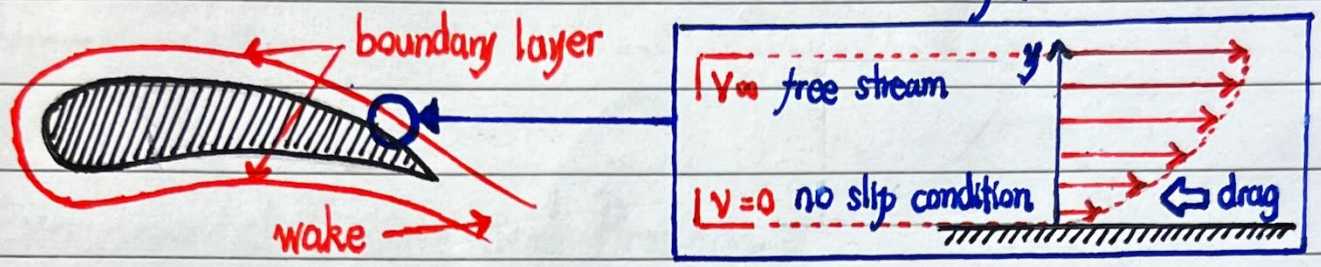
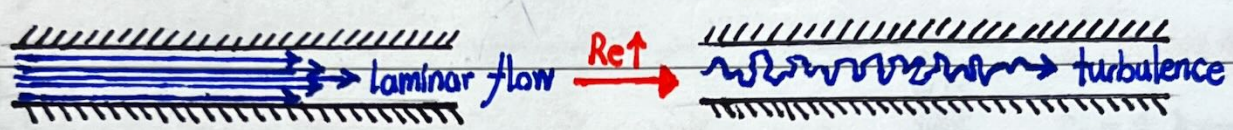
11/19/2022 Pipe Flow Pre-Lab

Introduction

- effect of soild walls on fluid flows
  - the interaction of flows with curved surfaces
  - effects of the boundary layer generated

better understand real world phenomena

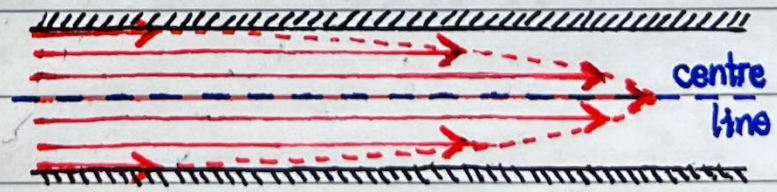




- examine the transition from laminar to turbulent
  - measuring the pressure drop along the length of the pipe
  - allow us to compute the sheur stress, τ
- investigate the C_f skin friction coefficient varies with Re_D
- deduce the Re_{crit} critical Reynolds number
- compare results to theory and past findings

Theory

fully developed pipe flow



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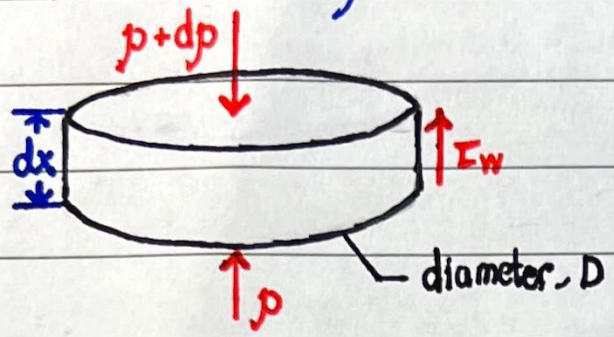


$$\frac{\pi D^2}{4}\frac{dp}{dx}dx = \pi D \tau_w dx$$

$$\downarrow$$

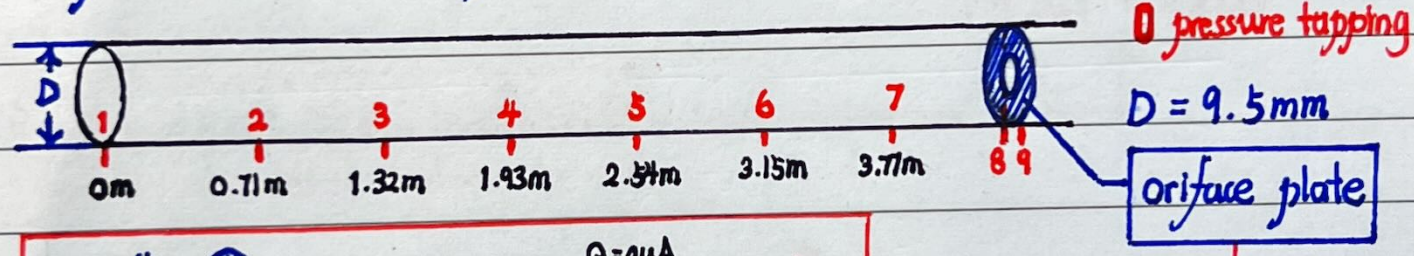
$$\tau_w = \frac{D}{4}\frac{dp}{dx}$$

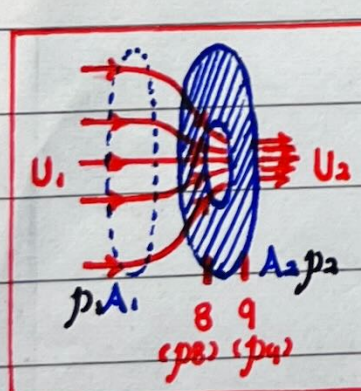
$$Re_D = \frac{\rho V D}{\mu}$$

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho V^2} = f(Re_D)$$

$$\longrightarrow \boxed{C_f = \frac{D}{4(\frac{1}{2}\rho V^2)}\frac{dp}{dx} = \frac{\Delta p}{\frac{1}{2}\rho V^2}\frac{D}{4L} = f(Re_D)}$$

Experimental Facility and Procedure





$$A_2 < A_1 \xrightarrow{Q=\rho u A} U_2 > U_1$$

$$p_1 + \frac{1}{2}\rho U_1^2 = p_2 + \frac{1}{2}\rho U_2^2$$

$\hookrightarrow p_1 < p_2$

$\hookrightarrow p_9 > p_8$ 突破梗阻

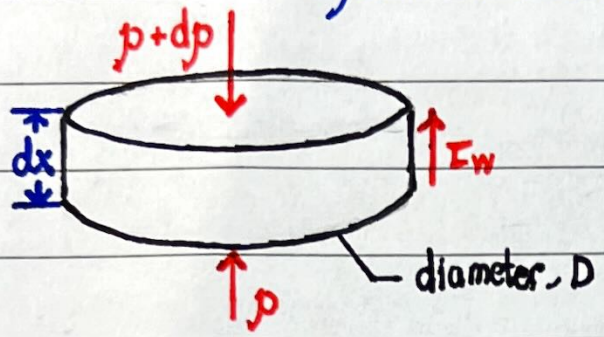
$\rightarrow k_{lam} = 0.10$

$\rightsquigarrow k_{turb} = 0.08$

$$\longrightarrow \boxed{\frac{1}{2}\rho_{air} V^2 = k\Delta p_0 = k(p_9 - p_8)}$$

determine the mean velocity in the flow

11/20/2022 Pipe Flow Pre-Lab



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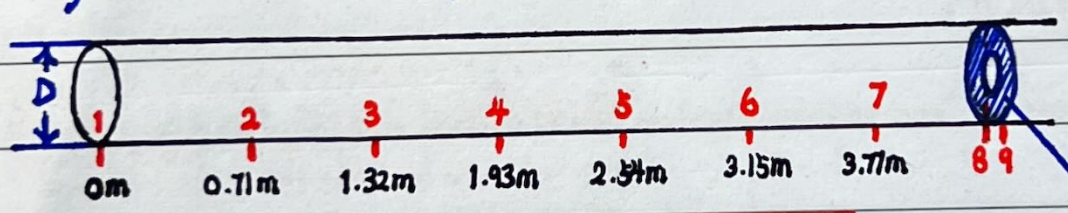
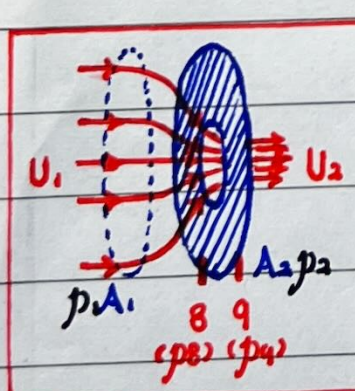
Experimental Facility and Procedure



0 pressure tapping

D = 9.5mm

orifice plate



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$p_1 + \frac{1}{2}\rho U_1^2 = p_2 + \frac{1}{2}\rho U_2^2$

↳ $p_1 < p_2$

↳ $p_9 > p_8$ 突破梗阻

→ $k_{lam} = 0.10$

⇝ $k_{turb} = 0.08$

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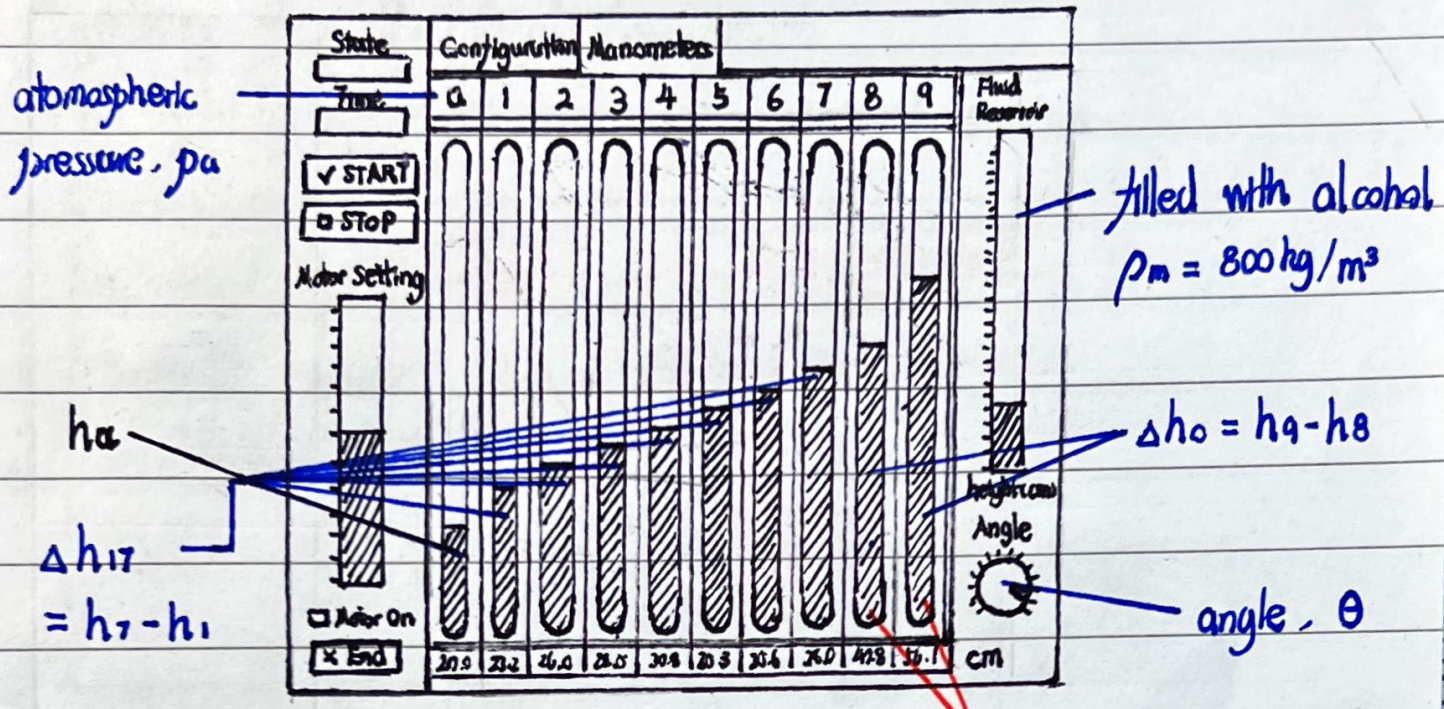
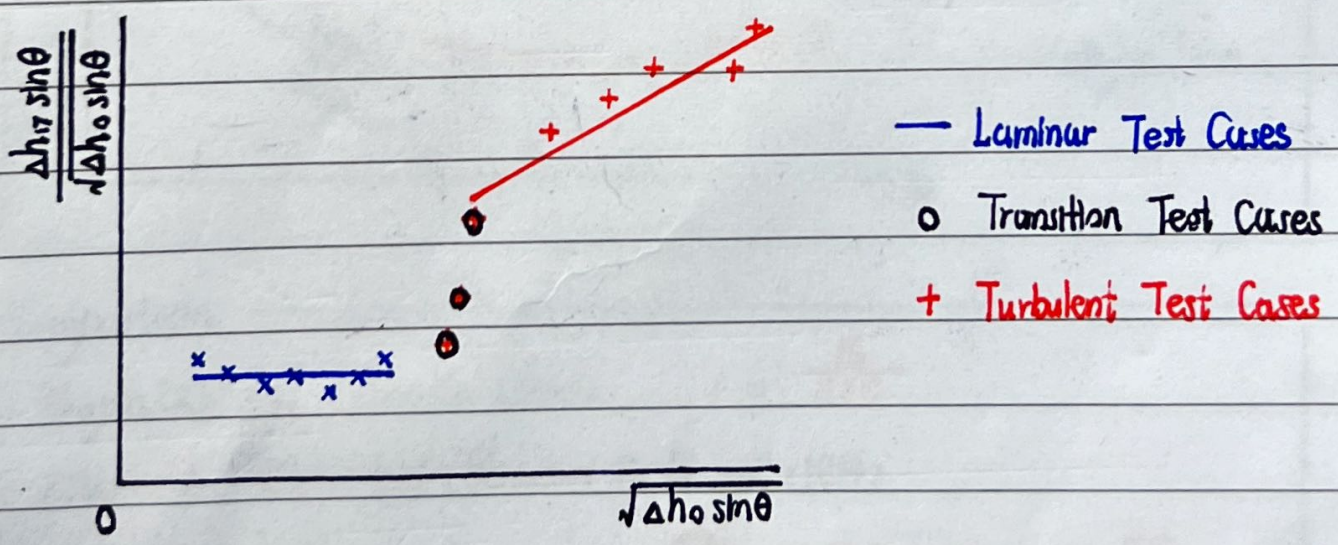
11/20/2022 Pipe Flow Pre-Lab



$$\frac{1}{2}\rho_a V^2 = k\Delta p_0$$

$$\Delta p_0 = \rho g \Delta h = \rho_m g \Delta h_0 \sin\theta$$



Running Plot

- isolate transition - determine the distribution of points

11/20/2022 Pipe Flow Pre-Lab

Preparing for the Oral Assessment

24 h after lab → 30 min oral assessment session

Calculation

velocity $V = \sqrt{\frac{2k\Delta p_0}{\rho_a}} = \sqrt{\frac{2k\rho_m g \Delta h_0 \sin\theta}{\rho_a}}$

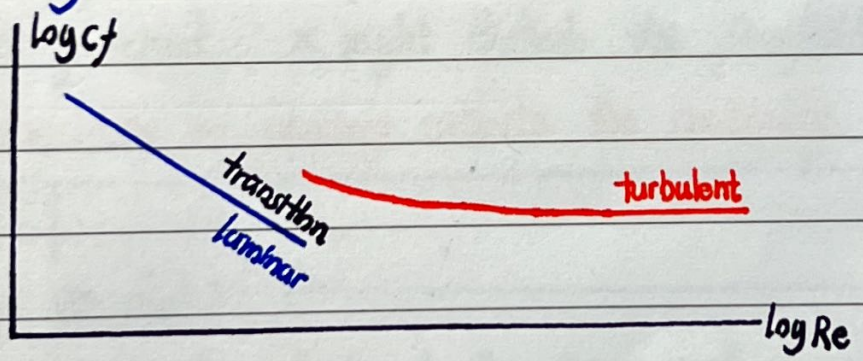
Reynolds number $Re_D = \frac{\rho V D}{\mu} = \frac{\rho_a V D}{\mu_{air}}$

skin-friction coefficient $C_f = \frac{\Delta p}{\frac{1}{2}\rho_a V^2} \frac{D}{4L}$

$= \frac{\rho_m g \Delta h \sin\theta}{k\rho_m g \Delta h_0 \sin\theta} \frac{D}{4L}$

$= \frac{\Delta h}{k\Delta h_0} \frac{D}{4L} = \frac{1}{4k} \boxed{\frac{d(\frac{h}{h_0})}{d(\frac{x}{D})}}$ gradient

Plotting



Determine the slope of the straight line

Comparison

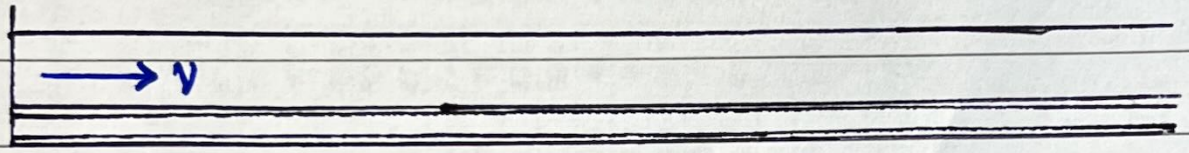
Hagen [2] and Poiseuille (1840) $C_f = \frac{16}{Re_D}$

Nikuradse (1932) and Stanton & Pannell (1914)

$$\frac{1}{\sqrt{C_f}} = -0.4 + 4\log(Re_D\sqrt{C_f})$$

11/21/2022 Pipe-flow During Lab

- $P_{atomsphere} = 989.9\ mbar = 98990\ Pa$
- $T = 24.2°C = 297.35\ K$



* pressure tapper 4 do not exist in equipment
  ignore the value record by tapping 4

* value is unstable at first few seconds in steady flow
* value cannot keep in a constant value in unsteady flow
  just approximate it at average

Other values

μ_{air} at $24.2°C \approx 1.84 \times 10^{-5}\ kg/ms^2$

$\rho_a = \frac{PaM}{RT} = 1.15967492\ kg/m^3$

$\rho_m = 800\ kg/m^3$

$D = 9.5mm = 9.5 \times 10^{-3}\ m$

fluid reservoir height
$h = 20cm$

* μ_{air} is estimated value from diagram standard

11/21/2022 Pipe-flow During Lab

Number of attempts	Motor Setting (V)	Angle (degrees)	Fluid Reservoir height (cm)
1	0	90	20
2	9.3	70.6767	20
3	9	70.6767	20
4	8	70.6767	20
5	7	70.6767	20
6	6	35.4344	20
7	5	35.4344	20
8	4	20	20
9	3	20	20
10	2	20	20
11	1	20	20
12	5	35.2683	20
13	5.6	35.2683	20
14	0.5	20	20
15	1.25	20	20
16	1.5	20	20
17	0.35	20	20
18	0.62	20	20
19	0.72	20	20

