MAE 560: Applied Computational Fluid Dynamics

Project 1

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(NO COLLABORATION)

Task 1a: Transient Solution with Earth Gravity

(D1)

Values of operating temperature, operating density, and thermal expansion coefficient for Boussinesq setting.

Project 1 ACFD   Varad Lad

D1
- Applied the Boussinesq approximation to density.
- The operating tempreture was calculated as the average of inlet and outlet tempreture.

$\therefore$ $T_{max} = 50°C$
$T_{min} = 20°C$

So,

$$T_o = \frac{T_{max} + T_{min}}{2} = \frac{50+20}{2} = 35°C$$

$$T_o = 35°C = \underline{308.15 K}$$

To calculate the operating density, we refer the formula from NIST paper.

$\therefore$

$$\rho_o = 999.85308 + 6.32693 \times 10^{-2} \times T_o - 8.523829 \times 10^{-3} \times T_o^2 + 6.943248 \times 10^{-5} \times T_o^3 - 3.821216 \times 10^{-7} T_o^4$$

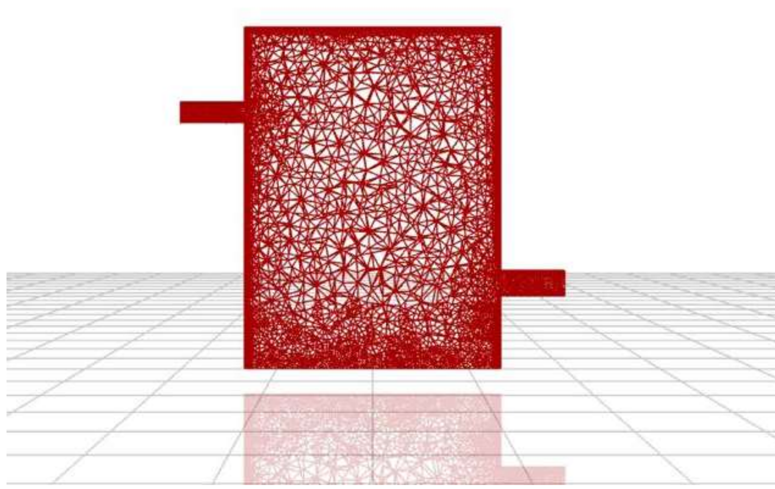
$$= 994.029 \ kg/m^3$$

Thermal Expansion coefficient for the system was calculated using the following formula:

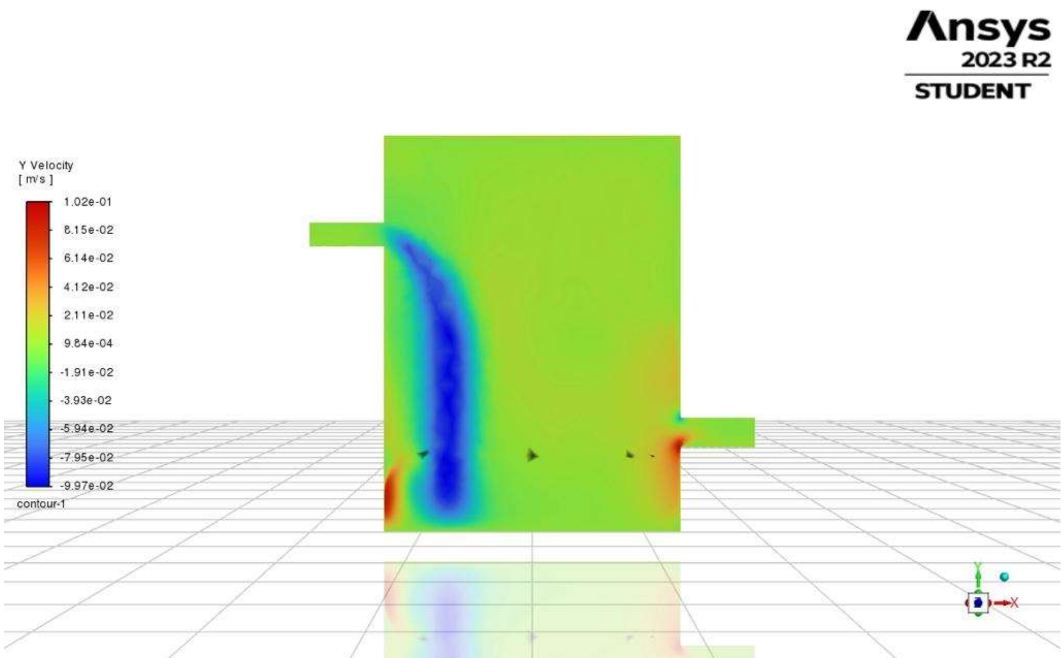
$$\beta = -\frac{1}{\rho_o}\left(\frac{d\rho}{dT}\right)_{T_o}$$

