# AAE 333L

# Lab 3: Pressure in Aerodynamics

**Post-Lab Assignment**

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**Lab Section/Team Color: Gold**

**I. Lab Objectives (5 points)**

In 500 words or less, discuss the objectives of this lab and how well they were met and to what extent they were not met. If applicable, discuss reasons why particular objectives were not met during your performance of the lab and how these challenges might be addressed in the future.

The first objective of this lab was to observe and experiment all the different types of pressure of air: stagnation, static, and dynamic pressure. We were able to meet this objective by measuring the pressure in 3 different ways using 3 different types of instruments throughout the experiment. One instrument we used was the digital manometer which gave us the difference between the stagnation and static pressure, which is the dynamic pressure to calibrate the wind tunnel. The second was an inclined U-tube manometer which allowed us to measure the height difference and calculate the pressure difference. The last method was using the pressure scanner to collectively figure out the pressure from data analysis. While using these various instruments, I believe we were able to deepen our understanding of what absolute, gauge, and differential pressures are and when to use each of them in our calculations. To understand those three types of pressure values was another objective of this experiment.

For the second part of the experiment we had to use a U-tube manometer to compute the pressure distribution around a cylinder in the wind tunnel. At first, we were somewhat puzzled of how to measure the height difference for the instrument, but once we received some advice from the TA, we were able to figure out and understand how it worked. This satisfies the third objective of understanding how to use an U-tube manometer. Also, in the very first part of the experiment we practiced the method of determining the velocity of the wind tunnel in different frequencies by measuring the dynamic pressure. During this process we were able to obtain accurate values for each frequencies of the wind tunnel, and therefore, the fourth objective of determining the velocity of an incompressible stream of air was satisfied.

For the second part of the lab, we measured the pressure distribution on a cylinder by changing the angle of the cylinder facing the air stream. We changed the angle of the cylinder to obtain the pressure difference for each angle by measuring the height difference in the inclined manometer. From the angle we are able to compute the theoretical pressure coefficients and from the pressure difference we are able to calculate the experimental pressure coefficients and by analyzing these results we were able to meet the fifth objective of understanding the pressure distribution on a cylinder in air flow.

The last objective of this lab involved the conversion of pressure units. In the lab, we were required to understand the differences and applications of absolute pressure, gauge pressure, and differential pressure as well as units such as psi, kPa, etc. The former three pressure types are often factors of calculation errors and are crucial to understand which to use at what situations. For units like psi and Pa we should be able to convert from imperial to metric system and vise versa.

**II. Data Presentation and Analysis (20 points)**

1. (5 points) Pressure Coefficient for a Circular Cylinder

Plot your experimental values of the pressure coefficient, , vs. angle. On the same plot, show the calculated values for , for ideal, frictionless, potential flow (equation in the Background document). Briefly discuss the differences between the two plots.



**Figure 1**

>> Analysis

There is a substantial deviation between the two plots at the second half of the x-value interval from around θ = 1.2. As the experimental data points approach the absolute minimum of the theoretical curve the tangential lines for each point starts to become horizontal, or in other words, the derivative of the curve becomes zero. This is due to the fact that in the experiment the air flow cannot maintain the conditions ideal, frictionless, and potential flow in order to satisfy the theoretical curve.

1. (15 points) Flow with Area Change
   1. (5 points) Plot the pressure vs. location down the nozzle for all three tests (three different plenum pressures). Briefly discuss and explain the trends you observe.

A close up of a map

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**Figure 2**

>>Analysis

For the pressures 16, and 18 psi the plot follows a somewhat same trend in which they proceed horizontally near 15 psi overall. But at the throat of the tunnel the pressure is lower for both of them, but gradually increases.

* 1. (5 points) For the first two cases (*p0* = 16 and 18 psi), use Bernoulli’s equation to calculate the velocity at each pressure tap location. Plot the velocity vs. location down the nozzle and discuss. Do the results make sense based on conservation of mass for incompressible flow, i.e. constant, where flow velocity and tunnel area.

A close up of a map

Description automatically generated

**Figure 3**

>>Analysis

The velocities at the taps 2-4 with relatively small cross-sectional areas have higher velocities which is congruent with the mass conservation law. Also, at the last several taps where the cross-sectional areas are the same the velocities are constant.

