SCHOOL OF MECHANICAL & AERONAUTICAL ENGINEERING (SP)
DIPLOMA IN AERONAUTICAL ENGINEERING
DIPLOMA IN AEROSPACE ELECTRONICS

EXPERIMENT 3: The Coefficient of Pressure & The Centre of Pressure

For the following modules:

ME2501 Fundamentals of Flight
ME0501 Aeronautical Engineering Science

Objective

The objectives of this experiment are:

1. Learn how to calculate the coefficient of pressure (C_P) and plot its distribution over the upper and lower surfaces of an aerofoil.
2. Find out how the C_P distribution changes at different angles of attack and how it affects the centre of pressure.

Background

The wind tunnel is an instrument which is used to test the effects of aerodynamics. It provides a controlled environment for tests to be carried out in a confined space. In real life, aircraft wings are often assumed to be flying through a mass of stationary air to produce the necessary lift. Testing under such conditions would have required a large airspace under dynamic environmental factors. By applying the principles of relative velocities, a stationary aircraft wing can be tested for similar aerodynamic effect in a wind tunnel. Therefore, wind tunnel test presents a situation where aircraft is stationary while the wind comes to it. Movement of wind could be enabled by using a fan to either push or suck the air to flow over a model. In this case, as the wind comes to a station model, this wind is moving relative to a stationary aircraft model and is called the 'relative wind'. In fact, application of Bernoulli's equation is via this moving airstream over a stationary model. However, its physical end effects compared to an aircraft flying in stationary air will be exactly the same.

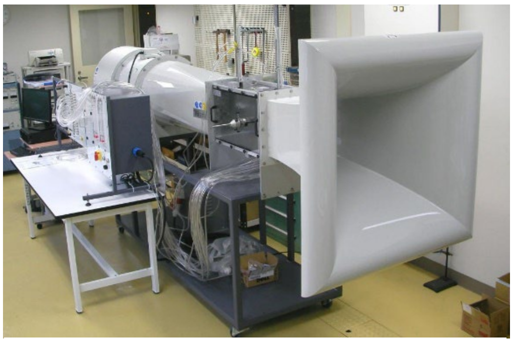


Figure 1: The AF100 subsonic wind tunnel

Figure 2: NACA 0012 aerofoil section

When air flows over a wing, the local acceleration of airflow on the upper and lower surfaces creates different reduction in local static pressures, which produces a pattern of pressure distribution from the leading edge to the trailing edge. Using this pressure distribution, a person would be able to find the coefficient of pressure (C_P) distribution and the centre of pressure on the aerofoil.

NACA 0012 Aerofoil Section

In this experiment, we will be testing a specially designed NACA 0012 aerofoil section that has 20 static pressure taps along its chord on the upper and lower surfaces. The locations of the pressure taps (from the leading edge) are shown in the table below:

Upper Surface

Tap No.	1	3	5	7	9	11	13	15	17	19
x (mm)	0.76	3.81	11.43	19.05	38.00	62.00	80.77	101.35	121.92	137.16

Lower Surface

Tap No.	2	4	6	8	10	12	14	16	18	20
x (mm)	1.52	7.62	15.24	22.86	41.15	59.44	77.73	96.02	114.30	129.54

Please note that the odd numbered pressure ports are located on the aerofoil upper surface while the odd ones are on the lower surface.

NACA 0012 is a symmetrical aerofoil with same curvature on the upper and lower surfaces with respect to the chord. The chord length (c) is 150mm and the span is 300mm. It will be subjected to airflow at different angles of attack. Local pressure readings will be measured through the static pressure taps and displayed on the reader.

Coefficient of Pressure

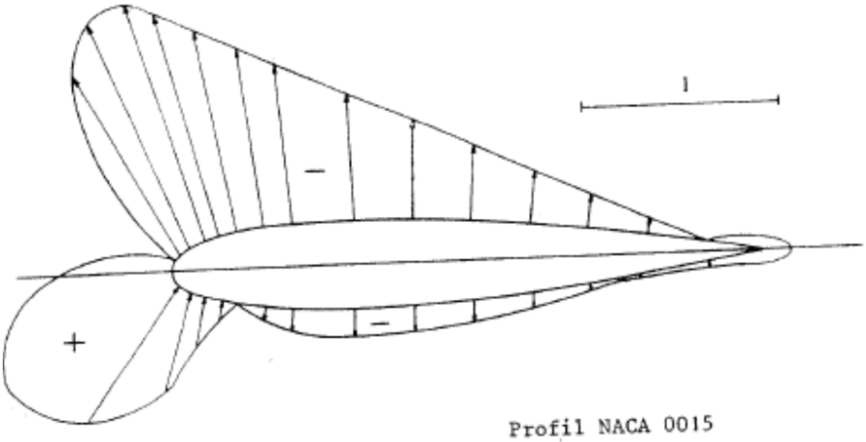
The coefficient of pressure (C_P) can be determined by the following formula:

$$C_P = \frac{P - P_\infty}{\frac{1}{2}\rho V_\infty^2}$$

Where P is the local static pressure, P_∞ is the freestream static pressure and V_∞ is the freestream air velocity.