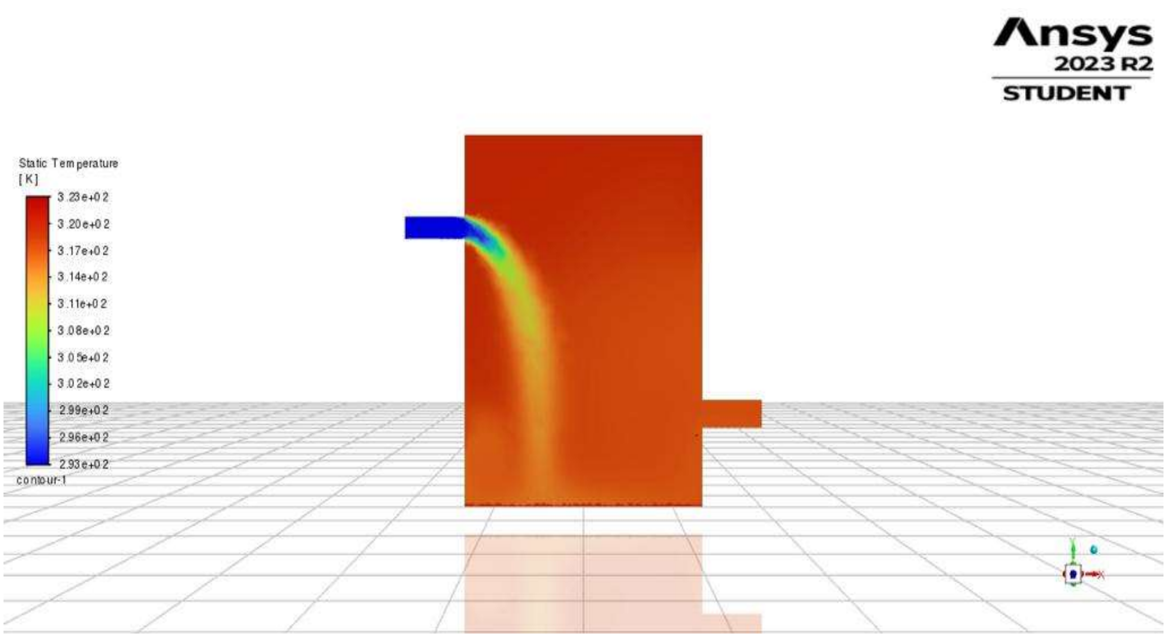
The thermal expansion coefficient was found to be 0.000338.

The number of time steps 150, the time step size (s) is 2, Max Iteration/time step is 20

