# AAE 333L

# Lab 5: Wakes and Drag Measurement II

**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 understand form and skin friction drag. In our lectures, we have learned that drag consists of two types: pressure drag (form drag) and skin friction drag. As can be told from the term, skin friction drag is caused by the friction that occurs on the surface of the object. It has a direction that is tangential to the object surface. Whereas, form drags acts perpendicular to the surface because the source is the pressure and the pressure always acts perpendicular to the object. We have experimented several objects with different geometries and measured the drags. From the geometry of the object, we were able to tell whether form drag or skin friction drag was greater of the overall drag. For analysis we were also required to use the equations to derive the theoretical values of each drag and we were able to deepen our understanding of the drags through mathematical interpretations. This implies that we have attained a sufficient understanding for the two types of drags.

Measurements using objects with various shapes and geometries were done to analyze how the differences would affect the drag and the drag coefficients. For example, the form drag is greater compared to the skin friction drag for the cylinder object. However, the skin friction drag becomes greater for a streamlined body such as an airfoil. A much more evident comparison similar to the cylinder and the airfoil might have been the horizontal plate and the vertical plate. Through these analyses we successfully fulfilled the second objective.

For each object we obtain a specific drag, and from the dimensions of the object and the known values (velocity, air density, and viscosity) we can compute the Reynold’s number. The next objective of this lab requires us to compare the two values and find out how they are related. The Reynolds number is proportional to the dimension of the object as well as the velocity of the airflow, and the drag is proportional to the square of velocity. From this relation we can make a rough estimate of how the two values influence each other in a positively proportional behavior. Furthermore, we can look closely observe the relation from data analysis.

The fourth objective is to get used to the software to measure the lift and drag of for each object. Throughout the experiment all the members of our lab team worked together to gather data smoothly. Everyone had a chance to monitor the software and were able to understand the basic operations. Thus, the fourth objective was satisfied.

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

1. Drag Coefficient vs. Reynolds Number (10 points)

Use the drag measurements and geometry/measurements to calculate the drag coefficient vs. Reynolds number for each model. Show all Cd vs. Re data on a single plot.



Figure : Lift Calibration Results

Linear model Poly1:

fitresult\_L(x) = p1\*x + p2

Coefficients (with 95% confidence bounds):

p1 = -0.9958 (-1.048, -0.9438)

p2 = -0.01259 (-0.3073, 0.2822)



Figure : Drag Calibration Results

Linear model Poly1:

fitresult\_D(x) = p1\*x + p2

Coefficients (with 95% confidence bounds):

p1 = 0.5317 (0.5034, 0.5601)

p2 = 0.008532 (-0.291, 0.308)



Figure : Horizontal Plate Results



Figure : Vertical Plate Results



Figure : Small Smooth Cylinder Results



Figure : Large Smooth Cylinder Results



Figure : Rough Cylinder Results



Figure : Airfoil Leading Edge Results



Figure : Airfoil Trailing Edge Results



Figure : All Models

1. Discussion of Results (15 points)
2. (8 points) Briefly compare your results with the drag coefficients presented in Figure 3 in the Lab 5 Background document. If there are significant differences, can you explain why?

Figure 3 in the LAB 5 Background document has a higher drag coefficient than what we have plotted from our data. For our smooth cylinder the drag coefficient ranges from approx. 0.35 to 0.5 which is less than half of that is presented in the background document. Possible explanations for this large difference are that the stand changes the skin friction and form drag in some way that reduces the amount of drag exerted on the cylinder or that the measuring tool had includes some glitches in calibration and overall measurement that results in erroneous data collections. Or perhaps there are some errors in my calculation that I have overlooked throughout the computations.

1. (7 points) For each test model, briefly discuss the results and include an explanation about which type of drag (form or skin friction) would most likely be dominant.
2. Horizontal Plate:

The drag coefficients were relatively small compared to the other models, and they ranged from 0.019 to 0.032. This seems too small. But the trend of how the drag coefficient increases is positively proportional to the Reynolds number is correct. For this model the skin friction drag is larger than the form drag.

1. Vertical Plate:

The drag coefficients for this much larger than the horizontal plate and the form drag is dominant for this model since the plate is facing perpendicular to the airflow.

1. Small Smooth Cylinder

For the small smooth cylinder the results were smaller than the large smooth cylinder which is obvious from the size. The range was 0.17 to 0.28. For this since the Cylinder has a very smaller diameter the form drag is also small compared to the skin friction drag. That is, the two do not have that much of a difference.

1. Large Smooth Cylinder

For this model the range was 0.35 to 0.5. The form drag is bigger for this model because it is a blunt object.

