Experimental determination of Lift coefficient

(AS2100: Basic Aerospace Engineering Lab)

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

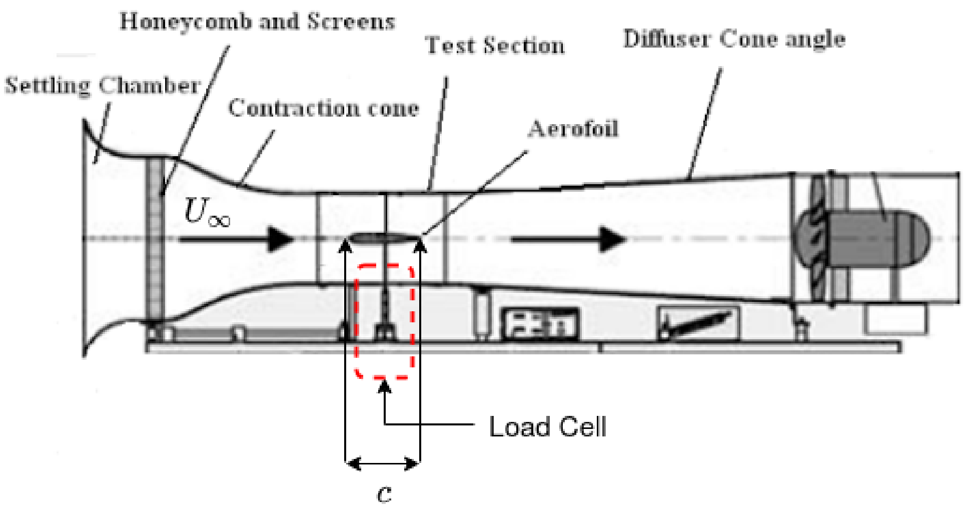

Figure 5: Schematics of the experimental setup.

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($y = a_1x + a_0$) 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.