Free Stream Turbulence Measurement Using a Sphere

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Nomenclature

D	= *Diameter of the sphere*
q	= *Dynamic pressure*
ΔP	= *Pressure difference between forward and rear pressure taps*
p_{static}	= *Static pressure*
p_{total}	= *Total pressure*
p_{rear}	= *Rear pressure*
$p_{forward}$	= *Forward (stagnation) pressure*
T_{test}	= *Test temperature*
T_{amb}	= *Ambient temperature*
P_{amb}	= *Ambient pressure*
R	= *Specific gas constant for air*
T_0	= *Reference temperature for Sutherland's formula*
μ_0	= *Reference viscosity*
S	= *Sutherland's constant*
$\frac{\Delta P}{q}_{crit}$	= *Critical normalized pressure difference*
ρ	= *Air density*
μ	= *Dynamic viscosity*
U	= *Flow velocity*
Re	= *Reynolds number*
Re_{crit}	= *Critical Reynolds number*
Re_{eff}	= *Free air critical Reynolds number*
TF	= *Turbulence factor*
Tu	= Turbulence intensity

I. Objectives

The purpose of this report will be to demonstrate the ability to calculate the Reynolds Number, Critical Reynolds Number, Pressure difference between the average pressure measured at the rear ports within the wind tunnel and the stagnation pressure at the leading edge, the flow dynamic pressure, and to plot the relation between the Reynolds number and the ratio of the two aforementioned pressure readings.

II. Equipment and Setup

The experiment performed for Lab 3 utilizes a number of complex and useful devices. The headline tool is the low-speed wind tunnel which has a closed return. This can generate high speeds for the purpose of sub sonic testing. The test section measures 34” x 45” x 65”, providing a controlled environment for testing. Inside the test area are spheres that range from 4”, 4.987”, and 6”, which provide analysis on the turbulent air with a range of sphere diameter. Each sphere is equipped with a pressure tap at the leading edge and at the trailing edge, and at the test section inlet there are total and static pressure taps. These will each be used for determining flow characteristics.

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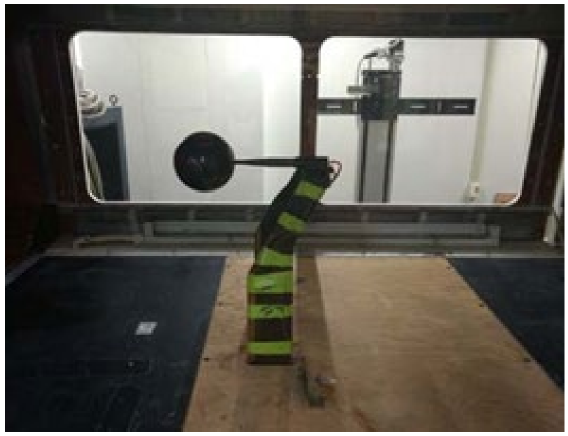

Figure 1: 4.987” Diameter sphere in test section of wind tunnel

A ZOC33 miniature pressure scanner is used to measure the pressure at the pitots, and will send the signal to the DSM4000, which is the data acquisition tool in the setup. This in turn sends the data to the computer equipped with ScanTel acquisiton software to record and analyze the pressure data. The ZOC33 pressure scanner measures the difference between the leading edge and the trailing edge. A barometer inside and outside the wind tunnel measures the ambient and test pressures, as does an electronic thermometer. These will be necessary for calculating density and viscosity using the Ideal Gas Law and Sutherland’s formula, respectively. A Meriam Instrument Co. water manomenter measures the pressure differences in the wind tunnel. This setup ensures that all necessary measurements are recorded in order to accurately calculate the Reynolds number and perform data interpretation.

Figure 2: ZOC33 Pressure Scanner used for experimentation

Figure 3: Digital Service Module (DSM4000) utilized in experiment.

The procedure for this lab will be broken down into the preparation and execution sections. By closely following all instructions, we can ensure safe and reliable test results.

Preparation

1. Connect wind tunnel Pitot tubes to the pressure scanner ports, according to their assigned number.
2. Lock external brace to prevent movement during testing.
3. Fix the balance support and install the sphere of choice.
4. Connect the air supply and set it to 65 psi.
5. Connect the ZOC33 manifold to the pressure line.
6. Turn on the DSM4000 and allow it to warm up.
7. Estimate the maximum dynamic pressure based on the free air critical Reynolds number.
    a. This step is detailed in Equation 1 and Table 1.
8. Define the dynamic pressure range from 0 to q_{max}, and divide by 15 for the interval of test points.

