AEE 558 - CFD

FLOW OVER BACKWARD FACING STEP

2D LAMINAR AND TURBULENT FLOW

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HW - 5

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INTRODUCTION

Backward-Facing Step (BFS) flow is a representative model for separation flows that can be found in a variety of places, including aerodynamic flows (airfoil, spoiler, high attack angle process), engine flows, condensers, vehicles (cars, boats), heat transfer systems, and even the flow around buildings. The creation, evolution, and re-attachment of separating bubbles after a basic stage is influenced by the BFS geometric design, inlet and outlet parameters, turbulence intensity, and heat transfer conditions. Various theoretical, experimental, and numerical methods have been used to study it over the last few decades. [1]

Separating and reattaching flows in channels, frequently in conjunction with recirculation bubbles, is a common industrial challenge. Such patterns are common in heat exchanger flows, for example. Despite the complexity of the flow topology, the Navier–Stokes equations describe the full behavior of most fluid flows. Because these equations rarely offer known analytical solutions, several numerical approaches have been devised to solve them over time. The finite element formulation, or, more commonly, the finite volume method, can be used to discretize the space. The flow around a backward-facing step can be considered to have a fairly simple geometry while preserving rich flow features like separation and recirculation bubbles.[2]

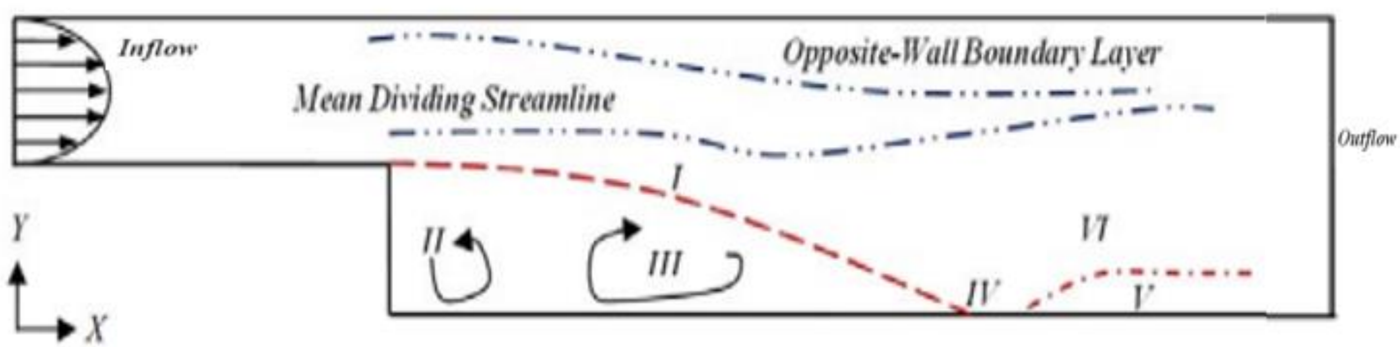

Figure 1 FLOW OVER A BACKWARD FACING STEP [3]

In this Project, we consider a 2D laminar and 2D turbulent flow around a Backward Facing Step(BFS) and using Cradle CFD we describe a 2D laminar and 2D Turbulent flow over the 2D BFS.

Laminar Flow

Considering a laminar flow over the Backward facing step and this Is used for Validation of numerous flow characteristics and has applications in combustion and HVAC. We assume the characteristic length of the step height is unity. The fluid properties at the inlet are taken as follows $u_x = 1$ m/s, $u_y = 0$ m/s, $\rho = 1$ kg/m^3 , and $\mu = 0.02$ Ns/m^2 yielding a Reynolds number of Re = 50. No-slip condition is applied both on the outlet boundary and the rest of the computational walls. Creating an appropriate mesh to show the plot of the convergence histories, pressure contours in the entire domain, velocity and the streamlines using Cradle CFD.

A grid convergence study for the reattachment location is targeted, with three different mesh densities to determine the sensitivity of the mesh to the reattachment point of the recirculation zone.

