# AAE 333L

# Lab 4: Wakes and Drag Measurement

**Post-Lab Assignment**

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**Lab Section/Team Color: GOLD**

**I. Lab Objectives (5)**

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 experiment was to learn the structures of wakes using the wind tunnel. Not like the experiment using water as the fluid medium, it was difficult to visualize the wake created by the airflow over cylinders and streamlined bodies. However, from the data, our team was able to see how the wake changed the velocity profile behind the object in the wind tunnel from the moving probe. From the velocity distribution we can plot the velocity field and as a result visualize the wake. Therefore, it is plausible to say that this objective was satisfied through this experiment.

Using the obtained data of the velocity profile and by using the given formula, the theoretical drag value was calculated. The calculation involved the free stream velocity and the velocity distribution behind the object which is influenced by the wake. For each of the objects used to measure the velocity there were distinctive characteristics which gave different kinds of velocity distributions, and by calculating the drags for each object gave us information of how the surface and shape of an object can change the resulting drag. Practicing the calculation of the drag has allowed us to satisfy the second objective of this lab to learn the calculations of drag.

For the last objective of this experiment we were required to obtain experience in using the hot-film anemometer which was mainly used to measure the voltage for each position in the air tunnel. Based on personal research, I have learned that the hot-film anemometer is a tool to measure the instantaneous velocity in a fluid flow, and it is based on the heat transfer from the fluid velocity, temperature, and composition to the sensor on the machine. Essentially the wire forms a Wheatstone bridge which allows the anemometer to acquire a particular resistance and voltage in response to the fluids heat transfers. During the operation, we had to use the software to change the position of the probe, check to see a file is created and to properly store data, remember and the basic operations to start the hot-film anemometer and to stop it from measuring. From these procedures, we were able to learn thoroughly how to operate a hot-film anemometer to measure fluid velocity.

**II. Data Presentation and Analysis (25 points)**

1. (10 points) Velocity Deficit Behind the Cylinder

Use your experimental data to plot the velocity deficit profile behind the cylinder for all four wind tunnel speeds/Reynolds numbers. The velocity deficit, , is defined as:

where is the position along the width of the wind tunnel (i.e. the locations where the probe stopped and recorded data) and is the freestream velocity. Because the probe recorded a large number of data points at each location , calculate mean of the data for . Briefly comment on any noticeable differences between the four profiles.

First from the calibration we were able to get this polynomial (Computed using MATLAB)

* Linear model Poly9:
  + val(x) = p1\*x^9 + p2\*x^8 + p3\*x^7 + p4\*x^6 + p5\*x^5 + p6\*x^4 + p7\*x^3 + p8\*x^2 + p9\*x + p10
  + Coefficients:
    - p1 = 0.121
    - p2 = -2.253
    - p3 = 17.85
    - p4 = -78.84
    - p5 = 212.9
    - p6 = -363.9
    - p7 = 393.2
    - p8 = -259.7
    - p9 = 100.6
    - p10 = -13.2
* Standard deviation of
  + 6.703719343855487e-22

And the graph looks like the following

A close up of a map

Description automatically generated

Figure : Voltage vs Velocity Polynomial

Then by computing the velocity by fitting the voltage data to this curve, we were able to find the velocity profile for all four frequencies of the wind tunnel and the mean of the four

A close up of a map

Description automatically generated

Figure : Velocity Profiles for all Frequencies

Finally, from these profiles we calculated the velocity deficit, which is plotted as the following

A close up of a map

Description automatically generated

Figure : Velocity deficit profiles of all frequencies

ANALYSIS

By examining the plot above we can tell that for high frequencies the velocity deficit becomes radical compared to the first three low frequencies. Especially, the positions far from the origin (0) fluctuates and does not show a smooth curve. Whereas, for the low frequencies, the plot shows a relatively smooth mountain-like curve (or should say similar to a normal distribution).

However, based on the overall trend, all four graphs have the maximum velocities at the center/origin (position 0) and the velocity becomes smaller as it gets farther from that point.

1. (7 points) Drag Behind the Cylinder

For the highest wind tunnel speed (30 Hz), calculate the cylinder Reynolds number and the drag behind the cylinder using equation from the Background document. You can use the values of you calculated in Question 1. You can use the trapezoidal rule to do the numerical integration. Compare your result to the accepted empirical curve.

