Applied Computational Fluid Dynamics

Project 1

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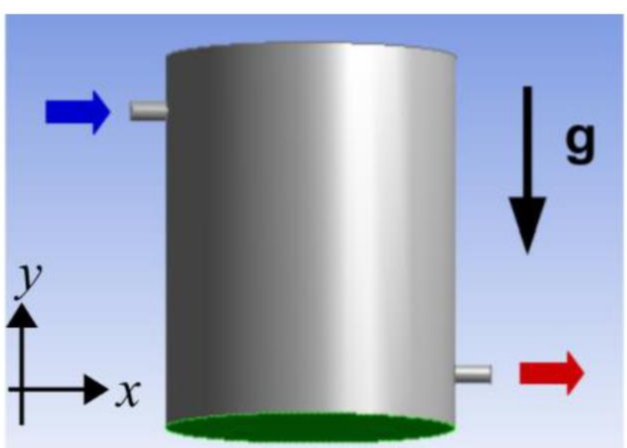
Task	Contribution to Collaborative Effort
Task 1	To find appropriate size of meshing and time step size
Task 3	Help in initialization.

Task 1

Internal flow with Thermal Convection:

A water tank with two pipes for inlet and outlet. To perform appropriate meshing and obtain velocity, temperature and value of temperature.

Given Conditions:
Inlet Velocity= 0.1m/s
Inlet Temperature: 15 degree C
Bottom Temperature: 40 degree C
Use *k-epsilon* mode and use *Boussinesq.*
Turbulence Kinetic Energy: 0.01m2s-2
Turbulence Dissipation Energy: 0.01m2s-3

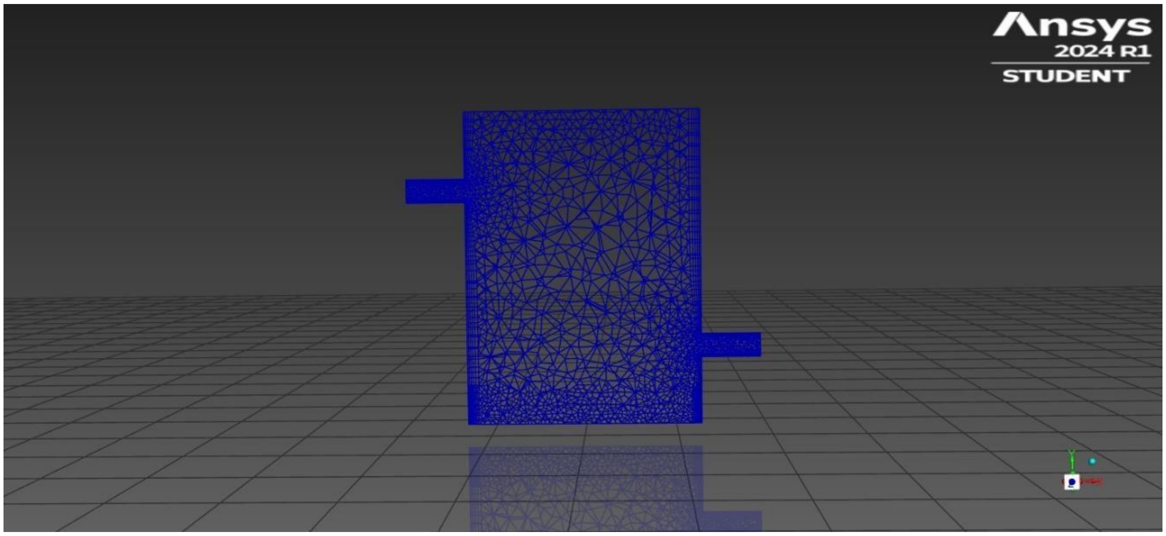


Task 1a:

Ran transient simulation = 3 minutes,

D1.

A plot of mesh in plane of symmetry:



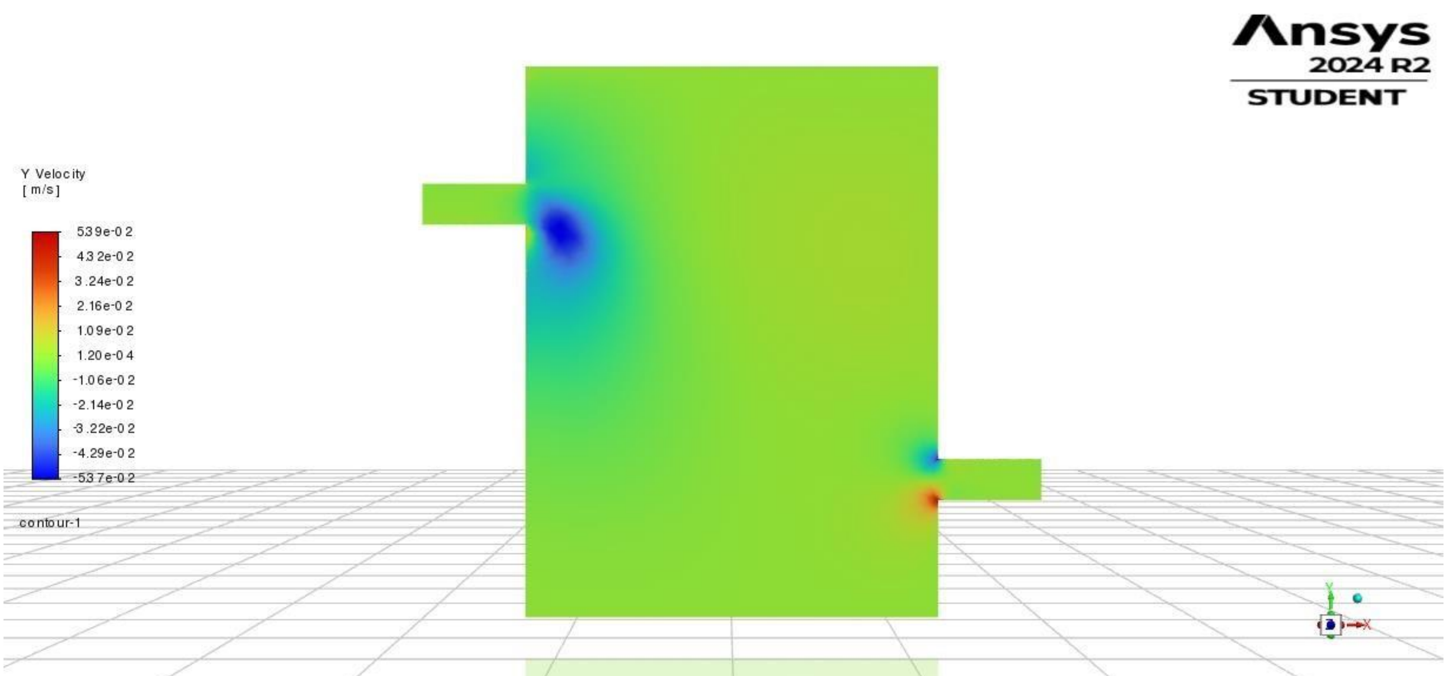
Operating Temperature: 15+40/2= 27.5 degrees Celsius.
Operating Density: 997 kg/m3 Thermal Expansion Coefficient:

Time Step Size: 0.5

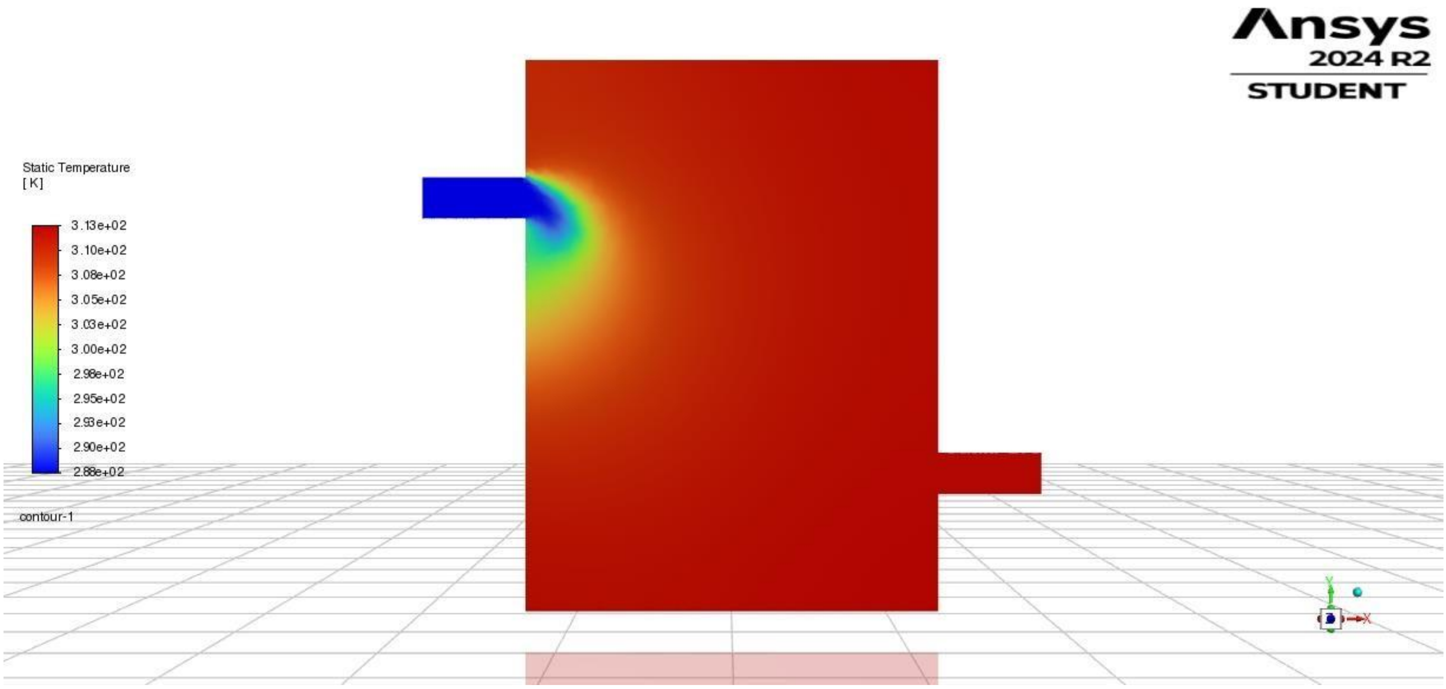
Max number of iterations per step: 100

D2.

Contour Plots of *y-velocity* at t=1min.