While creating the mesh we concentrate the mesh refinement over the walls of the Backward Facing Step as to get a much accurate result.

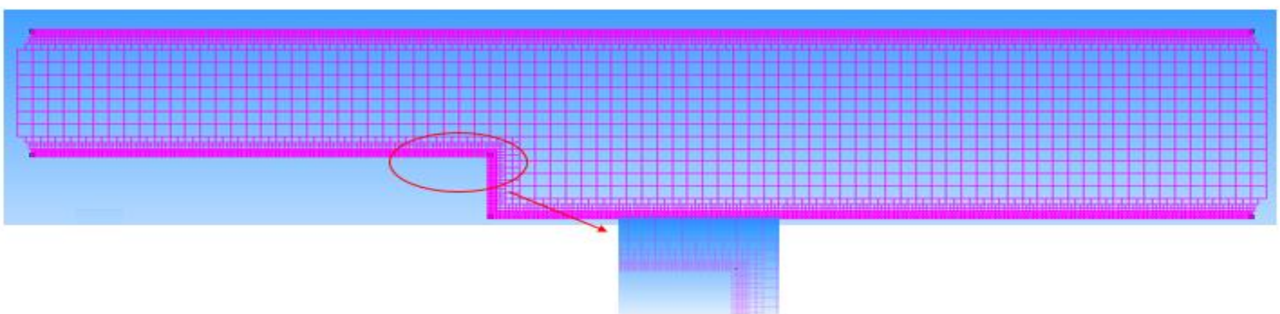

Figure 2 Octree

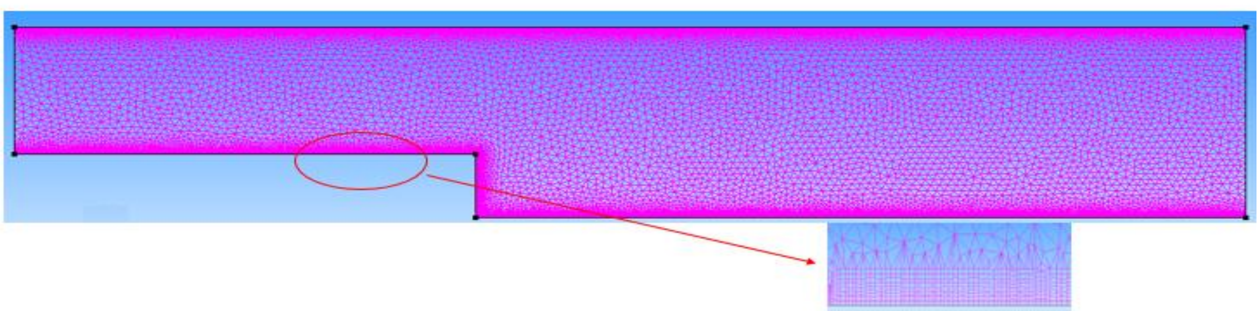

Figure 3 Mesh with prism layer

The calculated values for three different mesh densities are shown below in the table.

Mesh	1/No. of Cells	Reattachment point
Coarse	0.0001226993865	2.5621
Medium	0.00005576311827	2.6418
Fine	0.00001759262517	2.7883

Since we do not have the exact error values we use $N^{-p/d}$ for cells in our grid convergence study, where cradle is second order so p=2 and the dimension d=2.