Execution

1. Record the barometric pressure and room temperature.
2. Open the recording software and connect to the DSM4000 via IP address.
3. Initialize the pressure scanner by entering the following commands:
    a. calz → set chan1 0 → set chan 1-1..1-4 → set fps 10
4. Perfom final inspection of test section.
5. Close test section doors and lock them.
6. Set wind tunnel speed to 0 in H2O.
7. Turn on wind tunnel, and cooling system.
8. Begin recording via software and name the recording file.
9. Enter command *scan* to begin pressure scanning.
10. Gradually increase wind speed to the first test point and wait for stabilization.
11. Repeate the data recording process for the entire test.
12. Slowly reduce speed to zero and open the test section when done.
13. Replace the sphere with the next size, and close the test section.
14. Repeat the process until all spheres have been tested.
15. Cool down, turn off, and disconnect all apparatuses.

$$q_{max} = \frac{1}{2\rho}\left(\frac{R_c\mu}{D}\right)^2 \tag{1}$$

Sphere Diameter (in)	$q_{min}\ inH_2O$	$q_{max}\ inH_2O$
4.0	4.0	7.0
4.987	2.57	5.3
6.0	1.78	3.7

Table 1: q_{max} calculations for each Sphere

The above equation and table are the means to find the maximum value that each sphere should be tested at. For the experiment, the maximum value was divided by 15 for each of the tests, starting from zero.

III. Theory

The theory behind the lab is simple and follows most of what has already been covered from previous labs. Given the recorded static, total, rear, and forward pressure, the ambient and test temperatures and pressure, and the diameter of the sphere we can calculate $\frac{\Delta P}{q}$, Reynolds number, and more in order to find the Drag Crisis Region, Critical Reynolds number Re_c, and more. To begin, we will need to normalize the data. To get q, we can take the difference between static and total pressures respectively.

$$q = p_{total} - p_{static} \tag{2}$$

'q' in this case is dynamic pressure and is represented by bernoulli's equation and is given by:

$$q = \frac{1}{2}\rho V^2 \tag{3}$$

Total pressure is the sum of the the static pressure and the dynamic pressure. The total pressure captures the stagnation pressure, which is the pressure when the flow is brought to rest, and the static pressure is measuring the pressure of the flowing fluid without considering velocity. With equation 2, we can derive velocity using the following equation:

$$V = \sqrt{\frac{2\text{q}}{\rho}} \tag{4}$$

From the forward and rear pressure ports, we can find ΔP, which represents the pressure difference across the sphere. The forward pressure tap reads the stagnation pressure, which is the point where the fluid comes to a complete stop. The rear pressure tap measures the pressure in the wake region, which is found directly behind the sphere.

$$\Delta P = p_{forward} - p_{rear} \tag{5}$$

This will be used in conjunction with the dynamic pressure to find the normalized pressure difference:

$$Normalized\ Pressure\ Difference = \frac{\Delta P}{q} \tag{6}$$

The normalized pressure difference is a critical paremter for interpreting the flow regime around the sphere. This also is directly related to the drag coefficient (C_d) of the sphere. This will also be used in future graphing and data interpretation when considering the critical value of $\frac{\Delta P}{q}$, which, for a smooth sphere is defined to be at 1.220. This can be used to find the Critical Reynolds number, which is the number at which flow around the sphere is transitional between laminar and turbulent. This causes a sudden drop the drag coefficient, and is the beginning of what is known as the drag crisis. To get to Reynolds, we need density, which involves static pressure, Gas Constant, and Temperature:

$$\rho = \frac{|p_{static}|}{R \cdot T_{test}} \tag{7}$$

The static pressure is written as its absolute value because density is a scalar, and in the data, static is negative. The temperature value was the test value given at the beginning of each of the 15 runs for every sphere. R is the gas constant, and for metric R = 287.05 ($\frac{J}{kg \cdot K}$). Dynamic Viscosity is also used in Reynolds number. This is calculated with Sutherland's Formula:

$$\mu = \mu_0 \left(\frac{T}{T_0}\right)^{1.5} \left(\frac{T_0 + S}{T + S}\right) \tag{8}$$