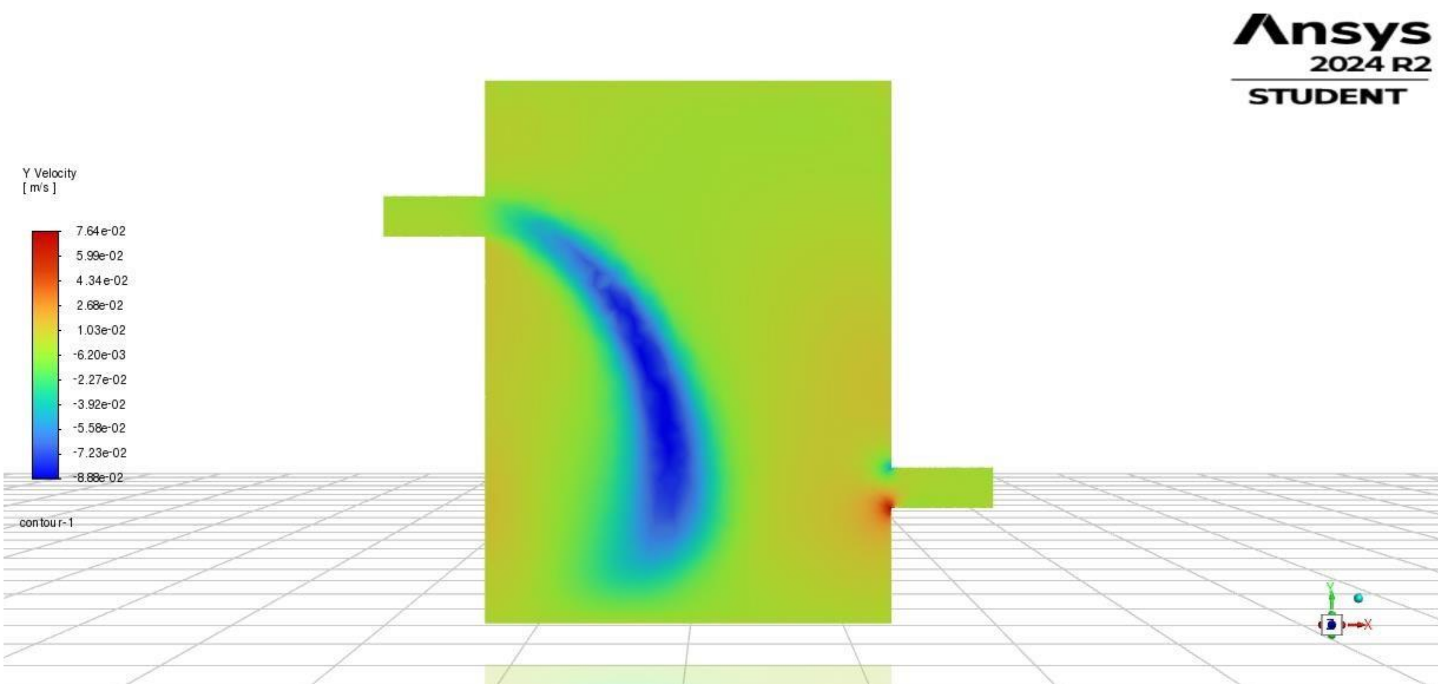


Temperature in the plane of symmetry at t=1min.

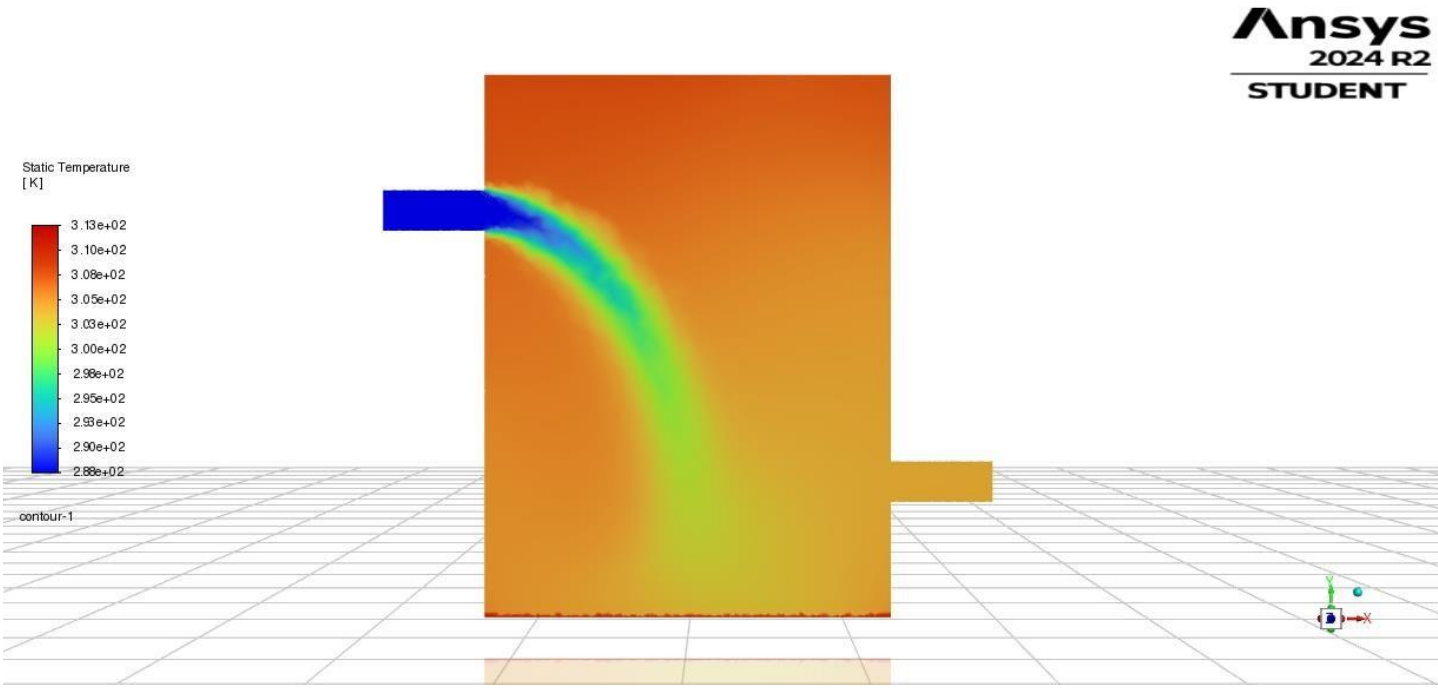


D3.

Contour plot of the *y-velocity* t=3min.

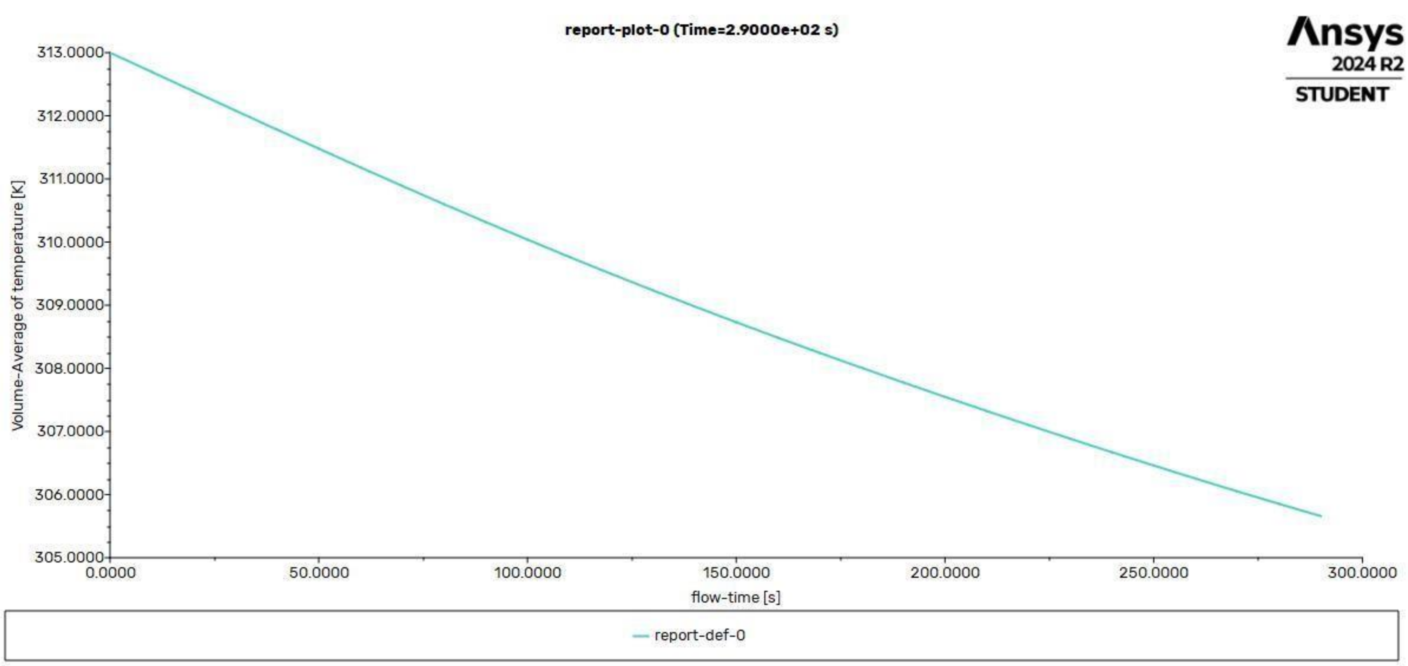


Contour plot of the temperature in the *plane of symmetry* at t=3min.



D4.

A line of the average temperature, TAVE in function over 0≤t≤3min.