Once the C_P values for all 20 tapping locations are found, it can be plotted against *x/c*, which is the distance from the leading edge, to show the C_P distribution. It should be noted that the plot should be inverted, such that the negative C_P on the upper aerofoil surface is drawn above the horizontal axis. (See Figure 3) on the positive y-axis. This way of plotting C_p is a convention in aerodynamics studies such that the resulting curve on the top represents the C_p plot for the upper surface while the lower curve represents the C_p for the lower surface.

Pressure Distribution Around A Profile



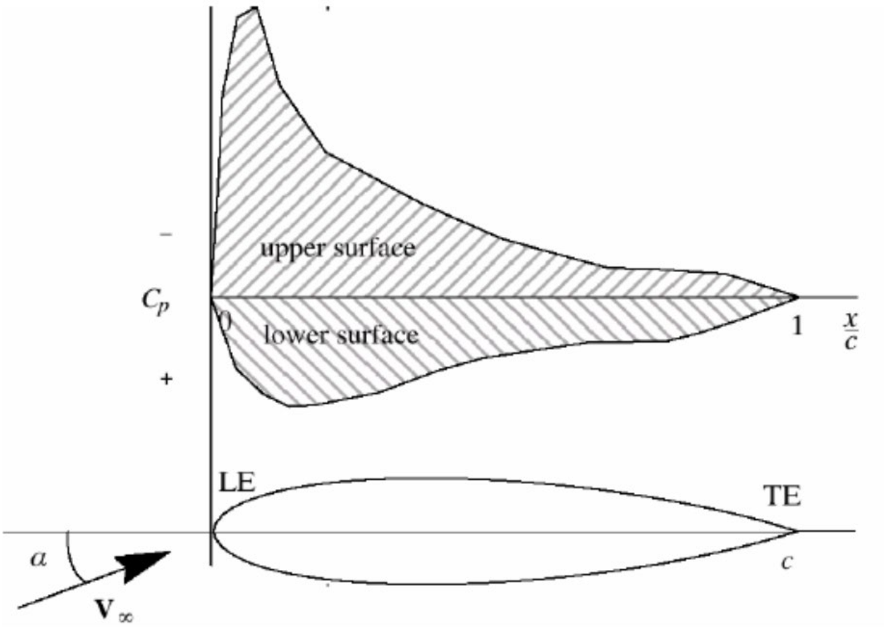


Figure 3: CP distribution for a symmetrical aerofoil

Significance of the Area Enclosed by the C_p Plots

From aerodynamic aerofoil theory, the area enclosed by the C_p plots actually represents the lift coefficient. To find the area, we can either integrate the resulting C_p equation if its function is known or we can approximate the area via numerical means by breaking up the area into many small rectangular area for summation.

In addition, the centre of this area is where the resultant pressure over the aerofoil is acting. Therefore, this point is of interest to us and known as the Centre of Pressure, CP.

One can imagine that as angle of attack (AOA) changes, the shape of this area will also change with higher AOA having more lift contribution from the front part of the aerofoil. As a result, this area will be more concentrated at the front resulting in forward shifting of the CP.

Centre of Pressure

The centre of an area is called the centroid. If we were to break up the area into a few small rectangular areas, the summation of all the moments in a dimension of the individual small areas divide by the total area which can be found by adding all the small rectangular areas, we would be able to obtain the area centre in that dimension. Therefore, the centre of pressure can be found using the following formula:

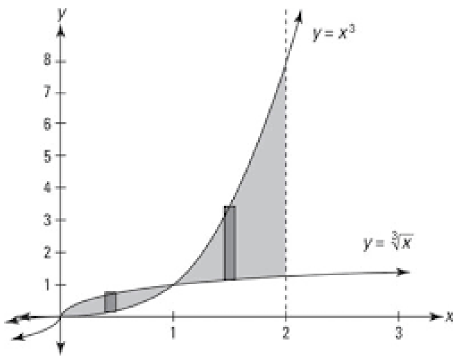
$$Location\ of\ the\ centre\ of\ pressure\ from\ the\ leading\ edge = \frac{\int x\, C_P(x)\, dx}{\int C_P(x)\, dx} \approx \frac{\sum x\ C_p(x)\ \delta x}{\sum C_P(x)\ \delta x}$$

In the above equation, in the numerator, ‘x’ is the moment arm of a small area having a width of δx and a height of C_p. Therefore, the denominator term is the total area.

