Aerodynamics and Fluid Mechanics 3 laboratories: Guide to data analysis

You took two laboratories at the Acre Road wind tunnel site. The first was an experiment on the flow over a bluff body (circular cylinder), and data for surface pressure and wake velocity and pressure (wake scan) were recorded at three test Reynolds numbers. The second laboratory was an aerodynamics experiment to determine the lift and drag characteristics of a finite wing model, and to investigate the trailing vortex and aerofoil section wake. Raw experimental data are on the moodle page.

Data analysis from measurements or computations is a very important task, there is often much to be discovered. A simple presentation of experimental data from this laboratory is not sufficient, and these notes are intended to help you understand what additional information can be gained from a set of experimental data. While you are being prompted to do this, treat this exercise as training for data analysis.

The laboratories presented to you are an important component of an aeronautics curriculum. It is unusual for students to be able to gain access to such large wind tunnel facilities for these types of experiments at this level in a curriculum, it is probably unique to this university. Experimental procedures have been mostly automated, this is the case with most wind tunnel experiments, the automation process requires a lot of preparation, and it is what you would tend to see in practice for all but the most basic facilities. The wind tunnels are high value pieces of equipment, laboratories such as these are not easy to run, but it is hoped that the experiments run have complemented the lecture courses in an appropriate way.

1 Flow over a circular cylinder

You need to reduce the raw experimental data into a meaningful form, and analyse data to produce drag and lift coefficients. Drag coefficient from the surface pressure does not include the contribution to drag due to surface friction, while an integration of the wake data will provide the actual body drag coefficient. Refer to the support notes for the basic theory for the data analysis, these are the notes "cpcyl_theory" and "drag_momentum_theory_analysis". The experiment relied on pressure measurements, and how these pressures are treated depends upon the reference pressure for measurement. *Take care of units of pressure, you must ensure all your calculated pressure are in consistent units before you calculate non-dimensional values.*

1.1 Surface pressure

You need to convert surface pressure into pressure coefficient C_p before proceeding with any additional data analysis. The azimuthal position θ of the pressure tapping can be calculated from the tapping number; there are 48 pressure tappings, and tappings 1 and 48 are symmetrically either side of the leading edge at θ=0. The spreadsheets have “SurfacePressure” in their filename. Table 1 summarises the data in the spreadsheets for the surface pressure measurement:

Table 1: Data measured in circular cylinder laboratory: surface pressure measurement

Parameter	column	reference pressure p_{ref}	physical parameter	recorded units	conversion
tapping number	A	N/A	azimuthal position	number	48 round azimuth
surface pressure	B	p_∞	$p - p_\infty$	V	7.07V/psi
dynamic pressure	C	p_∞	q	V	0.0255V/mmH_2O

Data check: C_p values for tappings 1 and 48 should be almost 1. See figure 1 for sample result.

Note that the spreadsheet also contains data for wind tunnel temperature and barometric pressure. Use these to get the air density and viscosity for the Reynolds number calculation.

Do *at least* the following:

1. Plot all Cp data, compare with result for potential flow.
2. Where are the separation points around the cylinder surface for each Reynolds number?
3. Calculate lift and drag coefficients from surface Cp. What is the drag coefficient for the potential flow (use this to benchmark the accuracy of your calculation)?

1.2 Wake survey

The purpose of the wake survey is to see the extent of the wake and to allow calculation of the drag. Drag requires wake velocity for the momentum integration and wake pressure for the pressure integration. You need to calculate the non-dimensional wake velocity u/U in its direct form along with the downstream wake pressure coefficient C_{p_d}, or the modified wake velocity u'/U. The spreadsheets have “WakeSurvey” in their filename. Table 2 summarises the data in the spreadsheets for the wake measurement:

Data check: the non-dimensional wake velocity at the edge of the wake should be very close to 1, and the value in the middle of the wake significantly less than 1. See figure 2 for sample result for wake velocity profile, this plot shows the modified wake velocity u' also.

