Lab 8 – Thin-walled section and shear center

Section 5, Group 5
Ethan Pickard, Isaac Pollard, Joseph Spewock, Lucas Tavares
11/03/2023

Introduction

Thin-walled sections play a pivotal role in aerospace structures due to their lightweight yet robust characteristics. Understanding their response to non-uniform loads is essential for the safe design of aircraft components, and the concept of the shear center is instrumental in such analysis. This laboratory experiment aims to empirically investigate the shear centers of open thin-walled sections and validate the theoretical principles presented in the lecture.

In the lab, the specimens will be mounted, and the initial twist angles will be measured. Weights will be applied at various locations, and the twist angles will be recorded to determine shear centers. The report will analyze the data, make comparisons to theoretical predictions, and emphasize the practical importance of shear centers in aerospace structures. This knowledge is critical for the design of efficient and safe aerospace components.

Objective

The objective of this lab was to test open thin-walled sections of materials and apply the shear center theory to these cross sections when there are masses applied to the sides of the beams.

Hypothesis

Prior to the experiment, hypotheses are formulated based on pre-lab preparations and the theoretical understandings of shear centers in thin-walled sections. It is expected that experimental measurements of shear centers in open thin-walled sections will closely align with their theoretical predicted values. Theoretical calculations provide specific locations for shear centers, reinforcing the anticipation that experimental data will validate these predictions. Any initial angles of twist observed are presumed to be minor and manageable, allowing for precise measurement and correction. A linear relationship between twist angles and crossbar locations is hypothesized, simplifying the accurate determination of shear centers. Additionally, applying loads at the shear center is predicted to result in minimal deflection in a selected specimen, highlighting the practical importance of shear centers in maintaining structural integrity under load. These hypotheses serve as a framework for expectations and will be instrumental in assessing the experiment's outcomes in relation to theoretical predictions.

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Variables

Table 1. List of variables

Symbol	Definition	Unit
h	height	inches
b	base	inches
t	thickness	inches
I	Moment of inertia	$inches^4$
e	Shear center	inches
π	pi	unitless
θ	twist angle	degrees
r	radius	inches
OD	outer diameter	inches
Y_R	Distance from initial height on right side	inches
Y_L	Distance from initial height on left side	Inches
L	Length of the bar	inches
m	Mass of test weight	kg

