# AAE 333L

# Lab 1: Flow Visualization, Boundary Layers and Wakes

**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 viscosity, boundary layers, and boundary layer separation, which are the basic concepts in fluid mechanics. This objective was sought to be observed by examining the water flow over various cylinders with different diameters. In the experiment, the objective was fairly met in that our team was able to observe a boundary layer and its separation clearly using the cylinder with the largest diameter submerged inside the water tunnel and exposed to the highest water flow speed (60Hz). Inside the boundary layer we were able to see how the velocity profile changed within the layer while being influenced by the effects of viscosity.

With the cylinder inside the water tunnel we were able to confirm Karman vortices shedding behind the circular cylinders. Following the lab instruction, our team counted the number of shedding vortices and we were able to identify that the Karman vortex shedding frequency became larger when the diameter of the cylinder became smaller. Beside the cylinder’s dimensions, the frequency of the water tunnel had a direct correlation with the Karman vortex shedding frequency. The correlation was that the two frequencies seemed to be linearly proportional. During this experiment there was a complication of counting the number of vortices. Though the hydrogen bubbles did aid clarity to examine the vortices, the vortices itself seemed to be disrupted by other factors inside the tunnel and showcased irregular behaviors such as collisions and merges of vortices. These made the counting difficult to do.

The third objective of this experiment was to quantify the boundary layer growth on a flat plate inside the water tunnel. For this objective we measured the thin boundary layer for 3 locations from the leading edge. For each point we measured the boundary layer thickness above and below the flat plate. From this measurement we were able to observe the characteristic of the boundary layer becoming thicker as it approached the trailing edge. However, when conducting these measurements, it was very difficult to see the borders of the boundary layers due to the hydrogen bubbles. Because the hydrogen bubbles went up the sink due to buoyancy force the measurement of the top boundary layer became larger than the bottom one. This did not disrupt the observation entirely but may have added a considerable amount of errors to our measurements. Moreover, the flat plate could have not been set inside the water tunnel completely horizontal, that is the plate was intersecting with the flow with a very small angle. This may have also affected our measurements. Therefore, our team was able to meet the third objective of this experiment but were not able to collect the most elaborate and precise data due to some complications.

**II. Data Presentation and Analysis (15 points)**

1. >>(10 points) Plot the accepted empirical Reynolds - Strouhal number curve, using the two relations. Connect them with a smooth curve. On the same plot, show the Strouhal numbers calculated using your experimental data. Use symbols (no connecting line!) for experimental data. Remember to label the axes and make the font sizes, line thicknesses, symbols, etc. sufficiently large so that the plot can be read easily.

A close up of a map

Description automatically generated

1. >>(5 points) In 250 words or less, discuss how well the experimental measurements compare with the empirical values of Strouhal number.

Observing the graph above we can say that our data propagation does follow the trend of the fitted curve for relatively low Reynold’s numbers. Whereas, for high Reynold’s number the data points tend to deviate from the curve substantially. With high Reynold’s number the calculated Strouhal numbers seem to be located in a higher position than the fitted curve.

Another observation we can make is that when you connect the point with the highest Reynold’s number and lowest Reynold’s number the data points create a somewhat linear propagation. This analysis is not cohesive with the curve’s trend.

I have created my original curve that is fitted into the data points. I have used Matlab’s “Curve Fitting” App. This curve is superimposed on to the plot given above.

A close up of a map

Description automatically generated

The fitted curve has a function of

General model Power1: f(x) = a\*x^b

Coefficients (with 95% confidence bounds):

1. a = 0.1305 (0.1077, 0.1533)
2. b = 0.07431 (0.04625, 0.1024)

Goodness of fit:

1. SSE: 0.0005503
2. R-square: 0.783
3. Adjusted R-square: 0.7613
4. RMSE: 0.007418

By doing this operation we can again observe the close trend of the data points and empirical curve by Roshko. If we rule out the last two points with the highest Reynold’s number as an outlier we may get a much more identical fitted curve.

**III. Error and Uncertainty (10 points)**

1. (6 points) Discuss the sources of error and uncertainty in your results and how large they might be. How repeatable were your measurements?

The possible sources of errors were mainly due to the measurements by our eyes. For example, in the first part of the experiment where we calibrated the velocity of the water flow for each water tunnel frequency from 30-60 Hz we had to use our own eyes to time the movements of the pulse flowing through the tunnel. This creates a lag between the actual time and the experimental time. This goes the same with the second part of the experiment where we counted the number of the Karman Vortices. As discussed in the previous sections there were times where the vortices behaved erratically and merged together or took an ambiguous shape making it hard to consider as a vortex or not. To aid our data collection, we did record videos and had several members count the number of vortices at the same time. This did add objectivity to our data but were not perfect.

1. (4 points) What would you change to get better data next time?

