ENG2037 Lab Handout

# Laboratory Objectives

By the end of this laboratory session you will:

* Learn how the pressure distribution around an aerofoil changes will angle of attack
* Understand the relationship between various aerodynamic parameters, i.e. lift and drag, with angle of attack

# Experimental Setup

## Wind tunnel

Wind tunnels are a useful tool for studying air flow around bodies. The wind tunnel you will be using for this lab is a Tecquipment AF1450 subsonic wind tunnel with a square clear acrylic (450mm×450mm×1000mm) working section, as shown in Figure 1 and Figure 2. Air is drawn in through the working section by a variable speed fan located at the discharge end of the tunnel. A honeycomb type flow straightener and contraction in the inlet effuser ensures well developed air flow through the working section.

A large white machine on wheels

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Figure : AF1450 subsonic wind tunnel

A diagram of a machine

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Figure : AF1450 general layout

## Pressure Tapped Aerofoil

A NACA0012 section aerofoil (AF1450b) test model that spans the full width of the working section is provided, see Figure 3. The aerofoil has a chord of 150 mm and a span of 445 mm. There are 20 pressure tappings, ten on the upper side and 10 on the lower side, see Table 1 for the exact locations and Figure 4 for a technical drawing – not that we have mounted the aerofoil ‘upside down’ compared to Figure 4, so the ‘upper’ and ‘lower’ surfaces are swapped in the experiment, which is reflected in Table 1. The tappings are staggered, so that those on the underside are at different positions to those on the upper side. They connect inside the aerofoil to a set of small diameter metal tubes that emerge from the end of the aerofoil and connect to labelled flexible pipes. The aerofoil is mounted in the horizontal plane through the side of the working section, and the angle of attack is adjustable by rotating the mounting rod. The effective pressure distribution on the upper (suction side) and lower (pressure side) of the aerofoil can be obtained by inclining the aerofoil at different angles of attack.

Wall static pressures are also measured at two locations, one upstream of the model and another downstream of the model.

A close-up of a machine

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Figure : The main parts of the aerofoil model

Table : Tapping positions

|  |  |  |  |
| --- | --- | --- | --- |
| Lower Surface Tapping | Distance From Leading Edge (mm) | Upper Surface Tapping | Distance From Leading Edge (mm) |
| 1 | 0.76 | 2 | 1.52 |
| 3 | 3.81 | 4 | 7.62 |
| 5 | 11.43 | 6 | 15.24 |
| 7 | 19.05 | 8 | 22.86 |
| 9 | 38.00 | 10 | 41.15 |
| 11 | 62.0 | 12 | 59.44 |
| 13 | 80.77 | 14 | 77.73 |
| 15 | 101.35 | 16 | 96.02 |
| 17 | 121.92 | 18 | 114.30 |
| 19 | 137.16 | 20 | 129.54 |

A diagram of a surface with a point and a point

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Figure : Aerofoil tappings drawing

### Theory

The density of the air in the wind tunnel can be found from the perfect gas law

where is the density, is the ambient pressure, is the ambient temperature, and is the specific gas constant for air.

The aerofoil fully spans the working section of the wind tunnel, so air cannot flow around the ‘wing tips’, as in a real aerofoil. The air flows only over the upper and lower surfaces; this is therefore a two-dimensional flow. Flow around the wing tips adds a third dimension but creates additional drag and other complications.

The wing area, , is simply the plan view of the aerofoil and is therefore the product of the span and the chord.

It is fairly obvious that a larger wing may give more actual or basic lift than a smaller wing of the same design, so to compare wings of different size, a non-dimensional value called the lift coefficient, , is used

where is the measured wind tunnel air velocity.

Aerofoil lift relies on relative differences in pressure between the atmospheric value around the aircraft and the local pressures around the aerofoil created as the aerofoil passes through the air (or as the air passes around the aerofoil in the wind tunnel reference frame). As the atmospheric pressure changes with weather and altitude, it is better to allow for these absolute values when comparing aerofoils. As with the coefficient of lift, a non-dimensional form of pressure called the pressure coefficient, , is used. It is the relative pressure difference over a function of the air properties.

Where the subscript represents the freestream pressure, density, and velocity away from the aerofoil. In terms of the experiment, becomes the pressure at the tapping, , and becomes the wall static pressure, . The density and velocity are those passing through the working section, so the expression can be rewritten

Textbooks show that the coefficient of lift can be found from the area under a chart of the coefficient of pressure against the distance along the aerofoil. The distance along the aerofoil must be non-dimensionalised by dividing the position, , by the chord length, , giving a fraction of and values between 0 and 1. Figure 5 and Figure 6 show two examples of these plots. The lift coefficient is calculated simply by the difference between areas A and B

The term is required because the difference in the areas simply gives the normal force, but lift force is the component of this force in the vertical direction. Since the lift coefficient is related to the difference between the two areas (B-A), it should be obvious that for a symmetrical aerofoil at 0 degrees angle of attack, both areas are negative and equal, giving a lift coefficient of 0, see Figure 5. If the upper surface curve is greater and negative, while the lower surface gives positive pressure coefficients, there is a net positive lift coefficient, as shown in Figure 6.

