MAE 560 - Fall 2021

Applied Computational Fluid Dynamics

Project-1

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Statement of Collaboration :-

Name of Collaborator– Devin Bizzack	
Tasks	**Contribution to collaborative effort**
Task 1	Discussed overall setup of task 1.
Task 2b	Helped with transient solution of task 2 = Discussion of reasoning for choice of time step.

Task 1 – Internal flow with thermal convection
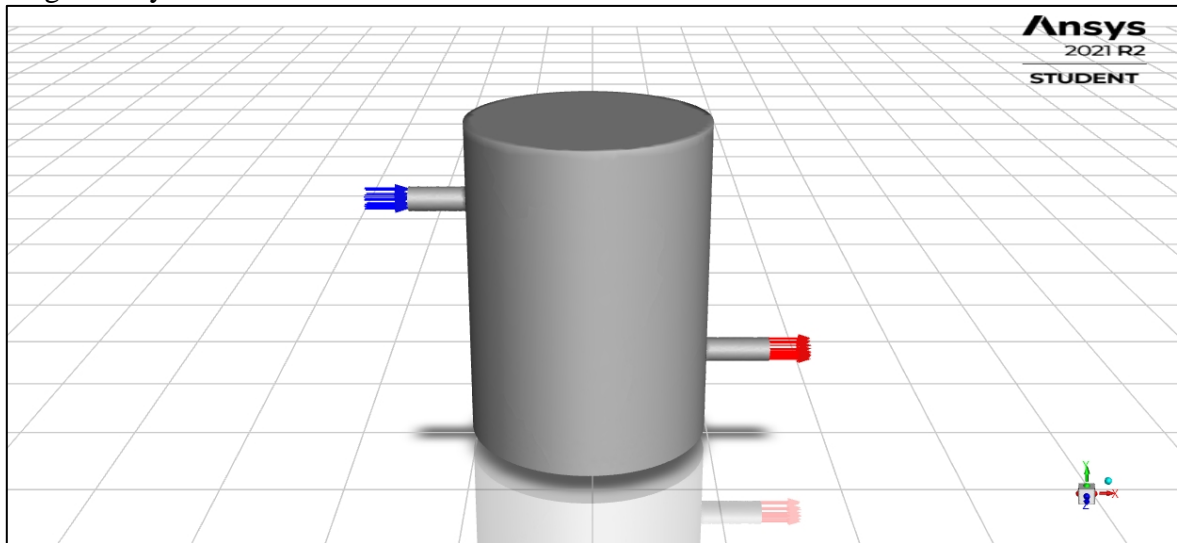
The geometry used for task 1 is as follows

Fig 1.1 – Cylindrical water heater

The model used for the simulation was set to standard k-epsilon.

The boundary conditions used for task 1 are as follows –

- Inlet – Velocity inlet (x component) = 0.05 m/s. Temperature = 283.15 °K
- Outlet is set to outflow.
- Bottom plate of the heater is set as wall to a constant temperature of 313 °K.

For task 1a we use gravity as 9.81 m/s^2 in the negative y-direction.

Note – For task 1b we use the same above boundary conditions. We only change the gravity to 9.81 m/s^2 in the positive x-direction.

Task 1a – Vertically oriented tank
Deliverable 1 (D1)

Figure 1 shows the mesh that is used for the simulation. The mesh size used is 2cm and inflation is set to program controlled. The mesh is also refined at the bottom surface of the heater.
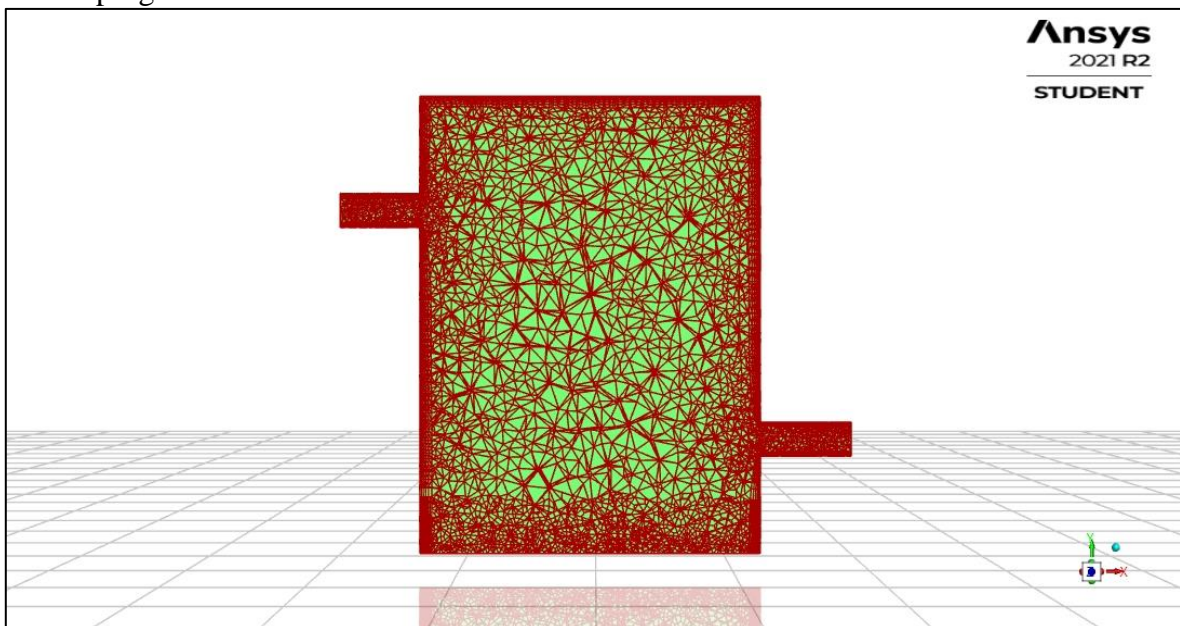

Fig 1.2 – Plot of mesh along the plane of symmetry

The operating temperature was calculated as the average of the minimum and maximum temperature in the system. Density was set to boussinesq to emulate the effect of variation of density with temperature.

