Part I. Problem Setup

Task 1.1

Calculate the problem Reynolds number ($Re = U_\infty D/\nu$) and confirm that the flow is laminar.

The working fluid is air. The properties of air at 25°C and 1 atm are taken from a textbook [1].

$$\begin{aligned}
\rho &= 1.184 \text{ kg/m}^3 \\
\mu &= 1.562 \times 10^{-5} \text{ kg/ms} \\
\nu &= \frac{\mu}{\rho} = 1.318 \times 10^{-5} \text{ m}^2/\text{s}
\end{aligned}$$

The Reynolds number is calculated as

$$\begin{aligned}
\text{Re} &= \frac{U_\infty D}{\nu} \\
&= \frac{0.24 \times 0.1}{1.318 \times 10^{-5}} \\
&= 1820.9
\end{aligned}$$

This is less than the critical Reynolds number of 2000, so the flow is laminar.

Task 1.3

Generate a CAD model for dimensions and the simulation setup discussed above (i.e., Figure 1) using ANSYS Design Modeler.

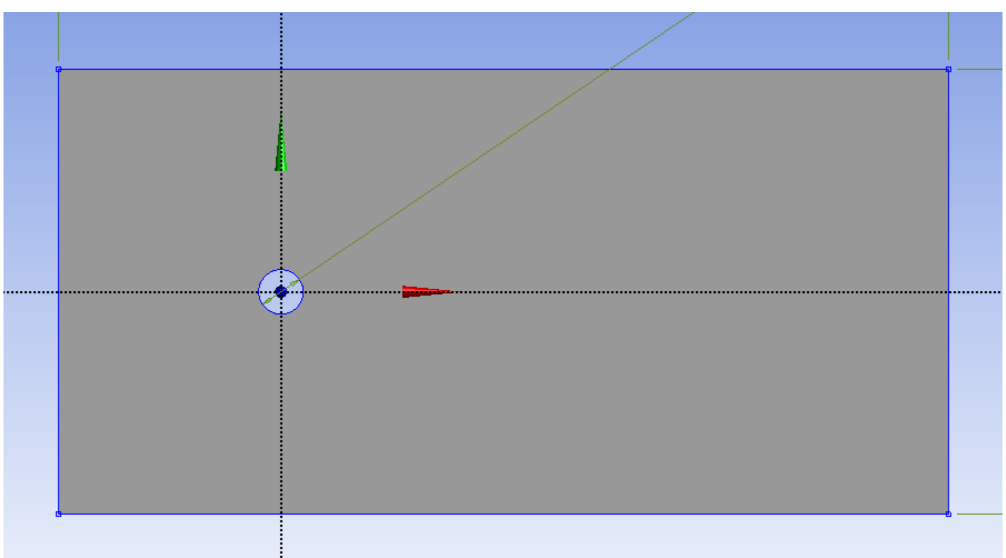

Figure 1: Geometry for the Flow Past a Circular Cylinder

Task 1.4

Generate a moderately fine mesh for the geometry built in the previous step. The minimum element length is D/5, which should be labeled "Grid 1". You should place 5 Prism Layers (Inflation Layers) around the cylinder at a "Transition Ratio" of 0.25, and "Growth Rate" of 1.2.

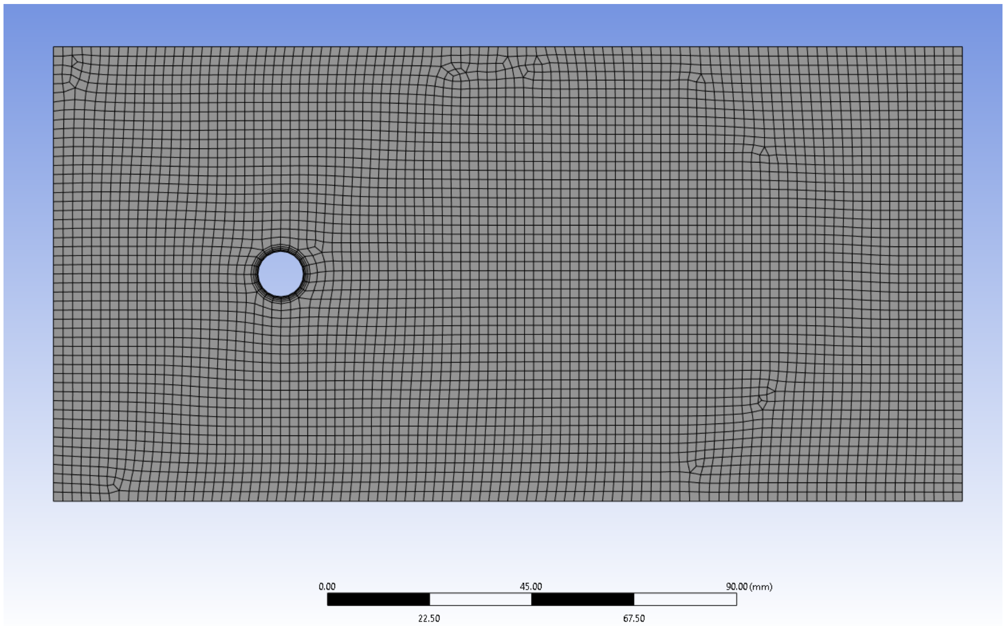

Figure 2: Mesh for Grid 1

Part II. Reference Simulation

Summary for Grids 1, 2, 3, and 4

Table 1: Summary of Results for Grids 1, 2, 3, and 4 (for ease of marking)

Grid	F_D (N)	C_d	L_r
1	4.08667×10^{-7}	1.2×10^{-4}	32.5
2	3.97047×10^{-7}	1.16×10^{-4}	43.0
3	3.97047×10^{-7}	1.16×10^{-4}	44.0
4	3.92433×10^{-7}	1.15×10^{-4}	44.0

Task 2.1

Complete the simulation of laminar flow of air over a 2D circular cylinder using "Grid 1". The pressure-velocity coupling scheme should be set as "Coupled". Spatial discretization methods for pressure and momentum should be second order accurate. You can change the solver method under Solution in ANSYS Fluent.

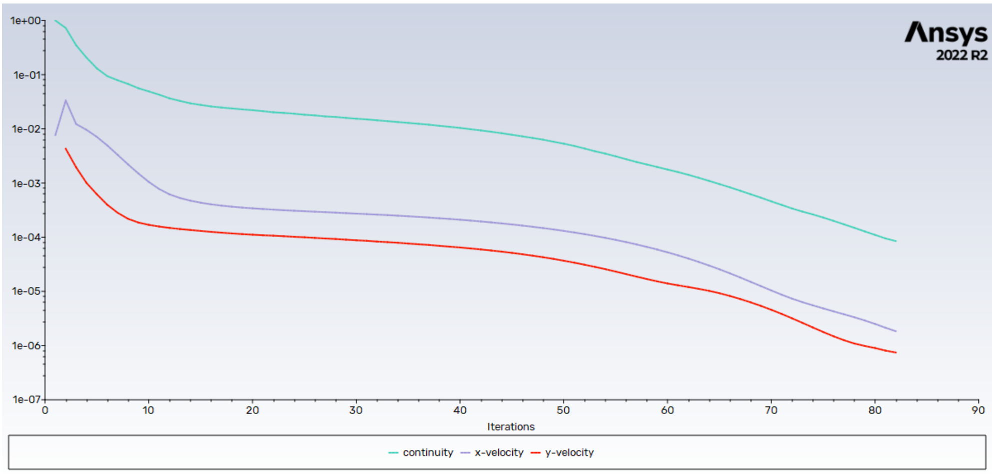

Figure 3: Residuals for Grid 1

Task 2.2

(I) Calculate the Mean Drag Force (force acting in the x-direction) acting on the cylinder.