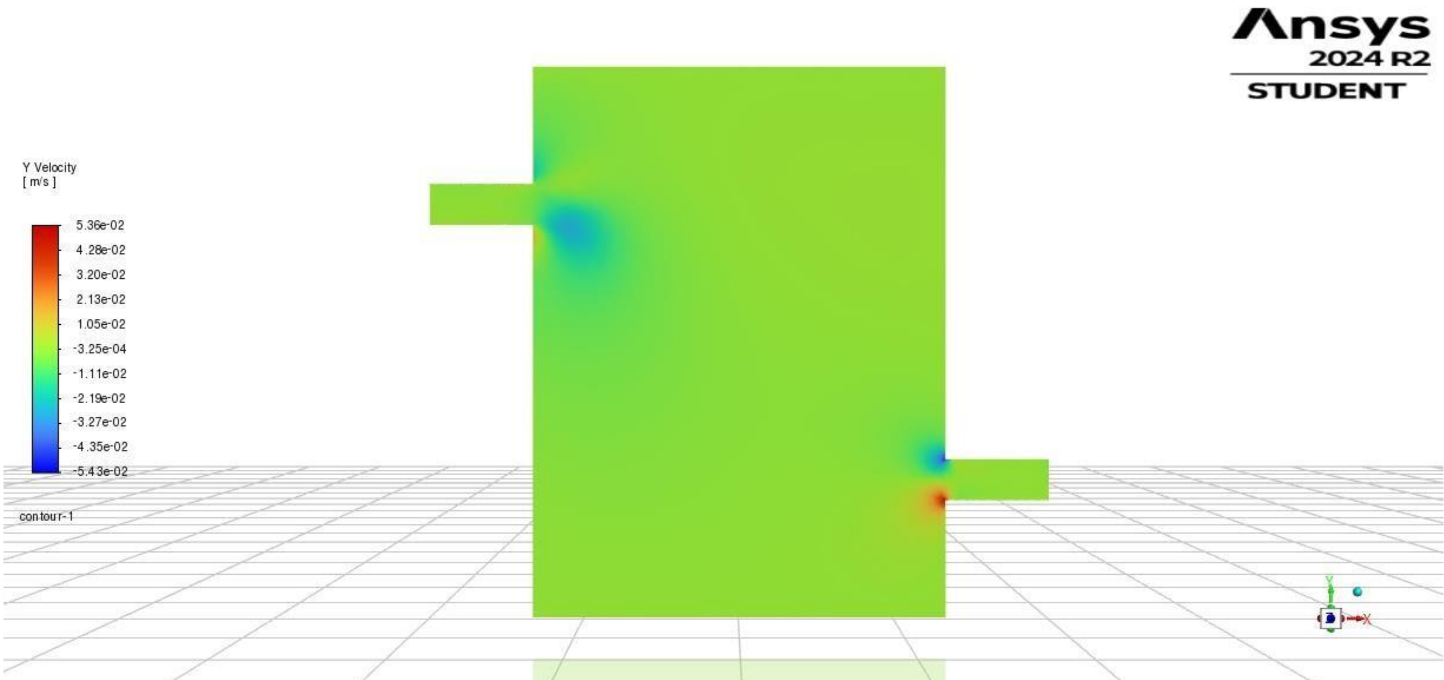


Task 1b

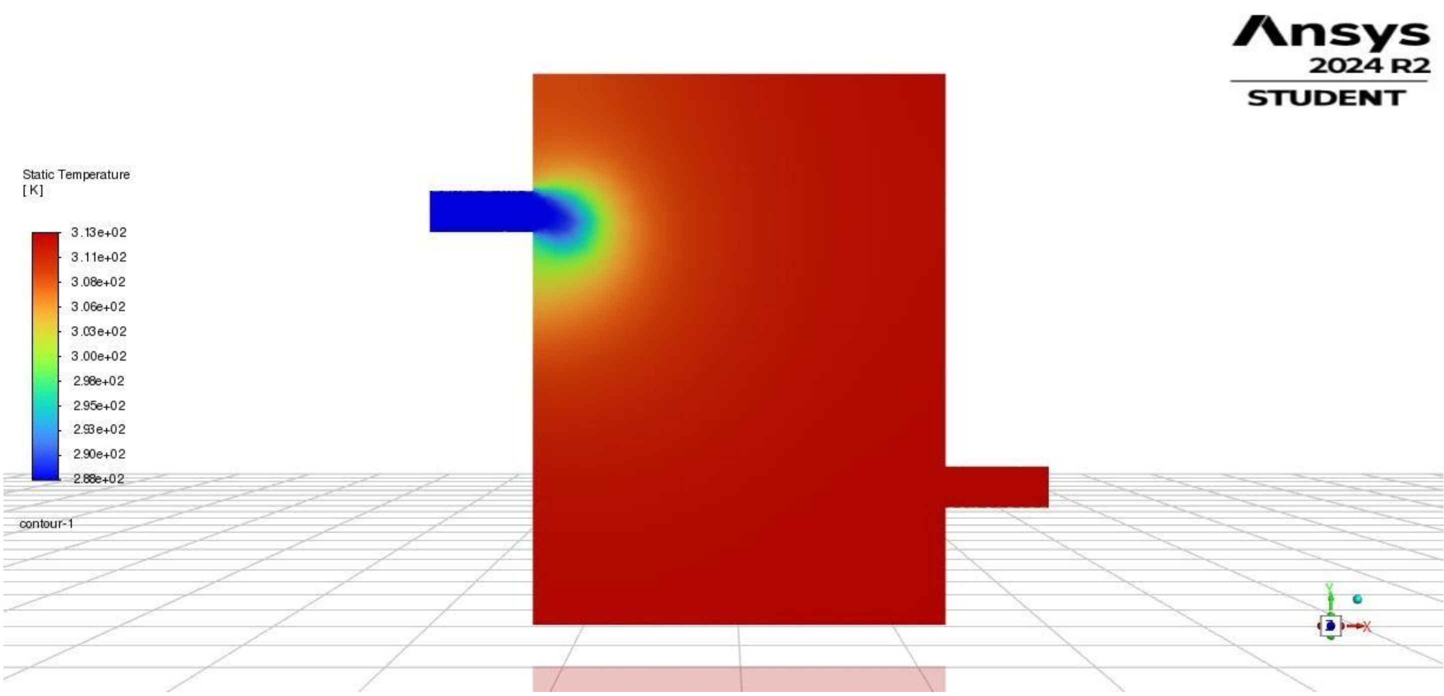
simulation in Task 1a, except changing gravity in y-direction from –9.81 to –3.72 ms–2. (This is the gravity at the surface of Mars.) Run the simulation to at least t = 1 minute.

D5.

Contour plots of the velocity at y-direction



Contour plot of the temperature in plane of symmetry:



The solution differs from that in D2 because, the buoyant forces that propel thermal convection are primarily responsible for these variations. The buoyancy-driven flow is less powerful on Mars due to its lower gravity, which causes the water flow dynamics to slow down and the temperature gradient to decrease. In comparison to the Earth scenario, this results in a more uniform temperature profile and lower y-velocity because the overall heat transmission and mixing processes are less efficient.

Task 2:

Internal Flow with heat source

We have to design helical pipe with its center traced by equation of helical curve X(t)=
Rcos(t)
T(t)=Rsin(t) Z(t)= C(t)
with its radius 4cm.

Task 2a

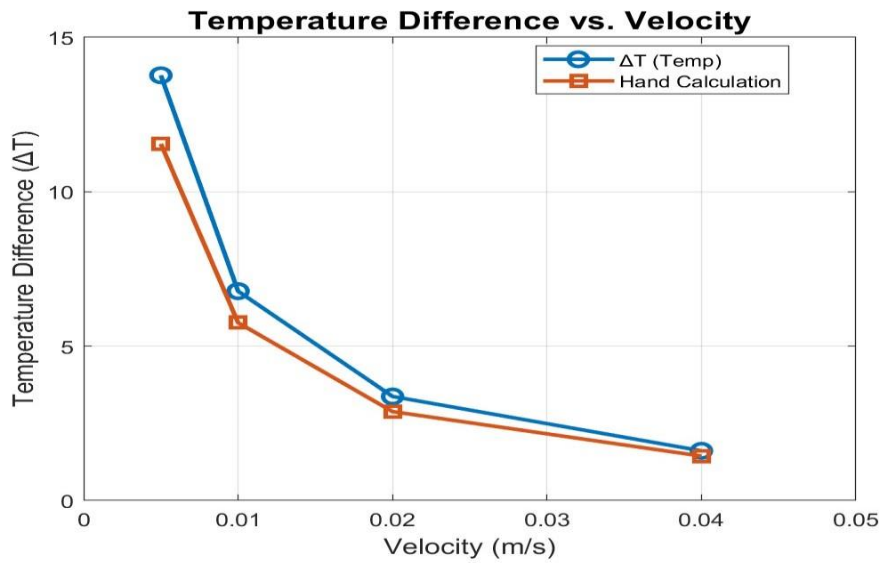
Flow with heated Wall

To perform 4 steady-state laminar flow simulations with water as the fluid, using constant properties from the Fluent database. The inlet velocity varies at 0.005, 0.01, 0.02, and 0.04 m/s with a fixed inlet temperature of 300K. A uniform energy input of 600 W/m² is applied at the helical pipe wall, and the focus is on the temperature difference between the inlet and outlet

D6.

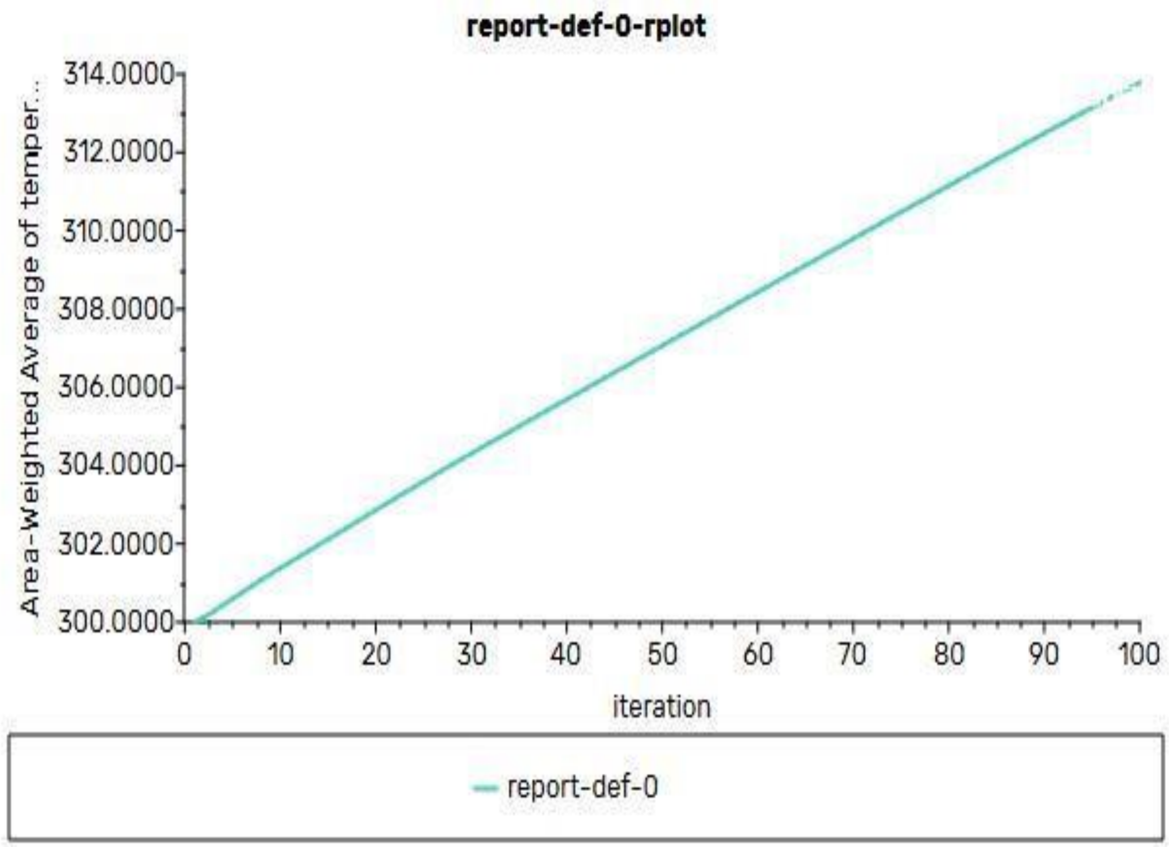
The values of ΔT for the 4 cases from the steady solution produced by Fluent, compared with the corresponding "hand calculation" $(\Delta T)H$. [We do not expect an exact match, since Eq. (6) is derived by assuming that the pipe is straight and the flow is uniform, etc.] This should be presented as a table. In addition, make a plot of "ΔT vs. inlet velocity" and "$(\Delta T)H$ vs. inlet velocity". Collect the two curves in the same plot.

Velocity	Temp (delta T)	Hand Calculation
0.005	13.77	11.55
0.01	6.78	5.76
0.02	3.37	2.88
0.04	1.61	1.44



D7.