1. Rough Cylinder

The rough Cylinder had close results to the large smooth cylinder. However, the large difference is that the rough surface creates a turbulent flow in the vicinity of the surface which increases the amount of skin friction drag. Therefore, compared to the smooth cylinder a rough cylinder has a larger fraction of skin fraction drag than form drag.

1. Airfoil (Leading Edge)

The airfoil with the leading edge facing the flow, has a very low drag coefficient because it is engineered to have a streamlined body which in result reduces the overall drag. Namely, the reduction of form drag is substantial. Thus, there is more skin friction drag on the body than the form drag.

1. Airfoil (Trailing Edge)

For this model the result has an inverse trend of the leading edge results, and also the drag coefficients show to be a negative values. This is true because the geometry of the drag is the direct opposite of the leading edge when the trailing edge is facing the flow. For this model the skin friction drag is larger than the form drag.

APPENDIX

## POSTLAB #5 MATLAB CODE AUTHOR: TOMOKI KOIKE

clear all

close all

clc

% Loading the data files

file1 = readmatrix('vel\_calibration.xlsx');

file2 = readmatrix('lift\_drag\_calibration.xlsx');

file3 = rmmissing(readmatrix('plates\_data.xlsx'));

file4 = rmmissing(readmatrix("cylinder\_data.xlsx"));

file5 = rmmissing(readmatrix("airfoil\_data.xlsx"));

file6 = readmatrix("dimensions.xlsx");

file6(isnan(file6)) = 0; % Replacing NaN with 0

% 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]

% From file1 get the calibrated dynamic pressures and velocities

% Dynamic pressures [Pa]

q\_10to30 = file1(:,2)\*1000;

% Velocities

vel\_10to30 = file1(:,4);

% From file 6 obtain the dimensions for each object to calculate the

% Reynolds number

c\_horzPlate = file6(1,4); % Horizontal plate

c\_vertPlate = file6(2,5); % Vertical plate

c\_smoothCydSmall = file6(3,3); % Smooth cylinder small

c\_smoothCydBig = file6(4,3); % Smooth Cylinder Big

c\_roughCyd = file6(5,3); % Rough cyllinder

c\_airfoil = file6(6,3); % Airfoil

% Finding the Reynolds number for each object

syms U c

Re = @(U, c) rho.\*U\*c/visc;

% Horizontal Plate

Re\_horzPlate\_10to30 = Re(vel\_10to30, c\_horzPlate);

% Vertical Plate

Re\_vertPlate\_10to30 = Re(vel\_10to30, c\_vertPlate);

% Smooth cylinder small

Re\_smoothCydSmall\_10to30 = Re(vel\_10to30, c\_smoothCydSmall);

% Smooth cylinder Big

Re\_smoothCydBig\_10to30 = Re(vel\_10to30, c\_smoothCydBig);

% Rough Cylinder

Re\_roughCyd\_10to30 = Re(vel\_10to30, c\_roughCyd);

% Airfoil

Re\_airfoil\_10to30 = Re(vel\_10to30, c\_airfoil);

% Finding the scale factor from the lift and drag calibration

% Lift

actual\_L = file2(:,1);

measured\_L = file2(:,2);

% Drag

actual\_D = file2(:,3);

measured\_D = file2(:,4);

% Fitting the calibration data to get scale factor

% Lift

[fitresult\_L, gof\_L] = dataFit(measured\_L, actual\_L, 'lift');

disp(fitresult\_L);

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

% Printing out the standard deviation for this polynomial

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

coeffs\_L = coeffvalues(fitresult\_L); % Obtaining the coefficients

a\_L = coeffs\_L(1);

b\_L = coeffs\_L(2);

% Drag

[fitresult\_D, gof\_D] = dataFit(measured\_D, actual\_D, 'drag');

disp(fitresult\_D);

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

% Printing out the standard deviation for this polynomial

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

coeffs\_D = coeffvalues(fitresult\_D); % Obtaining the coefficients

a\_D = coeffs\_D(1);

b\_D = coeffs\_D(2);

% Defining a equation expression for lift and drag scaling

% Lift

syms lift

scale\_lift = @(lift) a\_L\*lift + b\_L;

% Drag

syms drag

scale\_drag = @(drag) a\_D\*drag + b\_D;

% Calculating each drag coeeficients

% Horizontal Plate

standDrag = scale\_drag(lb2N(file3(1:5,4))); % Drag for the stand part

Cd\_horzPlate\_10to30 = calDragCoeff(scale\_drag(lb2N(file3(6:10,4))-standDrag), ...

q\_10to30, c\_horzPlate);

% Vertical Plate

Cd\_vertPlate\_10to30 = calDragCoeff(scale\_drag(lb2N(file3(11:15,4))-standDrag), ...

q\_10to30, c\_vertPlate);

% Smooth Cylinder small

Cd\_smoothCydSmall\_10to30 = calDragCoeff(scale\_drag(lb2N(file4(1:5,4))), q\_10to30, ...