Pressure Tapping										
	a	1	2	3	4*	5	6	7	8	9
Position x (m)		0	0.71	1.32	1.93	2.54	3.15	3.77		
h (cm)	20	19.9	20.1	20.1	20.3	20	19.9	20.1	22.1	20
	21.1	27.6	33.2	38.2	53.8	47.4	52.1	56.9	65	95.9
	21.1	27.2	32.5	37.1	51.8	45.7	50.2	54.7	62.4	90.9
	21.1	26	30.2	33.9	45.7	40.8	44.3	47.9	54.5	75.8
	21.1	24.8	28.2	31	40.2	36.4	39.1	41.9	47.5	62.7
	34.4	38.8	42.8	46.3	57.5	52.5	56	59.5	67	83.3
	34.4	37.2	39.6	42.3	50	47.4	49.5	52	58.4	68.1
	58.4	61.5	65	67.6	76.3	72.2	73.1	74.6	83.6	97.8
	58.4	61.1	63.1	64.1	69	66	66.8	69	76.8	78.3
	58.4	59.3	60.6	61.1	63.6	62.1	62.2	63	69.9	66.9
	58.4	58.3	59.2	59.2	60.2	59.4	59.2	59.5	66.1	60.1
	34.6	37.3	40	42	50.8	47	49.5	50.7	58.5	68.6
	34.6	38	41.3	44.5	53.9	50	52.5	55.6	62.5	75.3
	58.4	58.2	58.8	58.9	59.3	58.7	58.5	58.6	65	58.7
	58.4	58.6	59.5	59.6	60.8	60	59.9	60.2	66.9	61.3
	58.4	58.7	59.9	60	61.6	60.5	60.5	61.1	67.8	62.8
	58.4	58.1	58.8	58.7	59.1	58.6	58.2	58.5	64.9	58.6
	58.4	58.1	58.8	58.7	59.1	58.6	58.2	58.5	64.9	58.6
	58.4	58.2	59	58.9	59.6	59	58.6	58.9	65.4	59.2

*Ignore pressure tapping cause it is not exist

* Data need to be processed again with the error occurs at ground state

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17	0.35	20	20
18	0.62	20	20
19	0.72	20	20

Pressure Tapping										
	a	1	2	3	4	5	6	7	8	9
x (m)		0	0.71	1.32	1.93	2.54	3.15	3.77		
error (m)	0	0.001	-0	-0	-0	0	0.001	-0	-0.02	0
h (m)	0.211	0.277	0.331	0.381	0.535	0.474	0.522	0.568	0.628	0.959
	0.211	0.273	0.324	0.37	0.515	0.457	0.503	0.546	0.602	0.909
	0.211	0.261	0.301	0.338	0.454	0.408	0.444	0.478	0.523	0.758
	0.211	0.249	0.281	0.309	0.399	0.364	0.392	0.418	0.453	0.627
	0.344	0.39	0.426	0.461	0.57	0.525	0.562	0.593	0.634	0.833
	0.344	0.374	0.394	0.421	0.495	0.474	0.497	0.518	0.548	0.681
	0.584	0.618	0.647	0.673	0.754	0.722	0.734	0.743	0.775	0.978
	0.584	0.614	0.628	0.638	0.681	0.66	0.671	0.687	0.707	0.783
	0.584	0.596	0.603	0.608	0.627	0.621	0.625	0.627	0.638	0.669
	0.584	0.586	0.589	0.589	0.593	0.594	0.595	0.592	0.6	0.601
	0.346	0.375	0.398	0.418	0.503	0.47	0.497	0.505	0.549	0.686
	0.346	0.382	0.411	0.443	0.534	0.5	0.527	0.554	0.589	0.753
	0.584	0.585	0.585	0.586	0.584	0.587	0.588	0.583	0.589	0.587
	0.584	0.589	0.592	0.593	0.599	0.6	0.602	0.599	0.608	0.613
	0.584	0.59	0.596	0.597	0.607	0.605	0.608	0.608	0.617	0.628
	0.584	0.584	0.585	0.584	0.582	0.586	0.585	0.582	0.588	0.586
	0.584	0.584	0.585	0.584	0.582	0.586	0.585	0.582	0.588	0.586
	0.584	0.585	0.587	0.586	0.587	0.59	0.589	0.586	0.593	0.592

* Some value might be invalid due to the inaccurate estimate from reading

11/21/2022 Pipe-flow Post-Lab

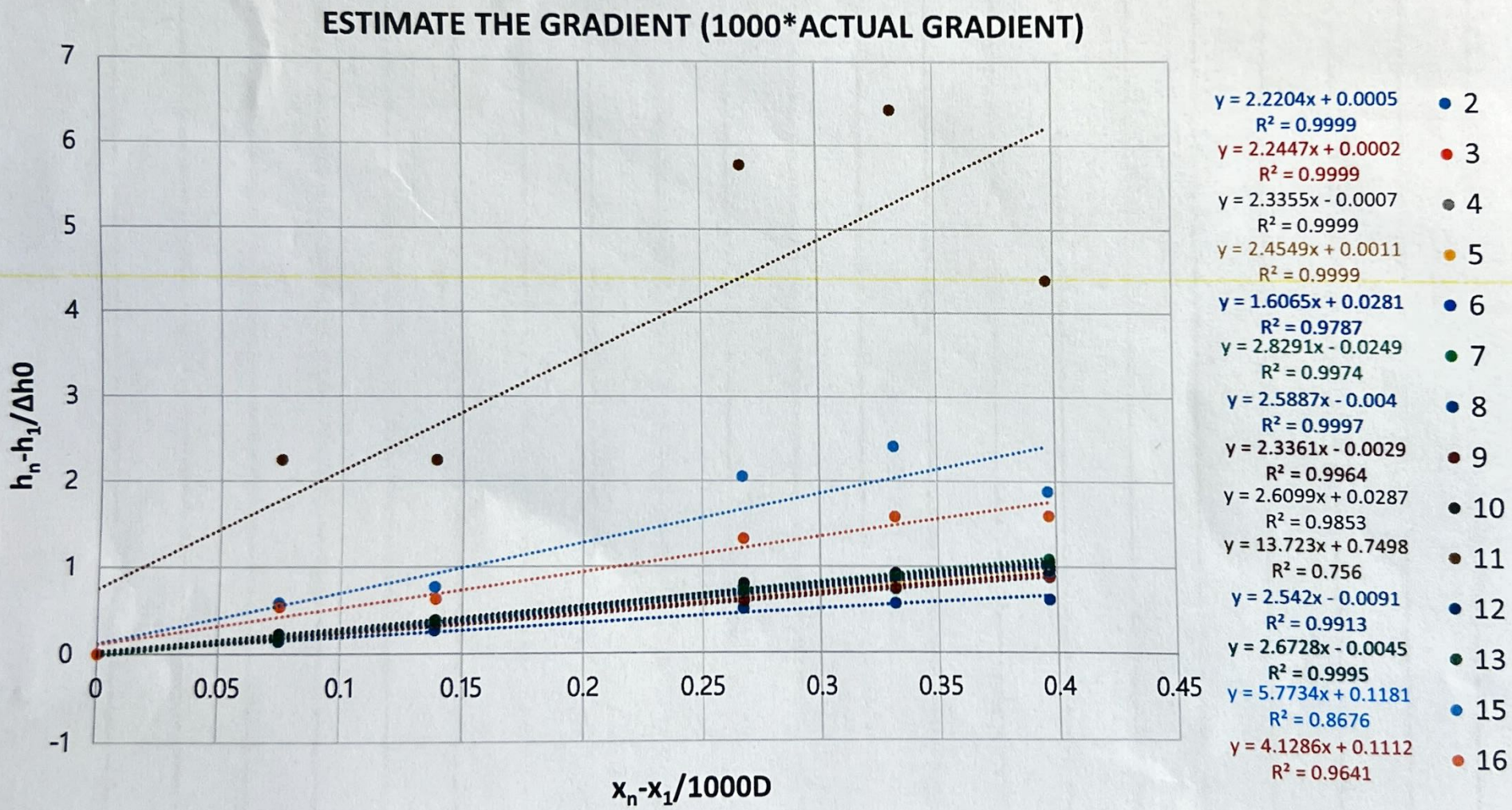
Number of attempts	Δh_0 (m)	Δh_{17} (m)	$(\Delta h_0 \sin\theta)^{1/2}$ ($m^{1/2}$)	$\Delta h_{17} \sin\theta$ (m)	$\Delta h_{17}\sin\theta / (\Delta h_0 \sin\theta)^{1/2}$ ($m^{1/2}$)	Pressure Tapping						
						x_1-x_1 /1000D	x_2-x_1 /1000D	x_3-x_1 /1000D	x_4-x_1 /1000D	x_5-x_1 /1000D	x_6-x_1 /1000D	x_7-x_1 /1000D
						0	0.0747	0.1389	0.2032	0.2674	0.3316	0.3968
						h_1-h_1 /Δh_0	h_2-h_1 /Δh_0	h_3-h_1 /Δh_0	h_4-h_1 /Δh_0	h_5-h_1 /Δh_0	h_6-h_1 /Δh_0	h_7-h_1 /Δh_0
2	0.33125363	0.29088061	0.55910011	0.27449427	0.490957286	0	0.1627	0.3136	0.7781	0.5945	0.7396	0.8781
3	0.30725363	0.27288061	0.53846536	0.25750828	0.478226266	0	0.1656	0.3153	0.7868	0.5987	0.7486	0.8881
4	0.23525363	0.21688061	0.47116978	0.20466296	0.434371997	0	0.1695	0.3268	0.8194	0.6246	0.7779	0.9219
5	0.17425363	0.16888061	0.4055087	0.15936697	0.39300505	0	0.183	0.3436	0.8594	0.6596	0.8206	0.9692
6	0.19922123	0.20355036	0.33985671	0.11801249	0.347241886	0	0.1835	0.3592	0.904	0.679	0.8634	1.0217
7	0.13322123	0.14455036	0.27791678	0.08380603	0.301550808	0	0.1543	0.3569	0.909	0.7527	0.9233	1.085
8	0.20339989	0.12515239	0.2637553	0.04280464	0.162289206	0	0.1433	0.2712	0.6701	0.5117	0.5703	0.6153
9	0.07639989	0.07315239	0.1616487	0.02501959	0.15477756	0	0.1852	0.3161	0.881	0.6031	0.7461	0.9575
10	0.03139989	0.03115239	0.10363106	0.01065475	0.102814212	0	0.2278	0.387	0.997	0.7986	0.9236	0.9921
11	0.00139989	0.00615239	0.0218813	0.00210424	0.0961662	0	2.2519	2.2519	5.2181	5.7692	6.4291	4.3949
12	0.13736956	0.13053623	0.28163452	0.0753724	0.26762487	0	0.1713	0.3169	0.9323	0.6935	0.8881	0.9503
13	0.16436956	0.17253623	0.30807137	0.09962345	0.323377845	0	0.1797	0.3744	0.9252	0.7195	0.8822	1.0497
14	-0.0016001	-0.0018476		-0.0006319								
15	0.00539989	0.01015239	0.04297525	0.00347232	0.08079819	0	0.5838	0.769	1.9083	2.0512	2.4075	1.8801
16	0.01139989	0.01815239	0.06244192	0.00620848	0.099428138	0	0.5397	0.6274	1.518	1.3225	1.579	1.5923
17	-0.0016001	-0.0018476		-0.0006319								
18	-0.0016001	-0.0018476		-0.0006319								
19	-0.0006001	0.00115239		0.00039414								

11/21/2022 Pipe-flow Post-Lab

Find gradient to estimate the C_f

C_f = (#6 gradient)

Laminar and turbulent flow have much higher gradient than transition flow, and laminar flow have very large-disturbed data point



11/21/2022 Pipe-flow Post-Lab

Number of attempts	Motor Setting (V)	Type of Flow	V (m/s)	Re_D	τ_w (Pa)	C_f	C_f comparison			
							Hagon and Poiseuille		Nikuradse and Stanton&Pannell	
			$(2k\Delta p_D/\rho_a)^{1/2}$	$\rho_a VD/\mu$	$(D/4)(dp/dx)$	$(1/4k)$gradient	$16/Re_D$	Δ	$1/(Cf)1/2=-0.4+4\log(ReD(Cf)1/2)$	Δ
1	0									
2	9.3	Turbulent	18.3975901	11015.4688	1.36178763	0.00693875	0.001452503	0.0055	0.007532702	-2.123
3	9	Turbulent	17.7185887	10608.9199	1.27694693	0.00701469	0.001508165	0.0055	0.007607457	-2.119
4	8	Turbulent	15.5041792	9283.05292	1.01726411	0.00729844	0.001723571	0.0056	0.007881615	-2.103
5	7	Turbulent	13.3435544	7989.38914	0.79201454	0.00767156	0.002002656	0.0057	0.008207024	-2.086
6	6	Turbulent	11.1832288	6695.90458	0.58664103	0.00808969	0.00238952	0.0057	0.00861519	-2.065
7	5	Turbulent	9.14505079	5475.55528	0.42872305	0.00884094	0.002922078	0.0059	0.009116483	-2.04
8	4	Transition	8.67905736	5196.54395	0.21927147	0.00502031	0.003078969	0.0019	0.009253604	-2.034
9	3	Transition	5.31916635	3184.82533	0.11976636	0.00730031	0.005023823	0.0023	0.010692976	-1.971
10	2	Laminar	3.81255647	2282.74989	0.05499241	0.00652475	0.00700909	-5E-04	0.01186093	-1.926
11	1	Laminar	0.80500677	481.993942	0.01289123	0.0343075	0.033195438	0.0011	0.020635207	-1.685
12	5	Transition	9.26738592	5548.80285	0.39559094	0.00794375	0.002883505	0.0051	0.009082106	-2.042
13	5.46	Turbulent	10.1373092	6069.66522	0.49770057	0.0083525	0.00263606	0.0057	0.008854774	-2.053
14	0.5									
15	1.25	Laminar	1.58104692	946.644257	0.02092028	0.0144335	0.016901809	-0.002	0.015975824	-1.797
16	1.5	Laminar	2.29721996	1375.44943	0.03158306	0.0103215	0.011632561	-0.001	0.014015148	-1.853
17	0.35									
18	0.62									
19	0.72									