There are 2 two ways to calculate the velocity deficit

1. Using all the data points and calculating by using
2. Using only the maximum velocity deficit and calculating with the formula

For method #1 we already have obtained the values, so we must first obtain the values for the second method. After obtaining the theoretical values we have computed the Reynold’s number for both the theoretical and empirical velocity deficits. The plot for this is the following

A close up of a map

Description automatically generated

Figure : Reynold's number of empirical and theoretical velocity deficits at 30Hz

And then, by using MATLAB we numerically integrated the drag for each empirical and theoretical velocity deficit values. The formula for this was

Subsequently the MATLAB command trapz() was used to calculate the area below the functions

and

which at the end gives a very close numerical solution for the integral formula noted above.

The drags calculated became the following

|  |  |
| --- | --- |
|  | **DRAGS [N]** |
| **EMPIRICAL** | 41334.4162 |
| **THEORETICAL** | 36779.1092 |

ANALYSIS

By looking at the Reynold’s number graph it is evident that, for the empirical data, the velocities at the positions near -7 and -6 are not congruent with the rest and theoretical curve. Moreover, the empirical data seem to fluctuate many times which also causes the empirical drag and theoretical drag to deviate.

3) (8 points) Wakes Behind the Rough Cylinder and Airfoil

Using the same procedure as in Question 1, plot the velocity deficit profiles for the rough cylinder and the airfoil **at the highest tunnel speed (30 Hz) ONLY**. Briefly discuss how the profiles compare vs. the smooth cylinder. Are the results what you expected?

Rough Cylinder

A close up of a map

Description automatically generated

Figure : Velocity deficit distribution for rough cylinder

Streamlined Body

A close up of a map

Description automatically generated

Figure : Velocity deficit distribution for streamlined body

ANALYSIS

For the rough cylinder, unlike the smooth one the velocity deficit seems to have big humps on both sides far from the center point. Additionally, the hump themselves are barely symmetric and makes the graph radical. However, it holds true that the maximum velocity is at the center and the points in the proximity of the center point, and that at point 7 the velocity goes to zero.

On the other hand, for the streamlined body there is a sharp hump at the center that rises to the maximum velocity and the sides have a fluctuating hump. Besides this sharp center hump the trend is familiar to that of the rough cylinder.

The rough cylinder creates more wake that is believed to create the radical humps on the velocity plots. Also, because the streamlined body has a sharp leading edge the velocity deficit shows a sharp rise in velocity near the center point.

**APPENDIX**

**>>EXCEL SHEETS**



**\*\*\* All the other excel sheets are too big to include so will not be on this report**

**>>MATLAB CODE <Author: Tomoki Koike>**

## POSTLAB #4 MATLAB CODE AUTHOR: TOMOKI KOIKE

clear all

close all

clc

% Loading the data files

file1 = readmatrix('calbration.xlsx');

file2 = readmatrix('smoothCylinder.xlsx');

file3 = readmatrix('roughCylinder.xlsx');

file4 = readmatrix("streamlinedBody.xlsx");

% Setting necessary constants

rho = 1.225; % Desity of air at standard condition [kg/m^3]

visc = 1.789\*10^(-5); % Viscosity of air at standard conditions [Pa-s]

## 1.

% First we must fit the voltage vs velocity curve to a polynomial function

% Extracting columns from the first file and assigning them to variables

dynP = file1(:,2); % Dynamic pressure [kPa]

dynP = dynP\*1000; % Convert pressure to Pa [Pa]

V = file1(:,3); % Voltages [V]

% Calculating the velocities from the dynamic pressures

vel = sqrt(2\*dynP/rho);

% Now fit the curve using function

[fitresult, gof] = vel\_vs\_vol\_Fit(V, vel);

disp(fitresult);

gof\_mat = cell2mat(struct2cell(gof)); % Convert structure to matrix

% Printing out the standard deviation for this polynomial

fprintf('\nThis fitted polynomial curve has a STD of %.5e.', gof\_mat(1,1));

coeffs = coeffvalues(fitresult); % Obtaining the coefficients

% Assigning the coefficient values to variables

c9 = coeffs(1);

c8 = coeffs(2);

c7 = coeffs(3);

c6 = coeffs(4);

c5 = coeffs(5);

c4 = coeffs(6);

c3 = coeffs(7);

c2 = coeffs(8);

c1 = coeffs(9);

c0 = coeffs(10);

% Defining the polynomial system for voltage vs velocity

syms E

vel = @(E) c0 + c1\*E + c2\*E.^2 + c3\*E.^3 + c4\*E.^4 + c5\*E.^5 ...