There are a few constants to cover with this formula. μ_0 is the Reference viscosity based on the Reference temperature T_0. For metric, and using Kelvin, these values are 1.716e-5 ($Pa \cdot s$) and 273.15 (K), respectively. S is sutherland's constant for air, which is given as S = 110.4 (K). by using these values and the test temperature, the dynamic viscosity is found for each given run. The final piece needed for Reynolds number is the velocity which was shown in equation 4, however, this velocity is defined using "U" in the Reynolds number equation:

$$Re = \frac{\rho U D}{\mu} \tag{9}$$

D is the diameter of the given sphere, which in the report has been translated to metric as with the rest of the data. To find the critical Reynolds number at the critical normalized pressure difference of 1.220, we can interpolate the critical Reynolds number. From Re_{crit}, the Turbulence Factor is found according to the expression:

$$TF = \frac{385000}{Re_{crit}} \tag{10}$$

The 385,000 from the formula represents the critical Reynolds number for a smooth sphere in an enviornmnet with no turbulence from variables such as atmosphere. With this, we can compare experimental data to a reference point to quantify how much the turbulence affects the flow compared to free air conditions. From Turbulence factor, we find the Turbulence intensity using the empirical relationship:

$$Tu = \frac{TF - 1}{0.15} \tag{11}$$

The relationship between TF and Tu is determined to be approximately linear for low turbulence levels, which can be found at the drag crisis. The slope of their linear relationship was determined to be $\frac{1}{.15}$, which is why it is in the equation. This is the sensitivity of TF to changes in Tu based on the behavior of the sphere.

IV. Results and Analysis

The interpretation of this data can be represented in the aforementioned graph comparing the Reynolds number with the normalized pressure difference. With this graph, we can interpolate the critical Reynolds number with the critical normalized pressure difference ($\frac{\Delta P}{q} = 1.220$).

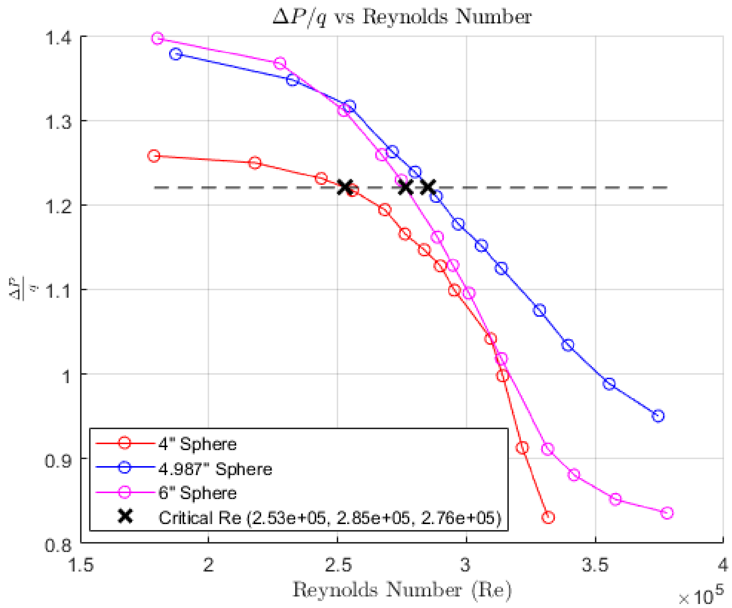

Figure 4: $Re\ vs. \frac{\Delta P}{q}$ for Diameters = 4", 4.987", and 6"

The data for each test clearly shows the sudden drop in pressure difference normalized across the wind tunney at a certain threshold in the Reynolds number. With this, there is also a leveling off happening over time. This figure shows the transition from laminar flow to turbulent as the windspeed and Reynolds number increases. Once the Reynolds number reaches the critical value, the normalized pressure difference drops sharply because of the boundary layer separation during the transition, which results in a smaller wake and a lowering of the pressure drag. This is known as the drag crisis.