* Attempts 14, 16, 18, 19 is invalid caused by the measurement error

Type of flow can be determined through the running plot in next page →

$k_{lam} = 0.10$

$k_{turb} = 0.08$

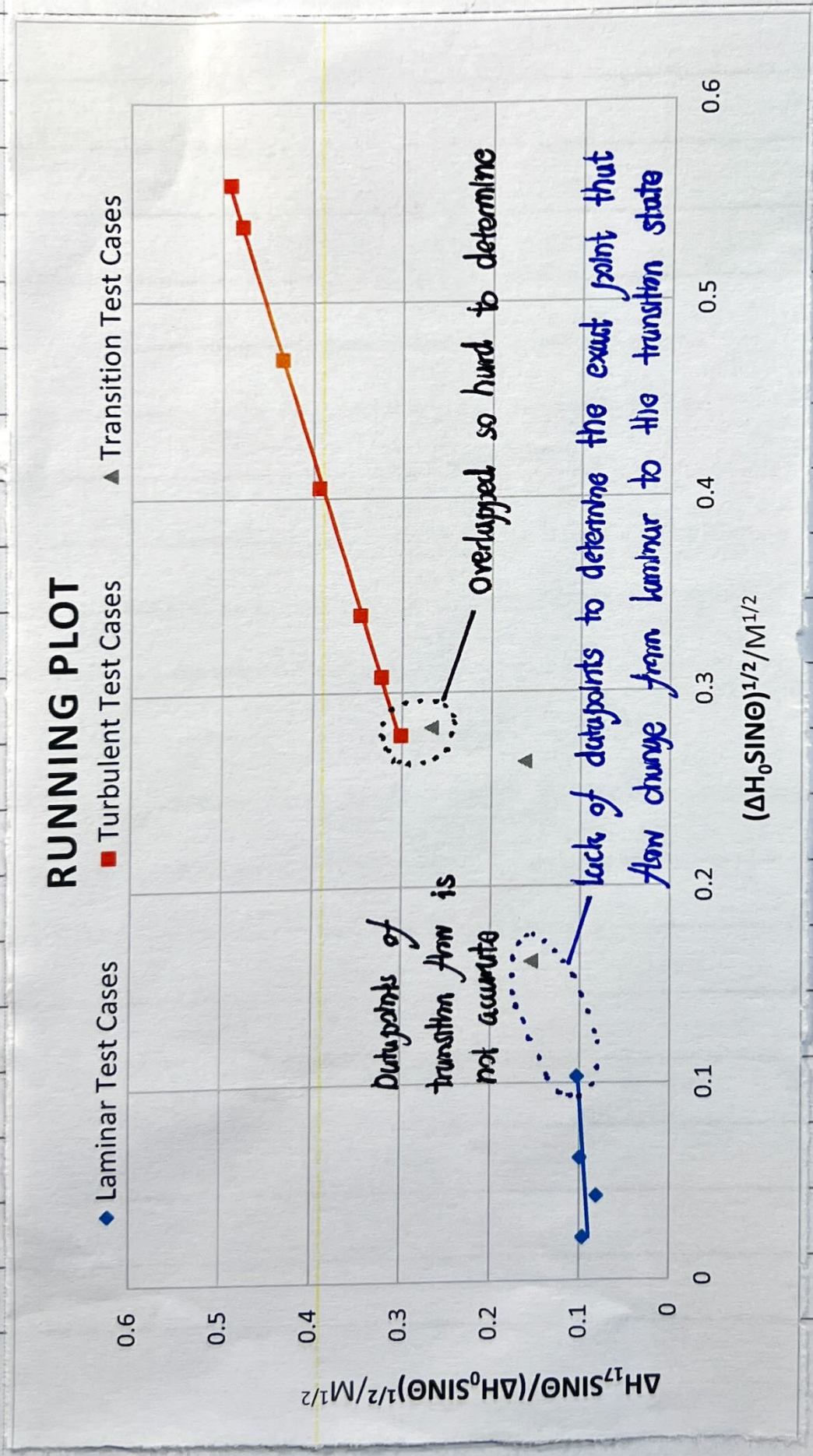
Assume that

$k_{tran} = 0.08$

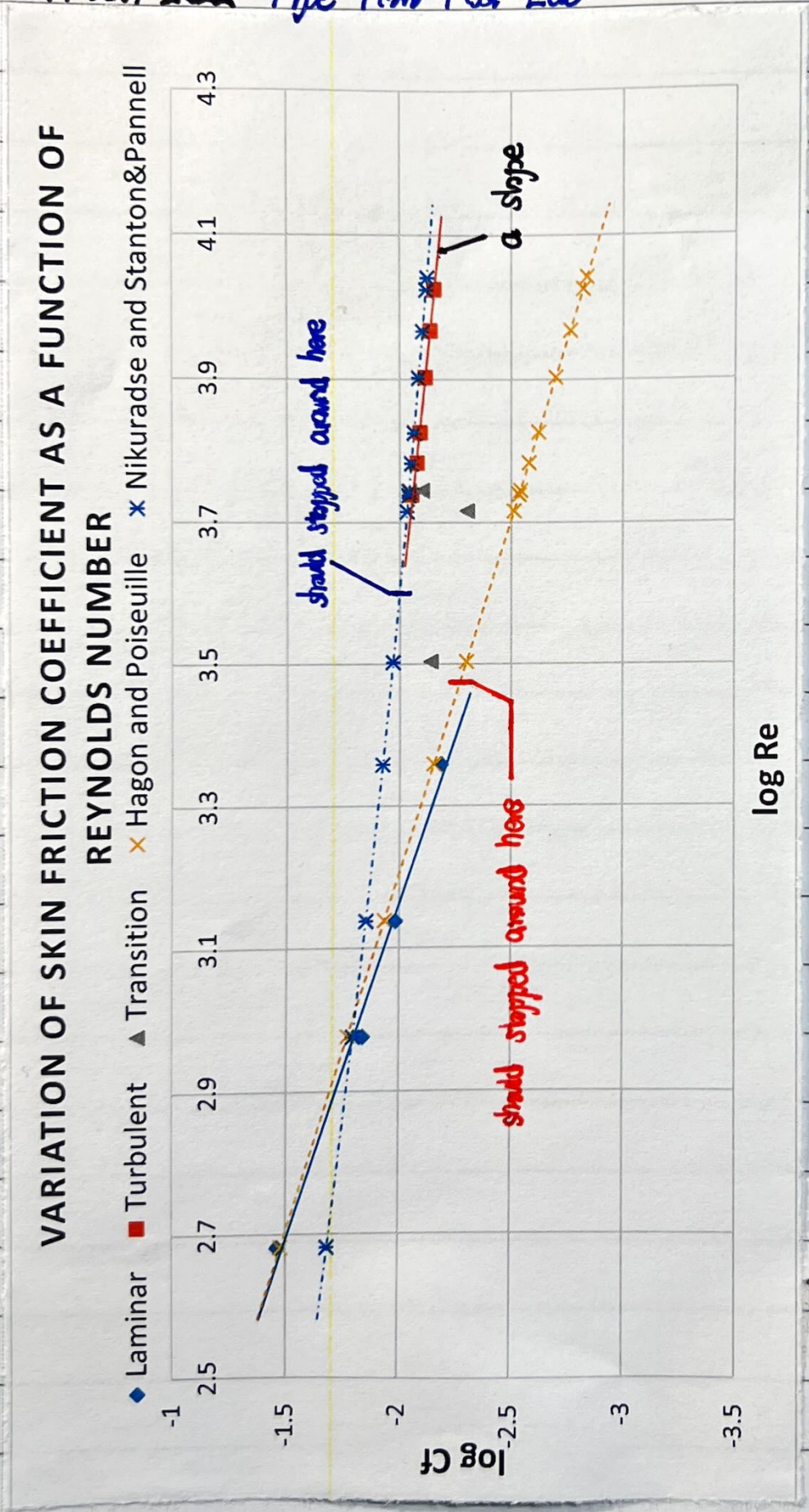
Δ might caused by the energy dissipation

Δ might caused by the measurement error

11/21/2022 Pipe-flow Post-Lab



11/22/2022 Pipe Flow Post-Lab



× Hagon and Poiseuille use to calculate the laminar flow slightly higher than experimental value

× Nikuradse and Stanton & Pannell use to calculate the turbulent flow slightly higher than experimental value

The gap is shown by the Δ in the graph in previous page

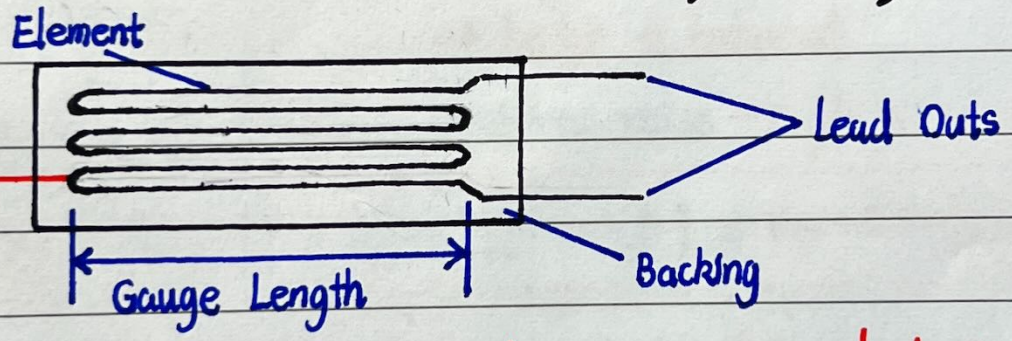
11/27/2022 Strain Measurement Pre-Lab

Resistance strain gauges

- $\varepsilon_{surface} = \varepsilon_{strain\ gauge\ conductor}$
- R of an electrical conductor varies if gauge deformed
- wire / acoustic 声音的 / capacitive 电容的 / inductive 感应的 / mechanical / optical 光学的 / piezoresistive 压阻的 / semi-conductive strain gauge

Wire strain gauge

- low cost
- established (most commonly used) product



serpentine 弯曲的 wire mainly run in measured direction

→ maximise length of conductor

→ maximise ΔR due to strain ε in that direction

* Approximate gauge as a conductive wire of constant cross-section A

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

l — wire length

A — cross-sectional area

ρ — resistivity of the material

If strain is not too large

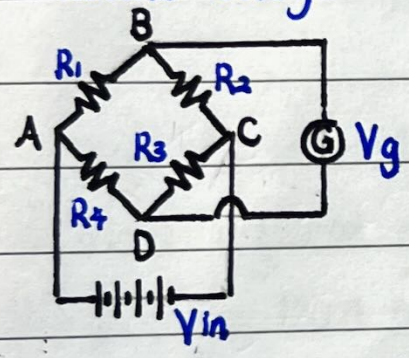
11/27/2022 Strain Measurement Pre-Lab

If strain is not too large $\boxed{\Delta R \propto \varepsilon}$

$$\boxed{\frac{\Delta R^*}{R} = S\varepsilon \quad S \text{ — gauge factor} \leftarrow \approx 2.1 \text{ in this lab}}$$

* $\Delta R \sim 0.1\%$ ← difficult to measure ← Wheatstone bridge circuit

Wheatstone bridge (electric circuit)



- $\Delta R = \Delta R_{thermal} + \Delta R_{actual}$
- $R_1 = R_2 = R_3 = R_4 = R$

→ output voltage, $V_g = 0$

→ bridge is balanced

After balanced → change resistors value → if Δ are relatively small

$$\boxed{V_g = \frac{V_{in}}{4}\left[\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right] = V_{in}\frac{\Delta R_1 - \Delta R_2 + \Delta R_3 - \Delta R_4}{4R}}$$

Replaced 1 'quarter-bridge' / 2 'half-bridge' / 4 'full-bridge' resistors

* if connect a strain gauge (120 / 350 Ω) to first arm of bridge AB

→ deformed → ΔR_1 while $\Delta R_2 = \Delta R_3 = \Delta R_4 = 0$

→ $V_g = V_{in}\frac{\Delta R_1}{4R}$

→ $\varepsilon = \frac{\frac{\Delta R_1}{R}}{S} = \frac{4V_g^*}{V_{in}S}$

* V_g is quite small → connect the voltmeter to voltage amplifier

→ $\bar{V}_g = GAIN \cdot V_g$

→ $\varepsilon = \frac{4V_g}{V_{in}S} = \frac{4\bar{V}_g}{V_{in}S \cdot GAIN}$

11/27/2022 Strain Measurement Pre-Lab

$$V_{in} \frac{\boxed{\Delta R_1 - \Delta R_2} + \boxed{\Delta R_3 - \Delta R_4}}{4R}$$ → if swap R_1 by gauge

$\Delta R_1 = \Delta R_{thermal} + \Delta R_{actual}$

→ swap R_2 by dummy gauge 补偿应变片

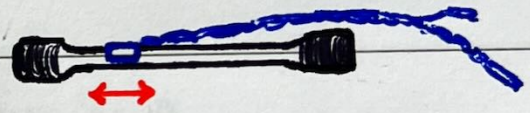
$\Delta R_2 = \Delta R_{thermal}$

$$\rightarrow V_g = V_{in} \frac{\Delta R_1 - \Delta R_2}{4R} = V_{in} \frac{\cancel{\Delta R_{thermal}} + \Delta R_{actual} - \cancel{\Delta R_{thermal}}}{4R} = V_{in} \frac{\Delta R_{actual}}{4R}$$

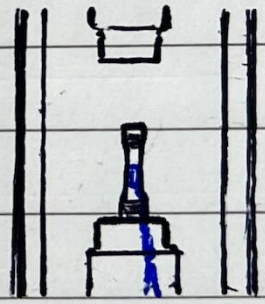
elimate thermal effects ← thermal compensation 抵消

Laboratory Experiment

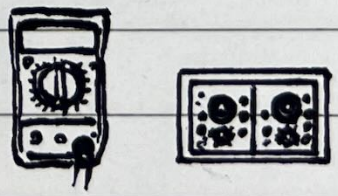
- Ⅱ round dogbone specimens



- strain gauge 120Ω in axial direction
- Place specimens in machine



- ↑ load 500N in steps up to 3.5kN (maximum)
- load > 3.5kN → break or yield specimen
  → invalid measure of E
- Wire connected to a simple Wheatstone bridge



- quarter-bridge configuration
- voltmeter - voltage amplifier record value

Procedure

- Measure D → calculate A

11/28/2022 Strain Measurement Pre-Lab

- Record S and GAIN

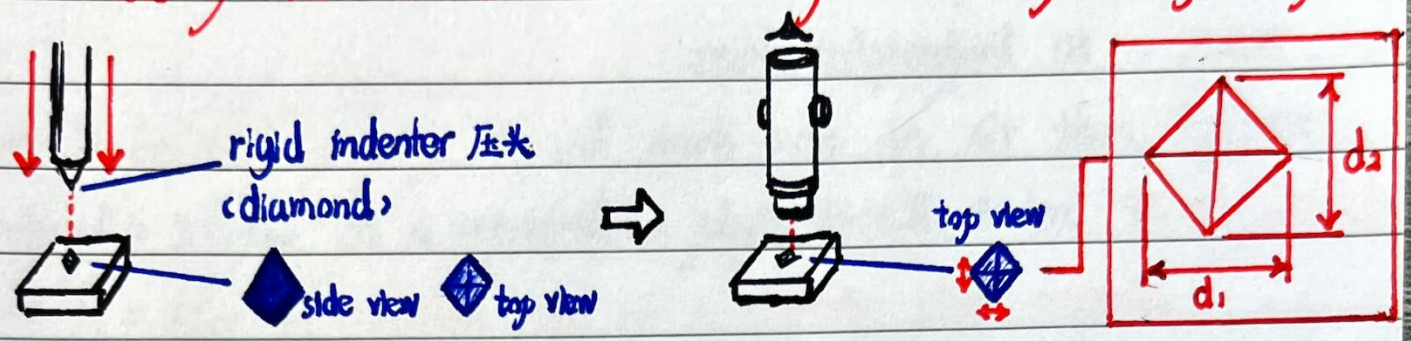
* Do not induced load when fasten the specimen's ends

- connect gauge wires to the Wheatstone bridge
- switch off the bridge → Record V_{in} by DC voltage voltmeter
- switch on the bridge → Read $\bar{V}_g$
- turn the dial of the potentiometer till $\bar{V}_g \approx 0$ → balanced
- very slowly operate wheel of tensile machine
  → $F = 0.5kN$ → Record $\bar{V}_g$ → calculate tensile strain ε
- Repeat till $F = 3.5kN \sim 3kN$
- Unload the specimen slowly until load drop to 0
- Remove specimen
- Repeat with next specimen
- Graph 1 F vs $\bar{V}_g$
- Graph 2 σ vs ε

11/28/2022 Tension and Hardness Pre-Lab

Measure the material hardness

· Hardness of the material = resistance to penetration by a rigid object

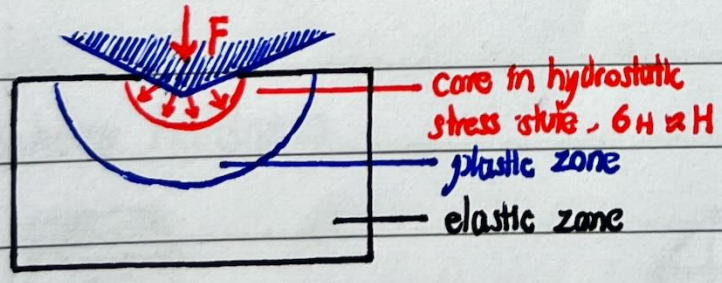


· Vickers square pyramid / Rockwell cone / Brinnel sphere / Berkovie triangular pyramid / Knoop pyramid with rhomboidal base / ... hardness tests

· hardness mm 10^{-3}m / micro-hardness μm 10^{-6}m / nano-hardness nm 10^{-9}m

→ use a Vickers micro-hardness test

Yield stress with hardness

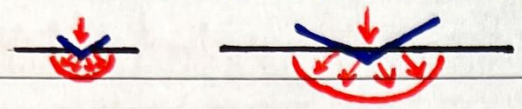


$$H = \frac{F}{A^*}$$

* A = area of contact between indenter and material projected on the plane perpendicular to the applied load

→ base of the pyramidal indentation 压痕 footprint this case

11/28/2022 Tension and Hardness Pre-Lab



penetrate distance ↑↑↑

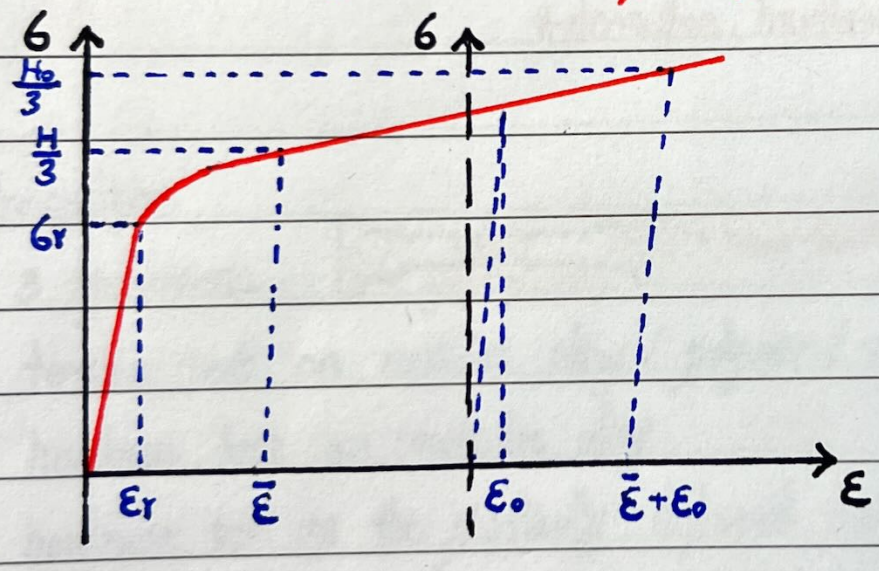
- shape of indentation footprint unchanged → self-similarity
- H ~~x~~ F or depth

  scale independent as a stress

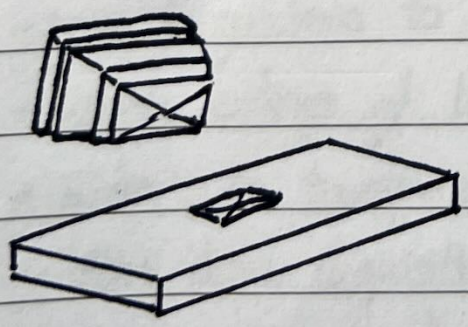
→ H mechanical property depend much more on σ_Y than stiffness

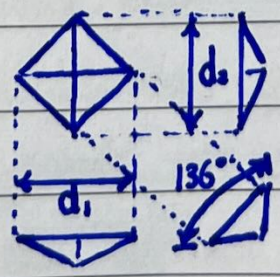
→ $H = 3\sigma_{flow}$ at a representative plastic strain $\bar{\varepsilon}$ 8-10% 9% in this lab

→ $H = 3\sigma_Y$ in particular case of a perfectly plastic material



Vickers hardness





11/28/2022 Tension and Hardness Pre-Lab

Vickers hardness HV = $\frac{\text{indentation Force}}{\text{entire area of contact}}$

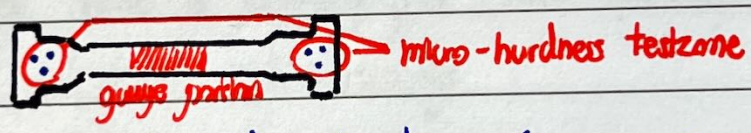
$$HV = \frac{F}{\frac{d^2}{2\sin(\frac{1}{2}\times 136^\circ)}} = \frac{2\sin(68^\circ)F}{d^2} \quad (kgf/mm^2)$$

xxx HV yy / zz
vickers hardness load time

* seperate indentations to avoid the large plastic zones created by 6* footprint diagonal → 2mm between adjacent indentation locations in this lab

Procedure

· 3 specimens



- tension test on metallic alloy / polymer / composite
- hardness test on metallic alloy

* hardness test on the plastically deformed metallic specimen / at different loads / on the polymeric material

· tension tests

- connect specimen to the machine's jaws
- balance readings of load and displacement gauges via software

* make sure transparent safty guards are in place

- start data acquisition 获取 via software
- slowly apply tensile load → V deformation = constant

11/28/2022 Tension and Hardness Pre-Lab

* $f_{max} = 1Hz$
- stop the data bigger when specimen fail
- Remove the repeat with another specimen