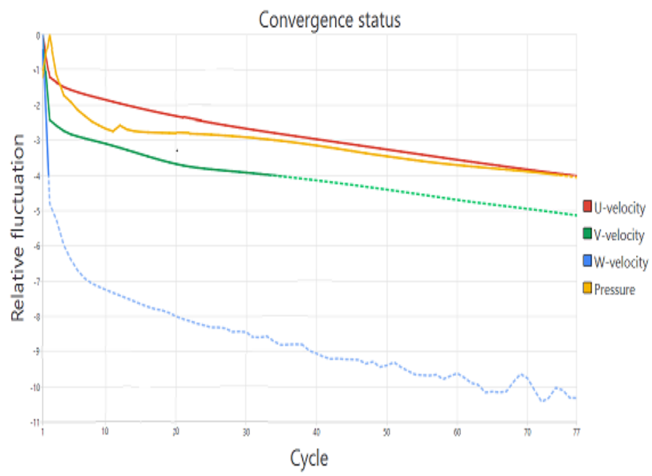

Figure 4 Convergence history

Figure 5 Pressure distribution over the BFS

The results converge in 77 cycles for coarse mesh, 94cycles for the medium mesh, and 300 cycles for fine mesh. In figure 5 we can see that the pressure is low at the leading edge of the step formed by the laminar flow in front of the BFS. At the inflow location of the BFS, we notice that there are bits of high pressure at the corners of the walls.

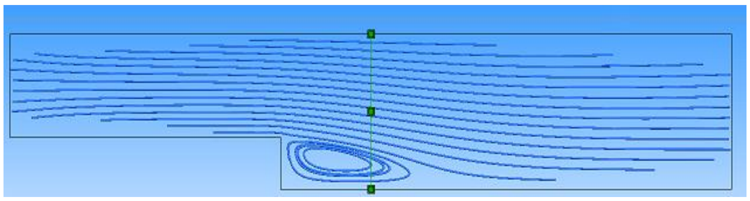

Figure 6 Streamlines of Laminar Flow around BFS

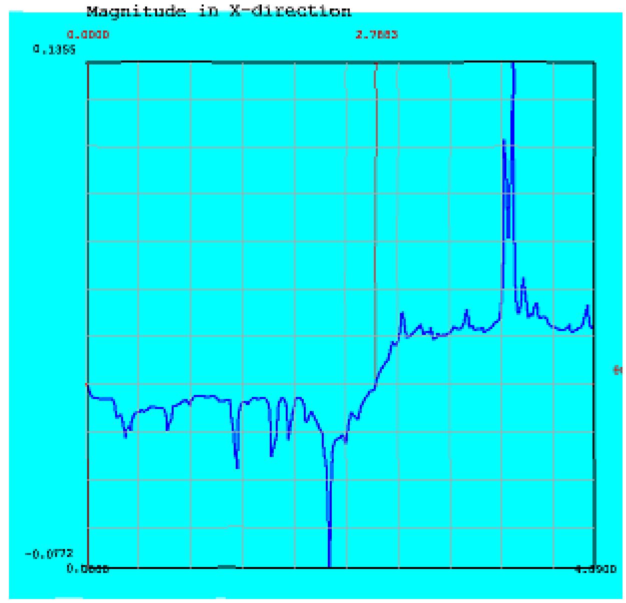

Figure 7 Velocity In X-direction

Figure 6 shows the streamlines around a BFS and it is noticed that the flow separates and reattaches near the step, i.e. the flow circulates near the step and figure 7 shows the plotted graph for the velocity in the X-direction where the X intercept is considered for the reattachment location value. Figure 8 shows the velocity vector of the laminar flow.

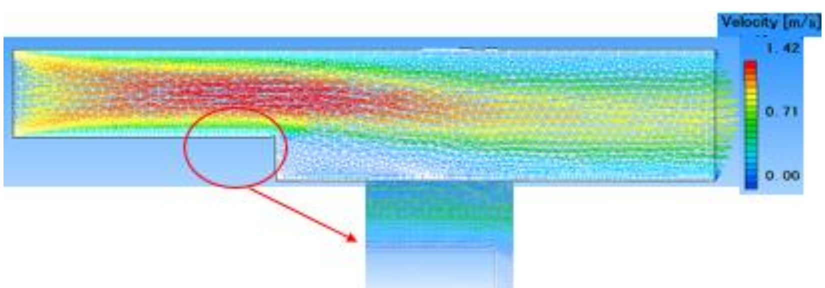

Figure 8 Velocity vectors over BFS

Below shown is the grid convergence study for three mesh resolutions and the Richardson's Extrapolation is found by extrapolating the line towards the y intercept.

