AS2100: Project topics

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1 Experimental determination of mass flow rate using Venturi meter

A Venturi meter is used for measuring the mass flow rate of a fluid by providing a restriction to the flow through reduction in the cross section length downstream with the minimum diameter at the throat as shown in the schematics in figure 2. The pressure heads ΔH are measured using a differential manometer. Using the pressure heads ΔH and the diameters of the pipe d_1 and throat d_2, the mass flow rate(Q_m) is estimated. The experiment is performed for 5 different flow rates indirectly indicated by significantly different pressure heads ΔH. The whole experiment is repeated 100 times thus giving us 100 observations for each flow rate.

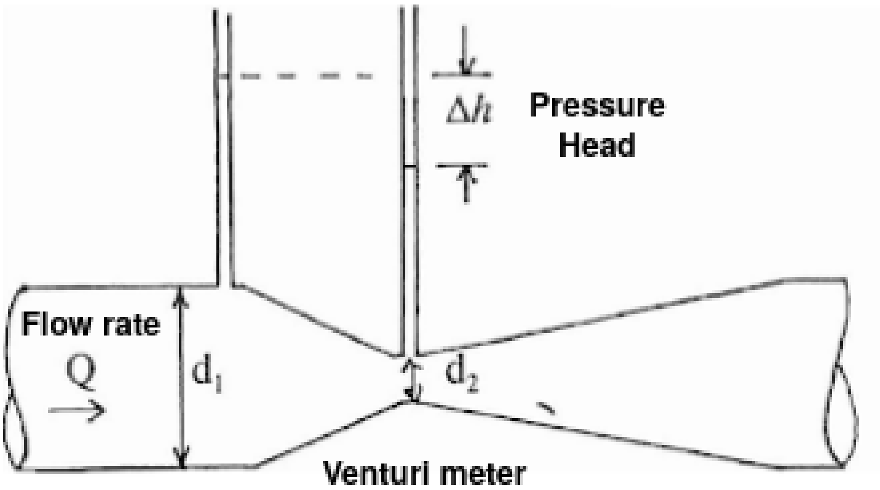

Figure 1: Schematics of the experimental setup.

The parameters used in this experiment are as follows:

- Acceleration due to gravity, $g = 9.81 m/s^2$
- Density $\rho_{water} = 997 kg/m^3$ at mean ambient temperature of $25°C$
- Kinematic Viscosity, $\nu = 8.917E - 07 m^2/s$
- Diameter of the pipe cross section $d_1 = 50cm$
- Diameter of throat $d_2 = 20cm$.

The data set provided in `P1_VenturiMeter.mat`) contains the following:

- Pressure head measurements (`"DeltaH_Exp"`) for 5 different flow conditions:

$$\boldsymbol{\Delta H} = \{\Delta H_1^{(i)}, \Delta H_2^{(i)}, \Delta H_3^{(i)}, \Delta H_4^{(i)}, \Delta H_5^{(i)}\}_{i=1}^{N=100}$$

- True mass flow rates (given as `"QmTrue"`) for 5 different flow conditions:

$$\boldsymbol{Q_m^{True}} = \{Q_{m1}, Q_{m2}, Q_{m3}, Q_{m4}, Q_{m5}\}$$

Using the given data, do the following:

1. Explain the theory behind the experiment. Detail the assumptions made. Given, the pressure head ΔH, throat diameter d_2, pipe diameter d_1, density of the fluid ρ_{water}, derive the theoretical relationship for mass flow rate $Q_m^{Theoretical}$.

2. Obtain the relationship for error in mass flow rate as a function of errors in pressure heads(Hint: Refer to "function of errors/propagation of errors" in your textbooks.). What are the possible sources of error in this experiment and how to minimise them?

3. Using the mean pressure difference values obtained from the experimental data as true pressure differences, plot the normalised histograms of the errors in pressure difference measurements. Also, plot the smoothened probability density trends over the corresponding histograms and determine if the probability density functions are normal in nature. Using the mean and standard deviations of the errors for each case, plot the corresponding normal distribution curve over the histograms and smoothened trends and compare.

4. Using the obtained theoretical relationship for mass flow rate $Q_m^{Theoretical}$ in question 1), estimate the mean mass flow rate $\bar{Q}_{mk}^{Theoretical}$ for $k = 1 \cdots 5$ from the pressure head data provided in `P1_VenturiMeter.mat`.

5. Given true mass flow rates in the data set(given as "`QmTrue`"), obtain the true Reynolds number values:

$$\{Re_D^{(1)}, Re_D^{(2)}, Re_D^{(3)}, Re_D^{(4)}, Re_D^{(5)}\}$$

   Where,

$$Re_D^{(k)} = \frac{V_1^{(k)} d_1}{\nu}$$

   for $k = 1 \cdots 5$ and V_1 is the fluid velocity at inlet, d_1 is the diameter of pipe cross section and ν is the kinematic viscosity of the fluid.

6. With the mean theoretical flow rates $\bar{Q}_{mk}^{Theoretical}$ for $k = 1 \cdots 5$ estimated previously from the data as in question 4), obtain the discharge coefficient C_d^k for $k = 1 \cdots 5$ as follows:

$$C_d^k = Q_{mk}^{True} / \bar{Q}_{mk}^{Theoretical}.$$

7. Using the given data, obtain a linear($y = a_1 x + a_0$) and polynomial($y = \Sigma_{i=1}^{n} a_i x^i + a_0$ with $n = 2, 3$) for coefficient of Discharge(C_d) as a function of Reynolds number(Re_D). Calculate the Mean Square Error for each fit.

8. On a conclusive note, outline the limitations/advantages of using a Venturi meter for estimating the flow rate. What other alternatives exist to measure the fluid flow rate experimentally?

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

2 Experimental determination of mass flow rate using Orifice meter

An Orifice meter is used for measuring the mass flow rate of a fluid by providing a restriction to the flow using an orifice plate. Orifice plate is a thin plate with a hole in it and in this experiment as shown in the schematics in figure 2. The pressure heads ΔH are measured upstream and downstream using a differential manometer and the pressure differences using the relationship $\Delta P = \rho_{water} g \Delta H$ are obtained, where ρ_{water} is the density of fluid. Using the pressure differences ΔP and the diameters of the pipe d_1 and orifice d_2, the mass flow rate Q_m is estimated. The experiment is performed for 5 different flow rates indirectly indicated by significantly different values of change in pressure ΔP downstream. The whole experiment is repeated 100 times thus giving us 100 observations for each flow rate.

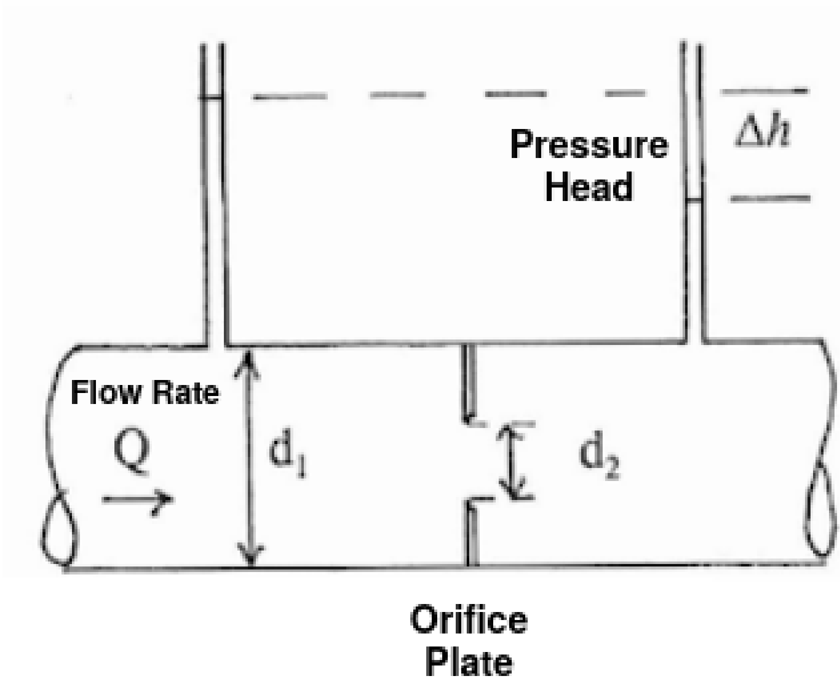

Figure 2: Schematics of the experimental setup.

