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.

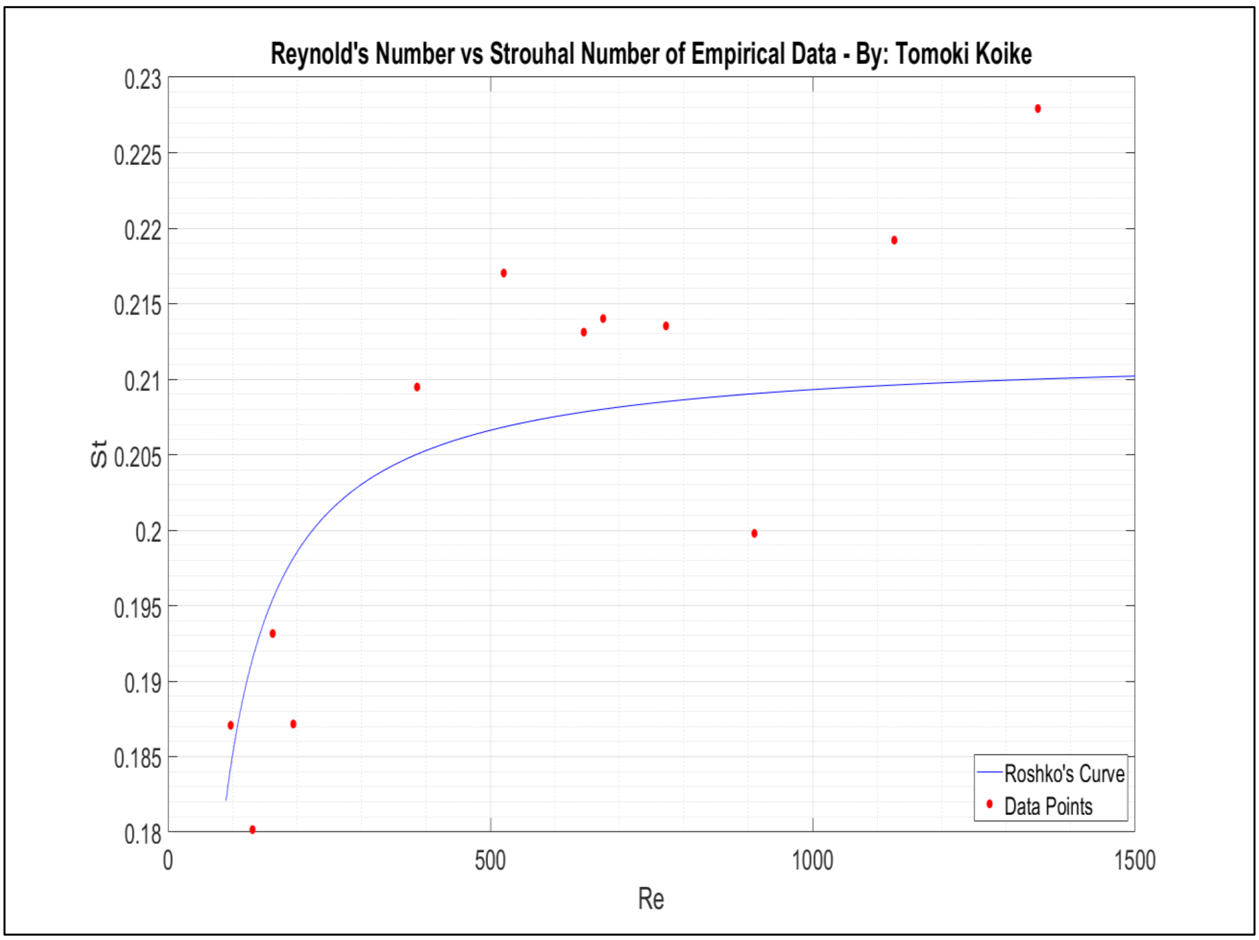
The first objective of this experiment was to understand viscosity, boundary layers, and boundary layer separation, which are the basic concepts in fluid mechanics. This objective was sought to be observed by examining the water flow over various cylinders with different diameters. In the experiment, 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.