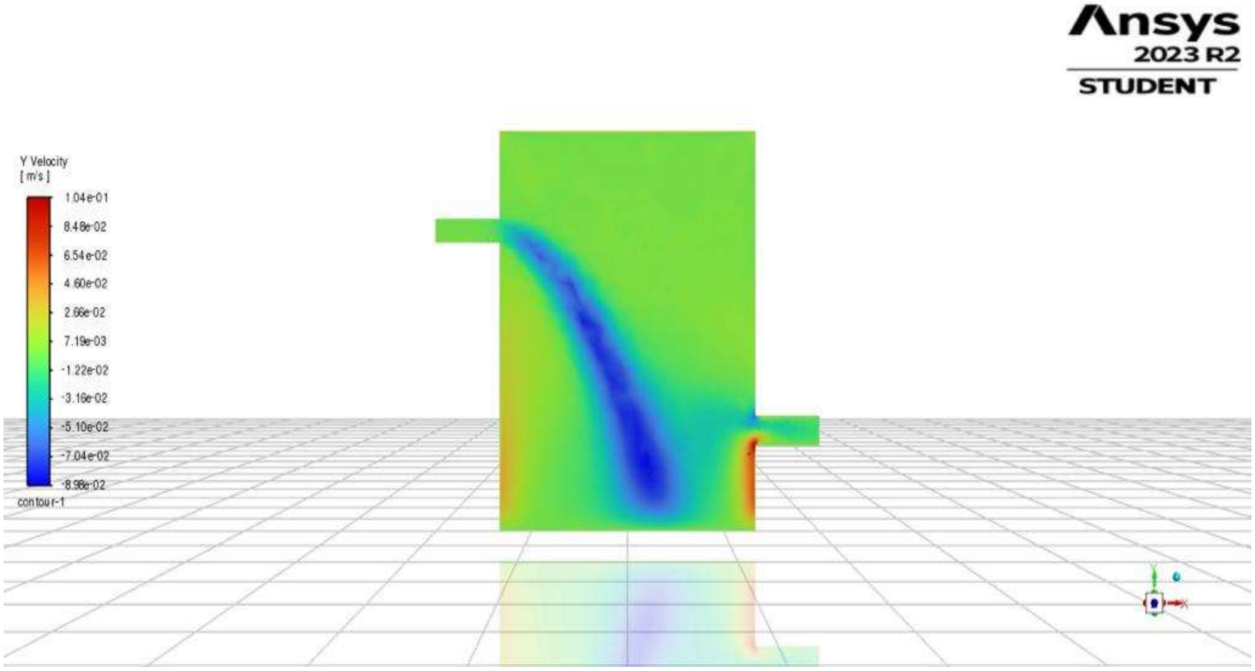


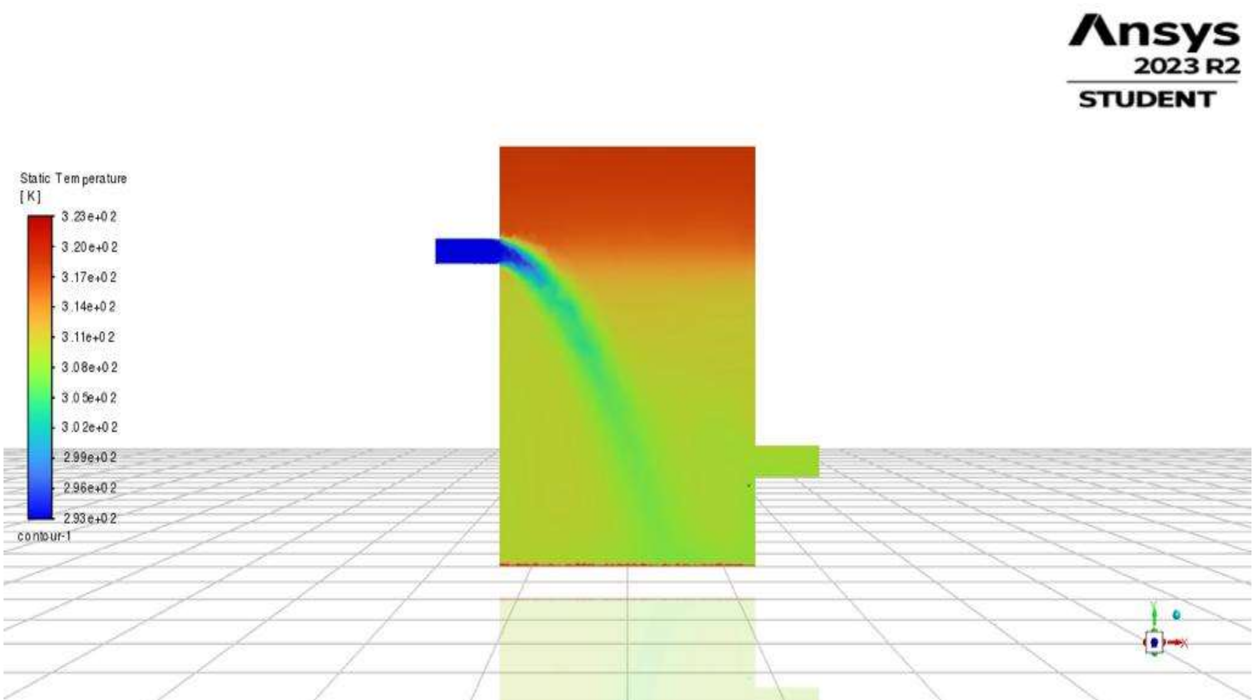
(D2) t = 1min


Ansys
2023 R2
STUDENT
Y Velocity
[m/s]
1.02e-01
8.15e-02
6.14e-02
4.12e-02
2.11e-02
9.84e-04
-1.91e-02
-3.93e-02
-5.94e-02
-7.95e-02
-9.97e-02
contour-1