The parameters used in this experiment are as follows:

- Acceleration due to gravity, $g = 9.81 m/s^2$
- Density $\rho_{water} = 997 kg/m^3$ at mean ambient temperature of $25°C$
- Kinematic Viscosity, $\nu = 8.917E - 07 m^2/s$
- Diameter of the pipe cross section $d_1 = 50cm$
- Internal diameter of orifice $d_2 = 10cm$.

The data set provided in `P1_OrificeMeter.mat`) contains the following:

- Pressure difference measurements ("DeltaP_Exp") for 5 different flow conditions:

$$\boldsymbol{\Delta P} = \{\Delta P_1^{(i)}, \Delta P_2^{(i)}, \Delta P_3^{(i)}, \Delta P_4^{(i)}, \Delta P_5^{(i)}\}_{i=1}^{N=100}$$

- True mass flow rates (given as "QmTrue") for 5 different flow conditions:

$$\boldsymbol{Q_m^{True}} = \{Q_{m1}, Q_{m2}, Q_{m3}, Q_{m4}, Q_{m5}\}$$

Using the given data, do the following:

1. Explain the theory behind the experiment. Detail the assumptions made. Given, the pressure differences ΔP, orifice diameter d_2, pipe diameter d_1, density of the fluid ρ_{water}, derive the theoretical relationship for mass flow rate $Q_m^{Theoretical}$.

2. Obtain the relationship for error in mass flow rate as a function of errors in pressure differences(Hint: Refer to "function of errors/propagation of errors" in your textbooks.). What are the possible sources of error in this experiment and how to minimise them?

3. Using the mean pressure difference values obtained from the experimental data as true pressure differences, plot the normalised histograms of the errors in pressure difference measurements. Also, plot the smoothened probability density trends over the corresponding histograms and determine if the probability density functions are normal in nature. Using the mean and standard deviations of the errors for each case, plot the corresponding normal distribution curve over the histograms and smoothened trends and compare.

4. Using the obtained relationship for theoretical mass flow rate ($Q_m^{Theoretical}$) in question 1), estimate the mean theoretical mass flow rate $\bar{Q}_{mk}^{Theoretical}$ for $k = 1 \cdots 5$ from the pressure difference data provided in `P1_OrificeMeter.mat`.

5. Given true mass flow rates in the data set, obtain the true Reynolds number values:

$$\{Re_D^{(1)}, Re_D^{(2)}, Re_D^{(3)}, Re_D^{(4)}, Re_D^{(5)}\}$$

   . Where,

$$Re_D^k = \frac{V_1^{(k)} d_1}{\nu}$$

   for $k = 1 \cdots 5$ and V_1 is the fluid velocity at inlet, d_1 is the diameter of pipe cross section and ν is the kinematic viscosity of the fluid.

6. With the mean theoretical flow rates $\{\bar{Q}_{mk}^{Theoretical}\}_{k=1}^{5}$ estimated previously from the data as in question 4), obtain the discharge coefficient C_d as follows:

$$C_d^k = Q_{mk}^{True} / \bar{Q}_{mk}^{Theoretical}.$$

7. Using the given data, obtain a linear($y = a_1 x + a_0$) and polynomial($y = \Sigma_{i=1}^{n} a_i x^i + a_0$ with $n = 2, 3$) for coefficient of Discharge(C_d) vs Reynolds number(Re_D).Calculate the Mean Square Error for each fit.

8. On a conclusive note, outline the limitations/advantages of using a Orifice meter for estimating the flow rate. What other alternatives exist to measure the fluid flow rate experimentally?

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

3 Experimental determination of force on the wall of a cubic tank

In this experiment the force on the side wall of a cubic tank of dimensions $2m \times 2m \times 2m$ is estimated through the pressure measurements. The cubic shaped tank of water has 5 pressure gauges attached to it in 5 different locations height wise ($\{h1 = 0.4m, h2 = 0.8m, h3 = 1.2m, h4 = 1.6m, h5 = 2m\}$) as shown in fig 3. The pressure measurements are made from the pressure gauges, $\{P_1, P_2, ...P_5\}$. This is repeated 100 times and the observations are recorded in the data set `P3_Hydrostatics.mat`

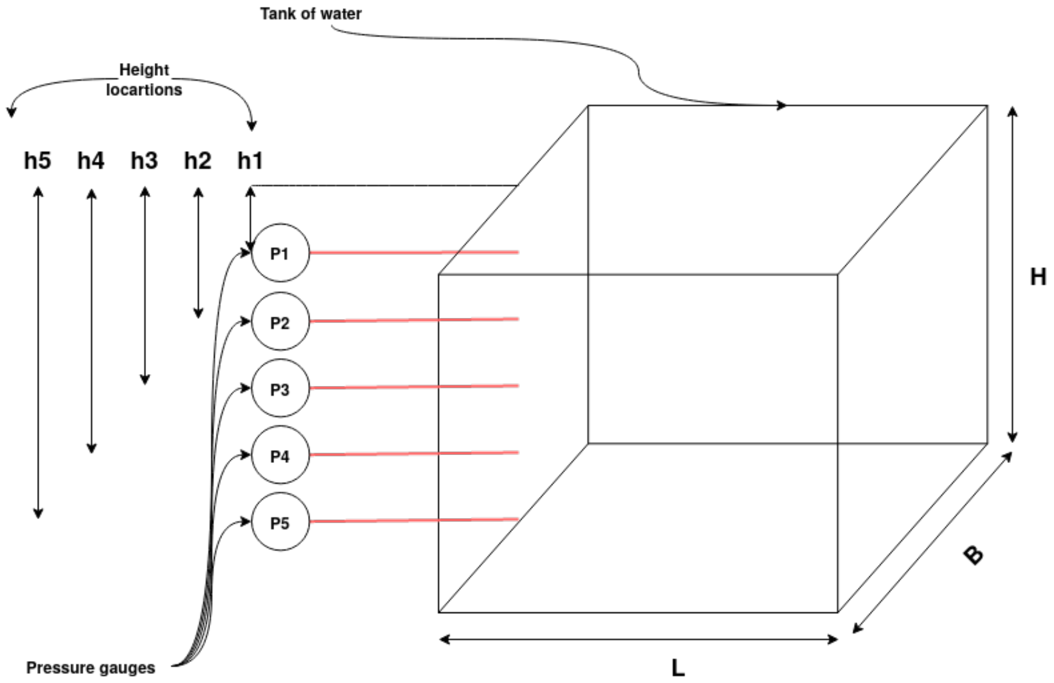

Figure 3: Schematics of the experimental setup.

Use the following properties for your calculations:

- Density of water (at $25°C$) $\rho_{water} = 997Kg/m^3$.
- Acceleration due to gravity, $g = 9.81m/s^2$

The data set provided in `P3_Hydrostatics.mat`) contains the following:

- Height locations (`H_Location`) where the pressure gauges are attached to the tank.

$$\boldsymbol{h} = \{h1 = 0.4m, h2 = 0.8m, h3 = 1.2m, h4 = 1.6m, h5 = 2m\}$$

- Pressure measurements(`P_Exp`) at different locations

$$\boldsymbol{P^{exp}} = \{P1^i, P2^i, P3^i, P4^i, P5^i\}_{i=1}^{N=100}$$

.

Using the above information and the data set, do the following:

1. Explain the theory behind this experiment and detail the assumptions involved.

2. Use Pascal's law to obtain the true values of pressure at the different locations where the pressure gauges are placed. Represent these true values as

$$\boldsymbol{P^{true}} = \{\hat{P}1, \hat{P}2, \cdots \hat{P}5\}$$

3. What are the possible sources of error in this experiment? How can we minimise them?

4. Plot the normalised histograms of error in pressure observations at each height location by considering the theoretical pressures obtained in question 2) as true values. Also, plot the smoothened probability density trends over the corresponding histograms. Determine if the probability density functions resemble Gaussian, Log normal or Uniform density functions. (Hint: Read up on Log normal density function and its relationship with the normal density function).