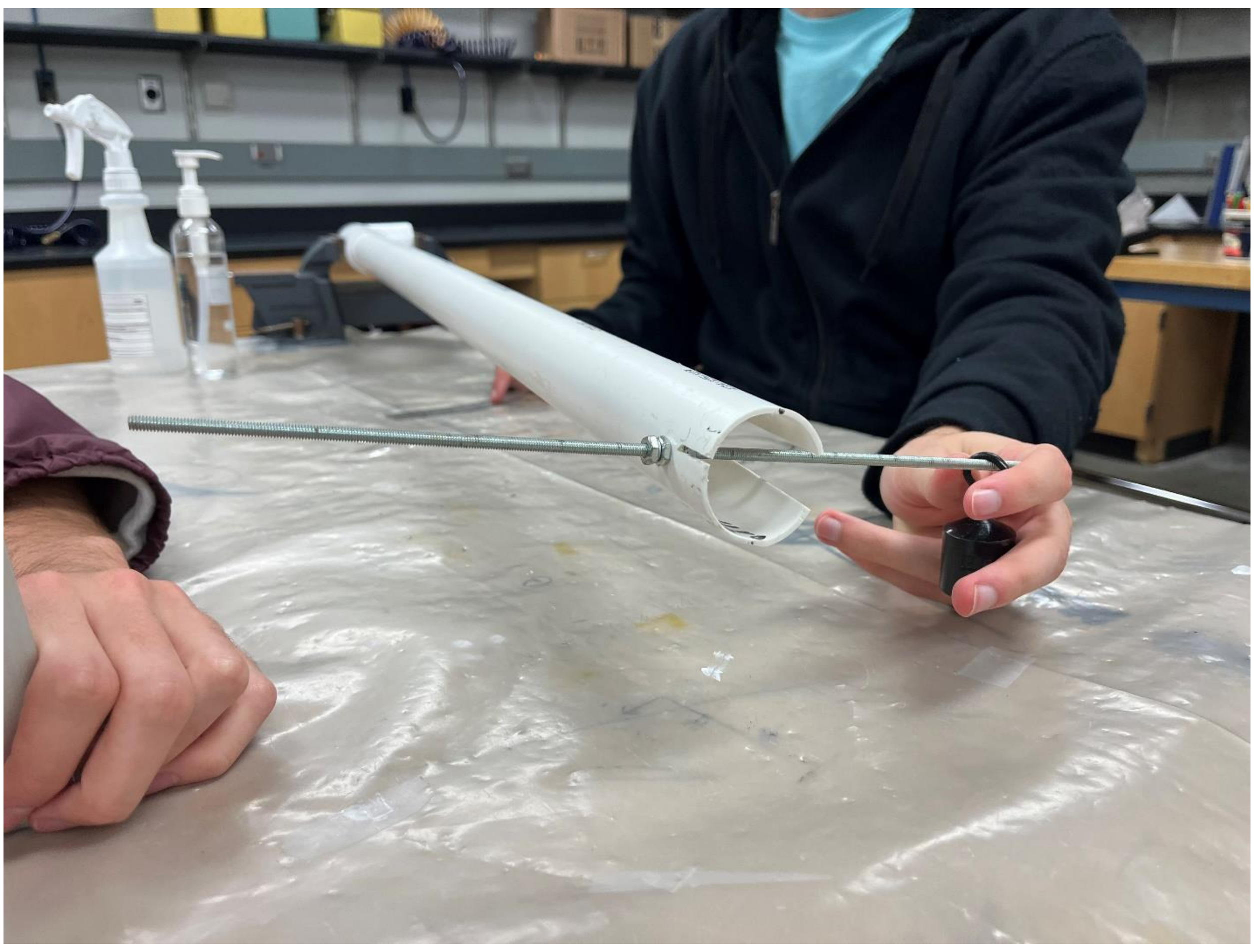
Work Assignments

For the in-lab assignments, Ethan did the recording of the data, and then Isaac, Lucas and Joseph alternated putting the weight on the specimen and measuring the deflection distances of the cross section.

For the report Ethan did the introduction, hypothesis, variables, and the tabulation of data in the data section. Isaac did the materials, apparatus, procedures section and part of the analysis. Joseph did the objective, part of the variables and part of the analysis. Lucas did the conclusion.

Materials, Apparatus, Procedures

The materials for this experiment consisted of five different section specimens, each held in a vice at one end and an unsupported cross bar at the other, two of the specimens were rectangular c-channel cross sections, the other three were cylindrical. To conduct the experiment, we also needed a set of weights and measuring tools. The test itself involved placing the weight at a varying distance along the crossbar with respect to the centroidal cross section. This was done 4 times per specimen. Twice on the right-hand side, twice on the left, at a different distance each time. For each test, the distance of the mass from the crossbar was measured, as well as the vertical displacement of the left and right crossbars. For specimen one, we were given a 100g mass and were also tasked with measuring the total displacement of the specimen beam due to bending, as well as its length. For specimens 2-5, the same procedure was conducted, making sure to measure both the distances and displacements as well as the length of the cross bar left and right side. All these values would be necessary in computing angle of twist due to the force and finally interpolating to find shear center.



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Data

Positive location of weight to the left, resulting in a positive angle of twist when the structure twists counterclockwise.

Table 2. Specimen 1 measurements

Specimen 1(.1 kg)					
	Height of crossbar (in.)	Location of weight (in.)	Height of left side (in.)	Height of right side (in.)	Twist angle θ (degrees)
Test 1	4.4 in (left side) 4.6 in (right side)	-5 (left side)	2.5	6.6	8.51
Test 2		-1 (left side)	4.2	4.8	3.00
Test 3		3 (right side)	6.85	1.75	-3.33
Test 4		5 (right side)	6.25	4.5	-5.16

Table 3. Specimen 2 measurements

Specimen 2(.2 kg)					
	Height of crossbar (in.)	Location of weight (in.)	Height of left side (in.)	Height of right side (in.)	Twist angle θ (degrees)
Test 1	4.5	-2 (left side)	3.9	5	5.26
Test 2		-5 (left side)	3	5.75	13.25
Test 3		2 (right side)	5	3.8	-5.74
Test 4		3 (right side)	5.25	3.5	-8.39

Table 4. Specimen 3 measurements

Specimen 3(.2 kg)					
	Height of crossbar (in.)	Location of weight (in.)	Height of left side (in.)	Height of right side (in.)	Twist angle θ (degrees)
Test 1	4.1	-3 (left side)	1.5	5.75	20.74
Test 2		-0.5 (left side)	2.1	4.7	12.51
Test 3		2 (right side)	4.5	2.9	-7.66
Test 4		3.5 (right side)	4.9	2.4	-12.02

Table 5. Specimen 4 measurements

Specimen 4(.1 kg)					
	Height of crossbar (in.)	Location of weight (in.)	Height of left side (in.)	Height of right side (in.)	Twist angle θ (degrees)
Test 1	4.0	-4 (left side)	2.9	5	10.08
Test 2		-2 (left side)	3.5	4.25	3.58
Test 3		1.5 (right side)	4.3	3.4	-4.30
Test 4		2.5 (right side)	4.5	3	-7.18