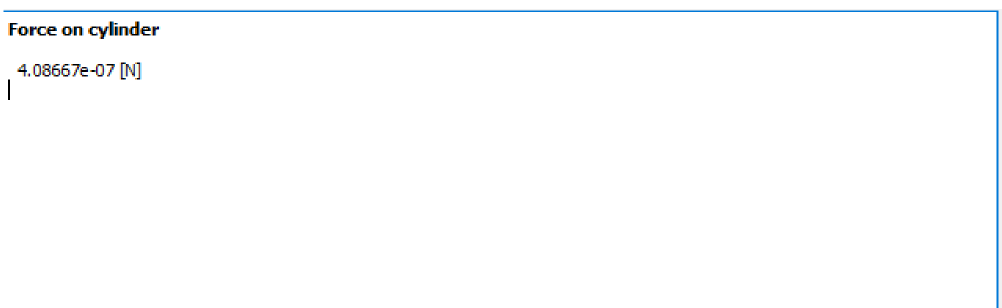

Figure 4: Mean Drag Force for Grid 1

(II) Calculate the Mean Drag Coefficient ($C_d = F_D/(0.5\rho U_\infty^2 D)$) for the cylinder.

By direct calculation, the mean drag coefficient is

$$\begin{aligned} C_{d1} &= \frac{F_{D1}}{0.5\rho U_\infty^2 D} \\ &= \frac{4.08667 \times 10^{-7}}{0.5 \times 1.184 \times 0.24^2 \times 0.1} \\ &= 1.2 \times 10^{-4} \end{aligned}$$

(III) Draw the plot of mean streamwise (x-direction) velocity (u) along the wake centerline (the horizontal line that starts at the center of the cylinder and extends to the end of the computational domain - only in the x-direction). Note the x-location at which this line crosses zero for the first time. This is referred to as the "Mean Recirculation Length" (L_r). Normalize this number using the problem characteristic length, which is the cylinder diameter (D).

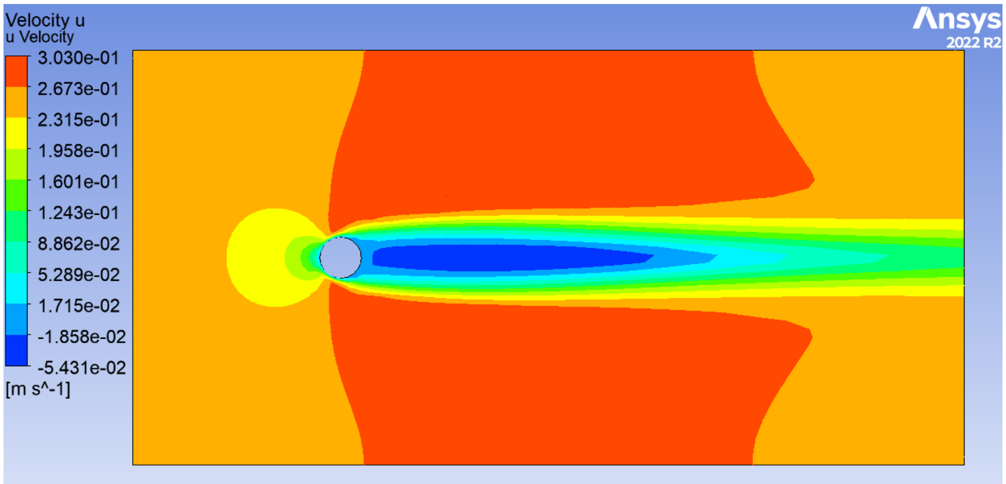

Figure 5: Mean Streamwise Velocity Contour for Grid 1

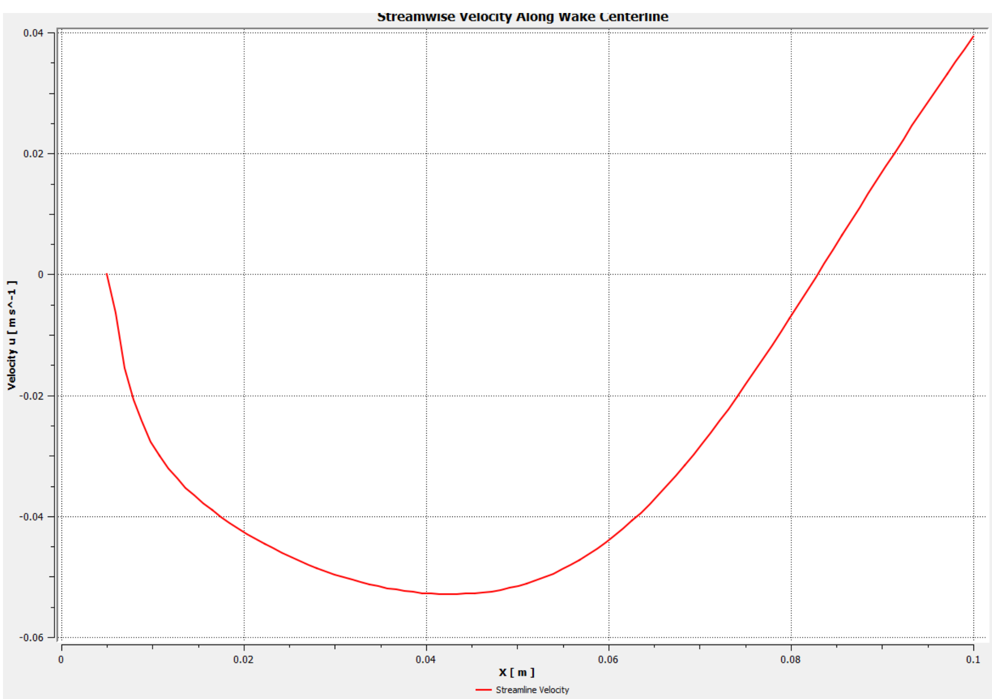

Figure 6: Mean Streamwise Velocity for Grid 1

From the plot, the recirculation length is approximately

$$L_{r1} = \frac{0.0825 - 0.05}{0.001}$$
$$= \boxed{32.5}$$

(IV) Create a contour plot of mean pressure (p) in the wake. Adjust the values of maximum and minimum pressure so that the recirculation vortex is distinguishable from the flow.