5. Determine the accuracy of the pressure gauges and identify the least accurate pressure gauge.(Hint: Greater the $|Pj^{true} - \bar{P}j^{exp}|$ for $j = 1 \cdots 5$, lesser the accuracy. Here, $\bar{P}j^{exp}$ is the mean pressure measured experimentally.)

6. Derive the theoretical relationship for the force on the side wall F_{wall} and maximum pressure. Calculate the theoretical value of F_{wall} using the obtained relationship (**Note:** Choose the side wall with pressure gauges attached.). The theoretical F_{wall} can be considered the true value, F_{wall}^{true} for further calculations.

7. Estimate the force on the side wall of the tank using numerical integration for each set of pressure data at different height locations ($F_{wall}^{exp\,(i)}$ for $i = 1 \cdots 100$). Obtain the error in the force estimation($e^{(i)} = F_{wall}^{true} - F_{wall}^{exp\,(i)}$ for $i = 1 \cdots 100$). Plot the normalised histogram of the errors obtained and also plot the smoothened probability density trend over the histogram.

8. Determine the accuracy($|F_{wall}^{true} - mean(F_{wall}^{exp\,(i)})|$ for $i = 1 \cdots 100$) and precision (given in terms of $\pm 1\sigma_{F_{wall}}$).

9. Obtain the best linear fit for pressure as a function of height location and comment on how the linear relationship obtained compares with the theoretical relationship obtained in question 2). If there is a difference, please estimate the mean squared error between these trends.

10. On a conclusive note, what improvements can be made in the experimental setup to obtain a better force estimate.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

4 Experimental determination of Meta center height

Metacenter is the point at which a vertical line through the centre of buoyancy crosses the line through the original and the metacenter remains directly above the centre of buoyancy by definition. The metacentric height is the distance between the centre of gravity of the body and metacenter(G_0M as shown below in figure 4).

In this experiment the metacentric height G_0M of a cubical solid block is determined as follows. Firstly the solid is slowly immersed in a tank initially filled with water up to height H. Once, the solid floats and stabilises, the rise in height of water column ΔH is then noted down.

Then weights(W_1) are loaded on to one end of the solid in steps of $100gms$ up to $W_1 = 500gms$ and the resulting static angular displacement(θ) is measured at each step and then the loads are removed one by until $W_1 = 0$ and the average angular displacement θ for each W_1 for loading and unloading cycle is recorded in the data set described below. The whole experiment is repeated by 25 members and the data is recorded by each of them. The experimental setup is shown below in figure.

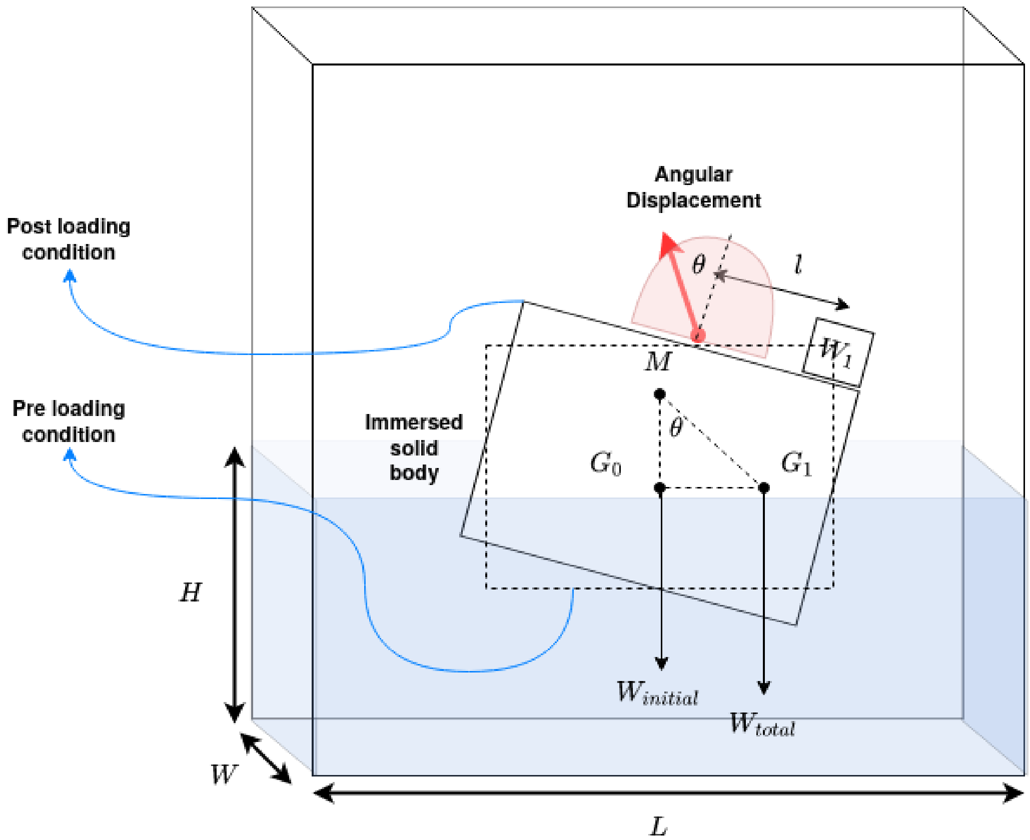

Figure 4: Schematics of the experimental setup.

Use the following parameters for your calculations: :

- Tank dimensions: $65cm \times\ 45cm \times\ 30cm$
- Dimensions of the cubical solid block: $20cm \times\ 20cm \times\ 20cm$
- Initial height of the water column, $H = 16cm$
- Rise in height of water column after immersing the solid, $\Delta H = 4cm$
- $\rho_{water} = 997kg/m^3$ at mean ambient temperature of $25°C$.
- Moment arm, $l = 10cm$

- Acceleration due to gravity, $g = 9.81 m/s^2$

The data set `P4_MetaCenter.mat` contains the following:

- Loaded weights(in grams) (`"W1"`):

$$\boldsymbol{W_1} = \{W_1^{(1)}, W_1^{(2)}, W_1^{(3)}, W_1^{(4)}, W_1^{(5)}\}$$

- Angular displacements(in degrees)((`"Theta_Exp"`)) corresponding to the zero load condition and $W_1^{(j)}$ for $j = 1 \cdots 5$:

$$\boldsymbol{\Theta} = \{\theta_0^{(i)}, \theta_1^{(i)}, \theta_2^{(i)}, \theta_3^{(i)}, \theta_4^{(i)}, \theta_5^{(i)}\}_{i=1}^{N=25}$$

Here, θ_0 is the angular displacement measured at zero load condition($W_{initial} = W_{body}$).

Using the data set, do the following:

1. Explain the theory behind this experiment and obtain the analytical relationship for metacentric height for a cubical solid using first principles. Detail all the assumptions made.
2. What are the possible sources of errors in the experiment and how to minimize them?
3. The dimensions of the immersed solid are $20cm \times 20cm \times 20cm$ and the rise of the water level as given earlier is $\Delta H = 4cm$. Using the fundamental principles as in question 1, determine the density of the solid. Also, obtain the theoretical metacentric height using the relationship obtained in question 1. (Consider the obtained metacentric height as the true value(G_0M^{True}) for further calculations).
4. Given that the empirical relationship between experimentally determined angular displacement θ, metacentric height G_0M^{Exp}, initial weight (W_{body}), loaded weight (W_1) and moment arm (l) is as follows:

$$G_0M^{Exp} = \frac{W_1\, l}{(W_{body} + W_1)\tan(\theta)},$$

   Estimate the experimental metacentric height from each observation of θ.
5. Plot the normalised histograms of the observed angular displacements (θ) for each W_1. Also, plot a smoothened probability density trend over each of the histograms. Determine if the probability density functions are Gaussian in nature. If so, using the statistical quantities μ and σ, of θ for each W_1 plot the corresponding Gaussian density functions over the histograms.
6. Using the theoretical value for metacentric height(obtained in question 3) as true value G_0M^{True}, plot the normalised histograms and corresponding smoothened probability density functions of the errors($e_{ij} = G_0M_j^{True} - G_0M_{ij}^{Exp}$ for $i = 1 \cdots 25$, and $j = 1 \cdots 5$) in the experimentally determined metacentric height G_0M^{Exp} for each W_1. Determine the accuracy($|G_0M^{True} - G_0M_{Mean}^{Exp}|$) and precision (given in terms of $\pm 1\sigma_{G_0M}$) in each case.
7. Using the given data set, obtain a linear($y = a_1x + a_0$) and polynomial($y = \Sigma_{i=1}^{n} a_i x^i + a_0$ with $n = 2, 3$) fits for the mean angular displacement($\bar{\theta}$) as a function of loaded weight(W_1) data. Calculate the mean squared error for each fit.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

