

Fluid Mechanics Lab Report - Avanthika Vuppala

Introduction:

The objective of this experiment was to determine the drag force acting on a cylinder placed in a wind tunnel by analyzing the velocity profile in its wake. Instead of measuring drag directly, a control volume approach was used to relate the loss of momentum in the wake to the force acting on the cylinder. A pitot static tube was used to measure pressure differences at multiple vertical positions downstream of the cylinder. These pressure measurements were then used to calculate the local velocity using Bernoulli's equation. By evaluating the velocity deficit in the wake, the drag force was determined through numerical integration. This method is commonly used in fluid mechanics when direct force measurements are difficult, and it provides a practical application of momentum conservation.

Theory:

The drag force on the cylinder is determined by analyzing the change in momentum of the fluid as it flows past the object. When air flows around the cylinder, a wake forms behind it where the velocity is lower than the upstream flow. This reduction in velocity represents a loss of momentum, which is directly related to the drag force acting on the cylinder. By comparing the uniform inlet velocity to the velocity distribution in the wake, the total momentum deficit can be calculated and used to determine the drag force. The velocity at each point in the wake is found using pressure measurements from the pitot static tube, which relates pressure differences to flow speed. Additionally, the density of the air is needed to relate velocity and momentum, and it is determined based on the measured temperature and standard atmospheric conditions. This method lets us calculate drag indirectly using the flow data instead of measuring the force directly.

Methodology:

Three experimental runs were performed at different wind tunnel speeds. For each run, pressure data was collected at multiple vertical positions behind the cylinder using a pitot static probe. The data was processed in Excel. Position values were converted from inches to meters. The provided pressure data in Pascals was used to calculate velocity using Bernoulli's equation. Air density was calculated using a temperature of 23.7°C and standard atmospheric pressure. The upstream velocity U_1 was estimated using the maximum velocity value in each dataset. The integrand $u(y)(U_1 - u(y))$ was computed at each position. Numerical integration was then performed using the trapezoidal rule by calculating the area between each pair of points and summing all contributions. The drag force was calculated by multiplying the total integral by ρW , where the tunnel width was 0.1524 m. All calculations were completed manually in Excel without using built in numerical integration functions.

Results:

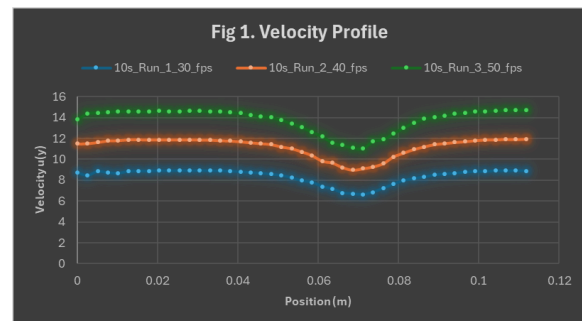


Figure 1 shows the wake velocity profiles for all three runs. In each case, the velocity decreases in the middle region of the flow, which represents the wake behind the cylinder. This drop in velocity indicates a loss of momentum caused by the presence of the cylinder. As the inlet velocity increases from Run 1 to Run 3, the overall velocity increases and the depth of the velocity deficit becomes more pronounced. This indicates that the wake becomes stronger at higher flow speeds. The profiles are smooth and

relatively symmetric, suggesting consistent measurements. A smooth best fit curve was applied to each dataset to better represent the wake velocity profile for each run.

The calculated values are summarized below:

Run	U1 (m/s)	Drag (N)
1	8.952583	0.081882
2	11.89452	0.147276
3	14.6283	0.220876

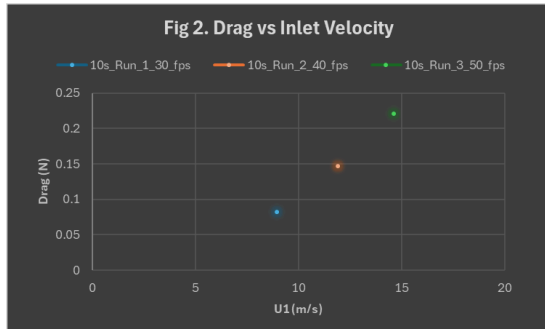


Figure 2 shows the relationship between drag force and inlet velocity. The drag force increases as the inlet velocity increases, which is expected since higher velocities result in greater momentum loss in the wake.

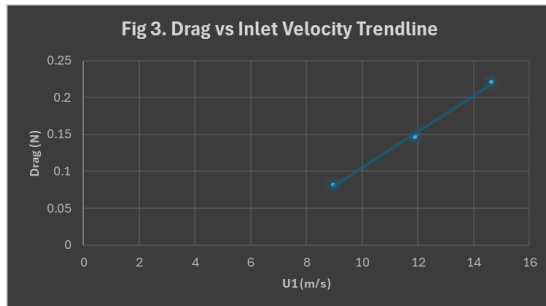


Figure 3 includes a trendline fitted to the drag data. The curve shows that drag does not increase linearly with velocity but instead follows a nonlinear trend. This suggests that drag is approximately proportional to the square of the velocity.

Overall, the results show a clear relationship between wake behavior and drag force. As the velocity increases, the wake becomes stronger and the drag force increases accordingly.

Discussion:

The results are consistent with theoretical expectations. As the inlet velocity increases, the momentum deficit in the wake increases, leading to a higher drag force. This behavior aligns with the general drag relation. Although the data does not perfectly follow a quadratic curve, the trend clearly shows that drag increases more rapidly than linearly with velocity. This suggests that drag is approximately proportional to the square of the velocity, indicating a quadratic relationship. The wake profiles provide further insight into this behavior. At higher velocities, the velocity deficit is larger and extends over a wider region, indicating greater energy loss in the flow. This directly contributes to the increase in drag. Some deviations from ideal behavior are expected due to experimental limitations. The estimation of upstream velocity from the wake data introduces uncertainty, and small errors in pressure measurement can significantly affect the calculated velocity due to the square root relationship in Bernoulli’s equation.

Sources of Error:

Several sources of error may have affected the results. The pitot static tube may not have been perfectly aligned with the flow, which would impact the pressure readings. Fluctuations in the measured pressure values introduce uncertainty in the calculated velocities. The limited number of measurement points reduces the accuracy of the trapezoidal integration. Additionally, the upstream velocity was estimated rather than directly measured, which may introduce error. Small inaccuracies in unit conversion or data processing could also affect the final drag values.

All calculations were performed in Excel. The trapezoidal rule was implemented manually by calculating the area between each pair of adjacent data points and summing the results to evaluate the integral. No built in integration functions were used.