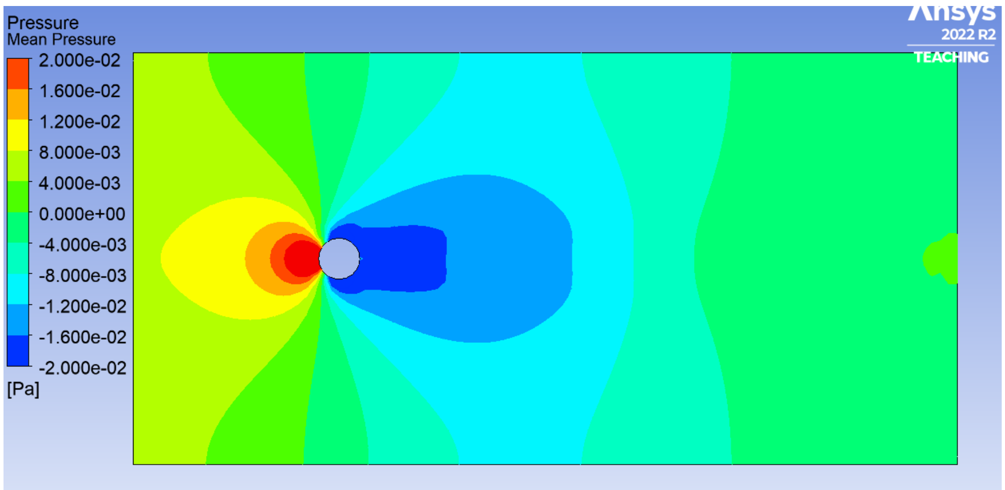

Figure 7: Mean Pressure Contour for Grid 1

(V) Has the solution converged? Do you believe that the results illustrate a steady state solution of the wake? Please justify your answer.

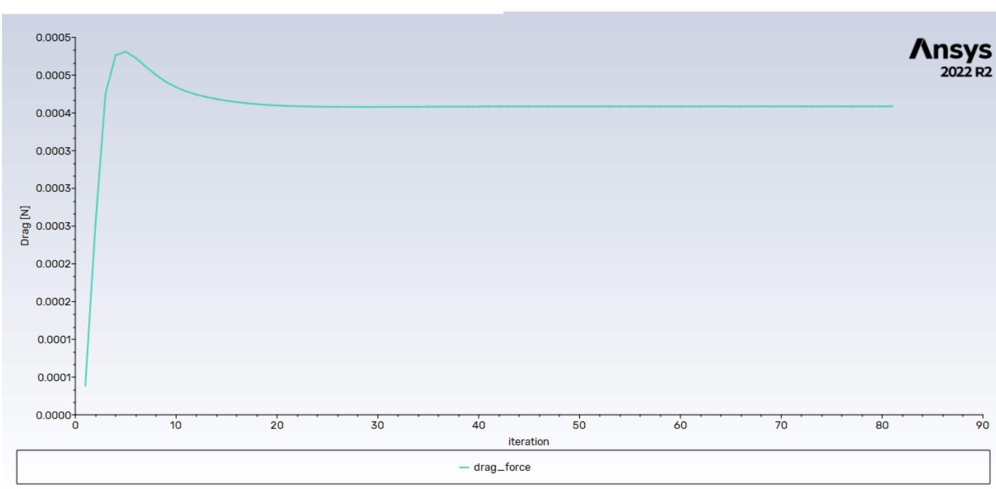

Figure 8: Drag force over iterations for Grid 1

The drag force converges to a constant steady-state value.

Part III. Grid Independence Analysis

Task 3.1

Create a new case in ANSYS Workbench called "Grid 2" and changed the minimum mesh size to $D/10 \approx 1$ mm. You should place at least 10 Prism Grid around the cylinder. Then, redo all tasks and complete the simulations. Re-generate all the plots and calculations from Task 2.2 for "Grid 2".