The extrapolated value is approximately 2.6.

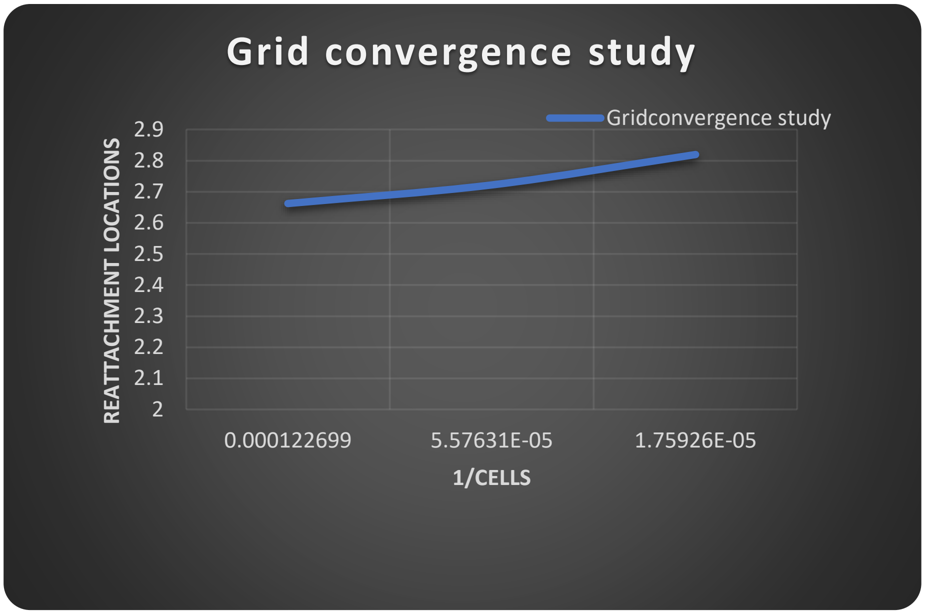

Figure 9 Grid convergence study

Turbulent Flow

Considering a 2D turbulent flow over the Backward facing step with Reynolds number of Re = 5100 and we take the characteristic length of the step height as h = 0.1 shown in figure 10. The fluid properties at the inlet are taken as follows u_x = 1 m/s, u_y = 0 m/s, ρ = 1 kg/m^3 , and µ = 1.96e^{-5} Ns/m^2. Similar to the laminar case the boundary specifications are the same with an incoming turbulent intensity of 10 % which corresponds to the turbulent kinetic energy of k = 0.015 m^2/s^2 at the inlet. The direct numerical simulations (DNS) has been determined that the reattachment of the separated boundary layer occurs on the bottom wall at x = 16.28h = 1.628m.

Creating an appropriate mesh to show the plot of the convergence histories, pressure contours in the entire domain, velocity, and the streamlines using Cradle CFD.

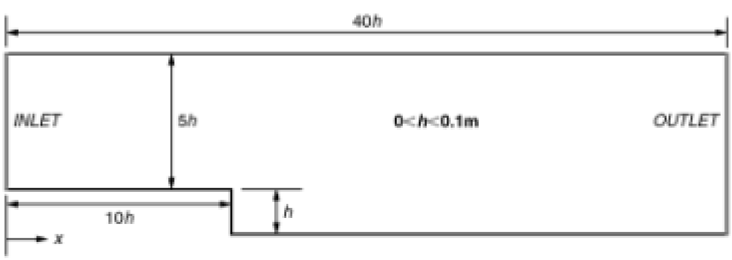

Figure 10 Geometry for turbulent flow over a backward-facing step

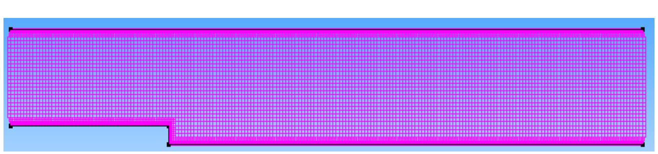

Figure 11 Octree (turbulent)

