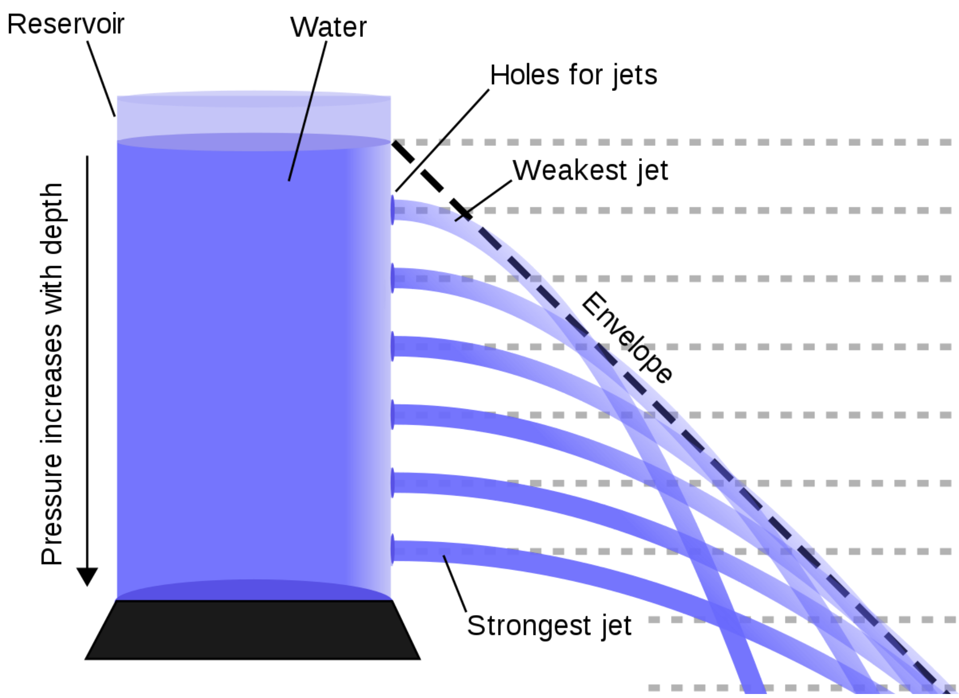
CL 254 - Course Project

FLOW FROM A TANK



Group 15

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Problem Statement

Analyze the flow through an orifice by varying its cross-sectional area and the tank water level. Compare the streamlines of flow near the orifice for laminar & turbulent flow. Tally the results for the exit velocity obtained with Torricelli's theorem and check its validity in the laminar and turbulent cases.

Bernoulli's Theorem

Assumptions: The compressibility and viscosity (internal friction) of the fluid having steady, or laminar flow is negligible.

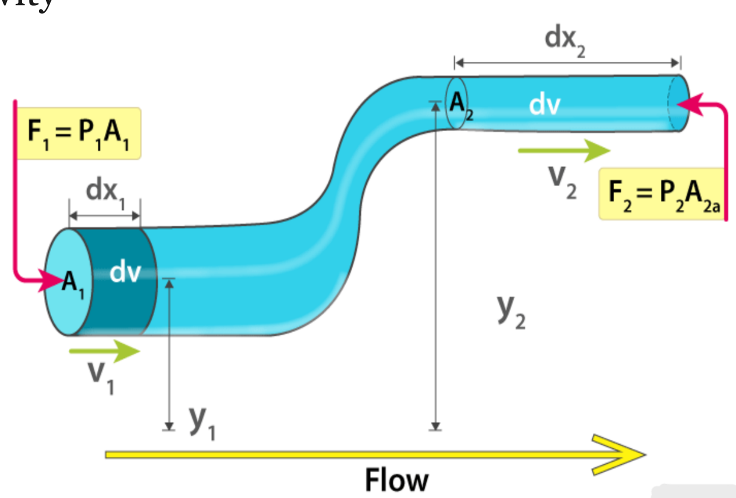
The theorem states that the total mechanical energy of the flowing fluid, comprising the energy associated with fluid pressure, the gravitational potential energy of elevation, and the kinetic energy of fluid motion, remains constant.

This is captured in the following equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

where

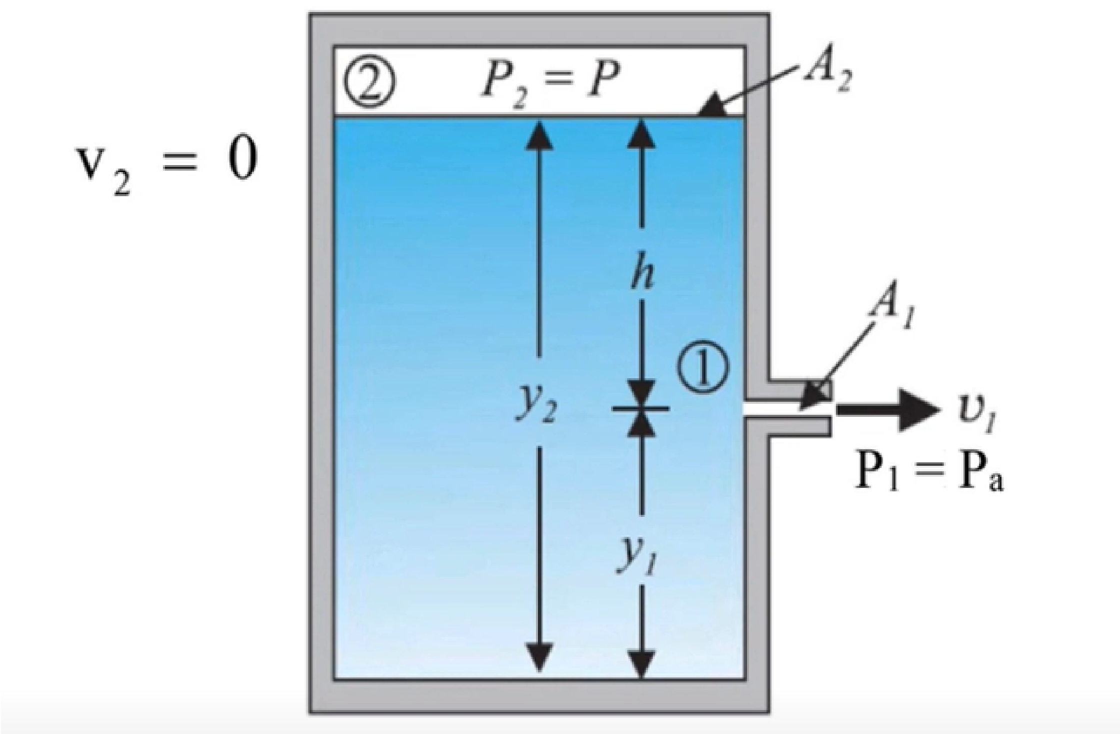
ρ = fluid density
g = acceleration due to gravity
P_1 = pressure at elevation 1
v_1 = velocity at elevation 1
h_1 = height of elevation 1
P_2 = pressure at elevation 2
v_2 = velocity at elevation 2
h_2 = height at elevation 2



Torricelli's Theorem

This theorem states that the speed 'v' of a liquid flowing under the force of gravity out of an opening (assumed negligibly small compared to the cross-sectional area of the tank) in a tank is proportional to the square root of the vertical distance 'h' between the liquid surface and the centre of the orifice and to the square root of twice the acceleration caused by gravity, $2g$. This result is thus independent of the density of the liquid in question.