Table 6. Specimen 5 measurements

Specimen 5(.1 kg)					
	Height of crossbar (in.)	Location of weight (in.)	Height of left side (in.)	Height of right side (in.)	Twist angle θ (degrees)
Test 1	5.0	5 (left side)	3	7	19.47
Test 2		2 (left side)	4	5.75	8.39
Test 3		-3 (right side)	6.5	3	-16.96
Test 4		-2 (right side)	6	3.5	-12.02

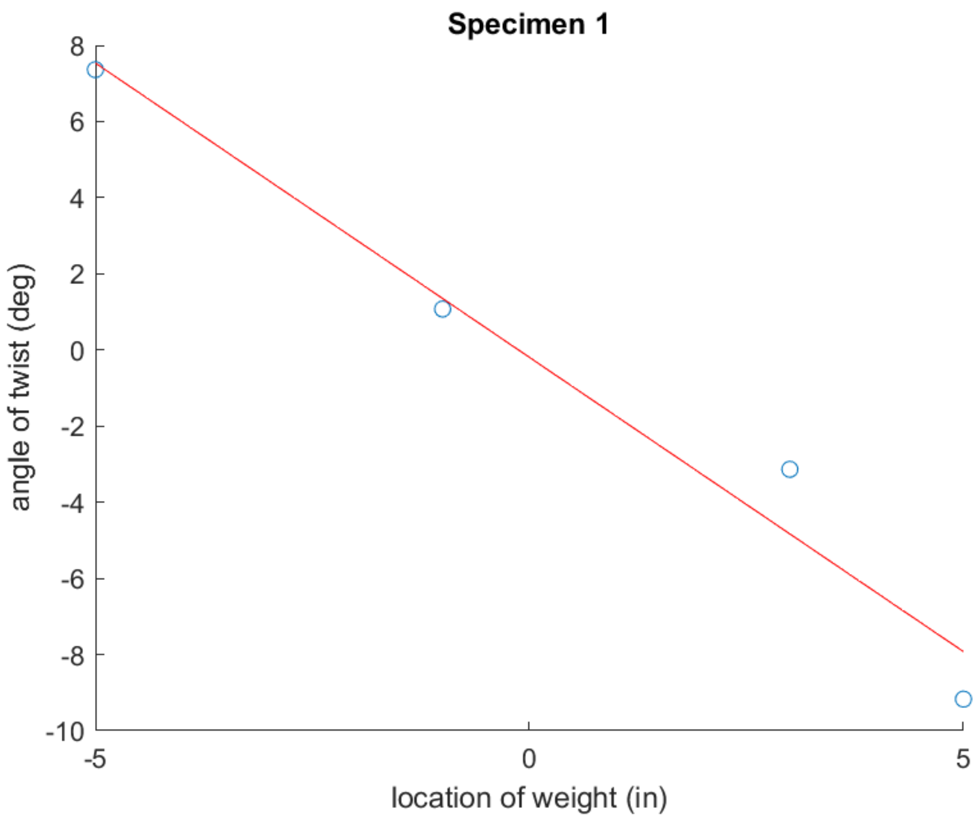

Figure 1: Scatter plot and line of best fit for specimen 1

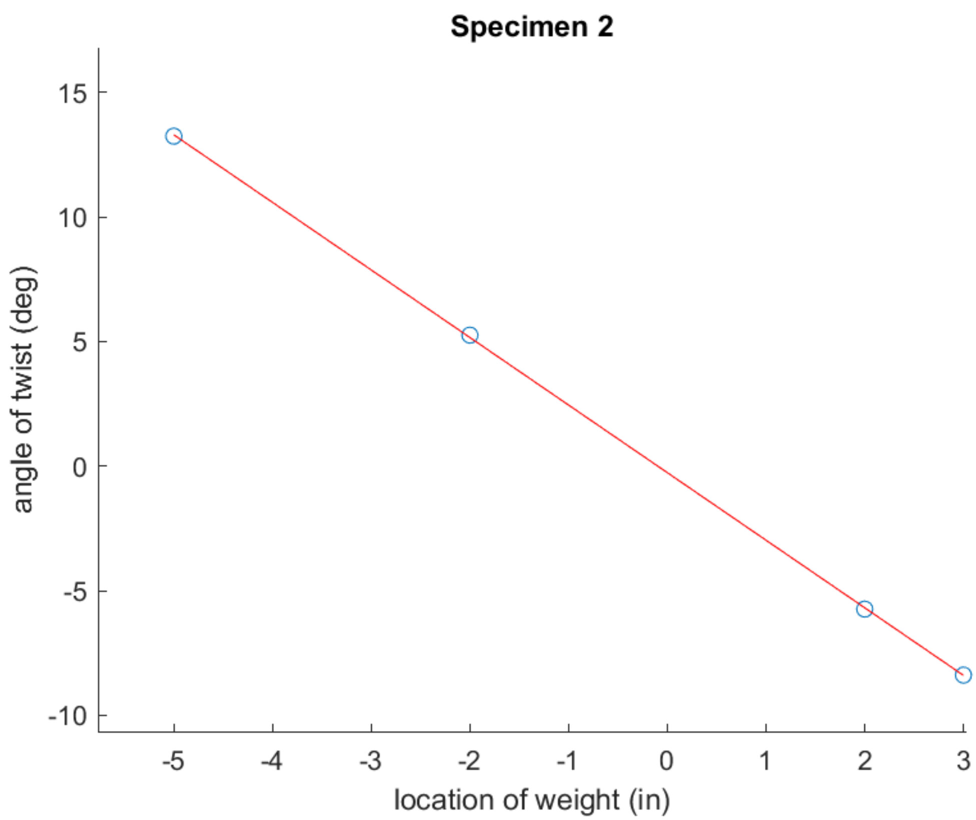

Figure 2: Scatter plot and line of best fit for specimen 2

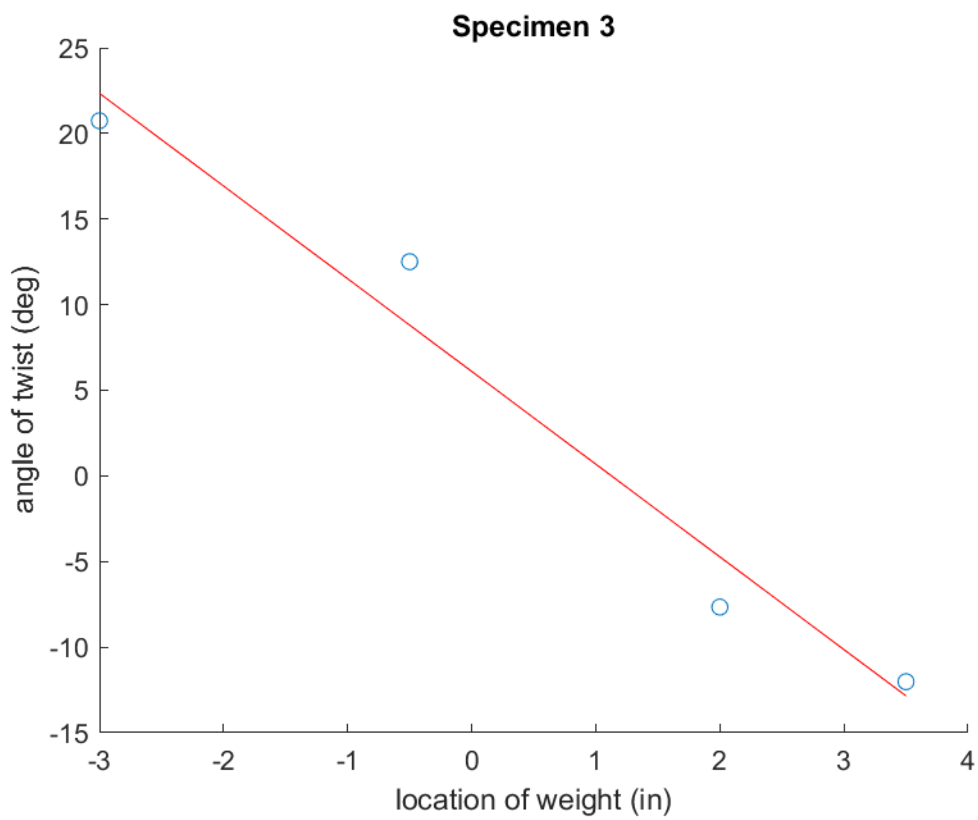

