AERO 40008

Structures 1

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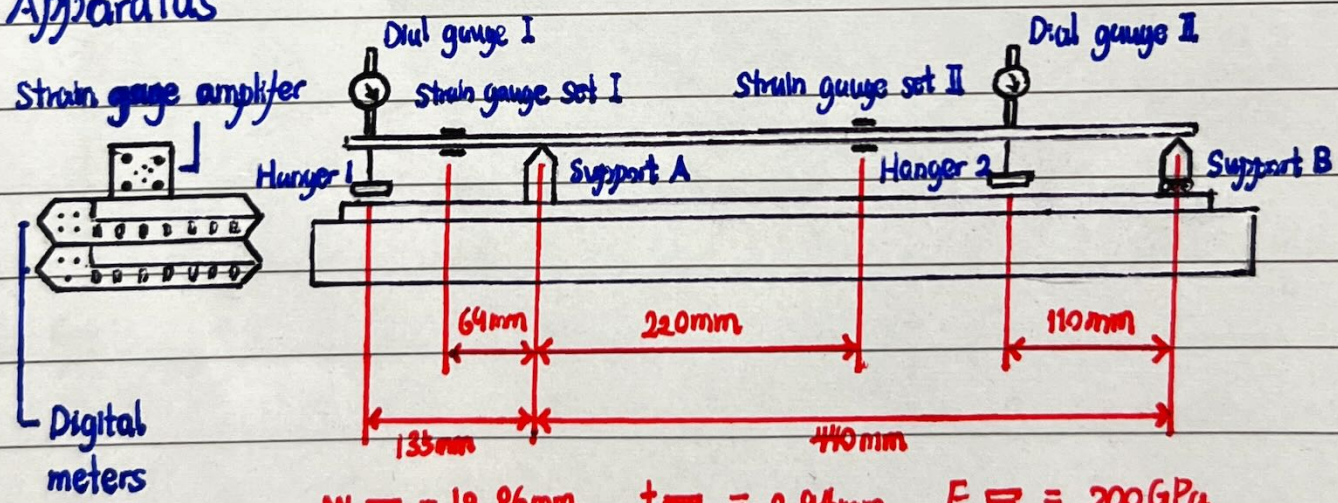
3/8/2023 Simple Beams Pre-Lab

Aiming

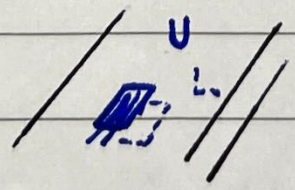
- 👁 behaviour of simple beam structures
  application of linear superposition
- ✓ response of a statically indeterminate beam
  → superposition of two statically determinate beams
- 👁 sensitivity of statically determine/indeterminate beams
  → change the height of a support
- compare experiment with theory

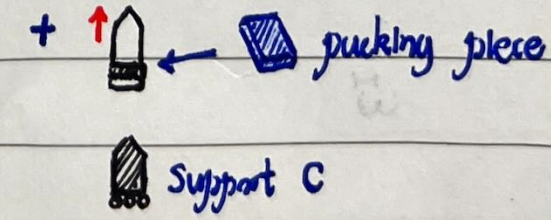
Apparatus



w = = 18.86mm , t = = 2.94mm , E = = 200GPa

* strain gauge





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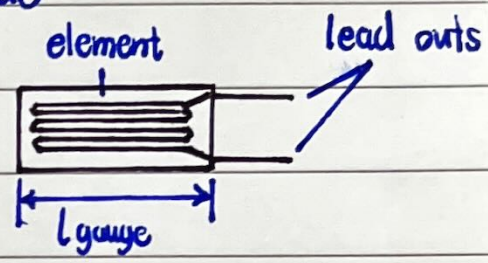
Procedure

- Reset equipment
- Connect the strain gauge, zero the SGA output in '~~200mV~~ 2V' scale

According to the Strain Measurement Pre-Lab

$R = \rho \frac{L}{A}$

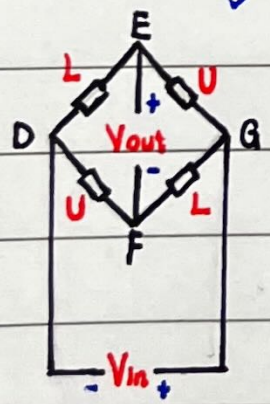


If ε is not too large

$\frac{\Delta R}{R} = S\varepsilon$

└ gauge factor = 2.12

└ measured by Wheatbridge since it is very small



$V_s = 1V$, GAIN = 500

$V_{out} = V_{in}\left[\frac{\Delta U}{U} - \frac{\Delta L}{L} + \frac{\Delta U}{U} - \frac{\Delta L}{L}\right]$

$\bar{V}_{out} = GAIN \cdot V_{out}$

$\varepsilon = \frac{\frac{\Delta R}{R}}{S} = \frac{V_{out}}{V_{in} S} = \frac{\bar{V}_{out}}{V_{in} S \cdot GAIN}$

If $\bar{V}_{out} = 1mV$, $V_{out} = 0.9433962264 \mu\varepsilon$*

① Apply load to Hanger 1

→ 20N at beginning 5N × 4

→ remove 5N each time

→ record reading

* '200mV' scale might switched as load rises

② Apply load to Hanger 2

→ 40N at beginning 5N × 8

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→ remove 5N each time

→ record reading

③ Apply load to both Hangers

→ 5N to 1 → 10N to 2

→ record reading

×4

→ 5N×4 at 1 → 10N×4 at 2

④ Lift support A

→ insert packing piece at A

→ repeat ①

→ remove packing piece and reset support

⑤ Statically indetermine condition

→ replace Hanger 1 by support C

→ 40N at Hanger 2 at beginning 5N×8

→ remove 5N each time

→ record reading

⑥ Lift support A in statically indetermine condition

→ repeat ④

→ repeat ⑤

Prepare an excel sheet to record the data

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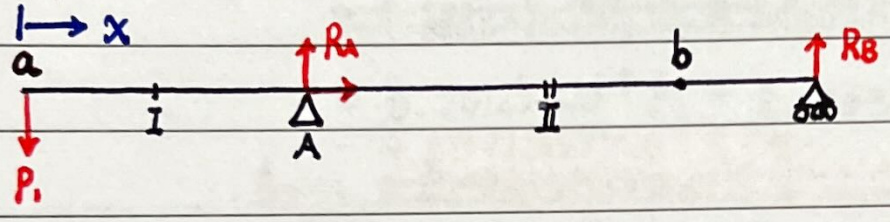
Prediction by theory

* ↻ ↺ positive

* calculate in m

① Apply load to Hanger 1



$E = 200\,GPa$

$l = 575\,m$

$w = 18.86\,mm$

$t = 2.94\,mm$

$I_x = 1.21766715 \times 10^{-9}\,m^4$

$P_1 + R_A + R_B = 0$

(B), $440 R_A + 575 P_1 = 0$ $\quad \therefore R_A = \frac{115}{88} P_1$ $\quad \therefore R_B = -\frac{27}{88} P_1$

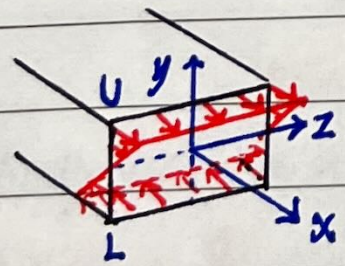
$\therefore M = P_1 x - \frac{115}{88} P_1 \langle x - 0.135 \rangle$

$\therefore M_I = 0.066 P_1$

$M_{II} = 0.355 P_1 - \frac{115}{88} P_1 \langle 0.355 - 0.135 \rangle = 0.0675 P_1$

$M_a = 0$

$M_b = 0.465 P_1 - \frac{115}{88} P_1 \langle 0.465 - 0.135 \rangle = 0.03375 P_1$



$M_y = 0$, $M_z = M$, $\sigma_x = \frac{M_z}{I_z} y = \varepsilon_x E$

$I_z = \frac{(0.01886)(2.94 \times 10^{-3})^3}{12}\,(m^4)$

$\therefore \varepsilon = \frac{M}{I_z E} y$

$\therefore \varepsilon_{U,I} = 1.214587595 \times 10^{-5} P_1$

$\varepsilon_{L,I} = -1.214587595 \times 10^{-5} P_1$

$\varepsilon_{U,II} = 1.242191858 \times 10^{-5} P_1$

$\varepsilon_{L,II} = -1.242191858 \times 10^{-5} P_1$

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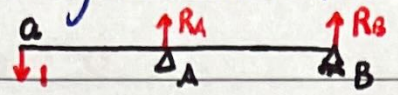
At a,



$\therefore \bar{R}_A = \frac{115}{88}$, $\bar{R}_B = -\frac{27}{88}$

$\therefore \bar{M} = x - \frac{115}{88}\langle x - 0.135\rangle$

$\because 1 \cdot \delta = \int_0^L \frac{M}{EI}\bar{M}\,dx$

$\therefore \delta EI_z = \int_0^{0.135} P_1 x^2\,dx + \int_{0.135}^{0.575} P_1 [x - \frac{115}{88}(x-0.135)]^2\,dx$

$\cancel{= 9.5832\times10^{-5} P_1 + 4.138036111\times10^{-3} P_1}$

$= 8.20125\times10^{-4} P_1 + 2.673\times10^{-3} P_1 = P_1 3.493125\times10^{-3}$

$\therefore \delta_a = \cancel{0.0143435133\ cm} \cancel{1.434351333\times10^{-5} P_1\ cm}$ $4.373022357\times10^{-4} P_1\ (m)$

At b,

$\therefore \bar{R}_A = \frac{1}{4}$, $\bar{R}_B = \frac{3}{4}$

$\therefore \bar{M} = -\frac{1}{4}\langle x - 0.135\rangle + \langle x - 0.465\rangle$

$\cancel{\therefore \delta EI = \int_{0.135}^{0.465} P_1 x [-\frac{1}{4}(x-0.135)]\,dx +}$

$\cancel{+ \int_{0.465}^{0.575} P_1}$

$\therefore \delta EI_z = \int_{0.135}^{0.465} P_1 [x - \frac{115}{88}(x-0.135)][-\frac{1}{4}(x-0.135)]\,dx$

$+ \int_{0.465}^{0.575} P_1 [x - \frac{115}{88}(x-0.135)][-\frac{1}{4}(x-0.135) + (x-0.465)]\,dx$

$= -9.1884375\times10^{-4} P_1 + (-1.0209375\times10^{-4}) P_1$

$= -1.0209375\times10^{-3} P_1$

$\therefore \delta b = \cancel{-4.192186264\times10^{-6}\ cm = P_1\ (m)}$ $-1.278105568\times10^{-4} P_1\ (m)$

② Apply load to Hanger 2

Similar to ①

$R_A = \frac{1}{4}P_2$, $R_B = \frac{3}{4}P_2$, $M = -\frac{1}{4}P_2\langle x - 0.135\rangle + P_2\langle x - 0.465\rangle$

$\therefore M_I = 0$, $M_{II} = -0.055 P_2$

$M_a = 0$, $M_b = -0.0825 P_2$

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$\therefore \varepsilon_{U,I} = 0$

$\varepsilon_{L,I} = 0$

$\varepsilon_{U,II} = \cancel{-6.458214323\times10^{-4}P_2} - 1.012156329\times10^{-5}P_2$

$\varepsilon_{L,II} = \cancel{6.458214323\times10^{-4}P_2} + 1.012156329\times10^{-5}P_2$

At a, $\delta EI_z = \int_{0.135}^{0.465} P_2\left[x - \frac{115}{88}(x-0.135)\right]\left(-\frac{1}{4}(x-0.135)\right]dx$

$+ \int_{0.465}^{0.575} P_2\left[\left(x - \frac{115}{88}(x-0.135)\right)\left(-\frac{1}{4}(x-0.135)\right) + (x-0.465)\right]dx$

$= -9.1884375\times10^{-4}P_2 + (-1.0209375\times10^{-4})P_2$

$= -1.0209375\times10^{-3}P_2$

$\therefore \delta a = \cancel{-4.142186264\times10^{-6}P_2\,(m)} - 1.278105568\times10^{-4}P_2\,(m)$

At b, $\delta EI_z = \int_{0.135}^{0.465} P_2\left(-\frac{1}{4}(x-0.135)\right)^2 dx$

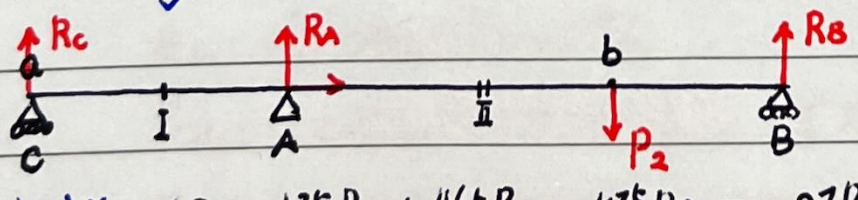
$+ \int_{0.465}^{0.575} P_2\left[-\frac{1}{4}(x-0.135) + (x-0.465)\right]^2 dx$

$= 7.486875\times10^{-4}P_2 + 2.495625\times10^{-4}P_2$

$= 9.9825\times10^{-4}P_2$

$\therefore \delta b = \cancel{4.049026564\times10^{-6}P_2\,(m)}\ 1.249703222\times10^{-4}P_2\,(m)$

③ statically indetermine condition



(C), $-135R_A + 465P_2 - 575R_B = -27R_A + 93P_2 - 115R_B = 0$

(B), $110P_2 - 440R_A - 575R_C = 22P_2 - 88R_A - 115R_C = 0$

$R_C + R_A + R_B = P_2$

$M = EIv'' = -R_C x - R_A\langle x-0.135\rangle + P_2\langle x-0.465\rangle$

$\therefore EIv' = -\frac{1}{2}R_C x^2 - \frac{1}{2}R_A\langle x-0.135\rangle^2 + \frac{1}{2}P_2\langle x-0.465\rangle^2 + C_1$

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$\therefore EIv^{x} = -\frac{1}{6}R_C x^3 - \frac{1}{6}R_A \langle x-0.135\rangle^3 + \frac{1}{6}P_2\langle x-0.465\rangle^3 + C_1 x + C_2$

When $x=0$, $v=0$ $\therefore C_2 = 0$

When $x = 0.575$, $v=0$

$\therefore -575^3 R_C - 440^3 R_A + 110^3 P_2 + 3450 C_1 = 0$

When $x = 0.135$, $v=0$

$\therefore -135^3 R_C + 810 C_1 = 0$

$\therefore -179630000 R_C - 85184000 R_A + 1331000 P_2 = 0$

$\therefore R_A = 0.6314 P_2 = \frac{91}{144} P_2$

$R_B = 0.6603 P_2 = \frac{243}{368} P_2$

$R_C = -0.2923 P_2 = -\frac{121}{414} P_2$ $\therefore C_1 = \cancel{\frac{81675}{92} P_2}$ $-8.8777\times10^{-4} P_2$

$\therefore M = +\frac{121}{414} P_2 x - \frac{91}{144}\langle x-0.135\rangle P_2 + P_2\langle x-0.465\rangle$

$\therefore M_I = \cancel{\frac{363}{4200} P_2}$ $\frac{1331}{64000} P_2$

$M_{II} = \cancel{\frac{8041}{33120} P_2}$ $-\frac{649}{18400} P_2$

$\therefore \varepsilon_{U,I} = \cancel{2.265054619\times10^{-4} P_2}$ $3.549881617\times10^{-6} P_2$

$\varepsilon_{L,I} = -3.549881617\times10^{-6} P_2$

$\varepsilon_{U,II} = \cancel{4.467912298\times10^{-5} P_2}$ $-6.491002546\times10^{-5} P_2$

$\varepsilon_{L,II} = \cancel{4.467912298\times10^{-5} P_2}$ $6.491002546\times10^{-6} P_2$

When $x = 0.465$,

$EI_2 v = \cancel{6.998600543\times10^{-4} P_2 - 1.525487172\times10^{-3} P_2}$ $6.998600543\times10^{-4} P_2$

$\therefore \delta_{II}(\downarrow) = \cancel{2.813774062\times10^{-6} P_2 \text{ (m)}}$ $8.761506286\times10^{-5} P_2$ (m)

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- Correct SGA output from 200 mV to 2V scale
- Is the relationship in Wheatstone bridge vaild ?

  $\varepsilon = \bar{V}_{out} \cdot (\frac{1}{1mV} \cdot 0.943\mu)$

  * linear ?

  ** Excited V_s is seperate from the voltage that measured
- When will the approximation by theory invaild ?

  * Exceed the small angle approximation
- Why 6 tests carried out instead of 1 ?
- Any errors/ uncertainties need to be considered ?
- When insert support C, the beam displace according to the deflection gauge !

- Error might occurs, remember to recording

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		Load Hanger 1 (N)	Load Hanger 2 (N)	Strain Gauge 1 (V)	Strain Gauge 2 (V)	Deflection Gauge 1 (mm)	Deflection Gauge 2 (mm)
Uncertainty				0.001	0.001	0.001	0.001
Error				0.004	0.001	0	0
Test 1	Loading Hanger 1	0	0	-0.038	0.007	0	0.001
		5	0	0.015	0.061	-2.055	0.567
		10	0	0.073	0.12	-4.233	1.18
		15	0	0.135	0.172	-6.251	1.741
		20	0	0.189	0.235	-8.451	3.393
	Unloading Hanger 1	20	0	0.189	0.235	-8.451	3.393
		15	0	0.135	0.176	-6.4	1.806
		10	0	0.073	0.119	-4.256	1.185
		5	0	0.017	0.064	-2.21	0.617
		0	0	-0.038	0.007	-0.002	-0.015
Test 2	Loading Hanger 2	0	0	-0.004	-0.04	0	0
		0	5	-0.002	-0.092	0.535	-0.577
		0	10	0	-0.136	1.111	-1.184
		0	15	0	-0.193	1.794	-1.853
		0	20	-0.006	-0.24	2.369	-2.451
		0	25	-0.005	-0.291	2.972	-3.08
		0	30	-0.006	-0.341	3.555	-3.688
		0	35	-0.007	-0.426	4.208	-4.334
		0	40	-0.006	-0.485	5.02	-5.033
	Unloading Hanger 2	0	40	-0.006	-0.485	5.02	-5.033
		0	35	-0.004	-0.442	4.435	-4.462
		0	30	-0.003	-0.398	3.86	-3.866
		0	25	-0.004	-0.352	3.182	-3.203
		0	20	-0.005	-0.297	2.614	-2.614
		0	15	-0.002	-0.238	1.935	-1.952
		0	10	-0.007	-0.196	1.372	-1.343
		0	5	-0.005	-0.134	0.593	-0.631
		0	0	-0.006	-0.088	0.045	-0.033
Test 3	Simultaneous Loading	0	0	-0.04	0.004	-0.001	0
		5	10	0.014	-0.031	-0.828	-0.603
		10	20	0.077	-0.07	-1.704	-1.193
		15	30	0.133	-0.104	-2.62	-1.774
		20	40	0.194	-0.14	-3.605	-2.328
	Simultaneous Unloading	20	40	0.194	-0.14	-3.605	-2.328
		15	30	0.134	-0.105	-2.656	-1.778
		10	20	0.075	-0.071	-1.791	-1.191
		5	10	0.014	-0.029	-0.879	-0.619
		0	0	0.004	0.04	-0.001	0
Test 4	Insert packing A and Simultaneous Loading	0	0	-0.038	0.007	7.883	1.537
		5	10	0.018	-0.032	7.082	0.912
		10	20	0.073	-0.064	6.123	0.346
		15	30	0.137	-0.1	5.195	-0.229
		20	40	0.195	-0.137	4.337	-0.825
	Insert packing A and Simultaneous Unloading	20	40	0.195	-0.137	4.337	-0.825
		15	30	0.135	-0.101	5.191	-0.236
		10	20	0.08	-0.064	6.107	0.326
		5	10	0.015	-0.028	7.004	0.912
		0	0	-0.038	0.007	7.883	1.537