- Operating Temperature   : 298.15 K
- Operating density   : 997.043 kg/m^3
- Thermal expansion coefficient : 0.00025738 K^{-1}
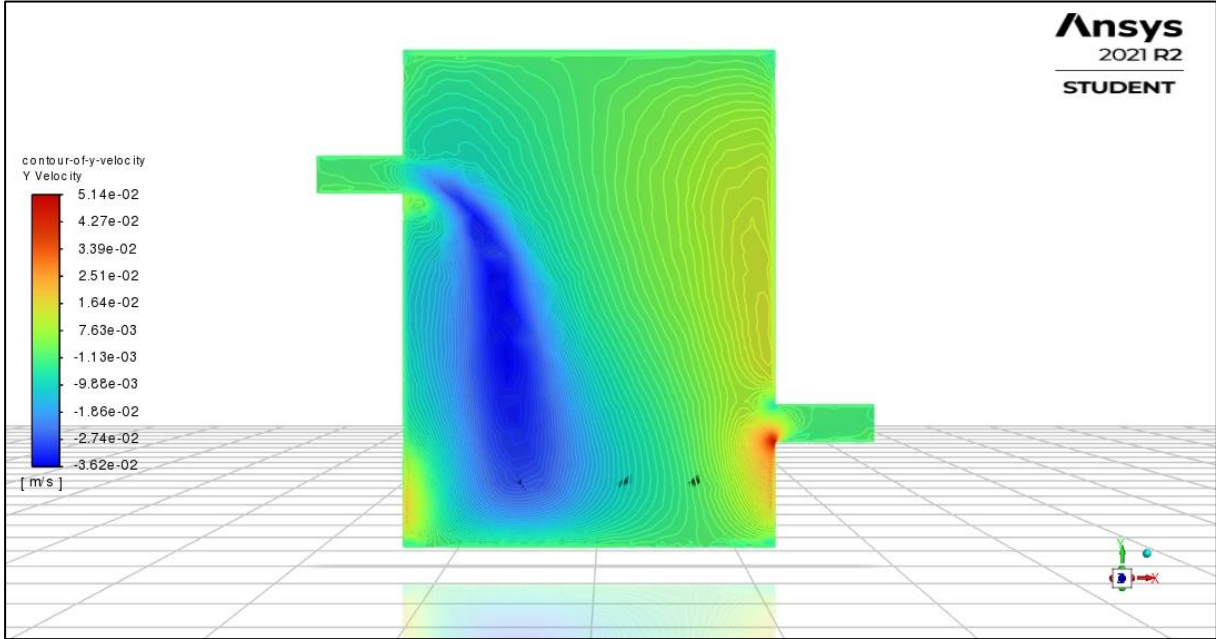
Deliverable 2 (D2) and Deliverable 3 (D3)

Fig 1.3 – Contour plot of the y-velocity in the plane of symmetry
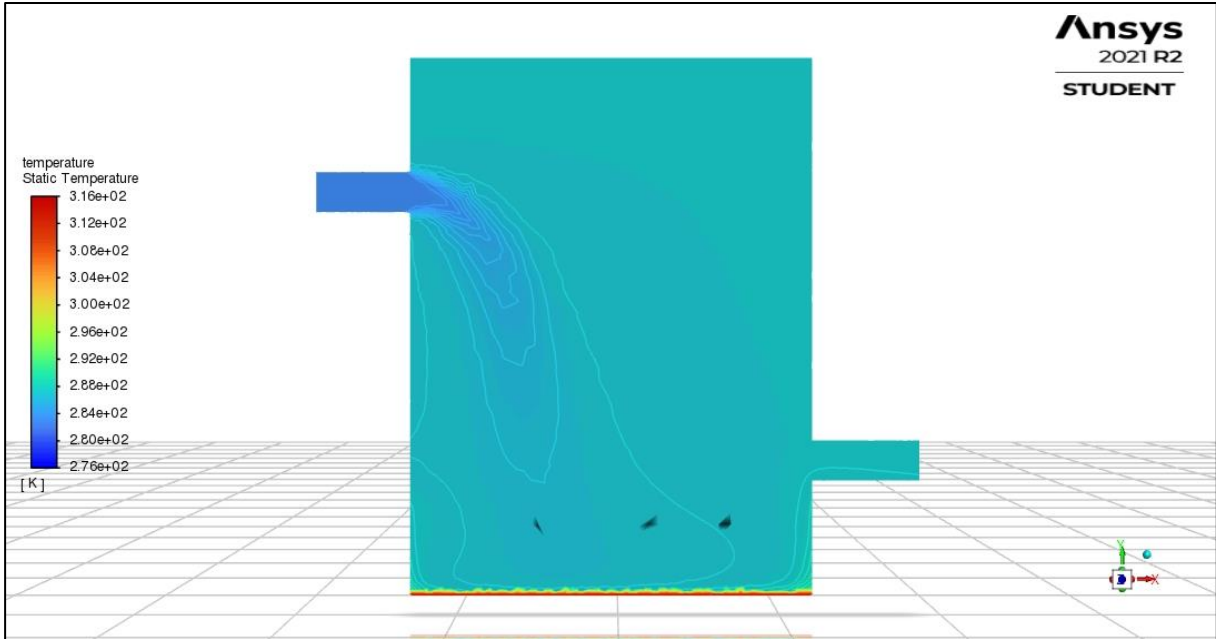

Fig 1.4 – Contour plot of temperature in the plane of symmetry

Deliverable 4 (D4)

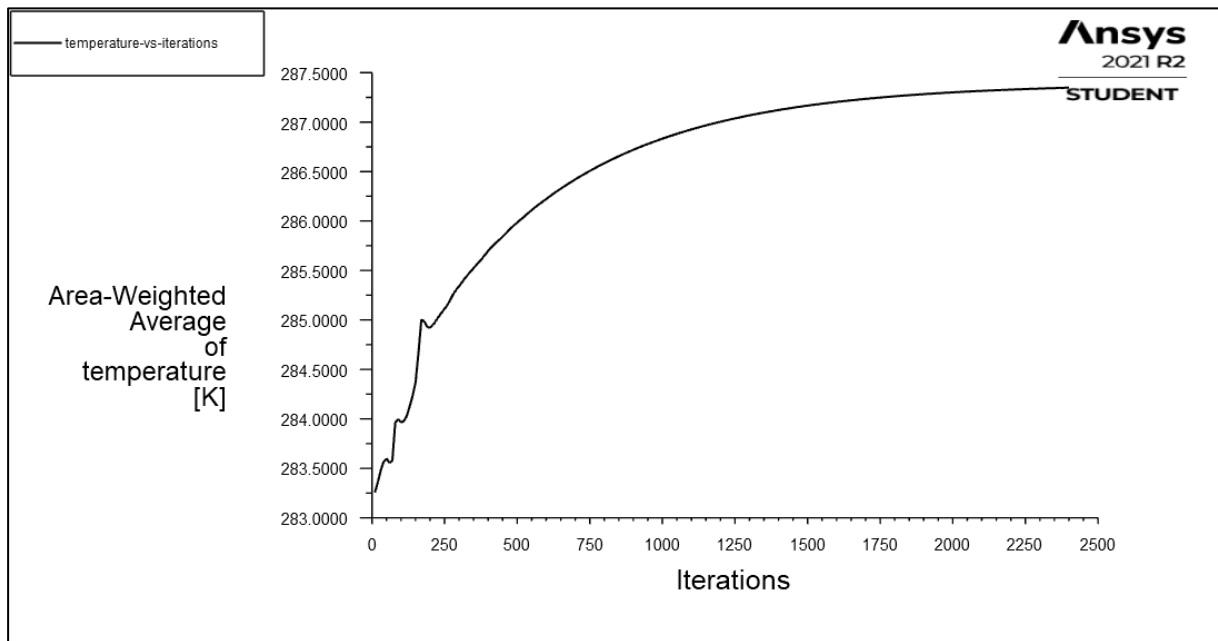The outlet temperature at the steady state is 287.35 ^{o}K.