Figure 3: Scatter plot and line of best fit for specimen 3

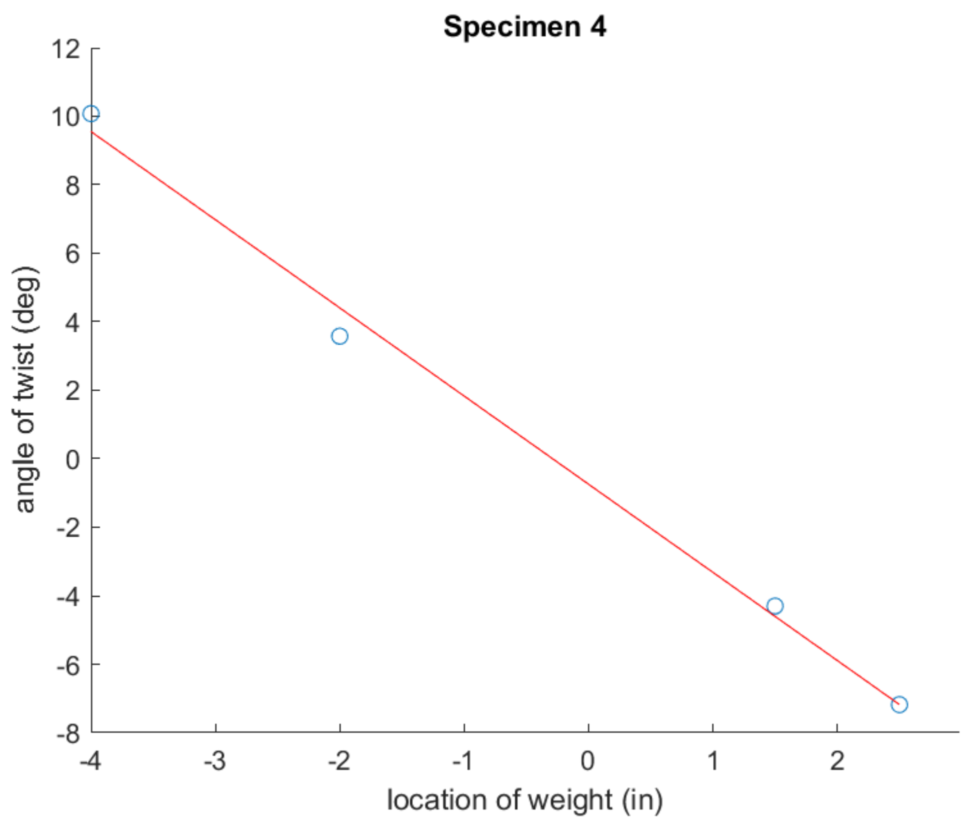

Figure 4: Scatter plot and line of best fit for specimen 4

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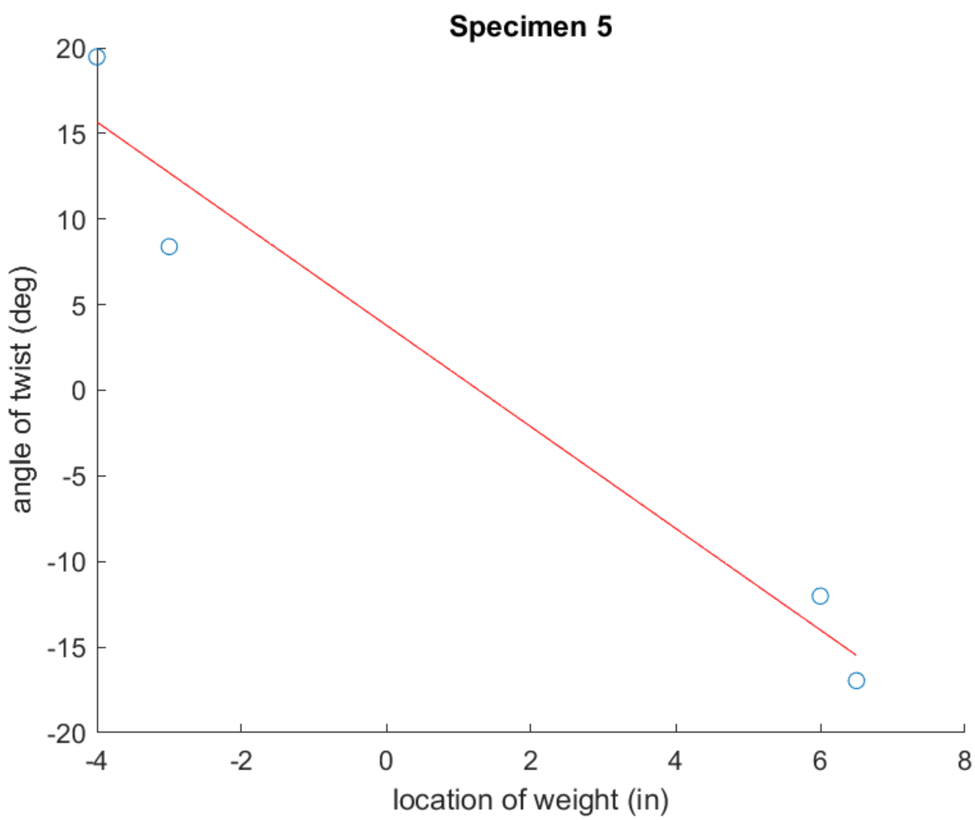