+ c6\*E.^6 + c7\*E.^7 + c8\*E.^8 + c9\*E.^9;

% Defining the symbolic equation for Reynold's number

syms Velocity

Re = @(Velocity,d) rho.\*Velocity\*d/visc;

% Datas from the smooth cylinder data file is going to be used for this

% section

% Extracting data columns and assigning them to variables

y = file2(:,1); % The positions, y

Vsmooth15 = file2(:,2); % The votages for 15 Hz

Vsmooth20 = file2(:,4); % The voltages for 20 Hz

Vsmooth25 = file2(:,6); % The voltages for 25 Hz

Vsmooth30 = file2(:,8); % The voltages for 30 Hz

Vsmooth\_all = [Vsmooth15, Vsmooth20, Vsmooth25, Vsmooth30];

std\_smooth15 = file2(:,3); % The standard deviations for 15 Hz

std\_smooth20 = file2(:,5); % The standard deviations for 20 Hz

std\_smooth25 = file2(:,7); % The standard deviations for 25 Hz

std\_smooth15 = file2(:,9); % The standard deviations for 30 Hz

% Calculating the velocities

vel\_smooth15 = vel(Vsmooth15);

vel\_smooth20 = vel(Vsmooth20);

vel\_smooth25 = vel(Vsmooth25);

vel\_smooth30 = vel(Vsmooth30);

vel\_smooth\_mean = vel(mean(Vsmooth\_all,2)); % Mean

% Calculating the Reynold's numbers

% Re\_smooth15 = Re(vel\_smooth15,d);

% Re\_smooth20 = Re(vel\_smooth20,d);

% Re\_smooth25 = Re(vel\_smooth25,d);

% Re\_smooth30 = Re(vel\_smooth30,d);

% Re\_smooth\_mean = Re(vel\_smooth\_mean); % Mean

% Calculating the velocity deficit

vel\_smooth15\_dfc = vel\_deficit(find\_u\_inf(vel\_smooth15), vel\_smooth15);

vel\_smooth20\_dfc = vel\_deficit(find\_u\_inf(vel\_smooth20), vel\_smooth20);

vel\_smooth25\_dfc = vel\_deficit(find\_u\_inf(vel\_smooth25), vel\_smooth25);

vel\_smooth30\_dfc = vel\_deficit(find\_u\_inf(vel\_smooth30), vel\_smooth30);

vel\_smooth\_mean\_dfc = vel\_deficit(find\_u\_inf(vel\_smooth\_mean), vel\_smooth\_mean);

% Plotting

% Velocities

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

plot(y, vel\_smooth\_mean, '-', 'LineWidth', 1.8)

xlabel('Probe Position')

ylabel('Velocity [m/s]')

title({'Velocity Profile Behind Smooth Cylinder for 15Hz ~ 30Hz', [' -By:' ...

' Tomoki Koike']})

hold on

plot(y, vel\_smooth15)

plot(y, vel\_smooth20)

plot(y, vel\_smooth25)

plot(y, vel\_smooth30)

hold off

grid on

grid minor

box on

xticks([-7:7])

ylim([5 40])

legend('mean', '15Hz', '20Hz', '25Hz', '30Hz')

% Plotting velocity deficit

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

plot(y, vel\_smooth\_mean\_dfc, '-', 'LineWidth', 1.8)

xlabel('Probe Position')

ylabel('Velocity [m/s]')

title({'Velocity Deficit Profile Behind Smooth Cylinder for 15Hz ~ 30Hz', [' -By:' ...

' Tomoki Koike']})

hold on

plot(y, vel\_smooth15\_dfc)

plot(y, vel\_smooth20\_dfc)

plot(y, vel\_smooth25\_dfc)

plot(y, vel\_smooth30\_dfc)

hold off

grid on

grid minor

box on

xticks([-7:7])

legend('mean', '15Hz', '20Hz', '25Hz', '30Hz')

## 2.

% Calculating the drags using a theoretical method for 30Hz

syms ys

% constants

u1\_max = max(vel\_smooth30\_dfc); % The maximum velocity deficit

b = 7; % Range of which probe moved sideways

h = pi^2/4;

% Symbolic equation to solve for the velocity deficit distribution

u1\_n = @(ys) u1\_max\*(1 - (-ys/b).^(3/2)).^2;

u1\_p = @(ys) u1\_max\*(1 - (ys/b).^(3/2)).^2;

% Acutally calcualting the velocity deficit theoretically

y\_n = -7:0.1:0;

y\_p = 0.1:0.1:7.0;

u1\_n = u1\_n(y\_n)';

u1\_p = u1\_p(y\_p)';

u1 = [u1\_n; u1\_p];

% Now compute the Reynold's number using the velocity deficit for the

% empirical and theoretical values

Re\_emp = Re(vel\_smooth30\_dfc,0.3); % Empirical method

Re\_the = Re(u1,0.3); % Theoretical method

% Plotting the Reynold's number

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

plot(y, Re\_emp, '-b', 'LineWidth', 1)

xlabel('Postion')

ylabel('Reynold''s Number')

title({['Empirical and Theoretical Reynold''s Number ' ...