The Critical Reynolds number is found through interpolation, and for the 4", 4.987", and 6" spheres, the values are 2.53e5, 2.85e5, and 2.76e5 respectivly. With these points, we can compare how the flow behavior changes with sphere diameter, and since larger spheres have higher critical Reynolds numbers, the flow transition is delayed. Within our dataset, something was likely to have gone wrong with either the second or third spheres. This is because the Re_{crit} is higher for the second test than the first. Error will be discussed in the conclusion section.

It is reasonable to see the critical Reynolds to be at the beginning of the slope downward for each test, since that is when the flow transitions to turbulent and the pressure difference will become lessened as the wake is shortened. The Reynolds values over the range are also reasonable for air near sea level at the windspeeds faced in the experiment. Besides figure 4, it is also beneficial to plot the turbulence factor, and percent turbulence against the critical unit Reynolds number. By showing those relations, we can derive an understanding of the relationship between the wind turbulence and the flow behavior around the spheres.

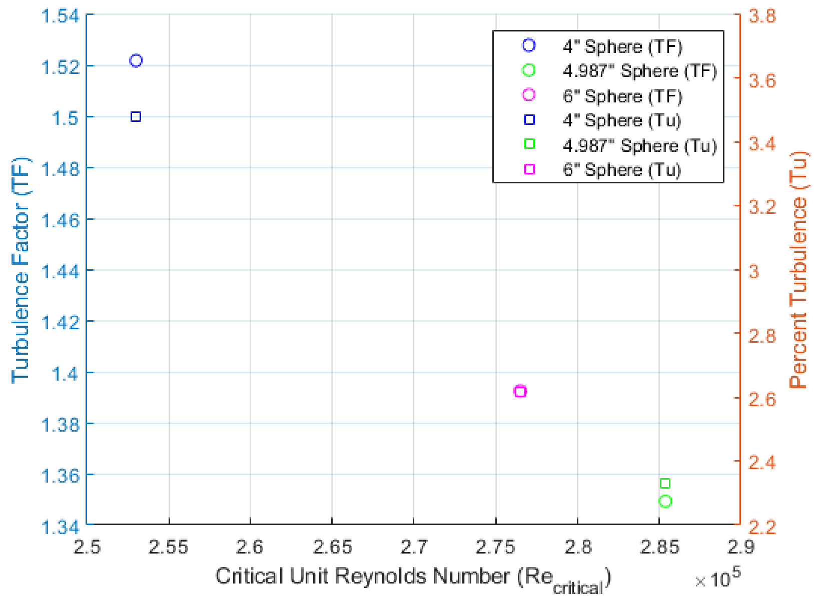

Figure 5: Re_{crit} vs. Turbulence Factor and Percent Turbulence for Diameters = 4", 4.987", and 6"

The difference in Critical Reynolds number makes a stronger appearance in this graph. It should be expected that as the Reynolds number increases, the TF and Tu will be lower. This is because as it increases and the flow transitions to turbulent, the flow transitions at a lower Reynolds number, resilting in the ratio between TF and Re_{crit} to be smaller. As previously mentioned, when defining the Percent turbulence with the empirical formula in equation 11, the 0.15 modifier represents the expected slope change between percent turbulence and trubulence factor. This can be seen in this figure as slowly Tu takes the less dramatic negative slope.

To properly understand the plot, it is important to keep in mind the difference between a low and a high Re_{crit}. For a low Re_{crit}, you can observe higher turbulence levels, and flow transitioning to turbulent at a lower Reynolds number, which would make sense for a sphere of smaller diameter, since there is a shorter contact difference between the surface and the boundary layer. The relationship between the three tests has some issues, since the 4.987" sphere has a greater critical Reynolds Number, which stems from small differences in the data, leading to a greater Reynolds number and Re_{crit}.

Sample Calculations

The sample calculations are performed using the initial values provided below, which represent the calculations for the final run of the 4" sphere, at the very first recording for that speed:

Values

D=4(in)=0.1016(m).

p_{static} *= -.09539 (psi) = 657.7 (Pa)*

p_{total} *= 0.1582 (psi) = 1091 (Pa)*

p_{rear} *= -0.1141 (psi) = 786.7 (Pa)*

$p_{forward}$ *= 0.1174 (psi) = 807.4 (Pa)*

q_{test} *= 7.0* (inH_2O) *= 1741.88 (Pa)*

$T_{test} = 105.4\ (F) = 313.93\ (K)$

Ambient Temperature, T_{amb}*=297.15 (K).*

Ambient Pressure, P_{amb}*=101325 (Pa).*

Specific Gas Constant for Air, R = 287.05 $(\frac{J}{kgK})$.