Fig 1.5 – Line plot of outlet temperature as a function of number of iterations

Task 1b – Horizontally Oriented tank
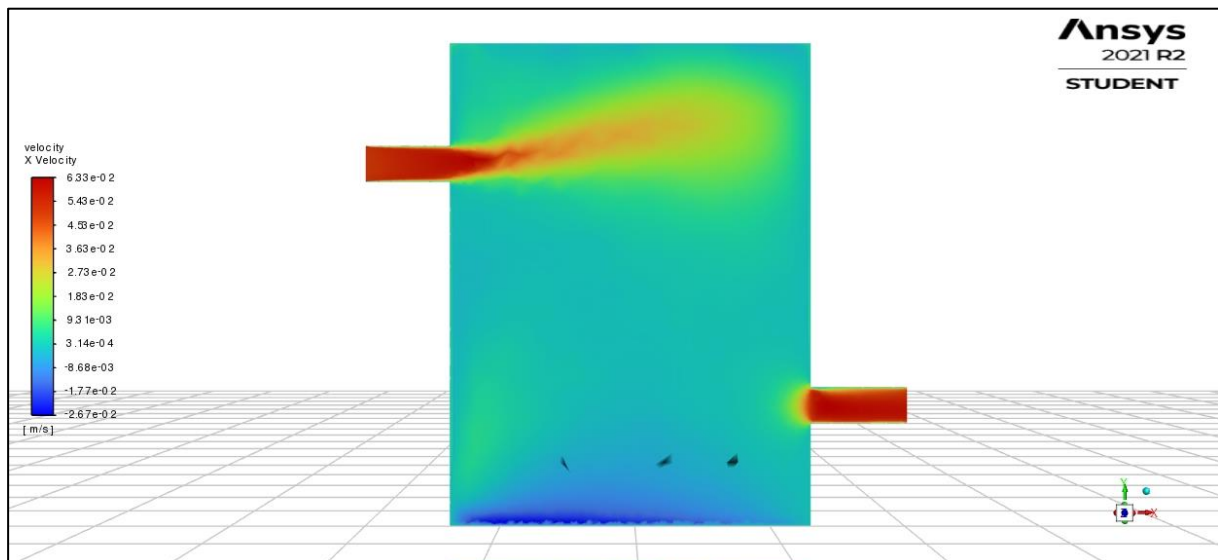## Deliverable 5 (D5)

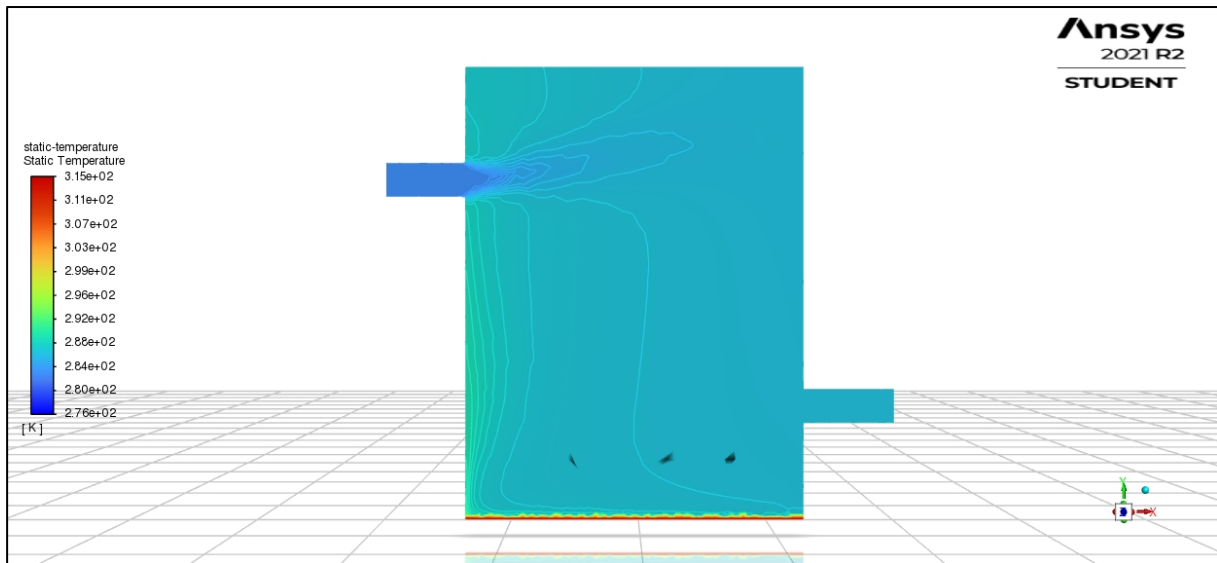Fig 1.6 – Contour plot of the x-velocity in the plane of symmetry

Deliverable 6 (D6)

Fig 1.7 – Contour plot of temperature in the plane of symmetry

Deliverable 7 (D7)