· Hardness tests
- polish 磨光 one side of the T-shaped ends with sand paper
- xxx HV 1/10
- place specimen and focus the microscope, bring indenter above
- start test
- bring microscope above the indention footprint when its over
- use software take a photograph then measure diagonals
- HV will be calculated automatically
- repeat for 3-5 times

· Graph 3 σ_t vs ε_t for tension test

· Graph 4/5/6 σ_n and σ_t vs ε_n and ε_t

11/28/2022 Strain Measurement During Lab

Gauge factors S	GAIN (V)	V_{in} (V)	Specimen	1st D (mm)	2nd D (mm)	3rd D (mm)	Speicimen's diameter D (mm)	Number of attempt	State	Applied force F (kN)	GAIN*V_g (V)
2.1	500	1.267	Aluminum	6.01	6.01	6.02	6.013333333	1	Load	0	0
								2		0.5	0.054
								3		1	0.118
								4		1.5	0.187
								5		2	0.254
								6		2.5	0.323
								7		3	0.394
								8		3.5	0.467
								9	Unload	3	0.411
								10		2.5	0.351
								11		2	0.288
								12		1.5	0.214
								13		1	0.141
								14		0.5	0.064
								15		0	0
			Copper	6.06	6.02	5.94	6.006666667	1	Load	0	0
								2		0.5	0.03
								3		1	0.073
								4		1.5	0.112
								5		2	0.152
								6		2.5	0.19
								7		3	0.229
								8		3.5	0.268
								9	Unload	3	0.238
								10		2.5	0.208
								11		2	0.175
								12		1.5	0.137
								13		1	0.1
								14		0.5	0.061
								15		0	0.008

* Copper do not return to zero even after re-doing the experiment

11/28/2022 Strain Measurement During Lab

Gauge factors S	GAIN (V)	V_{in} (V)	Specimen	1st D (mm)	2nd D (mm)	3rd D (mm)	Speicimen's diameter D (mm)	Number of attempt	State	Applied force F (kN)	GAIN*V_g (V)
2.1	500	1.267	Brass	5.98	5.95	5.95	5.96	1	Load	0	0
								2		0.5	0.046
								3		1	0.092
								4		1.5	0.144
								5		2	0.193
								6		2.5	0.244
								7		3	0.298
								8		3.5	0.354
								9	Unload	3	0.314
								10		2.5	0.268
								11		2	0.22
								12		1.5	0.168
								13		1	0.114
								14		0.5	0.058
								15		0	0
			Iron	6.03	6.02	6.02	6.023333333	1	Load	0	0
								2		0.5	0.022
								3		1	0.044
								4		1.5	0.068
								5		2	0.093
								6		2.5	0.116
								7		3	0.141
								8		3.5	0.168
								9	Unload	3	0.145
								10		2.5	0.124
								11		2	0.102
								12		1.5	0.076
								13		1	0.051
								14		0.5	0.024
								15		0	0

11/28/2022 Tension and Hardness During Lab

Specimen	Number of attempt	d1 (μm)	d2 (μm)	d (μm)	HV (kgf/mm^2)	1st Width (mm)	2nd Width (mm)	3rd Width (mm)	Width (mm)	1st Height (mm)	2nd Height (mm)	3rd Height (mm)	Height (mm)	A (m^2)
Aluminum	1	168.08	155.85	161.97	70.7									
	2	166.15	166.11	166.13	67.3									
	3	159.48	162.04	160.76	71.8	5.91	5.9	5.96	5.92333	3.07	2.99	3.07	3.04333	1.802668E-05
	4	162.37	160.41	161.39	71.2									
	5	156.02	157.09	156.56	75.7									
Carbon fiber						9.97	9.96	9.97	9.96667	1.08	1.13	1.12	1.11	1.106300E-05
Ploymer						12.21	12.19	12.19	12.1967	2.06	2.02	2.07	2.05	2.500317E-05

· adjust the machine by dial

* use different sand-paper with different items

\+ do not think the surface is flat enough with the not-enough polishing, which might affect the results and cause the wide-spread range of the data

11/28/2022 Tension and Hardness During Lab

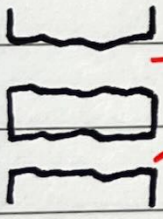
- wear goggles before tests
- cannot observe the deform directly through the eyes

looks like fluffs on the section

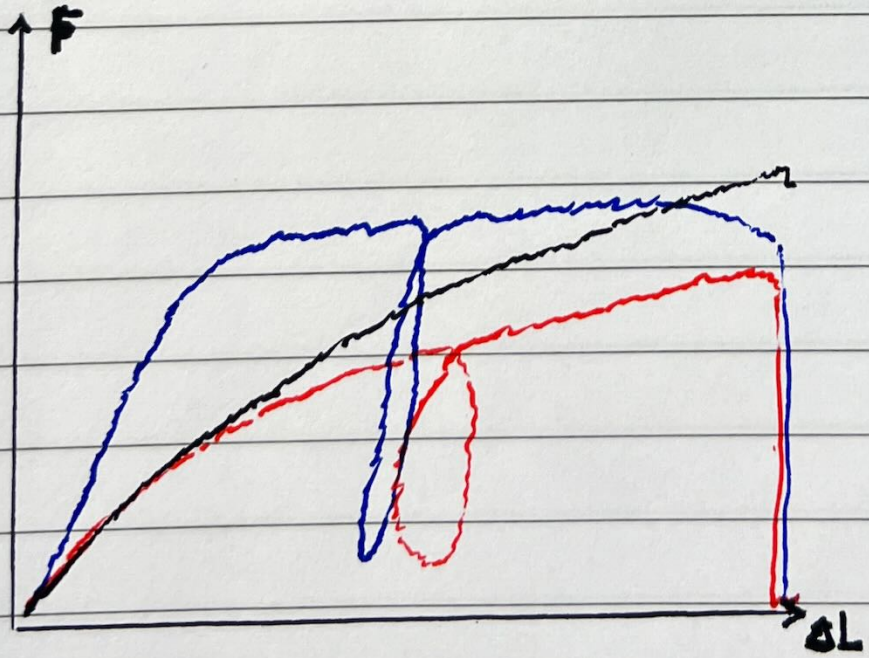
carbon fibre when break

smooth section

aluminium (alloy) when break


break into 3 pieces

rigid body when break



- aluminium alloy
- carbon fibre
- rigid body

(not scaled)

(draw independently)

Reading displayed on the screen during the test

11/29/2022 Strain Measurement Post-Lab

Gauge factors
S = 2.1

GAIN = 500

V_{in} = 1.257V

Specimen	Speicimen's diameter D (mm)	Number of attempt	State	Applied force F (N)	V_g (V)	Stress σ (N/m^2)	Strain ε
					V_g=GAIN*V_g/GAIN	σ=F/A	ε=4V_g/V_{in}*s
Aluminum	6.013333333	1	Load	0	0	0	0
		2		500	0.000108	17605548.74	0.000162363
		3		1000	0.000236	35211097.48	0.000354794
		4		1500	0.000374	52816646.22	0.000562258
		5		2000	0.000508	70422194.97	0.000763709
		6		2500	0.000646	88027743.71	0.000971173
		7		3000	0.000788	105633292.4	0.001184651
		8		3500	0.000934	123238841.2	0.001404142
		9	Unload	3000	0.000822	105633292.4	0.001235765
		10		2500	0.000702	88027743.71	0.001055361
		11		2000	0.000576	70422194.97	0.000865938
		12		1500	0.000428	52816646.22	0.00064344
		13		1000	0.000282	35211097.48	0.000423949
		14		500	0.000128	17605548.74	0.000192431
		15		0	0	0	0
Copper	6.006666667	1	Load	0	0	0	0
		2		500	0.00006	17644650.45	9.02018E-05
		3		1000	0.000146	35289300.9	0.000219491
		4		1500	0.000224	52933951.34	0.000336753
		5		2000	0.000304	70578601.79	0.000457023
		6		2500	0.00038	88223252.24	0.000571278
		7		3000	0.000458	105867902.7	0.000688541
		8		3500	0.000536	123512553.1	0.000805803
		9	Unload	3000	0.000476	105867902.7	0.000715601
		10		2500	0.000416	88223252.24	0.000625399
		11		2000	0.00035	70578601.79	0.000526177
		12		1500	0.000274	52933951.34	0.000411922
		13		1000	0.0002	35289300.9	0.000300673
		14		500	0.000122	17644650.45	0.00018341
		15		0	0.000016	0	2.40538E-05

11/29/2022 Strain Measurement Post-Lab

Gauge factors

S = 2.1

GAIN = 500

V_{in} = 1.257V

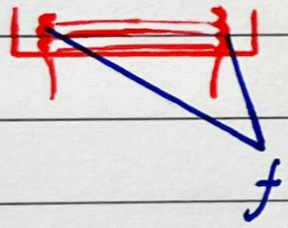
Specimen	Speicimen's diameter D (mm)	Number of attempt	State	Applied force F (N)	V_g (V)	Stress σ (N/m^2)	Strain ε
					V_g=GAIN*V_g/GAIN	σ=F/A	ε=4V_g/V_{in}*s
Brass	6.006666667	1	Load	0	0	0	0
		2		500	0.000092	17922046.65	0.000138309
		3		1000	0.000184	35844093.3	0.000276619
		4		1500	0.000288	53766139.96	0.000432969
		5		2000	0.000386	71688186.61	0.000580298
		6		2500	0.000488	89610233.26	0.000733642
		7		3000	0.000596	107532279.9	0.000896005
		8		3500	0.000708	125454326.6	0.001064382
		9	Unload	3000	0.000628	107532279.9	0.000944112
		10		2500	0.000536	89610233.26	0.000805803
		11		2000	0.00044	71688186.61	0.00066148
		12		1500	0.000336	53766139.96	0.00050513
		13		1000	0.000228	35844093.3	0.000342767
		14		500	0.000116	17922046.65	0.00017439
		15		0	0	0	0
Iron	5.96	1	Load	0	0	0	0
		2		500	0.000044	17547139.44	6.6148E-05
		3		1000	0.000088	35094278.88	0.000132296
		4		1500	0.000136	52641418.32	0.000204457
		5		2000	0.000186	70188557.76	0.000279626
		6		2500	0.000232	87735697.21	0.00034878
		7		3000	0.000282	105282836.6	0.000423949
		8		3500	0.000336	122829976.1	0.00050513
		9	Unload	3000	0.00029	105282836.6	0.000435975
		10		2500	0.000248	87735697.21	0.000372834
		11		2000	0.000204	70188557.76	0.000306686
		12		1500	0.000152	52641418.32	0.000228511
		13		1000	0.000102	35094278.88	0.000153343
		14		500	0.000048	17547139.44	7.21615E-05
		15		0	0	0	0