Thus, $v = \sqrt{2gh}$



Expected Results

A. Laminar vs Turbulent:

- We have used the icoFoam solver for laminar flow and pisoFoam solver for turbulent flow.
- For the laminar case, the value of viscosity coefficient, μ used is 10^{-2}
- For the turbulent case, the value of viscosity coefficient, μ used is 10^{-5}

Since the Bernoulli's equation holds true along a streamline only for inviscid flows, we expect the laminar flow (using a lower value of μ) to give results that match better with the Torricelli expression of $\sqrt{2gh}$

B. With changing Cross-sectional area

- As the cross-sectional area reduces, the results satisfy the approximation of a "point orifice" taken while obtaining Torricelli's expression for efflux velocity.
- Thus we expect closer results for a smaller orifice.
- We can verify the efflux velocity from larger cross-sectional areas using :

$$v = \sqrt{\frac{2gh}{1-\left(\frac{S1}{S2}\right)^2}}$$

Boundary Conditions

A. Pressure boundary conditions:

```
boundaryField
{
   top
```

```
  {
    type          fixedValue;
    value          uniform 20.1;
   }
  outlet
  {
    type          fixedValue;
    value          uniform 0;
   }
  fixedwall
  {
    type          zeroGradient;
  }
  empty
  {
    type          empty;
  }
}
```

B. Velocity boundary conditions:

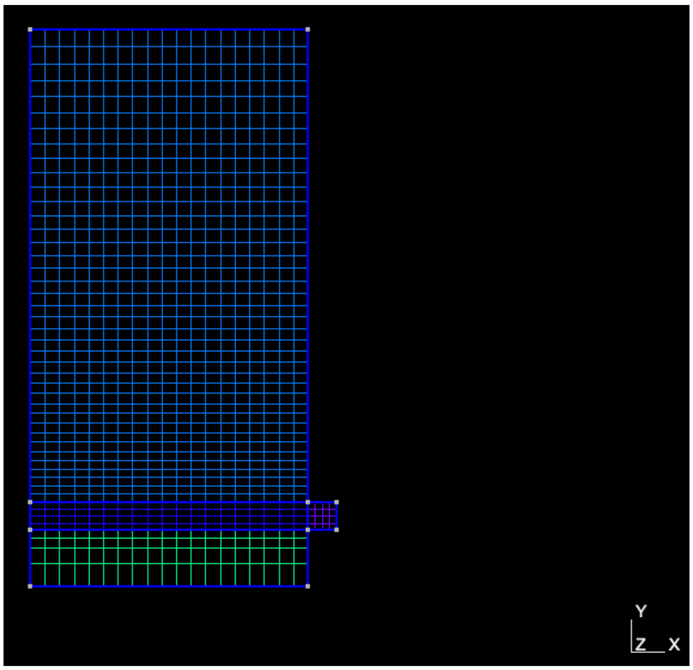
```
boundaryField
{
  fixedwall
  {
    type          noSlip;
  }
  empty
  {
    type          empty;
  }
  outlet
  {
    type          zeroGradient;
  }
  top
  {
    type          zeroGradient;
  }

}
```

Results & Plots

A. Streamlines, Pressure & Velocity profiles :

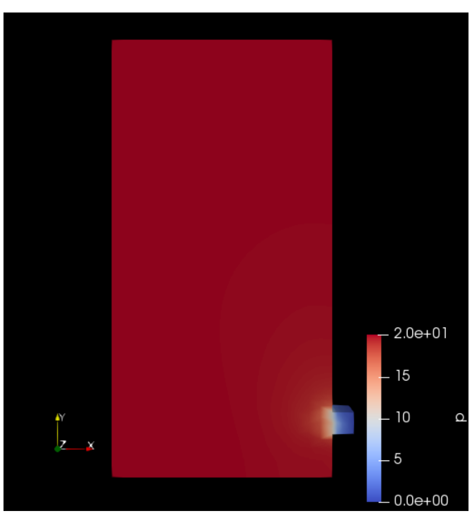
Plots using the initial mesh :