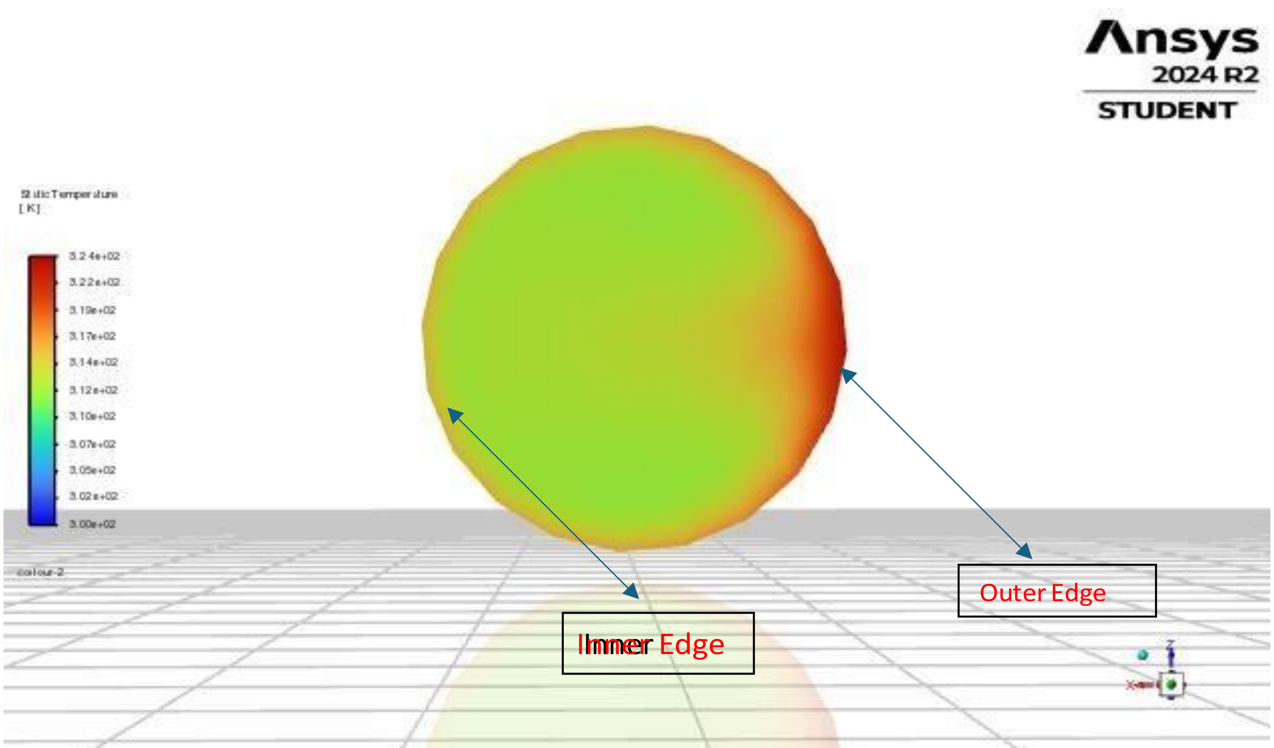
For the case of inlet velocity= 0.005m/s the line of Tout is:



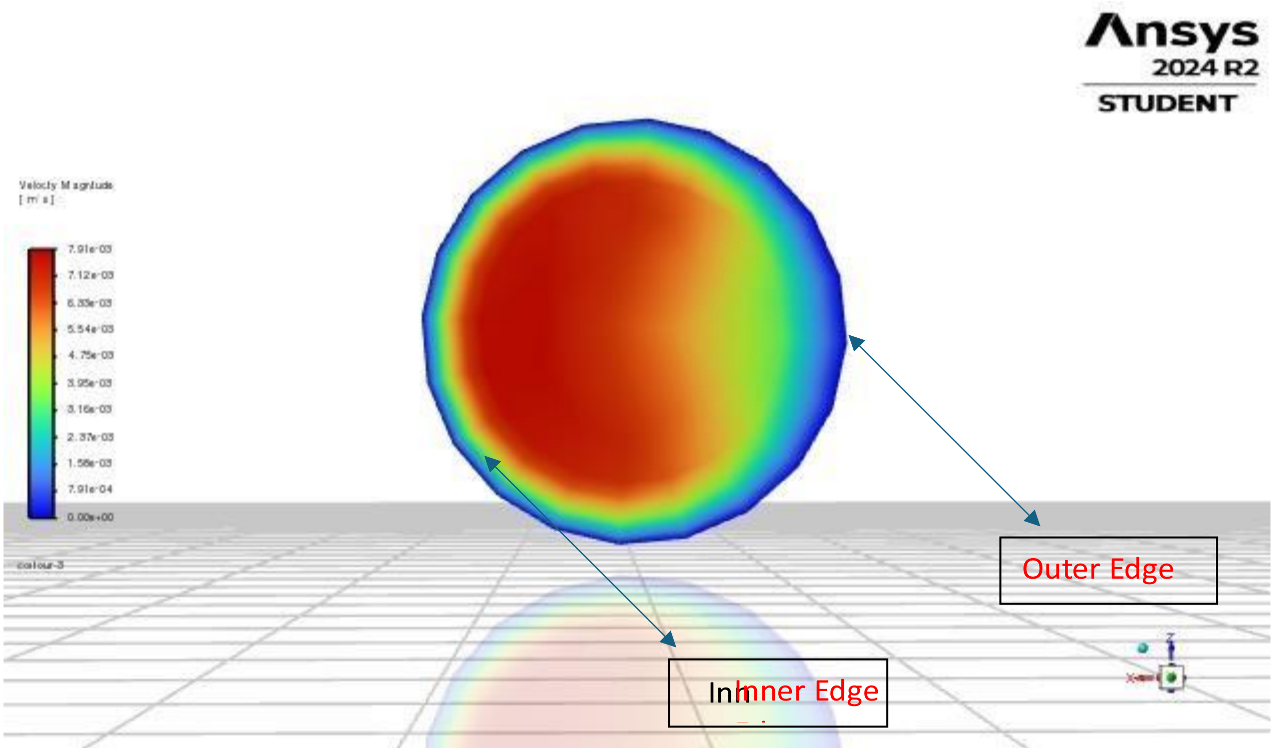
D8.

For the case with inlet velocity =0.005m/s,

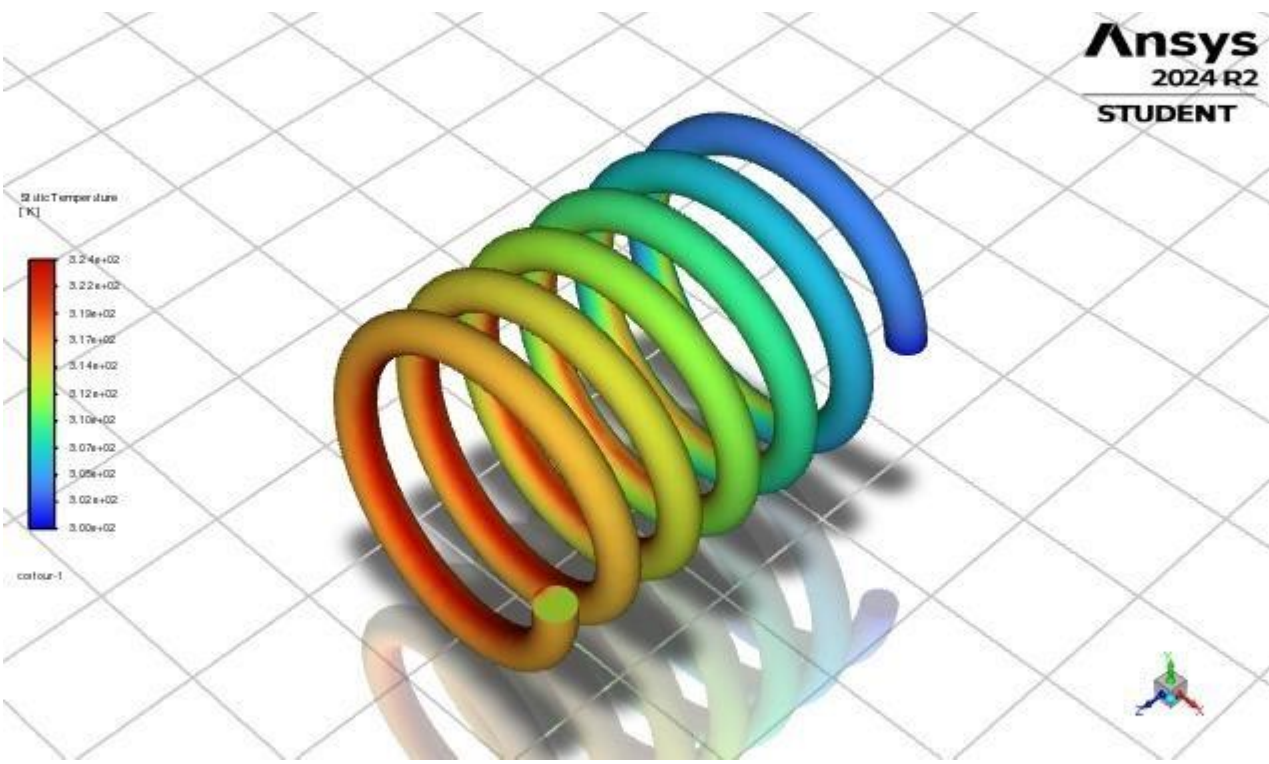
1. Contour of plots of Temperature over outlet:



2. Velocity Magnitude over outlet:



3. Contour plot of Temperature for the outer boundary for whole system:



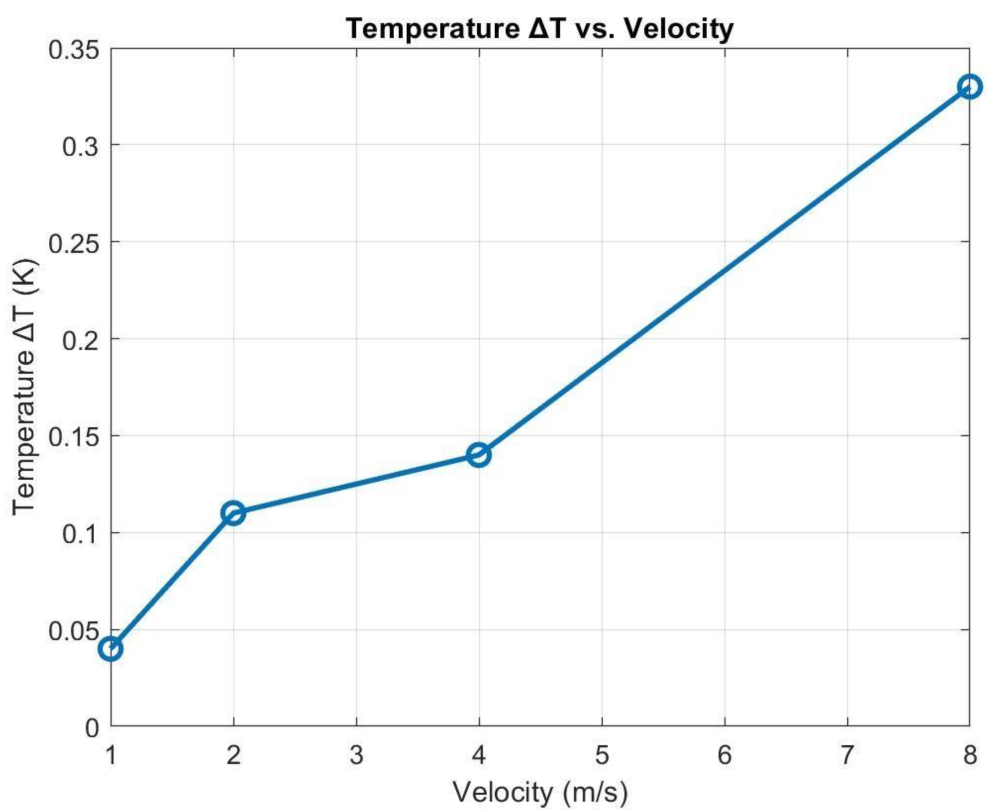
Task 2b
Viscous Heating

D9.