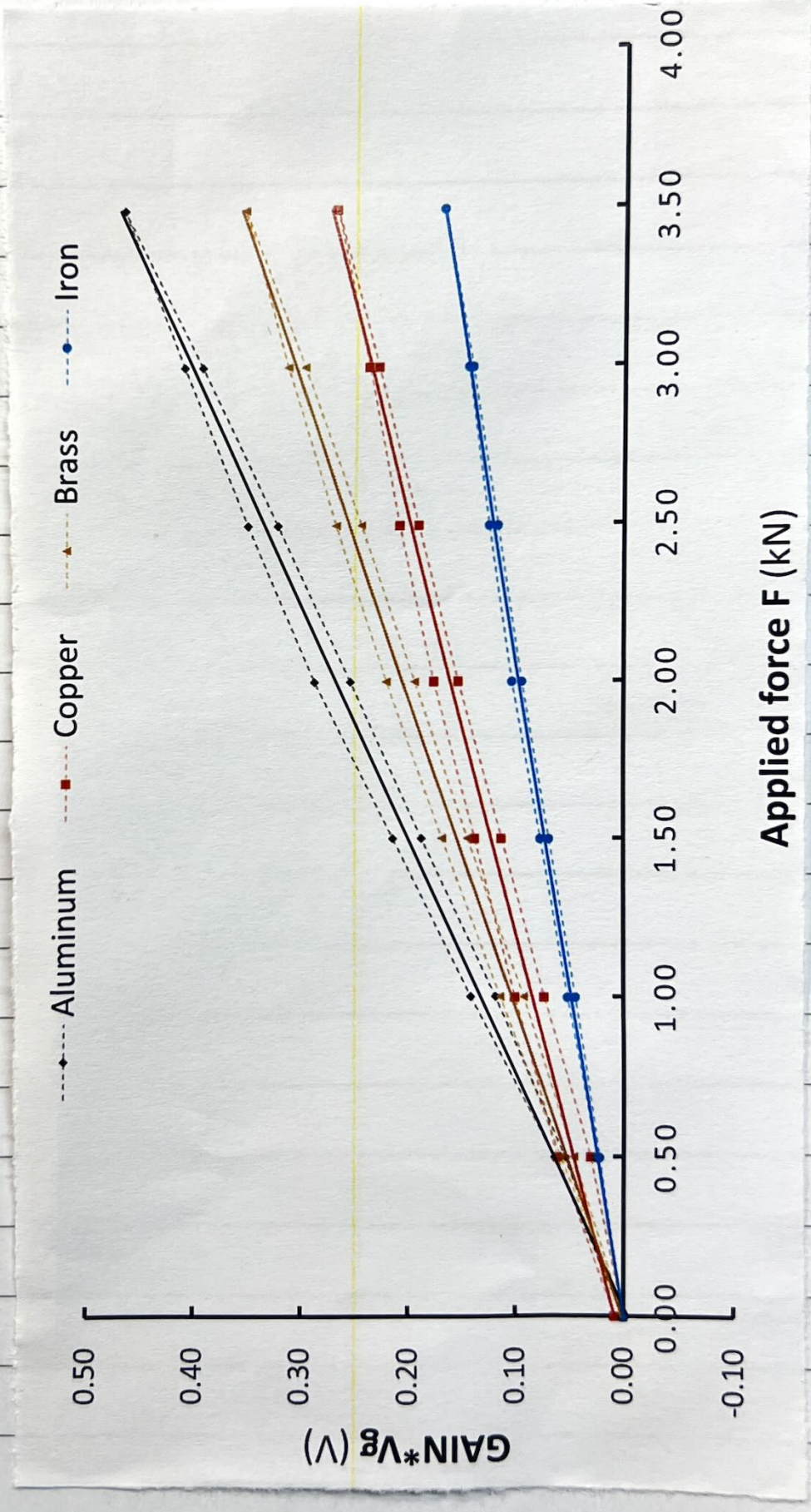
11/29/2022 Strain Measurement Post-Lab

Shape

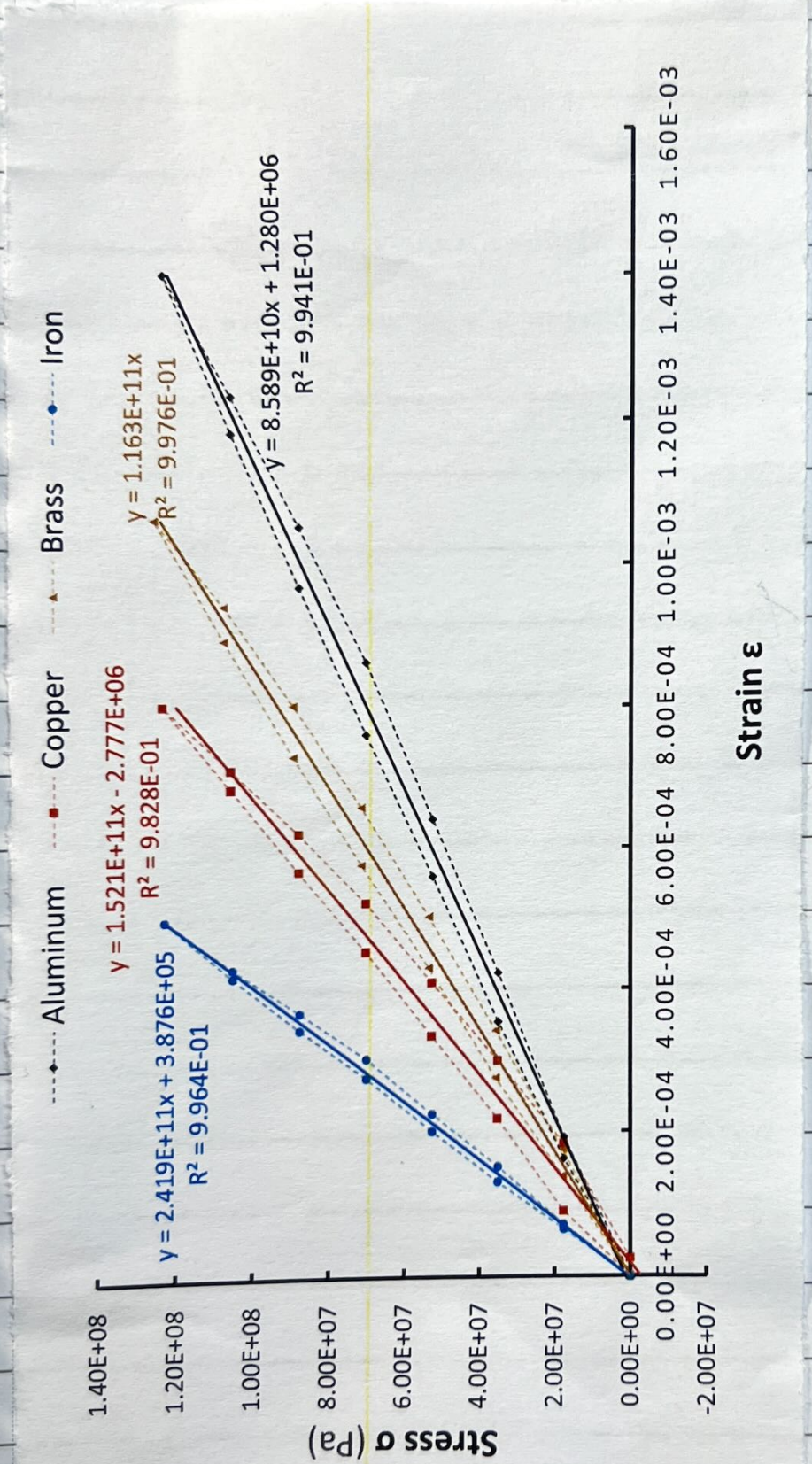
occurs because

- human error
- systematic error
- energy dissapation due to friction





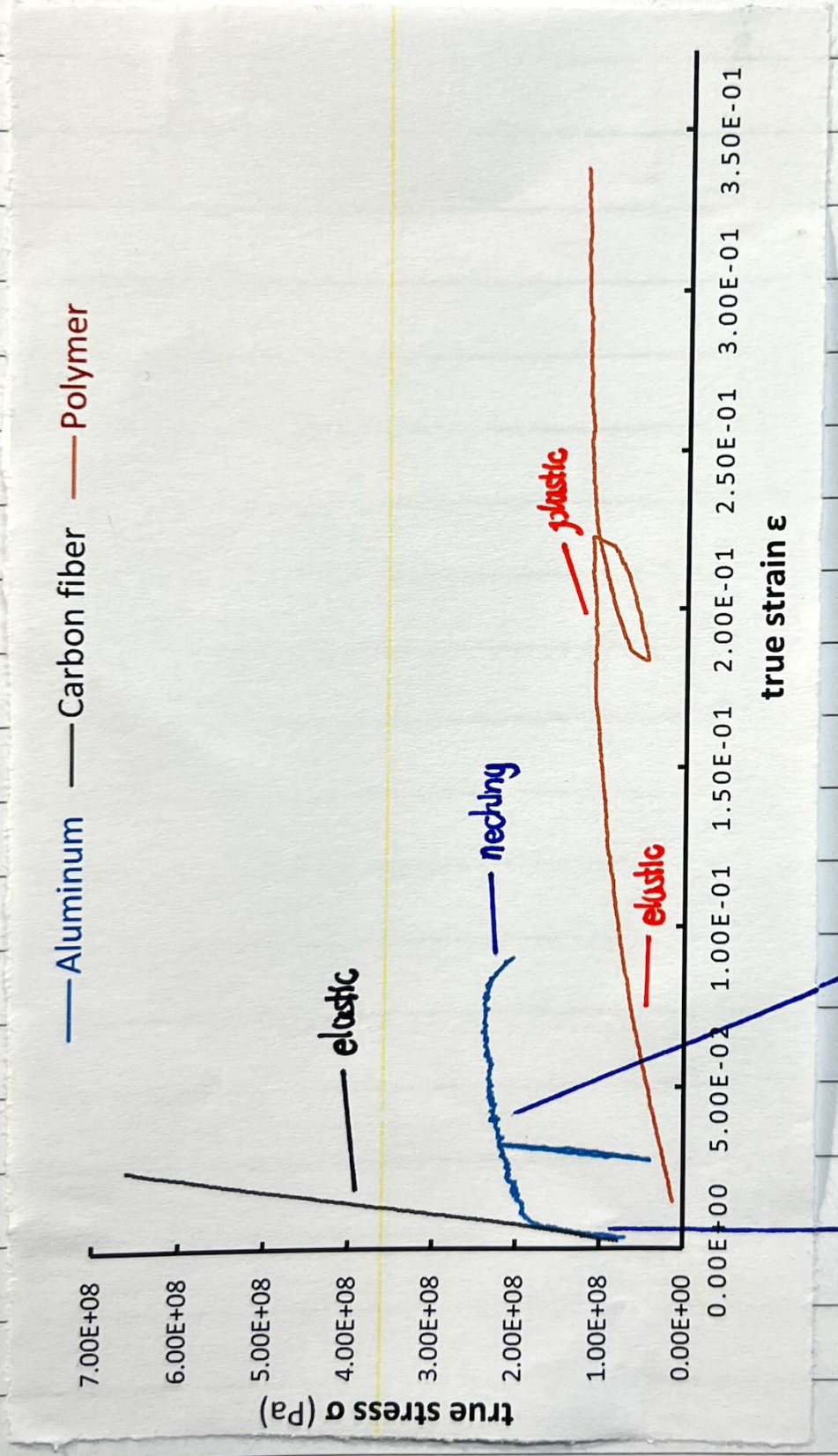
11/29/2022 Strain Measurement Post-Lab



$E_{Fe} > E_{Cu} > E_{H} > E_{Al}$

$E_{real} < E_{measured}$

11/29/2022 Tension and Hardness Post-Lab



Al ductile
Carbon fiber brittle
Polymer ductile+

Stiffness
Carbon fibre > Al >> Polymer

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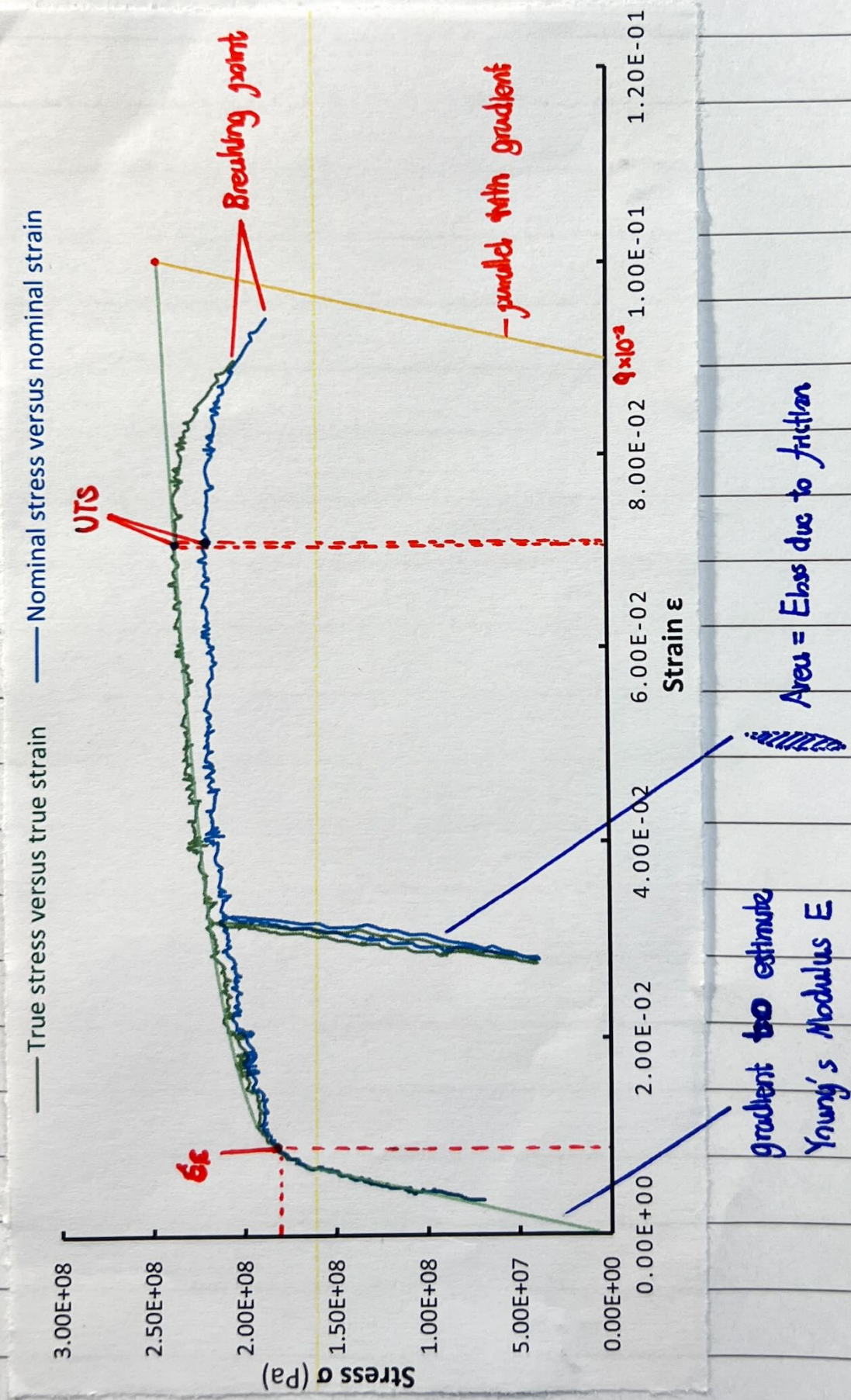

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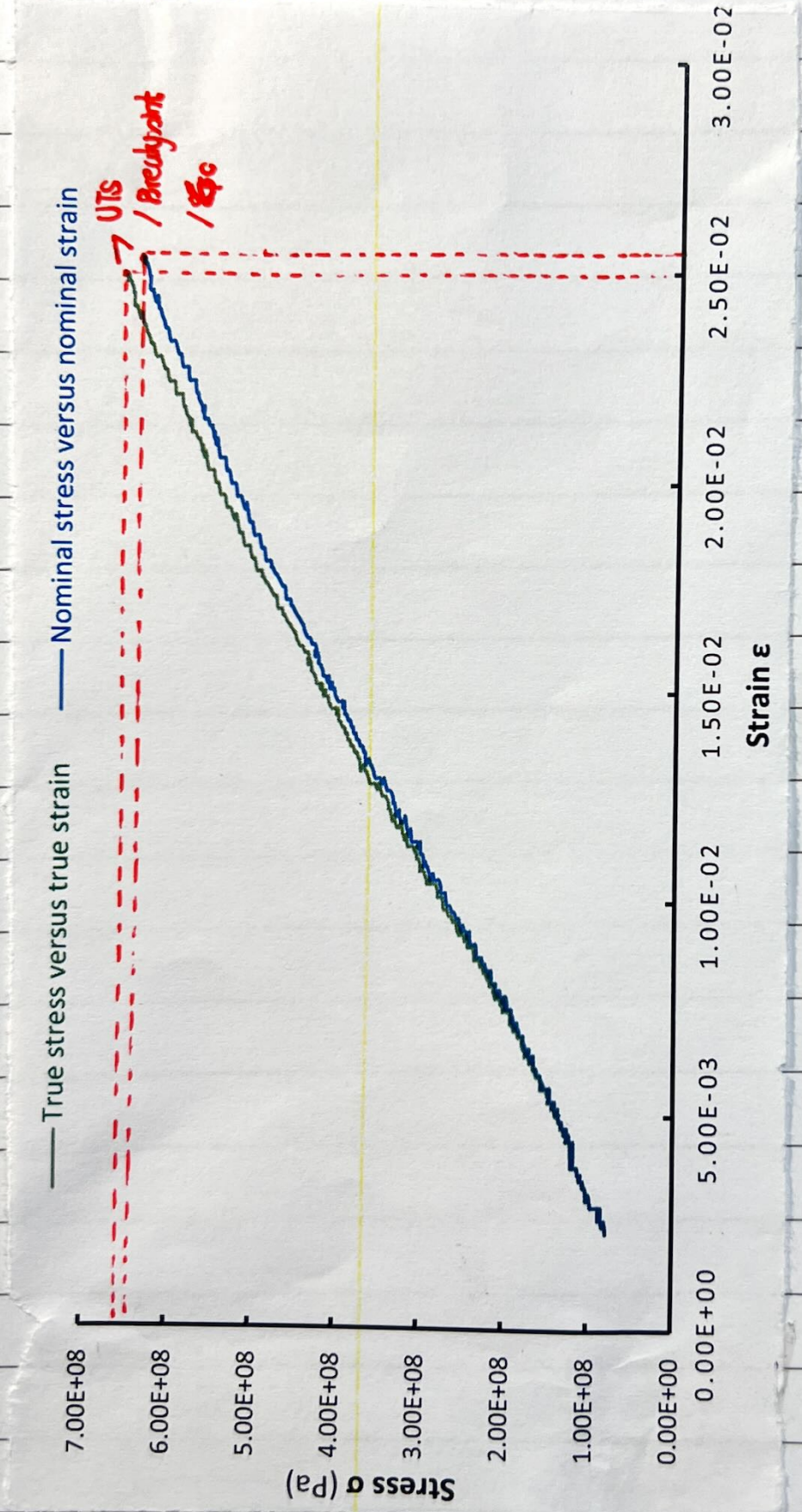
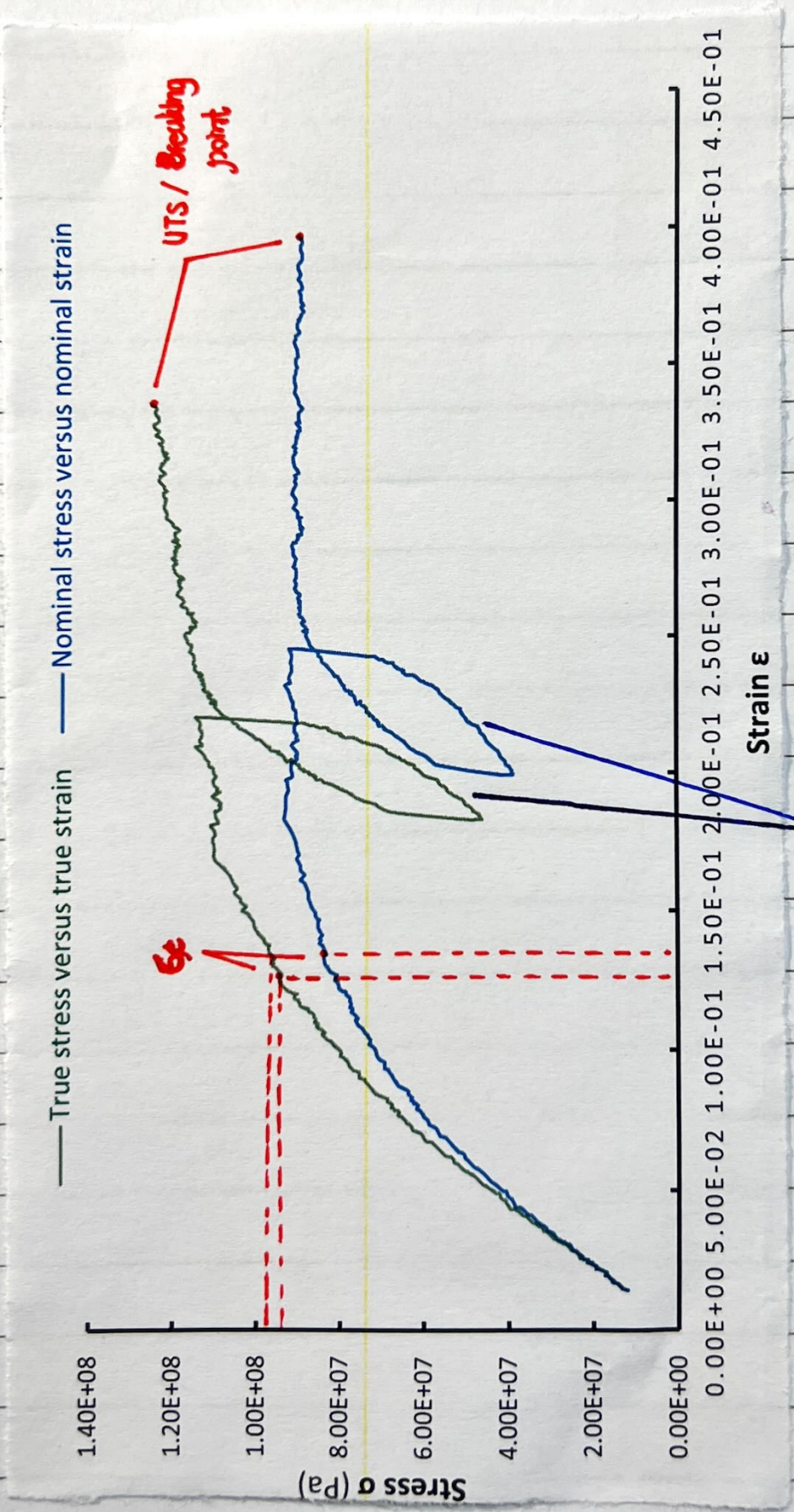


11/29/2022 Tension and Hardness Post-Lab



11/30/2022 Tension and Hardness Post-Lab

Table 1 : Tensile test results

specimen	A_0 (mm^2)	l (mm)	E (MPa)	critical σ (MPa)	UTS in nominal stress (MPa)	ε_F in true strain	specific stiffness (mm^2/s^2)	specific strength (mm^2/s^2)
Aluminium	18.03	56.00	23070.57	189.5635	221.82	0.09036	8.5447	0.07021
Carbon fibre	11.06	80.00	27544.63	641.61	641.61	0.02889	16.2027	0.37742
Rigid plastic	25.00	21.00	857.42	77.8180	92.12	0.33800	0.6124	0.05558

Specific stiffness
carbon fibre
> Al alloy
>> rigid plastic

Specific strength
carbon fibre
>> Al alloy
> rigid plastic

Young's Modulus
carbon fibre
> Al alloy
>>> rigid plastic

ε_F
Al alloy
>> carbon fibre
<<< rigid body

11/30/2022 Tension and Hardness Post-Lab

Table 2 : Hardness Test Results

average measured hardness=754.8523(MPa)

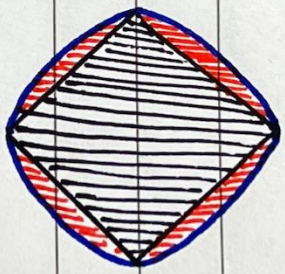
standard deviation of measured Vickers hardness=28.5425(MPa)

hardness $H*$ (estimate from the tensile true stress versus strain response)=741.7471(MPa)

Edentation conducted	d_1 (μm)	d_2 (μm)	HV (kgf/mm^2)	H (MPa)
1	168.08	155.85	70.6893	748.9902
2	166.15	166.11	67.1892	710.8908
3	159.48	162.04	71.7530	759.2251
4	162.37	160.41	71.1939	753.2893
5	156.02	157.09	75.6592	800.5163

$\bar{H} > H^*$

inaccurate estimated hardness by larger contact area than calculated one



○ actual area

◇ area in calculation

//// missing area by estimate

12/05/2022 Flow Visualisation Pre-Lab

Introduction

creation of images → build a mental picture / model of a flow

↓

chart the motion of a small suspended particle
(follow the path of a fluid element)

computer-assisted PTV (particle tracking velocimetry)
computer-assisted PIV (particle image velocimetry)

introduce of a visualising medium to selectively points of flow
× not precised × might disturb the flowfield
✓ using laser to selectively activate the continously dispersed dye

coating an object
× only shows the effect of the near wall flow
✓ highlight the seperation and reattachment points

interferometry 干涉法, Schlieren 纹影 and shadowgraph
✓ high speed, thermal and two phase flows