Do *at least* the following:

Table 2: Data measured in circular cylinder laboratory: wake survey

Parameter	column	p_{ref}	physical parameter	recorded units	conversion
sample number	A	N/A	N/A	N/A	N/A
position	B	N/A	y ordinate	mm	none
wake dynamic pressure	C	p_{wake}	q_{wake}	V	$0.01969\text{V/mmH}_2\text{O}$
wake static pressure	D	$p_{ambient}$	$p_{wake} - p_{ambient}$	V	$0.0198\text{V/mmH}_2\text{O}$
dynamic pressure	E	p_∞	$q = \frac{1}{2}\rho U^2$	V	$0.0255\text{V/mmH}_2\text{O}$
wind tunnel static pressure	F	$p_{ambient}$	$p_\infty - p_{ambient}$	V	$0.0198\text{V/mmH}_2\text{O}$

1. Plot the wake velocity and pressure profile for each case. Estimate the wake width.
2. Calculate the drag coefficient for each case. Use the most appropriate method, you may need to adjust or scale your data to account for errors.
3. How do the drag coefficients compare to the values for the pressure drag?
4. How do the drag coefficients change with Reynolds number?

2 Delta wing experiment

For the wing force measurements you need to calculate wing lift coefficient C_L and wing drag coefficient C_D. You should then be able to find a curve fit to $C_D = C_{D_o} + kC_L^2$. You can also look at the pitching moment and evaluate the centre of pressure and aerodynamic centre as a function of angle of attack. A wake survey using a 7 hole pressure probe was done also, this allows you to be able to determine characteristics of the trailed vortex wake, and a wake of the wing section at a given spanwise ordinate. Look at the laboratory notes to familiarise yourself with the axis systems of the various instruments used.

Delta wing aerodynamic load data are in the file 'DeltaWing2020.csv' and the probe traverse data are in the file 'alpha15fine_0.dat' (readable using matlab). Note that the loads data contains the zero aerodynamic load tares (wind tunnel off) and the loads with wind on.

2.1 Wing area and mean aerodynamic chord

The wing planform details are described in the supporting laboratory notes, the measurements you took are sufficient to be able to calculate the wing area.

2.2 Wing lift and drag

Raw balance data are given in the file, the column headings are self-explanatory, but note that L,D,S are in balance axes and not wind tunnel axes. You need to do an axis transformation to calculate wing lift L and drag D from load cell F_x and F_z forces and angle of attack. Calculate the lift, drag and pitching moment coefficients. Use the laboratory support notes for a description of the balance and wind tunnel axis systems.

Do *at least* the following:

1. Evaluate wing area, mean aerodynamic chord. What is the test Reynolds number?
2. Calculate and plot wing lift and drag coefficients in a suitable way.
3. Represent drag polar in the form $C_D = C_{D_o} + kC_L^2$; what are C_{D_o} and k?
4. This is a Delta wing, is there a stall angle?
5. How do the lift and drag behaviour change with angle of attack, is there any specific change of behaviour?
6. Find the centre of pressure on the model, how does it change with angle of attack?
7. Evaulate the aerodynamic centre position and moment at aerodynamic centre.
8. Wind tunnel measured forces are subject to wind tunnel constraint effects. How do you correct the wind tunnel lift and drag measurements?

2.3 Wake measurement

You have to perform a data reduction process to be able to get meaningful data from the 7 hole probe. This involves using the probe calibration data, and subsequent calculation of probe pressure parameters and the finally calculation of the velocity components and pressure values. This process requires an understanding of the theory of operation of the probe and a lengthy probe calibration process. A matlab script 'process_7hole_testdata_3rdyrlab_v2' takes care of all of this, and will give you the flow (u, v, w) velocity components, probe position in traverse axes, and wake pressure and wake stagnation pressure. You need to provide this script with the absolute filename of the file containing the raw laboratory data. YOU MUST MAKE SURE YOU UNDERSTAND THE RELATIONSHIP BETWEEN WIND TUNNEL AND PROBE AXES.

