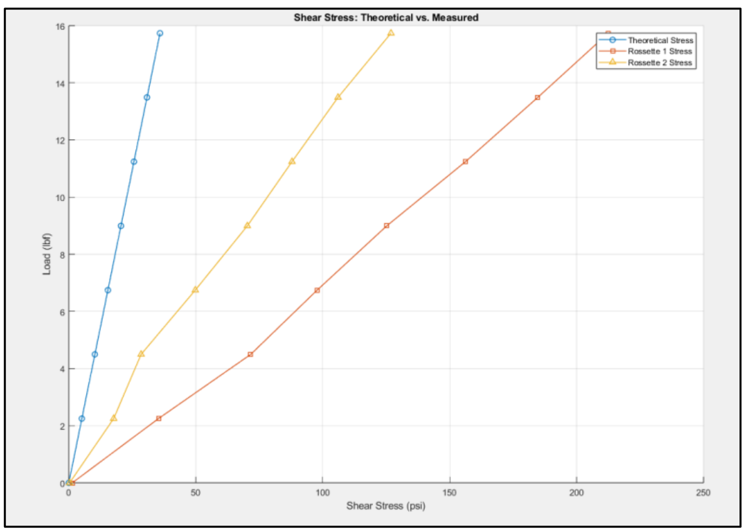

Figure 3

In Figure 3, we compare the experimental shear stress, calculated from strain gauge readings at the sides (gages 1, 2, 3, 5, 6, and 7) of the shaft, with the theoretical values we calculated. The experimental data aligns closely with the theoretical predictions, following a linear trend as expected in bending. Small errors between the two curves could be attributed to small errors in how the strain gauge was aligned, or variations in the shaft's material properties. Since each rosette was placed on opposite sides of the beam, it makes sense to see that the error is different from each rosette. Despite this, the data agrees overall and confirms the accuracy of the stress calculations and supports what we expect.

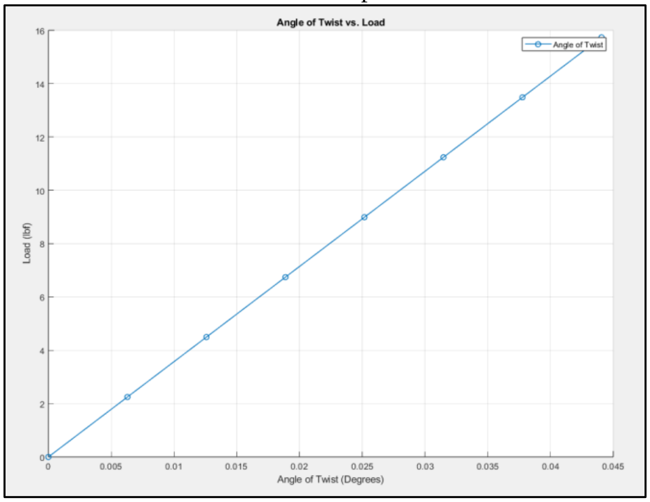

Figure 4

In Figure 4, the calculated angle of twist is plotted against the applied load. The data demonstrates a correlation between the applied load and the resulting angle of twist, confirming the expected relationship that increased loading leads to greater torsional deformation. The trend follows the theoretical predictions outlined in Equation 12, reflecting the material's response under torsional stress. Errors might have arisen from experimental limitations, including variations in material properties and alignment of measurement devices, but overall, the results support the anticipated behavior of the aluminum I-beam under torsional loads.

IV. Conclusion

In this experiment, we investigated the torsional behavior of a hollow aluminum shaft under applied loads, utilizing strain gauges to measure the angle of twist. The gauges were placed along the shaft, and we ensured that all connections to the LabVIEW system were properly configured for data collection. The results revealed a correlation between the applied load and the angle of twist as well as between the shear stress and applied load, consistent with theoretical expectations based on theory.

However, factors such as misalignment of the strain gauges or variations in material properties could have affected the accuracy of the measurements. Future investigations should focus on improving the alignment of strain gauges and refining the calibration process of the data acquisition system to ensure better outcomes. Overall, this experiment successfully demonstrated the relationship between applied load and torsional deformation, validating the use of strain gauges for analyzing shear stress in structural components.