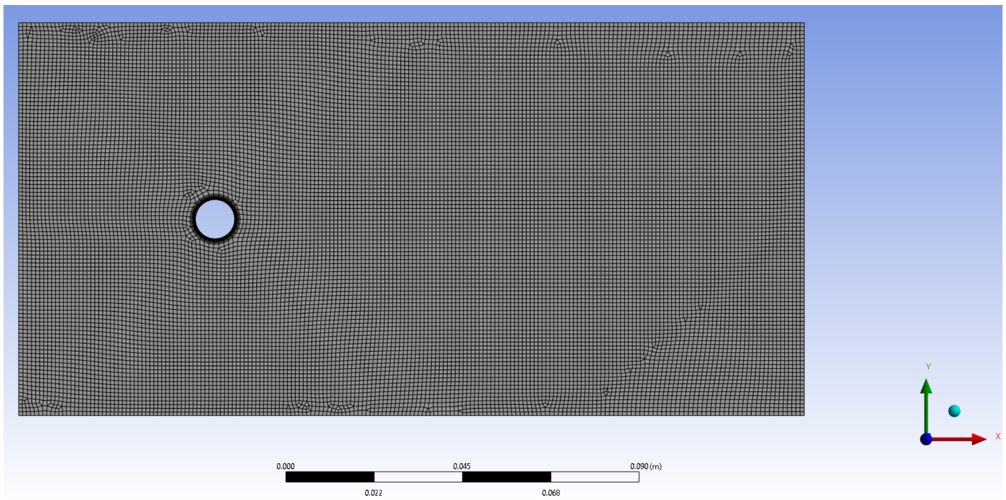

Figure 9: Mesh for Grid 2

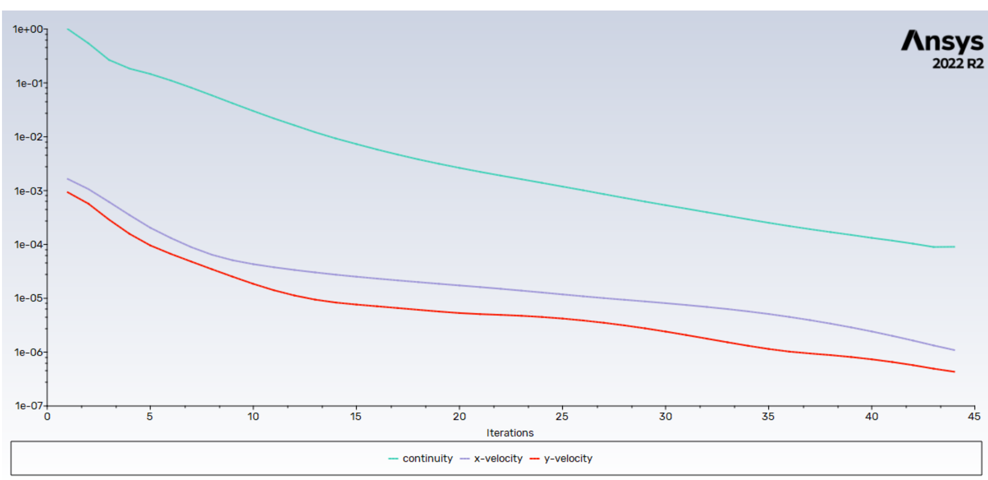

Figure 10: Residuals for Grid 2

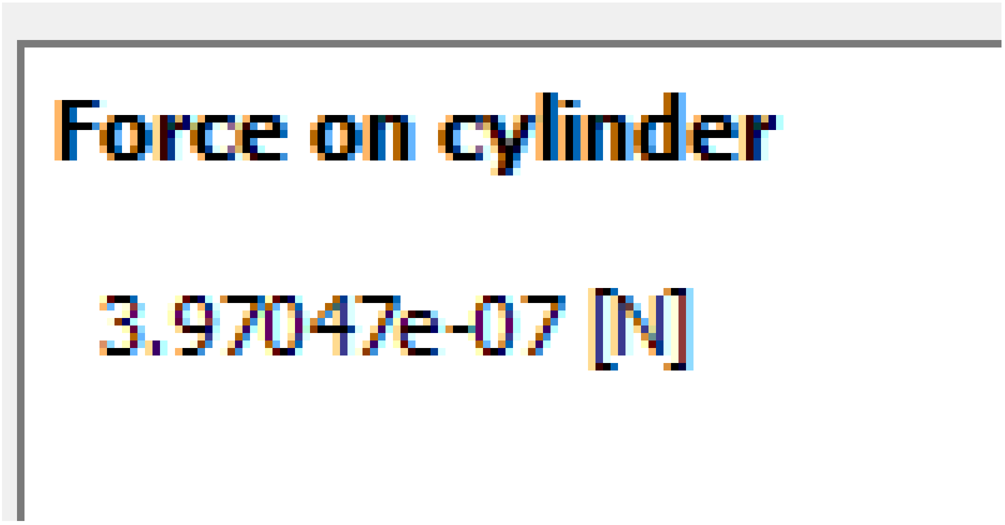

Figure 11: Mean Drag Force for Grid 2

By direct calculation, the mean drag coefficient is

$$\begin{aligned} C_{d2} &= \frac{F_{D2}}{0.5\rho U_\infty^2 D} \\ &= \frac{3.97047 \times 10^{-7}}{0.5 \times 1.184 \times 0.24^2 \times 0.1} \\ &= 1.16 \times 10^{-4} \end{aligned}$$

From the plot, the recirculation length is approximately

$$\begin{aligned} L_{r2} &= \frac{0.093 - 0.05}{0.001} \\ &= \boxed{43.0} \end{aligned}$$