A close up of a map

Description automatically generated

**Figure 4**

>>Analysis

In theory, from mass conservation law the plot for 16 and 18 psi should be a constant value. From the plot above, with the exception of the first few points the mass flow rate stays constant, whereby implies that the experiment has successfully obtained values that are consistent with the theory.

* 1. (2 points) Estimate the flow Mach number at the nozzle throat (Tap #3). Is it reasonable to use Bernoulli’s equation for this flow?

A screenshot of a cell phone

Description automatically generated

**Figure 5**

**>>**Analysis

The Mach numbers in figure 5 were calculated using Bernoulli’s equation and they meet the fact that for 16 and 18 psi the Mach number is lower than one and for 30 psi the Mach number is approximately one. Moreover, the plot agrees with the trend that as the pressure rises the Mach numbers also increases. Therefore, it is reasonable to calculate the velocities and Mach numbers using Bernoulli’s equation for cases of 16 and 18 psi.

* 1. (3 points) Discuss the pressure results for the third case with *p0* = 30 psi. Are the trends similar or different to the other two cases? Why?

For 30 psi, the Mach number exceeds one meaning that the air flow in the wind tunnel is in supersonic state. When the flow is supersonic many assumptions that could be applied to subsonic and lower flows are no longer applicable to the flow. These assumptions include incompressible flow, laminar flow, etc. Because of this, The pressure distribution as well as velocity and mass flow rate distribution deviate strongly from the other two cases 16 psi and 18 psi. For the pressure distribution the 30 psi case decreases where the other two increases, and as it goes further down the nozzle makes an unsmooth transition to a higher pressure.

**III. Error and Uncertainty (5 points)**

For the cylinder pressure measurements only, discuss the sources of error and uncertainty in your results and how large they might be. How would you suggest improving your measurements?

A close up of a map

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For the cylinder pressure distribution, from the figure above it is evident that at the last half from θ = 90° to 180° the pressure coefficients do not agree with the theoretical values. This is feasibly due to the fact that the pressure at the bottom of the cylinder was not properly measured due to change of flow due to drag and turbulence and other aerodynamical factor. Or in other words, this error might be because of the limitations of an inclined manometer. Therefore, to improve the experiment it would be better to use a different instrument to measure the pressure.

**APPENDIX**

**EXCEL SHEETS**

**<expr\_part1.xlsx>**



**<expr\_part2.xlsx>**



**<expr\_part2extra.xlsx>**



**<expr\_part3.xlsx>**



**MATLAB**

**<postlab3\_matlab.mlx>**

**POSTLAB #3 MATLAB CODE AUTHOR: TOMOKI KOIKE**

clear all; close all; clc;

% Loading the excel file

fpart1 = readmatrix("expr\_part1.xlsx");

fpart2\_1 = readmatrix("expr\_part2.xlsx");

fpart2\_2 = readmatrix('expr\_part2extra.xlsx');

fpart3 = readmatrix("expr\_part3.xlsx");

**1.**

% Assigning columns of the read file to variables

cp\_expr = fpart1(:,10); % Experimental pressure ceofficients

cp\_th = fpart1(:,11); % Theoretical pressure coefficients

theta = fpart1(:,5); % Angle values [rad]

% Plotting

figure('Renderer', 'painters', 'Position', [10 10 900 600])

plot(theta, cp\_expr, '.r', 'MarkerSize', 15)

xlabel('Angle, theta [rad]')

ylabel('Pressure Coefficient')

title({'Experimental and Theoretical Pressure Distribution on a Cylinder', ['- ' ...

'By: Tomoki Koike']})

hold on

plot(theta, cp\_th, '-b')

hold off

ylim([-3.2 1.5])

grid on

grid minor

box on

legend('Experimental Values', 'Theoretical Values', 'Location', 'southeast')

**2a.**

% Assigning columns or rows of the read files to variables

% Pressures are in gauage so should be converted to absolute pressure

avgP\_16 = (fliplr((fpart2\_1(17,3:16))))' + 14.7; % The average pressure distribution for 16 psi

avgP\_18 = (fliplr((fpart2\_1(42,3:16))))' + 14.7; % The average pressure distribution for 18 psi

avgP\_30 = (fliplr((fpart2\_1(57,3:16))))' + 14.7; % The average pressure distribution for 30 psi

tapPos = fpart2\_2(:,1); % The tap positions [in]

tapPos = tapPos(1:length(avgP\_16));

% Plotting

figure('Renderer', 'painters', 'Position', [10 10 900 600])

plot(tapPos, avgP\_16, '-b')

xlabel('Location down the nozzle [in]')

ylabel('Absolute Pressure [psi]')

title({['The Pressure vs. Location Down the Nozzle for Supersonic Wind Tunnel ' ...