The values of ΔT for 4 cases,
ΔT= Tout-Tin
where Tin is 300K

Tout values are:

Velocity	Tout	Temperature ΔT
1	300.04	0.04
2	300.11	0.11
4	300.14	0.14
8	300.33	0.33



D10.

Task 2a's decreased heat absorption capacity and shorter residence durations are the main causes of the ΔT reduction with increasing intake velocity. Fluid packets spend less time in contact with the heated walls as the inflow velocity rises, which results in less heat energy absorption and a slower temperature rise. On the other hand, Task 2b's growing ΔT with higher inflow velocity points to better mixing and increased heat transfer efficiency. Greater heat absorption from the wall is possible and thermal mixing is enhanced when there is a shift from laminar to turbulent flow, which can be facilitated by higher velocities. The constant relationship between heat transfer mechanisms and flow parameters greatly affects the reported temperature variations in each job.

Task 3

A simple Compressible flow:

For Case 1:

In Case 1, the device is filled with air, utilizing a density-based solver for a transient solution. Boundary conditions include a pressure outlet at 10,000 Pa and backflow temperature of 300 K. The initial conditions set chamber A at 10,200 Pa, with zero velocity and uniform temperature of 300 K, while turbulence kinetic energy kkk is 1 m²/s² and specific dissipation rate ω\omega is 1 s⁻¹. The k-omega model is used with the energy equation enabled to account for compressibility effects.

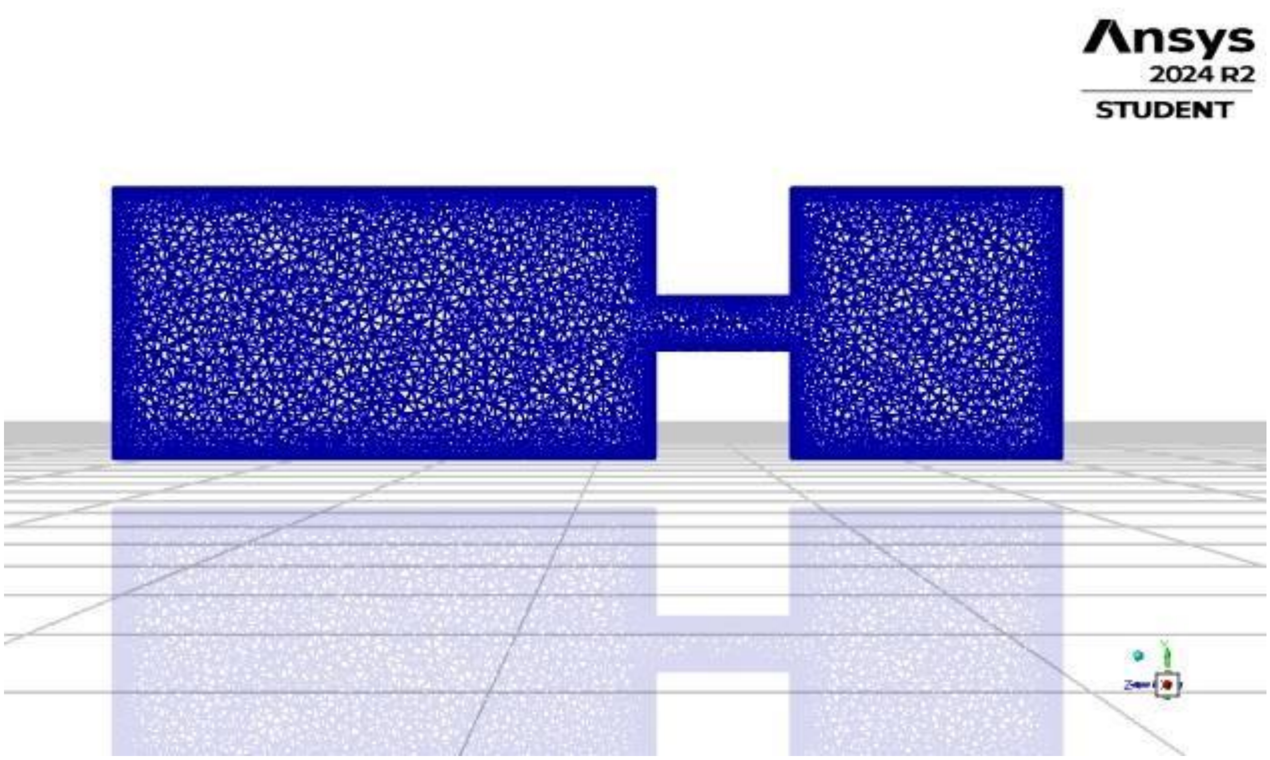
D11.

The Choice of time step size is :0.01

Max number of iterations per time step is100.

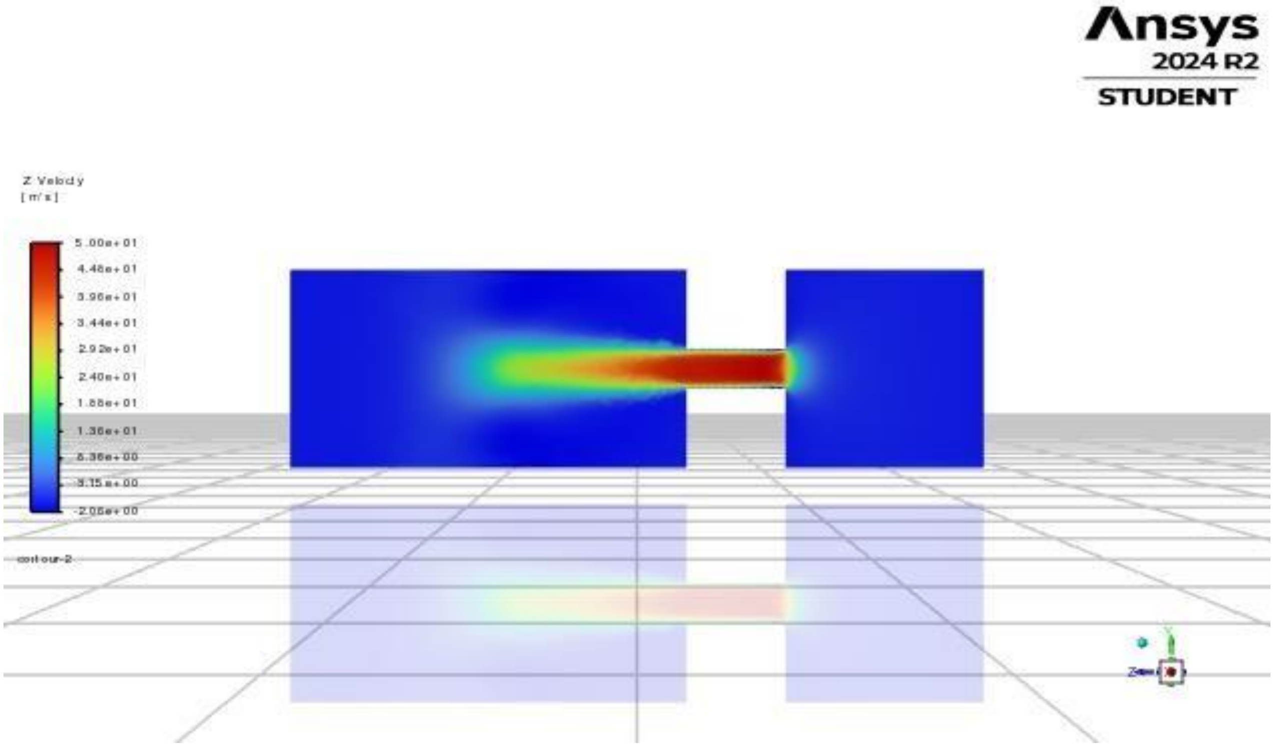
The transient simulation is t=0.01s.

Plot of mesh in the plane of symmetry:

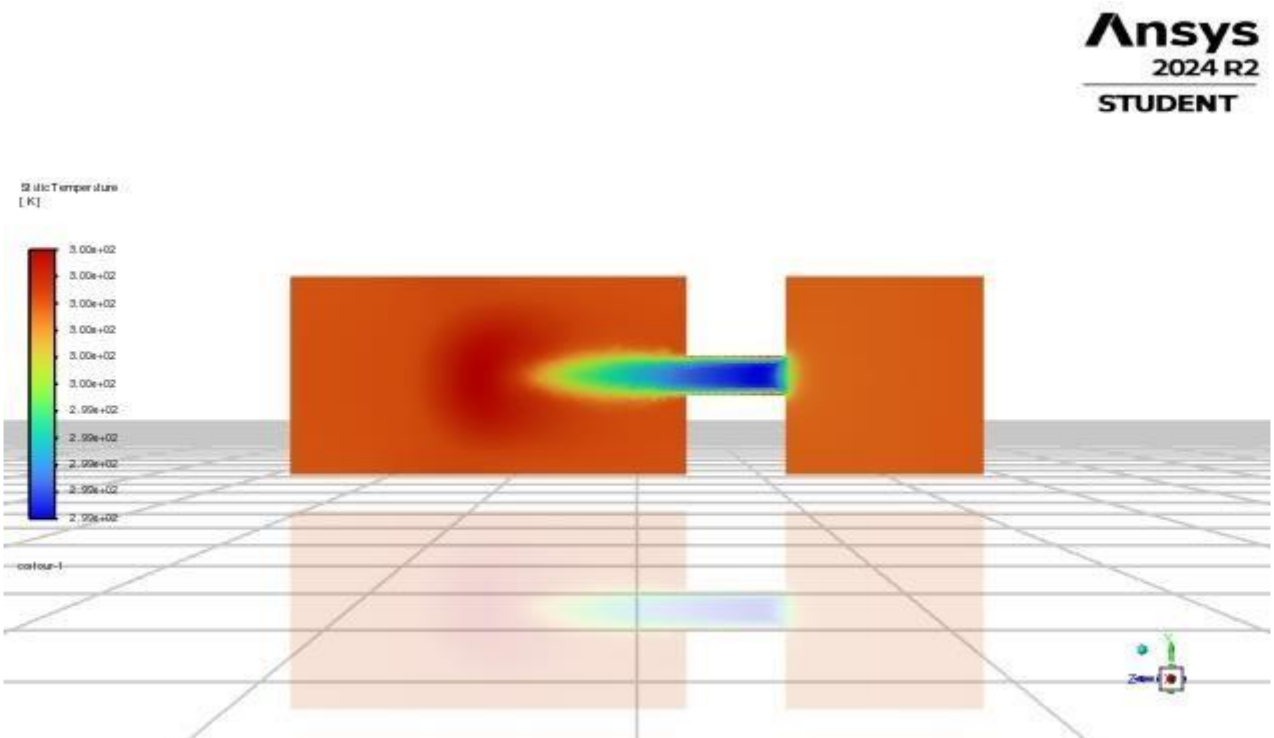


D12.