↓ Hanger 1

↓ Hanger 2

↓ both hanger ↓

↓ packing ↓ A ⇧

Statically determine condition

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		Load Hanger 1 (N)	Load Hanger 2 (N)	Strain Gauge 1 (V)	Strain Gauge 2 (V)	Deflection Gauge 1 (mm)	Deflection Gauge 2 (mm)
Uncertainty				0.001	0.001	0.001	0.001
Error				0.004	0.001	0	0
Test 5	Loading Hanger 2 ↓2	0	0	0.005	-0.198	-0.428	0.1
		0	5	0.018	-0.241	-0.428	-0.323
		0	10	0.038	-0.285	-0.428	-0.766
		0	15	0.053	-0.323	-0.426	-1.25
		0	20	0.07	-0.363	-0.425	-1.689
		0	25	0.09	-0.401	-0.424	-2.134
		0	30	0.109	-0.447	-0.423	-2.603
		0	35	0.121	-0.484	-0.422	-3.044
		0	40	0.141	-0.516	-0.42	-3.611
	Unloading Hanger 2 ↓2	0	40	0.141	-0.516	-0.42	-3.611
		0	35	0.125	-0.485	-0.422	-3.072
		0	30	0.105	-0.462	-0.423	-2.631
		0	25	0.089	-0.439	-0.425	-2.165
		0	20	0.072	-0.414	-0.426	-1.721
		0	15	0.053	-0.385	-0.427	-1.267
		0	10	0.037	-0.355	-0.428	-0.826
		0	5	0.02	-0.324	-0.429	-0.371
		0	0	0	-0.291	-0.429	0.084
Test 6	Insert packing A and Loading Hanger 2 ↓2+A	0	0	-0.26	0.016	-0.061	-3.803
		0	5	-0.01	-0.013	-0.06	-4.218
		0	10	0.004	-0.044	-0.058	-4.645
		0	15	0.022	-0.071	-0.058	-5.072
		0	20	0.038	-0.099	-0.058	-5.49
		0	25	0.056	-0.131	-0.057	-5.921
		0	30	0.072	-0.161	-0.051	-6.362
		0	35	0.092	-0.195	-0.049	-6.778
		0	40	0.108	-0.22	-0.047	-7.212
	Insert packing A and Unloading Hanger 2 ↓2+A	0	40	0.108	-0.22	-0.047	-7.212
		0	35	0.095	-0.189	-0.046	-6.788
		0	30	0.08	-0.16	-0.047	-6.373
		0	25	0.055	-0.132	-0.049	-5.94
		0	20	0.038	-0.106	-0.05	-5.53
		0	15	0.025	-0.077	-0.052	-5.1
		0	10	0.006	-0.048	-0.053	-4.675
		0	5	-0.014	-0.019	-0.055	-4.257
		0	0	-0.26	0.016	-0.061	-3.803

Statically indetermine condition

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Prediction by theory

* Test 1.2.5 already done in Pre-Lab

* For M, ↺ positive

For ε, extension is positive

For δ, downward ↓ positive

① P_1 at Hanger 1

$$M = P_1 \left(x - \frac{115}{88} P_1 \langle x - 0.135 \rangle \right)$$

$M_I = 66 P_1$ $\qquad$ $M_a = 0$

$M_{II} = 67.5 P_1$ $\qquad$ $M_b = 33.75 P_1$

$\varepsilon_{U,I} = -\varepsilon_{L,I} = 1.214587595 \times 10^{-5} P_1$

$\varepsilon_{U,II} = -\varepsilon_{L,II} = 1.242191858 \times 10^{-5} P_1$

$\delta_a = 4.313022357 \times 10^{-1} P_1$

$\delta_b = -1.278105568 \times 10^{-1} P_1$

② P_2 at Hanger 2

$$M = P_2 \left(-\frac{1}{4} \langle x - 135 \rangle + \langle x - 465 \rangle \right)$$

$M_I = 0$ $\qquad$ $M_a = 0$

$M_{II} = -55 P_2$ $\qquad$ $M_b = -82.5 P_2$

$\varepsilon_{U,I} = -\varepsilon_{L,I} = 0$

$\varepsilon_{U,II} = -\varepsilon_{L,II} = -1.012156329 \times 10^{-5} P_2$

$\delta_a = \cancel{-1.020431515 P_2} \; -1.278105568 \times 10^{-1} P_2$

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$\delta_b = 1.249703222 \times 10^{-1} P_2$

③ P_1 at Hanger 1, P_2 at Hanger 2

$\varepsilon_{u,I} = -\varepsilon_{l,I} = 1.214587595 \times 10^{-5} P_1 + 0$

$\varepsilon_{u,II} = -\varepsilon_{l,II} = 1.242191858 \times 10^{-5} P_1 - 1.012156329 \times 10^{-5} P_2$

$\delta_a = 4.313022357 \times 10^{-1} P_1 - 1.278105568 \times 10^{-1} P_2$

$\delta_b = -1.278105568 \times 10^{-1} P_1 + 1.249703222 \times 10^{-1} P_2$

④ Lift support A then ③

$\varepsilon_{u,I} = -\varepsilon_{l,I} = 1.214587595 \times 10^{-5} P_1 + 0$

$\varepsilon_{u,II} = -\varepsilon_{l,II} = 1.242191858 \times 10^{-5} P_1 - 1.012156329 \times 10^{-5} P_2$

$\delta_a = 4.313022357 \times 10^{-1} P_1 - 1.278105568 \times 10^{-1} P_2 + h_a$

$\delta_b = -1.278105568 \times 10^{-1} P_1 + 1.249703222 \times 10^{-1} P_2 + h_b$

⑤ Stutically indeteminate

$M = \frac{121}{144} P_2 x - \frac{91}{144} \langle x - 135 \rangle P_2 + \langle x - 465 \rangle P_2$

$M_I = \frac{1331}{64000} P_2$

$M_{II} = -\frac{644}{18400} P_2$

$\varepsilon_{u,I} = -\varepsilon_{l,I} = 3.549881617 \times 10^{-6} P_2$

$\varepsilon_{u,II} = -\varepsilon_{l,II} = -6.491002546 \times 10^{-6} P_2$

$\delta_b = 8.761506286 \times 10^{-2} P_2$

⑥ Lift support A then ⑤

ε changes

δ changes

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				Experiment Data								Prediction by theory			
		Load Hanger 1 (N)	Load Hanger 2 (N)	Strain 1	Absolute error	Strain 2	Absolute error	Deflection a (mm)	Absolute error	Deflection b (mm)	Absolute error	Strain 1	Strain 2	Deflection a (mm)	Deflection b (mm)
Test 1	Loading Hanger 1	0	0	0	0	0	0	0	0.001	0	0.001	0	0	0	0
		5	0	0.000049979	0.000004715	0.000050922	0.000001886	-2.055	0.001	0.566	0.001	6.07294E-05	6.21096E-05	-2.186511179	0.639052784
		10	0	0.000104673	0.000004715	0.000106559	0.000001886	-4.233	0.001	1.179	0.001	0.000121459	0.000124219	-4.373022357	1.278105568
		15	0	0.000163139	0.000004715	0.000155595	0.000001886	-6.251	0.001	1.74	0.001	0.000182188	0.000186329	-6.559533536	1.917158352
		20	0	0.000214061	0.000004715	0.000215004	0.000001886	-8.451	0.001	3.392	0.001	0.000242918	0.000248438	-8.746044714	2.556211136
	Unloading Hanger 1	20	0	0.000214061	0.000004715	0.000215004	0.000001886	-8.451	0.001	3.392	0.001	0.000242918	0.000248438	-8.746044714	2.556211136
		15	0	0.000163139	0.000004715	0.000159367	0.000001886	-6.4	0.001	1.805	0.001	0.000182188	0.000186329	-6.559533536	1.917158352
		10	0	0.000104673	0.000004715	0.000105616	0.000001886	-4.256	0.001	1.184	0.001	0.000121459	0.000124219	-4.373022357	1.278105568
		5	0	0.000051865	0.000004715	0.000053751	0.000001886	-2.21	0.001	0.616	0.001	6.07294E-05	6.21096E-05	-2.186511179	0.639052784
		0	0	0	0	0	0	-0.002	0.001	-0.016	0.001	0	0	0	0
Test 2	Loading Hanger 2	0	0	0	0	0	0	0	0.001	0	0.001	0	0	0	0
		0	5	0.000001886	0.000004715	-0.000049036	0.000001886	0.535	0.001	-0.577	0.001	0	-5.06078E-05	0.639052784	-0.624851611
		0	10	0.000003772	0	-0.000090528	0.000001886	1.111	0.001	-1.184	0.001	0	-0.000101216	1.278105568	-1.249703222
		0	15	0.000003772	0	-0.000144279	0.000001886	1.794	0.001	-1.853	0.001	0	-0.000151823	1.917158352	-1.874554833
		0	20	-0.000001886	0.000004715	-0.0001886	0.000001886	2.369	0.001	-2.451	0.001	0	-0.000202431	2.556211136	-2.499406444
		0	25	-0.000000943	0.000004715	-0.000236693	0.000001886	2.972	0.001	-3.08	0.001	0	-0.000253039	3.19526392	-3.124258055
		0	30	-0.000001886	0.000004715	-0.000283843	0.000001886	3.555	0.001	-3.688	0.001	0	-0.000303647	3.834316704	-3.749109666
		0	35	-0.000002829	0.000004715	-0.000363998	0.000001886	4.208	0.001	-4.334	0.001	0	-0.000354255	4.473369488	-4.373961277
		0	40	-0.000001886	0.000004715	-0.000419635	0.000001886	5.02	0.001	-5.033	0.001	0	-0.000404863	5.112422272	-4.998812888
	Unloading Hanger 2	0	40	-0.000001886	0.000004715	-0.000419635	0.000001886	5.02	0.001	-5.033	0.001	0	-0.000404863	5.112422272	-4.998812888
		0	35	0	0	-0.000379086	0.000001886	4.435	0.001	-4.462	0.001	0	-0.000354255	4.473369488	-4.373961277
		0	30	0.000000943	0.000004715	-0.000337594	0.000001886	3.86	0.001	-3.866	0.001	0	-0.000303647	3.834316704	-3.749109666
		0	25	0	0	-0.000294216	0.000001886	3.182	0.001	-3.203	0.001	0	-0.000253039	3.19526392	-3.124258055
		0	20	-0.000000943	0.000004715	-0.000242351	0.000001886	2.614	0.001	-2.614	0.001	0	-0.000202431	2.556211136	-2.499406444
		0	15	0.000001886	0.000004715	-0.000186714	0.000001886	1.935	0.001	-1.952	0.001	0	-0.000151823	1.917158352	-1.874554833
		0	10	-0.000002829	0.000004715	-0.000147108	0.000001886	1.372	0.001	-1.343	0.001	0	-0.000101216	1.278105568	-1.249703222
		0	5	-0.000000943	0.000004715	-0.000088642	0.000001886	0.593	0.001	-0.631	0.001	0	-5.06078E-05	0.639052784	-0.624851611
		0	0	-0.000001886	0.000004715	-0.000045264	0.000001886	0.045	0.001	-0.033	0.001	0	0	0	0
Test 3	Simultaneous Loading	0	0	0	0	0	0	0	0.001	0	0.001	0	0	0	0
		5	10	0.000050922	0.000004715	-0.000033005	0.000001886	-0.827	0.001	-0.603	0.001	6.07294E-05	-3.9106E-05	-0.908405611	-0.610650438
		10	20	0.000110331	0.000004715	-0.000069782	0.000001886	-1.703	0.001	-1.193	0.001	0.000121459	-7.82121E-05	-1.816811221	-1.221300876
		15	30	0.000163139	0.000004715	-0.000101844	0.000001886	-2.619	0.001	-1.774	0.001	0.000182188	-0.000117318	-2.725216832	-1.831951314
		20	40	0.000220662	0.000004715	-0.000135792	0.000001886	-3.604	0.001	-2.328	0.001	0.000242918	-0.000156424	-3.633622442	-2.442601752
	Simultaneous Unloading	20	40	0.000220662	0.000004715	-0.000135792	0.000001886	-3.604	0.001	-2.328	0.001	0.000242918	-0.000156424	-3.633622442	-2.442601752
		15	30	0.000164082	0.000004715	-0.000102787	0.000001886	-2.655	0.001	-1.778	0.001	0.000182188	-0.000117318	-2.725216832	-1.831951314
		10	20	0.000108445	0.000004715	-0.000070725	0.000001886	-1.79	0.001	-1.191	0.001	0.000121459	-7.82121E-05	-1.816811221	-1.221300876
		5	10	0.000050922	0.000004715	-0.000031119	0.000001886	-0.878	0.001	-0.619	0.001	6.07294E-05	-3.9106E-05	-0.908405611	-0.610650438
		0	0	0.000041492	0.000004715	0.000033948	0.000001886	0	0.001	0	0.001	0	0	0	0
Test 4	Insert packing A and Simultaneous Loading	0	0	0	0	0	0	7.883	0.001	1.537	0.001	0	0	7.883	1.537
		5	10	0.000052808	0.000004715	-0.000036777	0.000001886	7.082	0.001	0.912	0.001	6.07294E-05	-3.9106E-05	6.97459439	0.926349562
		10	20	0.000104673	0.000004715	-0.000066953	0.000001886	6.123	0.001	0.346	0.001	0.000121459	-7.82121E-05	6.066188779	0.315699124
		15	30	0.000165025	0.000004715	-0.000100901	0.000001886	5.195	0.001	-0.229	0.001	0.000182188	-0.000117318	5.157783169	-0.294951314
		20	40	0.000219719	0.000004715	-0.000135792	0.000001886	4.337	0.001	-0.825	0.001	0.000242918	-0.000156424	4.249377558	-0.905601752
	Insert packing A and Simultaneous Unloading	20	40	0.000219719	0.000004715	-0.000135792	0.000001886	4.337	0.001	-0.825	0.001	0.000242918	-0.000156424	4.249377558	-0.905601752
		15	30	0.000163139	0.000004715	-0.000101844	0.000001886	5.191	0.001	-0.236	0.001	0.000182188	-0.000117318	5.157783169	-0.294951314
		10	20	0.000111274	0.000004715	-0.000066953	0.000001886	6.107	0.001	0.326	0.001	0.000121459	-7.82121E-05	6.066188779	0.315699124
		5	10	0.000049979	0.000004715	-0.000033005	0.000001886	7.004	0.001	0.912	0.001	6.07294E-05	-3.9106E-05	6.97459439	0.926349562
		0	0	0	0	0	0	7.883	0.001	1.537	0.001	0	0	7.883	1.537

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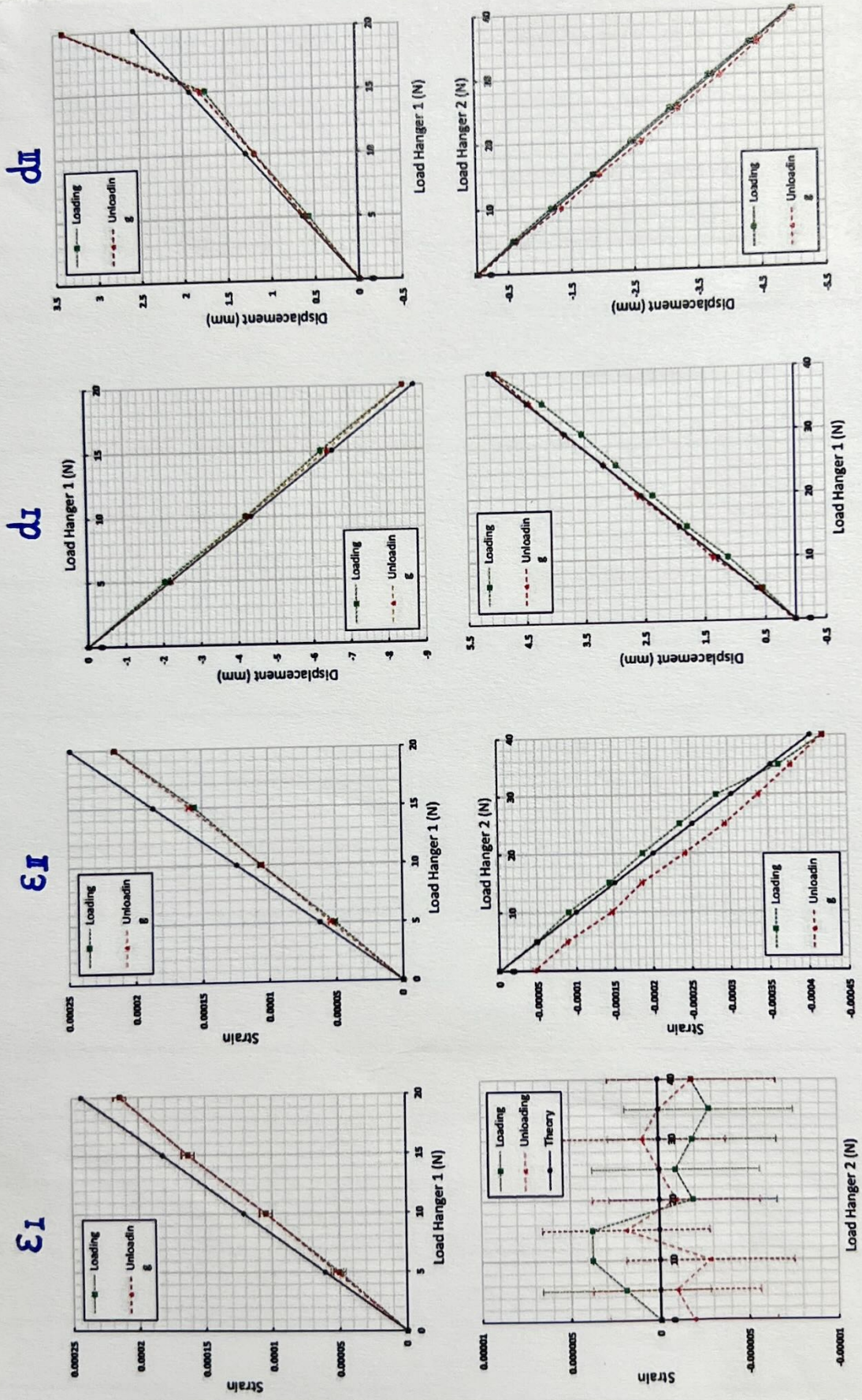

Test 1

Test 2

#4

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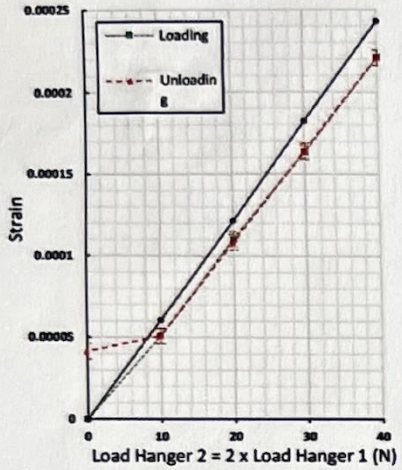
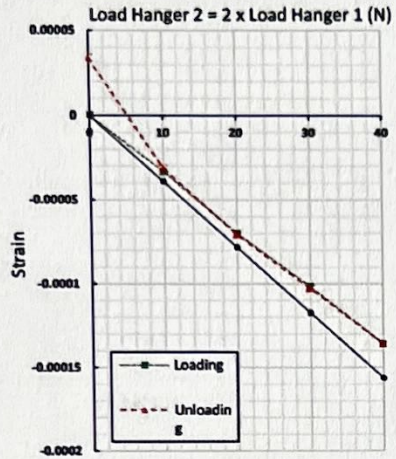
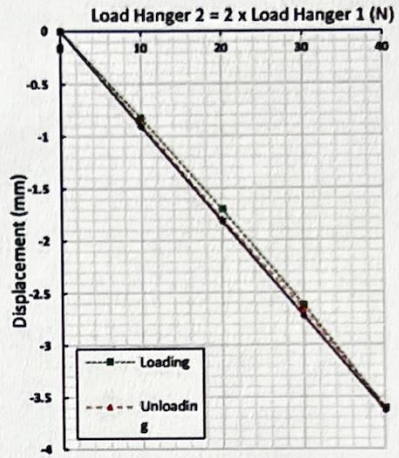
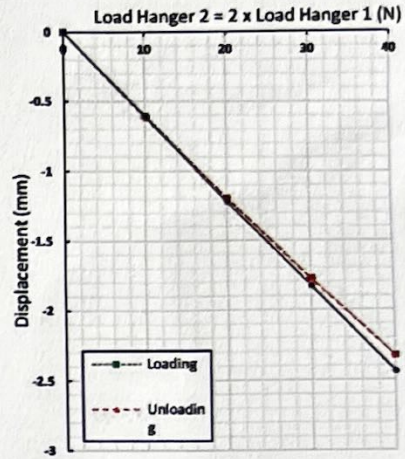
ε_I ε_{II} d_I d_{II}