You need to obtain sensible plots of the vortex wake. The matlab 'quiver' function is the quickest way to get a view of the measured data, e.g. 'quiver(-Ypos,Xpos,w,v)' will provide a sensible looking plot of the measured velocity field. Be very careful how the data are presented, however. You will have seen sketches of idealised vortex systems in the lectures where the only velocity is the azimuthal component u_θ; the wind tunnel provides you with velocity in cartesian axis system components, with w the component in the horizontal direction, v in the vertical direction. This is a 3-dimensional vortex created by a separated shear layer from a swept leading edge, the wing surface is always in close proximity to the vortex, it is very different to any of the vortex flows presented in the lectures. You have one set of wake data recorded with the model at 15 degrees angle of attack with the probe around 10cm downstream of the trailing edge, the data file is 'alpha15fine_0.dat'.

A sample plot of the Delta wing flow streamwise u velocity component is shown in figure 3. Do *at least* the following:

1. Plot the in-plane (w, v) velocity for the course grid measurement. What does it show you? What is the circulation in the measured field of view?
2. Evaluate vorticity in the flow field, plot this out. What does it reveal, where is the main vortex system? The probe is downstream of the trailing edge, but the leading edge separation shear layer is still evident; where is it?
3. Evaluate circulation from the vorticity.
4. Plot the pressure in the wake flow, what does it show?
5. Plot stagnation pressure. The data analysis from the probe does give negative stagnation pressure which is non-physical, but this is just relative. What does the stagnation pressure profile indicate?
6. Plot the streamwise velocity u in the flow. This is a vortex from a Delta wing, it is a 3-D vortex, whereas in lectures only 2-D vortices have been discussed. What does the u component in the flow show?

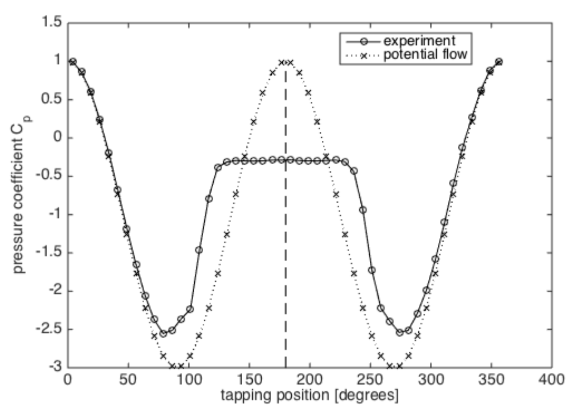

Figure 1: Sample surface pressure distribution for circular cylinder

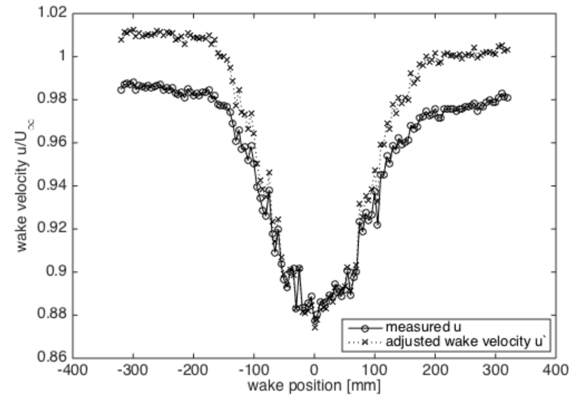

Figure 2: Sample wake velocity profile for circular cylinder. Measured and adjusted values are plotted.

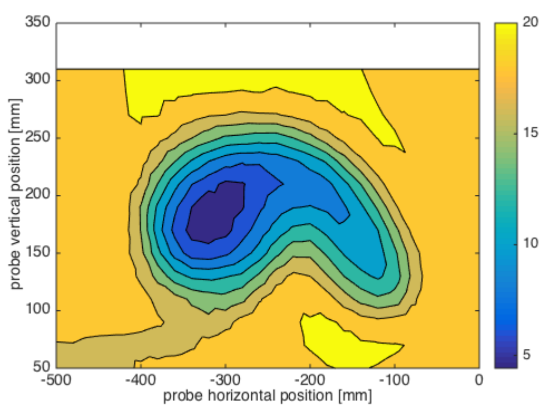

Figure 3: Delta wing u-component (streamwise) velocity component, contours are in ms^{-1}