5 Experimental determination of Lift coefficient

In a wind tunnel setup as shown below, with a test section of NACA 0012 airfoil with chord length $c = 0.1m$ and Span, $S = 1m$, the lift force is measured 25 times using a load cell for various angles of attack($\{\alpha^i\}_{i=1}^{6}$) and the experiment is repeated for different Reynolds numbers $\{Re_k\}_{k=1}^{3}$ by varying the free stream velocity U_∞. It was observed that for Re_1, the Lift force measurements didn't show any noticeable random error but the measurements for Re_2 and Re_3 were containing errors.

Finally, we obtain a data set (`P5_LiftCoefficient.mat`) as follows:

1. Free stream Velocity (`"U_freestream"`) represented as:

$$\boldsymbol{U_\infty} = \{U_1, U_2, U_3\}$$

2. Angles of attack(`"alpha"`):

$$\boldsymbol{\alpha} = \{\alpha_i\}_{i=1}^{6}.$$

3. Mean Lift force(`"Lift_force"`) measurements for $\{Re_k\}_{k=1}^{3}$ at various angles of attack(`"alpha"`).

$$\boldsymbol{\bar{L}_{Re_k}} = \{\{\bar{L}^i_{Re_k}\}_{i=1}^{6}\} \text{ where, } k = 1 \cdots 3.$$

4. Lift force measurements for $\{Re_k\}_{k=2}^{3}$ (Given in `"Lift_Re2_noisy"`, `"Lift_Re3_noisy"`) at various angles of attack (`"alpha"`):

$$\boldsymbol{L_{Re_k}} = \{\{L^{ij}_{Re_k}\}_{i=1}^{6}\}_{j=1}^{25}, \text{ where, } k = 2 \cdots 3.$$

Use the following parameters wherever necessary:

- Density of air, $\rho_{air} = 1.225 kg/m^3$

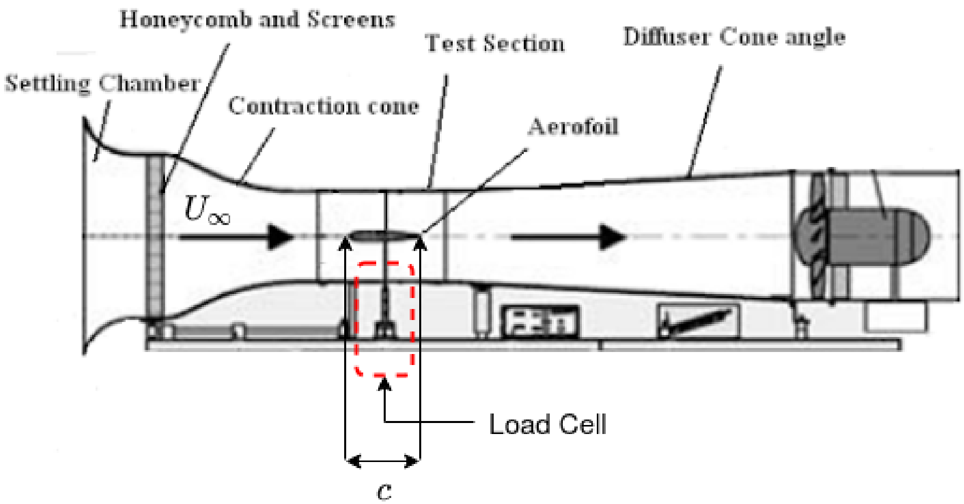

Figure 5: Schematics of the experimental setup.

Using the data obtained, do the following:

1. Explain the theory behind the experiment. Outline the assumptions involved.

2. Using dimensional analysis, arrive at the relation between Lift force (L), dynamic pressure(q_∞) given by,

$$q_\infty = \frac{\rho_{air} U_\infty^2}{2},$$

plan form area($A = cS$) and lift coefficient (Cl).

3. What are the possible sources of error in this experiment and how to minimise them? Will the probability distributions of lift coefficient (Cl) and lift force(L) belong to the same family of distributions?

4. Obtain the operating Reynolds number values, Re_k for $k = 1 \cdots 3$ from the given free stream velocity data("`U_freestream`").

5. Estimate the experimental lift coefficients (Cl_{ijk}^{exp} for $i = 1 \cdots 6, j = 1 \cdots 25$, and $k = 1 \cdots 3$) from the lift forces data for each lift force reading corresponding to each Reynolds number and angle of attack using the relationship obtained in question 2. (Use the lift data given in "`Lift_Re2_noisy`" for Re_2, and "`Lift_Re3_noisy`" for Re_3 and column 1 of "`Lift_force`" for Re_1)

   Note: Here, for lift data at Reynolds number Re_1, $i = 1 \cdots 6, j = 1$ and $k = 1$ as the observations for Re_1 don't show any noticeable errors.

6. Using the estimated lift coefficients(from question 5), plot the normalised histograms of errors in lift coefficient(Cl_{ijk}^{exp}) for $i = 2, 4, 6$ (i.e for angles of attack $\alpha_2, \alpha_4, \alpha_6$) for each $k = 2, 3$ (i.e. for Reynolds numbers Re_2, Re_3) for $j = 1 \cdots 25$. Also, plot the smoothened probability density trends over all of the 6 histograms obtained.

   Note: Assume that the mean values of the lift coefficients($\bar{Cl}_{ik}^{exp}$ for $i = 2, 4, 6$ and $k = 2, 3$) are true values.

7. Using the given data set `P5_LiftCoefficient.mat`, Obtain linear($y = a_1 x + a_0$) and polynomial($y = \Sigma_{i=1}^{n} a_i x^i + a_0$ with $n = 2$) fits for mean lift coefficients($\bar{Cl}^{exp}$) vs angle of attack (α) for Reynolds numbers Re_1, Re_2, and Re_3. For each Reynolds number compare with the theoretical estimate of lift coefficient,

$$Cl = 2\pi\alpha.$$

8. Comment on the effect of Reynolds number on the lift coefficient. Explain the causes for deviation from the theoretical value of lift coefficient at higher angles of attack.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

6 Experimental determination of thrust of a gas turbine engine

In this experimental setup a Gas turbine engine is mounted on a test bed strongly attached to the ground as shown in the figure. The cross sectional area of the intake A_{intake} is already given. Intake and exhaust velocities $\boldsymbol{v_{in}}$, $\boldsymbol{v_e}$ are also measured accurately and it is assumed that there are no errors in their measurement. The thrust T is measured directly from the strain gauge attached to the test bed. For each exhaust velocity $\boldsymbol{v_e}^j$ with $j = 1 \cdots 5$, 100 observations are recorded to quantify the error.