Test 3

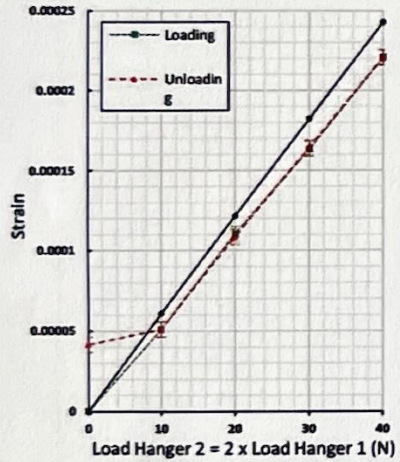


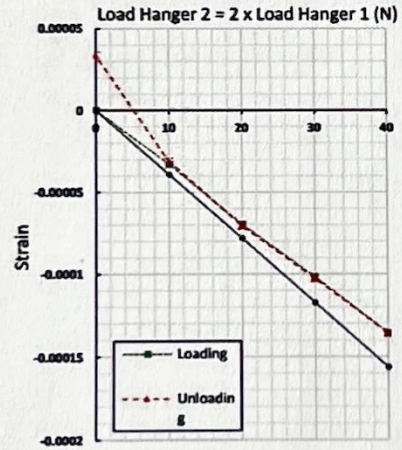


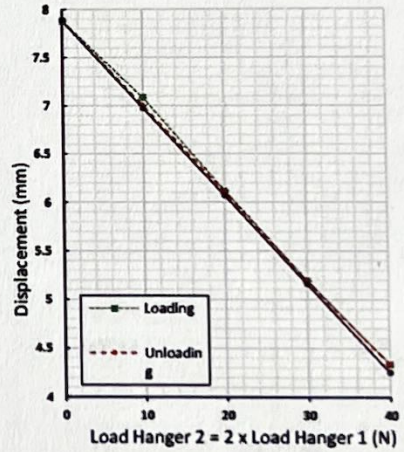


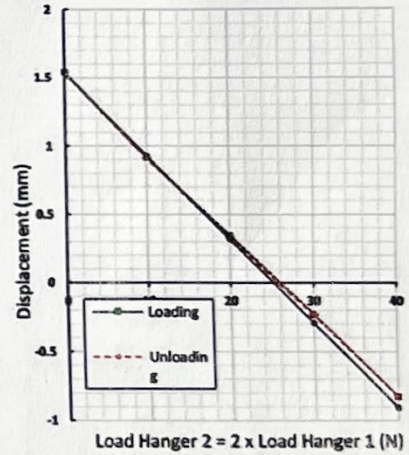


Test 4









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		Experiment Data										Prediction by theory		
		Load Hanger 1 (N)	Load Hanger 2 (N)	Strain 1	Absolute error	Strain 2	Absolute error	Deflection a (mm)	Absolut error	Deflection b (mm)	Absolute error	Strain 1	Strain 2	Deflection b (mm)
Test 5	Loading Hanger 2	0	0	0	0	0	0	-0.428	0,001	0	0,001	0	0	0
		0	5	0.000012259	0.000004715	-0.000040549	0.000001886	-0.428	0.001	-0.423	0.001	1.77494E-05	-3.2455E-05	-0.438075314
		0	10	0.000031119	0.000004715	-0.000082041	0.000001886	-0.428	0,001	-0.866	0,001	3.54988E-05	-6.491E-05	-0.876150629
		0	15	0.000045264	0.000004715	-0.000117875	0.000001886	-0.428	0.001	-1.35	0.001	5.32482E-05	-9.7365E-05	-1.314225943
		0	20	0.000061295	0.000004715	-0.000155595	0.000001886	-0.426	0.001	-1.789	0.001	7.09976E-05	-0.00012982	-1.752301257
		0	25	0.000080155	0.000004715	-0.000191429	0.000001886	-0.425	0.001	-2.234	0.001	8.8747E-05	-0.000162275	-2.190376572
		0	30	0.000098072	0.000004715	-0.000234807	0.000001886	-0.424	0.001	-2.703	0.001	0.000106496	-0.00019473	-2.628451886
		0	35	0.000109388	0.000004715	-0.000269698	0.000001886	-0.423	0.001	-3.144	0.001	0.000124246	-0.000227185	-3.0665272
		0	40	0.000128248	0.000004715	-0.000299874	0.000001886	-0.422	0.001	-3.711	0.001	0.000141995	-0.00025964	-3.504602514
	Unloading Hanger 2	0	40	0.000128248	0.000004715	-0.000299874	0.000001886	-0.422	0.001	-3.711	0.001	0.000141995	-0.00025964	-3.504602514
		0	35	0.00011316	0.000004715	-0.000270641	0.000001886	-0.422	0.001	-3.172	0.001	0.000124246	-0.000227185	-3.0665272
		0	30	0.0000943	0.000004715	-0.000248952	0.000001886	-0.423	0.001	-2.731	0.001	0.000106496	-0.00019473	-2.628451886
		0	25	0.000079212	0.000004715	-0.000227263	0.000001886	-0.425	0.001	-2.265	0.001	8.8747E-05	-0.000162275	-2.190376572
		0	20	0.000063181	0.000004715	-0.000203688	0.000001886	-0.426	0.001	-1.821	0.001	7.09976E-05	-0.00012982	-1.752301257
		0	15	0.000045264	0.000004715	-0.000176341	0.000001886	-0.427	0.001	-1.367	0.001	5.32482E-05	-9.7365E-05	-1.314225943
		0	10	0.000030176	0.000004715	-0.000148051	0.000001886	-0.428	0.001	-0.926	0.001	3.54988E-05	-6.491E-05	-0.876150629
		0	5	0.000014145	0.000004715	-0.000118818	0.000001886	-0.429	0.001	-0.471	0.001	1.77494E-05	-3.2455E-05	-0.438075314
		0	0	-0.000004715	0.000004715	-0.000087699	0.000001886	-0.429	0.001	-0.016	0.001	0	0	0
Test 6	Insert packing A and Loading Hanger 2	0	0	0	0	0	0	-0.061	0.001	-3.803	0.001			
		0	5	0.00023575	0.000004715	-0.000027347	0.000001886	-0.06	0.001	-4.218	0.001			
		0	10	0.000248952	0.000004715	-0.00005658	0.000001886	-0.058	0.001	-4.645	0.001			
		0	15	0.000265926	0.000004715	-0.000082041	0.000001886	-0.058	0.001	-5.072	0.001			
		0	20	0.000281014	0.000004715	-0.000108445	0.000001886	-0.058	0.001	-5.49	0.001			
		0	25	0.000297988	0.000004715	-0.000138621	0.000001886	-0.057	0.001	-5.921	0.001			
		0	30	0.000313076	0.000004715	-0.000166911	0.000001886	-0.051	0.001	-6.362	0.001			
		0	35	0.000331936	0.000004715	-0.000198973	0.000001886	-0.049	0.001	-6.778	0.001			
		0	40	0.000347024	0.000004715	-0.000218399	0.000001886	-0.047	0.001	-7.212	0.001			
	Insert packing A and Unloading Hanger 2	0	40	0.000347024	0.000004715	-0.000218399	0.000001886	-0.047	0.001	-7.212	0.001			
		0	35	0.000334765	0.000004715	-0.000193315	0.000001886	-0.046	0.001	-6.788	0.001			
		0	30	0.00032062	0.000004715	-0.000165968	0.000001886	-0.047	0.001	-6.373	0.001			
		0	25	0.000297045	0.000004715	-0.000139564	0.000001886	-0.049	0.001	-5.94	0.001			
		0	20	0.000281014	0.000004715	-0.000115046	0.000001886	-0.05	0.001	-5.53	0.001			
		0	15	0.000268755	0.000004715	-0.000087699	0.000001886	-0.052	0.001	-5.1	0.001			
		0	10	0.000250838	0.000004715	-0.000060352	0.000001886	-0.053	0.001	-4.675	0.001			
		0	5	0.000231978	0.000004715	-0.000033005	0.000001886	-0.055	0.001	-4.257	0.001			
		0	0	0	0	0	0	-0.061	0.001	-3.803	0.001			

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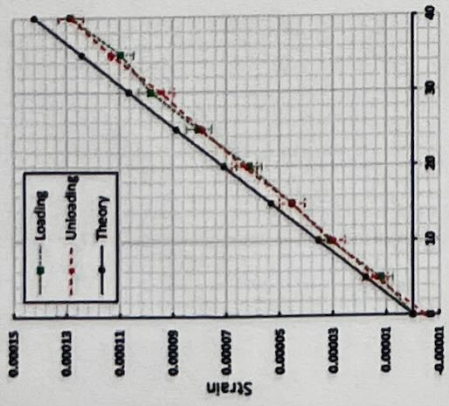
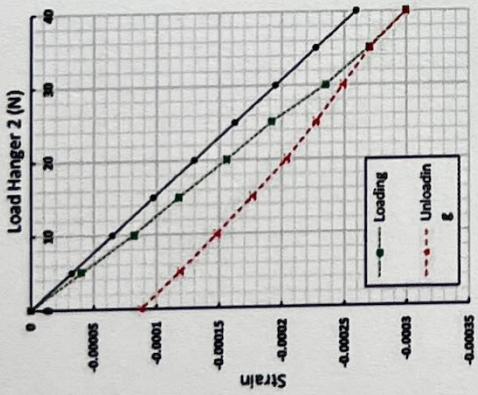
Test 5

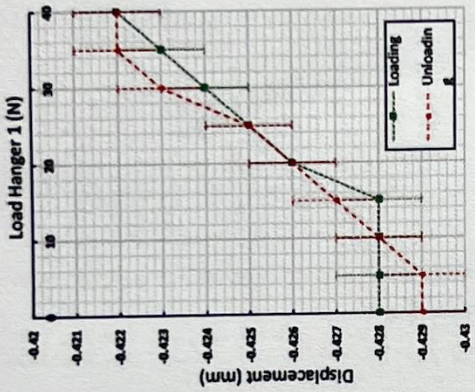
ε_1



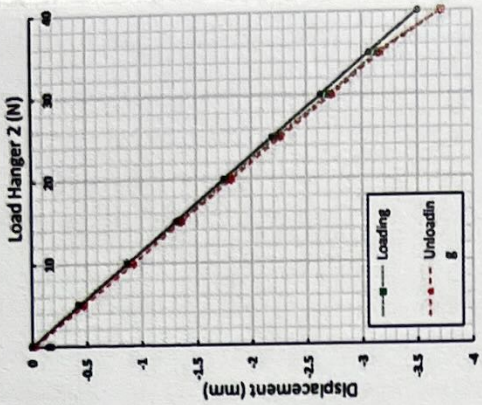
ε_3



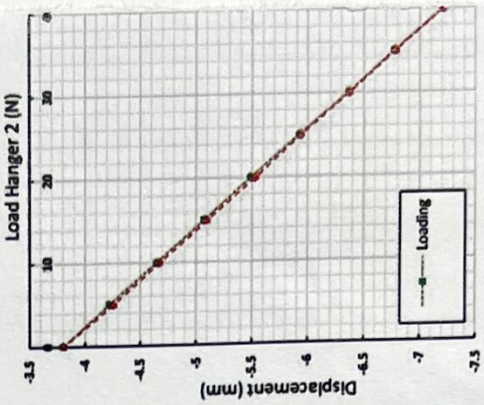
d_1

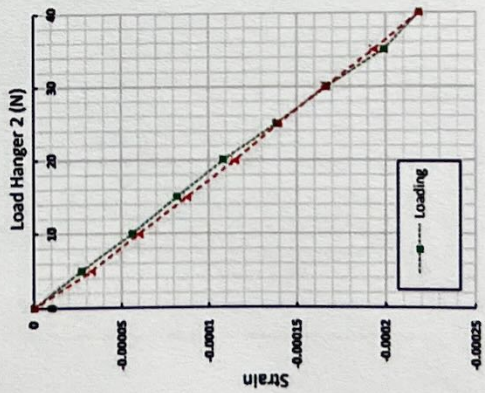


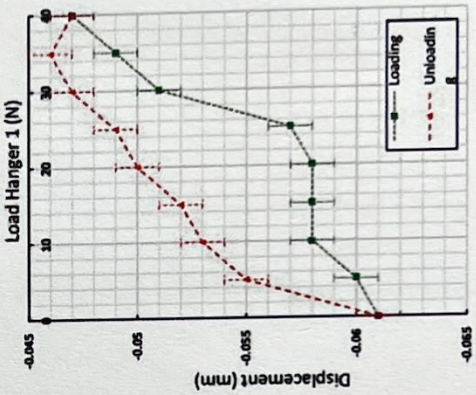
d_2



Test 6







X7

3/10/2023 Simple Beams Post-Lab

Validation Plot matches theory from experiments ✓

Effect of Raising Support see previous page (page 7 Pre-Lab)

stutically determinate strain dont change, displuement change

statically indeterminate strain and displuement change

Validation of superposition

work for stutically determinate beam (Test 3 = Test 1 + Test 2)

Error analysis

- see during-lab parts
- some possible source of error might occurs
  - disturbances on the workbench (工作台) as people leun/hit it
  - uneven loading and sudden jolts to the equipment when loading and unloading the weights may lead errors
  - ☆ small angle approximation becomes invalid at higher loads
  - ☆ hysteresis 迟滞现象 (which can be observed from the data)
  - imperfections in the cross-section of the beam from material cause the different E across the beam

3/10/2023 Simple Beams Post-Lab

Further improvement

- If can, consider if the incremental merit justify the effort
  i.e. consider the error from wearing of the weights

Addition points

About hyteresis:

a. if there are any valid sources of hyteresis:
   1. beam strain a lot;
   2. repeating loading leads fatigue;
   3. loading and unloading;

b. at what relative proportions? that their effects are.

3/23/2023 Pin-jointed Pre-Lab

Design the lab by myself!

Introduction

The aims of the pin-jointed frame lab are:

- to observe and compare the behaviour of statically-determinate and statically-indeterminate pin-jointed frameworks when applying force on it;
- to compare the experimetally observed behaviour with predictions from theory.

Apparatus

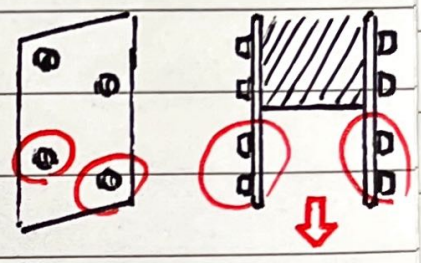
- CST114
- CST100 Structures Platform
- $T_{operating}$ = +5°C to +40°C
- Humidity 湿气 Range = 80% (T < 31°C) $\xrightarrow{\text{linearly}}$ 50% (40°C)
- Hexagon Tools
- Inclinometer 倾角计
- Supports: Pinned (2.8kg) and Roller (2.7kg)
- Upright: Hold supports (3 kg)
- Load cell: Max capacity 650N (1.85kg)

3/23/2023 Pin-jointed Pre-Lab

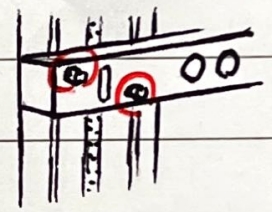
Procedure

1. Setup

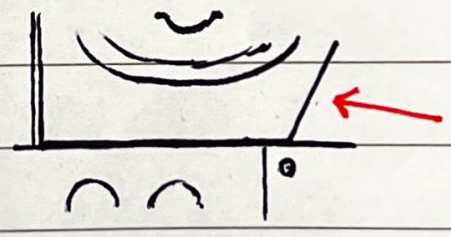
(i) Fixing Upright to CST 100 Structure Platform by M8 Fixings (lower 2 fixings at each side)



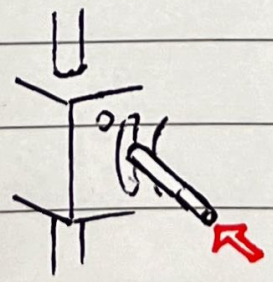
(ii) Fitting the Supports by M8 Fixings (2 fixing at each side at each support - 2 supports in total)



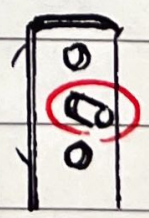
(iii) Using the Inclinometer to make sure supports are tangent to the Upright by reading



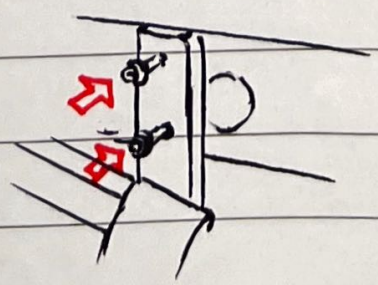
(iv) Fitting the Load Cell Locking Pin, and using Inclinometer to make sure the struss is horizontal for the lowest one

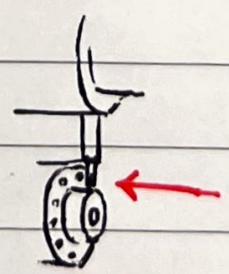


(v) Placed Support Pin in Middle hole of support



(vi) Fitting the Trammel and Dial Indicator by M4 Fixings on the upper support





3/23/2023 Pin-jointed Pre-Lab

(vii) Fitting the Strain Gauge Amplifier to one of the rear beams of the platform and use the cable supplied to connect it's DIGITAL OUTPUT socket to any DIGITAL INPUT sockets on the HUB of the CSTNO Platform

(viii) Connecting the load cell to any of the DIGITAL INPUT sockets on the HUB of the CSTNO Platform

(ix) Fitting the battery into the Dial Indicator

(x) Connecting the cable to the Interface Hub

2. Statically ~~Indeterminate~~ Determine

(i) Checking the temperature and humidity of the laboratory and record if possible. the experiment could not start when temperature and humidity out of range

(ii) Checking if all cables are connected correctly and all devices is turn on

(iii) Setting the Dial Indicator to zero

(iv) Input Calibration Factor of cables and input them into software

(v) Select 'Determinate' tab in software

(vi) Apply load 25N each time from 0N to 400N on load-cell. record deflection and click the record data

3/23/2023 Pin-jointed Pre-Lab

(vii) Reduce load 20N each time from 400N to 0N

same as (vi)

* Noticed that pre-load is 200N

3. Statically Indeterminate

same as process above, despite change tab to 'Indeterminate' at step (v) and add truss '8'

4. After experiment

(i) Reset all reading to zero

(ii) Disallocate CST114 and CST100, go back to the original states

5. Preliminary Data Processing

(i) Plot the deflection curve (Load vs. Deflection) with the experiment value compare to the prediction value to verify the experiment

6. Further Data Processing

(i) Plot the force readings for each truss with load, compare them with the prediction from theory

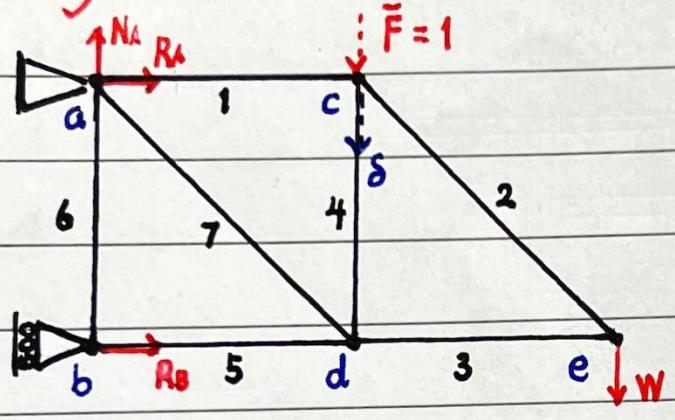
(ii) What could possibly go wrong?

(iii) Plot the error bar by the recorded error from lab alongside the curve.