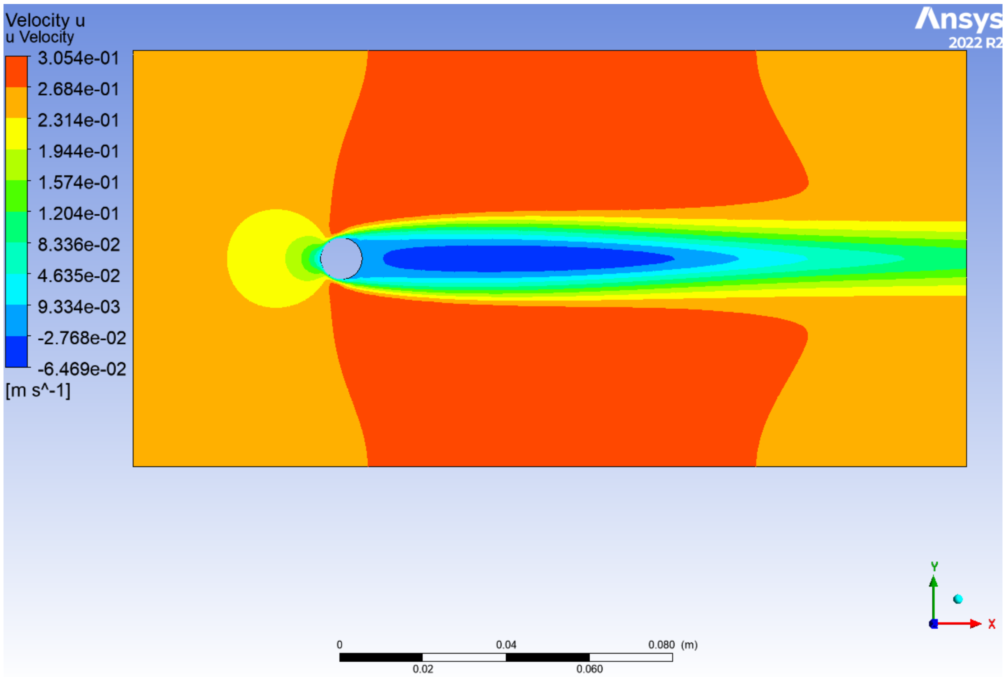

Figure 12: Mean Streamwise Velocity Contour for Grid 2

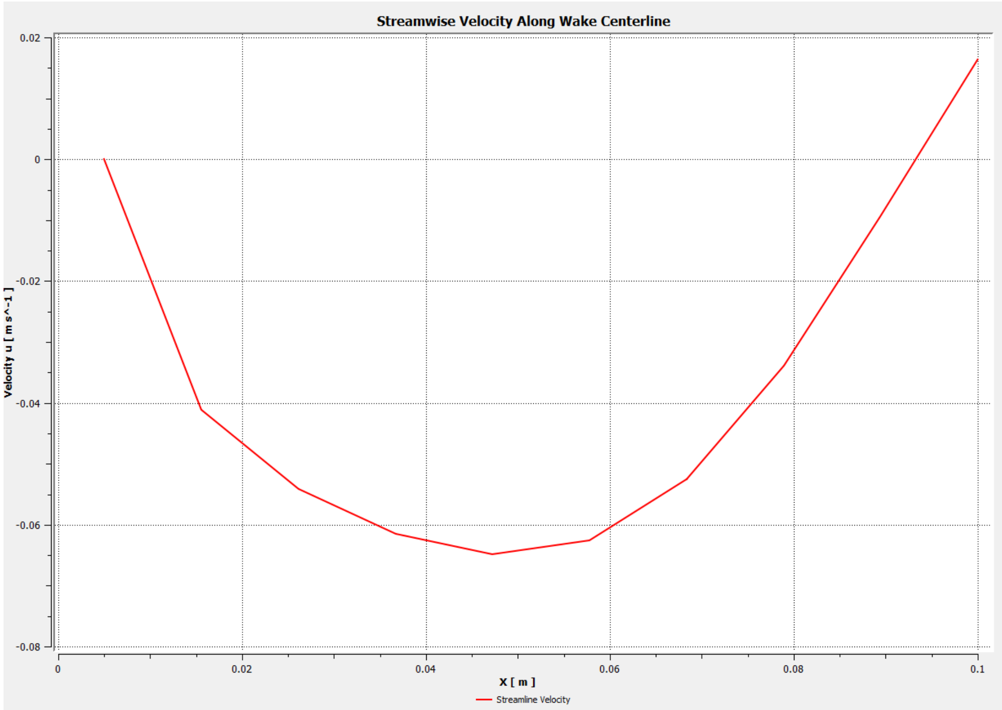

Figure 13: Mean Streamwise Velocity for Grid 2

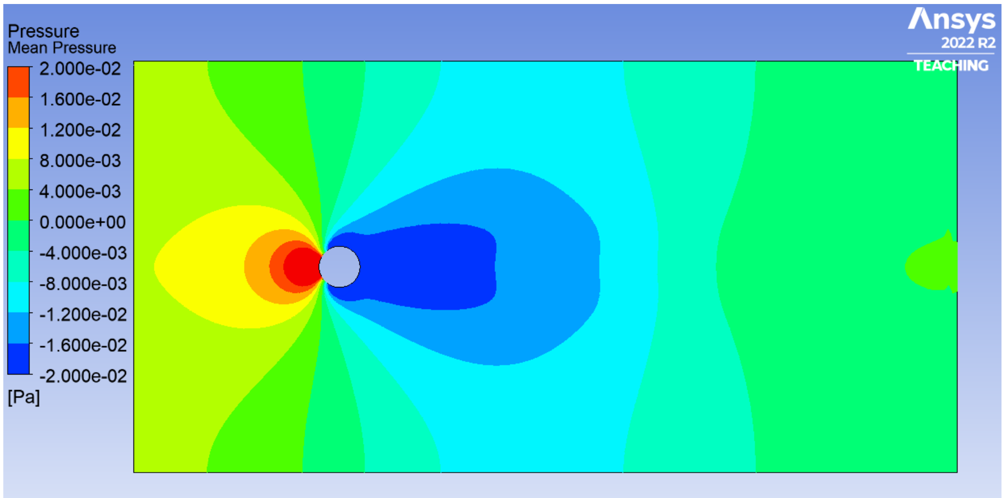

Figure 14: Mean Pressure Contour for Grid 2

Task 3.2

Create two more case in ANSYS Workbench "Grid 3" and "Grid 4" using ANSYS Fluent and change the minimum mesh size to $D/15 \approx 0.667$ mm and $D/20 \approx 0.5$ mm. Complete the simulations and re-generate all the plots and calculations from Task 2.2 for "Grid 3" and "Grid 4".

Grid 3

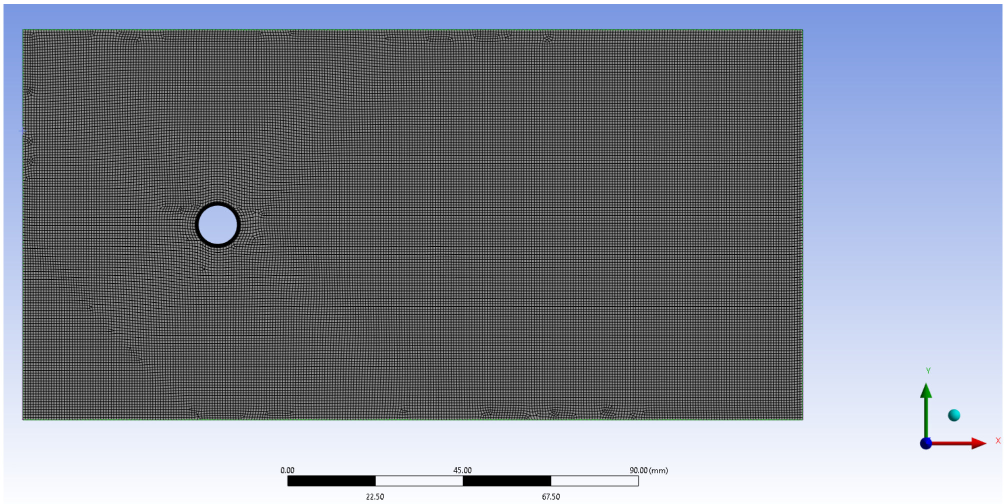

Figure 15: Mesh for Grid 3

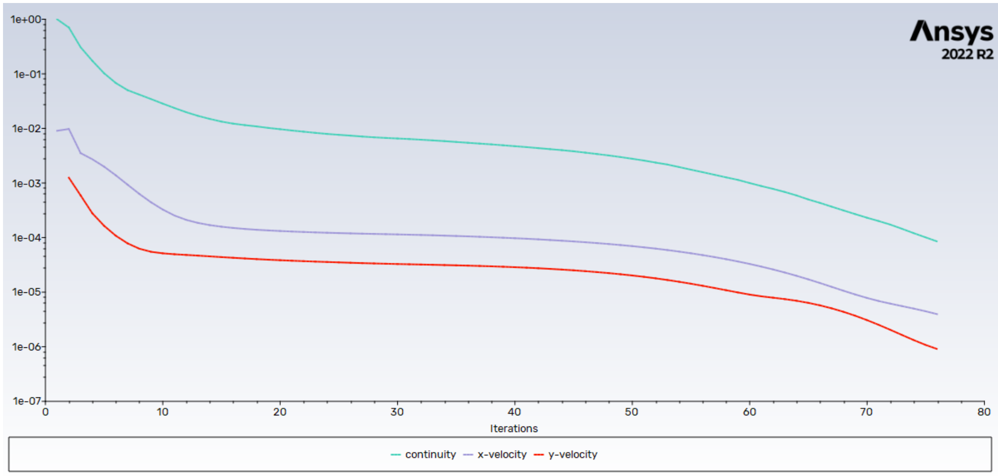

Figure 16: Residuals for Grid 3

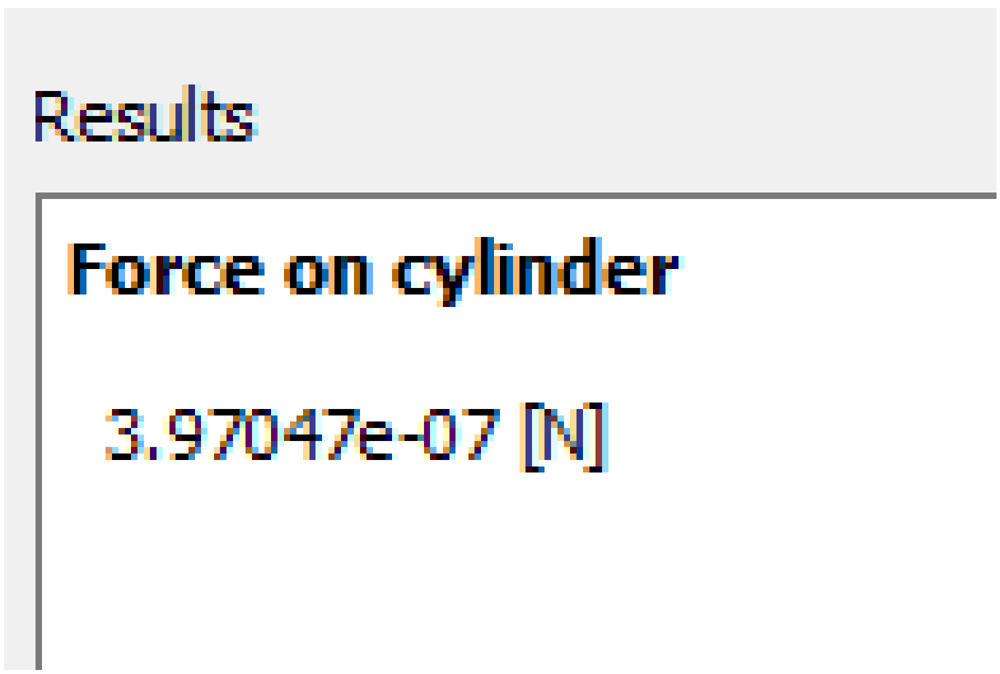

Figure 17: Mean Drag Force for Grid 3

By direct calculation, the mean drag coefficient is

$$\begin{aligned} C_{d3} &= \frac{F_{D3}}{0.5\rho U_\infty^2 D} \\ &= \frac{3.97047 \times 10^{-7}}{0.5 \times 1.184 \times 0.24^2 \times 0.1} \\ &= 1.16 \times 10^{-4} \end{aligned}$$