c\_smoothCydSmall);

% Smooth Cylinder Big

standDrag = scale\_drag(lb2N(file4(6:10,4))); % Drag for the stand part

Cd\_smoothCydBig\_10to30 = calDragCoeff(scale\_drag(lb2N(file4(11:15,4))-standDrag),...

q\_10to30, c\_smoothCydBig);

% Rough cylinder

Cd\_roughCyd\_10to30 = calDragCoeff(scale\_drag(lb2N(file4(16:20,4))-standDrag),...

q\_10to30, c\_roughCyd);

% Airfoil leading edge

standDrag = scale\_drag(lb2N(file5(1:5,4))); % Drag for the stand part

Cd\_airfoil\_LE = calDragCoeff(scale\_drag(lb2N(file5(6:10,4))-standDrag),...

q\_10to30, c\_airfoil);

% Airfoil trailing edge

Cd\_airfoil\_TE = calDragCoeff(lb2N(scale\_drag(file5(11:15, 4))-standDrag),...

q\_10to30, c\_airfoil);

% Plotting

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

plot(Re\_horzPlate\_10to30, Cd\_horzPlate\_10to30, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Horizontal Plate',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_vertPlate\_10to30, Cd\_vertPlate\_10to30, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Vertical Plate',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_smoothCydSmall\_10to30, Cd\_smoothCydSmall\_10to30, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Small Smooth Cylinder',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_smoothCydBig\_10to30, Cd\_smoothCydBig\_10to30, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Big Smooth Cylinder',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_roughCyd\_10to30, Cd\_roughCyd\_10to30, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Rough Cylinder',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_airfoil\_10to30, Cd\_airfoil\_LE, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Leading Edge of Airfoil',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_airfoil\_10to30, Cd\_airfoil\_TE, '\*', 'MarkerSize', 10)

title({'Reynolds Number vs Drag Coefficient for Trailing edge of Airfoil',['- By:' ...

'Tomoki Koike']})

xlabel('Re')

ylabel('C\_d')

grid on

grid minor

box on

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

plot(Re\_horzPlate\_10to30, Cd\_horzPlate\_10to30, '.', 'MarkerSize', 10)

title('All C\_d vd Re Plot - By: Tomoki Koike')

xlabel('Re')

ylabel('C\_d')

hold on

plot(Re\_vertPlate\_10to30, Cd\_vertPlate\_10to30, '.', 'MarkerSize', 10)

plot(Re\_smoothCydSmall\_10to30, Cd\_smoothCydSmall\_10to30, '.', 'MarkerSize', 10)

plot(Re\_smoothCydBig\_10to30, Cd\_smoothCydBig\_10to30, '.', 'MarkerSize', 10)

plot(Re\_roughCyd\_10to30, Cd\_roughCyd\_10to30, '.', 'MarkerSize', 10)

plot(Re\_airfoil\_10to30, Cd\_airfoil\_LE, '.', 'MarkerSize', 10)

plot(Re\_airfoil\_10to30, Cd\_airfoil\_TE, '.', 'MarkerSize', 10)

hold off

grid on

grid minor

box on

legend('Horizontal Plate', 'Vertical Plate', 'S Smooth Cylinder', 'L Smooth Cylinder', ...

'Rough Cylinder', 'LE Airfoil', 'TE Airfoil')

### FUNCTIONS

function [fitresult, gof] = dataFit(measured, actual, type)

%DATAFIT(MEASURED,ACTUAL)

% Create a fit.

%

% Data for 'Lift\_calibrate' fit:

% X Input : measured\_L

% Y Output: actual\_L

% Output:

% fitresult : a fit object representing the fit.

% gof : structure with goodness-of fit info.

%

% See also FIT, CFIT, SFIT.

%% Fit: 'Lift\_calibrate'.

[xData, yData] = prepareCurveData( measured, actual);

% Set up fittype and options.

ft = fittype( 'poly1' );

% Fit model to data.

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

% Plot fit with data.

figure( 'Name', 'Lift\_calibrate' );

h = plot( fitresult, xData, yData );

if type == 'lift'

title('Calibration of Lift - By: Tomoki Koike')

else

title('Calibration of Drag - By: Tomoki Koike')

end

legend( h, 'Actual vs. Measured', 'Lift\_calibrate', 'Location', 'NorthEast', 'Interpreter', 'none' );

% Label axes

xlabel( 'measured', 'Interpreter', 'none' );

ylabel( 'actual', 'Interpreter', 'none' );

grid on

end

function Cd = calDragCoeff(D, dynP, l)

% Function to compute the drag coefficient

Cd = D./dynP/l;

end

function F = lb2N(f)

% Function to convert pounds to Newtons

F = f ./ 0.22480894244318;

end