Figure 5: Scatter plot and line of best fit for specimen 5

Analysis

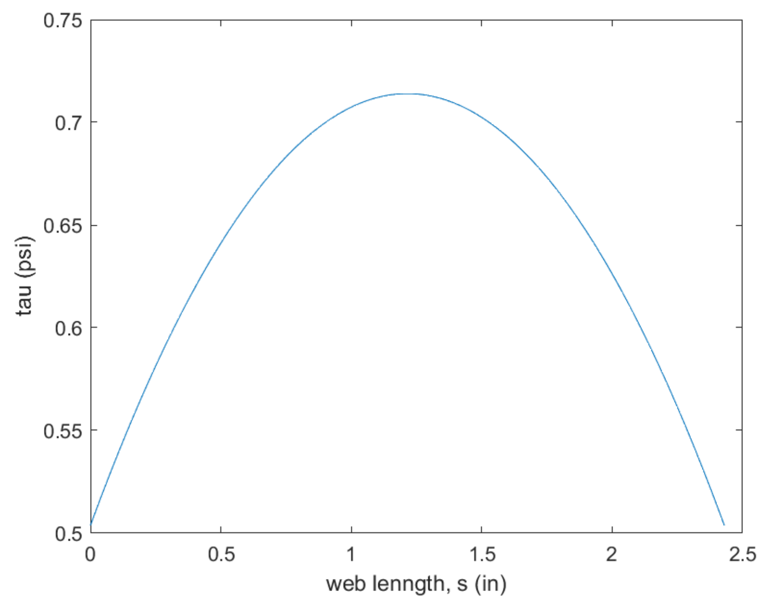
I.

Specimen ID	Theoretical shear center (in)	Experimental shear center (in)
I	0.5816	1.06
II	0.2323	-0.1
III	1.5884	1.13
IV	1.5253	-0.2883
V	1.2654	1.278

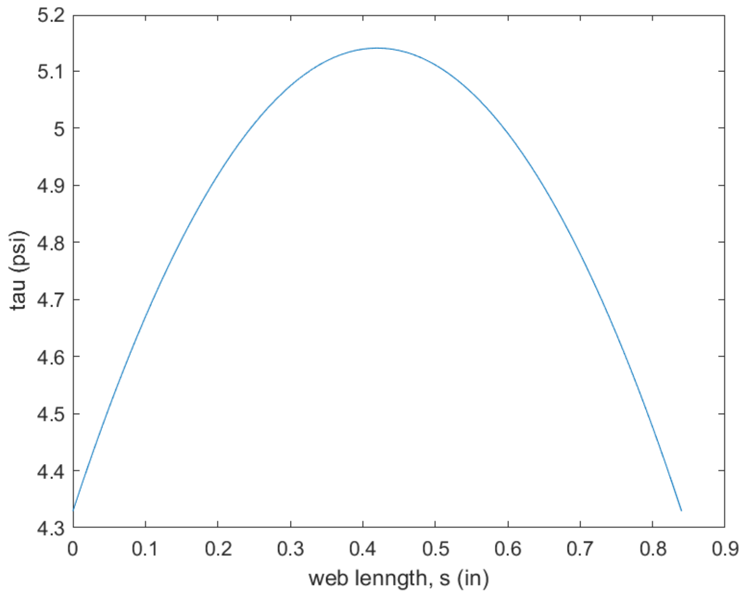
As you can see above there are some very large discrepancies between the theoretical shear center and the experimental shear center that was calculated. There could be multiple reasons for this, some of which being corrupted data that was used for the calculations, or that the calculated theoretical shear stress was incorrect.

II. For beam deflection analysis we can use the formula $\delta = \frac{PL^3}{3*E*I}$ that was given in EM 324. The elastic modulus for this material is 3 GPa, the moment of inertia is 6.5911*10^4 mm^4. The force acting on the beam was 0.1*9.81 = 0.981 Newtons. Finally, the length was 17.25 in which can be converted to 438.15 mm. This brings us to a final deflection value of 0.417 millimeters or 0.0164 inches, which matches what we experimentally acquired in the lab.