From the plot, the recirculation length is approximately

$$\begin{aligned} L_{r3} &= \frac{0.094 - 0.05}{0.001} \\ &= \boxed{44.0} \end{aligned}$$

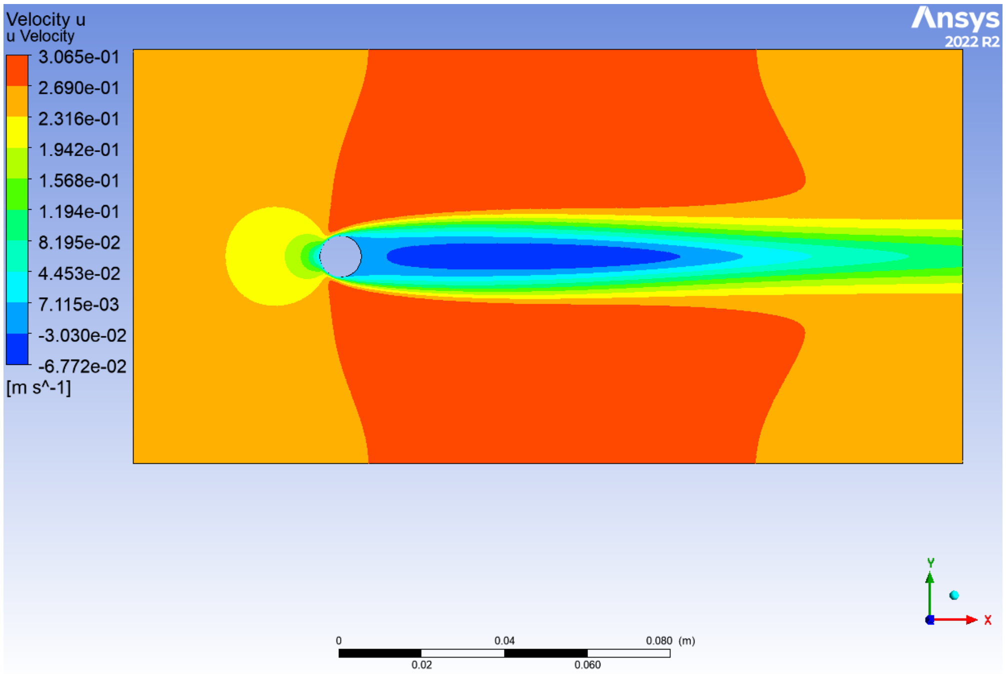

Figure 18: Mean Streamwise Velocity Contour for Grid 3

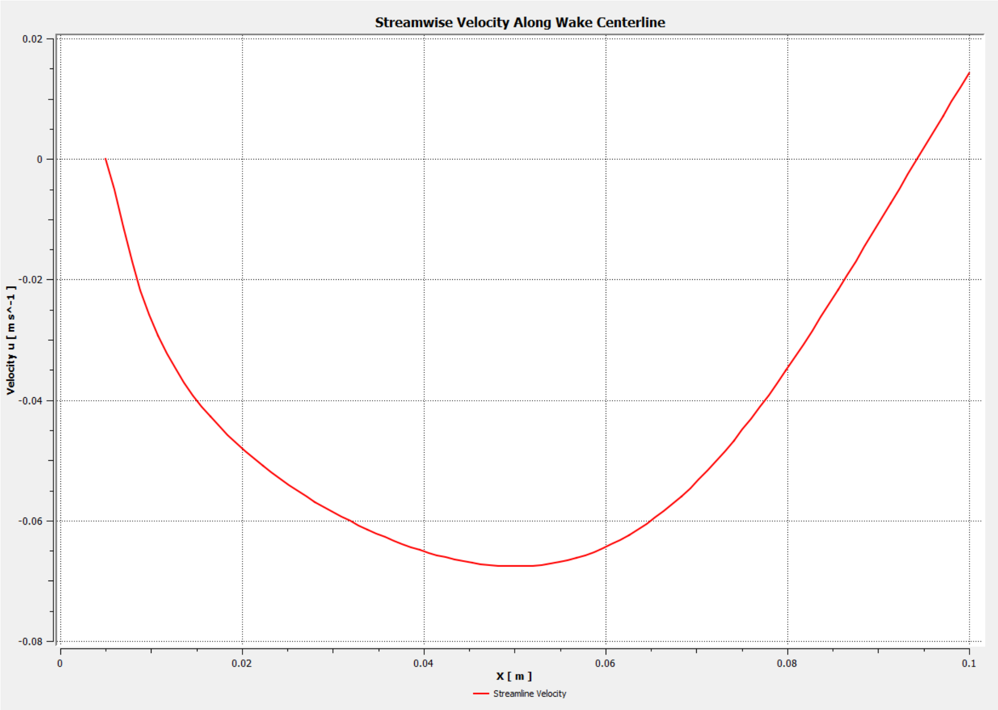

Figure 19: Mean Streamwise Velocity for Grid 3

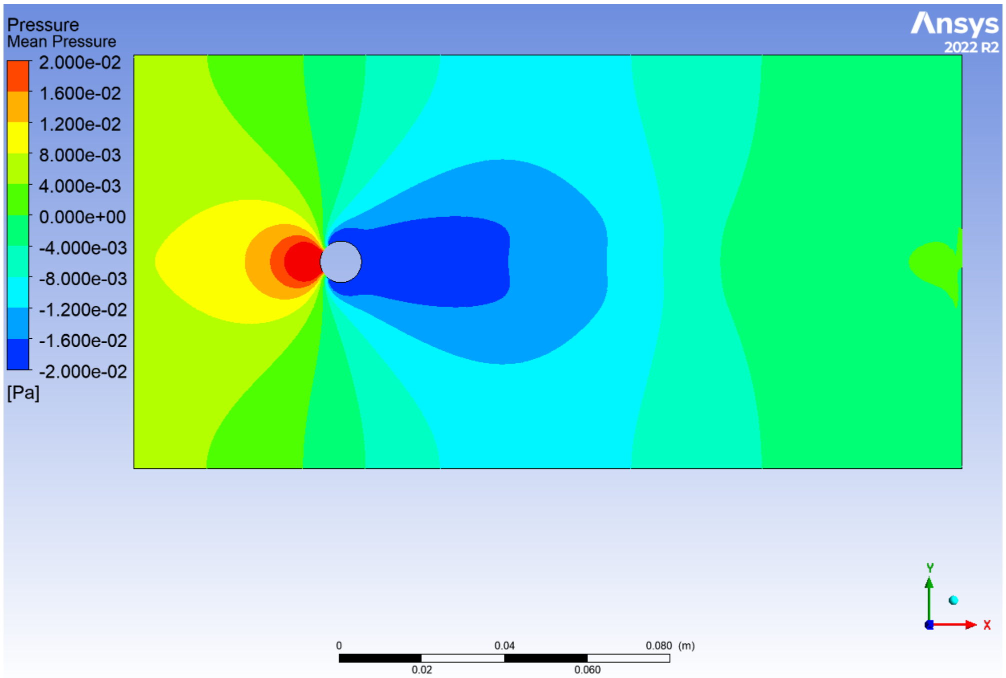

Figure 20: Mean Pressure Contour for Grid 3

Grid 4

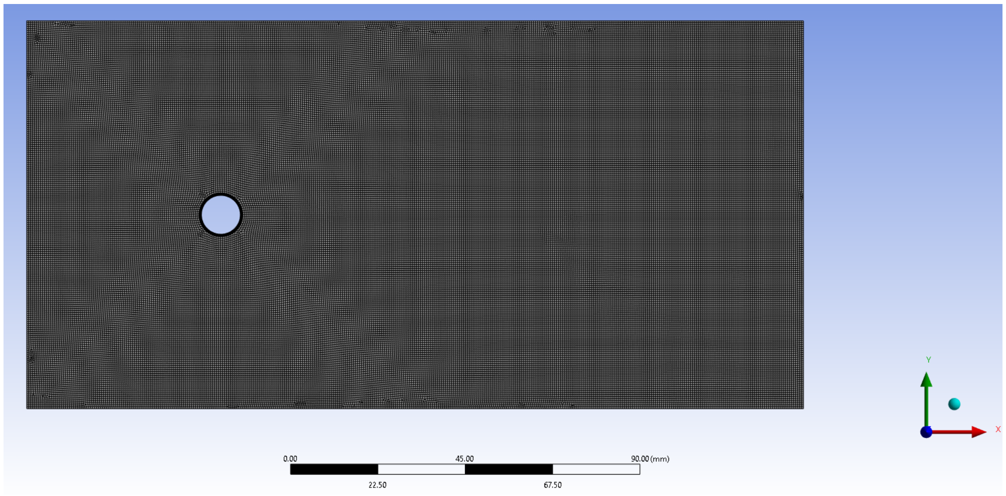

Figure 21: Mesh for Grid 4

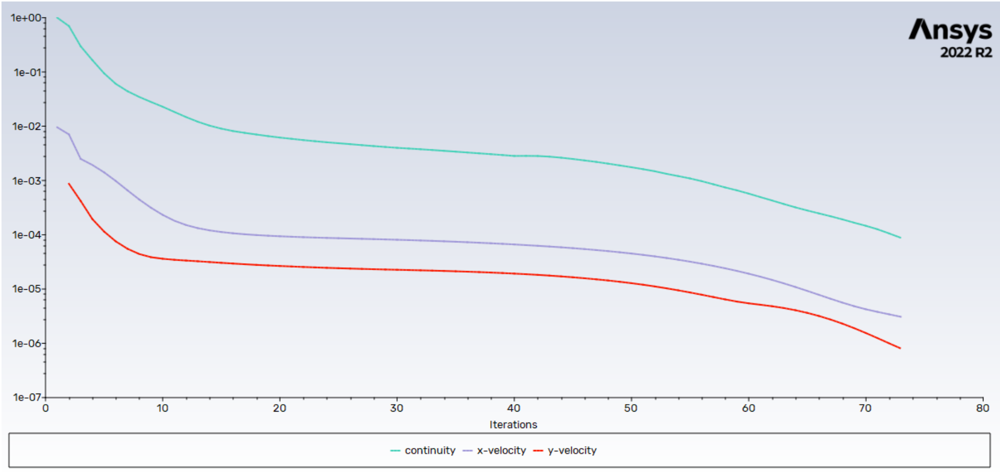