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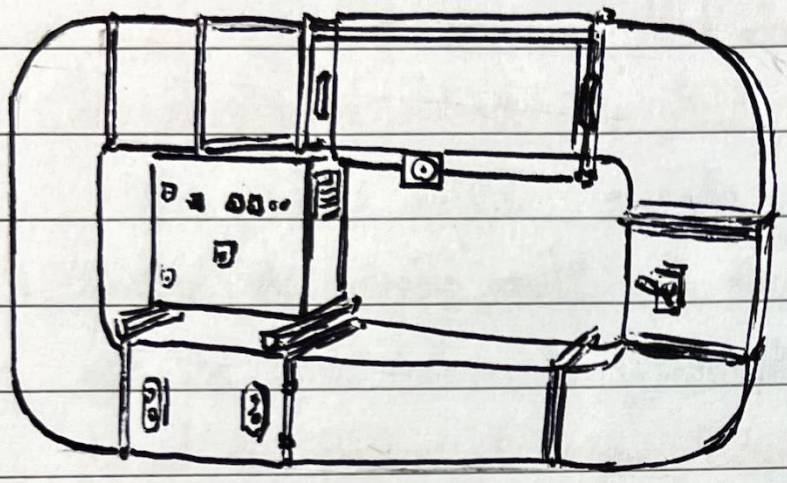
Experimental apparatus



- small wind tunnel
- low speed
- powered by a fan

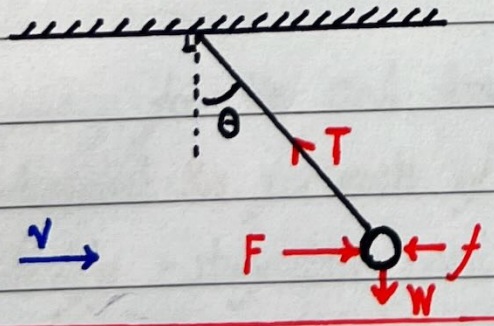
+ vapour generator
↔ fog effect 雾化
+ electrically heated wire
↔ generate streaklines
+ small foam cylinder
↔ estimated the airspeed

- a circular cylinder model
- a cambered airfoil model

+ mounted on a base plate

Experimental technique

estimation of airspeed



$$\frac{\text{mass } m}{\text{frontal Area } A} \approx 0.3192 \text{ kg/m}^2$$

Drag force $f = 0.5\rho A V^2$

* represent drag force as D than f

Experimental procedure

1. Mount the circular cylinder and start the flow

   estimate the speed and Reynolds number of the flow by θ

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2. Record the significant features of the cylinder flow
   Consider seperately the near filed flow about the cylinder and the characteristics of the far field flow
   + use gridded outline + make approximate measurement
3. Replace the cylinder model with the airfoil model
   set the airfoil indence to approximately 5° / 10° / 30°
   record the pattern of vapour filaments about the airfoil
4. One additional study of my own choosing
   * stall leading by the large angle of attack

Experimental uncertainty

Take particle to comprise spherical drops of water $D = 3-9\mu m$

$F_{Drag} = 3\pi \mu_{air} D (U_a - U_p)$ valid for the very low Re

Preparing for the Oral Assessment

- calculated Re for each of my studies
- identify - stagnation point - seperation point - Areas of laminar and turbulent flow - Areas of steady and unsteady flow in my sketches
- Map the extent of unstedy region on the sketches
- Indicate the special extent boundary between steady and unsteady flow

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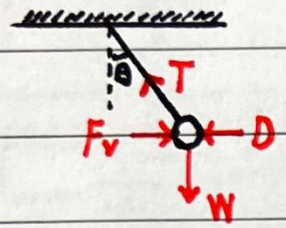
Calculation

- Find μ_a in related temperature T
- 

$(\uparrow)\ T\cos\theta = W = mg$

$(\rightarrow)\ T\sin\theta = D = \frac{1}{2}\rho A V^2$

$\therefore \tan\theta = \frac{T\sin\theta}{T\cos\theta} = \left(\frac{mg}{\frac{1}{2}\rho A V^2}\right)^{-1} = \frac{\rho A V^2}{2mg} = \left(\frac{1}{0.1596}\right)^{-1}\frac{\rho V^2}{g}$

$\therefore \theta = \arctan\left(6.2657\frac{\rho V^2}{g}\right)$

$V = \sqrt{0.1596\tan\theta\frac{g}{\rho}}\ \left(= \sqrt{\frac{2\tan\theta\, g m}{\rho A}}\right)$

- St Strouhal number $= \frac{f \text{ frequency of vortex shedding behind bodies } L}{V}$
- $Re = \frac{\rho U D}{\mu}$
- $F_D = 3\pi\mu_a D(U_a - U_p) = ma = m\frac{dU_p}{dt}$

$\therefore \int \frac{1}{U_a - U_p}\, dU_p = \int \frac{3\pi\mu_a D}{m}\, dt$

$\therefore \int (U_a - U_p)^{-1}\, dU_p = \left(\frac{3\pi\mu_a D}{m}\right)t + C$

Let $u = U_a - U_p \quad \therefore \frac{du}{dU_p} = -1 \quad \therefore dU_p = -du$

$\therefore \int -u^{-1}\, du = -\ln|u| + D = -\ln|U_a - U_p| + D = \left(\frac{3\pi\mu_a D}{m}\right)t + C$

When $t=0,\ U_p = 0 \quad \therefore -\ln|U_a| + D = 0 \quad \therefore D = \ln|U_a|,\ C = 0$

$\therefore -\ln|U_a - U_p| + \ln|U_a| = \left(\frac{3\pi\mu_a D}{m}\right)t + C = \left(\frac{3\pi\mu_a D}{m}\right)t$

$\therefore \ln\left|\frac{U_a}{U_a - U_p}\right| = \left(\frac{3\pi\mu_a D}{m}\right)t \quad \therefore t = \frac{m}{3\pi\mu_a D}\ln\left|\frac{U_a}{U_a - U_p}\right|$

$\because m = \rho\frac{4}{3}\pi r^3$

$\therefore t = \frac{4\rho\pi r^3}{9\pi\mu_a D}\ln\left|\frac{U_a}{U_a - U_p}\right| = \frac{4\rho r^3}{9\mu_a D}\ln\left|\frac{U_a}{U_a - U_p}\right|$

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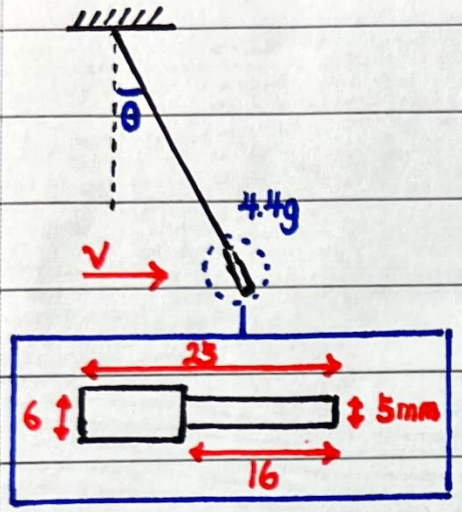
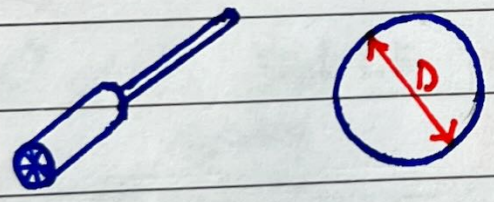
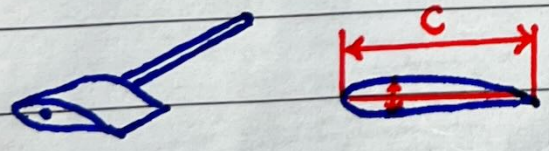


Dial	θ	$V = \sqrt{\tan\theta \frac{9.81}{1.225} \frac{2 \times 0.0044}{1.34 \times 10^{-4}}}$ (m/s)
10	7°	8.035765913
8	5.5°	7.116129505
6	4°	6.064252285
4	2.5°	4.791836061
2	1°	3.029815134
1	0.5°	2.142321244

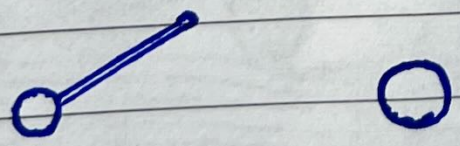
$T = 16°C = 289.15K$

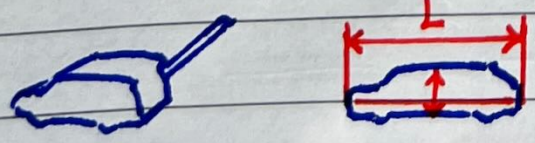


$D = 52mm = 0.052m$



$C = 98mm = 0.098m$ thickness $= 0.013m$





$L = 16.6cm = 0.166m$ thickness $= 0.058m$

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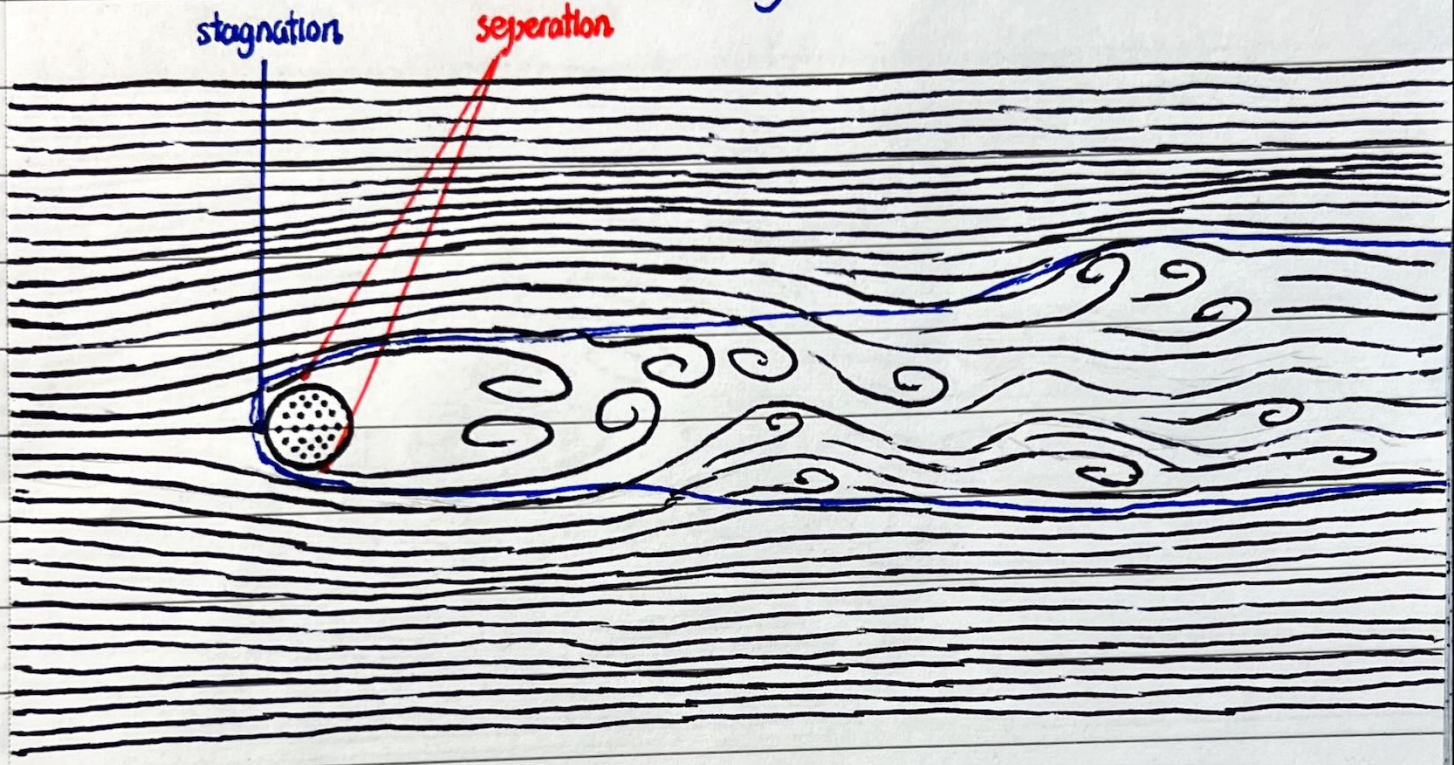
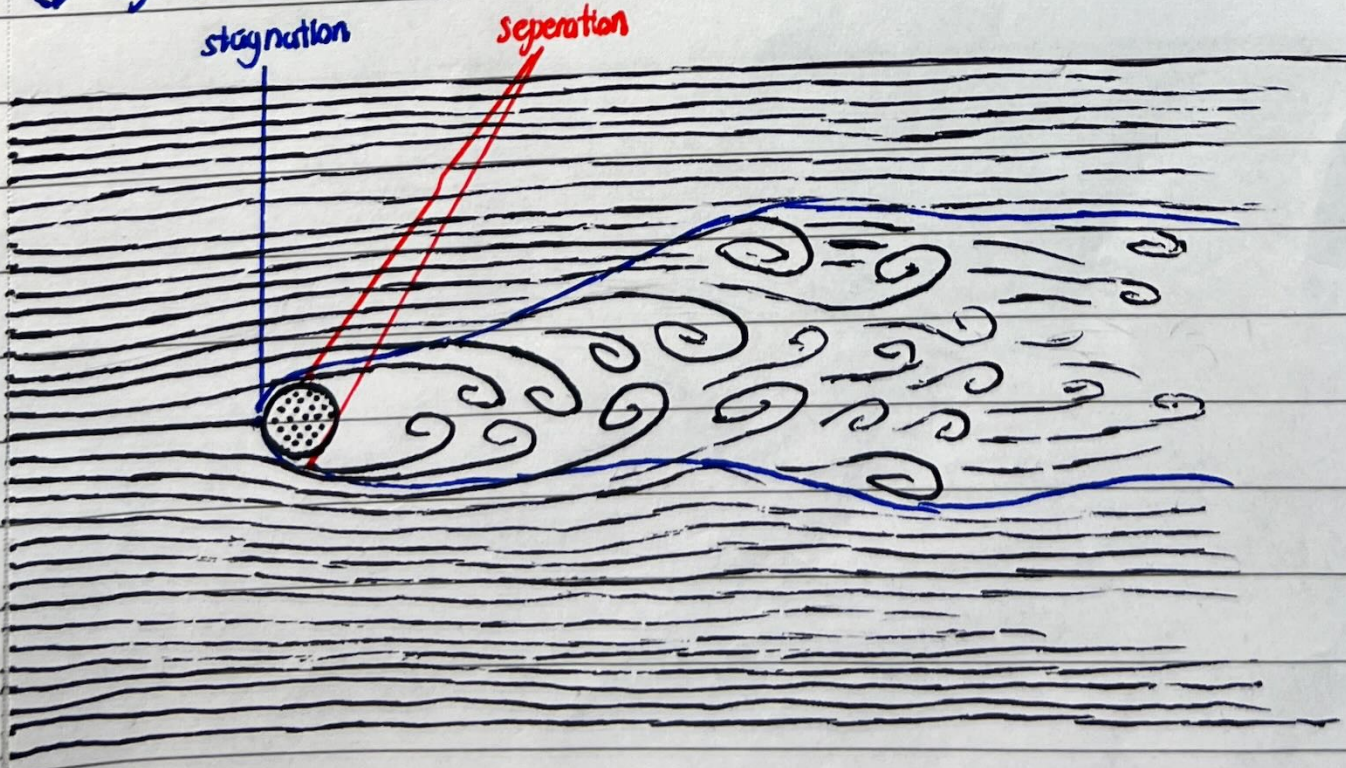


cylinder Dial 1.5 $V = 2.60\ m/s$ $Re = 9.23 \times 10^3$ $f = 8Hz$ $St = 0.180$



cylinder Dial 2.0 $V = 3.02\ m/s$ $Re = 1.08 \times 10^4$ $f = 13Hz$ $St = 0.223$