Appendix

```
% Structures Lab 2
% James Garmon
clear;clc; close all;

% Import Data
Data = readcell("Lab2_data.xlsx");

Width = Data(2:end,1);
Width = cell2mat(Width);
Width = Width(1,1);% Beam Width [in]

Thick = Data(2:end,2);
Thick = cell2mat(Thick);
```

```
% Structures Lab 3
% James Garmon
clear;clc; close all;
% Import Data from Excel
Data = readcell("Lab3_data.xlsx");
% Extract relevant data (Tube dimensions, Gage locations, Load, etc.)
TubeOuterD = cell2mat(Data(2:end,1));
TubeOuterD = TubeOuterD(1,1);  % Tube Outer Diameter [in]
TubeThickness = cell2mat(Data(2:end,2));
TubeThickness = TubeThickness(1,1);  % Tube Thickness [in]
TubeLength = cell2mat(Data(2:end,3));
TubeLength = TubeLength(1,1);  % Tube Length [in]
GageLoc = cell2mat(Data(2:end,4));
GageLoc = GageLoc(1,1);  % Gage Location from Root [in]
Arm = cell2mat(Data(2:end,5));
Arm = Arm(1,1);  % Arm Length [in]
Load = cell2mat(Data(2:end,6)) ./ 4.448;  % Load [N -> lbf]
% Convert strain data from microstrain to strain
Gage1 = cell2mat(Data(2:end,7)) * 1e-6;
Gage2 = cell2mat(Data(2:end,8)) * 1e-6;
Gage3 = cell2mat(Data(2:end,9)) * 1e-6;
Gage4 = cell2mat(Data(2:end,10)) * 1e-6;
Gage5 = cell2mat(Data(2:end,11)) * 1e-6;
Gage6 = cell2mat(Data(2:end,12)) * 1e-6;
Gage7 = cell2mat(Data(2:end,13)) * 1e-6;
% Material properties
E = 10000000; % [psi]
G = 3800000;  % [psi]
v = 0.33;     % Poisson's Ratio
% Plot load vs. strain for each gage
figure;
plot(Gage1, Load, 'o-', 'DisplayName', 'Gage 1', 'LineWidth', 1.5); hold on;
plot(Gage2, Load, 's-', 'DisplayName', 'Gage 2', 'LineWidth', 1.5);
plot(Gage3, Load, 'd-', 'DisplayName', 'Gage 3', 'LineWidth', 1.5);
plot(Gage4, Load, '^-', 'DisplayName', 'Gage 4', 'LineWidth', 1.5);
plot(Gage5, Load, 'x-', 'DisplayName', 'Gage 5', 'LineWidth', 1.5);
plot(Gage6, Load, 'v-', 'DisplayName', 'Gage 6', 'LineWidth', 1.5);
plot(Gage7, Load, 'p-', 'DisplayName', 'Gage 7', 'LineWidth', 1.5);
xlabel('Strain');
ylabel('Load (lbf)');
title('Load vs. Strain Readings');
legend show; grid on; hold off;
% Calculate theoretical shear stress
J = (pi / 32) * (TubeOuterD^4 - (TubeOuterD - 2 * TubeThickness)^4);  % Polar moment
of inertia
T = Load .* Arm;  % Torque
tau_theoretical = (T .* 2) ./ (TubeOuterD .* J);  % Theoretical shear stress
% Calculate shear stress from strain gage rosette
gamma_xy1 = Gage3 - Gage1;
tau_rossette1 = gamma_xy1 .* G;
gamma_xy2 = Gage7 - Gage5;
tau_rossette2 = gamma_xy2 .* G;
% Plot shear stress vs. load (theoretical vs. measured)
figure; hold on;
```

```
plot(tau_theoretical, Load, 'o-', 'DisplayName', 'Theoretical Stress', 'LineWidth',
1);
plot(tau_rossette1, Load, 's-', 'DisplayName', 'Rossette 1 Stress', 'LineWidth', 1);
plot(tau_rossette2, Load, '^-', 'DisplayName', 'Rossette 2 Stress', 'LineWidth', 1);
xlabel('Shear Stress (psi)');
ylabel('Load (lbf)');
title('Shear Stress: Theoretical vs. Measured');
legend show; grid on; hold off;
% Calculate angle of twist
theta = (T .* TubeLength) ./ (G .* J) * (180 / pi);  % Angle of twist [degrees]
% Plot angle of twist vs. load
figure; hold on;
plot(theta, Load, 'o-', 'DisplayName', 'Angle of Twist', 'LineWidth', 1);
xlabel('Angle of Twist (Degrees)');
ylabel('Load (lbf)');
title('Angle of Twist vs. Load');
legend show; grid on; hold off;
```