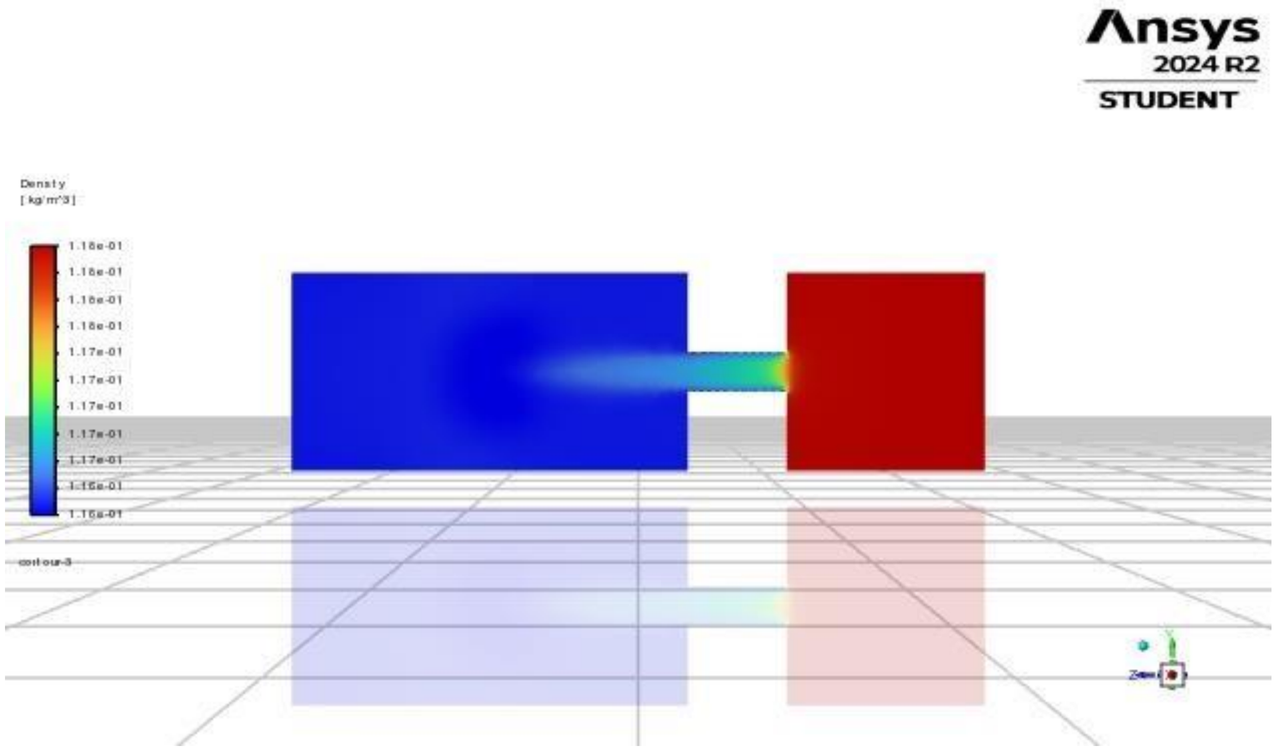
Contour plot of *Z- Velocity* in plane of symmetry at t=0.01s in Case 1.



Contour plot of temperature in plane of symmetry at t=0.01s for Case 1.



Contour plot of density in plane of symmetry at t=0.01s for Case 1.

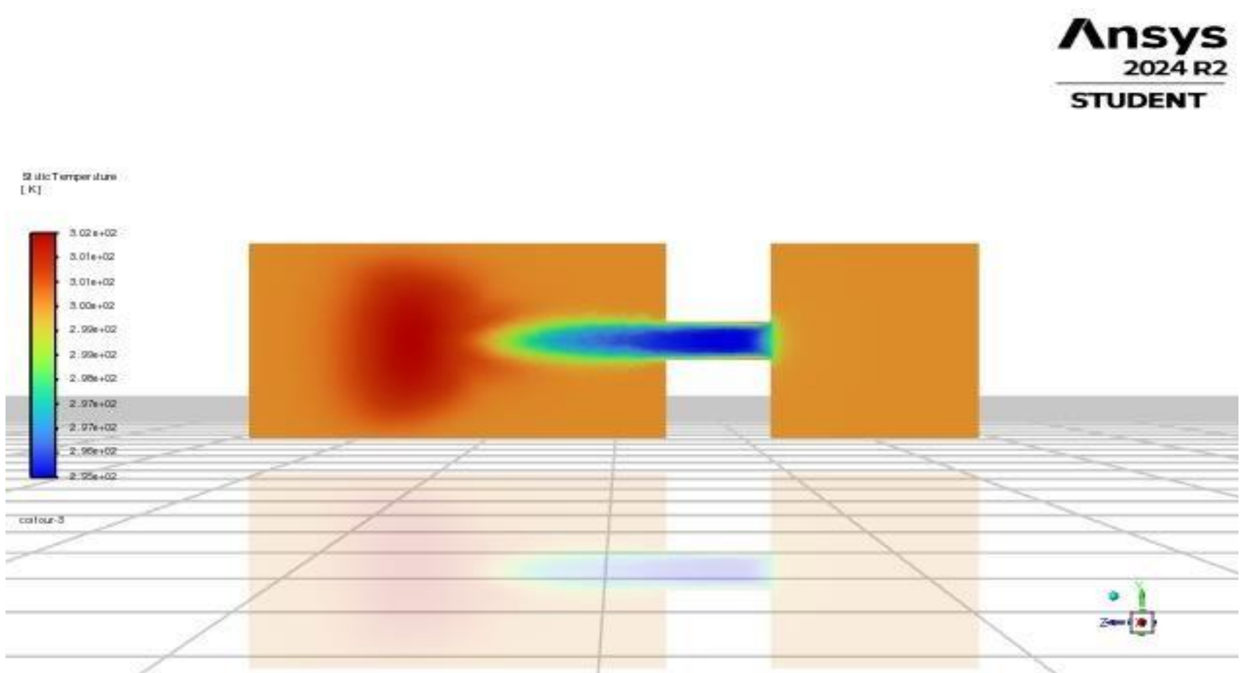


For Case 2:

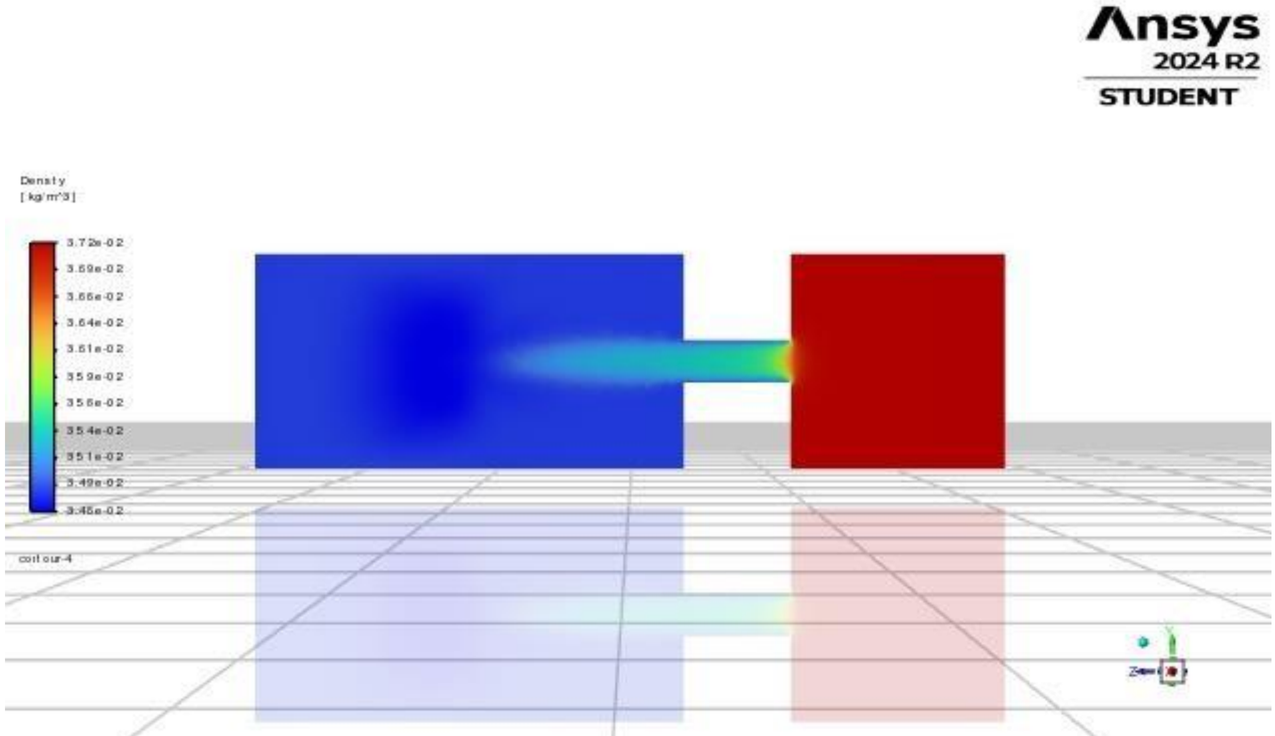
The outlet absolute pressure to 3000 Pa, change the initial absolute pressure in the inner chamber to 3200 Pa, and change the initial absolute pressure elsewhere in the domain to 3000 Pa. Run the transient simulation to t = 0.01 s.

D13.

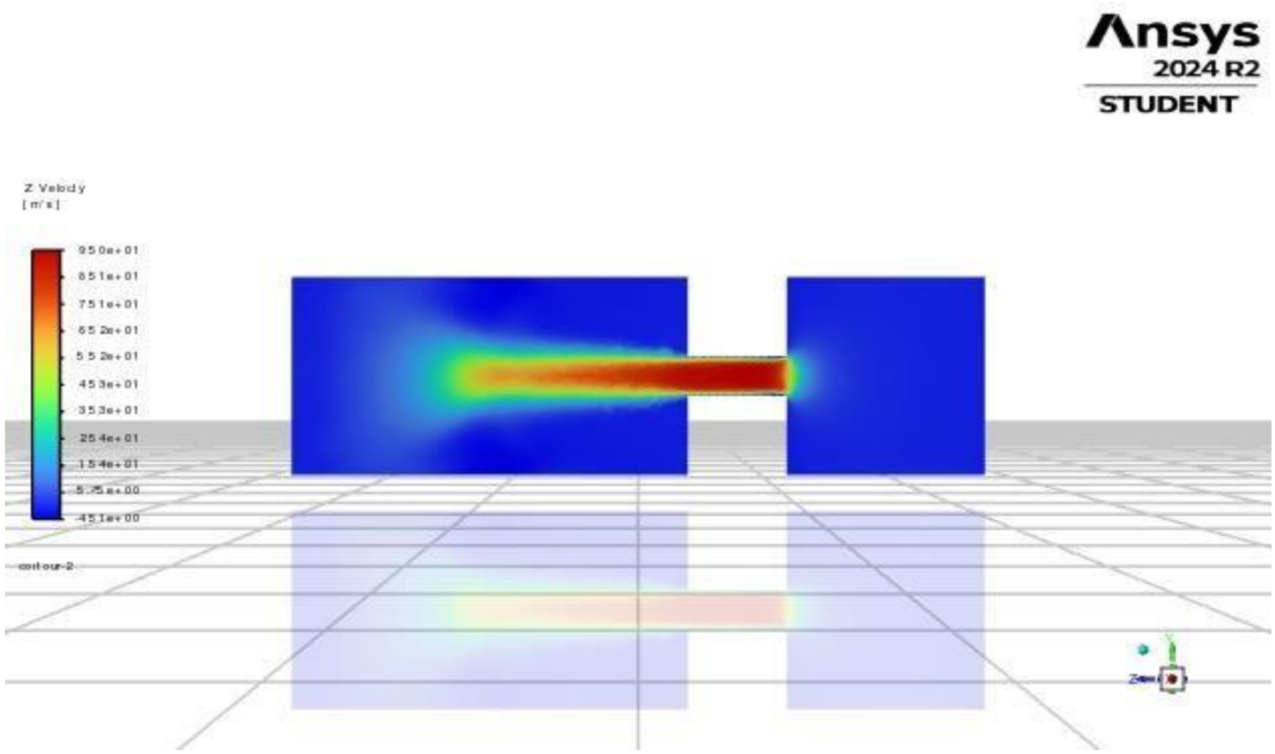
Contour plot of temperature at plane of symmetry at t=0.01 for Case 2.