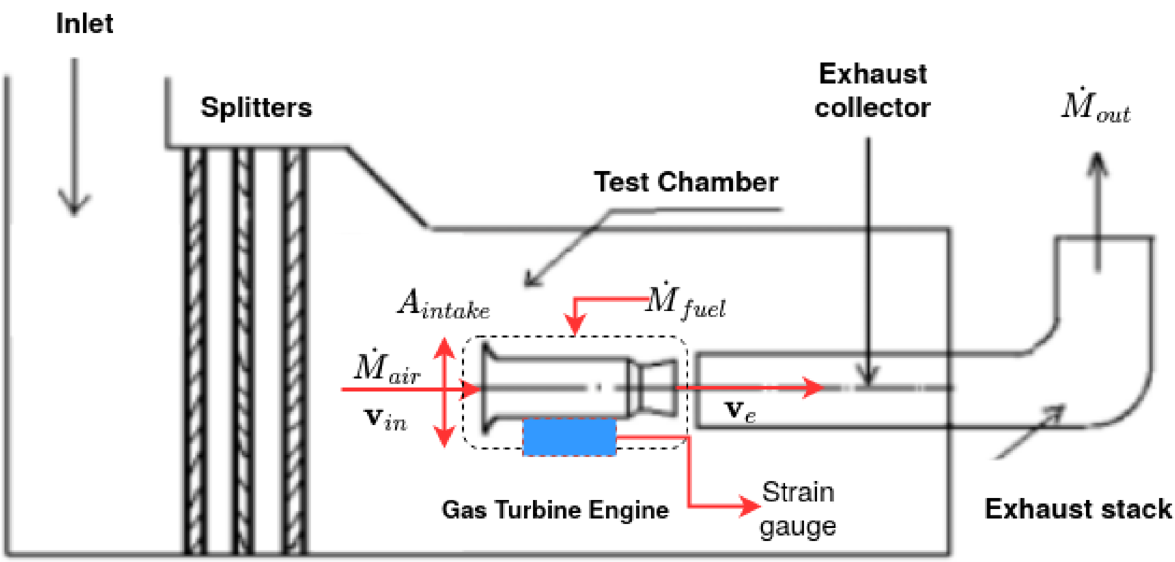

Figure 6: Schematics of the experimental setup.

Parameters used in the experiment are as follows:

- Area of intake cross section $A = 0.7854m^2$
- Stoichiometric air-fuel ratio: 14.7 : 1
- Inlet velocity $V_{in} = 50m/s$

The data set `P6_GasTurbine.mat` contains the following:

- Area of Intake (`"Area_intake"`)
- Exhaust velocities (`"Vexhaust"`):

$$\boldsymbol{v_e} = \{v_{e1}, v_{e2}, v_{e3}, v_{e4}, v_{e5}\}$$

- True thrust values(`"Thrust_True"`) calculated using Stoichiometric air-fuel ratio:

$$\boldsymbol{T^{True}} = \{T_1, T_2, T_3, T_4, T_5\}$$

- Experimental thrust measurements(`"Thrust_Exp"`) from the strain gauges:

$$\boldsymbol{T^{Exp}} = \{T_1^i, T_2^i, T_3^i, T_4^i, T_5^i\}_{i=1}^{N=100}$$

Using the given data set, do the following:

1. Explain the theory behind the experiment of thrust determination using a test bed with strain gauge attached to it. Outline the assumptions involved. At higher exhaust velocities, if the temperature of the outer casing of the turbine increases and is of the order $O(10^3)K$, how would this affect the strain gauge measurements? What are the alternatives to using strain gauges in measuring the thrust of a gas turbine engine?

2. What are the possible sources of errors in this experiment? How can we minimise them?

3. From the given measurement data of thrust($\boldsymbol{T^{Exp}}$), obtain the mean value of air-fuel ratio and compare with the stoichiometric air-fuel ratio. Obtain the mass flow rates of air($\dot{m}_{air}$) and fuel($\dot{m}_{fuel}$) respectively.

4. Using the true thrust values(T^{True}) given in the data set, plot the normalised histograms of the errors in measurements of thrust ($e_{ij} = T_j^{True} - T_{ij}^{Exp}$ for $i = 1 \cdots 100$ and $j = 1 \cdots 5$). Determine the mean and standard deviations of the errors in each case. Also plot the smoothened probability density function trends over the histogram plots.

5. Determine if the probability distributions obtained above for the errors are Gaussian, if so, then using the mean and standard deviations of the errors, e_j for $j = 1 \cdots 5$, plot smooth Gaussian density function over the corresponding histograms and smoothened probability density function plots obtained previously in question 4.

6. Determine the accuracy(given by mean absolute error $|T_j^{True} - \bar{T}_j^{Exp}|$ for $j = 1 \cdots 5$ where $\bar{T}_j^{Exp}$ is the mean experimental thrust) and precision in the measurements(given by $\pm 1\sigma_{T_j}$ for $j = 1 \cdots 5$).

7. Obtain a linear fit for thrust(T) vs exhaust velocity($\boldsymbol{v_e}$).

   Note: Obtain fits for both, mean experimental thrust data $\bar{T}_j^{Exp}$ and true thrust values T_j^{True} for $j = 1 \cdots 5$. Compare the slopes and intercepts obtained for both the cases.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

7 Experimental determination of Young's modulus of aluminium using three point bend test

The three point bend test fig-7 is a classical experiment in mechanics, used to measure the Young's modulus (E) of a material in the shape of a beam. The experiment is performed by hanging a set of known weights at point B and measuring the corresponding deflection(w_0) using a dial gauge. The experiment was performed by 5 different groups using instruments with same precision and each experiment consist of 20 cycles of measurements. Each cycle of measurement in an experiment corresponds to increasing the load from 0 to a maximum value P_{max} in fixed steps of ΔP and decreasing from maximum to 0 with same step size of ΔP. The ΔP and P_{max} values for each group is fixed but different groups can have different values. The applied load (P) and the corresponding dial gauge readings (w_0)are given in the file `P7_ThreePointBending.mat`. The value of L - length of beam, the cross-sectional dimensions a and b are known to be same for each group and known exactly. The beam is made of an aluminium alloy.

Use the following parameters wherever necessary:

- Length of beam, L = 1m
- Height of cross section, a = 0.03m
- Width of cross section, b = 0.03m

The data set `P7_ThreePointBending.mat` contains,

- Applied loads for each experiment in newton (each variable is an array of size 13, as there are 7 sets of weights and each cycle consist of loading and unloading)

  $\Longrightarrow$ `"P_exp1", "P_exp2", "P_exp3", "P_exp4", "P_exp5"`

- Corresponding deflection values (each variable is a 13×20 matrix, as there are 20 cycles for each loads per experiment)

  $\Longrightarrow$ `"w_0exp1","w_0exp2","w_0exp3","w_0exp4""w_0exp5"`

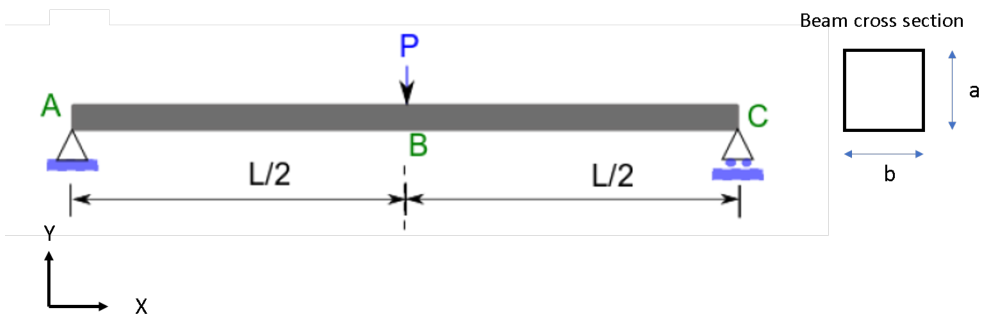

Figure 7: Schematic of three point bend test

1. Explain the theory behind the experiment and outline the experimental procedure.
2. Derive the relation between the applied load (P) and deflection (w_o) for a simply supported beam.
3. What are the possible sources of error in the experiment and how to minimize them?

4. How does changing the number of cycles per experiment affect the mean value of E ? Also does load increment value (ΔP) have any effect in accuracy or precision of the E for a given P_{max}?

5. Using the given dataset `P7_ThreePointBending.mat` make plots of Load (P)vs deflection(w_0) for each experiment for the first cycle and fit a linear curve over these data points. What does the slope of the best fit linear curves represent?

6. Calculate the best estimate of E for each cycle for all the 5 experiment.(i.e, from each experiment you get 20 values for E)

7. Using the values of E obtained in question-6 plot normalised histograms of E for all the 5 experiments. Also plot the smoothened probability density function trends over the histogram plot.