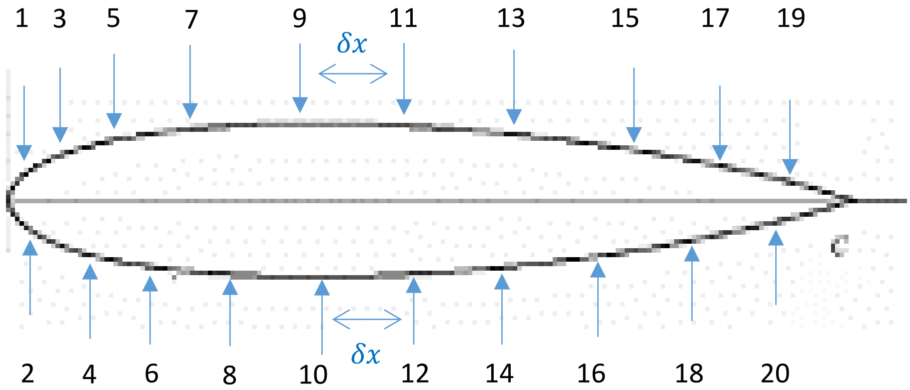
It is important to highlight that if we were to use the equation for CP as presented above, as some C_p are negative, the addition of negative value with positive value has the effect of taking out the information. Therefore, to retain all the information, it is suggested to use the absolute values in the equation such that the equation should be:

$$Location\ of\ the\ centre\ of\ pressure\ from\ the\ leading\ edge = \frac{\int x\, C_P(x)\, dx}{\int C_P(x)\, dx} \approx \frac{\sum x\ \left|C_p(x)\right|\ \delta x}{\sum \left|C_p(x)\right|\ \delta x}$$

In doing the above correction using the absolute value, we have to be careful as not all terms are to be added as if the term is not covered within the curve, it should be subtracted out instead. For example, if we were to find the area covered by the two curves in the figure below for x value from 1 to 2:



We have to find the area covered under the lower curve $y = \sqrt[3]{x}$ and subtract it from the area covered under the curve $y = x^3$.



As illustrated by the above figure, because the pressure ports are not evenly spaced with closer placement nearer to the leading edge motivated by more 'aerodynamic action' there, the width of the small rectangles are not the same.

Experiment Procedures and Data Reduction

The experiment procedure are as follows. (Refer to the section on Test Procedure in the AF102 User Guide for more information)

1. Ensure that the wind speed knob is at NIL power (turn knob in clockwise direction until it stops)

2. Turn on power to the wind tunnel

3. Adjust wind speed to about 30 m/s

   Record pressure readings (20 values) at the following angles of attack by snapping a picture of the data display panel for different test AOA of (a) 5º, (b) 10º and (c) 15^0

4. Data reduction – calculation of C_p
   (i) Use the static port at front of test section which is connected to P_{22} on the data panel

   (ii) Local pressure ports on aerofoil are recorded as $P_{1,2,\dots 20}$ on data panel

   (iii) Use the pitot-static tube located at the front of test section to obtain the dynamic pressure. The differential pressure is connected to the data panel and displayed as $Cell_1$

   (iv) Then to calculate C_p for any port, say port 10, simply compute:

$$C_{p_{10}} = \frac{P_{10} - P_{22}}{Cell_1}$$

   One needs to be careful with different data magnitudes for data shown in the data panel in this computation.

5. Plot C_P against x for the above angles of attack.

6. Determine the centre of pressure for each angle of attack and draw its location on the graphs obtained in Step 5.

7. Comment on your observations and results

Lab Report and Submission

Prepare a proper lab report with sample calculations for all the 20 C_p values for one of the tests.
The report will include three plots, one for each AOA. Calculate the three Centre of Pressure locations for the three AOA and comment on the movement of the CP locations as AOA varies.

Report is to be submitted two weeks after the conduct of the Lab.

Points to Note

As we are actually finding the area enclosed by the curves, To prevent the negative area to cloud the calculation, it is suggested to take the absolute values of the areas before doing the summation. However, for this to work properly, one must be careful about when an area and its moment is to be added or subtracted. The key to this to know when a curve criss-crosses the x-axis. For example, if the curve for upper surface is above the axis while the lower surface crosses the x-axis, then the area and moment from the lower surface that crosses the x-axis needs to be subtracted.