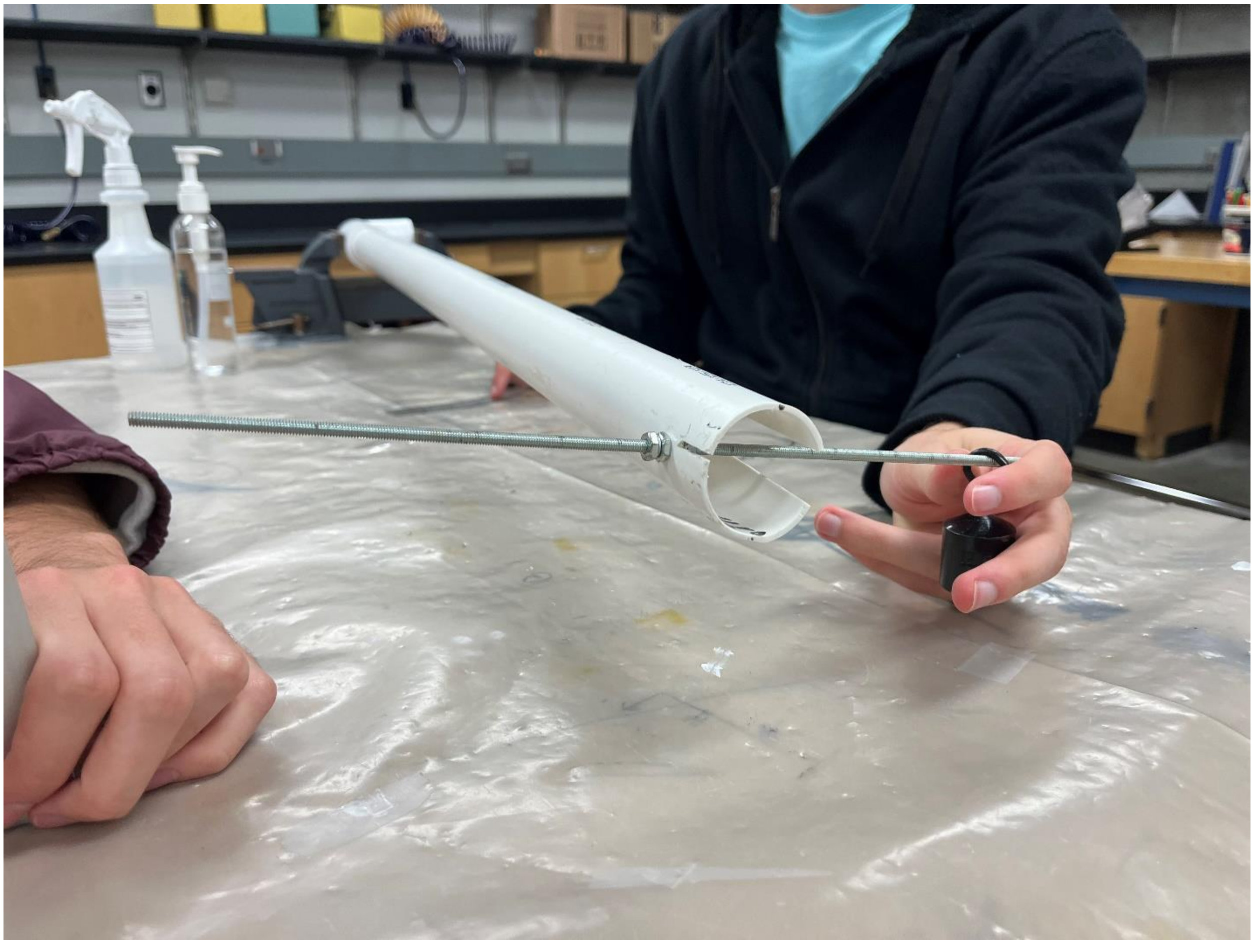
III. For the flange of the C-channels, the shear stress distribution can be found by a simplification of the line integral multiplied by the shear force which is equal to the force on the weight due to vertical equilibrium. Since the contents of the integral are constant, it can be evaluated as $\tau = \frac{Vhs}{2I}$, for s=b this is .5038 psi and for the web the integral becomes $\frac{V}{I}\int_0^s\left(\frac{h}{2} - s\right)ds + \tau_{0,}$, where tau0 is the value of the shear stress distribution at the flange. Evaluating the integral, we get 1.54s - .633s^2 + tau0. Plotting this through the whole length of the flange for specimen 1, we get:



For specimen 2, tau flange, uses the same equation with s = b2, which equals 4.329 psi. And the line integral for the web becomes tau = 3.87s – 46s^2 + tau0. Plotting this for h from 0 to .84:



V. With a hundredfold increase in web length h, the location of the shear center would decrease proportionally by a significant margin. From a physical viewpoint this would seem to be due to



the far greater influence of the vertical section compared with the shorter horizontal sections, so the ratio between the rigidity of the two components would be significantly more weighted towards the vertical section. An example for specimen one shows the exact theoretical value of e with a hundredfold increase:

$$e = \frac{b^2 h^2 t}{\frac{2 b t^3}{3} + \frac{t\,(h-t)^3}{3} + 4 b h^2 t}, \ e(h*100) = .0244$$

Mathematically we can show this relationship by taking the limit of e, with respect to the web length as it heads to infinity with L'Hopital's rule:

```
emax = limit(e,h,inf)
```

using MATLAB, gives a value of 0, which is mathematically accurate and verifies our initial estimate.