Reference Temperature for Sutherland's Formula, T_0*=273.15 (K).*

Reference Viscosity, μ_0 *= 1.716e-5 (Pa·s).*

Sutherland's Constant, S=110.4 (K).

Critical Normalized Pressure Difference, $\frac{\Delta P}{q}_{crit}$ *=1.220.*

Free Air Critical Reynolds Number, $Re_{free\ air}$*=3.85×105*

Calculations

$$Pressure\ adjustment\ p_{static,total,rear,forward} = p + P_{amb} = 100732, 102475, 100749, 102196\ (Pa)$$

$$Dynamic\ Pressure\ q = P_{total} - P_{static} = 102475 - 100732 = 1743\ (Pa)$$

$$Pressure\ Difference\ \Delta P = P_{forward} - P_{rear} = 102196 - 100749 = 1447\ (Pa)$$

$$\frac{\Delta P}{q} = \frac{1447}{1743} = 0.8302$$

$$\rho = \frac{|p_{static}|}{R \cdot T_{test}} = 1.1173\ (\frac{kg}{m^3})$$

$$\mu = \mu_0 \left(\frac{T}{T_0}\right)^{1.5} \left(\frac{T_0 + S}{T + S}\right) = 1.716e - \left(\frac{313.9}{273.15}\right)^{1.5} \left(\frac{273.15 + 110.4}{313.9 + 110.4}\right) = 0.1911e - 4\ (Pa \cdot s)$$

$$U = \sqrt{\frac{2 \cdot q}{\rho}} = \sqrt{\frac{2 \cdot 1.7428}{1.1178}} = 55.842\ \left(\frac{m}{s}\right)$$

$$Re = \frac{\rho U D}{\mu} = \frac{1.1173 \cdot 55.842 \cdot 0.1016}{0.1911} = 3.3183e5$$

$$Re_{crit} = Re_1 + \frac{Re_2 - Re_1}{\frac{\Delta P}{q}_2 - \frac{\Delta P}{q}_1} \cdot \left(\frac{\Delta P}{q} - \frac{\Delta P}{q}_1\right) = 2.5301e5$$

$$Turbulence\ Factor = \frac{3.85e5}{Re_{crit}} = \frac{3.85e5}{2.5301e5} = 1.5217$$

$$Turbulence\ Intensity = \frac{TF - 1}{0.15} = \frac{1.5217 - 1}{.15} = 3.478$$

$$Effective\ Reynolds\ Number = TF \cdot Re = 1.5217 \cdot 3.3183e5 = 5.0494$$

V. Conclusions

With the figures shown and the correct interpretation of the data, the objectives of the experiment have been met. This lab covered the theory and application of theory in order to read the data from pitots in a wind tunnel with a sphere of varying diameters. From this data we calculate the Reynolds number, and compare it to the normalized pressure difference, which gives us a visual on how the airflow transitions from laminar to turbulent. On top of that, by comparing the Critical Reynolds number with the Turbulence factor and turbulence intensity, we may understand the relationship between them, and how the experimental critical Reynolds number compares to the theoretical Reynolds number for a sphere.

The interpretation of this lab is seemingly valid, and it is clear that the relationship holds in all cases, with there being a steep drop off after Re_{crit} is met, and that it would lead to a tapering off as the flow becomes more and more turbulent, leading to a decrease in the pressure difference. On top of that, the linear decreasing of TF and Tu as Re_{crit} increases follows theory, since the increase of Re_{crit} would, by equation 10, lower the ratio of TF, and by extension Tu.

The only part of this lab that shows extensive error, besides the data that needed disregarding from the beginning as per the professors instructions due to a data entry error in the programming of the wind tunnel software, is the larger Re_{crit} for the 4.987" sphere over the 6" sphere. This should not have been the case, since the increase of diameter in the sphere would increase the Reynolds number (equation 9), as well as Re_{crit}. The only explanation I could offer for this is a lack of time normalizing the wind speed in the wind tunnel for the second test, in addition to struggling to balance the water manometer in the wind tunnel that gauges speed. If the speed is increased higher than expected for the expected data, that would directly affect the velocity in the wind tunnel.