3/23/2023 Pin-jointed Pre-Lab

Prediction by theory

Statically Determine

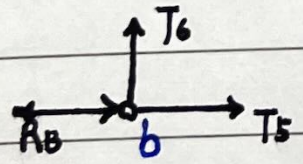


$M = b + r - 2j = 0$

$\Sigma F_x (\uparrow) = N_A - W = 0 \qquad \therefore N_A = W$

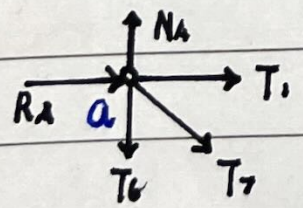
$\Sigma F_y (\rightarrow) = R_A + R_B = 0 \qquad \therefore R_A = -R_B$

$M_b (\circlearrowleft) = R_A L + W(2L) = 0 \qquad \therefore R_A = -2W \qquad \therefore R_B = 2W$



$(\rightarrow)\ R_B + T_5 = 0 \qquad \therefore T_5 = -2W$

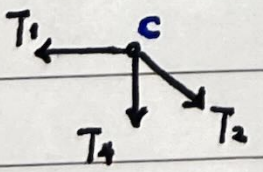
$(\uparrow)\ T_6 = 0$



$(\rightarrow)\ R_A + T_1 + \frac{\sqrt{2}}{2} T_7 = 0$

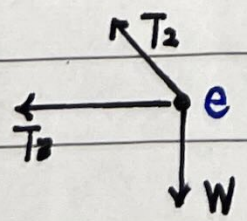
$(\uparrow)\ T_6 + \frac{\sqrt{2}}{2} T_7 = N_A \qquad \therefore T_7 = \sqrt{2} W$

$\therefore T_1 = W$



$(\rightarrow)\ T_1 = \frac{\sqrt{2}}{2} T_2 \qquad \therefore T_2 = \sqrt{2} W$

$(\uparrow)\ T_4 + \frac{\sqrt{2}}{2} T_2 = 0 \qquad \therefore T_4 = -W$



$(\rightarrow)\ T_3 + \frac{\sqrt{2}}{2} T_2 = 0 \qquad \therefore T_3 = -W$

3/23/2023 Pin-jointed Pre-Lab

For virtual work, $\bar{F} = 1$

$\therefore N_A = 1,\ \bar{R}_A = -\bar{R}_B = -1$

At b, $\bar{T}_5 = -1,\ \bar{T}_6 = 0$

At a, $\bar{T}_7 = \sqrt{2},\ \bar{T}_1 = 0$

At c, $\bar{T}_2 = 0,\ \bar{T}_4 = -1$

At e, $\bar{T}_3 = 0$

$$\therefore 1 \cdot \delta = \bar{T}_1 e_1 + \bar{T}_2 e_2 + \dots + \bar{T}_7 e_7$$

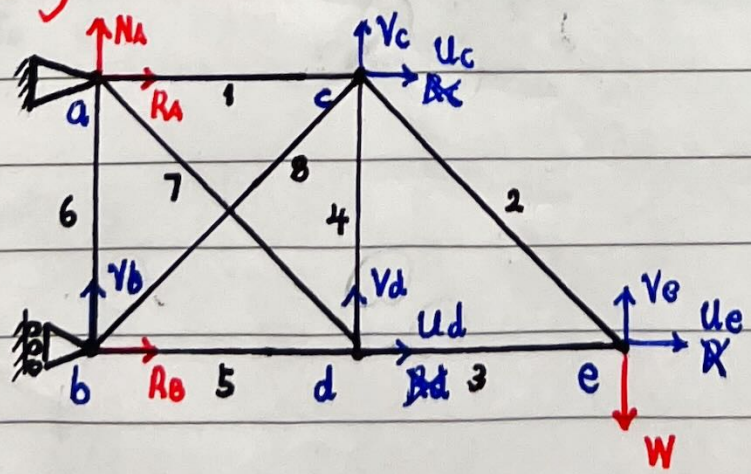
$$= 0 + 0 + 0 + (-1)\cdot\left(\frac{-WL}{AE}\right) + (-1)\cdot\left(\frac{-2WL}{AE}\right) + 0 + \sqrt{2}\cdot\frac{(\sqrt{2}W)(\sqrt{2}L)}{AE}$$

$$\therefore \delta(\downarrow) = (3 + 2\sqrt{2})\frac{WL}{AE}$$

$\therefore T_1 = W,\quad T_2 = \sqrt{2}W,\quad T_3 = -W,\quad T_4 = -W,$

$T_5 = -2W,\quad T_6 = 0,\quad T_7 = \sqrt{2}W$

Stutically Indeterminate



$M = b + r - 2j = 1$

3/23/2023 Pin-jointed Pre-Lab

$e_1 = u_0 = T_1 \frac{L}{AE}$ $\qquad \therefore T_1 = u_c \frac{AE}{L}$

$e_2 = \frac{\sqrt{2}}{2}(v_c - v_e + u_e - u_c) = T_2 \frac{\sqrt{2}L}{AE}$ $\qquad \therefore T_2 = \frac{v_c - u_c - v_e + u_e}{2} \frac{AE}{L}$

$e_3 = u_c - u_d = T_3 \frac{L}{AE}$ $\qquad \therefore T_3 = (u_e - u_d)\frac{AE}{L}$

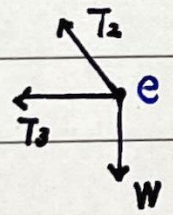
$e_4 = v_c - v_d = T_4 \frac{L}{AE}$ $\qquad \therefore T_4 = (v_c - v_d)\frac{AE}{L}$

$e_5 = u_d = T_5 \frac{L}{AE}$ $\qquad \therefore T_5 = u_d \frac{AE}{L}$

$e_6 = -v_b = -T_6 \frac{L}{AE}$ $\qquad \therefore T_6 = -v_b \frac{AE}{L}$

$e_7 = \frac{\sqrt{2}}{2}(\cancel{v_d} - v_d + u_d) = T_7 \frac{\sqrt{2}L}{AE}$ $\qquad \therefore T_7 = \frac{u_d - v_d}{2} \frac{AE}{L}$

$e_8 = \frac{\sqrt{2}}{2}(v_c - v_b + u_c) = T_8 \frac{\sqrt{2}L}{AE}$ $\qquad \therefore T_8 = \frac{v_c - v_b + u_c}{2} \frac{AE}{L}$

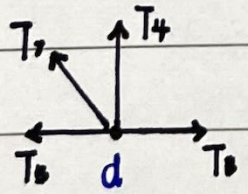


$(\uparrow)\ \frac{\sqrt{2}}{2}T_2 = W$

$\therefore \frac{\sqrt{2}}{4}(v_c - u_c - v_e + u_e)\frac{AE}{L} = W$ ①

$(\rightarrow)\ T_3 + \frac{\sqrt{2}}{2}T_2 = 0$

$\therefore (u_e - u_d)\frac{AE}{L} = -W$ ②

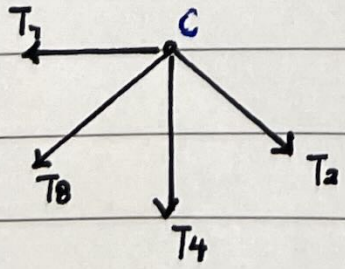


$(\uparrow)\ T_4 + \frac{\sqrt{2}}{2}T_7 = 0$

$\therefore (v_c - v_d - \frac{\sqrt{2}}{4}v_d + \frac{\sqrt{2}}{4}u_d)\frac{AE}{L} = 0$ ③

$(\rightarrow)\ T_3 = T_5 + \frac{\sqrt{2}}{2}T_7$

$\therefore (u_d + \frac{\sqrt{2}}{4}u_d - \frac{\sqrt{2}}{4}v_d)\frac{AE}{L} = -W$ ④



$(\uparrow)\ T_4 + \frac{\sqrt{2}}{2}T_8 + \frac{\sqrt{2}}{2}T_2 = 0$ $\qquad + \frac{\sqrt{2}}{4}u_e - \frac{\sqrt{2}}{4}v_e = 0$

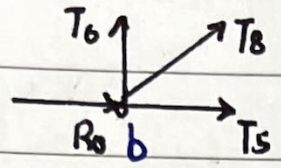
$\therefore (v_c + \frac{\sqrt{2}}{4}v_c + \frac{\sqrt{2}}{4}v_c - v_d - \frac{\sqrt{2}}{4}v_b + \frac{\sqrt{2}}{4}u_c - \frac{\sqrt{2}}{4}u_c$ ⑤

$(\rightarrow)\ T_4 + \frac{\sqrt{2}}{2}T_8 = \frac{\sqrt{2}}{2}T_2$

$\therefore (u_c + \frac{\sqrt{2}}{4}u_c + \frac{\sqrt{2}}{4}v_c - \frac{\sqrt{2}}{4}v_b)\frac{AE}{L} = W$ ⑥

* ⑤ $\rightarrow (v_c + \frac{\sqrt{2}}{4}v_c - v_d - \frac{\sqrt{2}}{4}v_b + \frac{\sqrt{2}}{4}u_c)\frac{AE}{L} = -W$

3/23/2023 Pin-jointed Pre-Lab



$(\uparrow)\ T_6 + \frac{\sqrt{2}}{2}T_8 = 0$

$\therefore -V_b - \frac{\sqrt{2}}{4}V_b + \frac{\sqrt{2}}{4}V_c + \frac{\sqrt{2}}{4}u_c = 0$ ⑦

From ②, $u_e = u_d - \frac{WL}{AE}$

to ④, $V_d = 2\sqrt{2}\frac{WL}{AE} + (u_d + \frac{\sqrt{2}}{4}u_d)\frac{4}{\sqrt{2}} = (1+2\sqrt{2})u_d + 2\sqrt{2}\frac{WL}{AE}$

to ③, $V_c = (1+\frac{\sqrt{2}}{4})V_d - \frac{\sqrt{2}}{4}u_d = (2+2\sqrt{2})u_d + (1+2\sqrt{2})\frac{WL}{AE}$

to ⑤ and ⑥, $u_c = 2\frac{WL}{AE} + V_c - V_d = u_d + 3\frac{WL}{AE}$

$V_b = (1+2\sqrt{2})u_c + V_c - 2\sqrt{2}\frac{WL}{AE}$

$= (3+4\sqrt{2})u_d + (4+6\sqrt{2})\frac{WL}{AE}$

to ⑦, $-(5+\frac{14}{4}\sqrt{2})u_d - (7+7\sqrt{2})\frac{WL}{AE} + (1+\frac{\sqrt{2}}{2})u_d + (1+\frac{\sqrt{2}}{4})\frac{WL}{AE} + \frac{\sqrt{2}}{4}u_d$

$+ \frac{3}{4}\sqrt{2}\frac{WL}{AE} = 0$

$\therefore -(4+4\sqrt{2})u_d = (6+6\sqrt{2})\frac{WL}{AE}$ $\therefore u_d = -\frac{3}{2}\frac{WL}{AE}$

to ①, $V_e = (2+2\sqrt{2})u_d - 3\frac{WL}{AE}$

~~$\therefore V_b = (\frac{17}{2}+12\sqrt{2})\frac{WL}{AE}$, $V_c = (4+5\sqrt{2})\frac{WL}{AE}$, $u_c = \frac{9}{2}\frac{WL}{AE}$,~~

~~$V_d = (\frac{3}{2}+5\sqrt{2})\frac{WL}{AE}$, $u_d = \frac{3}{2}\frac{WL}{AE}$, $V_e = 3\sqrt{2}\frac{WL}{AE}$,~~

~~$u_e = \frac{1}{2}\frac{WL}{AE}$~~

$\therefore \delta(\uparrow) = V_c = (-2-\sqrt{2})\frac{WL}{AE}$

$\therefore V_b = -\frac{1}{2}\frac{WL}{AE}$, $V_c = (-2-\sqrt{2})\frac{WL}{AE}$, $u_c = \frac{3}{2}\frac{WL}{AE}$, $V_d = (-\frac{3}{2} * \sqrt{2})\frac{WL}{AE}$.

$u_d = -\frac{3}{2}\frac{WL}{AE}$, $V_e = (-6-3\sqrt{2})\frac{WL}{AE}$, $u_e = -\frac{5}{2}\frac{WL}{AE}$

$\therefore T_1 = \frac{3}{2}W$, $T_2 = \sqrt{2}W$, $T_3 = -W$, $T_4 = -\frac{1}{2}W$,

$T_5 = -\frac{3}{2}W$, $T_6 = \frac{1}{2}W$, $T_7 = \frac{\sqrt{2}}{2}W$, $T_8 = \cancel{-\sqrt{2}W}\ -\frac{\sqrt{2}}{2}W$

3/23/2023 Pin-jointed During Lab

E = 195 GPa , L = 230mm

Error and uncertainty from reading

T 5N Load 3N deflection 0.001mm

	width (mm)	height (mm)
Mesurement 1	6.19	6.15
Mesurement 2	6.11	6.14
Mesurement 3	6.13	
Average	6.143333333	6.145
Area	3.77508E-05	

3/23/2023 Pin-jointed Truss Lab

	A (m^2)	E (Pa)	L (m)	Load (N)	Deflection (mm)			Tension 1 (N)			Tension 2 (N)			Tension 3 (N)			Tension 4 (N)			Tension 5 (N)			Tension 6 (N)			Tension 7 (N)		
					1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Loading	3.8E-05	2E+11	0.23	0	0	0.14	0	4	-2	-1	-1	-1	5	-5	1	-3	0	1	2	-1	1	-3	6	-1	1	0	-1	1
	3.8E-05	2E+11	0.23	50	-0.03	0.1	-0.04	56	49	53	67	68	78	-51	-49	-53	-47	-45	-46	-101	-97	-100	4	-5	0	65	72	69
	3.8E-05	2E+11	0.23	100	-0.06	0.06	-0.07	104	98	102	140	138	147	-101	-95	-99	-94	-96	-97	-197	-194	-201	6	-5	-3	134	141	139
	3.8E-05	2E+11	0.23	150	-0.09	0.03	-0.11	157	149	155	210	211	220	-153	-146	-147	-144	-143	-142	-303	-296	-300	5	-3	0	208	208	211
	3.8E-05	2E+11	0.23	200	-0.12	0	-0.13	205	199	204	282	280	290	-195	-194	-193	-188	-192	-192	-396	-398	-400	0	-3	1	274	279	279
	3.8E-05	2E+11	0.23	250	-0.15	-0.03	-0.16	255	250	252	354	354	358	-245	-242	-238	-238	-239	-239	-499	-496	-498	3	-2	-2	346	352	349
	3.8E-05	2E+11	0.23	300	-0.17	-0.05	-0.19	308	301	303	430	424	431	-298	-289	-289	-290	-287	-289	-603	-594	-599	1	-3	-5	421	422	422
	3.8E-05	2E+11	0.23	350	-0.2	-0.08	-0.21	358	349	355	501	498	508	-345	-334	-338	-341	-336	-335	-704	-695	-702	-2	-8	-8	493	491	494
	3.8E-05	2E+11	0.23	400	-0.22	-0.1	-0.24	408	401	407	573	569	577	-390	-382	-387	-384	-383	-383	-804	-792	-804	-4	-9	-6	561	561	563
Unloading	3.8E-05	2E+11	0.23	350	-0.2	-0.08	-0.21	357	348	356	503	499	506	-343	-338	-339	-340	-337	-336	-703	-695	-702	0	-7	-4	491	491	491
	3.8E-05	2E+11	0.23	300	-0.18	-0.06	-0.19	311	303	306	428	426	438	-295	-287	-291	-289	-287	-290	-603	-598	-605	-1	-3	-1	419	424	424
	3.8E-05	2E+11	0.23	250	-0.16	-0.03	-0.17	259	255	259	359	355	367	-248	-243	-245	-245	-240	-243	-510	-498	-509	1	-5	-1	351	350	353
	3.8E-05	2E+11	0.23	200	-0.13	-0.01	-0.14	208	203	208	285	282	294	-200	-195	-200	-193	-192	-194	-407	-400	-409	2	-1	1	281	280	283
	3.8E-05	2E+11	0.23	150	-0.1	0.02	-0.11	164	154	159	215	210	222	-153	-143	-150	-147	-142	-146	-308	-298	-308	4	-4	1	212	211	215
	3.8E-05	2E+11	0.23	100	-0.07	0.06	-0.08	108	102	106	144	140	149	-103	-97	-99	-96	-97	-97	-207	-201	-207	4	-3	-1	139	142	144
	3.8E-05	2E+11	0.23	50	-0.04	0.09	-0.05	58	52	59	73	73	83	-55	-51	-55	-48	-49	-51	-107	-102	-111	1	-3	0	67	74	75
	3.8E-05	2E+11	0.23	0	-0.01	0.13	-0.02	5	-2	4	-1	-4	8	-11	-2	-3	0	1	0	-9	1	-11	5	-2	3	2	2	3

Stutically determinate

3/23/2023 Pin-jointed During Lab

	A (m^2)	E (Pa)	L (m)	Load (N)	Deflection (mm)			Tension 1 (N)			Tension 2 (N)			Tension 3 (N)			Tension 4 (N)			Tension 5 (N)			Tension 6 (N)			Tension 7 (N)			Tension 8 (N)		
					1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Loading	3.8E-05	2E+11	0.23	0	0	0.01	0	1	0	-1	-4	-6	3	0	1	1	0	1	3	-1	-1	1	0	-1	-3	2	-4	6	3	5	-1
	3.8E-05	2E+11	0.23	50	-0.1	-0.1	-0.1	140	134	118	67	65	72	-49	-45	-48	43	34	23	-6	-14	-25	88	82	66	-56	-46	-25	-125	-116	-100
	3.8E-05	2E+11	0.23	100	-0.1	-0.2	-0.1	254	260	232	137	137	145	-96	-94	-92	55	57	32	-39	-43	-63	146	152	126	-71	-75	-34	-214	-222	-187
	3.8E-05	2E+11	0.23	150	-0.2	-0.3	-0.1	365	358	335	212	209	215	-143	-141	-141	61	47	34	-85	-100	-108	206	195	174	-76	-60	-33	-303	-280	-261
	3.8E-05	2E+11	0.23	200	-0.2	-0.3	-0.2	477	433	416	287	276	285	-192	-190	-192	66	30	14	-129	-164	-180	262	221	203	-84	-38	-11	-383	-320	-304
	3.8E-05	2E+11	0.23	250	-0.2	-0.3	-0.2	553	519	498	353	354	359	-240	-246	-242	49	10	-6	-192	-236	-246	288	256	233	-56	-9	20	-423	-370	-346
	3.8E-05	2E+11	0.23	300	-0.2	-0.4	-0.2	629	592	580	420	417	429	-286	-287	-290	24	-12	-24	-262	-300	-317	312	280	265	-25	15	46	-461	-404	-388
	3.8E-05	2E+11	0.23	350	-0.3	-0.4	-0.2	710	676	657	494	496	498	-339	-342	-337	3	-35	-44	-332	-376	-379	340	308	293	1	46	69	-502	-448	-426
	3.8E-05	2E+11	0.23	400	-0.3	-0.4	-0.3	794	759	746	570	566	574	-388	-395	-395	-19	-52	-63	-403	-446	-450	369	342	323	32	72	95	-545	-491	-477
Unloading	3.8E-05	2E+11	0.23	350	-0.3	-0.4	-0.2	710	680	665	497	497	508	-342	-342	-341	-3	-34	-46	-344	-376	-386	338	312	297	13	46	72	-498	-445	-434
	3.8E-05	2E+11	0.23	300	-0.3	-0.4	-0.2	631	601	582	429	429	431	-289	-295	-293	15	-17	-27	-274	-317	-320	310	284	263	-15	26	48	-454	-406	-389
	3.8E-05	2E+11	0.23	250	-0.2	-0.4		552	521		360	358		-241	-244		30	-1		-212	-247		278	252		-37	1		-410	-360	
	3.8E-05	2E+11	0.23	200	-0.2	-0.3		462	434		285	287		-190	-197		49	15		-146	-186		246	220		-61	-24		-359	-316	
	3.8E-05	2E+11	0.23	150	-0.2	-0.3		367	344		214	220		-141	-148		54	24		-91	-130		201	178		-69	-32		-298	-255	
	3.8E-05	2E+11	0.23	100	-0.2	-0.3		252	251		142	144		-92	-94		43	34		-54	-66		143	142		-57	-48		-210	-198	
	3.8E-05	2E+11	0.23	50	-0.1	-0.3		132	148		72	73		-47	-43		23	31		-30	-22		75	89		-27	-42		-107	-124	
	3.8E-05	2E+11	0.23	0	-0.1	-0.2		8	15		4	3		-2	4		-2	3		-5	-3		1	10		4	-4		-4	-8	

Statically Indeterminate

3/23/2023 Pre-jointed Post-lab

	A (m^2)	E (Pa)	L (m)	Load (N)	Deflection (mm)			Tension 1 (N)			Tension 2 (N)			Tension 3 (N)			Tension 4 (N)			Tension 5 (N)			Tension 6 (N)			Tension 7 (N)		
					1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Loading	3.8E-05	2E+11	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3.8E-05	2E+11	0.23	50	-0.03	-0.05	-0.04	52	51	54	68	69	73	-46	-50	-50	-47	-46	-48	-100	-98	-99	-2	-4	-1	65	73	68
	3.8E-05	2E+11	0.23	100	-0.07	-0.08	-0.07	100	100	103	141	139	142	-96	-96	-96	-94	-97	-99	-196	-195	-196	0	-4	-4	134	142	138
	3.8E-05	2E+11	0.23	150	-0.1	-0.11	-0.11	153	151	156	211	212	215	-148	-147	-144	-144	-144	-144	-302	-297	-298	-1	-2	-1	208	209	210
	3.8E-05	2E+11	0.23	200	-0.12	-0.14	-0.13	201	201	205	283	281	285	-190	-195	-190	-188	-193	-194	-395	-399	-400	-6	-2	0	274	280	278
	3.8E-05	2E+11	0.23	250	-0.15	-0.17	-0.16	251	252	253	355	355	353	-240	-243	-235	-238	-240	-241	-498	-497	-498	-3	-1	-3	346	353	348
	3.8E-05	2E+11	0.23	300	-0.18	-0.2	-0.19	304	303	304	431	425	426	-293	-290	-286	-290	-288	-291	-602	-595	-596	-5	-2	-6	421	423	421
	3.8E-05	2E+11	0.23	350	-0.2	-0.22	-0.21	354	351	356	502	499	503	-340	-335	-335	-341	-337	-337	-703	-696	-697	-8	-7	-9	493	492	493
	3.8E-05	2E+11	0.23	400	-0.22	-0.25	-0.24	404	403	408	574	570	572	-385	-383	-384	-384	-384	-385	-803	-793	-794	-10	-8	-7	561	562	562
Unloading	3.8E-05	2E+11	0.23	350	-0.2	-0.23	-0.21	353	350	357	504	500	501	-338	-339	-336	-340	-338	-338	-702	-696	-697	-6	-6	-5	491	492	490
	3.8E-05	2E+11	0.23	300	-0.18	-0.2	-0.19	307	305	307	429	427	433	-290	-288	-288	-289	-288	-292	-602	-599	-600	-7	-2	-2	419	425	423
	3.8E-05	2E+11	0.23	250	-0.16	-0.18	-0.17	255	257	260	360	356	362	-243	-244	-242	-245	-241	-245	-509	-499	-500	-5	-4	-2	351	351	352
	3.8E-05	2E+11	0.23	200	-0.13	-0.15	-0.14	204	205	209	286	283	289	-195	-196	-197	-193	-193	-196	-406	-401	-402	-4	0	0	281	281	282
	3.8E-05	2E+11	0.23	150	-0.1	-0.12	-0.11	160	156	160	216	211	217	-148	-144	-147	-147	-143	-148	-307	-299	-300	-2	-3	0	212	212	214
	3.8E-05	2E+11	0.23	100	-0.07	-0.09	-0.08	104	104	107	145	141	144	-98	-98	-96	-96	-98	-99	-206	-202	-203	-2	-2	-2	139	143	143
	3.8E-05	2E+11	0.23	50	-0.04	-0.05	-0.05	54	54	60	74	74	78	-50	-52	-52	-48	-50	-53	-106	-103	-104	-5	-2	-1	67	75	74
	3.8E-05	2E+11	0.23	0	-0.01	-0.01	-0.02	1	0	5	0	-3	3	-6	-3	0	0	0	-2	-8	0	-1	-1	-1	2	2	3	2