1. Mesh :

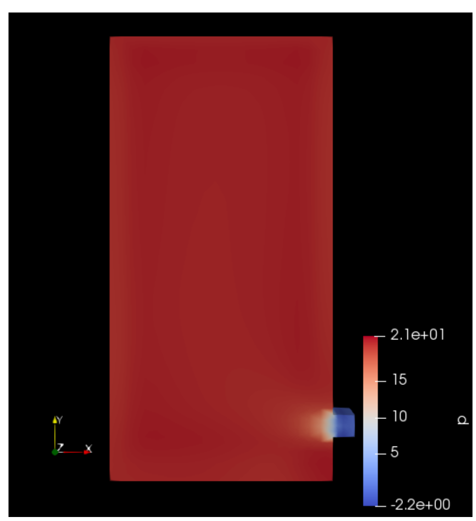


2. Pressure profile :

Laminar

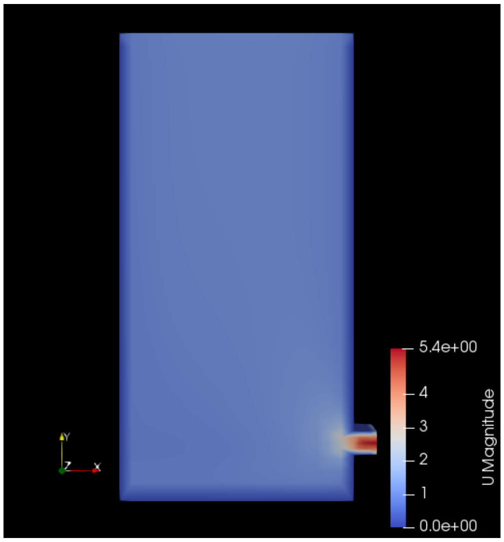


Turbulent

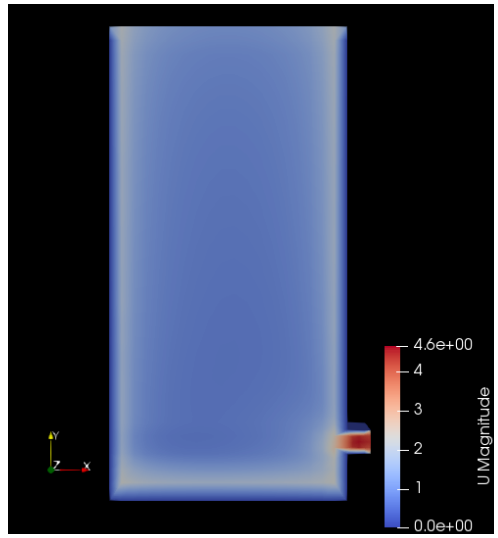


3. Velocity profile :

Laminar