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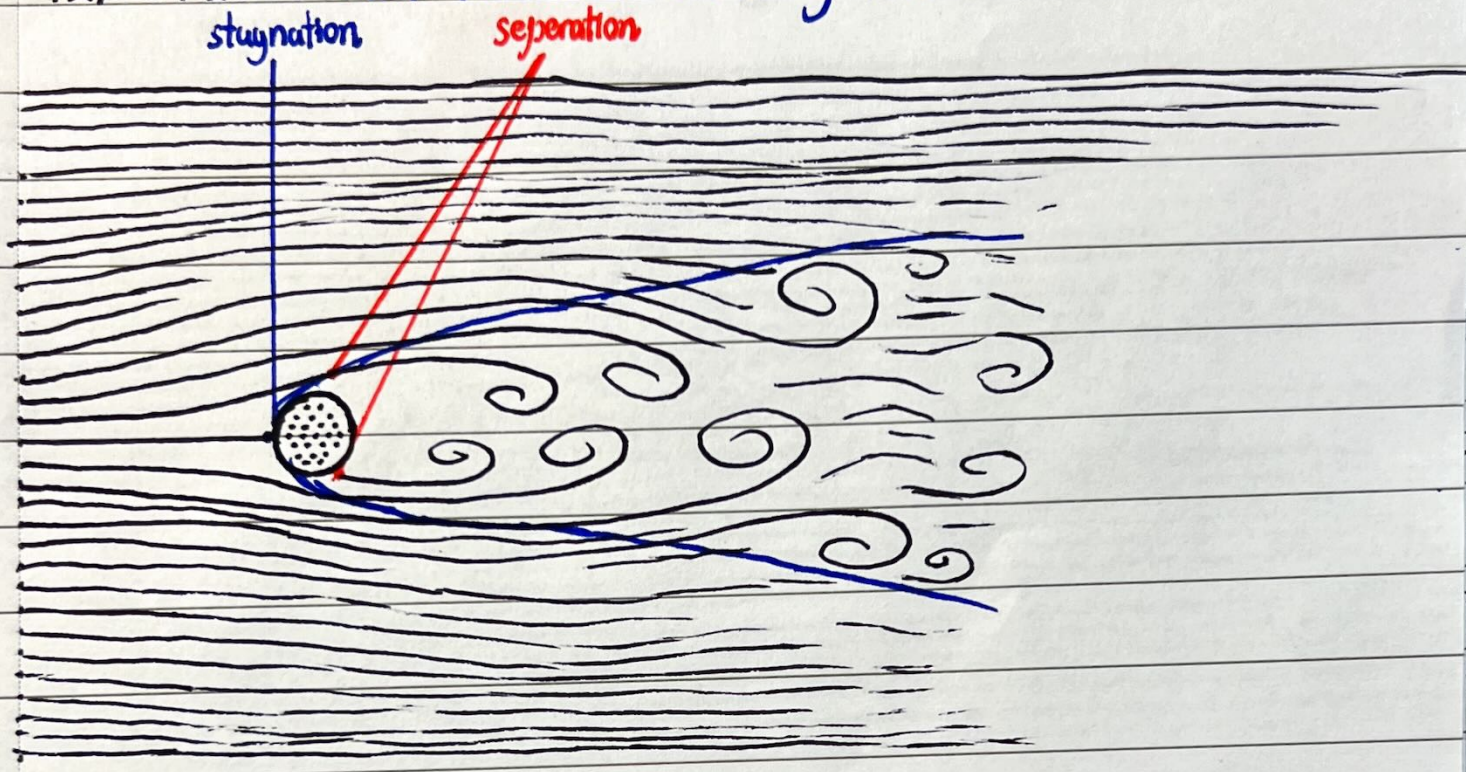
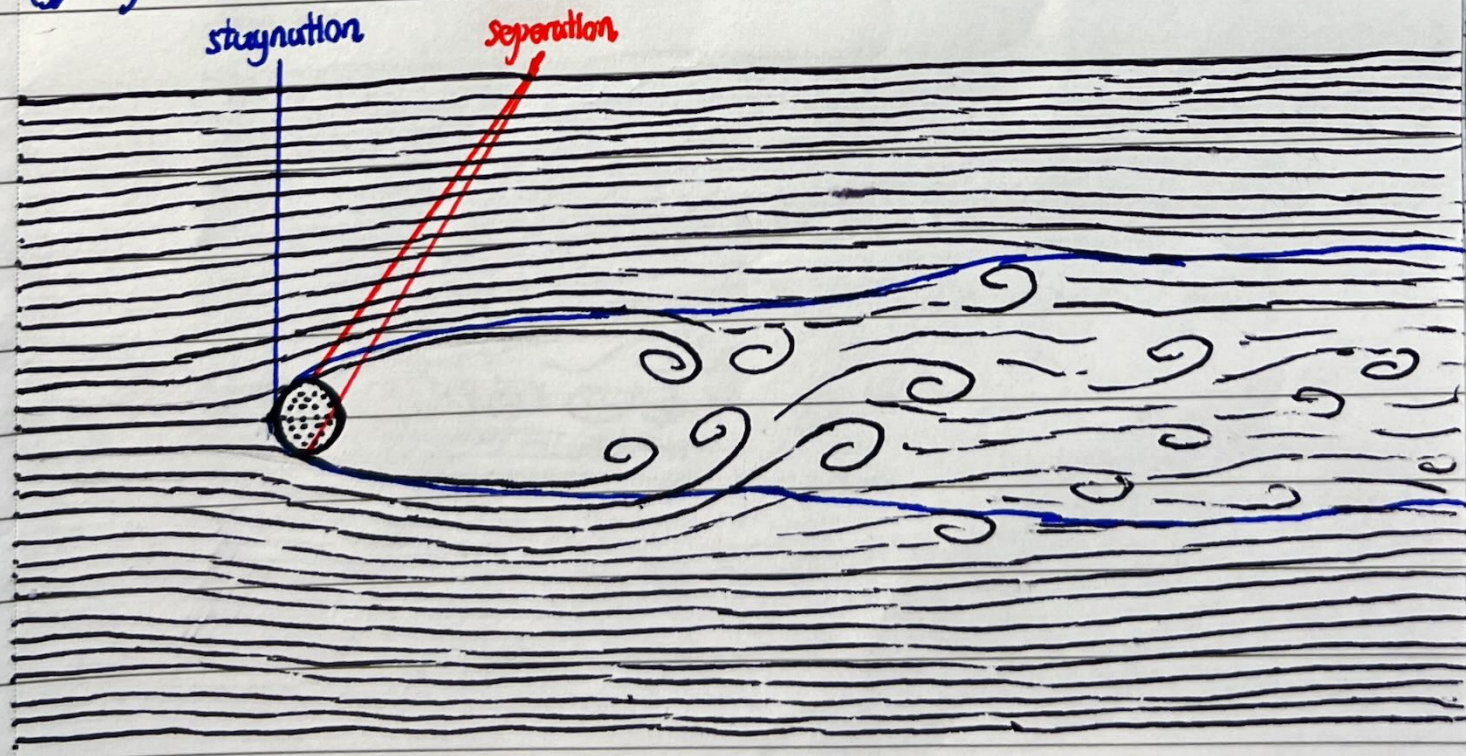


Ø cylinder Dial 2.5 $V = 3.50 m/s$ $Re = 1.24 \times 10^4$ $f = 23 Hz$ $St = 0.342$



Ø cylinder Dial 1.0 $V = 2.14 m/s$ $Re = 7.60 \times 10^3$ $f = 3 Hz$ $St = 0.073$

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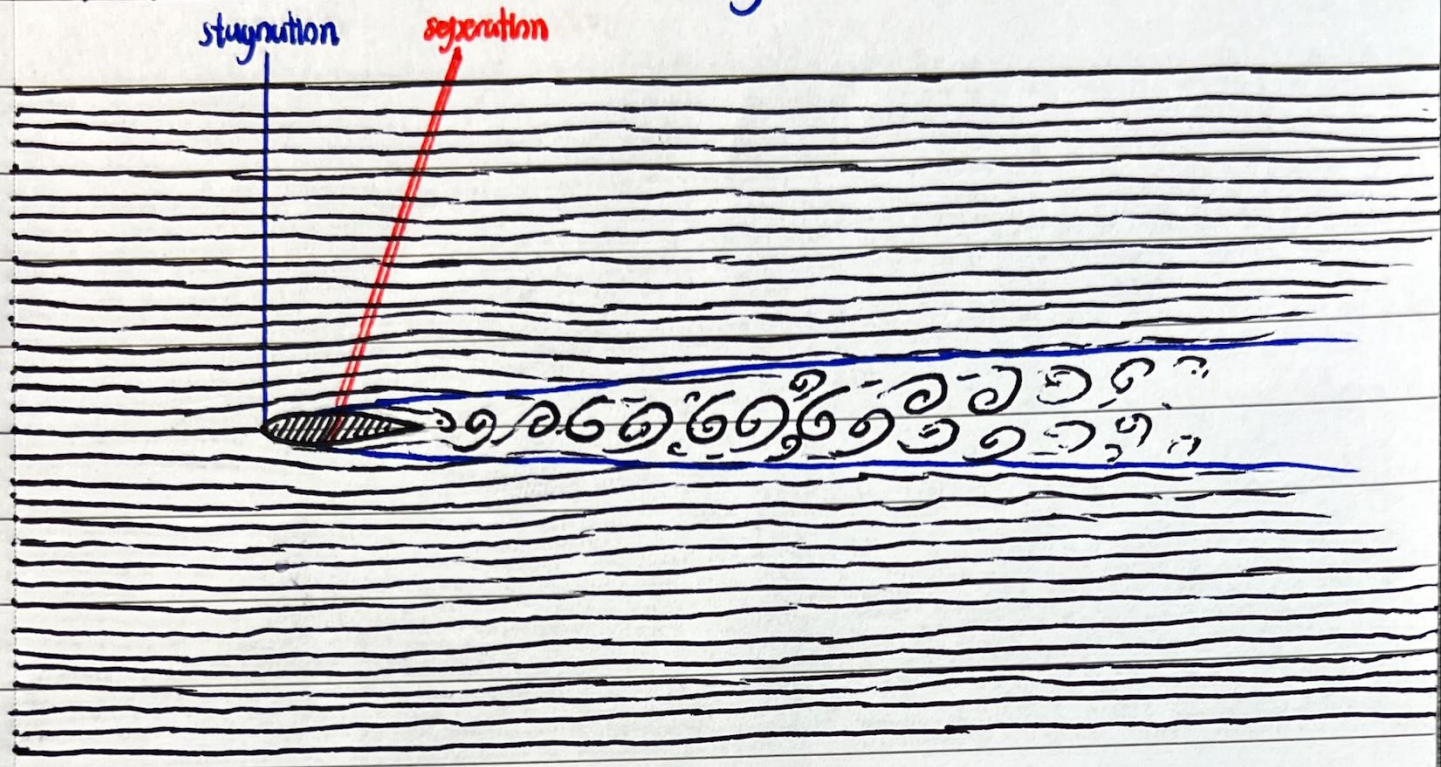
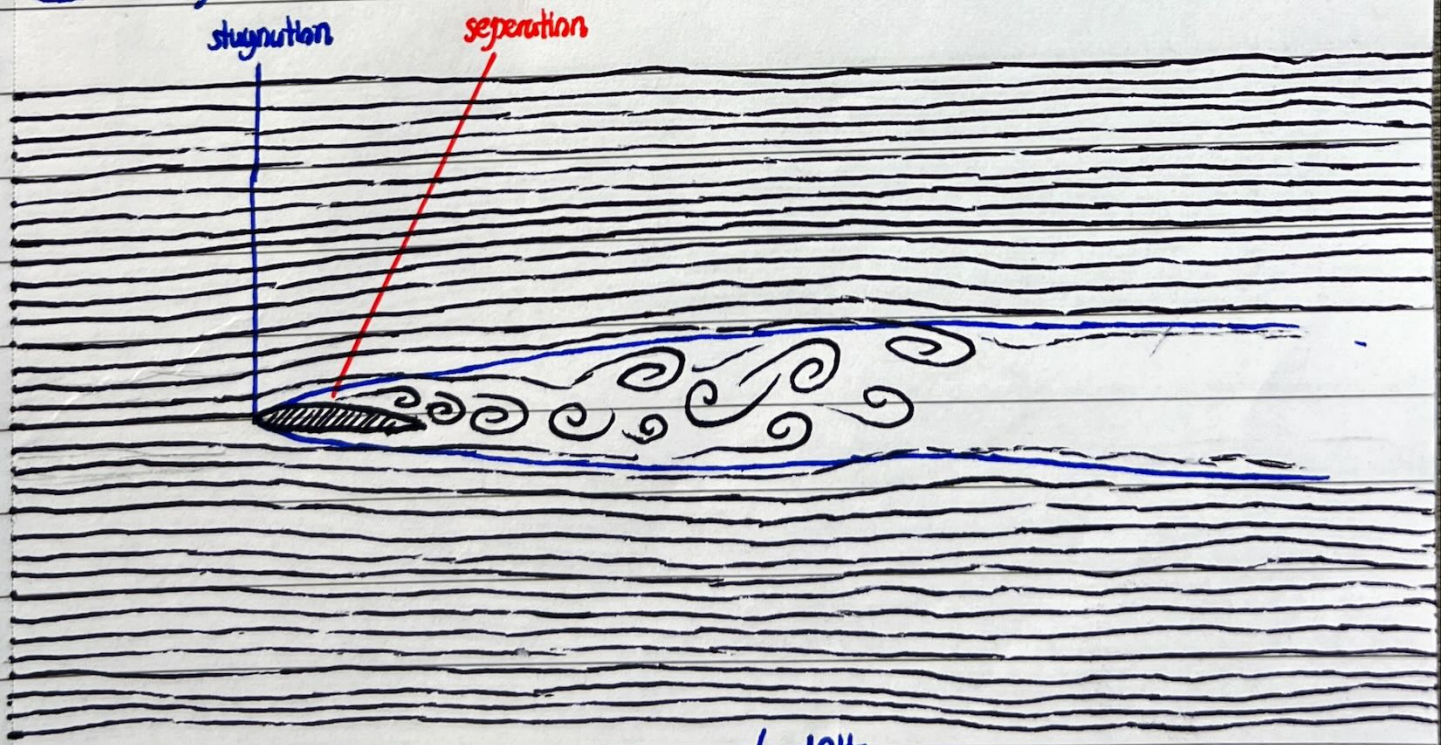


$f = 9Hz$

aerofoil Dial 1.5 $V = 2.60 m/s$ $\alpha = 0°$ $Re = 1.74 \times 10^4$ $St = 0.045$



$f = 10Hz$

aerofoil Dial 1.5 $V = 2.60 m/s$ $\alpha = 5°$ $Re = 1.74 \times 10^4$ $St = 0.050$

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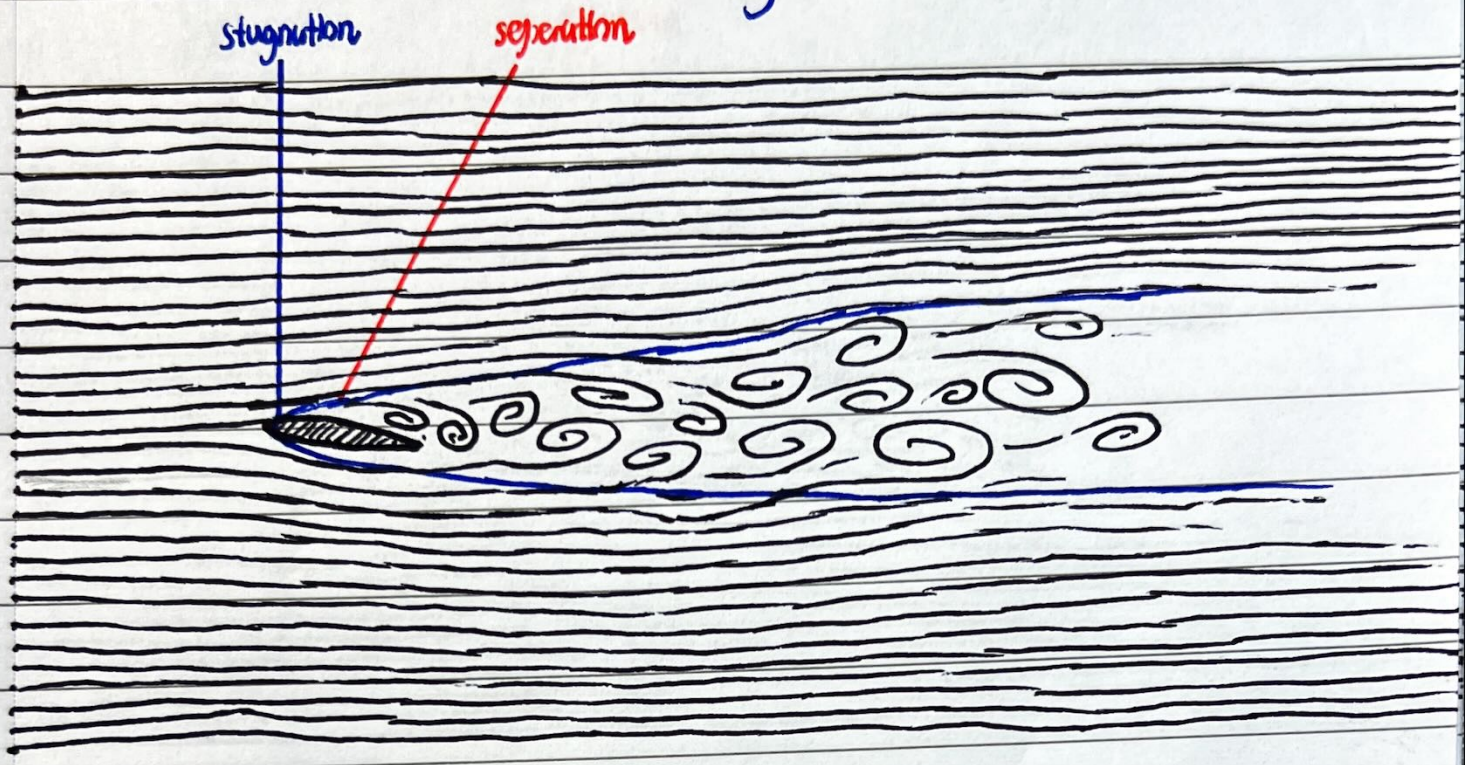
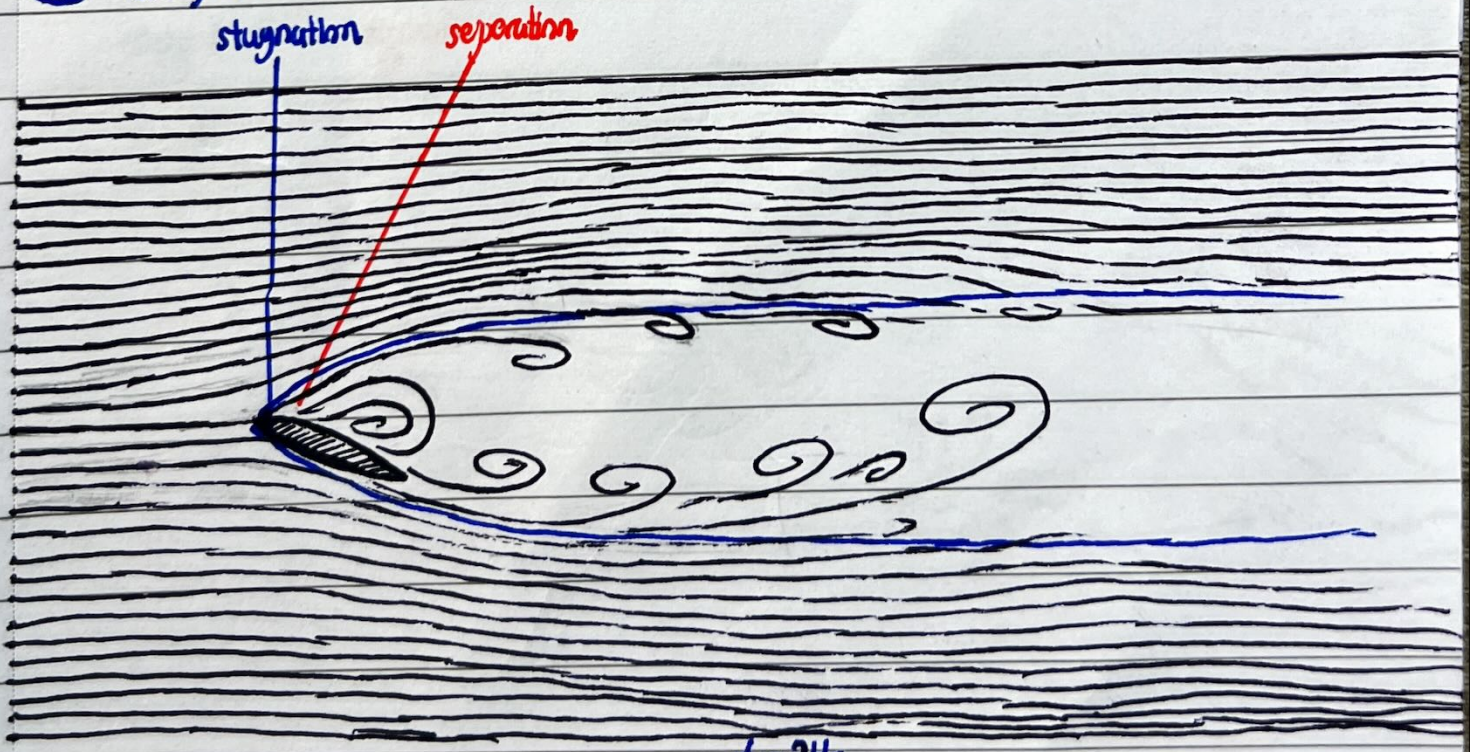