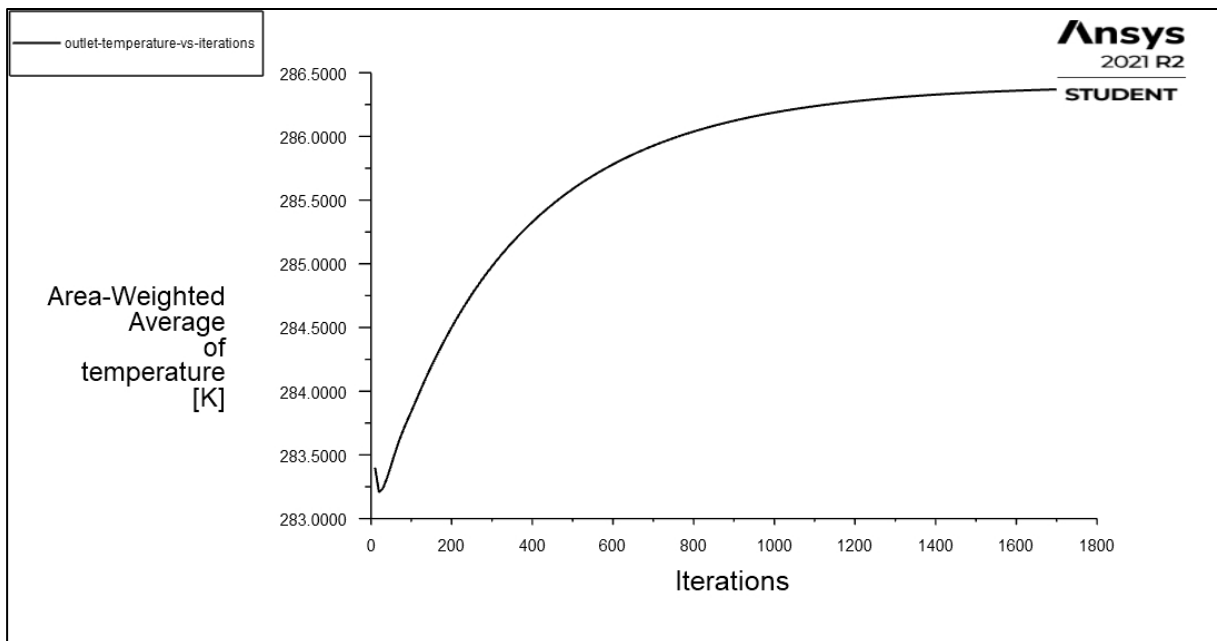The outlet temperature at the steady state is 286.369 ^{o}K.

Fig 1.8 – Line plot of outlet temperature as a function of number of iterations

Task 2 – Internal flow with heat transfer

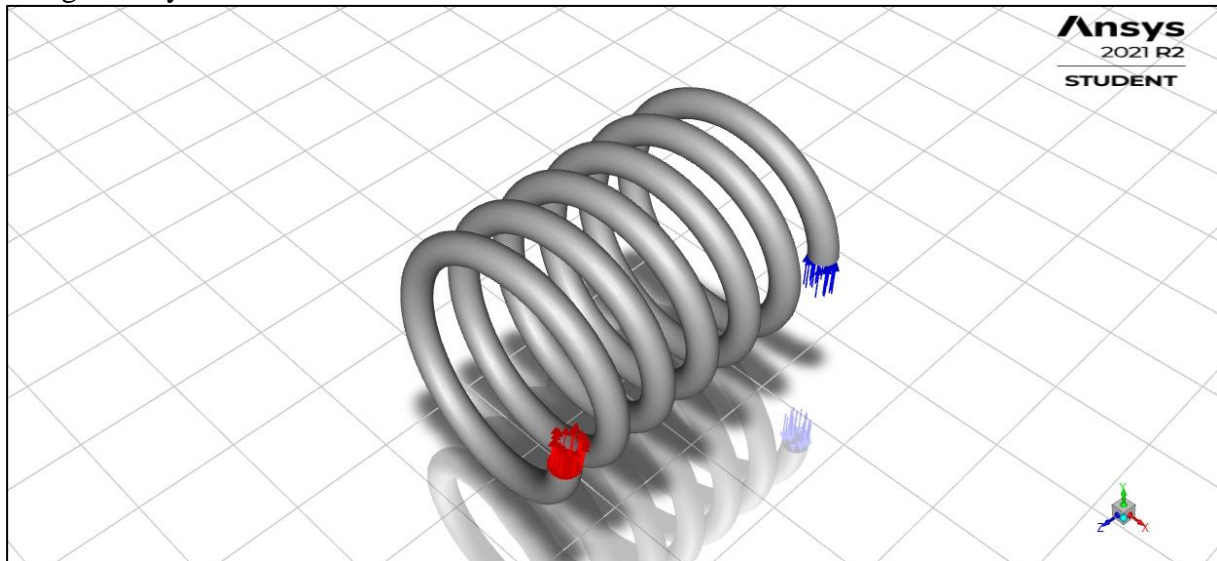The geometry used for the simulation is as follows –

Fig 2.1 – 3D helical pipe for task 2

The model used for this simulation was set to Laminar model.
The boundary conditions used for the simulation for task 2-b are as follows –

- Wall of helical pipe – Body with a thermal flux of 1000 Wm^{-2}.
- Inlet – Velocity = 0.005, 0.01, 0.02, 0.04 m/s. Temperature = 300 ^{o}K
- Outlet – was set to outflow.

Note – Task 2b has the same boundary conditions, where only inlet velocity of 0.02m/s is taken into consideration for the simulation. Also, we seek transient solution in task 2b.

Task 2a – Steady Solution
Deliverable 8 (D8)

The values of temperature difference $\Delta T = T_{out} - T_{in}$ for 4 cases of inlet velocities are shown in the following table. Note that the inlet temperature for all cases is 300 ^{o}K.

Inlet Velocity (m/s)	Outlet temperature (T_{out}) (^{o}K)	Temperature Difference (ΔT)
0.005	328.7155	28.7155
0.01	314.5691	14.5691
0.02	307.4182	7.4182
0.04	303.7874	3.7874

Table 2.1 – ΔT values for different inlet velocities.