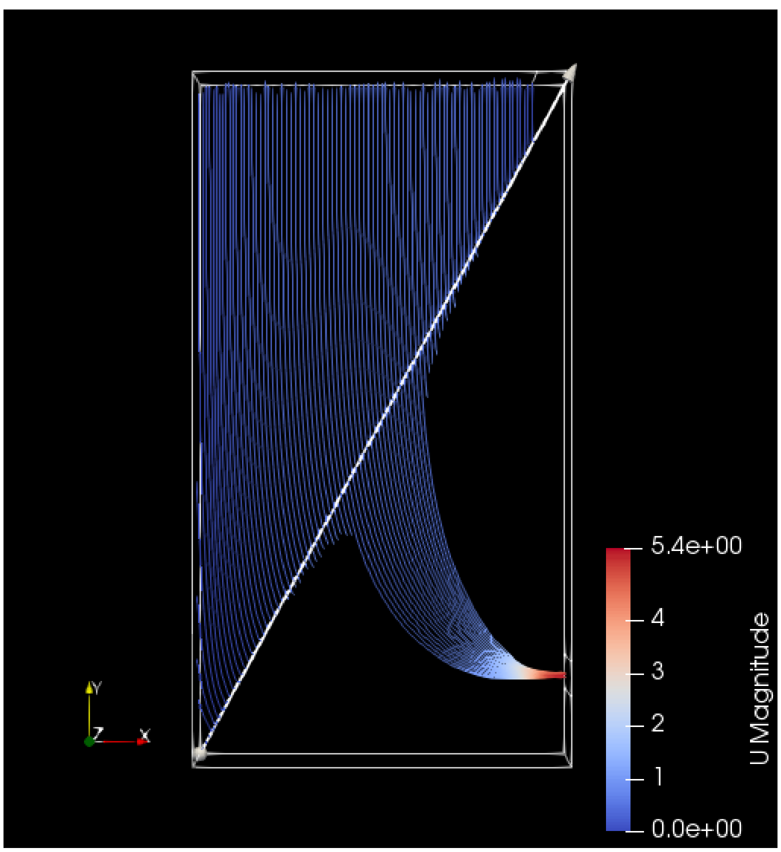


Turbulent

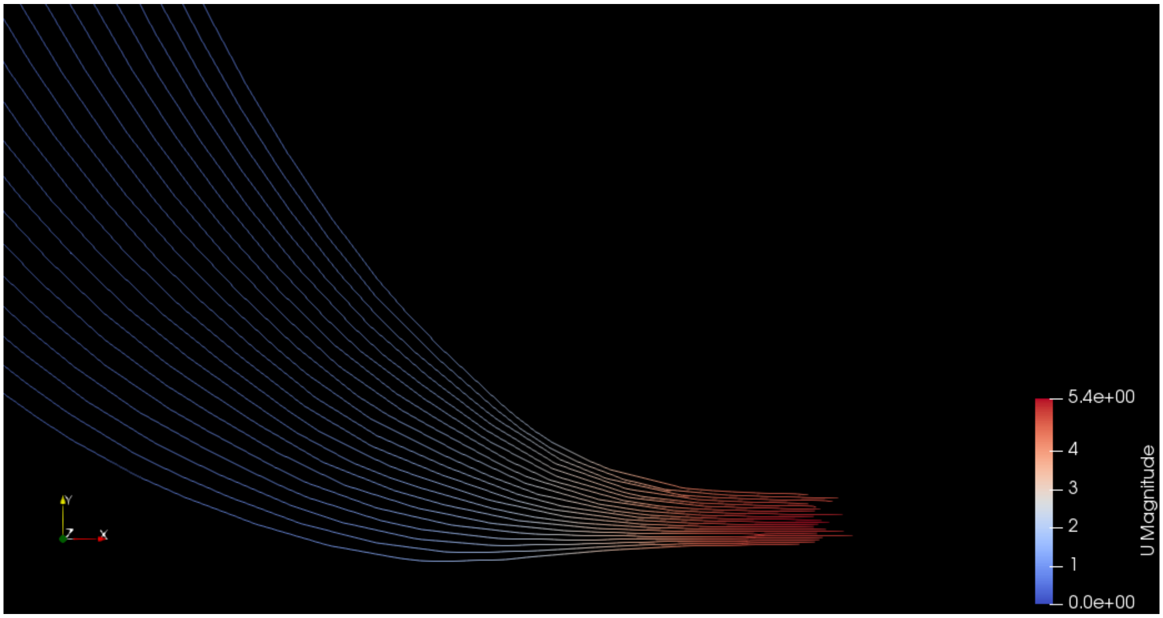


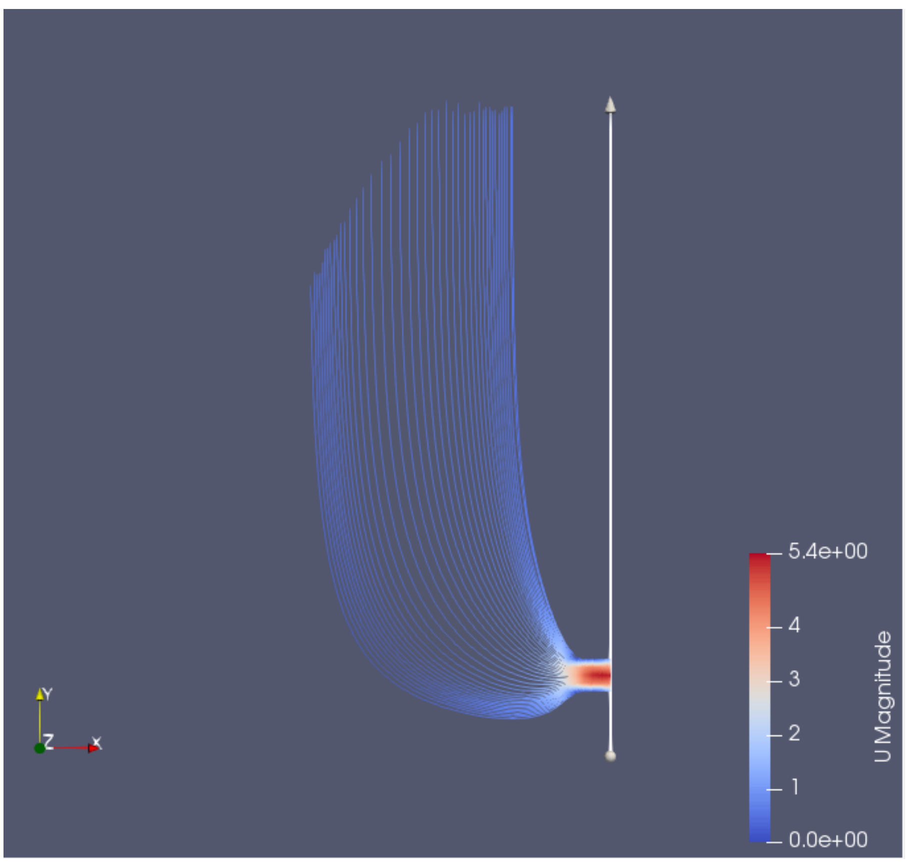
4. Streamlines :

Laminar flow :

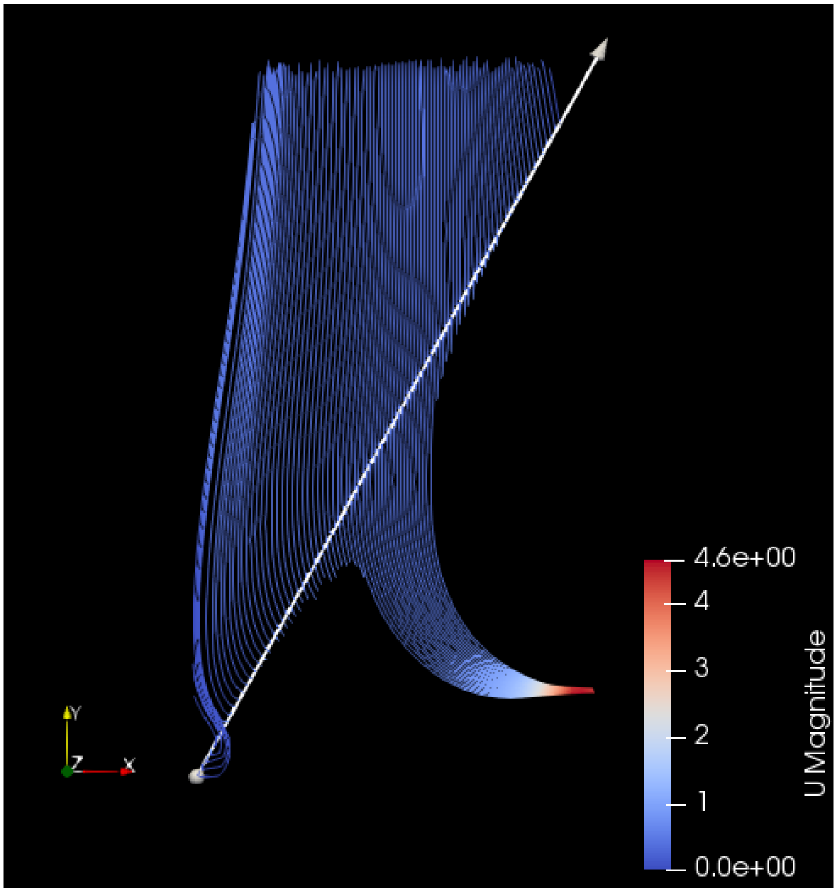


Closer to the orifice:

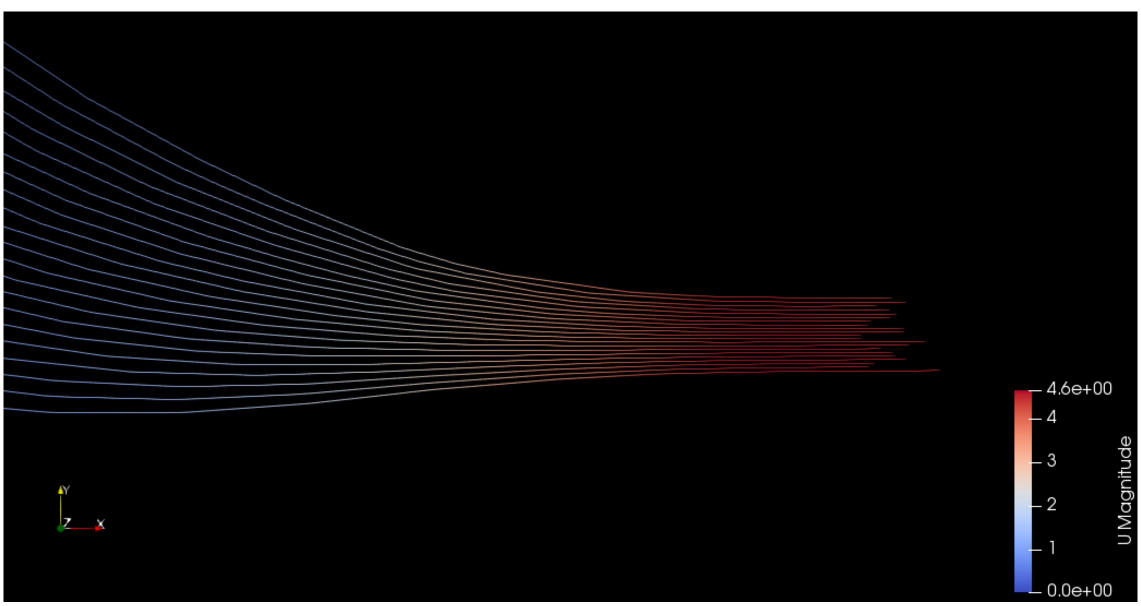


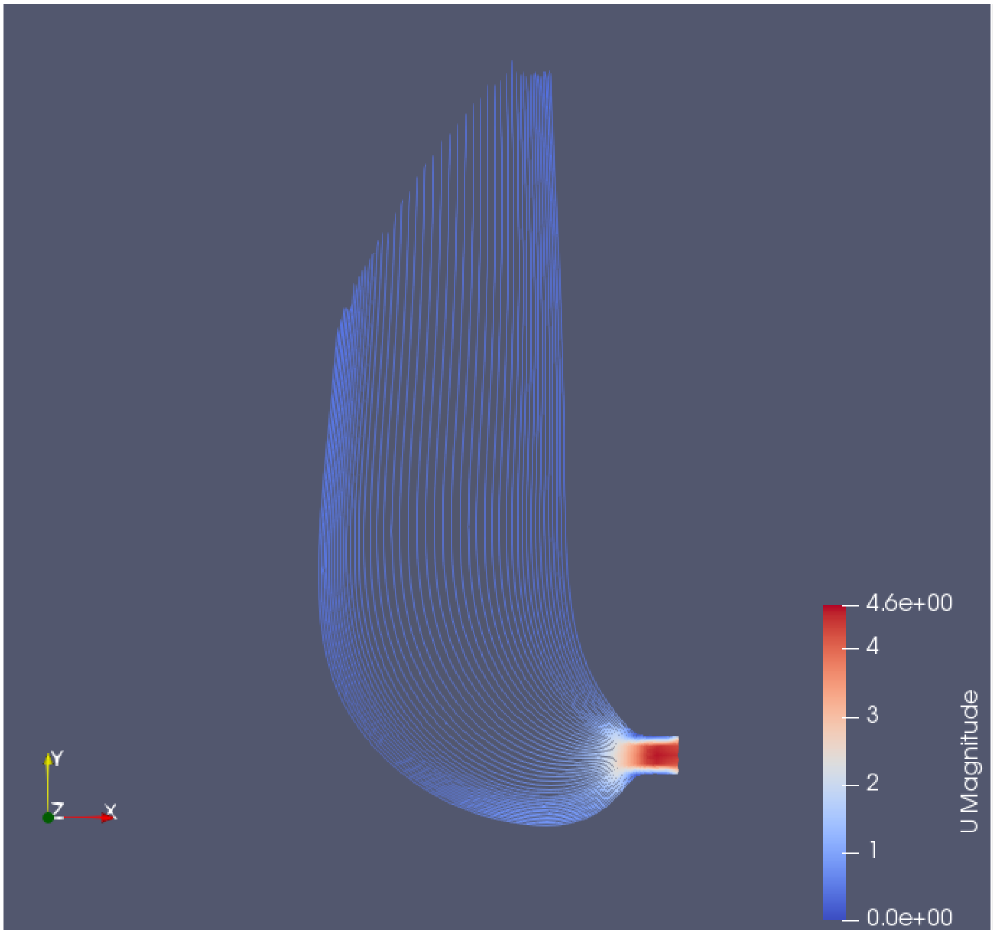


Turbulent flow :



Closer to the orifice:





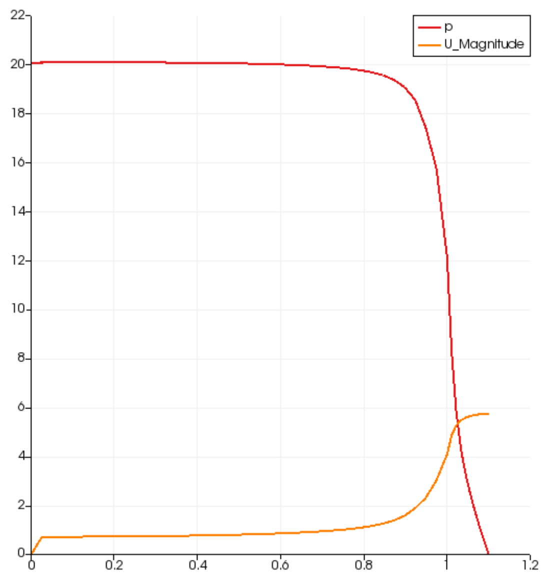
Comparison between the streamlines at the orifice for laminar vs turbulent flows :

Laminar flow near the orifice	Turbulent flow near the orifice
The velocity is very high at the centre of the orifice and it is comparatively lower at the edges.	The velocity is nearly the same throughout the entire orifice
This indicates a parabolic profile	This indicates plug flow
No eddy formation	Eddy formation is visible at the edges

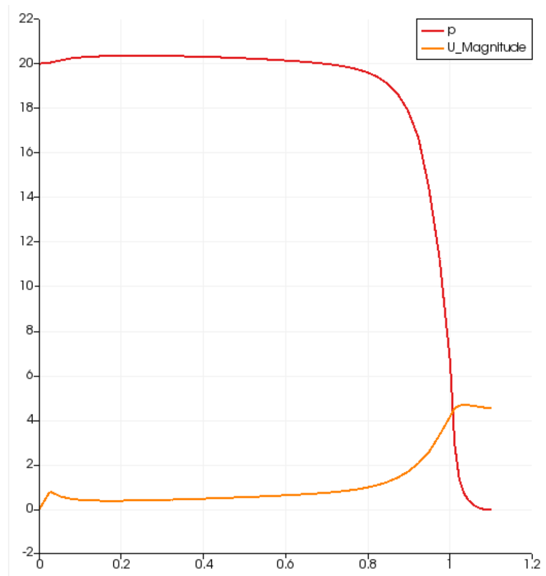
5. Plots over line at the orifice :

