Pressure distribution of cylinder in wind tunnel

This lab delved into the concepts of fluid mechanics to calculate the drag coefficient of airflow around a smooth cylinder resulting from variations in pressure distribution. An apparatus consisting of a wind tunnel, pitot-tube, rotatable cylinder, and well-inclined manometer were used to conduct the experiment. Airflow generated by the wind tunnel was the driving factor, causing a measurable pressure difference around the cylinder. The well-inclined manometer was used to measure this varying pressure at ten degree intervals around the rotating cylinder, while the pitot-tube was utilized to measure free-stream velocity. After measuring and recording the necessary data for three different air speeds, calculations were made to determine Reynolds Number (Re), coefficient of pressure (Cp), and coefficient of drag (Cd). The resulting plots of Cp vs. Theta (angle of pressure measurement around cylinder) were consistent with the shape of the graph for laminar flow found within the text, indicating separation at about 75-80 degrees. The plot of Cd vs. Re was also successful considering our Cd showed a small increase and a slight decrease over the range of Reynolds values (remaining more or less constant). This result is consistent with the figure provided from the Fluid Mechanics text, as it is clear that Cd remains relatively steady for a smooth circular cylinder for the range 1000 Objective:

The objective of this lab was:

1. To measure the pressure distribution around a circular cylinder placed in a rectangular crossâ€ section wind tunnel, and to calculate the drag force based on the pressure measurements.

2. To Compare the measured pressure and drag force with the values calculated using the potential flow theory.

Introduction:

Because fluid matter is so abundant and plays such a significant role in science, fluid mechanics is a large area of study for scientists and engineers. One aspect of particular interest is in studying how fluids flow over different objects. Understanding this concept is crucial to solving problems that impact the modern world, such as atmospheric flight and automobile design (to name a few). By using a wind-tunnel, a smooth cylinder, and a few measuring devices to aid us, we were able to formulate a basis of experimental knowledge with which to observe fluid flow over an object made relatable by the parameters of pressure, drag, and Reynolds Number. Differing flow speeds allowed us further opportunity to compare and contrast the observations and calculations made relating to these parameters.

In order to fully accomplish the objectives of this lab and report, background and theory concerning fluid mechanics must first be introduced to provide core, foundational knowledge. This knowledge is expanded upon by dictating the necessary equipment requirements to conduct the lab. From there, the experimental procedure is outlined to allow for reproducibility of the lab by the reader should the need arise. Finally, an analytical approach is used to examine the overall results of the lab as performed before generating several conclusions and recommendations for the future.

Background & Theory:

The background of the experiment is to calculate the drag coefficient in a controlled environment using a wind tunnel, a rotating cylindrical object, pitot tube, and an inclined manometer. When developing the drag coefficient values it is important to specify the reference area (cylindrical object) used to develop the drag coefficient value. This value is valuable to engineers in developing models for many different aspects, such as, cars, airplanes, and many other areas as fluids affects just about everything. Fluid consists of air, water, gas which are Newtonian Fluids and in this experiment air was used to understand the effects experimentally with a rotating cylindrical object and checking the values on a manometer at 10 degree intervals at 3 different speeds low, medium, and high.

Figure 1 – Airflow around Cylindrical Object (3)

Theory:

1. The pitot tube at the point that is hit in the central part has a velocity of zero (see figure 2 below) and point2 is known as stagnation point. From the Bernoulli equation this point can be calculated per [(p1/â„˜)+(u1^2/2)=(p2/â„˜)], which can be re-written as p2 = p1+(. 5*â„˜*u1^2). U1 = velocity, p1 & p2 = pressure, â„˜ = density and for stagnation at point 2, u2 = 0 and z1 = z2. (3)

Figure 2 – Pitot Tube Point 1 & 2 (3)

When using a pitot static tube also known as Prandtl tubes (see figure 3), which is used to measure the pressure difference. The tube is mounted in the wind tunnel so that the main hole along the axis direction through the tube is pointed in the direction of the fluid flow and other small holes are drilled on the outside of the tube perpendicular to main hole and kept separately. The small perpendicular holes are considered the static pressure and the main hole is the total pressure (pressure of flow & static) used in the Bernoulli equation.