Contour plot of density at plane of symmetry at t=0.01 for Case 2.

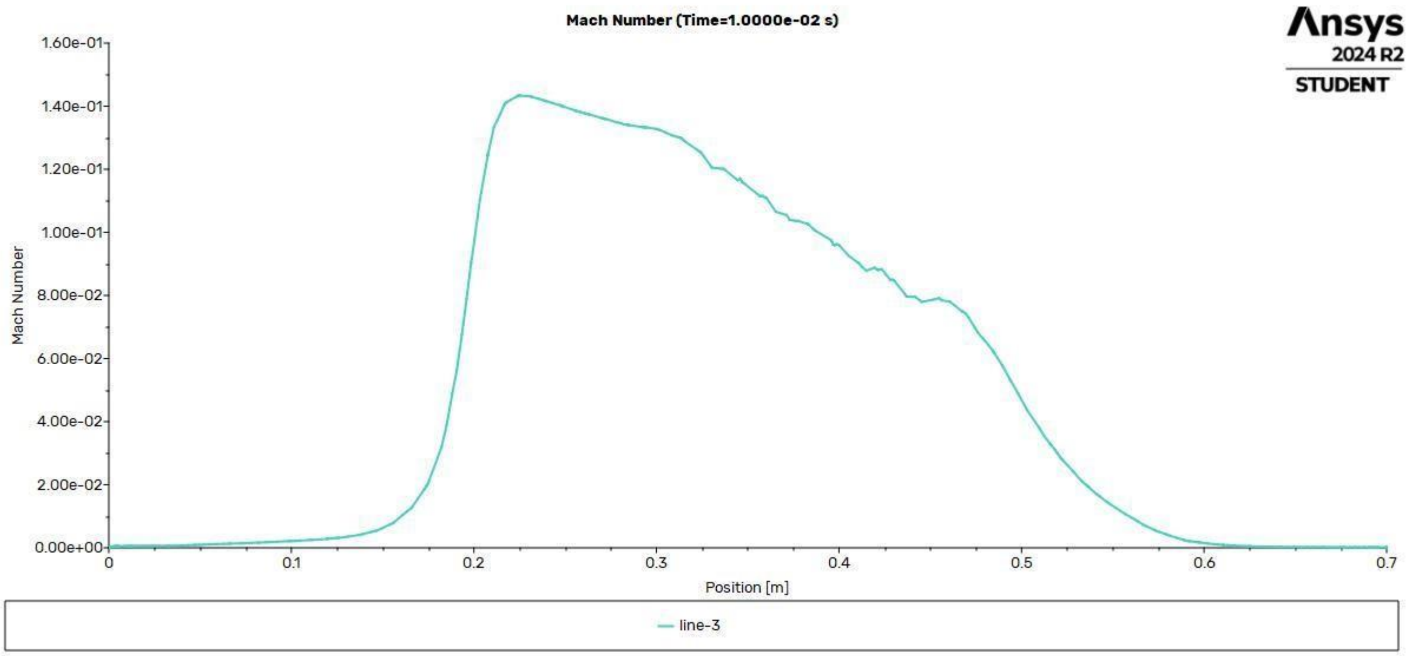


Contour plot of *Z- Velocity* in plane of symmetry at t=0.01s in Case 2.

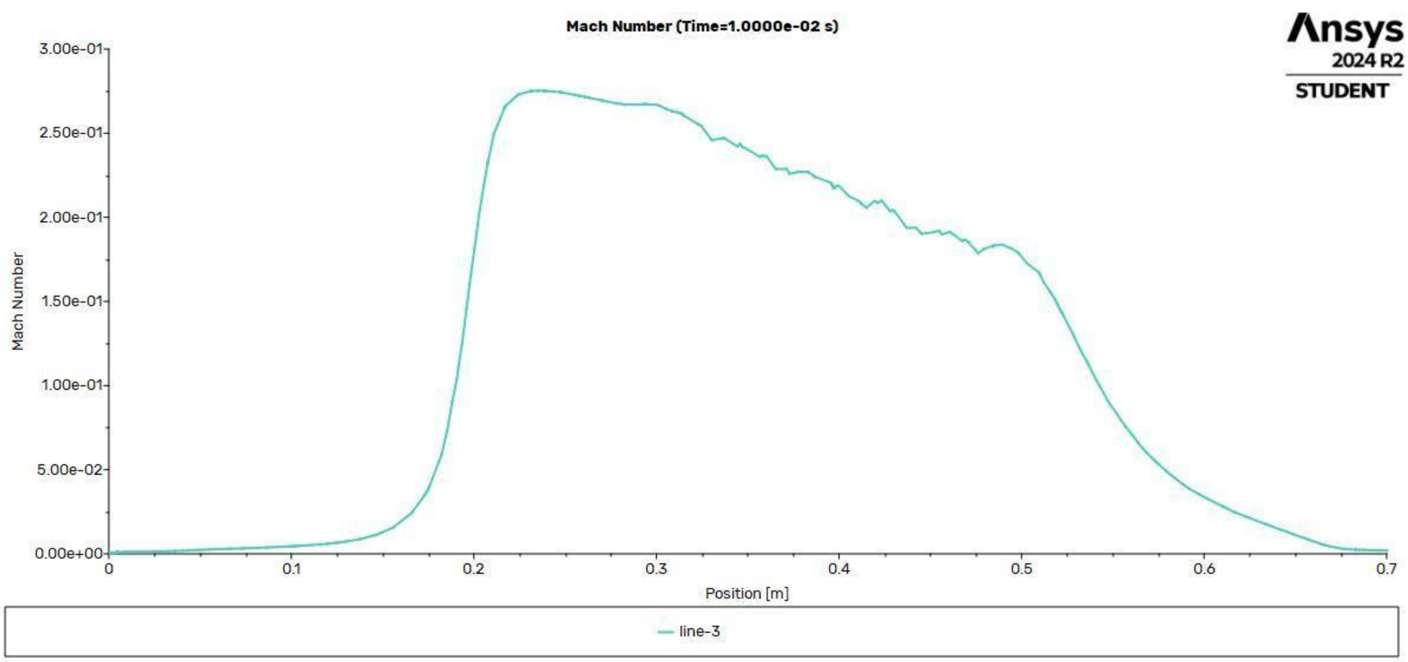


D14.

Line plot for Mach Number at t=0.01s as function along Z along the axis of symmetry for case 1:



Line plot for Mach Number at t=0.01s as function along Z along the axis of symmetry for case 2:



D15.

Case 1 produces a higher velocity of the air jet compared to **Case 2**. This can be explained by analyzing the momentum equation for fluid flow, which can be expressed in simple terms as:

$$D(mV)/Dt = \text{Force} + \text{Pressure gradient}$$

The mass flow rate is represented by m, the velocity by V, and the forces operating on the fluid, such as pressure differentials, are represented by the right side. Case 1 sets the exit pressure at 10,000 Pa and the initial absolute pressure in chamber A at 10,200 Pa. As a result, there is a notable 200 Pa pressure gradient that propels the flow from chamber A, which is at high pressure, to the output, which is at low pressure.

According to the momentum equation, the fluid will be subjected to a stronger force as the pressure differential increases, which will cause the air to escape at a higher velocity. This greater pressure differential produces a stronger driving force in Case 1, which accelerates the fluid more efficiently and raises the air jet's exit velocity. In contrast, Case 2 has an output pressure of 3,000 Pa and a starting absolute pressure of 3,200 Pa in chamber A. The overall lower pressure in both chambers causes a weaker force to work on the fluid, which in turn results in a reduced exit velocity even though the pressure differential stays at 200 Pa.

The air jet's temperature drops in Case 2, suggesting a bigger cooling effect brought on by adiabatic expansion. The first law of thermodynamics states that when a gas expands adiabatically—that is, without exchanging heat with its surroundings—it exerts heat-trapping effects on its surrounds and uses up internal energy.
In Case 2, the exit pressure is much lower at 3,000 Pa than the initial absolute pressure in chamber A, which is set at 3,200 Pa. When the gas escapes through the outlet, it expands quickly and significantly because of this large drop in pressure during the expansion phase. The gas's internal energy drops as it tries to expand against the reduced outlet pressure, resulting in a drop in temperature.

Task 4 MAE 560

We simulate two cases of a 2D flow through nozzle, one in the supersonic regime and other in subsonic regime.