Statically determinate

3/24/2023 Pin-jointed Post-Lab

	A (m^2)	E (Pa)	L (m)	Load (N)	Deflection (mm)			Tension 1 (N)			Tension 2 (N)			Tension 3 (N)			Tension 4 (N)			Tension 5 (N)			Tension 6 (N)			Tension 7 (N)			Tension 8 (N)		
					1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Loading	3.8E-05	2E+11	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3.8E-05	2E+11	0.23	50	-0.1	-0.1	-0.1	139	134	119	71	71	69	-49	-46	-49	43	33	20	-5	-13	-26	88	83	69	-58	-42	-31	-128	-121	-99
	3.8E-05	2E+11	0.23	100	-0.1	-0.2	-0.1	253	260	233	141	143	142	-96	-95	-93	55	56	29	-38	-42	-64	146	153	129	-73	-71	-40	-217	-227	-186
	3.8E-05	2E+11	0.23	150	-0.2	-0.3	-0.1	364	358	336	216	215	212	-143	-142	-142	61	46	31	-84	-99	-109	206	196	177	-78	-56	-39	-306	-285	-260
	3.8E-05	2E+11	0.23	200	-0.2	-0.3	-0.2	476	433	417	291	282	282	-192	-191	-193	66	29	11	-128	-163	-181	262	222	206	-86	-34	-17	-386	-325	-303
	3.8E-05	2E+11	0.23	250	-0.2	-0.4	-0.2	552	519	499	357	360	356	-240	-247	-243	49	9	-9	-191	-235	-247	288	257	236	-58	-5	14	-426	-375	-345
	3.8E-05	2E+11	0.23	300	-0.2	-0.4	-0.2	628	592	581	424	423	426	-286	-288	-291	24	-13	-27	-261	-299	-318	312	281	268	-27	19	40	-464	-409	-387
	3.8E-05	2E+11	0.23	350	-0.3	-0.4	-0.2	709	676	658	498	502	495	-339	-343	-338	3	-36	-47	-331	-375	-380	340	309	296	-1	50	63	-505	-453	-425
	3.8E-05	2E+11	0.23	400	-0.3	-0.4	-0.3	793	759	747	574	572	571	-388	-396	-396	-19	-53	-66	-402	-445	-451	369	343	326	30	76	89	-548	-496	-476
Unloading	3.8E-05	2E+11	0.23	350	-0.3	-0.4	-0.2	709	680	666	501	503	505	-342	-343	-342	-3	-35	-49	-343	-375	-387	338	313	300	11	50	66	-501	-450	-433
	3.8E-05	2E+11	0.23	300	-0.3	-0.4	-0.2	630	601	583	433	435	428	-289	-296	-294	15	-18	-30	-273	-316	-321	310	285	266	-17	30	42	-457	-411	-388
	3.8E-05	2E+11	0.23	250	-0.2	-0.4		551	521		364	364		-241	-245		30	-2		-211	-246		278	253		-39	5		-413	-365	
	3.8E-05	2E+11	0.23	200	-0.2	-0.4		461	434		289	293		-190	-198		49	14		-145	-185		246	221		-63	-20		-362	-321	
	3.8E-05	2E+11	0.23	150	-0.2	-0.3		366	344		218	226		-141	-149		54	23		-90	-129		201	179		-71	-28		-301	-260	
	3.8E-05	2E+11	0.23	100	-0.2	-0.3		251	251		146	150		-92	-95		43	33		-53	-65		143	143		-59	-44		-213	-203	
	3.8E-05	2E+11	0.23	50	-0.1	-0.3		131	148		76	79		-47	-44		23	30		-29	-21		75	90		-29	-38		-110	-129	
	3.8E-05	2E+11	0.23	0	-0.1	-0.2		7	15		8	9		-2	3		-2	2		-4	-2		1	11		2	0		-7	-13	

Statically Indeterminate

3/24/2023 Pin-jointed Post-Lab

		A (m^2)	E (Pa)	L (m)	Load (N)	Deflection		Tension 1		Tension 2		Tension 3		Tension 4		Tension 5		Tension 6		Tension 7	
						(mm)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error
Experiment	Loading	3.78E-05	1.95E+11	0.23	0	0	0.001	0	5	0	5	0	5	0	5	0	5	0	5	0	5
		3.78E-05	1.95E+11	0.23	50	-0.04	0.0034	52.33333	8.14	70	9.2	-48.6667	7.92	-47	7.82	-99	10.94	-2.33333	5.14	206	17.36
		3.78E-05	1.95E+11	0.23	100	-0.073	0.00319	101	8.03	140.6667	9.22	-96	7.88	-96.6667	7.9	-195.667	10.87	-2.66667	5.08	414	17.42
		3.78E-05	1.95E+11	0.23	150	-0.10433	0.003087	153.3333	8.066667	212.6667	9.253333	-146.333	7.926667	-144	7.88	-299	10.98	-1.33333	5.026667	627	17.54
		3.78E-05	1.95E+11	0.23	200	-0.13333	0.003	202.3333	8.035	283	9.245	-191.667	7.875	-191.667	7.875	-398	10.97	-2.66667	5.04	832	17.48
		3.78E-05	1.95E+11	0.23	250	-0.16033	0.002924	252	8.024	354.3333	9.252	-239.333	7.872	-239.667	7.876	-497.667	10.972	-2.33333	5.028	1047	17.564
		3.78E-05	1.95E+11	0.23	300	-0.18633	0.002863	303.6667	8.036667	427.3333	9.273333	-289.667	7.896667	-289.667	7.896667	-597.667	10.97667	-4.33333	5.043333	1265	17.65
		3.78E-05	1.95E+11	0.23	350	-0.21067	0.002806	353.6667	8.031429	501.3333	9.297143	-336.667	7.885714	-338.333	7.9	-698.667	10.98857	-8	5.068571	1478	17.66857
		3.78E-05	1.95E+11	0.23	400	-0.234	0.002755	405	8.0375	572	9.29	-384	7.88	-384.333	7.8825	-796.667	10.975	-8.33333	5.0625	1685	17.6375
	Unloading	3.78E-05	1.95E+11	0.23	350	-0.21333	0.002829	353.3333	8.028571	501.6667	9.3	-337.667	7.894286	-338.667	7.902857	-698.333	10.98571	-5.66667	5.048571	1473	17.62571
		3.78E-05	1.95E+11	0.23	300	-0.19033	0.002903	306.3333	8.063333	429.6667	9.296667	-288.667	7.886667	-289.667	7.896667	-600.333	11.00333	-3.66667	5.036667	1267	17.67
		3.78E-05	1.95E+11	0.23	250	-0.167	0.003004	257.3333	8.088	359.3333	9.312	-243	7.916	-243.667	7.924	-502.667	11.032	-3.66667	5.044	1054	17.648
		3.78E-05	1.95E+11	0.23	200	-0.14	0.0031	206	8.09	286	9.29	-196	7.94	-194	7.91	-403	11.045	-1.33333	5.02	844	17.66
		3.78E-05	1.95E+11	0.23	150	-0.112	0.00324	158.6667	8.173333	214.6667	9.293333	-146.333	7.926667	-146	7.92	-302	11.04	-1.66667	5.033333	638	17.76
		3.78E-05	1.95E+11	0.23	100	-0.08067	0.00342	105	8.15	143.3333	9.3	-97.3333	7.92	-97.6667	7.93	-203.667	11.11	-2	5.06	425	17.75
		3.78E-05	1.95E+11	0.23	50	-0.04833	0.0039	56	8.36	75.33333	9.52	-51.3333	8.08	-50.3333	8.02	-104.333	11.26	-2.66667	5.16	216	17.96
		3.78E-05	1.95E+11	0.23	0	-0.01233	0.001	2	5	0	5	-3	5	-0.66667	5	-3	5	0	5	7	5
Theory	Loading	3.78E-05	1.95E+11	0.23	0	0		0		0		0		0		0		0		0	
		3.78E-05	1.95E+11	0.23	50	-0.00911		50		70.71068		-50		-50		-100		0		70.71068	
		3.78E-05	1.95E+11	0.23	100	-0.01821		100		141.4214		-100		-100		-200		0		141.4214	
		3.78E-05	1.95E+11	0.23	150	-0.02732		150		212.132		-150		-150		-300		0		212.132	
		3.78E-05	1.95E+11	0.23	200	-0.03642		200		282.8427		-200		-200		-400		0		282.8427	
		3.78E-05	1.95E+11	0.23	250	-0.04553		250		353.5534		-250		-250		-500		0		353.5534	
		3.78E-05	1.95E+11	0.23	300	-0.05463		300		424.2641		-300		-300		-600		0		424.2641	
		3.78E-05	1.95E+11	0.23	350	-0.06374		350		494.9747		-350		-350		-700		0		494.9747	
		3.78E-05	1.95E+11	0.23	400	-0.07284		400		565.6854		-400		-400		-800		0		565.6854	

Statically Determinate

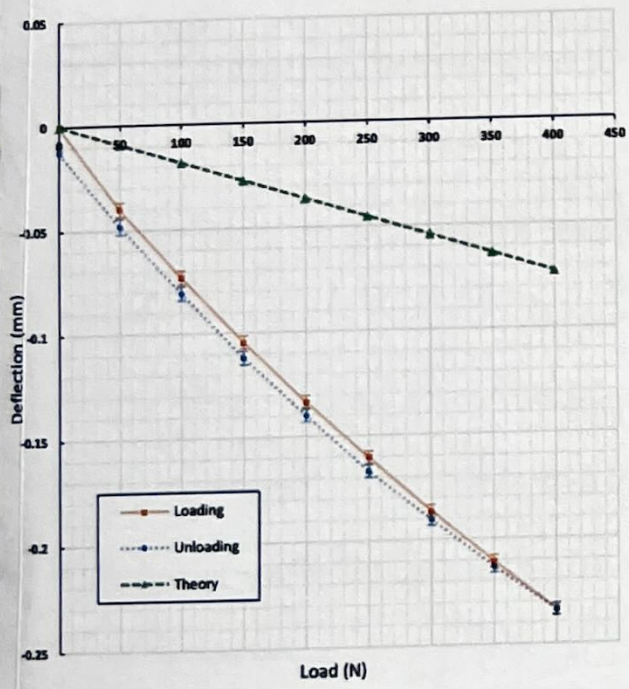
3/24/2023 Pin-jointed Post-Lab

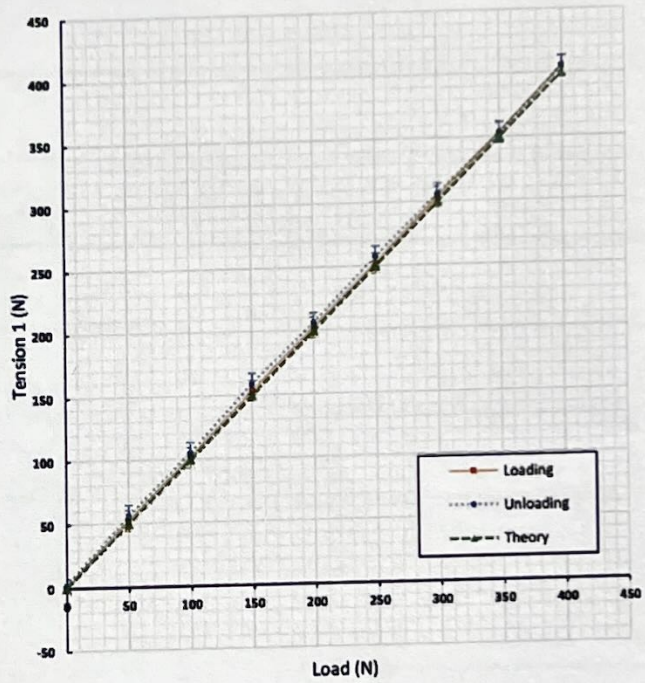
		A (m^2)	E (Pa)	L (m)	Load (N)	Deflection		Tension 1		Tension 2		Tension 3		Tension 4		Tension 5		Tension 6		Tension 7		Tension 8	
						(mm)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error	(N)	error
Experiment	Loading	3.78E-05	1.95E+11	0.23	0	0	0.001	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5
		3.78E-05	1.95E+11	0.23	50	-0.07	0.0052	130.6667	12.84	70.33333	9.22	-48	7.88	32	6.92	-14.6667	5.88	80	9.8	-43.6667	7.62	-116	11.96
		3.78E-05	1.95E+11	0.23	100	-0.142	0.00526	248.6667	12.46	142	9.26	-94.6667	7.84	46.66667	6.4	-48	6.44	142.6667	9.28	-61.3333	6.84	-210	11.3
		3.78E-05	1.95E+11	0.23	150	-0.18967	0.004793	352.6667	12.05333	214.3333	9.286667	-142.333	7.846667	46	5.92	-97.3333	6.946667	193	8.86	-57.6667	6.153333	-283.667	10.67333
		3.78E-05	1.95E+11	0.23	200	-0.22167	0.004325	442	11.63	285	9.275	-192	7.88	35.33333	5.53	-157.333	7.36	230	8.45	-45.6667	5.685	-338	10.07
		3.78E-05	1.95E+11	0.23	250	-0.25433	0.004052	523.3333	11.28	357.6667	9.292	-243.333	7.92	16.33333	5.196	-224.333	7.692	260.3333	8.124	-16.3333	5.196	-382	9.584
		3.78E-05	1.95E+11	0.23	300	-0.28367	0.003837	600.3333	11.00333	424.3333	9.243333	-288.333	7.883333	-5.33333	5.053333	-292.667	7.926667	287	7.87	10.66667	5.106667	-420	9.2
		3.78E-05	1.95E+11	0.23	350	-0.30467	0.003611	681	10.83714	498.3333	9.271429	-340	7.914286	-26.6667	5.228571	-362	8.102857	315	7.7	37.33333	5.32	-461	8.951429
		3.78E-05	1.95E+11	0.23	400	-0.325	0.003438	766.3333	10.7475	572.3333	9.2925	-393.333	7.95	-46	5.345	-432.667	8.245	346	7.595	65	5.4875	-506.667	8.8
	Unloading	3.78E-05	1.95E+11	0.23	350	-0.313	0.003683	685	10.87143	503	9.311429	-342.333	7.934286	-29	5.248571	-368.333	8.157143	317	7.717143	42.33333	5.362857	-461.333	8.954286
		3.78E-05	1.95E+11	0.23	300	-0.29633	0.003963	604.6667	11.04667	432	9.32	-293	7.93	-11	5.11	-303.333	8.033333	287	7.87	18.33333	5.183333	-418.667	9.186667
		3.78E-05	1.95E+11	0.23	250	-0.3085	0.004702	536	11.432	364	9.368	-243	7.916	14	5.168	-228.5	7.742	265.5	8.186	-17	5.204	-389	9.668
		3.78E-05	1.95E+11	0.23	200	-0.2845	0.005268	447.5	11.7125	291	9.365	-194	7.91	31.5	5.4725	-165	7.475	233.5	8.5025	-41.5	5.6225	-341.5	10.1225
		3.78E-05	1.95E+11	0.23	150	-0.2545	0.00609	355	12.1	222	9.44	-145	7.9	38.5	5.77	-109.5	7.19	190	8.8	-49.5	5.99	-280.5	10.61
		3.78E-05	1.95E+11	0.23	100	-0.226	0.00778	251	12.53	148	9.44	-93.5	7.805	38	6.14	-59	6.77	143	9.29	-51.5	6.545	-208	11.24
		3.78E-05	1.95E+11	0.23	50	-0.194	0.01264	139.5	13.37	77.5	9.65	-45.5	7.73	26.5	6.59	-25	6.5	82.5	9.95	-33.5	7.01	-119.5	12.17
		3.78E-05	1.95E+11	0.23	0	-0.138	0.001	11	5	8.5	5	0.5	5	0	5	-3	5	6	5	1	5	-10	5
Theory	Loading	3.78E-05	1.95E+11	0.23	0	0		0		0		0		0		0		0		0		0	
		3.78E-05	1.95E+11	0.23	50	-0.00533		75		70.71068		-50		-25		-75		25		35.35534		-35.3553	
		3.78E-05	1.95E+11	0.23	100	-0.01067		150		141.4214		-100		-50		-150		50		70.71068		-70.7107	
		3.78E-05	1.95E+11	0.23	150	-0.016		225		212.132		-150		-75		-225		75		106.066		-106.066	
		3.78E-05	1.95E+11	0.23	200	-0.02133		300		282.8427		-200		-100		-300		100		141.4214		-141.421	
		3.78E-05	1.95E+11	0.23	250	-0.02667		375		353.5534		-250		-125		-375		125		176.7767		-176.777	
		3.78E-05	1.95E+11	0.23	300	-0.032		450		424.2641		-300		-150		-450		150		212.132		-212.132	
		3.78E-05	1.95E+11	0.23	350	-0.03734		525		494.9747		-350		-175		-525		175		247.4874		-247.487	
		3.78E-05	1.95E+11	0.23	400	-0.04267		600		565.6854		-400		-200		-600		200		282.8427		-282.843	