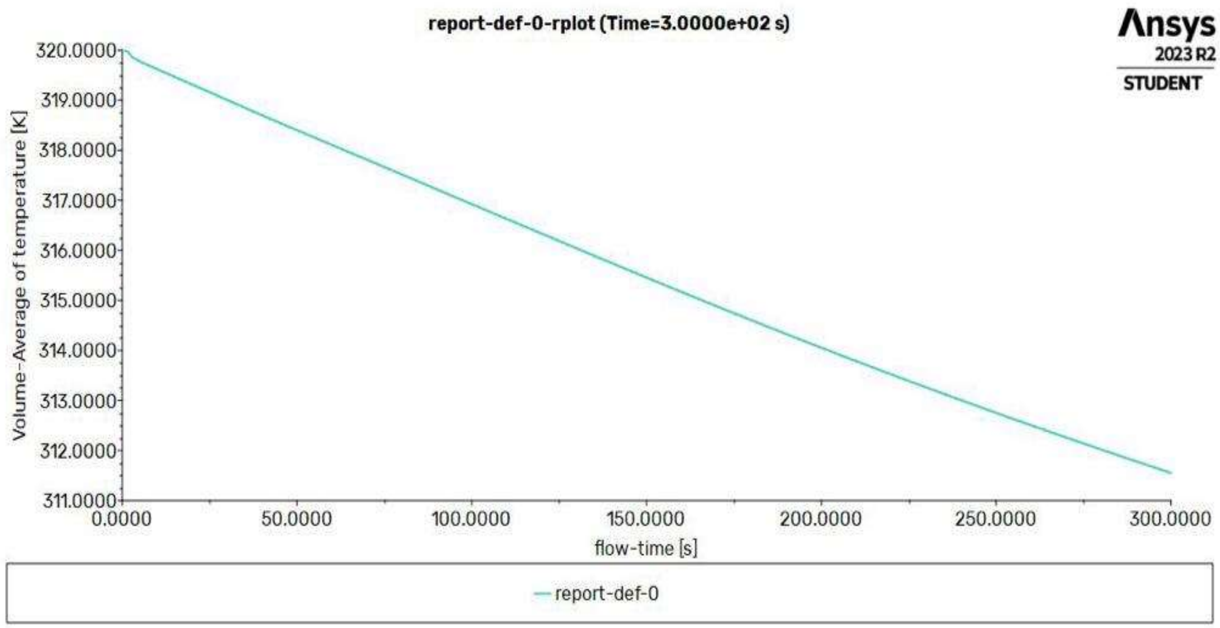

Ansys
2023 R2
STUDENT
Static Temperature
[K]
3.23e+02
3.20e+02
3.17e+02
3.14e+02
3.11e+02
3.08e+02
3.05e+02
3.02e+02
2.99e+02
2.96e+02
2.93e+02
contour-1

(D3) t = 5 min


Ansys
2023 R2
STUDENT
Y Velocity
[m/s]
1.04e-01
8.48e-02
6.54e-02
4.60e-02
2.66e-02
7.19e-03
-1.22e-02
-3.16e-02
-5.10e-02
-7.04e-02
-8.98e-02
contour-1