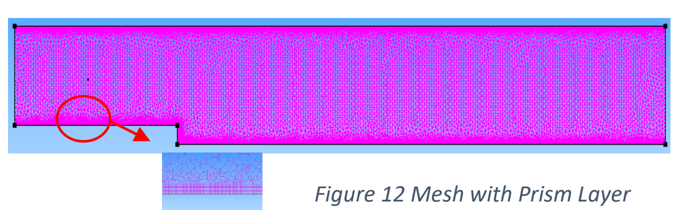

Figure 12 Mesh with Prism Layer

Figure 13 Pressure distribution over BFS(turbulent)

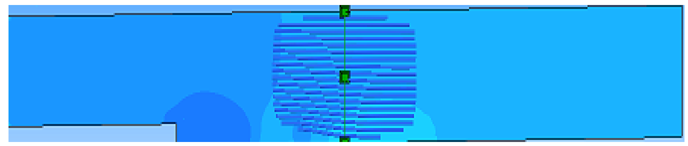

Figure 14 Streamlines over BFS

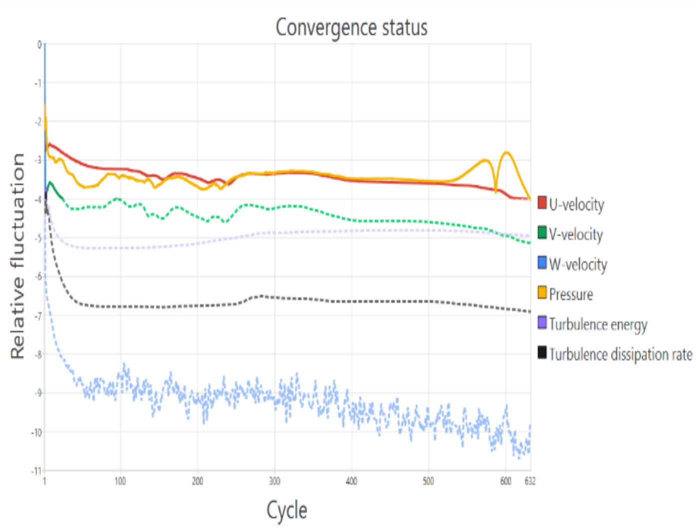

Figure 15 convergence history (K-ω)

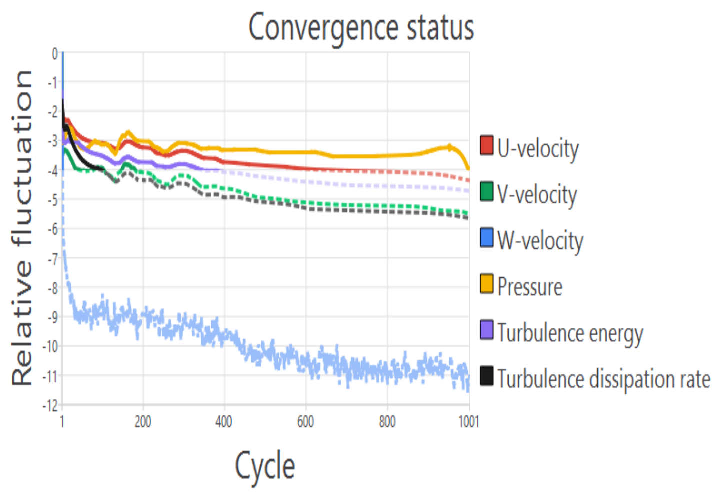

Figure16 convergence history (K-ε)

The results converge in 635 cycles for K-ω turbulent model, and for K - ε turbulent model the mesh did not reach steady-state even after 1000 cycles.