Figure 2.2 shows the plot of change in temperature vs the inlet velocities. It can be concluded that change in temperature ΔT is inversely proportional to the inlet velocity. As the velocity of inlet water increases, the water spends less time in the heater and thus the external heat flux provided is not sufficient enough to heat the fast-moving water which leads to low outlet temperature.
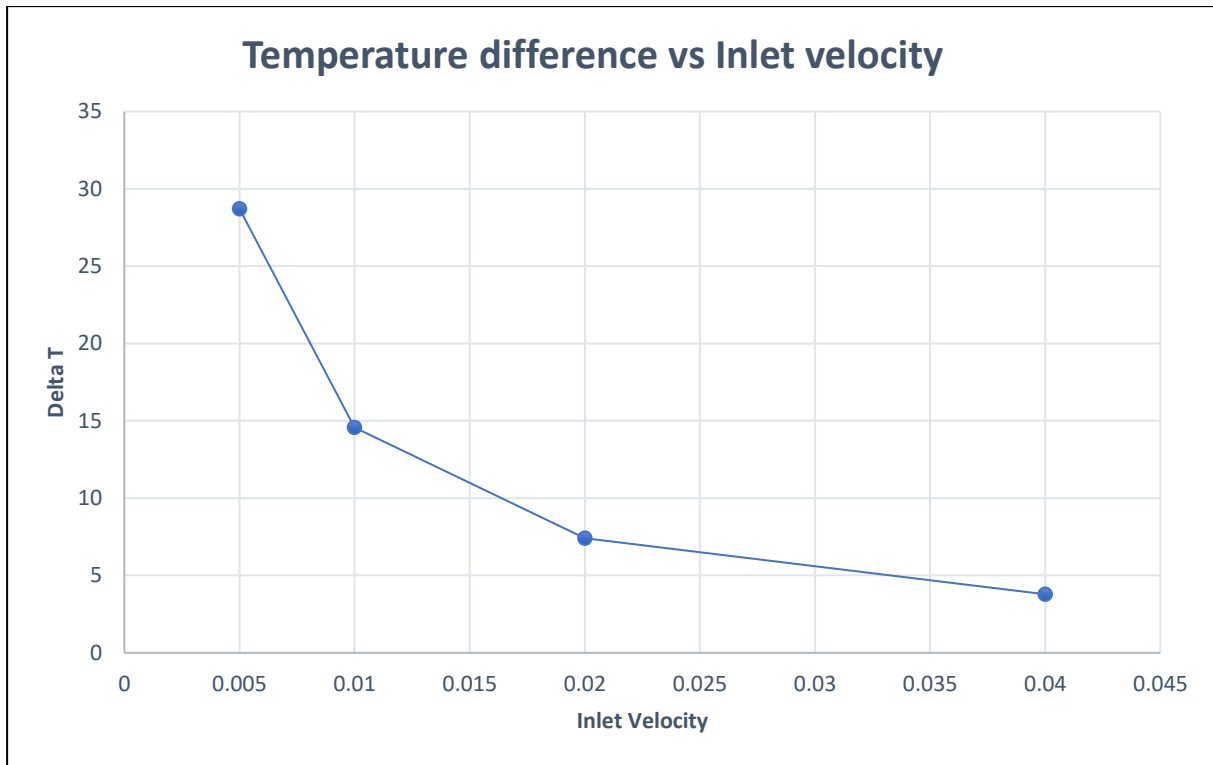
Fig 2.2 – Plot of ΔT vs inlet velocity

Deliverable 9 (D9)

The contour plot of velocity and temperature magnitude are shown for the case where inlet velocity is 0.02 m/s.
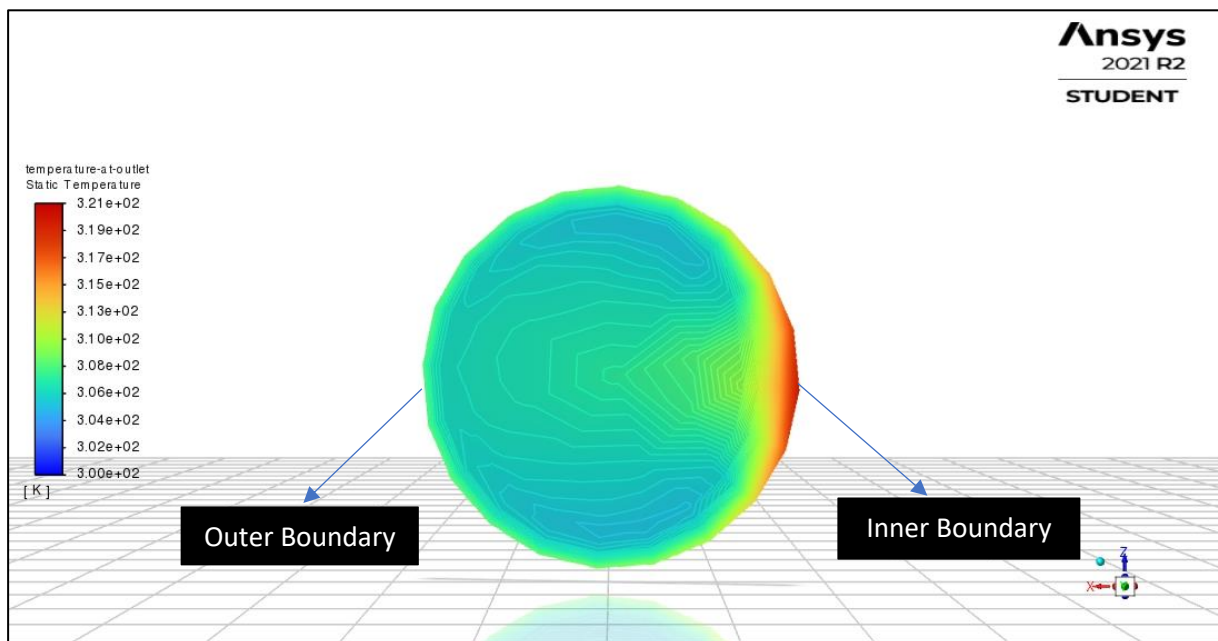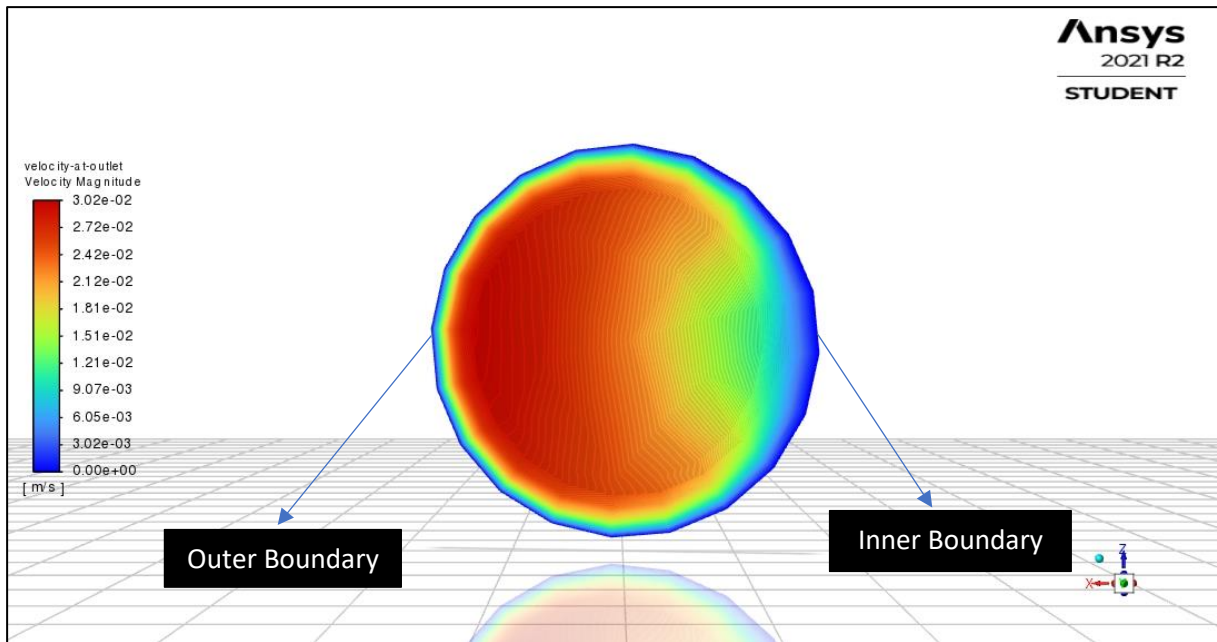