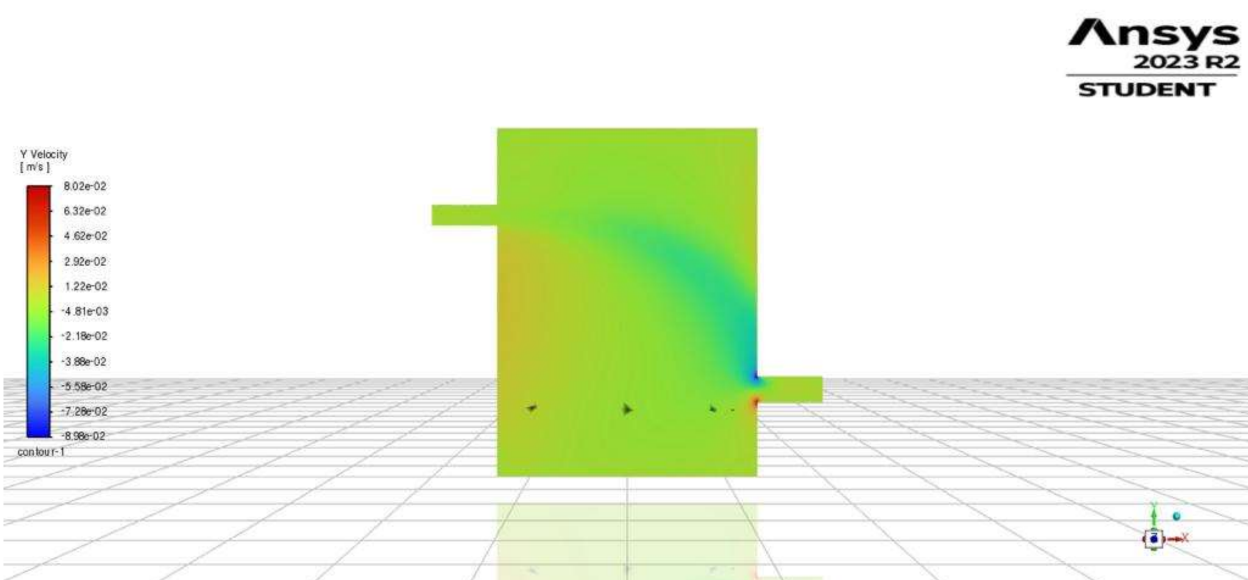

Ansys
2023 R2
STUDENT
Static Temperature
[K]
3.23e+02
3.20e+02
3.17e+02
3.14e+02
3.11e+02
3.08e+02
3.05e+02
3.02e+02
2.99e+02
2.96e+02
2.93e+02
contour-1

(D4) The value of avg. temperature 315.51 k, at t = 5mins

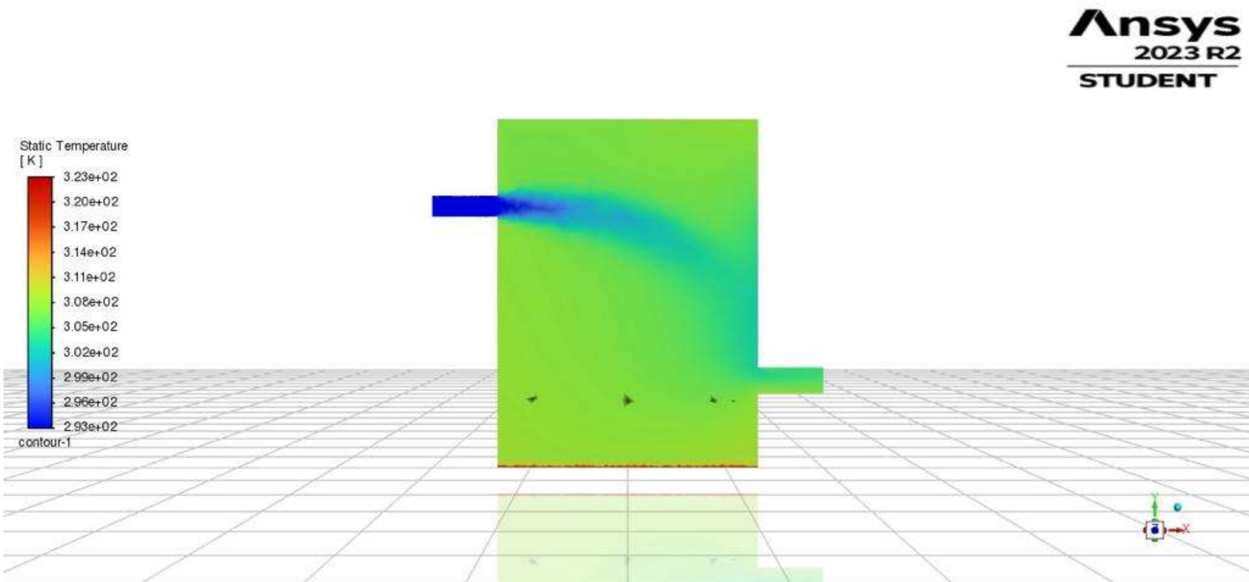


Task 1b: Transient solution with Moon gravity

(D5)