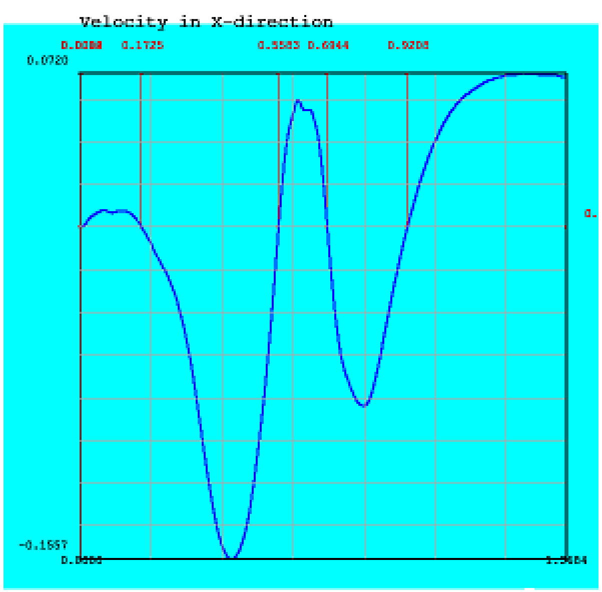

Figure 17 Velocity in the X direction with Y-Intercept

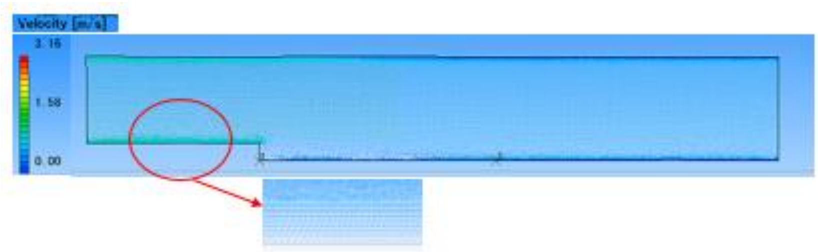

Figure 18 Velocity vector field K-ω

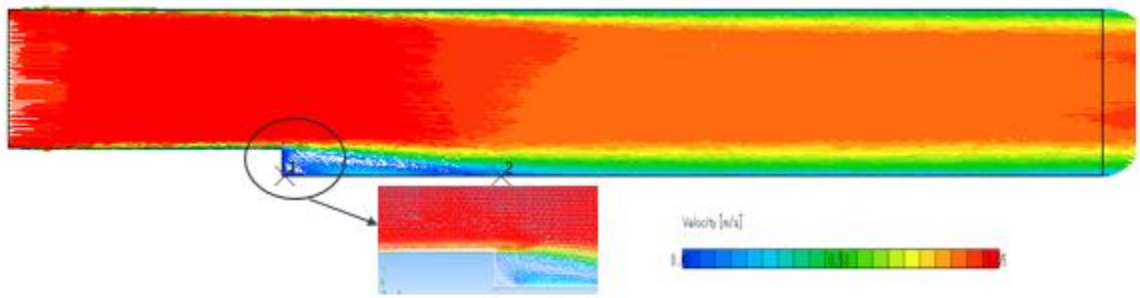

Figure 19 Velocity vector field K - ε

A circulation bubble is observed near the step for turbulent flow. Both the K – ε and K-ω

Are compared and the results are obtained.

The y-intercept. i.e. the reattachment location is shown for the standard K - ε turbulent model and K-ω turbulent model.

Reattachment location K - ε turbulent model = 1.6523

Reattachment location K-ω turbulent model = 1.5583

References

1. L.Chena, K.Asaia, T.Nonomuraa, G.Xib, T.Liuc "Review of Backward-Facing Step(BFS) flow mechanisms, heat transfer, and control," Thermal Science and Engineering Progress, pp 194-216, 2018.
2. Y.Rouizia, Y.Favennecb, J.Venturaa, D.Petita "Numerical model reduction of 2D steady incompressible laminar flows: Application on the flow over a backward-facing step," Journal of computational physics, vol (228), pp 2239-2255, 2009.
3. H. Nowruzi , S. Salman Nourazar, H. Ghassemi "On the Instability of Two Dimensional Backward-Facing Step Flow using Energy Gradient Method," Journal of Applied Fluid Mechanics, Vol. 11, No. 1, pp. 241-256, 2018.