Figure 3 – Pitot Static Tube (3)

2. The manometer are used to measure the pressure and is one of the oldest measurement devices. There are different types of manometers that can be used, such as, the U-tube, Inclined, Reservoir, and Float types. For this experiment an inclined manometer is used so that the pressure changes can be read easier and has an increased sensitivity level compared to the others.

(Equations for the Manometer) (3)

(Note – The scale of the installed manometer in this setup reads h directly, so you do not need to multiply it by sin Î¸)

Figure 4 – Typical Inclined Manometer (3)

3. Drag force on a circular cylinder in a stream of flow per Figure 5, 6, 7 below shows that the flow past a cylinder will go through several transitions based on the velocity. In this experiment as the cylindrical object rotates the fluid flow changes within the same velocity and delivers different values and is repeated between 3 different velocities and then compared.

Figure 5 – Separation of air flow around cylindrical object (3)

Figure 6 – Typical graph for separation of airflow (3)

(a) Laminar Flow separates at about 80°, CD = 0. 5

(b) Turbulent flow separates at 120°, CD = 0. 2

Figure 7 – Graph of separation of airflow around an object (3)

(a) Laminar Flow separates at about 80°, CD = 0. 5

(b) Turbulent flow separates at 120°, CD = 0. 2

Equipment:

The equipment used for this experiment were:

1. A rectangular crossâ€ section wind tunnel.

2. An adjustable air blower responsible of pumping the air throughout the wind tunnel.

3. A rotatable circular cylinder placed across the whole height of the tunnel.

4. A pitotâ€ tube to allow measurement of free stream air velocity.

5. A honeyâ€ section to achieve a uniform flow across the tunnel.

6. A wellâ€ inclined manometer to measure pressure around the cylinder.

Procedure:

Starting the experiment after reading the parameters of and required steps in the experiment we had to set a baseline for a further measurement in this experiment. This was done by taking readings for the inclined manometer, href used it this experiment with no added flow from the fan at ambient pressure. All measurements were recorded by two measurement takers and only dispute on a measurement was decided by a third party.

Next the blower was turned on to slowest of the the three speeds to be used and reading was allowed some time to stabilize. The valve lever was then rotated to the horizontal position to record the manometer reading for the pitot tube which was lowered to be the same height as the hole in the cylinder. A manometer measurement was recorded for the pitot tube at this position. Following this, the valve handle was rotated to the vertical position and the pitot tube returned to its original position at the top of the apparatus in order to read the pressure around the cylinder. The cylinder was rotated to the zero degree position and that reading should, in principle, be the same as huâˆž.

The next stage of the experiment was to rotate the cylinder to the 10 degree position, re-read the manometer and record that value. The Î” h now represented (href – h), where h was the current reading on the manometer from the pressure probe connected to the hole in the cylinder. This process was repeated for the -10 degree position and then for the positive 20 degree, -20 degree position and so on for the rest of the experiment increasing by 10 degrees and the same increase for the negative direction. All of the data collected was put in an excel spreadsheet for every 10 degrees around the cylinder and its corresponding negative value as well.

for the next part of the experiment we completed these same steps for the other two required blower speeds of medium and high with all the data logged in another book of the same spreadsheet

Data Sheet:

Results and Analysis:

Because this lab was aimed to determine the drag force by measuring the pressure distribution and compare them to the actual results, we found that the drag forces are generated by the aero-dynamical resistance. Measurements of static pressure coefficient on the cylinder surface were used to determine the drag coefficient by adjusting the wind speeds at low, medium and high velocities and recording the respective values. Our experimental data was set to observe, collect data and analyze the accuracy of the appearing drag forces, FD the drag, CD and pressure, Cp coefficients at various pressure distributions of different angles and the Reynolds Numbers, Re. Results are presented in figures 10, 11 & 12

Figure 10: Drag force for 1. 673 in. diameter of cylinder

This figure above gives us an understanding of the relationship between the drag force and the wind speeds at various velocities. We can assume from the graph that the drag force becomes greater by increasing wind speeds.