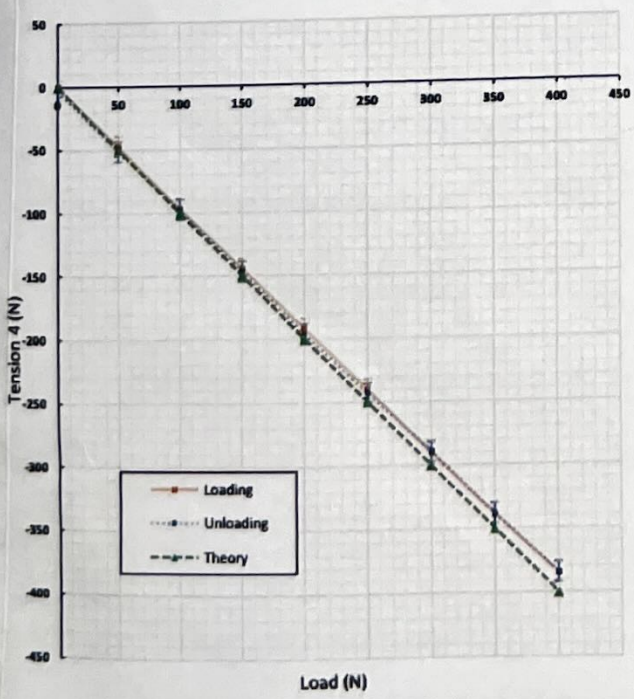
Statically Indeterminate

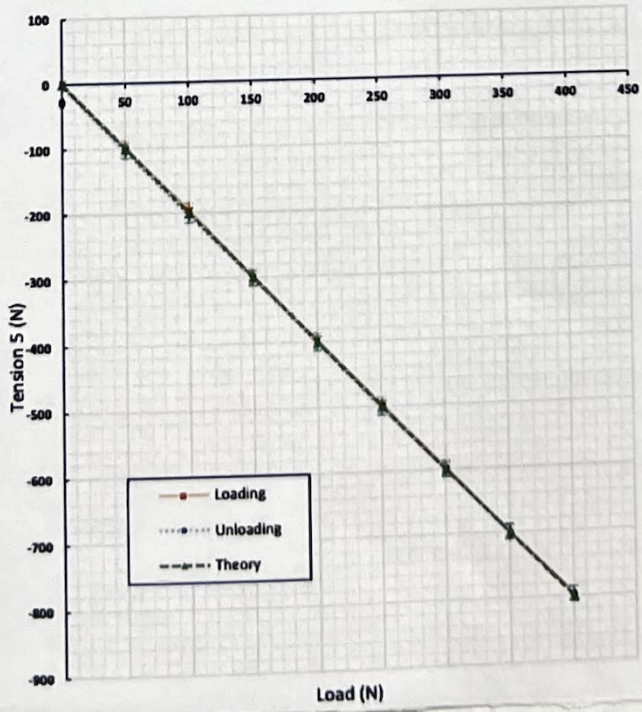
3/24/2023 Pin-jointed Post-Lab

Statically Determinate

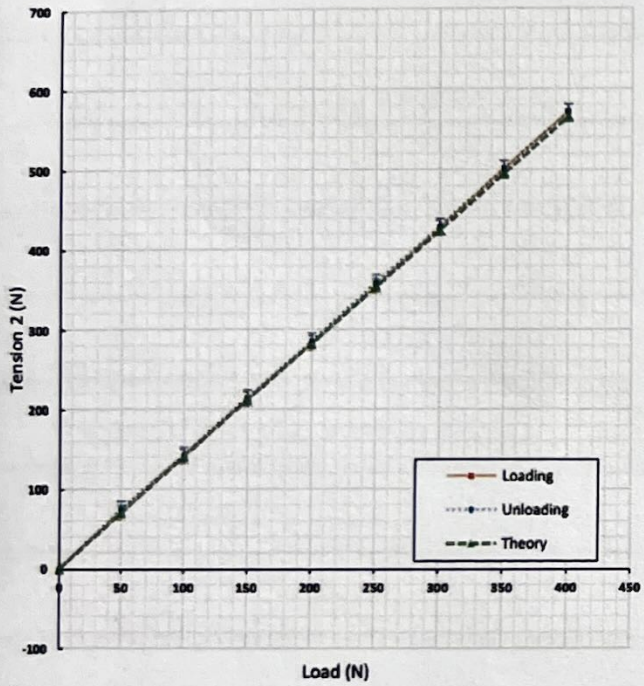


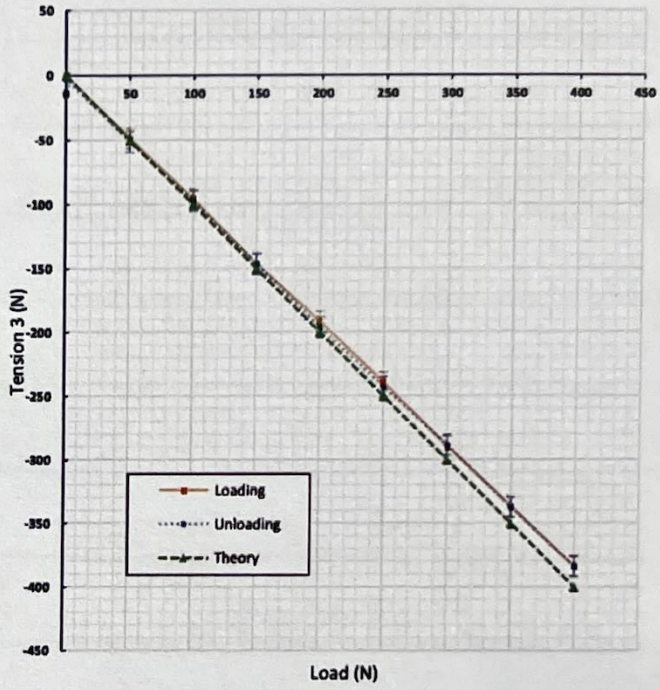


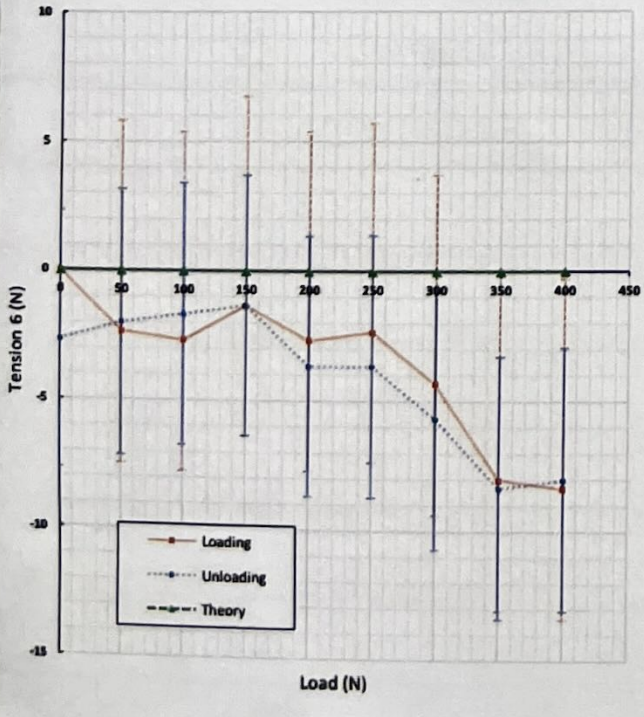


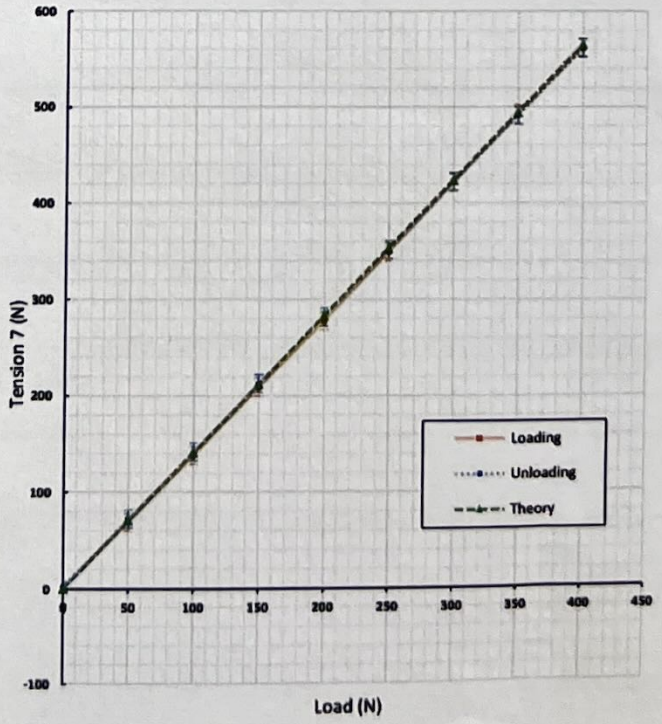


3/24/2023 Pin-jointed Post-Lab



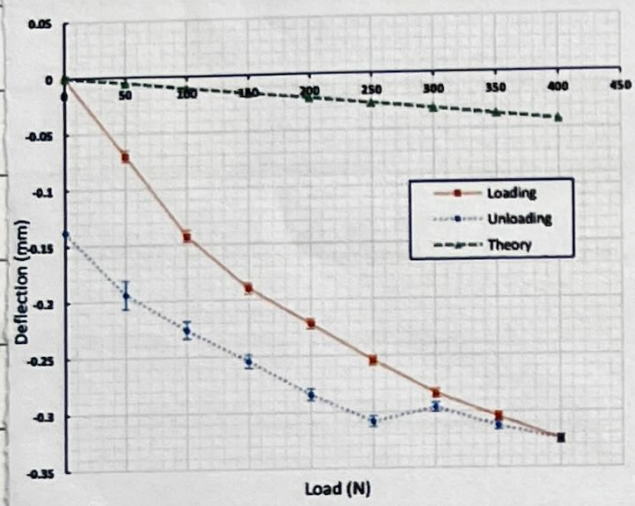


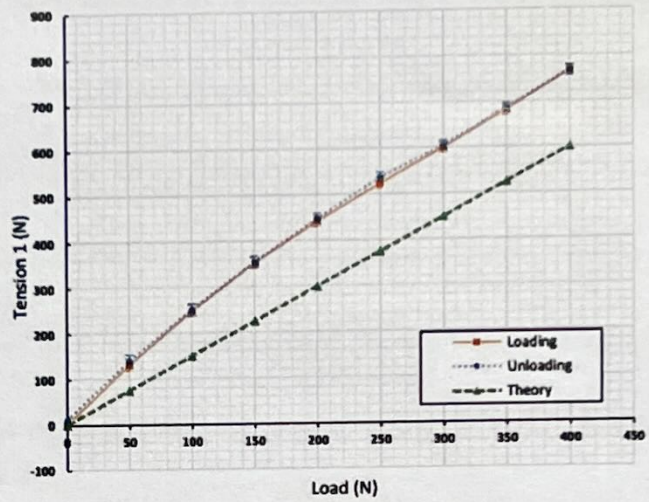


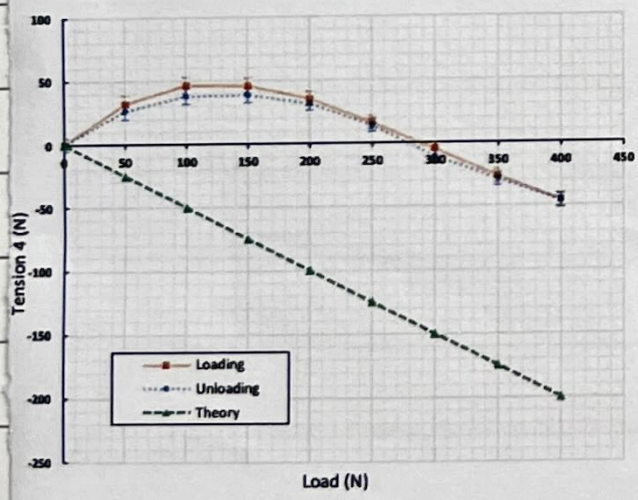


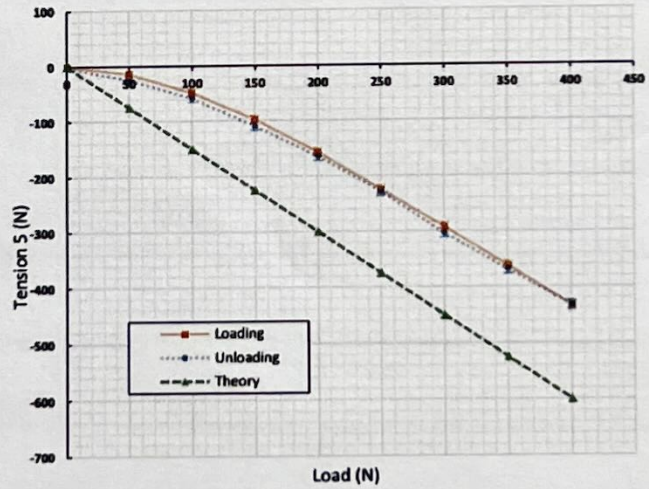
3/24/2023 Pin-jointed Post-Lab

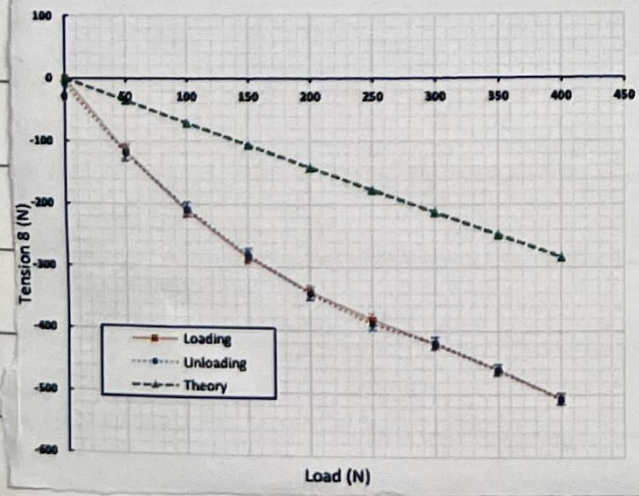
Statically Indeterminate











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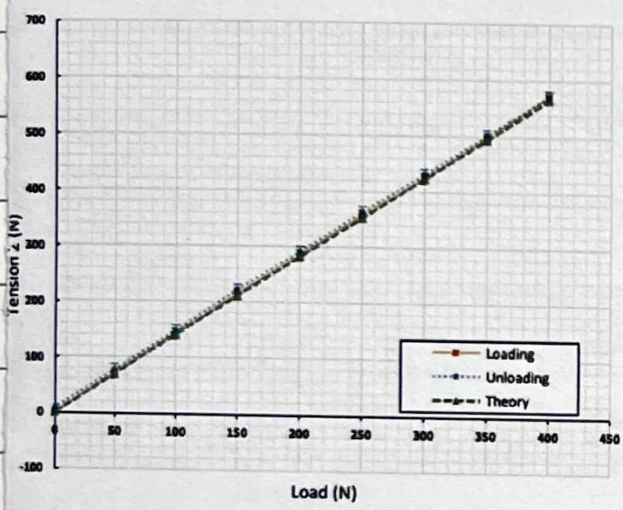
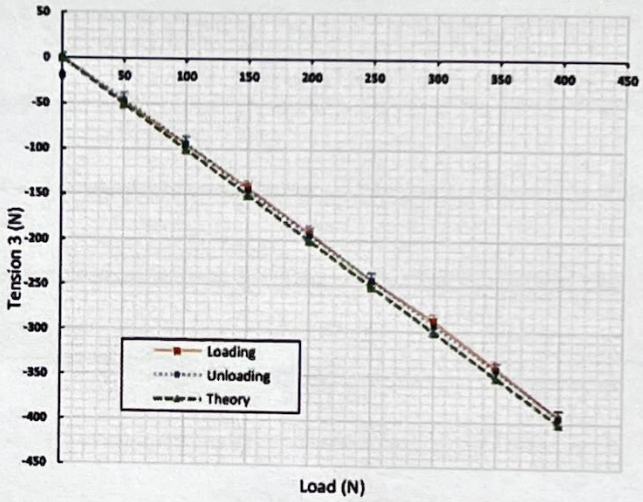
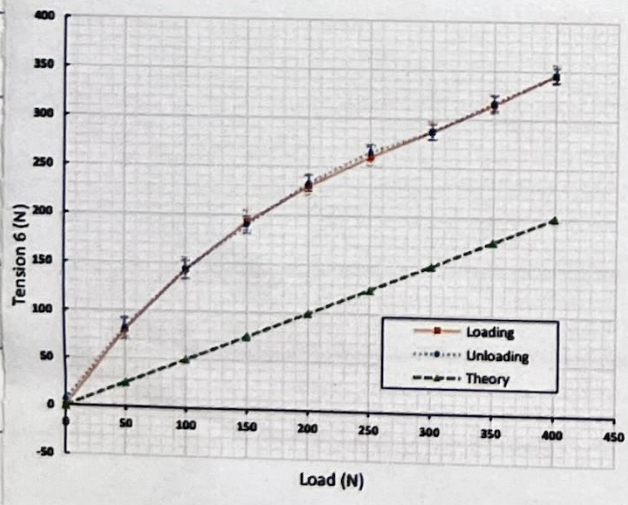
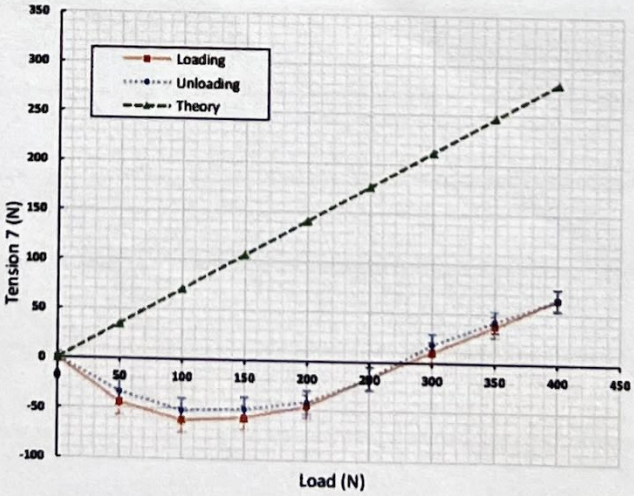








AERO40002

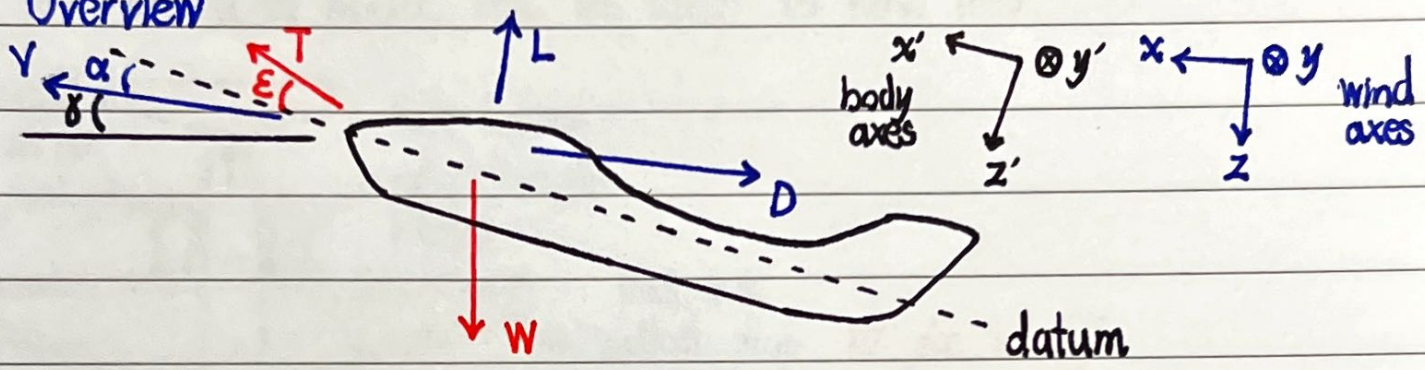
Intro to Aerospace

Hanchen Li

李瀚宸

3/2/2023 Flight Simulator Pre-Lab

Overview



Mathematical model

↳ Predicted performance and behaviour ← uncertainty

- Actual performance and behaviour ←
- actual stall speed
- rate of climb
- turn performance
- max speed profile
- mission performance
- field performance
- stability characteristics
- response to pilot inputs