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Experiment Data

TEST 1

Angle of attack:	5°
Ambient density:	
Calculated windspeed:	
Average freestream static pressure (P_∞):	

Upper Surface

Tap No.	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**
x (mm)	*0.76*	*3.81*	*11.43*	*19.05*	*38.00*	*62.00*	*80.77*	*101.35*	*121.92*	*137.16*
δx	*2.29*	*5.34*	*7.62*	*13.29*	*21.48*	*21.39*	*19.68*	*20.58*	*17.91*	*20.46*
P										
C_P										
$C_P\,\delta x$										
$x\,C_P\,\delta x$										

Lower Surface

Tap No.	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
x (mm)	*1.52*	*7.62*	*15.24*	*22.86*	*41.15*	*59.44*	*77.73*	*96.02*	*114.30*	*129.54*
δx	*4.57*	*6.86*	*7.62*	*12.955*	*18.29*	*18.29*	*18.29*	*18.285*	*16.76*	*28.08*
P										
C_P										
$C_P\,\delta x$										
$x\,C_P\delta x$										

Using data from both the upper and lower surfaces, find location of Centre of Pressure, CP:

$$Location\ of\ the\ centre\ of\ pressure\ from\ the\ leading\ edge \approx \frac{\sum x\,|C_p|\delta x}{\sum |C_P|\,\delta x} \approx \_\_\_\_\_\_\_\_\_\_\_\_$$

Note: Not all small rectangular areas are to be added. Some need to be subtracted.

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TEST 2

Angle of attack:	10º
Ambient density:	
Calculated windspeed:	
Average freestream static pressure (P_∞):	

Upper Surface

Tap No.	1	3	5	7	9	11	13	15	17	19
x (mm)	*0.76*	*3.81*	*11.43*	*19.05*	*38.00*	*62.00*	*80.77*	*101.35*	*121.92*	*137.16*
δx	*2.29*	*5.34*	*7.62*	*13.29*	*21.48*	*21.39*	*19.68*	*20.58*	*17.91*	*20.46*
P										
C_P										
$C_P\ \delta x$										
$x\ C_P\ \delta x$										

Lower Surface

Tap No.	2	4	6	8	10	12	14	16	18	20
x (mm)	*1.52*	*7.62*	*15.24*	*22.86*	*41.15*	*59.44*	*77.73*	*96.02*	*114.30*	*129.54*
δx	*4.57*	*6.86*	*7.62*	*12.955*	*18.29*	*18.29*	*18.29*	*18.285*	*16.76*	*28.08*
P										
C_P										
$C_P\ \delta x$										
$x\ C_P \delta x$										

Using data from both the upper and lower surfaces, find location of Centre of Pressure, CP:

$$Location\ of\ the\ centre\ of\ pressure\ from\ the\ leading\ edge \approx \frac{\sum x\,|C_p|\delta x}{\sum |C_P|\ \delta x} \approx \underline{\qquad\qquad}$$

Note: Not all small rectangular areas are to be added. Some need to be subtracted.

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TEST 3

Angle of attack:	15º
Ambient density:	
Calculated windspeed:	
Average freestream static pressure (P_∞):	

Upper Surface

Tap No.	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**
x (mm)	*0.76*	*3.81*	*11.43*	*19.05*	*38.00*	*62.00*	*80.77*	*101.35*	*121.92*	*137.16*
δx	*2.29*	*5.34*	*7.62*	*13.29*	*21.48*	*21.39*	*19.68*	*20.58*	*17.91*	*20.46*
P										
C_P										
$C_P\ \delta x$										
$x\ C_P\ \delta x$										

Lower Surface

Tap No.	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
x (mm)	*1.52*	*7.62*	*15.24*	*22.86*	*41.15*	*59.44*	*77.73*	*96.02*	*114.30*	*129.54*
δx	*4.57*	*6.86*	*7.62*	*12.955*	*18.29*	*18.29*	*18.29*	*18.285*	*16.76*	*28.08*
P										
C_P										
$C_P\ \delta x$										
$x\ C_P \delta x$										

Using data from both the upper and lower surfaces, find location of Centre of Pressure, CP:

$$Location\ of\ the\ centre\ of\ pressure\ from\ the\ leading\ edge \approx \frac{\sum x\,|C_p|\delta x}{\sum|C_P|\ \delta x} \approx \underline{\hspace{3cm}}$$

Note: Not all small rectangular areas are to be added. Some need to be subtracted.

Note: Experiment Report must be submitted not later than 2 weeks from the date of the conduct of the lab. No Marks will be given for late submissions. All reports must be on A4 paper and double-sided. This report requires a formal report. No Marks will be given for late submissions.