8. Find statistical quantities μ ,σ of E for each experiment and plot Gaussian probability density functions for E using the above obtained quantities and compare with the corresponding smoothened plots in question-7.

9. Basic principles behind the experiment are the Hooke's law and Euler Bernoulli beam theory.Upon careful examination it was concluded that one experiment had violated Hooke' law and Euler Bernoulli beam theory. Which experiment is that? and why ?

10. Find the best estimate of E from all the experiments.(express your final answer inclusive of the associated error in terms of $\pm 1\sigma$). Compare your result with the published value of the Young's modulus of aluminium 2024.

11. What are the short comings of the current experiment? Suggest better experiments to measure Young's modulus of a material

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

8 Determination of Shear Modulus of an aluminium rod using Torsion Test

Like Bending, Torsion is an important type of loading that can produce critical stresses in engineering applications. Torsion test is a classical test which can be used to determine Shear Modulus (G) of a material. Figure 9 shows the apparatus for the torsion test, where the rod is fixed at one end and the other end is free to rotate. At the free end a disc of radius d is attached to the rod which act as a lever, which also has a provision to hang weights. To The experiment was performed by 5 different groups using instruments with same precision and each experiment consists of 20 cycles of measurement. Each cycle of measurement in an experiment corresponds to increasing the load from 0 to a maximum value m_{max} in fixed steps of Δm and decreasing from m_{max} to 0 with same step size of Δm. The Δm and m_{max} values for each group is fixed but different groups can have different value. The applied load and corresponding value of angle measurement reading are given in the file 'P8_TorsionTest.mat'. The value of D- rod diameter ,L- rod length, d- length of lever are known to be same for all the 5 experimental setup and known exactly. The rod is made of an aluminium alloy. Use the following parameters wherever necessary:

- Length of beam ,L = 1m
- Diameter of the rod, D = 0.01m
- Length of lever, d = 0.1m
- Acceleration due to gravity, g = 9.81 m/s^2

The data set `P8_TorsionTest.mat` contains,

- Applied masses for each experiment in kg (each variable is an array of size 13, as there are 7 sets of weights and each cycle consist of loading and unloading the weights)

  $\Longrightarrow$ `"m_exp1", "m_exp2","m_exp3","m_exp4","m_exp5"`

- Corresponding angle of deflection in radians (each variable is a 10×20 matrix, as there are 23 cycles for each loads per experiment)

  $\Longrightarrow$ `"theta_0exp1","theta_0exp2","theta_0exp3","theta_0exp4""theta_0exp5"`

1. Explain the theory behind the experiment and give the experimental procedure.
2. What are the possible sources of errors in the experiment and how to minimize them?
3. Derive the relation between applied mass m and angle of deflection ($theta_o$) for a simply supported beam.
4. How does changing the number of cycles per experiment affect the mean value of G ? Also does mass increment value (Δm) have any effect in accuracy or precision of the G for a given m_{max}?
5. Using the dataset `P8_TorsionTest.mat`, make plots of Shear stress vs shear strain for each experiment for the first cycle and find the best linear fit using least square method . What does the slope of the best fit curves represent?
6. Find the best estimate of G for each cycle for all the 5 experiments.(i.e, from each experiment you get 20 values for G)

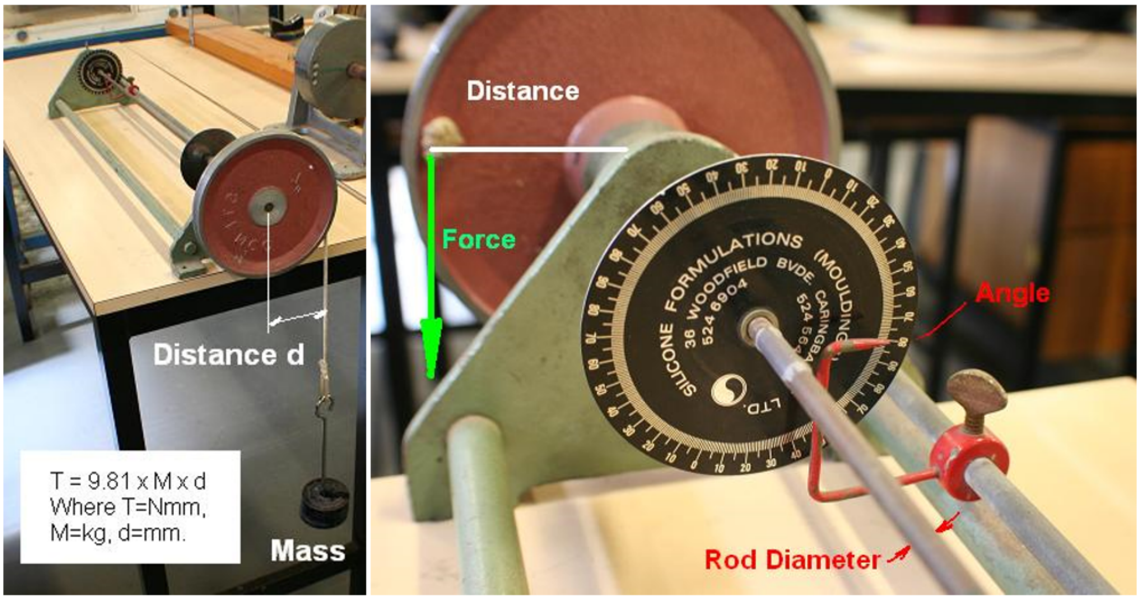

Figure 8: Torsion test apparatus

7. Using the values of G obtained in question-5 plot normalised histograms of G for all the 5 experiments. Also plot the smoothened probability density function trends over the histogram plot.

8. Find statistical quantities μ ,σ of G for each experiment and plot Gaussian probability density functions for G using the above obtained quantities and compare with the corresponding smoothened plots in question-7

9. From literature find the graph of torsion vs angle of twist and compare it with the plots obtained in the experiment. Upon careful examination it was concluded that the results from one experiment violated some of the basic assumptions of the experiment. Which experiment is that? and why ? (hint: Shear modulus is a modulus of elasticity)

10. Find the best estimate of G from all the experiments.(express your final answer inclusive of the associated error in terms of $\pm 1\sigma$). Compare your result with the published value of the G for aluminium 6061.

11. What are the short comings of the current experiment? Suggest better experiments to measure shear modulus of a material .

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

9 Determining the material properties of a thin walled cylinder using strain gauges

A thin walled cylinder made of an unknown metal is given. An experiment was designed to find the Young's modulus E and Poisson ratio ν of the cylinder material. The cylinder is known to have uniform material thickness $'t'$. The experimental apparatus consist of two strain gauges attached perpendicular to each other on the surface of the cylinder. The strain gauges are connected to a strain indicator device which can directly give the strain values. There are also provisions to vary and measure the internal pressure in the cylinder. The experimental procedure is as follows. Once apparatus has been setup and verified to be working, the pressure (p) inside the cylinder is set to a fixed value and noted down.The readings from the strain indicator can be fluctuating owing to random errors, so the readings are sampled for 2s with a sample frequency of 20 readings per second automatically by the device. After noting down the strain readings for both the strain gauges, the pressure inside the cylinder is increased by ΔP this is repeated several times. The same experiment was repeated by 5 different groups using the same instruments. The values of measured pressure P and geometric parameters are known exactly unless specified. You can also neglect any the end effects of the cylinder.