Figure 22: Residuals for Grid 4

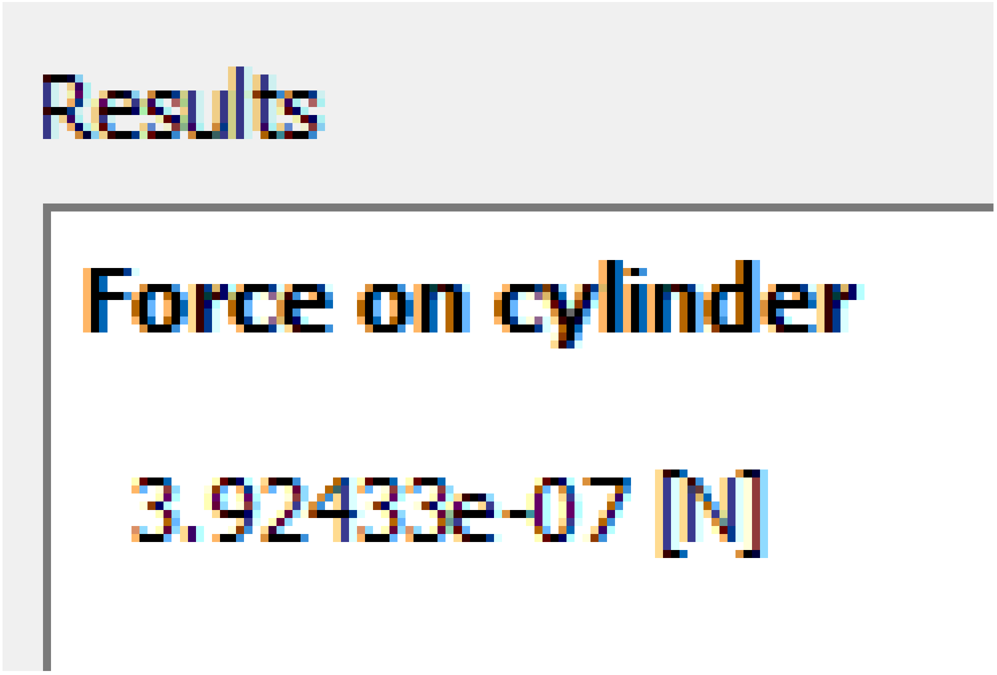

Figure 23: Mean Drag Force for Grid 4

By direct calculation, the mean drag coefficient is

$$
\begin{aligned}
C_{d4} &= \frac{F_{D4}}{0.5\rho U_\infty^2 D} \\
&= \frac{3.92433 \times 10^{-7}}{0.5 \times 1.184 \times 0.24^2 \times 0.1} \\
&= 1.15 \times 10^{-4}
\end{aligned}
$$

From the plot, the recirculation length is approximately

$$
\begin{aligned}
L_{r4} &= \frac{0.094 - 0.05}{0.001} \\
&= \boxed{44.0}
\end{aligned}
$$