'Operation'], '- By: Tomoki Koike'})

hold on

plot(tapPos, avgP\_18, '-r')

plot(tapPos, avgP\_30, '-g')

hold off

grid on

grid minor

box on

legend('16 psi', '18 psi', '30 psi', 'Location', 'southeast')

**2b.**

% Defining constants

rho = 1.225; % Density of air [kg/m^3]

g = 9.81; % Gravitational acceleration [m/s^2]

% Assigning from read file

h = fpart2\_2(:,2); % Heights from base to nozzle [in]

h = h(1:length(avgP\_16));

% Converting data from imperial to metric

avgP\_16 = avgP\_16 \* 6894.757; % psi to Pa

avgP\_18 = avgP\_18 \* 6894.757;

avgP\_30 = avgP\_30 \* 6894.757;

h = h \* 0.0254; % in to m

p16 = 16 \* 6894.757; % 16 psi to Pa

p18 = 18 \* 6894.757; % 18 psi to Pa

p30 = 30 \* 6894.757; % 30 psi to Pa

% Calculating the velocity

v16 = sqrt(2\*(p16 - avgP\_16 + rho\*g.\*h)./rho); % Velocity for Po=16psi

v18 = sqrt(2\*(p18 - avgP\_18 + rho\*g.\*h)./rho); % Velocity for Po=18psi

v30 = sqrt(2\*(p30 - avgP\_30 + rho\*g.\*h)./rho); % Velocity for Po=30psi

% Plotting

figure('Renderer', 'painters', 'Position', [10 10 900 600])

plot(tapPos, v16, '-b')

xlabel('Location down the nozzle [in]')

ylabel('Velocity [m/s]')

title({['Velocity vs. Location Down the Nozzle for the Supersonic wind ' ...

'tunnel '], '- By: Tomoki Koike'})

hold on

plot(tapPos, v18, '-r')

plot(tapPos, v30, '-g')

hold off

grid on

grid minor

box on

legend('16 psi', '18 psi', '30 psi')

% Checking with mass flow rate

A = fpart2\_2(:,3); % Assigning the area values to column vector [m^2]

A = A(1:length(avgP\_16));

mfr16 = A.\*v16; % Mass flow rate for 16psi

mfr18 = A.\*v18; % Mass flow rate for 18psi

mfr30 = A.\*v30; % Mass flow rate for 30psi

%Plotting

figure('Renderer', 'painters', 'Position', [10 10 900 600])

plot(tapPos, mfr16, '-b')

xlabel('Location Down the Nozzle [in]')

ylabel('Mass flow Rate [m^3/s]')

title({['Mass Flow Rate vs Location down the nozzle for the Supersonic wind' ...

' tunnel'], '- By: Tomoki Koike'})

hold on

plot(tapPos, mfr18, '-r')

plot(tapPos, mfr30, '-g')

hold off

grid on

grid minor

box on

legend('16 psi', '18 psi', '30 psi', 'Location', 'southeast')

**2c.**

% A vector with the base pressure

ps = [p16 p18 p30];

% A vector with mach numbers at tap 3 for corresponding base pressures

machs = [v16(3)/343 v18(3)/343 v30(3)/343];

%Plotting

figure('Renderer', 'painters', 'Position', [10 10 900 600])

plot(ps, machs, '.r', 'MarkerSize', 25)

xlabel('Base Pressures [Pa]')

ylabel('Mach Number')

title({'Mach Numbers at Tap #3 for all Pressure 16, 18, and 30 psi', ['- By:' ...

'Tomoki Koike']})

grid on

grid minor

box on

**Error Analysis**

errs = fpart1(:,12); % The column vector for error values

%Plotting

figure('Renderer', 'painters', 'Position', [10 10 900 600])

plot(theta, errs, '\*r', 'MarkerSize', 10)

xlabel('Angles [rad]')

ylabel('Errors [%]')

title({'Error of Pressure Distribution Along a Cylinder - By: Tomoki Koike'})

grid on

grid minor

box on