a. Along x axis

Laminar

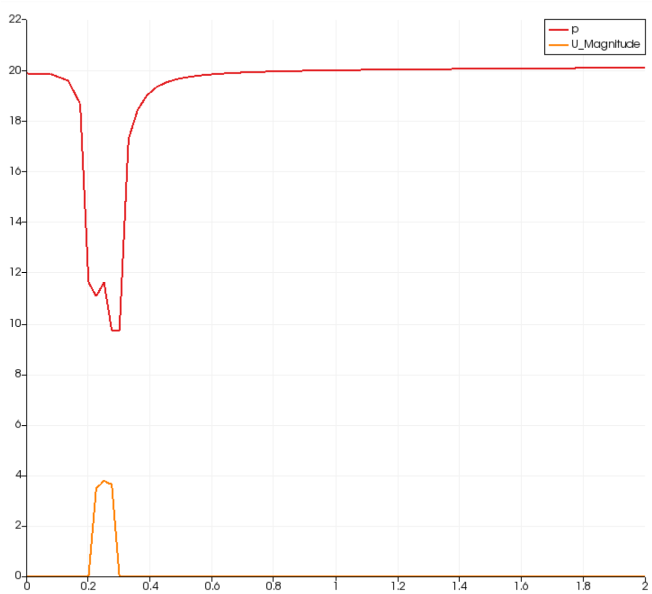


Turbulent

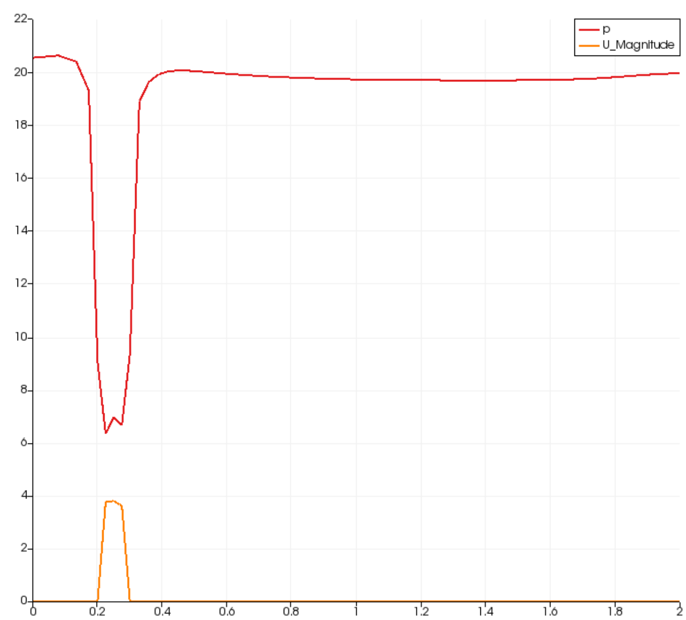


b. Along y axis

Laminar

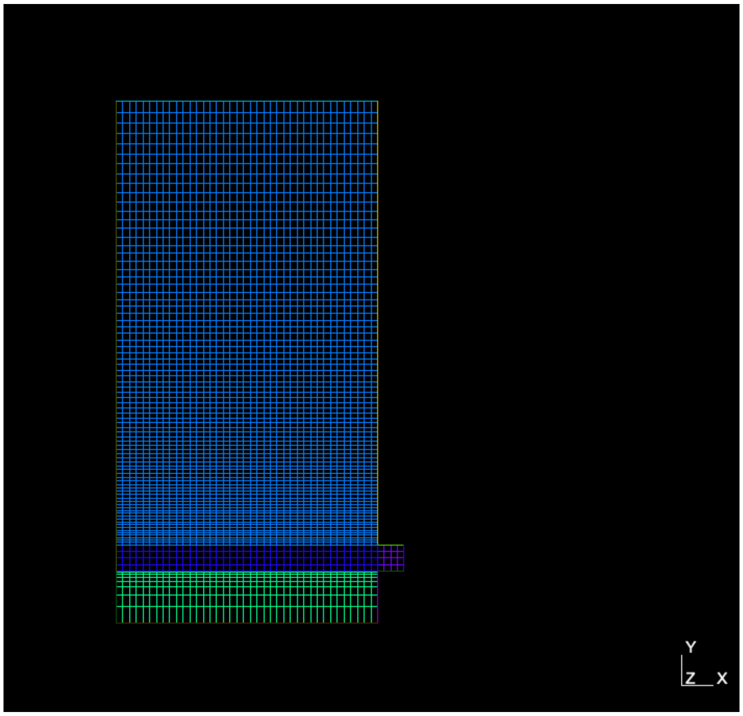


Turbulent



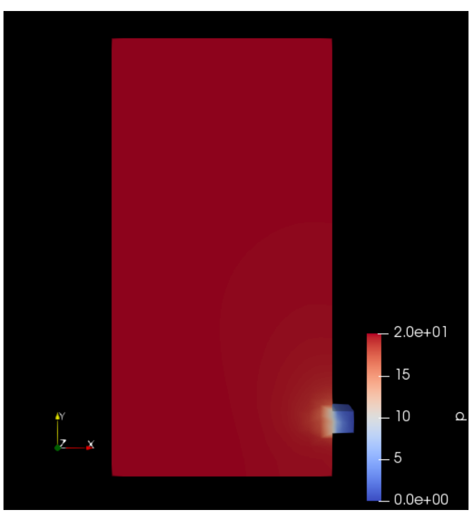
Plots using a finer mesh *:

1. Refined Mesh

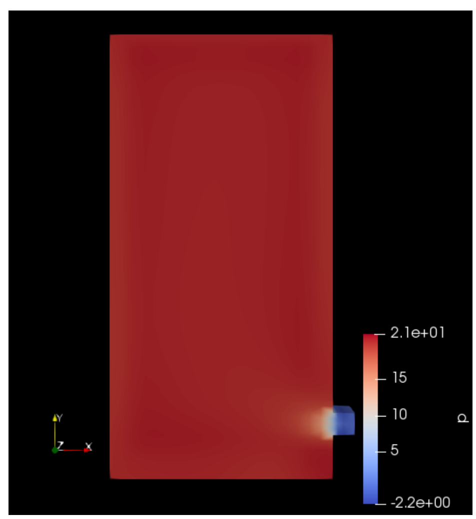


2. Pressure profile

Laminar



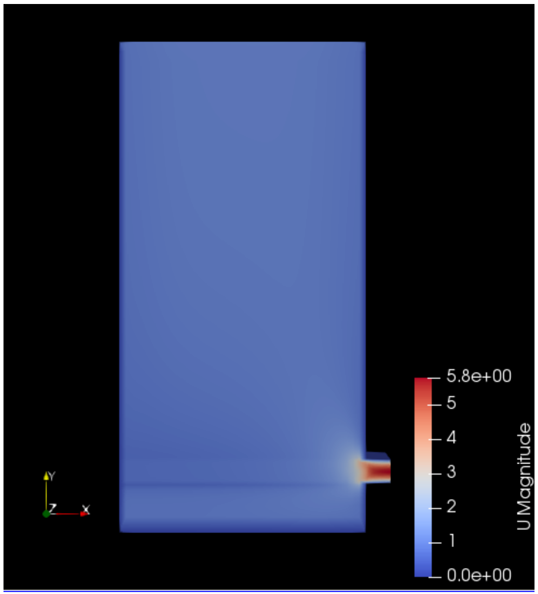
Turbulent



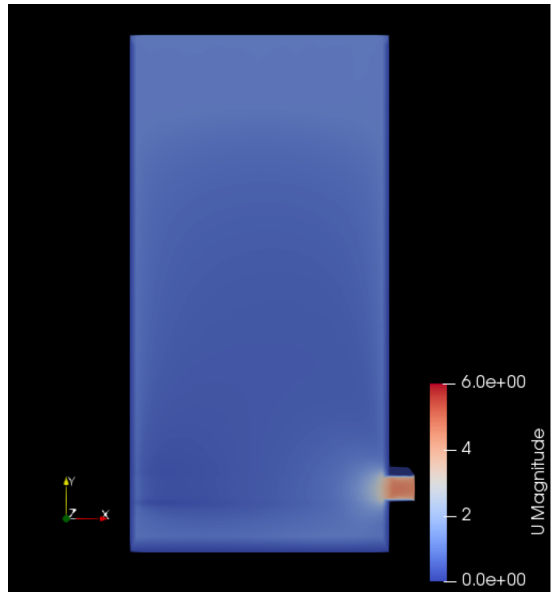
* Note : We changed the value of delT from 0.005 to 0.002 in the turbulent case in order to maintain the required courant number