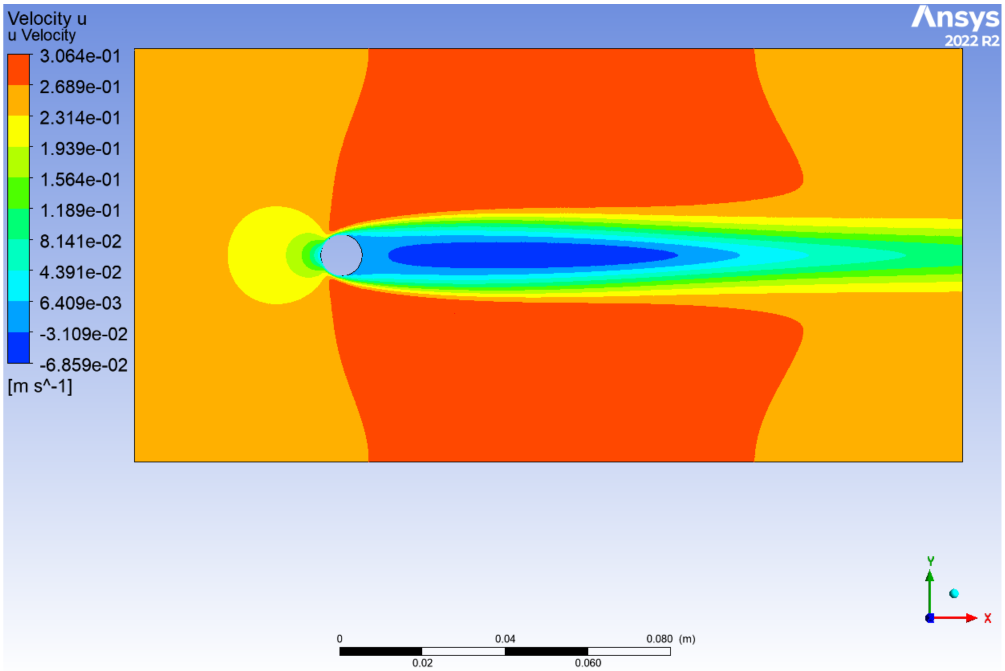

Figure 24: Mean Streamwise Velocity Contour for Grid 4

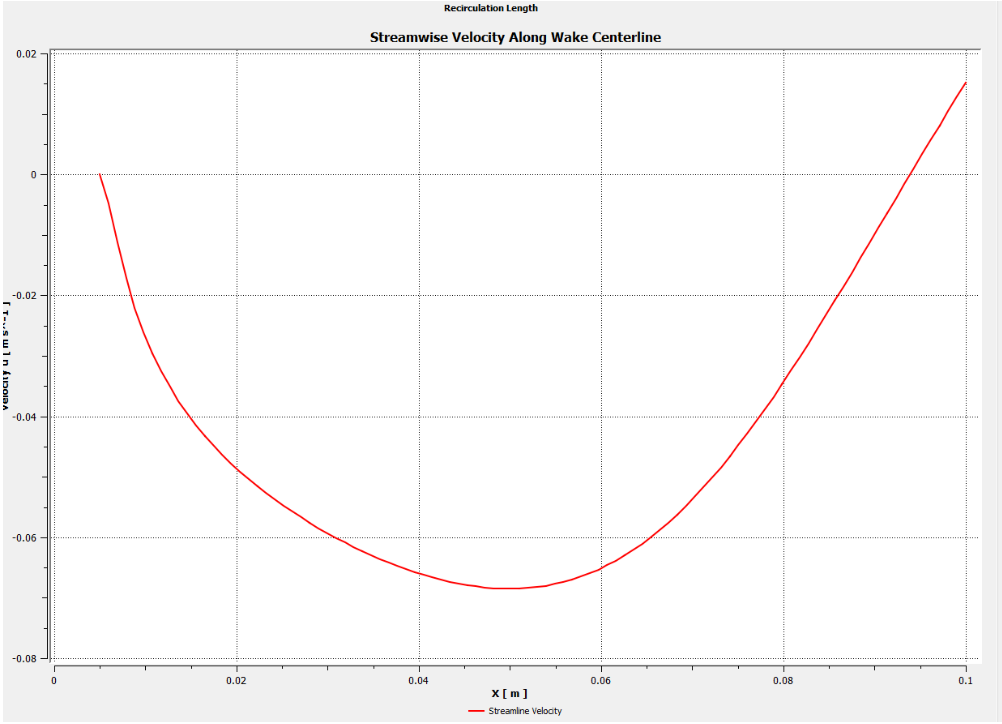

Figure 25: Mean Streamwise Velocity for Grid 4

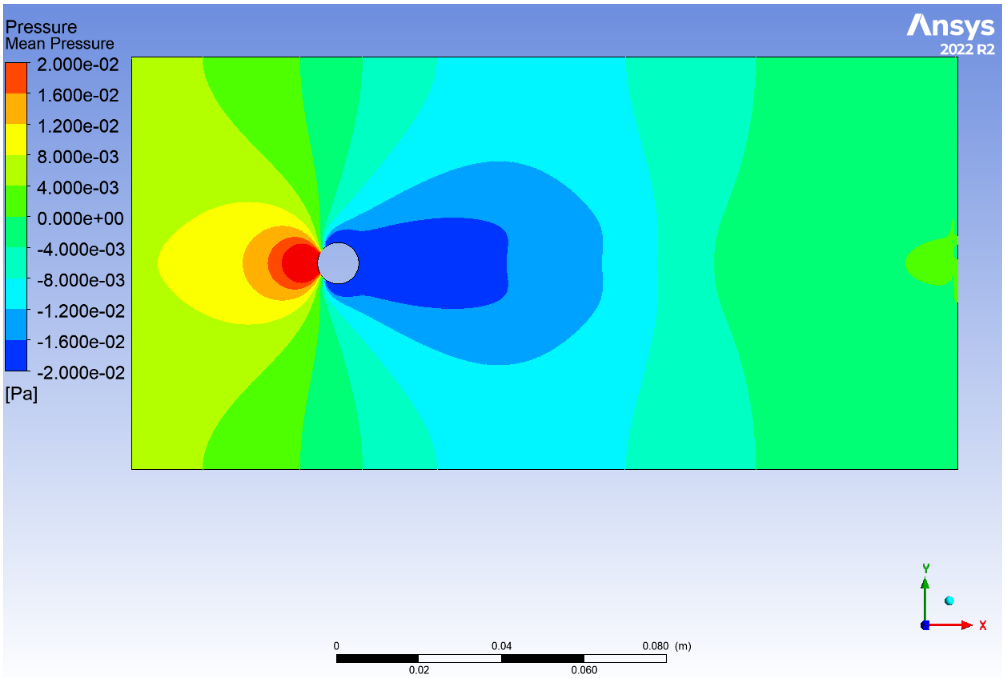

Figure 26: Mean Pressure Contour for Grid 4

References

[1] Y. A. Cengel and J. M. Cimbala, *Fluid mechanics: Fundamentals and applications*. Columbus, OH: McGraw-Hill Education, 4 ed., Feb. 2017.