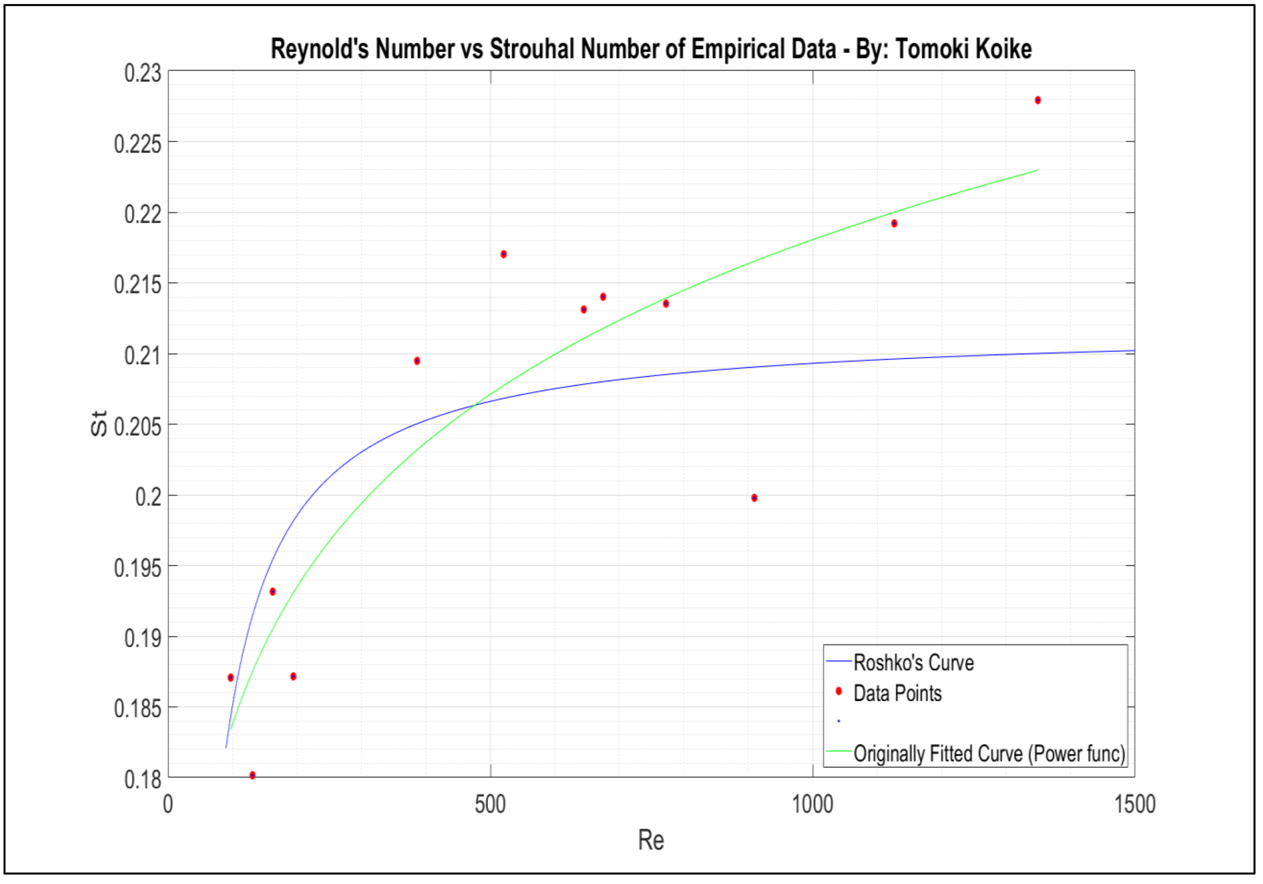


2) >>(5 points) In 250 words or less, discuss how well the experimental measurements compare with the empirical values of Strouhal number.

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.



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.

2) (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

PART1					
Tunnel Speed (Hz)	Distance (m)	Time 1, t (sec)	Time 2, t (sec)	Average Time (sec)	Pulse Velocity (m/s)
60.00	0.30	5.43	5.70	5.57	0.05391
50.00	0.30	6.73	6.60	6.67	0.04501
40.00	0.30	8.43	8.08	8.26	0.03634
30.00	0.30	11.20	11.05	11.13	0.02697

Fig1: Excel Data Sheet of Experiment Part1

PART2												
	Number of Vortices											
Cylinder Diameter (m)	30Hz		30Hz AVG	40Hz		40Hz AVG	50Hz		50Hz AVG	60Hz		60Hz AVG
0.00322	95	93	94	120	124	122	164	160	162	188	188	188
0.01279	26	27	27	38	36	37	44	46	45	55	53	54
0.02234	15	16	16	19	20	20	26	27	27	33	33	33

Fig2: Excel Data Sheet of Experiment Part2

PART4			
	Boundary Layer Thickness (m)		Length of Flat Plate (m)
x, Distance from LE (m)	top	bottom	0.406
0.1015	0.003	0.002	
0.2030	0.005	0.001	
0.4060	0.100	0.100	

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);
```