Possible solutions to this error are to use a video editing tool and examine the pulse and vortex movements much more deliberately. In retrospect, I believe our adjustment of the voltage for each water tunnel frequency was insufficient, regarding the fact that we were crunching on time. Thus, if we had calibrated the voltage better so that the bubbles shaped the pulses and vortices much more clearly, we could have gotten more precise data. However, it would have still been difficult to count the numbers for the smallest diameter cylinder due to its high shedding frequency.

**APPENDIX**

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Fig1: Excel Data Sheet of Experiment Part1



Fig2: Excel Data Sheet of Experiment Part2



Fig3: Excel Data Sheet of Experiment Part4

### AAE333 Lab1 Matlab Codes (Author: Tomoki Koike)

**<lab1\_matlab.mlx>**

% Reading the excel files into matlab

file1 = readmatrix('datasheet\_part1.xlsx');

file2 = readmatrix('datasheet\_part2.xlsx');

file3 = readmatrix('datasheet\_part4.xlsx');

% Setting variables

rho = 997; % Density of water [kg/m^3]

myu = 8.90\*10^(-4); % Viscosity of water at room temperature [Pa.s]

% Velocities for all water tunnel speeds 30Hz - 60Hz

vel\_col = file1(:,6);

% Diameter of cylinders

d\_col = file2(:,1);

% Karman Vortices shedding frequency for each cylinder diameter

n\_30 = file2(:,4) / 60;

n\_40 = file2(:,7) / 60;

n\_50 = file2(:,10) / 60;

n\_60 = file2(:,13) / 60;

% Reynold's numbers for 30Hz - 60Hz with each cylinder diameter

Re\_30 = rho\*vel\_col(4,1).\*d\_col/myu; % Experimental Reynold's number 30Hz

Re\_40 = rho\*vel\_col(3,1).\*d\_col/myu; % Experimental Reynold's number 40Hz

Re\_50 = rho\*vel\_col(2,1).\*d\_col/myu; % Experimental Reynold's number 40Hz

Re\_60 = rho\*vel\_col(1,1).\*d\_col/myu; % Experimental Reynold's number 40Hz

% Strouhal numbers for 30Hz - 60Hz with each cylinder diameter

S\_30 = n\_30 .\* d\_col / vel\_col(4,1); % Experimental Strouhal number 30Hz

S\_40 = n\_40 .\* d\_col / vel\_col(3,1); % Experimental Strouhal number 40Hz

S\_50 = n\_50 .\* d\_col / vel\_col(2,1); % Experimental Strouhal number 50Hz

S\_60 = n\_60 .\* d\_col / vel\_col(1,1); % Experimental Strouhal number 60Hz

% Concatenate vectors to create one vector with experimental Reynold's

% number and Strouhal number

Re\_exp = [Re\_30' Re\_40' Re\_50' Re\_60'];

S\_exp = [S\_30' S\_40' S\_50' S\_60'];

% Plotting the accepted the empirical Reynolds - Strouhal number curve.

Re0 = linspace(90,1500,5); % Empirical Reynold's number

S0 = 0.212 \* (1 - 12.7 ./ Re0); % Empirical Strouhal number 0<Re<100,000

figure(1)

plot(Re0, S0, '-b')

xlabel('Re')

ylabel('St')

title(['Reynold''s Number vs Strouhal Number of Empirical Data ' ...

'- By: Tomoki Koike'])

grid on

grid minor

box on

hold on

plot(Re\_exp, S\_exp, '.r','MarkerSize',24)

hold off

legend('Roshko''s Curve', 'Data Points', 'location', 'southeast')

fig = gca;

fig.FontSize = 22;

## Analysis

figure(2)

plot(Re0, S0, '-b')

title(['Reynold''s Number vs Strouhal Number of Empirical Data ' ...

'- By: Tomoki Koike'])

grid on

grid minor

box on

hold on

plot(Re\_exp, S\_exp, '.r','MarkerSize',24)

[result gof plt] = data\_curve\_fitting(Re\_exp, S\_exp);

plt

hold off

xlabel('Re')

ylabel('St')

legend('Roshko''s Curve', 'Data Points', '','Originally Fitted Curve (Power func)','location', 'southeast')

fig = gca;

fig.FontSize = 22;

**<data\_curve\_fitting.mlx>**

DATA\_CURVE\_FITTING(RE\_EXP,S\_EXP)

Create a fit.

Data for 'untitled fit 1' fit: X Input : Re\_exp Y Output: S\_exp Output: fitresult : a fit object representing the fit. gof : structure with goodness-of fit info.

See also FIT, CFIT, SFIT.

function [fitresult, gof, h] = data\_curve\_fitting(Re\_exp, S\_exp)

## Fit:

[xData, yData] = prepareCurveData( Re\_exp, S\_exp );

% Set up fittype and options.

ft = fittype( 'power1' );

opts = fitoptions( 'Method', 'NonlinearLeastSquares' );

opts.Display = 'Off';

opts.StartPoint = [0.157314492940035 0.0435338772076528];

% Fit model to data.

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

h = plot( fitresult, '-g', xData, yData);