Fig 2.3 – Contour plot of temperature at the outlet

Fig 2.4 – Contour plot of velocity at the outlet

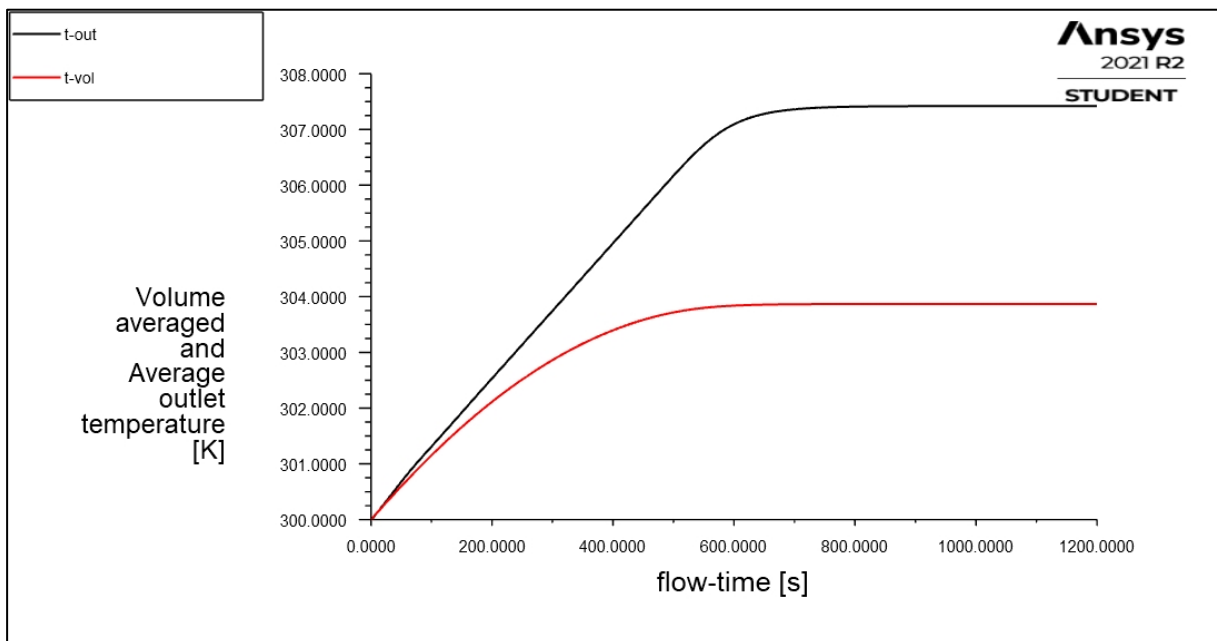## Task 2b – Transient solution
Deliverable 10 (D10)

Fig 2.5 – Plot of $Tout$ and $Tvol$ as a function of time

Deliverable 11 (D11)

The following parameters were taken into consideration while running the simulation for transient solution –

- Time Step size   = 1 second
- Number of time steps   = 1200
- Number of iterations per time step = 10 iterations

Task 3 – Compressible flow

The convergent divergent nozzle used for this simulation is as follows –
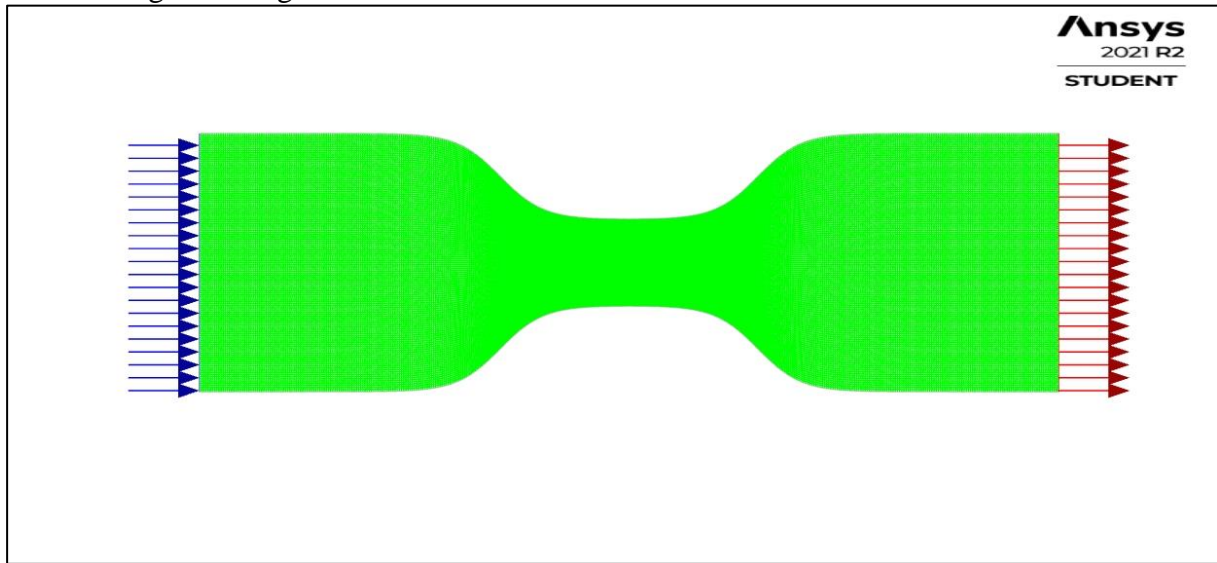

Fig 3.1 – 2D convergent divergent nozzle

The density-based solver was used in fluent to determine the steady state solution and the model used for the simulation is Inviscid. The fluid used for the simulation is air and its density is set to ideal gas for task 3a.