For future experimentation, it is important to be as exact as possible (which proves difficult with the current setup), as well as to allow time for the wind tunnel to normalize to the speed set by the controller. Beyond that, verifying data as best as possible when at the lab will avoid mixups where data needs to be scrubbed due to inaccuracies and to avoid outliers. Thank you to our professor for instructing us on this lab and its theory, and thank you to our teacher assistants, who have been receptive to questions and concerns, and have done a lot to help prepare students to understand the fundamentals of this class.

MATLAB Code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% AE302 Lab 3 - Wyatt Welch
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc, clear all, load('Raw4.mat'), load('Raw5.mat'), load('Raw6.mat'), load('TP4.mat'), load('TP5.mat'), load('TP6.mat')

% Data Setup
Raw4 = mean(table2array(Raw4),2);
Raw5 = mean(table2array(Raw5),2);
Raw6 = mean(table2array(Raw6),2);

for i = 1:size(Raw4, 1)-4
   Raw4(i+4, :) = Raw4(i+4, :) - Raw4(mod(i-1,4)+1, :);
end
Rows = [1:4,41:44];
rows = [1,11];
Raw4 = Raw4(~ismember(1:size(Raw4, 1), Rows), :);
Raw4 = mean(Raw4, 2);
Raw4 = Raw4 * 6894.76;

for i = 1:size(Raw5, 1)-4
   Raw5(i+4, :) = Raw5(i+4, :) - Raw5(mod(i-1,4)+1, :);
end
Raw5 = Raw5(~ismember(1:size(Raw5, 1), Rows), :);
Raw5 = mean(Raw5, 2);
Raw5 = Raw5 * 6894.76;

for i = 1:size(Raw6, 1)-4
   Raw6(i+4, :) = Raw6(i+4, :) - Raw6(mod(i-1,4)+1, :);
end
Raw6 = Raw6(~ismember(1:size(Raw6, 1), Rows), :);
Raw6 = mean(Raw6, 2);
Raw6 = Raw6 * 6894.76;

TP4 = table2array(TP4);
TP4 = TP4(~ismember(1:size(TP4, 1), rows), :);
TP5 = table2array(TP5);
TP5 = TP5(~ismember(1:size(TP5, 1), rows), :);
TP6 = table2array(TP6);
TP6 = TP6(~ismember(1:size(TP6, 1), rows), :);

T_amb4 = (76.6 - 32) * (5/9) + 273.15;
T_amb5 = (73.6 - 32) * (5/9) + 273.15;
T_amb6 = (75.7 - 32) * (5/9) + 273.15;

T4 = (TP4(:,2) - 32) .* (5/9) + 273.15;
T5 = (TP5(:,2) - 32) .* (5/9) + 273.15;
T6 = (TP6(:,2) - 32) .* (5/9) + 273.15;

P_a4 = 29.94 * 3386.39;
P_a5 = 29.93 * 3386.39;
P_a6 = 29.93 * 3386.39;

Raw4 = Raw4 + P_a4;
Raw5 = Raw5 + P_a5;
Raw6 = Raw6 + P_a6;

P4 = TP4(:,1) .* 249.0889;
P5 = TP5(:,1) .* 249.0889;
P6 = TP6(:,1) .* 249.0889;
```

```
R = 287.05;

D4 = 0.1016;
D5 = 0.1267;
D6 = 0.1524;

% Calculations
% 1 = Static, 2 = Total, 3 = Rear, 4 = Forward

delP4 = Raw4(4:4:end,:) - Raw4(3:4:end,:);
delP5 = Raw5(4:4:end,:) - Raw5(3:4:end,:);
delP6 = Raw6(4:4:end,:) - Raw6(3:4:end,:);

q4 = Raw4(2:4:end,:) - Raw4(1:4:end,:);
q5 = Raw5(2:4:end,:) - Raw5(1:4:end,:);
q6 = Raw6(2:4:end,:) - Raw6(1:4:end,:);

dP_div_q4 = delP4 ./ q4;
dP_div_q5 = delP5 ./ q5;
dP_div_q6 = delP6 ./ q6;
dP_div_q_crit = 1.220;

den4 = abs(Raw4(1:4:end,:)) ./ (R .* T4);
den5 = abs(Raw5(1:4:end,:)) ./ (R .* T5);
den6 = abs(Raw6(1:4:end,:)) ./ (R .* T6);