$f = 7Hz$

aerofoil Dial 1.5 $v = 2.60 m/s$ $\alta = 10°$ $Re = 1.74 \times 10^4$ $St = 0.035$



$f = 3Hz$

aerofoil Dial 1.5 $v = 2.60 m/s$ $\alta = 30°$ $Re = 1.74 \times 10^4$ $St = 0.015$

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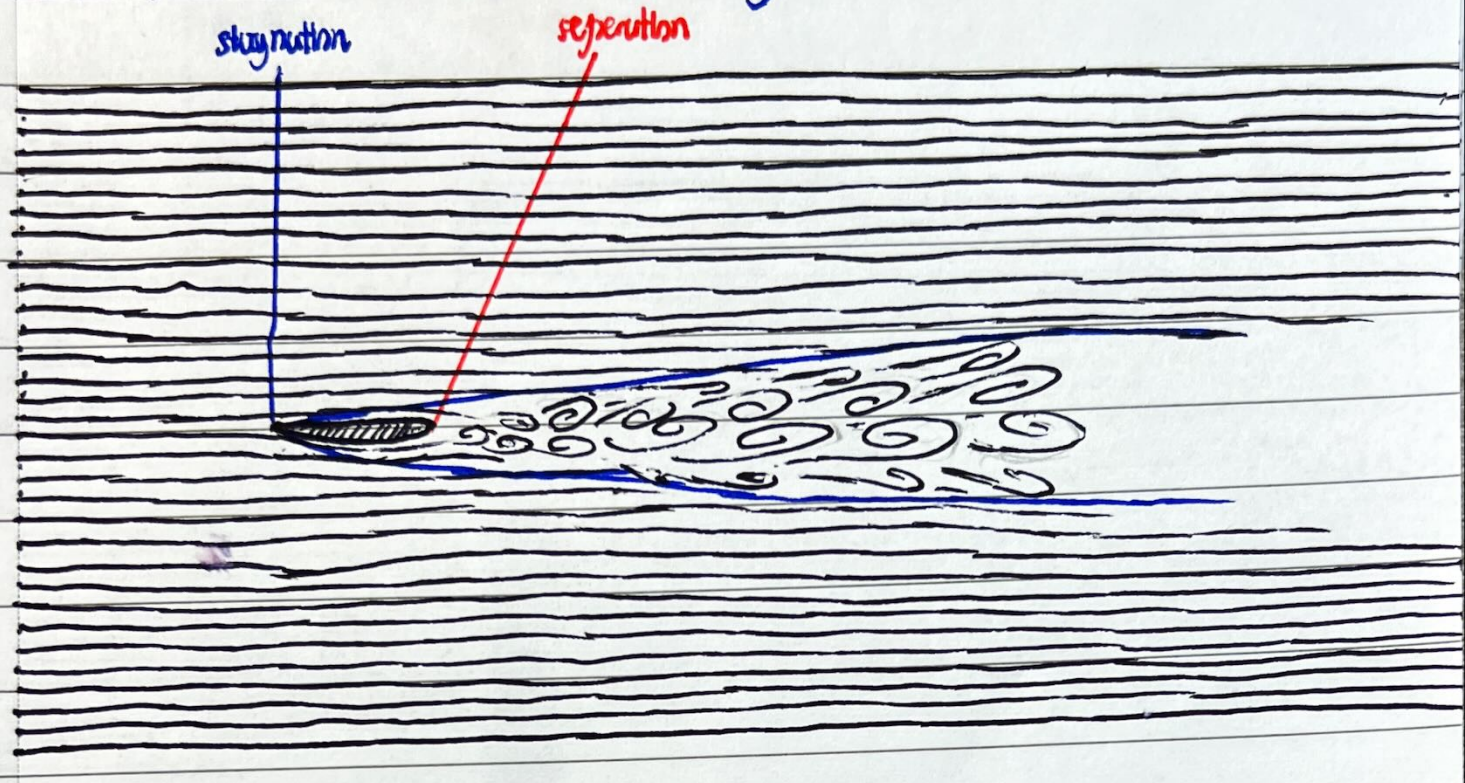
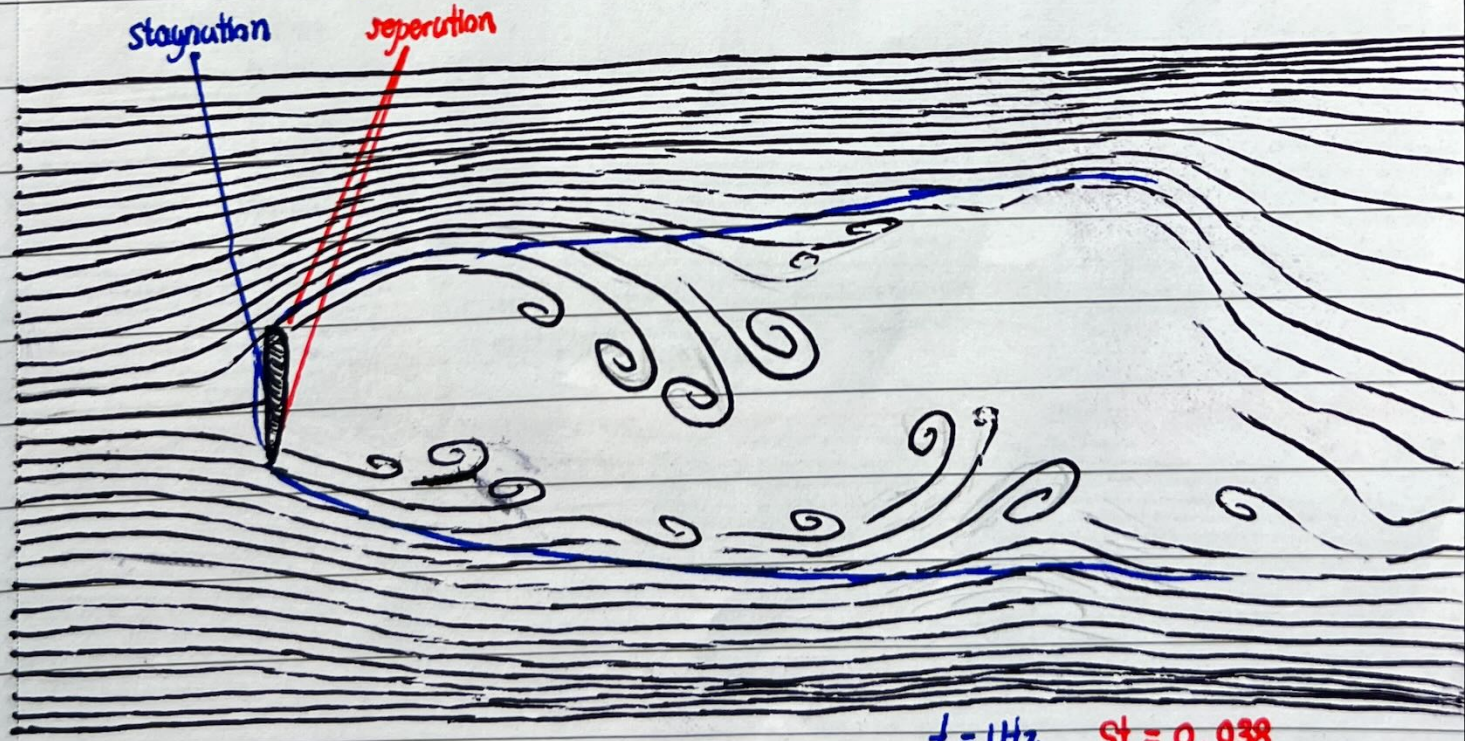


$f = 26\,Hz$ $St = 0.130$

reversed aerofoil Dial 1.5 $V = 2.60\,m/s$ $\alpha = 180°$ $Re = 1.74 \times 10^4$



$f = 1\,Hz$ $St = 0.038$

perpendicular aerofoil Dial 1.5 $V = 2.60\,m/s$ $\alpha = 90°$ $Re = 2.31 \times 10^3$

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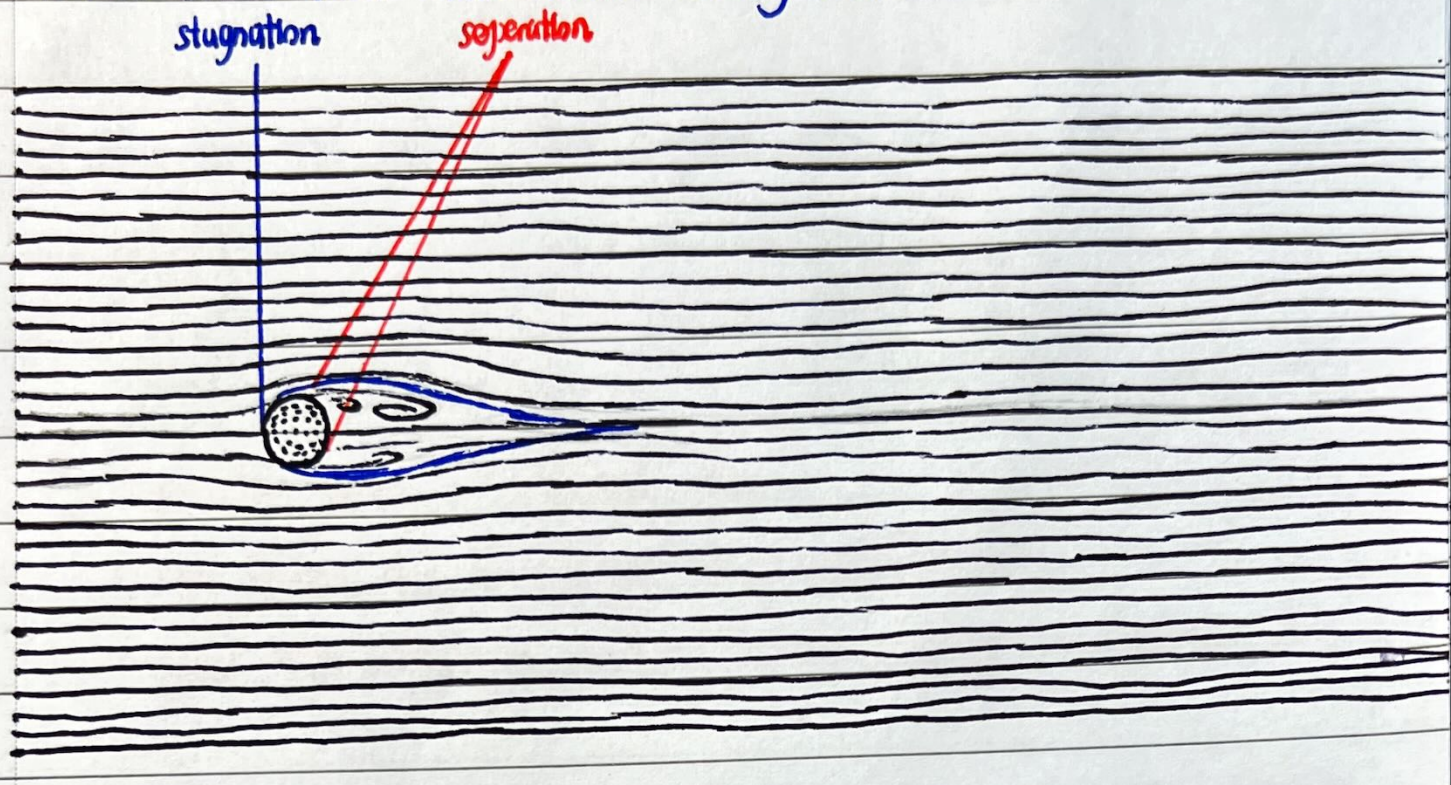
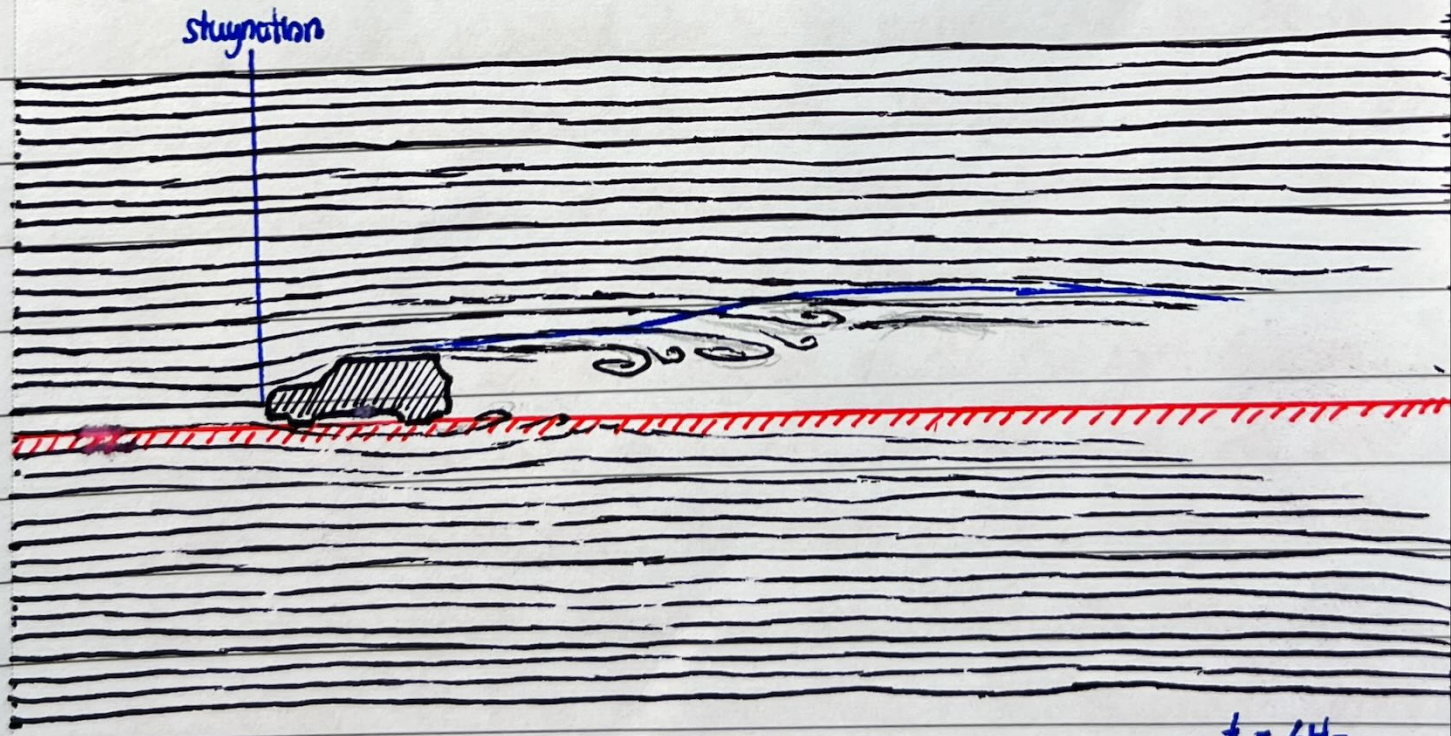


O ball Dial = 1.5 $v = 2.60\,m/s$ $f = 6Hz$



car model Dial = 1.5 $v = 2.60\,m/s$ $Re = 2.95 \times 10^4$ $f = 6Hz$ $St = 0.134$

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1 How does real cylinder flow compare with inviscid, incompressible flow?

inviscid, incompressible flow

real cylinder flow

- seperation point
- turbulent flow

+ skin friction due to viscosity that causes vorticity
+ speed high enough to adverse pressure gradient to seperate flow

2 Briefly explain the extent to which the upstream flow is affected by the presence of the body

The upstream flow is affected due to the pressure caused by the fluid not perfectly flowing around the objects. This affects the oncoming flow by deflecting the air. This deflection propagates forwards until the pressure is too low to affect the oncoming air.

The spacing between streamlines decreases as the flow speed increases. Since the streamlines closer to the body are most curved and closer together closer to the body, the pressure gradient is higher as the flow has to squeeze through the space around the body.

In experiments, the larger the surface area, the less smooth airflow will move over the object as the seperation points move further apart

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to each other. The distruption of upstream

3 Is the stagnation point at the geometric leading edge in all cases?

Yes, but more downward with the rise of angle of attack

4 Where does seperation occur on the models? Are there any locations where flow reattachment can be observed?

Flow reattachment only happened when test the steel ball.

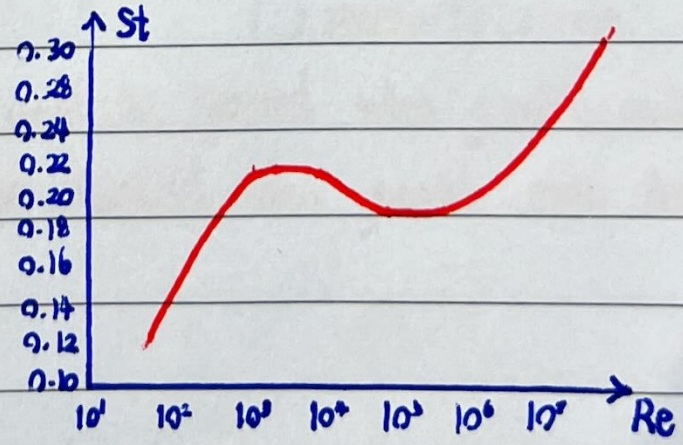
seperation always occurs when flow leaving the trailing edge.

5 How does the flow field and St number compare to those suggested by literature for the Re number?

Experiment

Dial	Re	St
1	7600	0.073
1.5	9230	0.180
2	10800	0.223
2.5	12400	0.342

Suggested value



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6 Briefly summarise any sources of experimental error and uncertainty that identified during the experiment

- Small boundary layer between walls of wind tunnel and objects which interact with downstream flow due to proximity
  + Affect particle drag
  + Affect the observation and sketching
  + Affect the frequency of vortex when counting
- Heating by the wire
- Water particles (but very slightly)

time particles need to reach n% of air speed = t

$\because t = \frac{4\rho r^3}{9\mu_a D} \ln\left|\frac{U_a}{U_a - U_p}\right|$

n	mass of particles (r)		t (s)	
50%	1.310×10^{-13} kg (3μm)	3.5036×10^{-12} kg (9μm)	7.7447×10^{-5}	6.9702×10^{-4}
75%			1.5484×10^{-4}	0.0014
95%			3.3472×10^{-4}	0.0030

t is really small which could be ignored when particle radius is small, but need to be considered when particle mass become larger.