The boundary conditions used for the simulation is as follows –

- Pressure Inlet – Gauge Pressure   = 101360 Pa
           Initial gauge pressure = 98910 Pa
           Temperature   = 500 $^\circ$K
- Pressure outlet – Gauge Pressure = 5000 Pa. Temperature = 200 $^\circ$K

Note – For task 3b we keep the same boundary conditions. The only thing changed is the density of air which is set to constant instead of ideal gas.

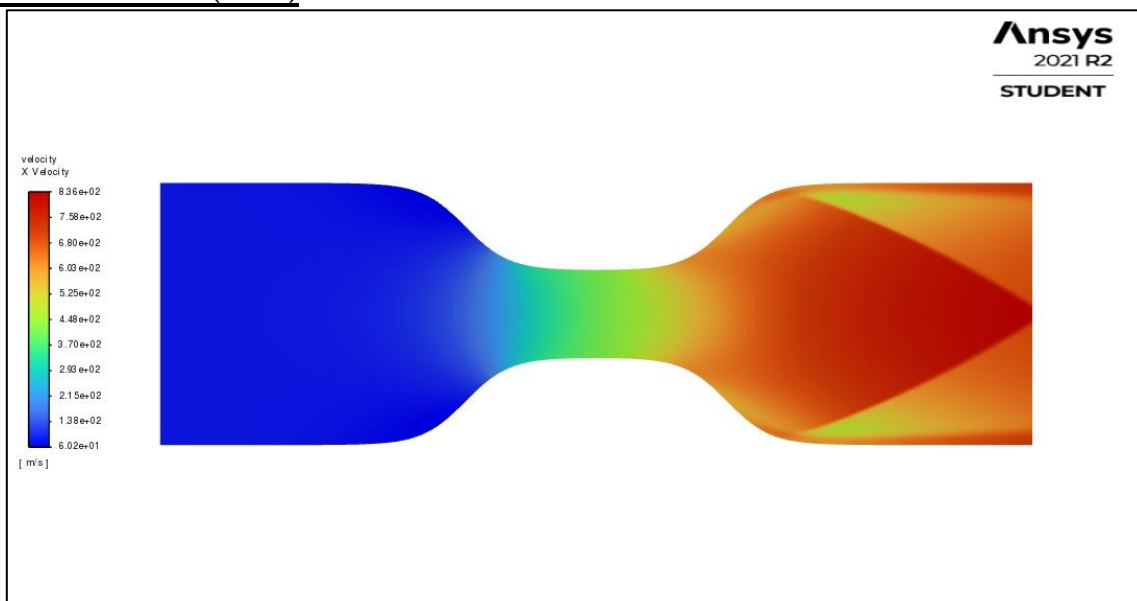## Task 3a – High speed flow in a 2D nozzle
Deliverable 12 (D12)