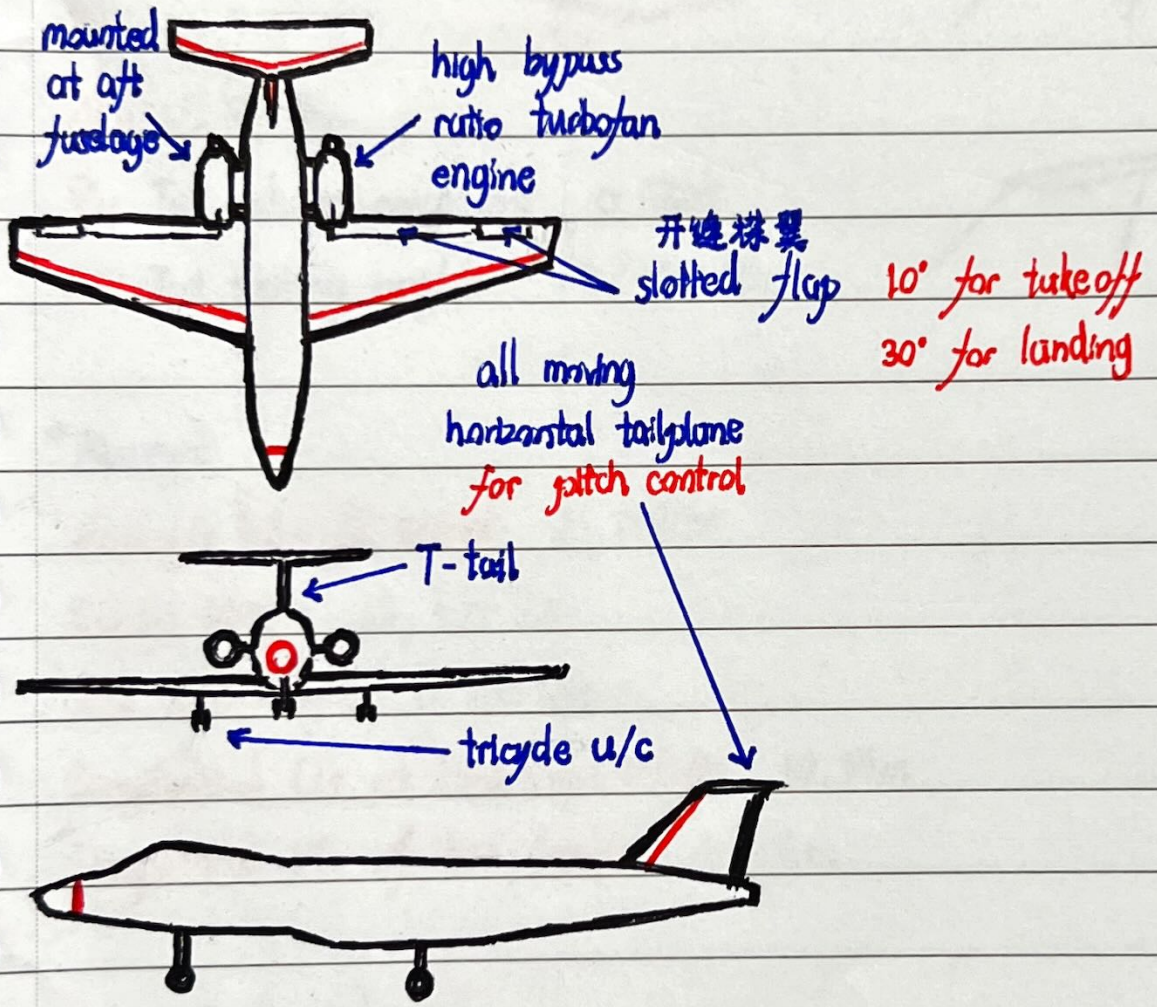
↑

Lengthy flight-testing programs

3/2/2023 Flight Simulator Pre-Lab

The Aircraft

* 1:24 scale model will be used in next lab

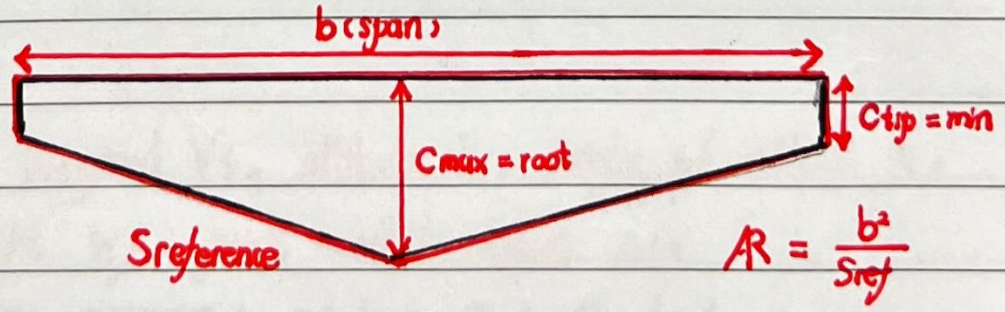


*Wing

S_{ref} 73.73 m²

$\bar{c}$ 3.79 m

AR 5.93



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*Horizontal tail

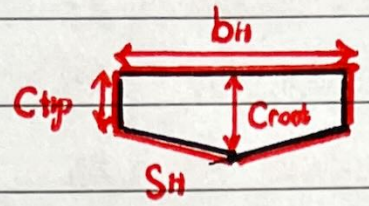
S_H 18.43 m^2

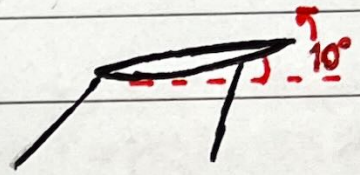
$\bar{C}_H$ 1.97m

AR_H 4.74

$\bar{V}_H$ Tail volume coefficient 0.6305

Δi_H Tail setting angles +5/-10 deg





*Aircraft

Maximum Take off Weight 24,398 lbs

Empty Weight 13,434 lbs

Max Fuel Weight 8,800 lbs

Longitudinal CG at Zero-Fuel Weight 10.14m

Longitudinal CG of fuel tanks 10.06m

Setup & Procedure

- act as pilot
- act as engineer

↳ record indicated airspeed V_i, altitude h, angle of attack α, fuel weight W_f, pitch control input Δi_H

* MAKE AN EXCEL SHEET! ** Use Test Cards!

3/2/2023 Flight Simulator Pre-Lab

↳ data → determine aircraft's lift curve (α, α_0, C_{Lmax})

drag polar (C_{D0}, k)

zero-lift pitching moment (C_{M0})

neutral point (x_{np})

① Stall test

$h = 4000 \sim 4500 ft$

↳1 flying aircraft level $V \geq 150\% V_s$ → $V \approx 140 kn$ IAS 指示空速

↳2 engine throttle → ideal → slowly pull back on the controls $\alpha \uparrow$

↳ maintain level flight → $V \downarrow$

↳3 stall warner → keep 2 – until → "7" buffeting of the controls

OR

further ↑ of α → no further control authority

* record V_s ** record any wing drop tendency

↳4 stall recovery procedure – same time → full throttle

→ -5° nose down attitude

* × flaps (flaps up)

× undercarriage (u/c up)

– first attempt

✓ landing configurations 30° flaps + u/c down second attempt

At least two measurement for each configuration !!!

② Glide test

Test rate of descent at different V

determine ($\frac{L}{D}$) vs. h and V

↳ $\frac{dh}{dt} = V\left(\frac{T}{W} - \frac{1}{L/D}\right) = \eta_p \frac{P}{W} - \frac{V}{L/D}$

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↳ when V constant in glide → $\frac{P}{W} = \frac{T}{W} = 0$ → L/D by $\frac{dh}{dt}$

↳1 climbing h = 2000ft > test altitude if possible 4500 ft

↳2 throttle → ideal

↳3 attain test air speed

↳4 keep speed constant as possible

* V_{IAS} ↓ ← nose up + release some back pressure (for 4)

V_{IAS} ↑ ← nose down + apply some back pressure (for 4)

↳5 measure time

$t = h_{test} + 500ft \rightarrow h_{test} - 500ft$

Repeat by different V_{IAS} !!! Repeat with same V_{IAS} if possible!

③ Steady Level Flight

Test lift curve slope, tail lifting characteristics, zero-lift pitching moment and static margin by estimate through steady flight with different V and CG

↳1 required amount of fuel → set weight

to achieve correct CG offset for zero-fuel CG position

+6, -6 and 0 from the instructor's console

↳2 climb/descend h = $h_{desired}$ = 5500ft

↳3 throttle → full

adjust stick input to maintain altitude

α↑ → nose down ↑

3/2/2023 Flight Simulator Pre-Lab

4 → when V constant, V = 100, 150, 200, 250 ...

record air speed, tailplane angle, α and m_{fuel}

(3.1) test lower air speed 1

1 → throttle → reduce by 20% → decelerate → V = V desired

2 → maintain altitude adjust stick input

- α↑ → nose up↑

3 → throttle → increase → until V constant when reach IAS

4 → when V constant

record air speed, tailplane angle, α and m_{fuel}

5 → Repeat 1-4 for V↓

(3.2) test lower air speed 2 (easier)

1 → climb until reach IAS

2 → maintain IAS required adjust stick

3 → throttle → reduce slowly → maintain TAS till flying level

4 → record air speed, tailplane angle, α and m_{fuel}

5 → Repeat 1-4 for V↓

Completing the Lab

① Safety

② Conduct of the lab

4 stall test + 5~6 glide test + 12 level flight test (4V + 3CG)

3/2/2023 Flight Simulator Pre-Lab

③ Take-off

1. throttle → full, flaps 10°
2. maintain centre line → rudder pedal
3. V = 90 knots → pull back → climb angle 10°
4. V = 120 knots → raise u/c → raise flaps
5. h = h desired

   throttle → ≈ 60%

   adjust pitch to maintain altitude

3/2/2023 Flight Simulator During Lab

Stall test - cruise configuration

Pilot:	Emre Aslan	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	5105	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps (UP) 10° 30°				

Check	Action			
	DEPARTURE & SETUP			
✓	Set takeoff configuration (flaps 10°)			
✓	Disengage parking break			
✓	Apply full throttle & maintain runway centreline			
✓	Rotate at 90 kts IAS			
✓	Retract undercarriage and flaps			
✓	Climb at 120 kts IAS to test altitude			
✓	Set aircraft to test configuration			
✓	Adjust throttle & pitch to maintain altitude at 140 kts IAS			
	STALL TEST - POWER-OFF, WINGS LEVEL			
✓	Set throttle to idle			
✓	Increase pitch angle to maintain altitude			
✓	Keep balance ball centred using rudder			
✓	Fuel Weight:	4136.2 lbs		
✓	Record IAS at STALL HORN:	60 kn		
✓	Record IAS at STALL:	34 kn		
✓	Record Roll tendency:	(NONE) LEFT RIGHT		
✓	Recover – Full throttle & Lower nose			

Pilot:		Date:		Time:
CG offset (in):		Empty Weight:		
Test Altitude (ft):		Payload Weight:		

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
	Set aircraft to clean configuration			
	Ascend to 2000 ft above test altitude			
	Adjust throttle & pitch to maintain altitude at test speed			
	Set throttle to idle			
	Pitch down to maintain test speed			
	Start timer 500 ft over test altitude			
	Maintain test speed			
	Record time 500 ft below test altitude			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			

Notes:

3/2/2023 Flight Simulator During Lab

Trim test

Pilot:	Dila Senturk	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	5500	Payload Weight:	1081.81 lbs		

Check	Action			
	TRIM TEST			
✓	Climb/Descend to the test altitude			
✓	Adjust pitch & throttle to fly level flight at desired IAS			
✓	Record data			
	Test 1			
	IAS (kn)	250	Fuel Weight:	3987 lbs
	Stabilator (deg)	1.04	AoA (deg):	-1.5
	Test 2			
	IAS (kn)	200	Fuel Weight:	3935 lbs
	Stabilator (deg)	0.46	AoA (deg):	-0.5
	Test 3			
	IAS (kn)	150	Fuel Weight:	3840 lbs
	Stabilator (deg)	-0.17	AoA (deg):	0.7
	Test 4			
	IAS (kn)	100	Fuel Weight:	3810 lbs
	Stabilator (deg)	-1.60	AoA (deg):	4.5

Notes:

Trim test

Pilot:	Emre Aslan	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	5000	Payload Weight:	1081.81 lbs		

Check	Action			
	TRIM TEST			
✓	Climb/Descend to the test altitude			
✓	Adjust pitch & throttle to fly level flight at desired IAS			
✓	Record data			
	Test 1			
	IAS (kn)	250	Fuel Weight:	4184 lbs
	Stabilator (deg)	1.08	AoA (deg):	-1.2
	Test 2			
	IAS (kn)	200	Fuel Weight:	4132 lbs
	Stabilator (deg)	0.64	AoA (deg):	-0.3
	Test 3			
	IAS (kn)	150	Fuel Weight:	4019 lbs
	Stabilator (deg)	-0.90	AoA (deg):	0.5
	Test 4			
	IAS (kn)	100	Fuel Weight:	3999 lbs
	Stabilator (deg)	-1.90	AoA (deg):	4.3

Notes:

3/2/2023 Flight Simulator During Lab

Stall test - cruise configuration

Pilot:	Sam Shenker	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4000	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps (UP) 10° 30°				

Check	Action	
	DEPARTURE & SETUP	
✓	Set takeoff configuration (flaps 10°)	
✓	Disengage parking break	
✓	Apply full throttle & maintain runway centreline	
✓	Rotate at 90 kts IAS	
✓	Retract undercarriage and flaps	
✓	Climb at 120 kts IAS to test altitude	
✓	Set aircraft to test configuration	
✓	Adjust throttle & pitch to maintain altitude at 140 kts IAS	
	STALL TEST - POWER-OFF, WINGS LEVEL	
✓	Set throttle to idle	
✓	Increase pitch angle to maintain altitude	
✓	Keep balance ball centred using rudder	
✓	Fuel Weight:	N/A
✓	Record IAS at STALL HORN:	81 kn
✓	Record IAS at STALL:	65 kn
✓	Record Roll tendency:	(NONE) LEFT RIGHT
✓	Recover – Full throttle & Lower nose	

Notes:

Pilot:		Date:		Time:	
CG offset (in):		Empty Weight:			
Test Altitude (ft):		Payload Weight:			

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
	Set aircraft to clean configuration			
	Ascend to 2000 ft above test altitude			
	Adjust throttle & pitch to maintain altitude at test speed			
	Set throttle to idle			
	Pitch down to maintain test speed			
	Start timer 500 ft over test altitude			
	Maintain test speed			
	Record time 500 ft below test altitude			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			

Notes:

3/2/2023 Flight Simulator During Lab

Trim test

Pilot:	Sam Shenker	Date:	2/3/2023	Time:	N/A
CG offset (in):	-6	Empty Weight:	13434 lbs		
Test Altitude (ft):	4900	Payload Weight:	1081.81 lbs		

Check	Action			
	TRIM TEST			
✓	Climb/Descend to the test altitude			
✓	Adjust pitch & throttle to fly level flight at desired IAS			
✓	Record data			
	Test 1			
	IAS (kn)	341	Fuel Weight:	3722 lbs
	Stabilator (deg)	1.2	AoA (deg):	-1.7
	Test 2			
	IAS (kn)	207	Fuel Weight:	3709 lbs
	Stabilator (deg)	0.39	AoA (deg):	-0.6
	Test 3			
	IAS (kn)	N/A	Fuel Weight:	N/A
	Stabilator (deg)	N/A	AoA (deg):	N/A
	Test 4			
	IAS (kn)	N/A	Fuel Weight:	N/A
	Stabilator (deg)	N/A	AoA (deg):	N/A

Notes: +

Trim test

Pilot:	Sam Shenker	Date:	2/3/2023	Time:	N/A
CG offset (in):	-6	Empty Weight:	13434 lbs		
Test Altitude (ft):	4900	Payload Weight:	1081.81 lbs		

Check	Action			
	TRIM TEST			
✓	Climb/Descend to the test altitude			
✓	Adjust pitch & throttle to fly level flight at desired IAS			
✓	Record data			
	Test 1			
	IAS (kn)	344	Fuel Weight:	3826 lbs
	Stabilator (deg)	1.1	AoA (deg):	-2.4
	Test 2			
	IAS (kn)	226	Fuel Weight:	3865 lbs
	Stabilator (deg)	0.62	AoA (deg):	-0.9
	Test 3			
	IAS (kn)	172	Fuel Weight:	3797 lbs
	Stabilator (deg)	0	AoA (deg):	0.2
	Test 4			
	IAS (kn)	N/A	Fuel Weight:	N/A
	Stabilator (deg)	N/A	AoA (deg):	N/A

Notes:

3/2/2023 Flight Simulator During Lab

Stall test - landing configuration

Pilot:	Sam Shenker	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4000	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps UP 10° (30°)				

Check	Action	
	DEPARTURE & SETUP	
✓	Set takeoff configuration (flaps 10°)	
✓	Disengage parking break	
✓	Apply full throttle & maintain runway centreline	
✓	Rotate at 90 kts IAS	
✓	Retract undercarriage and flaps	
✓	Climb at 120 kts IAS to test altitude	
✓	Set aircraft to test configuration	
✓	Adjust throttle & pitch to maintain altitude at 140 kts IAS	
	STALL TEST - POWER-OFF, WINGS LEVEL	
✓	Set throttle to idle	
✓	Increase pitch angle to maintain altitude	
✓	Keep balance ball centred using rudder	
✓	Fuel Weight:	N/A
✓	Record IAS at STALL HORN:	64 kn
✓	Record IAS at STALL:	50 kn
✓	Record Roll tendency:	(NONE) LEFT RIGHT
✓	Recover – Full throttle & Lower nose	

Notes:

Glide test

Pilot:	Sam Shenker	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4500	Payload Weight:	1081.1 lbs		

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
✓	Set aircraft to clean configuration			
✓	Ascend to 2000 ft above test altitude			
✓	Adjust throttle & pitch to maintain altitude at test speed			
✓	Set throttle to idle			
✓	Pitch down to maintain test speed			
✓	Start timer 500 ft over test altitude			
✓	Maintain test speed			
✓	Record time 500 ft below test altitude			
	IAS (kn)	100	Fuel Weight:	4109 lbs
	Time to Descend:		103.71 s	
	IAS (kn)	N/A	Fuel Weight:	N/A
	Time to Descend:		N/A	
	IAS (kn)	N/A	Fuel Weight:	N/A
	Time to Descend:		N/A	
	IAS (kn)	N/A	Fuel Weight:	N/A
	Time to Descend:		N/A	

Notes:

3/2/2023 Flight Simulator During Lab

Trim test

Pilot:	William Lowe	Date:	2/3/2023	Time:	N/A
CG offset (in):	+6	Empty Weight:	13434 lbs		
Test Altitude (ft):	4900	Payload Weight:	1081.81 lbs		

Check	Action			
	TRIM TEST			
✓	Climb/Descend to the test altitude			
✓	Adjust pitch & throttle to fly level flight at desired IAS			
✓	Record data			
	Test 1			
	IAS (kn)	340	Fuel Weight:	3948 lbs
	Stabilator (deg)	1.2	AoA (deg):	-1.8
	Test 2			
	IAS (kn)	230	Fuel Weight:	3900 lbs
	Stabilator (deg)	0.8	AoA (deg):	-1.0
	Test 3			
	IAS (kn)	192	Fuel Weight:	3894 lbs
	Stabilator (deg)	0.5	AoA (deg):	-0.3
	Test 4			
	IAS (kn)	N/A	Fuel Weight:	N/A
	Stabilator (deg)	N/A	AoA (deg):	N/A

Notes:

Pilot:		Date:		Time:	
CG offset (in):		Empty Weight:			
Test Altitude (ft):		Payload Weight:			

Check	Action			
	TRIM TEST			
	Climb/Descend to the test altitude			
	Adjust pitch & throttle to fly level flight at desired IAS			
	Record data			
	Test 1			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	
	Test 2			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	
	Test 3			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	
	Test 4			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	

Notes:

3/2/2023 Flight Simulator Parking Lab

Stall test - cruise configuration

Pilot:	William Lowe	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4000	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps (UP) 10° 30°				

Check	Action	
	DEPARTURE & SETUP	
✓	Set takeoff configuration (flaps 10°)	
✓	Disengage parking break	
✓	Apply full throttle & maintain runway centreline	
✓	Rotate at 90 kts IAS	
✓	Retract undercarriage and flaps	
✓	Climb at 120 kts IAS to test altitude	
✓	Set aircraft to test configuration	
✓	Adjust throttle & pitch to maintain altitude at 140 kts IAS	
	STALL TEST - POWER-OFF, WINGS LEVEL	
✓	Set throttle to idle	
✓	Increase pitch angle to maintain altitude	
✓	Keep balance ball centred using rudder	
✗	Fuel Weight:	N/A
✓	Record IAS at STALL HORN:	78 kn
✓	Record IAS at STALL:	58 kn
✓	Record Roll tendency:	(NONE) LEFT RIGHT
✓	Recover – Full throttle & Lower nose	

Notes:

Glide test

Pilot:	William Lowe	Date:	2/3/2023	Time:	N/A
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4500	Payload Weight:	1081.1 lbs		

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
✓	Set aircraft to clean configuration			
✓	Ascend to 2000 ft above test altitude			
✓	Adjust throttle & pitch to maintain altitude at test speed			
✓	Set throttle to idle			
✓	Pitch down to maintain test speed			
✓	Start timer 500 ft over test altitude			
✓	Maintain test speed			
✓	Record time 500 ft below test altitude			
	IAS (kn)	228 ± 4	Fuel Weight:	4158 lbs
	Time to Descend:		(23 ± 1) s	
	IAS (kn)	175 ± 2	Fuel Weight:	4126 lbs
	Time to Descend:		(50.98 ± 0.5) s	
	IAS (kn)	☐ N/A	Fuel Weight:	N/A
	Time to Descend:		N/A	
	IAS (kn)	N/A	Fuel Weight:	N/A
	Time to Descend:		N/A	

Notes:

3/2/2023 Flight Simulator During Lab

Stall test - landing configuration

Pilot:	Daisy Xia	Date:	2/3/2023	Time:	13:56
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4420	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps UP 10° (30°)				

Check	Action
	DEPARTURE & SETUP
✓	Set takeoff configuration (flaps 10°)
✓	Disengage parking break
✓	Apply full throttle & maintain runway centreline
✓	Rotate at 90 kts IAS
✓	Retract undercarriage and flaps
✓	Climb at 120 kts IAS to test altitude
✓	Set aircraft to test configuration
✗	Adjust throttle & pitch to maintain altitude at 140 kts IAS
	STALL TEST - POWER-OFF, WINGS LEVEL
✓	Set throttle to idle
✗	Increase pitch angle to maintain altitude
✗	Keep balance ball centred using rudder
✓	Fuel Weight: 4307.78 lbs
✗	Record IAS at STALL HORN: N/A
✗	Record IAS at STALL: N/A
✓	Record Roll tendency: NONE (LEFT) RIGHT
✗	Recover – Full throttle & Lower nose

Notes: stall test failed as the V too high

Pilot:		Date:		Time:	
CG offset (in):		Empty Weight:			
Test Altitude (ft):		Payload Weight:			