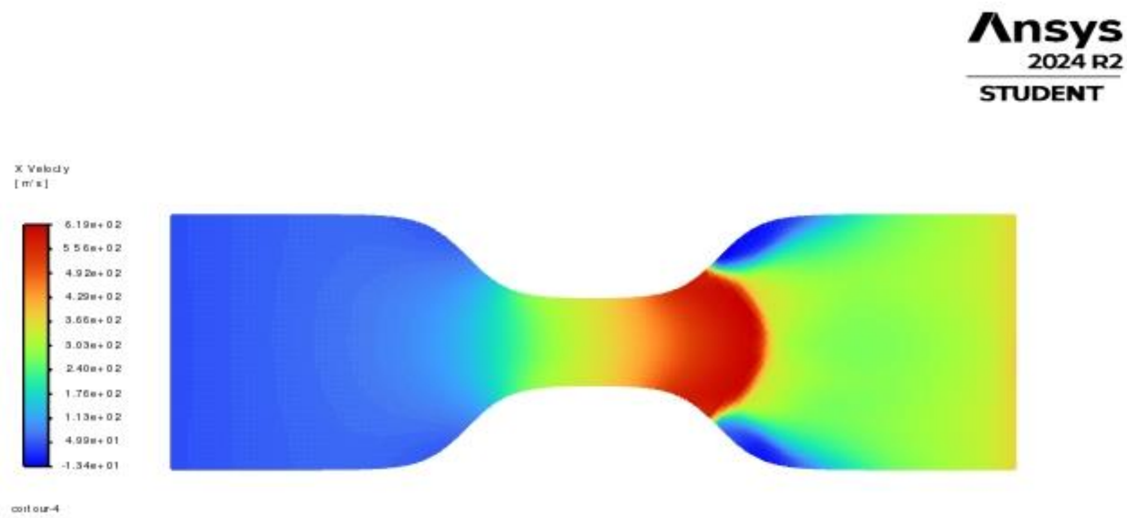
Task4a:
Supersonic:

Consider a 2-D flow through a nozzle as illustrated in Fig. 8 (not drawn to scale). The system is symmetric with respect to the x-axis. The profile of the wall of the nozzle is given by:

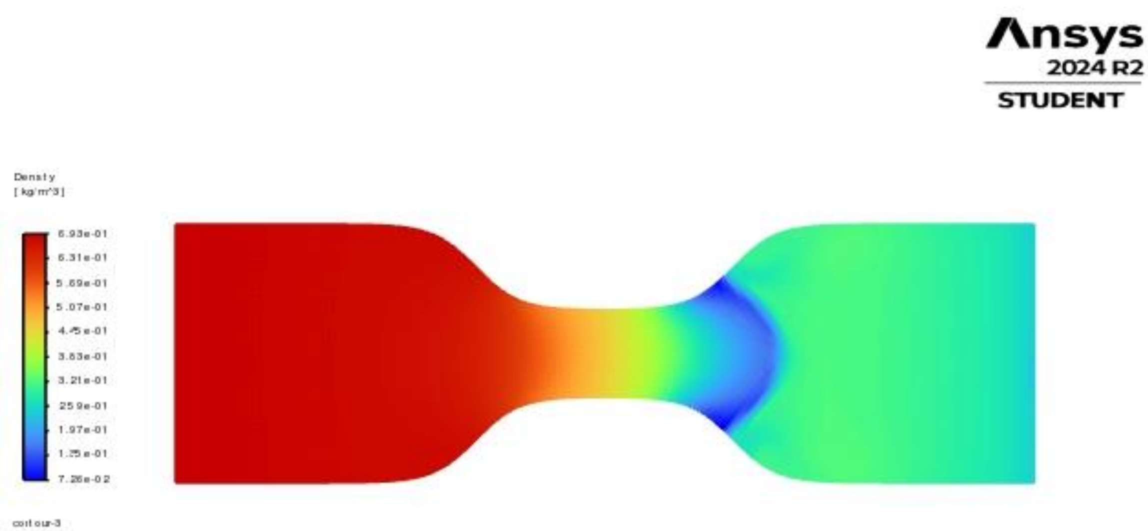
$F(x) = 0.3 + 0.1\,[\tanh(10x-13) - \tanh(10x-7)], \quad 0 \leq x \leq 2$
The unit of x and F(x) is meter. The system is filled with air, higher pressure is imposed at the left opening and a lower pressure at right opening. The pressure difference drives the flow through nozzle.

D16.

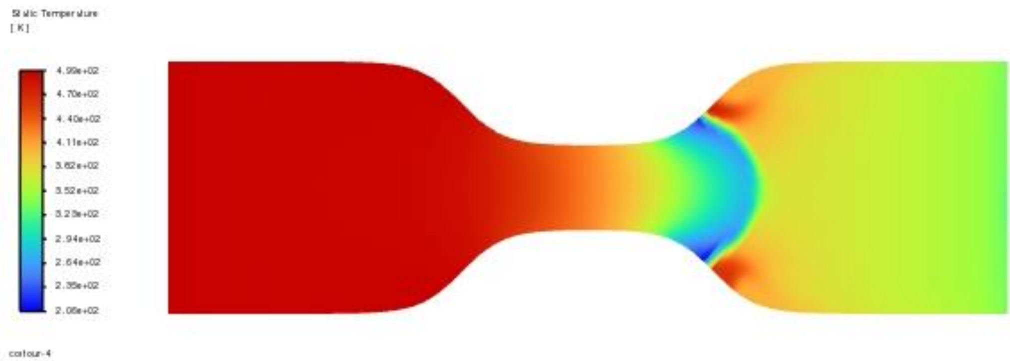
Contour Plots of x-velocity in supersonic condition:



Contour plots of Density in supersonic conditions:

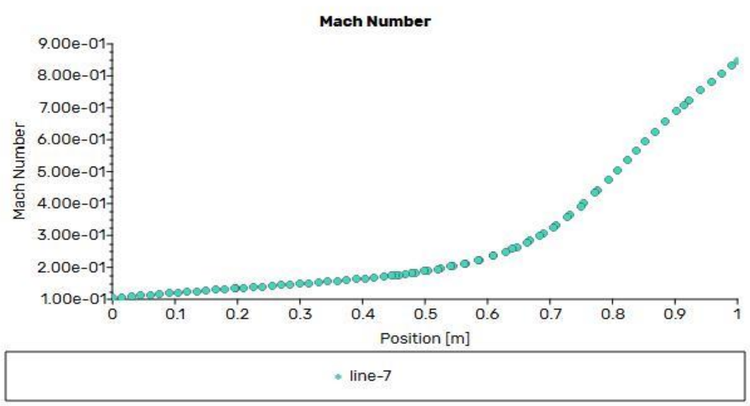


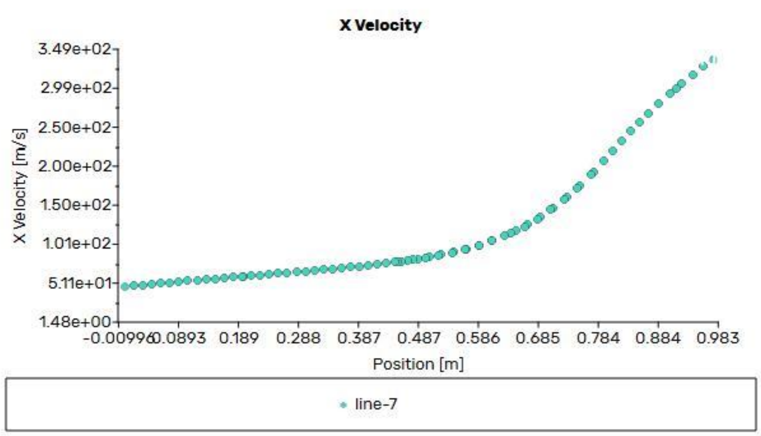
Contour plots of static temperature at supersonic conditions:



D17.

Line of plot X velocity and Mach number along axis of symmetry.



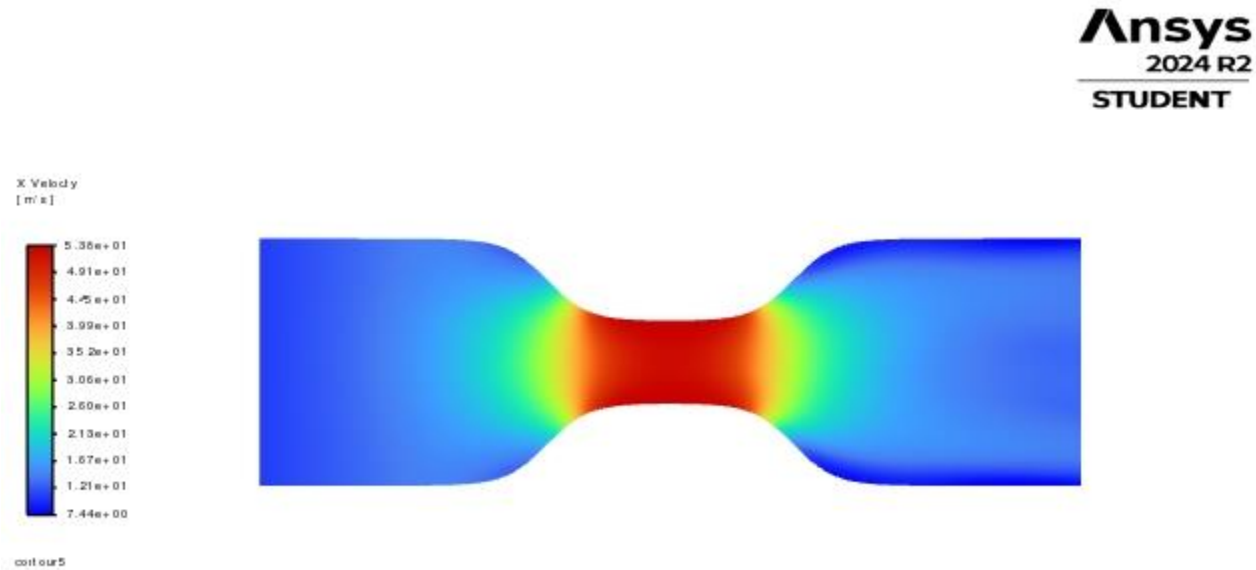


Task 4b

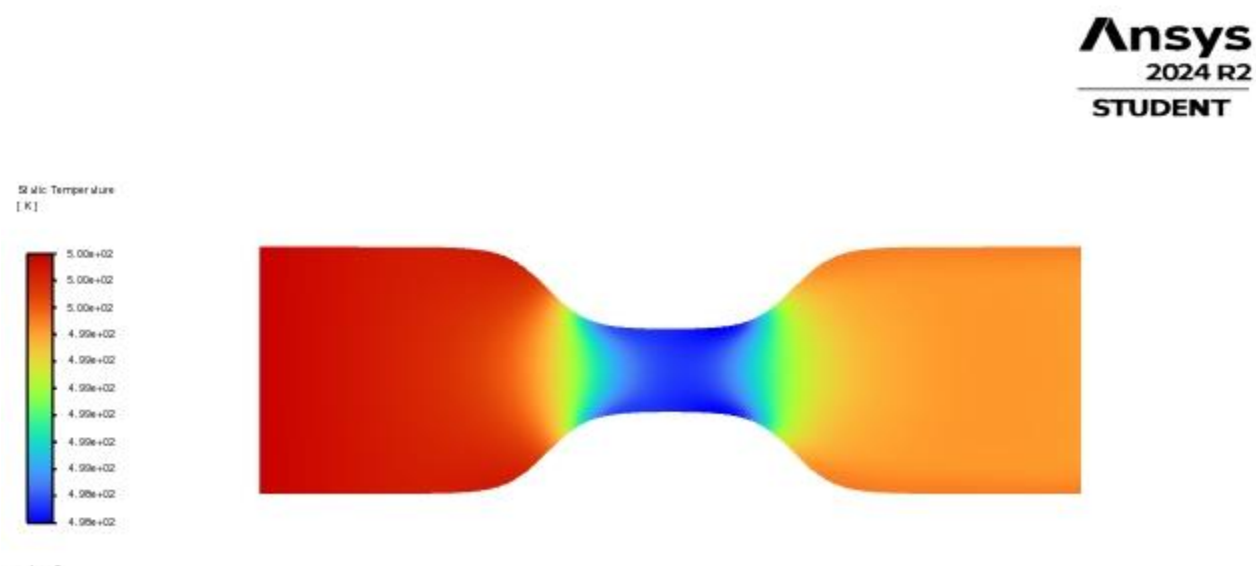
Subsonic Case:

D18.

Contour plots of x-velocity:



Contour plots of static temperature:



D19.

Line plot x-velocity and Mach number along its X-axis.