A graph of a function

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Figure : Finding lift coefficient, symmetrical aerofoil at 0 degrees angle of attack

A diagram of a graph

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Figure : Finding lift coefficient, symmetrical aerofoil at non-zero angle of attack

## Experiment: Pressure Distribution Around an Aerofoil at Different Angles of Attack

The pressure acting on the surface of an aerofoil in a steady air stream (as in steady flight) is not uniform across the chord. Taking positive to refer to pressure greater than the static pressure of the surrounding air, there is commonly a region of positive pressure at the nose of the aerofoil, and another at the tail. The pressure around the rest of the aerofoil is typically negative, with the minimum pressure on the upper surface occurring somewhere between the point of maximum chord and the nose.

The pressure distribution also varies depending on the angle of attack of the aerofoil. The point of minimum pressure tends to shift towards the nose, and the region of positive pressure at the tail increases in area and magnitude. This is illustrated in the diagrams in Figure 7. Arrows pointing towards the aerofoil surface indicate pressures greater than the overall static pressure. Arrows pointing away from the aerofoil indicate pressures lower than static.

A diagram of a plane

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Figure : Example of aerofoil pressure distribution at 0 degrees (left) and 12 degrees (right) angle of attack

### Procedure

1. Record the ambient temperature and pressure from the thermometer and barometer in the lab.
2. Open the VDAS software on the PC connected to the wind tunnel’s data acquisition system (DAQ). Update the temperature to that measured in step 1.
3. Hit the ‘play’ button on the menu bar to start real time communication. The pressures and wind tunnel velocity will now be updated in real time on the screen.
4. Click Data -> Display Data Table to open a table, which will be empty for now.
5. Start the wind tunnel at a velocity of 20 m/s or higher. The model will initially be at an angle of attack of -6 degrees.
6. Hit F4 on the VDAS software to take the first reading. The surface static pressures at the locations in Table 1 will be recorded in Pressures 1-20 of the AFA6 Multi-Channel Pressure System section of the table (location 1 in Table 1 corresponds to channel 1, location 2 to channel 2, and so on). The upstream wall static pressure, which is also required to convert to pressure coefficient, is recorded in channel 31. Note that these are gauge pressures in units of kPa.
7. Repeat the experiment at different angles of attack, e.g. -6 degrees to 16 degrees in increments of 2 degrees, hitting F4 in the VDAS software to add a reading at each AoA.
8. Export the results to an Excel spreadsheet using File -> Export to Excel XLSX. Save the file. The demonstrator will upload it to Moodle, where it can be downloaded to begin the data analysis.

### Presentation and Analysis of Results

For each angle of attack, use the pressures with the air density and velocity to find the coefficient of pressure at each tapping. Create a chart of against and find the area under the curves to calculate the coefficient of lift. When calculating , remember that the pressures from VDAS are gauge pressures in kPa and care must be taken to get the correct units otherwise the magnitude of will be wrong. It is recommended that the results are entered into a suitable program and used to find the area under the curves using a trapezoidal method. It is not necessary to present your raw data in the report. Figure 8 shows an example of what typical results look like. Note that is real experimental data and the results will be slightly different for each lab group, so this plot is for guidance only.

Once the lift coefficient for each angle of attack has been calculated, plot against angle of attack, . Noting that it is a symmetrical aerofoil and should produce zero lift at zero AoA, you may have to shift the data if the ‘zero’ AoA in the experiment is slightly off. Identify the stall angle for this aerofoil and include this result in the report. State this conclusion and explain it in the report. Calculate the Reynolds number for this experiment and state it in the report.

Three sets of lift curve slops from previous NACA0012 experiments[[1]](#footnote-1) are provided on Moodle; choose the correct set of data based on the Reynolds number and compare it to your experimental data by plotting it on the same set of axes. Discuss how good the agreement is and potential reasons for the disagreement.

For three angles of attack, 0 degrees, pre-stall, and post-stall, draw the expected streamlines around the aerofoil and discuss them.

The drag force cannot be obtained from this experiment, but explain what happens to the drag coefficient of an aerofoil with varying incidence, making reference to the stall angle.

A graph of a graph showing the surface and surface

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Figure : Example of typical results at 8 degrees angle of attack and 20 m/s

# Report

Write up the experiment as a formal lab report, including all the important sections:

1. Abstract that tells the reader what is in the report, the key methods used, and what the main findings are.
2. Introduction that explains the motivation, giving engineering context and societal importance and impact, and introduces the theory required.
3. Methodology that explains the laboratory process and introduces the equations required to analyse the data.
4. Results section showing and discussing the plots produced.
5. Conclusions.
6. References.
7. An Appendix may be required to show most of the pressure coefficient against non-dimensional tapping location plots, as there will be many of these. Some key plots can be shown in the results, but the rest should be in this Appendix.

Information on writing a lab report is included on Moodle. The report is a **maximum of 8 sides of A4** (not including the Appendix). *Assessment is based on report presentation as well as technical content.* Use the data generated to draw your own conclusions. *Make sure to use figure captions and numbers, referring to figures by their numbers in the text.* **Plot titles are not required** (Excel puts them in by default, just delete them!), captions should be descriptive and tell readers what the figure shows.

**The report is due 2 weeks after your lab session and should be uploaded to Moodle. Standard University penalties will be applied for late submission.**

1. B.D. Mattos, J. Meneghini, B.R. Padilha and A.A. de Paula. "The Airfoil Thickness Effect on Wavy Leading Edge Performance," AIAA 2016-1306. *54th AIAA Aerospace Sciences Meeting*, January 2016. [↑](#footnote-ref-1)