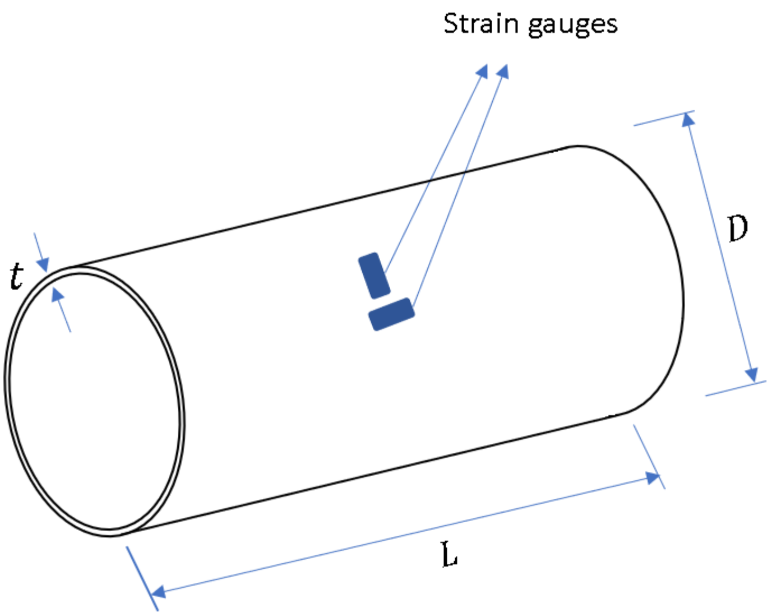

Figure 9: Thin Cylinder diagram

Use the following parameters wherever necessary:

- Length of the cylinder, L = 1m
- Diameter of the cylindrical tank, D = 0.15m
- Thickness of the walls,t = 0.0001m

The data set `P9_ThinCylinder.mat` contains,

- The gauge pressure inside the cylinder in pascal (each variable is an array of size 10 as there are 10 pressure values)

  $\Longrightarrow$ `"P_exp1","P_exp2","P_exp3","P_exp4","P_exp5"`

- Corresponding hoop and longitudinal strain readings (each variable is a 10×40 matrix, as the total number of readings taken over 2s is 40)

- Hoop strain readings
  $\Longrightarrow$ `"eps_h_exp1","eps_h_exp2","eps_h_exp3","eps_h_exp4","eps_h_exp5"`

- Longitudinal strain readings
  $\Longrightarrow$ `"eps_l_exp1","eps_l_exp2","eps_l_exp3","eps_l_exp4","eps_l_exp5"`

1. Explain the theory behind the experiment and derive the governing equations

2. What are the possible sources of errors in the experiment and how to minimize them?

3. Using the dataset `P9_ThinCylinder.mat` plot normalised histograms of longitudinal and hoop strain readings for $P = 33333.33Pa$ for all the 5 experiments. Also plot the smoothened probability density function trends over the corresponding histogram plot.

4. Does the smoothened probability density curve obtained in the previous question resemble a normal probability density function? Determine the statistical quantities μ and σ for each histogram and plot Gaussian probability density functions using these values. Compare it with corresponding smoothened plots obtained in question-3.

5. Derive analytical relations relating the pressure inside the cylinder to longitudinal strain (ϵ_l) and hoop strain (ϵ_h). Also Obtain the relationship for errors in E and ν as a function of errors in pressure, strain and cylinder geometric parameters, if all these quantities have errors associated with them. (Hint:Refer to "function of errors/propagation of errors" in your textbooks.)

6. Find the mean value of ϵ_l and ϵ_h for each reading and make plots of ϵ_l vs P and ϵ_h vs P for each experiment.Fit the best linear curve over the data points for each case. What does the slope of each curve represent?

7. Find the best estimate for E and ν from all the experimental results(express your final answer inclusive of the associated error in terms of $\pm 1\sigma$). Can you tell which metal the cylinder is made of ?

8. What are the short comings of the current experiment? Suggest better experiments to measure Young's modulus and Poisson ratio of a material.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

10 Determining the Young's Modulus of material using strain gauges

An experiment was setup as shown in figure 10 to measure the Young's modulus (E) of a material. The setup consists of a cantilever beam held rigidly at point A, a concentrated load is applied at the other end, at point B, by hanging weights of known values. A resistance strain gauge is place at a distance x_o from the fixed end. The resistance strain gauge is connected to a strain indicator device which can directly give the strain value. But it was found that the strain indicator device was faulty and that the readings had a periodically fluctuating component of error with a frequency of 50Hz (same frequency as the mains power supply) along with random errors. After the experimental apparatus has been setup and verified to be working correctly the first set of weights is loaded at one end and the readings from the strain indicator device are recorded. The process is repeated to get a final set of readings. In order to mitigate the issue of fluctuating error in the strain readings, the strain readings are recorded for 2s with a sampling frequency of 500Hz for each set of weights (1000 strain readings per load) The value of L - length of beam, the cross-sectional dimensions a and b are known exactly. (neglect any effect due to gravity)

Use the following parameters wherever necessary:

- Length of beam ,L = 1m
- Height of cross section, a = 0.03m
- Width of cross section, b = 0.03m

The data set `P10\_CantileverBeam.mat` contains,

- Applied loads (each variable is an array of size 6, as there are 6 sets of weights)

  $\Longrightarrow$ `"P"`

- Corresponding strain readings (each variable is a 6×1000 matrix, as the total number of readings taken 2s is 1000)

  $\Longrightarrow$ `"eps_0"`

1. Explain the theory behind the experiment and derive the governing equations
2. What are the possible sources of errors in the experiment and how to minimize them?
3. Discuss a method and use it to remove periodically fluctuating components of error from strain readings (ϵ) given in the data set `P10_CantileverBeam.mat`
4. Plot normalized histograms of the resultant strain readings from question-4 for all non-zero values of P. Also plot the smoothened probability density function trends over the corresponding histogram.
5. Does the smoothened probability density curve obtained in the previous question resemble a normal probability density function? Determine the statistical quantities μ and σ for each histogram and plot Gaussian probability density functions using these values. Compare it with corresponding smoothened plots obtained in question-4.
6. Find the best estimate of ϵ for each value of P
7. Using the values obtained in question-6 make a plot of P Vs ϵ. Obtain the best linear fit for above plot. What does the slope of this linear fit represent?

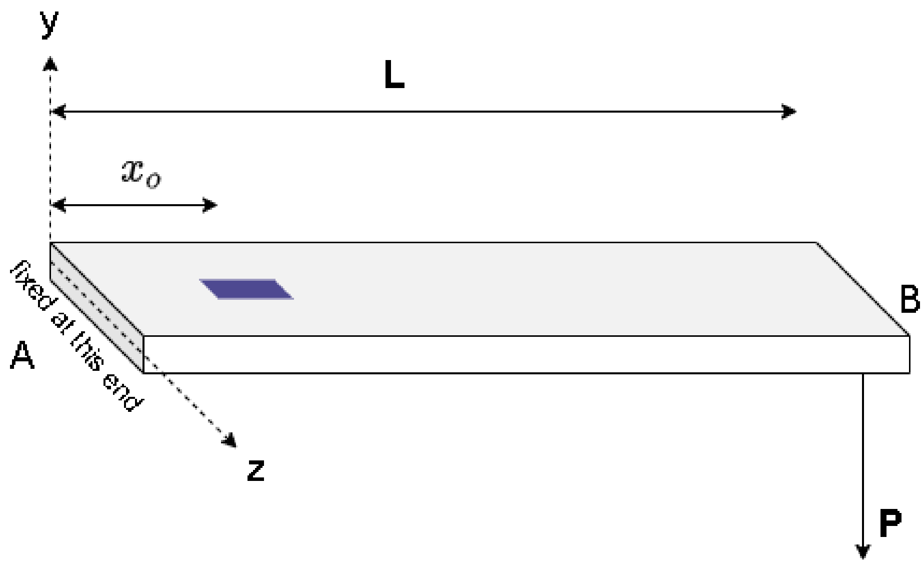

Figure 10: Experimental setup

8. What is the best estimate for E of the material(express your final answer inclusive of the associated error in terms of $\pm 1\sigma$). Compare the results with values from literature. Can you tell which metal the beam is made of ?