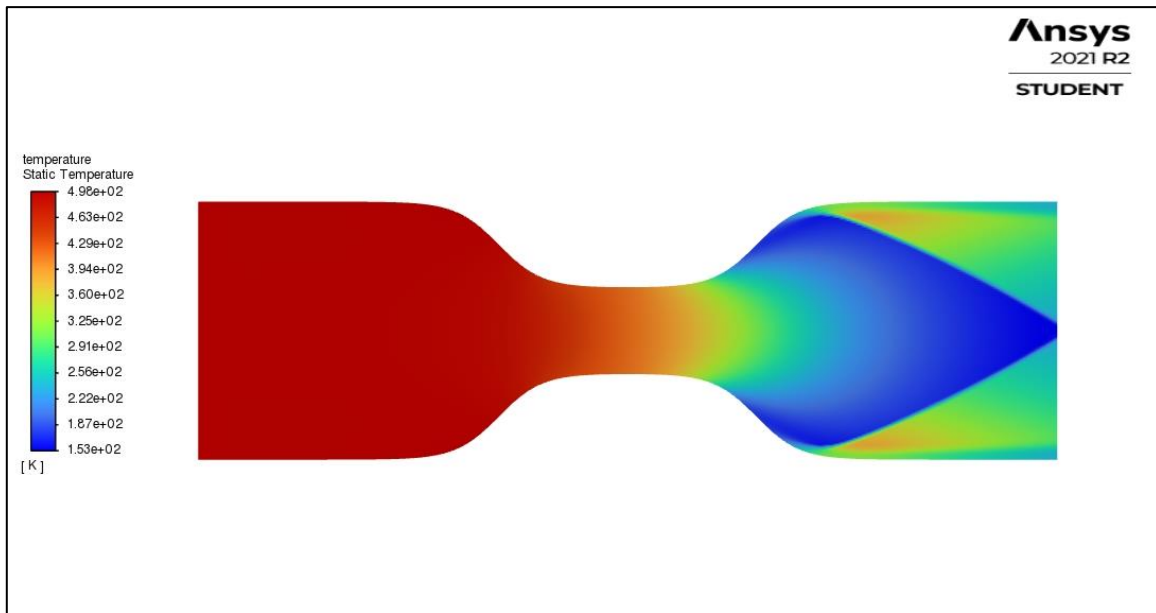Fig 3.2 – Contour plot of 'x' velocity

Fig 3.3 – Contour plot of static temperature
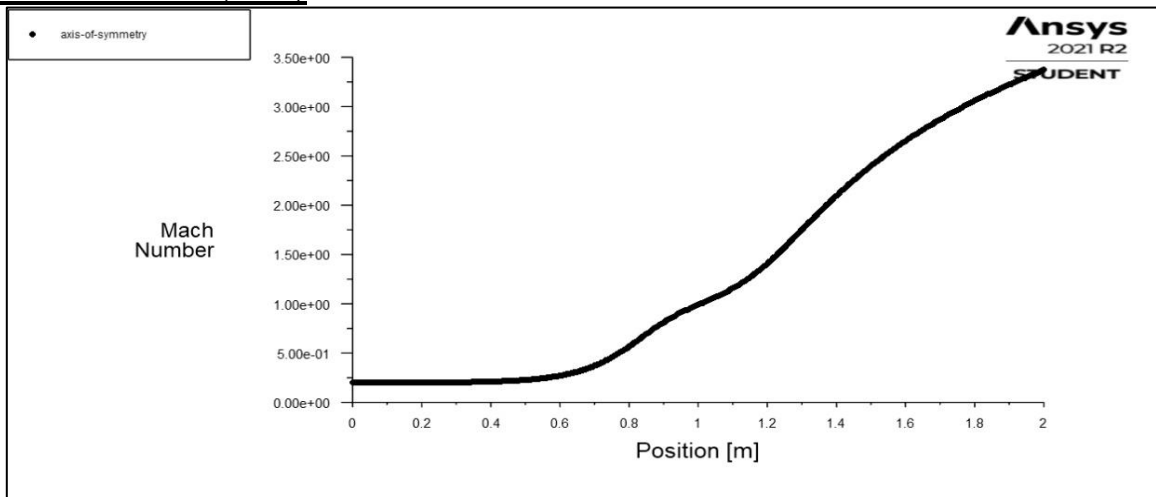
Deliverable 13 (D13)

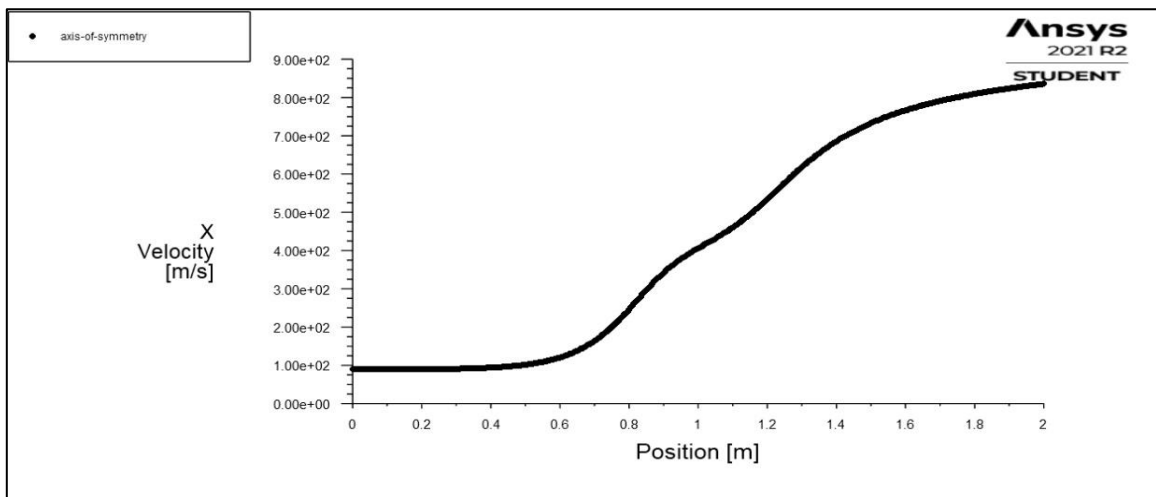Fig 3.4 – Line plot of x velocity along x axis

Fig 3.5 – Line plot of Mach number along x axis

Task 3b – Demonstrating the effect of compressibility
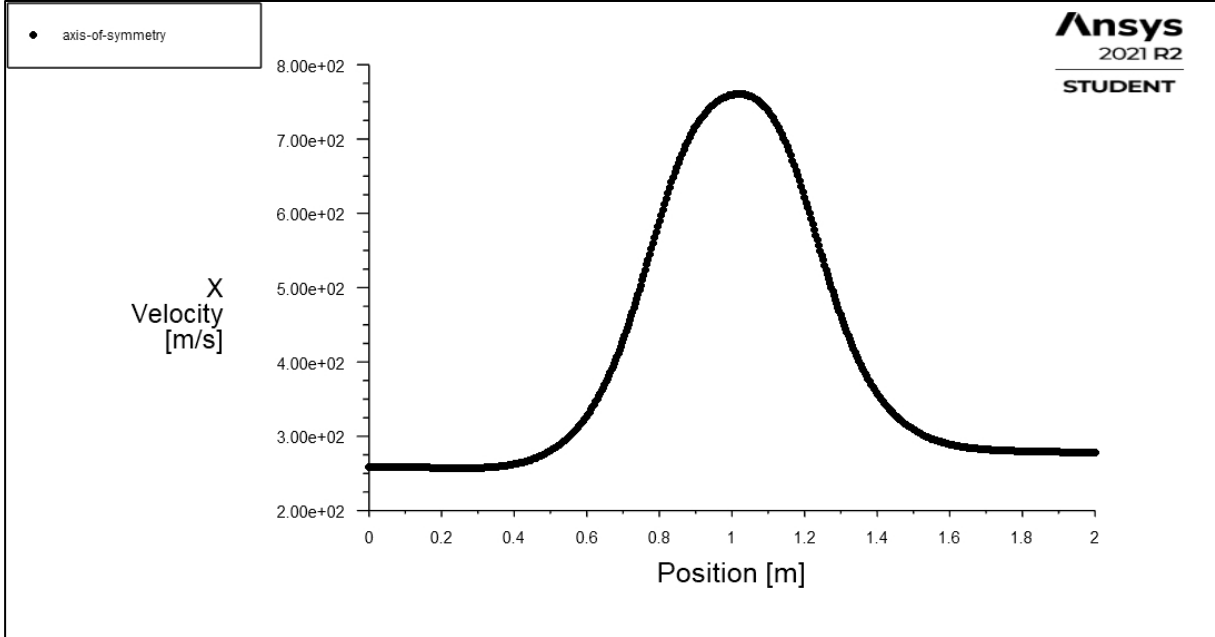## Deliverable 14 (D14)

Fig 3.6 – Line plot of x velocity along x axis

The density of air is set to constant for the above graph. The mass flow rate remains constant throughout the nozzle. We can say that the velocity of air varies inversely with the area of cross section of nozzle. Thus, the velocity of air increases when the area of cross section decreases which explains the sudden rise in velocity in the above graph which corresponds to the throat of the nozzle. As the area further increases the velocity starts decreasing. This explains the difference in the fig 3.6 and fig 3.4 which is associated to constant density and ideal gas density respectively.