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
	Set aircraft to clean configuration			
	Ascend to 2000 ft above test altitude			
	Adjust throttle & pitch to maintain altitude at test speed			
	Set throttle to idle			
	Pitch down to maintain test speed			
	Start timer 500 ft over test altitude			
	Maintain test speed			
	Record time 500 ft below test altitude			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			

Notes:

3/2/2023 Flight Simulator During Lab

Stall test - landing configuration

Pilot:	Hanchen Li	Date:	2/3/2023	Time:	14:02
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4420	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps UP 10° (30°)				

Check	Action	
	DEPARTURE & SETUP	
✓	Set takeoff configuration (flaps 10°)	
✓	Disengage parking break	
✓	Apply full throttle & maintain runway centreline	
✓	Rotate at 90 kts IAS	
✓	Retract undercarriage and flaps	
✓	Climb at 120 kts IAS to test altitude	
✓	Set aircraft to test configuration landing gear down	
✓	Adjust throttle & pitch to maintain altitude at 140 kts IAS	
	STALL TEST - POWER-OFF, WINGS LEVEL	
✓	Set throttle to idle	
✓	Increase pitch angle to maintain altitude	
✓	Keep balance ball centred using rudder	
✓	Fuel Weight:	4211.878 lbs
✓	Record IAS at STALL HORN:	60 kn
✓	Record IAS at STALL:	58 kn
✓	Record Roll tendency:	NONE LEFT (RIGHT)
✓	Recover – Full throttle & Lower nose	

Notes:

Pilot:		Date:	Time:
CG offset (in):		Empty Weight:	
Test Altitude (ft):		Payload Weight:	

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
	Set aircraft to clean configuration			
	Ascend to 2000 ft above test altitude			
	Adjust throttle & pitch to maintain altitude at test speed			
	Set throttle to idle			
	Pitch down to maintain test speed			
	Start timer 500 ft over test altitude			
	Maintain test speed			
	Record time 500 ft below test altitude			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			
	IAS (kn)		Fuel Weight:	
	Time to Descend:			

Notes:

3/2/2023 Flight Simulator During Lab

Trim test

Pilot:	Hanchen Li	Date:	2/3/2023	Time:	18:16
CG offset (in):	+6	Empty Weight:	13434 lbs		
Test Altitude (ft):	5600	Payload Weight:	1081.81 lbs		

Check	Action			
	TRIM TEST			
✓	Climb/Descend to the test altitude			
✓	Adjust pitch & throttle to fly level flight at desired IAS			
✓	Record data			
	Test 1			
	IAS (kn)	249	Fuel Weight:	4134 lbs
	Stabilator (deg)	0.74	AoA (deg):	-1.2
	Test 2			
	IAS (kn)	172	Fuel Weight:	4222 lbs
	Stabilator (deg)	0.04	AoA (deg):	0.2
	Test 3			
	IAS (kn)	206	Fuel Weight:	4197 lbs
	Stabilator (deg)	0.55	AoA (deg):	-0.6
	Test 4			
	IAS (kn)	115	Fuel Weight:	4253 lbs
	Stabilator (deg)	-1.11	AoA (deg):	3.3

Notes:

Pilot:		Date:		Time:	
CG offset (in):		Empty Weight:			
Test Altitude (ft):		Payload Weight:			

Check	Action			
	TRIM TEST			
	Climb/Descend to the test altitude			
	Adjust pitch & throttle to fly level flight at desired IAS			
	Record data			
	Test 1			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	
	Test 2			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	
	Test 3			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	
	Test 4			
	IAS (kn)		Fuel Weight:	
	Stabilator (deg)		AoA (deg):	

Notes:

3/2/2023 Flight Simulator During Lab

Stall test - cruise configuration

Pilot:	Hanchen Li	Date:	2/3/2023	Time:	14:35
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4560	Payload Weight:	1081.81 lbs		
Stall Test Configuration:	Flaps (UP) 10° 30°				

Check	Action
	DEPARTURE & SETUP
✓	Set takeoff configuration (flaps 10°)
✓	Disengage parking break
✓	Apply full throttle & maintain runway centreline
✓	Rotate at 90 kts IAS
✓	Retract undercarriage and flaps
✓	Climb at 120 kts IAS to test altitude
✓	Set aircraft to test configuration
✓	Adjust throttle & pitch to maintain altitude at 140 kts IAS
	STALL TEST - POWER-OFF, WINGS LEVEL
✓	Set throttle to idle
✓	Increase pitch angle to maintain altitude
✓	Keep balance ball centred using rudder
✓	Fuel Weight: 4232.832 lbs
✓	Record IAS at STALL HORN: 81 kn
✓	Record IAS at STALL: 67 kn
✓	Record Roll tendency: NONE LEFT (RIGHT)
✓	Recover – Full throttle & Lower nose

Notes:

Glide test

Pilot:	Hanchen Li	Date:	2/3/2023	Time:	18:25
CG offset (in):	0	Empty Weight:	13434 lbs		
Test Altitude (ft):	4500	Payload Weight:	1081.1 lbs		

Check	Action			
	GLIDE TEST - POWER-OFF, WINGS LEVEL			
✓	Set aircraft to clean configuration			
✓	Ascend to 2000 ft above test altitude			
✓	Adjust throttle & pitch to maintain altitude at test speed			
✓	Set throttle to idle			
✓	Pitch down to maintain test speed			
✓	Start timer 500 ft over test altitude			
✓	Maintain test speed			
✓	Record time 500 ft below test altitude			
	IAS (kn)	200	Fuel Weight:	4105 lbs
	Time to Descend:		33.05 s	
	IAS (kn)	150	Fuel Weight:	4071 lbs
	Time to Descend:		70.19 s	
	IAS (kn)	☐ 100	Fuel Weight:	4038 lbs
	Time to Descend:		105.56 s	
	IAS (kn)	250	Fuel Weight:	4129 lbs
	Time to Descend:		17.26 s	

Notes: Account uncertainty when measuring the time, etc.

3/15/2023 Wind Tunnel Test Pre-Lab

Intro

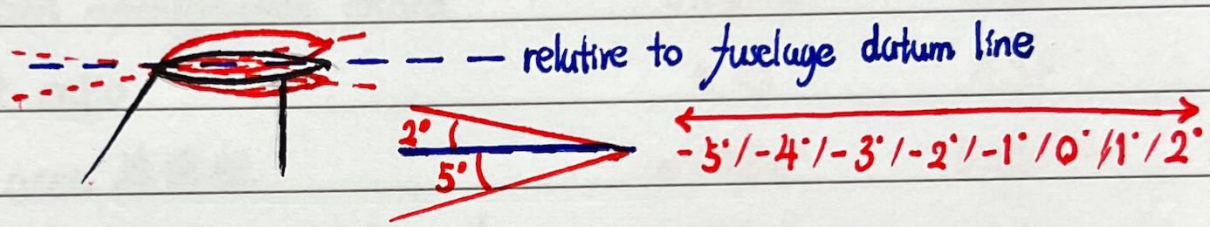
cryogenic 低温的 wind tunnels ← dynamic similarity

→ Nitrogen gas → Re required, M required, P (high), T (low)

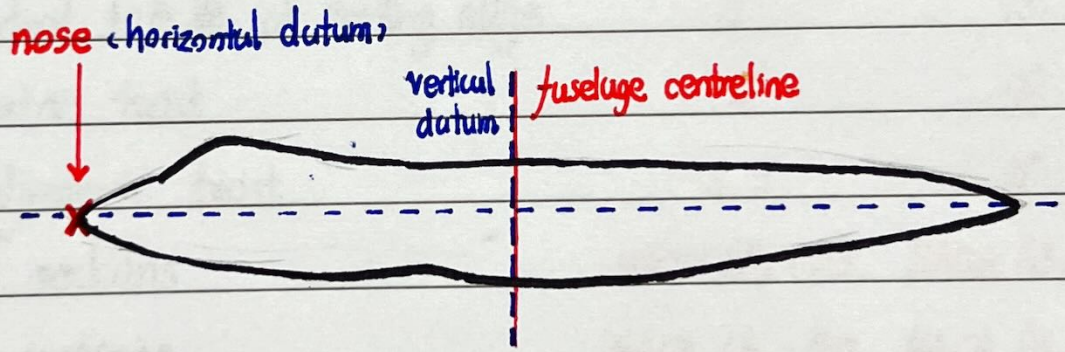
Model

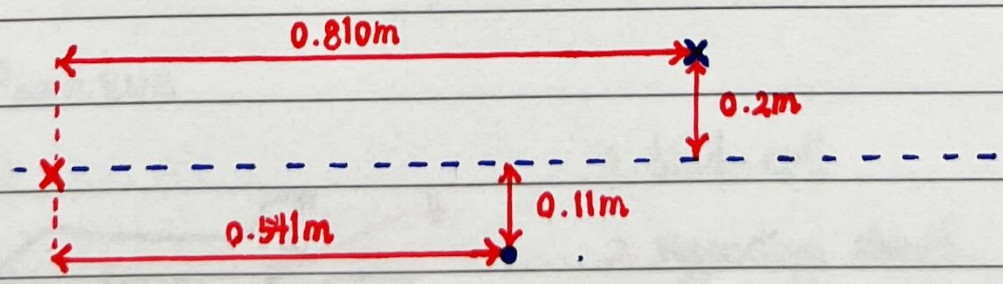
* see 'The Aircraft' in Flight Simulator Pre-Lab

Tail plane



Fuselage





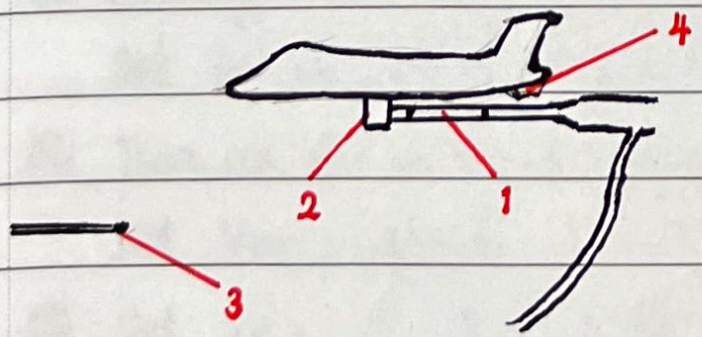
× The quarter-chord point of the tail's mean aerodynamic chord

• The load-cell 称重传感器

3/15/2023 Wind Tunnel Test Pre-Lab

		Wing	Tailplane
b	span	0.873 m	0.388 m
c_{root}	root chord	0.203 m	0.108 m
c_{cen}	chord at aircraft centre-line	0.215 m	0.108 m
c_{tip}	tip chord	0.081 m	0.051 m
$\bar{c}_{geo}$	geometric mean chord	0.147 m	0.082 m
$\bar{c}_{aero}$	mean aerodynamic chord	0.158 m	0.085 m
AR	aspect ratio	5.93	4.74
A	gross area 总面积	0.128 m²	0.032 m²
Γ	dihedral 上反角 at trailing edge	2°	0°
	geometric twist	-3°	0°
	aerodynamic twist	-3.5°	0°
	root sections	NACA 64_2-415	NACA 63_1-A012
	tip sections	NACA 64_2-412	NACA 63_1-A012

Setup & Procedure



1 load-cell

2 supporting struct

3 the Pitot-static tube

4 tailplane angle setting pins

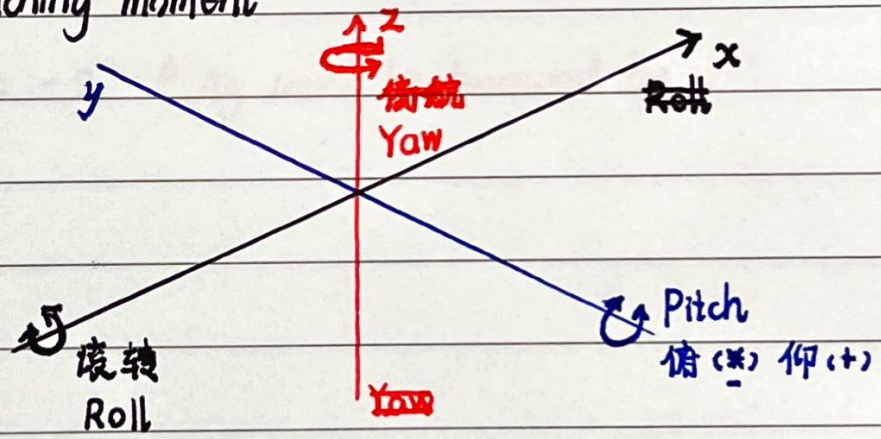
3/15/2023 Wind Tunnel Test Pre-Lab

α_g geometric angle of attack = θ string's pitch angle + 0.8°

* only considered F_x +ve backwards (horizontal)

F_z +ve upwards (vertical)

M_c pitching moment



$\dot{W}_{motor} = P_{motor}$ 30kW

A_{work} 1.6m × 1.1m

P $P_{atmospheric}$

V_{max} 40 m/s

$V_{experiment}$ 25 m/s

P, T read from micromanometer

* provide by temperature probe and barometer (p.75)

Procedure

① Record T and P * may be varies throughout the lab session

② Set $\theta = 0°$

③ Ensuring $V_{air} = 0$

Set balance reading = 0 (tare 皮重)

④ Turn on the wind tunnel

set V_{air} = 25 m/s * slowly increase the fan frequency

⑤ Set $\alpha_g = -2°$ ($\theta = -2.8°$) * range -2° ~ 12° in steps of 2°

3/15/2023 Wind Tunnel Test Pre-Lab

Record L, D, M_c * 5s average reading

Record standard deviation

⑥ Set for next test

⑦ Reduce V_{air} the adjust tailplane $i_H = +1°$

Repeat procedure

⑧ Repeat procedure $i_H = -2°$ * α_g could be increased by 17°

Avoid model vibrate

⑨ Return $\theta = 0°$

Observe

observe the wool tufts attached to the aircraft

① Onset 开始 of the wing stall and its spread across the wing

② Location of the wing wake in relation to the tail

③ Stalling of the tail

④ other...

3/16/2023 Windtunnel During Lab

* The change of the wool tufts is pre-recorded

iH (deg)	String's pitch angle θ (deg)	Geometric angle of attck a_g (deg)	Load-cell horizontal axial force Fx		Load-cell vertical axial force Fz		Pitching moment Mc (My)		Temperature		Dynamic Pressure	
			(N)	standard deviation	(N)	standard deviation	(Nm)	standard deviation	(C°)	Uncertainty (±)	(Pa)	Uncertainty (±)
Remove tailplane	-2.8	-2	-0.923	0.346	0.728	0.643	0.157	0.109	23.3	0.05	370.9	0.2
	-0.8	0	1.563	0.392	8.044	0.75	1.047	0.131	23.4	0.1	371.4	0.2
	1.2	2	3.755	0.365	15.44	0.635	2.258	0.129	23.5	0.05	371.6	0.2
	3.2	4	5.475	0.345	23.525	0.655	3.435	0.113	23.6	0.05	371.7	0.2
	5.2	6	6.869	0.335	31.215	0.562	4.563	0.096	23.7	0.05	371.6	0.2
	7.2	8	8.223	0.338	37.062	0.792	5.543	0.089	23.7	0.05	371.1	0.7
	9.2	10	9.443	0.363	42.435	0.805	6.399	0.13	23.8	0.05	370.6	0.1
	11.2	12	10.565	0.462	45.562	0.979	7.151	0.156	23.8	0.05	369.8	0.5
1	-2.8	-2	-1.052	0.329	-0.623	0.757	0.022	0.128	24.2	0.05	368.5	0.2
	-0.8	0	1.673	0.568	8.13	0.642	0.975	0.187	24.2	0.05	369.3	0.2
	1.2	2	3.901	0.38	16.852	0.696	1.945	0.134	24.3	0.05	369.7	0.2
	3.2	4	5.753	0.358	25.758	0.591	2.858	0.102	24.3	0.05	370.1	0.2
	5.2	6	7.244	0.364	34.153	0.652	3.678	0.111	24.4	0.1	370.1	0.1
	7.2	8	8.525	0.4	41.362	0.651	4.339	0.125	24.4	0.05	369.5	0.3
	9.2	10	9.709	0.511	47.114	0.715	4.921	0.131	24.4	0.05	368.9	0.3
	11.2	12	10.893	0.442	52.226	0.815	5.365	0.129	24.4	0.05	367.4	0.2
-2	-2.8	-2	-0.904	0.43	-3.497	0.761	0.766	0.125	24.4	0.05	368.2	0.1
	-0.8	0	1.735	0.455	5.233	0.659	1.664	0.133	24.4	0.05	369.2	0.2
	1.2	2	4.15	0.384	14.567	0.459	2.673	0.104	24.5	0.05	369.5	0.2
	3.2	4	5.993	0.325	23.219	0.6	3.001	0.087	24.4	0.05	369.6	0.2
	5.2	6	7.514	0.388	31.635	0.563	4.475	0.101	24.5	0.05	369.8	0.2
	7.2	8	8.68	0.403	38.755	0.76	5.11	0.111	24.6	0.05	369.4	0.3
	9.2	10	9.927	0.446	45.107	0.835	5.622	0.112	24.6	0.05	368.8	0.1
	11.2	12	10.945	0.438	50.644	0.737	6.052	0.117	24.6	0.05	367.3	0.3
	13.2	14	13.683	1.316	53.011	1.196	6.196	0.305	24.7	0.1	365	0.2
	15.2	16	19.605	1.205	49.897	1.723	5.77	0.529	24.7	0.05	362.7	0.3
	17.2	18	24.625	1.913	45.091	1.621	4.335	0.708	24.7	0.05	369.9	0.2
	18.2	19	26.546	1.644	43.559	2.47	4.898	0.492	24.8	0.05	369.1	0.1
	19.2	20	27.565	2.266	43.747	2.608	5.371	0.72	24.9	0.05	368.2	0.2
	20.2	21	29.429	1.839	45.744	3.586	5.707	0.718	24.9	0.05	367.6	0.2
	21.2	22	30.652	2.247	46.765	3.687	6.184	0.794	24.9	0.05	367.3	0.2
	22.2	23	32.027	2.43	48.066	4.2	6.622	0.937	25	0.05	366.5	0.1
	23.2	24	32.454	1.829	49.189	3.967	6.695	0.836	25	0.05	365.5	0.4
	24.2	25	34.43	2.376	49.529	3.005	7.325	0.819	25	0.05	364.5	0.1

* When Yaw = -1.5143° by automatic adjustment

** Noticed that wind speed is always below 25m/s during lab, with uncertainty ±0.02m/s

3/16/2023 Windtunnel During Lab

* Extra test to see what happened when turning / not facing wind

iH (deg)	String's pitch angle θ (deg)	Geometric angle of attck a_g (deg)	Load-cell horizontal axial force Fx		Load-cell vertical axial force Fz		Pitching moment Mc (My)		Temperature		Dynamic Pressure	
			(N)	standard deviation	(N)	standard deviation	(Nm)	standard deviation	(C°)	Uncertainty (±)	(Pa)	Uncertainty (±)
-2	-2.8	-2	-0.692	0.423	-3.913	0.637	0.844	0.092	24.9	0.05	368.4	0.2
	-0.8	0	1.826	0.463	4.694	0.548	1.772	0.118	25	0.05	368.8	0.2
	1.2	2										
	3.2	4	6.051	0.462	22.015	0.62	3.583	0.118	25	0.05	369.7	0.2
	5.2	6	7.51	0.29	30.452	0.641	4.403	0.07	25	0.1	369.6	0.1
	7.2	8	8.794	0.39	37.204	0.51	5.044	0.103	25.1	0.05	368.9	0.2
	9.2	10	9.981	0.343	43.645	0.71	5.621	0.078	25.1	0.05	368	0.2
	11.2	12	10.989	0.36	49.174	0.566	6.068	0.065	25.1	0.05	366.5	0.2
* When Yaw = 5°												
-2	-2.8	-2	-1.703	0.407	-3.004	0.703	0.755	0.125	25.1	0.05	366.7	0.2
	-0.8	0	1.01	0.36	6.013	0.473	1.678	0.099	25.1	0.05	368	0.3
	1.2	2	3.31	0.508	14.782	0.174	2.594	0.127	25.1	0.05	368	1.5
	3.2	4	5.258	0.588	23.325	0.672	3.521	0.129	25.2	0.05	368.7	0.3
	5.2	6	6.745	0.563	32.048	0.562	4.395	0.13	25.2	0.05	368.8	0.1
	7.2	8	8.109	0.599	38.906	0.683	5.051	0.129	25.2	0.05	368.2	0.2
	9.2	10	9.276	0.444	45.429	0.816	5.612	0.078	25.2	0.05	367.8	0.2
	11.2	12	10.465	0.491	51.473	1.007	6.114	0.145	25.2	0.05	366.1	0.1
* When Roll = -10°												