9. What are the short comings of the current experiment? Suggest a better experiment to measure Young's modulus of a material.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

11 Forced vortex flow

The experiment is carried out to study the relationship between the surface shape of a forced vortex flow and the angular velocity (ω) of the rotating fluid . The height (h) of the free surface from the bottom of the container at different radial distances 'r' was measured using a set of electrical probes. Due to some unknown source of vibration in the setup the free surface of the fluid was found to have a wavy motion. This induces a periodically fluctuating error of frequency 30Hz in the measurement of free surface height along with the random errors. In order to remove the fluctuating component of error, readings from each probe was recorded for 2s with a sample frequency of 500Hz (each probe takes 1000 readings per ω value). The experiment is repeated for 5 sets of ω values The value of r, R, ω etc are known exactly unless specified.
The values of parameters are:

- Radius of the Cylinder, R = 0.05m
- Acceleration due to gravity, g = 9.8 m/s^2

The data set `P11_ForcedVortex.mat` contains,

- The angular velocity of the cylinder in rad/s (each variable is an array of size 5, as the experiment is performed for 5 ω values)

  $\implies$ `"w"`

- Corresponding values of free surface height in meters (each variable is a 20×1000 matrix, as there are 20 probes and the total number of taken by each probe over 2s is 1000)

  $\implies$ `"h_w1","h_w2","h_w3","h_w4","h_w5"`

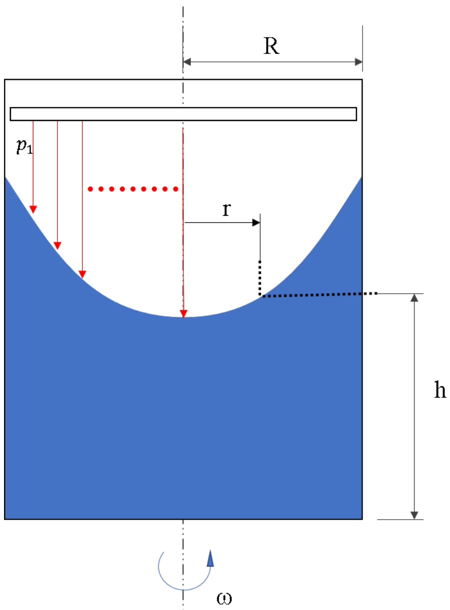

Figure 11: Forced vortex apparatus

1. Explain the theory behind the experiment
2. What are the possible sources of errors in the experiment and how to minimize them?

   Discuss a method and use it to remove periodically fluctuating components of error from strain readings given in the data set `P11_ForcedVortex.mat`.

3. Plot normalised histograms of resultant value of h for $r = 0.0m$ for all the 5 ω values.Also plot the smoothened probability density function trends over the corresponding histograms.

4. Does the smoothened probability density curve obtained in the previous question resemble a normal probability density function? Determine the statistical quantities μ and σ for each histogram and plot Gaussian probability density functions using these values. Compare it with corresponding smoothened plots obtained in question-4.

5. Derive an expression relating h,r and ω. Also Obtain the relationship for errors in h as a function of errors in all the quantities in the above expression. (Hint:Refer to "function of errors/propagation of errors" in your textbooks.)

6. For each ω make a plot of r vs h. Obtain a best fit curve. What is the mathematical form of this curve? Compare it with the theoretically derived curve in question-6.

7. What are the disadvantages of the current experimental setup? Suggest some improvements.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.

12 Measurement of drag on a circular cylinder using Wake Survey method

In this experiment the total drag force acting on a cylinder in a fluid flow is measured using the Wake Survey method. A diagram showing the basic principle of the method is shown in figure 12. A cylinder is placed in a wind tunnel with uniform free stream velocity U_∞. It is assumed that U_∞ is known without any error unless specified. A set of 20 pitot tubes that gives the difference between stagnation and static pressure values are placed behind the cylinder at a distance of $15d$. For each set of measurements, U_∞ is brought upto a certain value and once it stabilises, the pitot tube readings are recorded. But it was known that the pitot tube readings had a periodically fluctuating error of 50hz, along with random errors owing to some fault in the instrument, in order to improve the results the readings of the pitot tubes were recorded for 2s with a sampling frequency of 500Hz Hz (each probe takes 1000 readings for each U_∞).The experiment is performed for 4 different values of U_∞. All the distances specified are known without any error unless specified.

The values of parameters are:

- Diameter of the Cylinder, d = 0.1m
- Density of air at 15^oC, $\rho_{air} = 1.225\ kg/m^3$
- Kinematic viscosity of air at $15^oC = 1.470 * 10^{-5}\ m^2/s$

The data set `P12_WakeSurveyMethod.mat` contains,

- The free stream velocities U_∞ (m/s) (each variable is an array of size 4, as the experiment is performed for 4 U_∞ values)

  $\Longrightarrow$ `U_inf`

- Pitot tube readings for each U_∞ in pascal (each variable is a 20×1000 matrix, as there are 20 pitot probes and the total number of readings taken by each probe over 2s is 1000)

  $\Longrightarrow$ `"del_p1","del_p2","del_p3","del_p4"`

1. Explain the theory behind the experiment
2. What are the possible sources of errors in the experiment and how to minimize them?

   Discuss a method and use it to remove periodically fluctuating components of error from strain readings given in the data set `P12_WakeSurveyMethod.mat`.
3. Plot histograms of the resultant values from question-3 for the pitot tube placed at y=0 for all U_∞ cases. Also plot the smoothened probability density function trends over the corresponding histograms.
4. Does the smoothened probability density curve obtained in the previous question resemble a normal probability density function? Determine the statistical quantities μ and σ for each histogram and also plot a Gaussian probability density function corresponding to each.
5. Derive an expression for drag force per unit length 'D' on the cyinder as function of momentum loss of the fluid. Also Obtain the relationship for errors in D as a function of errors in all the quantities in the above expression. (Hint:Refer to "function of errors/propagation of errors" in your textbooks.)

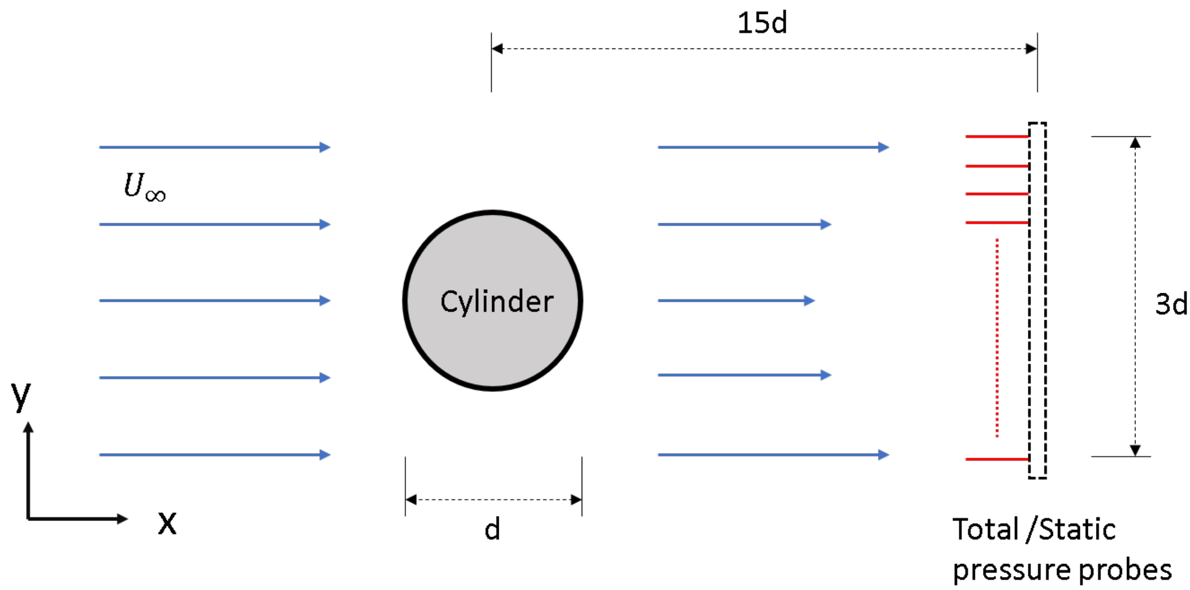

Figure 12: Forced vortex apparatus

6. Obtain the best estimate of drag force on the cylinder for each U_∞ using the expression obtained in question-6. (neglect any pressure drop effects)
7. Find the best estimate of drag coefficients C_D and make plot of C_D Vs Re. What trend do you expect? Obtain the best curve and compare it with theoretical predictions.(hint: find out the relation between C_D and Re from literature)
8. What are the short comings of the current experiment? Suggest better experiments to measure the drag force experienced by a cylinder in a fluid flow.

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.