Visc4 = (1.716e-5) .* ((T4 ./ 273.15) .^ 1.5) .* ((273.15 + 110.4) ./ (T4 + 110.4));
Visc5 = (1.716e-5) .* ((T5 ./ 273.15) .^ 1.5) .* ((273.15 + 110.4) ./ (T5 + 110.4));
Visc6 = (1.716e-5) .* ((T6 ./ 273.15) .^ 1.5) .* ((273.15 + 110.4) ./ (T6 + 110.4));

U4 = sqrt((2 .* q4) ./ den4);
U5 = sqrt((2 .* q5) ./ den5);
U6 = sqrt((2 .* q6) ./ den6);

Re4 = (den4 .* U4 .* D4) ./ Visc4;
Re5 = (den5 .* U5 .* D5) ./ Visc5;
Re6 = (den6 .* U6 .* D6) ./ Visc6;

Re4_interp = interp1(dP_div_q4, Re4, 1.220);
Re5_interp = interp1(dP_div_q5, Re5, 1.220);
Re6_interp = interp1(dP_div_q6, Re6, 1.220);
Re_crit = [Re4_interp Re5_interp Re6_interp];

TF4 = 3.85e5 / Re4_interp;
TF5 = 3.85e5 / Re5_interp;
TF6 = 3.85e5 / Re6_interp;
TF = [TF4 TF5 TF6];

Tu4 = (TF4 - 1) / 0.15;
Tu5 = (TF5 - 1) / 0.15;
Tu6 = (TF6 - 1) / 0.15;
Tu = [Tu4 Tu5 Tu6];

Re_eff4 = TF4 * Re4;
Re_eff5 = TF5 * Re5;
Re_eff6 = TF6 * Re6;


% Plots

figure(1)
```

```
hold on, grid on
plot(Re4, dP_div_q4, '-o', 'Color', 'red')
plot(Re5, dP_div_q5, '-o', 'Color', 'blue')
plot(Re6, dP_div_q6, '-o', 'Color', 'magenta')
plot(Re4_interp, 1.220, 'kx', 'MarkerSize', 10, 'LineWidth', 2)
plot(Re5_interp, 1.220, 'kx', 'MarkerSize', 10, 'LineWidth', 2)
plot(Re6_interp, 1.220, 'kx', 'MarkerSize', 10, 'LineWidth', 2)
plot([min([Re4; Re5; Re6]), max([Re4; Re5; Re6])], [1.220, 1.220], 'Color', 'black', 'LineStyle', '--', 'LineWidth', 0.5);

xlabel('Reynolds Number (Re)', 'Interpreter', 'latex')
ylabel('$\frac{\Delta P}{q}$', 'Interpreter', 'latex')
title('$\Delta P / q$ vs Reynolds Number', 'Interpreter', 'latex')
criticalReString = sprintf('Critical Re (%.2e, %.2e, %.2e)', Re4_interp, Re5_interp, Re6_interp);
legend('4" Sphere', '4.987" Sphere', '6" Sphere', criticalReString, 'Location', 'best')


figure(2)
hold on, grid on
yyaxis left;
plot(Re4_interp, TF4, 'o', 'Color', 'blue', 'DisplayName', '4" Sphere (TF)');
plot(Re5_interp, TF5, 'o', 'Color', 'green', 'DisplayName', '4.987" Sphere (TF)');
plot(Re6_interp, TF6, 'o', 'Color', 'magenta', 'DisplayName', '6" Sphere (TF)');
ylabel('Turbulence Factor (TF)');

yyaxis right;
plot(Re4_interp, Tu4, 's', 'Color', 'blue', 'DisplayName', '4" Sphere (Tu)');
plot(Re5_interp, Tu5, 's', 'Color', 'green', 'DisplayName', '4.987" Sphere (Tu)');
plot(Re6_interp, Tu6, 's', 'Color', 'magenta', 'DisplayName', '6" Sphere (Tu)');
ylabel('Percent Turbulence (Tu)');

xlabel('Critical Unit Reynolds Number (Re_{critical})');
legend('Location', 'northeast');



fprintf("Completed Run \n")
```