Figure 11: Drag coefficient at different Reynold’s Number

The figure shows surface pressure coefficient distributions at three Reynolds numbers compared with a theoretical distribution on the left computed assuming unbounded potential flow. If you observe the theoretical distribution on smooth circular cylinder, it shows us that the curve is exponentially decreasing as it comes to an equilibrium state within the Reynolds numbers range. But calculated distribution has a slight linear increase in the pressure coefficient and the Reynold numbers increase. The unexpected form of the pressure distribution on the cylinder may be partly explained by three dimensionality in the flow. The big difference between the measured and the theoretical value cannot be explained, but it was found, that the inlet velocity in front of the cylinder has a strong influence on the determined drag coefficient. Maybe a velocity measurement with a pitot tube in front of the cylinder would bring better results for the drag coefficient.

Figure 12: Pressure coefficient of different angels

The above graphs show a theoretical figure on the left and an experimented figure on the right. In the experiment we recorded the static and surface pressures of a cylinder having a diameter of 1. 673 in and 6 in long. We rotated a built in protractor in 10 degree interval for readings over 00 to ±1800. The experimental data of pressure coefficient, Cp obtained under the various angels of incidence for different conditions of low, medium and high velocities. We can observe from the two graphs that the curves are similar in shape. However, the high and medium curves turned out to be slightly similar. The slight error is quite visible comparing the two graphs but this can be caused due to various experimental situations.

The pressure and velocity measurements with the pitot tubes are influenced by a chain of errors. Most of the measurement set-ups are linked: sensors, transducers and data acquisition systems. Each part of the system is influencing the measurements and adds a deviation. The signal chain is going through a lot of steps for the Pitot tube: It starts with the Pitot tube themselves, which e. g. influences the flow. The pressure is transduced to an analogue electrical signal, which is conducted and transformed to a digital signal in the data acquisition system. These signals are set into account with the alcohol manometer data. The manometer is subjected to reading, adjustment and surface tension of liquids deviation. In the following a deviation estimation is done for the manometer. Pitot tubes are in general suitable to measure turbulent flows, but the output can be wrong or different, if the flow is highly turbulent and contains back flows. Also flows that hit the Pitot tube from the side or in big angles can induce lower measured velocities.

From the appropriate formulas for calculating and plotting the coefficient of pressure Cp to determine the drag coefficient, Cd the above graphs shows us that:

- At elevated speeds the anticipated amount of lift and speed must be lower.
- Greater wind speed resulted in a larger speed coefficient
- The pressure on the circular cylinder seems to be higher at increased wind speeds from low to medium to high. We could presumably say that this is consistent with the theoretical aspect of flight control and aerodynamics.

  Note: The estimations of the quantities in dependency of the wind velocity, drag force and Reynolds Numbers are found on the attached excel file data sheets.

Conclusion and Recommendations:

This lab was successful in introducing and utilizing a variety of statistical concepts and their uses in describing data. Using the statistical analysis tools shown in this experiment were very helpful in organizing the data, identifying any outliers, being able to show trends and compare them. Understanding of key concepts such as drag and how it affects any design or system is very important. The two key components of the momentum suffered by the fluid, air, is this system are skin friction and form drag. Both of these interrupt the ideal laminar of the fluid. At the front of the cylinder the pressure is about equal to the stagnation pressure and, from there, start to accelerate further around the curved surface the readings are taken. This acceleration causes a drop in pressure relative to the position on the cylinder. These readings do accelerate until about 90/ 270 degrees from 0/180 degrees then the pressure slowly if not exactly linearly until it then levels off as the flow becomes more turbulent. All of the data that we collected in this experiment seems to support this conclusion at each of the three measured speeds.