3. Velocity profile

Laminar

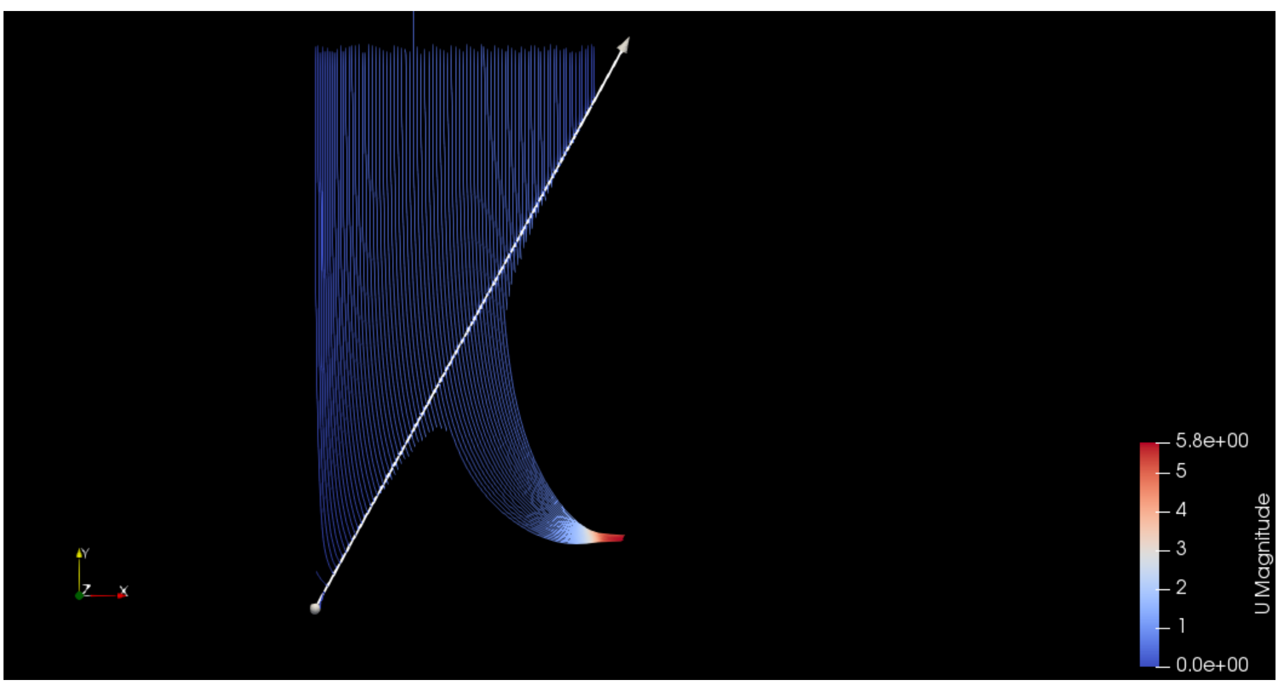


Turbulent

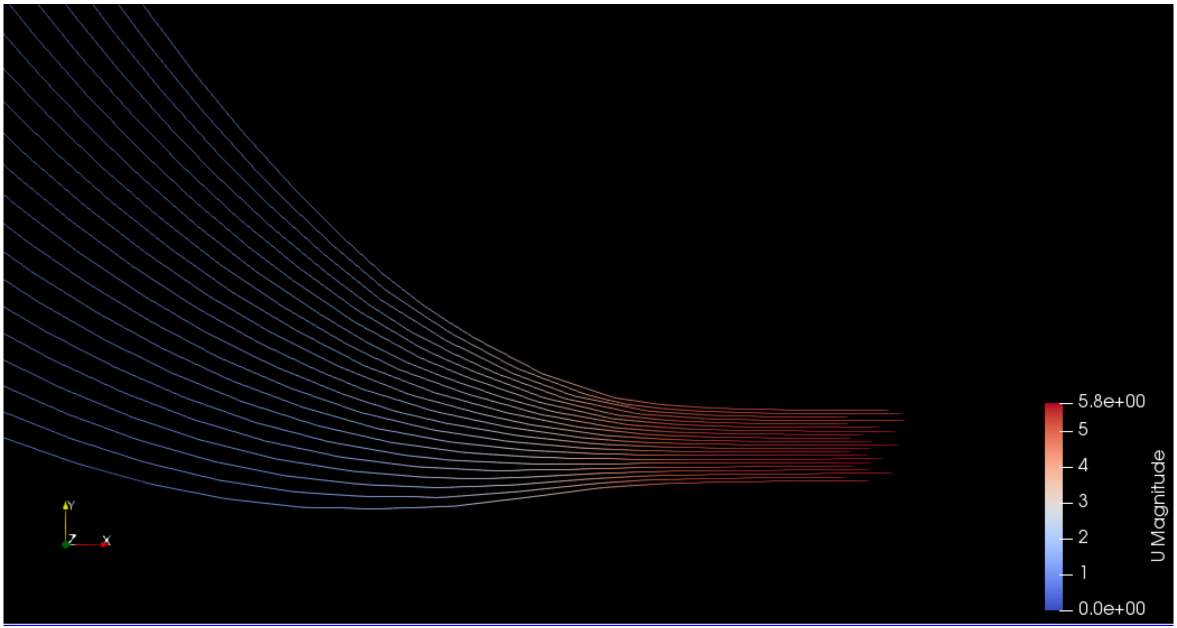


4. Streamlines

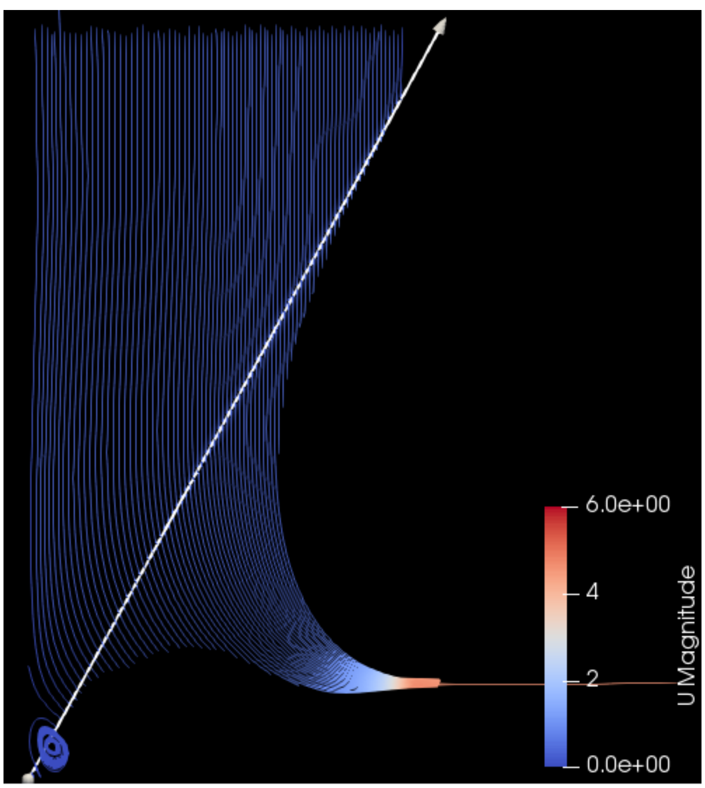
Laminar



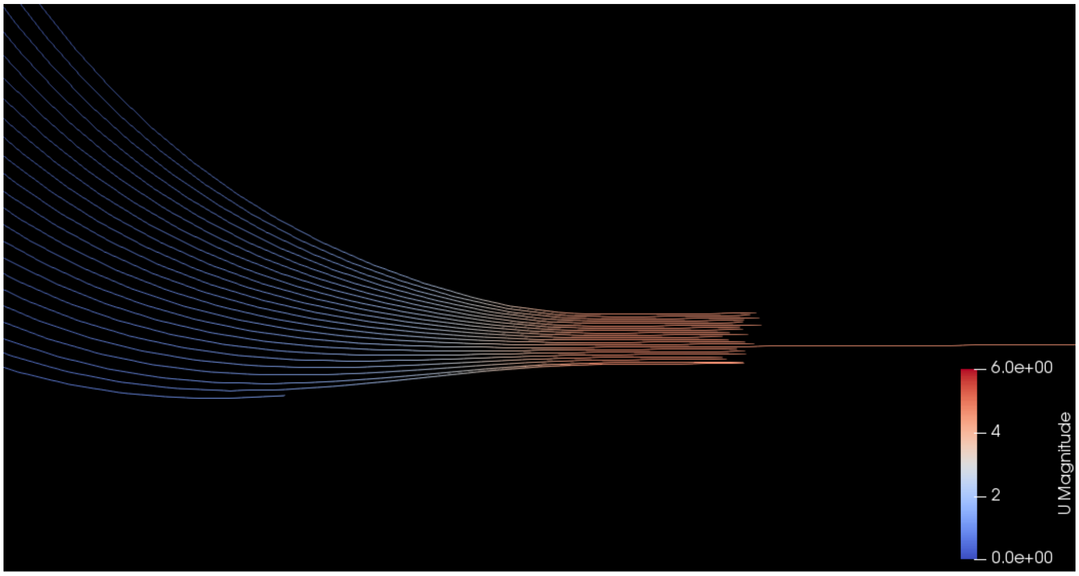
Closer to the orifice:



Turbulent



Closer to the orifice:



B. Variations in the cross-sectional area :

For Laminar flow

D_o	V_{max}
0.1	5.4
0.075	5.1
0.05	4.7
0.025	3.4

For turbulent flow

D_o	V_{max}
0.1	4.6
0.075	4.6
0.05	4.6
0.025	4.4

Conclusion

1. The expected value of velocity as obtained from the Bernoulli's equation for our mesh $= \sqrt{2gh} = 6.26$ m/s

   Upon refining the mesh, the values of efflux velocity obtained are :
   - 5.8 m/s in case of laminar flow
   - 6 m/s in case of turbulent flow

   which are much closer to the expected value as compared to the original values of :
   - 5.4 m/s in case of laminar flow
   - 4.6 m/s in case of turbulent flow

2. There is a significant difference in the plots of the streamlines obtained in the case of laminar and turbulent flows. These can be summarised mainly on the basis of eddy formation and velocity profiles.

3. Upon varying the diameter of the orifice we obtain a decreasing velocity trend in the case of laminar flows, while for the turbulent case the velocity is nearly unchanged. The values of velocity obtained are significantly different from the expected value of 6.26 m/s.

   This may be attributed to viscosity which remains unaccounted for in Bernoulli's equation, apart from the fact that the orifice is not a perfect "point source" and that our mesh size can always be refined further.

Appendix

Polymesh file with appropriate changes made:

```
/*--------------------------------*- C++ -*----------------------------------*\
  =========                 |
  \\      /  F ield         | OpenFOAM: The Open Source CFD Toolbox
   \\    /   O peration     | Website:  https://openfoam.org
    \\  /    A nd           | Version:  8
     \\/     M anipulation  |
\*---------------------------------------------------------------------------*/
FoamFile
{
    version     2.0;
    format      ascii;
    class       polyBoundaryMesh;
    location    "constant/polyMesh";
    object      boundary;
}
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

4
(
    empty
    {
        type            empty;
        physicalType    patch;
        nFaces          7650;
        startFace       52830;
    }
    top
    {
        type            patch;
        physicalType    patch;
        nFaces          195;
        startFace       60480;
    }
    fixedwall
    {
        type            wall;
        physicalType    patch;
        nFaces          1200;
        startFace       60675;
    }
    outlet
    {
        type            patch;
        physicalType    patch;
        nFaces          45;
        startFace       61875;
    }
)

// ************************************************************************* //
```