' on Smooth Cylinder at 30Hz'], ['' ...

' by Position of Probe - By: Tomoki Koike']})

hold on

plot(y, Re\_the, '-r', 'LineWidth', 1)

hold off

grid on

grid minor

box on

legend('empirical data', 'theoretical data')

% Next compute the drag using both empirical and theoretical velocity

% deficit

D\_emp = dragCal(rmmissing(vel\_smooth30\_dfc), find\_u\_inf(vel\_smooth30)); % Empirical

D\_the = dragCal(u1, find\_u\_inf(vel\_smooth30)); % Theoretical

fprintf('--------The drags computed for each methods--------');

fprintf('Empirical: %.4f N', D\_emp);

fprintf('Theoretical: %.4f N', D\_the);

## 3.

% Analyzing the rough cylinder and the streamlined body

% Rough Cylinder

Vrough30 = file3(:,8); % The voltages for 30 Hz

% Calculating the velocities

vel\_rough30 = vel(Vrough30);

% Calculating the velocity deficit

vel\_rough30\_dfc = vel\_deficit(find\_u\_inf(vel\_rough30), vel\_rough30);

% Streamlined body

Vstream30 = file4(:,8);

% Calculating the velocities

vel\_stream30 = vel(Vstream30);

% Calculating the velocity deficit

vel\_stream30\_dfc = vel\_deficit(find\_u\_inf(vel\_stream30), vel\_stream30);

% Plotting

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

plot(y, vel\_rough30\_dfc, '-', 'LineWidth', 1.8)

xlabel('Probe Position')

ylabel('Velocity [m/s]')

title({'Velocity Deficit Profile Behind Rough Cylinder for 30Hz', [' -By:' ...

' Tomoki Koike']})

grid on

grid minor

box on

xticks([-7:7])

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

plot(y, vel\_stream30\_dfc, '-', 'LineWidth', 1.8)

xlabel('Probe Position')

ylabel('Velocity [m/s]')

title({'Velocity Deficit Profile Behind Streamlined Body for 30Hz', [' -By:' ...

' Tomoki Koike']})

grid on

grid minor

box on

xticks([-7:7])

## FUNCTIONS

function U\_df = vel\_deficit(U\_inf, u)

% This function calculates the velocity deficit

U\_df = U\_inf - u;

end

function U\_inf = find\_u\_inf(u)

% This function finds the U\_inf from the positions 7 or -7

if u(1) >= u(end-1)

U\_inf = u(1);

else

U\_inf = u(end-1);

end

end

function D = dragCal(u1, u\_inf)

% constants

h = pi^2/4;

rho = 1.225;

u1\_n = u1(1:71,1);

u1\_p = u1(72:end,1);

D\_n = u1\_n.\*(u\_inf - u1\_n);

D\_p = u1\_p.\*(u\_inf - u1\_p);

D = h\*rho\*trapz(D\_n) + h\*rho\*trapz(D\_p);

end

function [fitresult, gof] = vel\_vs\_vol\_Fit(V, vel)

%VEL\_VS\_VOL\_FIT(V,VEL)

% Create a fit.

% Data for 'Voltage vs. Velocity Curve' fit:

% X Input : V

% Y Output: vel

% Output:

% fitresult : a fit object representing the fit.

% gof : structure with goodness-of fit info.

%

%% Fit: 'Voltage vs. Velocity Curve'.

[xData, yData] = prepareCurveData( V, vel );

% Set up fittype and options.

ft = fittype( 'poly9' );

% Fit model to data.

[fitresult, gof] = fit( xData, yData, ft );

% Plot fit with data.

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

figure( 'Name', 'Voltage vs. Velocity Curve' );

h = plot( fitresult, xData, yData );

title('Voltage vs Velocity Polynomial - By: Tomoki Koike')

legend( h, 'vel vs. V', 'Voltage vs. Velocity Curve', 'Location', ['' ...

'NorthEast'], 'Interpreter', 'none' );

% Label axes

xlabel( 'Voltage [V]', 'Interpreter', 'none' );

ylabel( 'Velocity [m/s]', 'Interpreter', 'none' );

grid on

grid minor

box on

end