VI. If both r and theta were to increase simultaneously, the sinusoid would oscillate, causing the radius to eventually dominate. Visually this would look like an expanding open circle with a simultaneous widening opening. In a similar fashion, we can take the limit of the circular expression for shear center as theta heads to pi, and since r is a singular term, we can then surmise it's behavior from the following expression. Using L'Hopital's rule the sinusoids would remain while the solitary theta terms would disappear.

e = $\frac{2\,r\;(2\sin(\theta) - \cos(\theta)\;(2\,\theta - 2\,\pi))}{2\,\pi - 2\,\theta + \sin(2\,\theta)}$, lim e (h->pi) = r

From this we can very easily predict the behavior of the shear center as r increases, since the shear center simply reaches a maximum value of r.

Conclusion

Significant disparities were observed between the theoretically predicted shear centers and the experimentally determined values, suggesting potential data inaccuracies or calculating theoretical models that require further investigation. Using the δ=(PL^3)/(3EI) formula, the deflection analysis closely matched experimental measurements. An increase in web length (h) caused a proportional shift in the shear center, emphasizing the importance of understanding the relative rigidity of different components in thin-walled sections. The shear center's behavior was found to follow a predictable sinusoidal pattern as r and θ changed, with a maximum value of r confirmed through theoretical analysis.

In conclusion, this experiment confirmed the practical importance of shear centers in aerospace engineering and the value of theoretical models in predicting the behavior of thin-walled sections, even tough some discrepancies between theory and experiment were observed. The knowledge gained from this experiment is essential for designing aerospace components that are both lightweight and strong, especially when dealing with uneven loads. This balance is vital for ensuring the safety and efficiency of aerospace structures.

References

Chiou, Thomas. "Lab 8 thin-walled section and shear center (starts Oct 26).pdf" Iowa State University. 2023

```
clear, clc, close all

%Plot 1
twist1 = [8.51 3 -3.33 -5.16];
dist1 = [-5 -1 5 3];
figure(1)
scatter(dist1,twist1)
title('Speciman 1')
xlabel('location of weight')
ylabel('angle of twist')
hold on
p = polyfit(dist1,twist1,1);
SCloc1 = -p(2)/p(1);
x_val = min(dist1):0.1:max(dist1);
y_val = polyval(p,x_val);
plot(x_val,y_val,'r')

% plot 2
twist2 = [5.26 13.25 -5.74 -8.39];
dist2 = [-2 -5 2 3];
figure(2)
scatter(dist2,twist2)
title('Speciman 2')
xlabel('location of weight')
ylabel('angle of twist')
hold on
p = polyfit(dist2,twist2,1);
SCloc2 = -p(2)/p(1);
x_val = min(dist2):0.1:max(dist2);
y_val = polyval(p,x_val);
plot(x_val,y_val,'r')


% Plot 3
twist3 = [20.74 12.51 -7.66 -12.02];
dist3 = [-3 -0.5 2 3.5];
```

```
figure(3)
scatter(dist3,twist3)
title('Speciman 3')
xlabel('location of weight')
ylabel('angle of twist')
hold on
p = polyfit(dist3,twist3,1);
SCloc3 = -p(2)/p(1);
x_val = min(dist3):0.1:max(dist3);
y_val = polyval(p,x_val);
plot(x_val,y_val,'r')


% plot 4
twist4 = [10.08 3.58 -4.3 -7.18];
dist4 = [-4 -2 1.5 2.5];
figure(4)
scatter(dist4,twist4)
title('Speciman 4')
xlabel('location of weight')
ylabel('angle of twist')
hold on
p = polyfit(dist4,twist4,1);
SCloc4 = -p(2)/p(1);
x_val = min(dist4):0.1:max(dist4);
y_val = polyval(p,x_val);
plot(x_val,y_val,'r')

% plot 5
twist5 = [19.47 8.39 -16.96 -12.02];
dist5 = [-3 -4 6.5 6];
figure(5)
scatter(dist5,twist5)
title('Speciman 5')
xlabel('location of weight')
ylabel('angle of twist')
hold on
p = polyfit(dist5,twist5,1);
SCloc5 = -p(2)/p(1);
x_val = min(dist5):0.1:max(dist5);
y_val = polyval(p,x_val);
plot(x_val,y_val,'r')
```