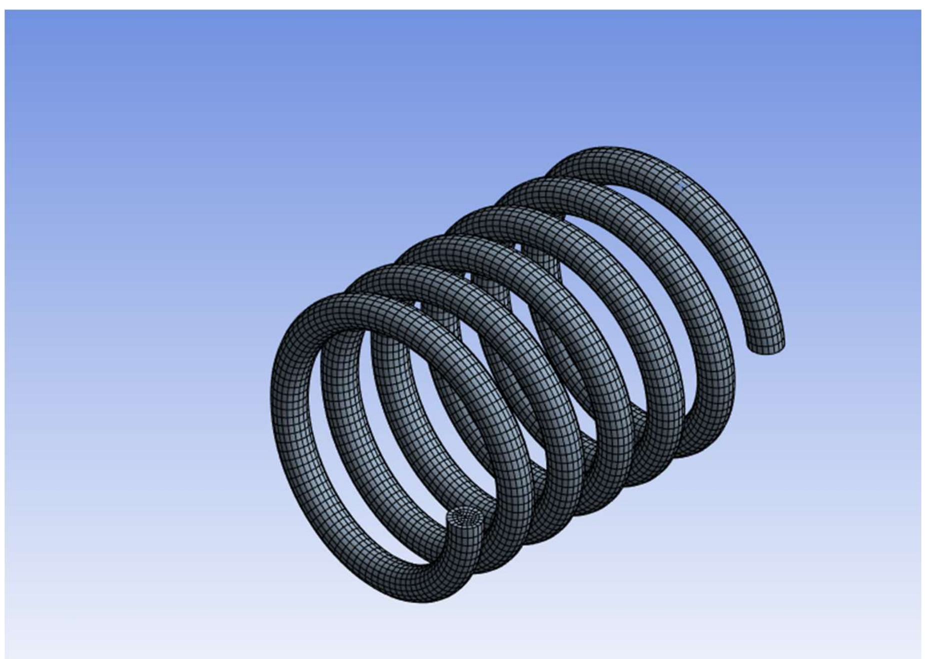


Task 2 Internal Flow with the Heat Source

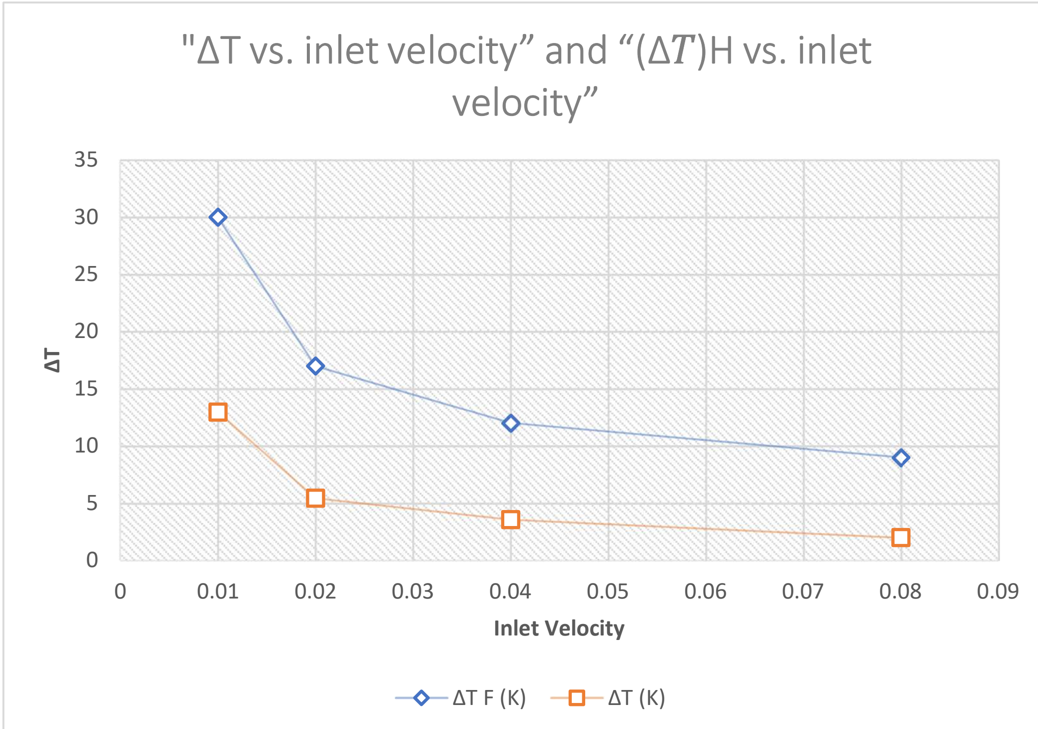


Task 2a: Flow with heated wall

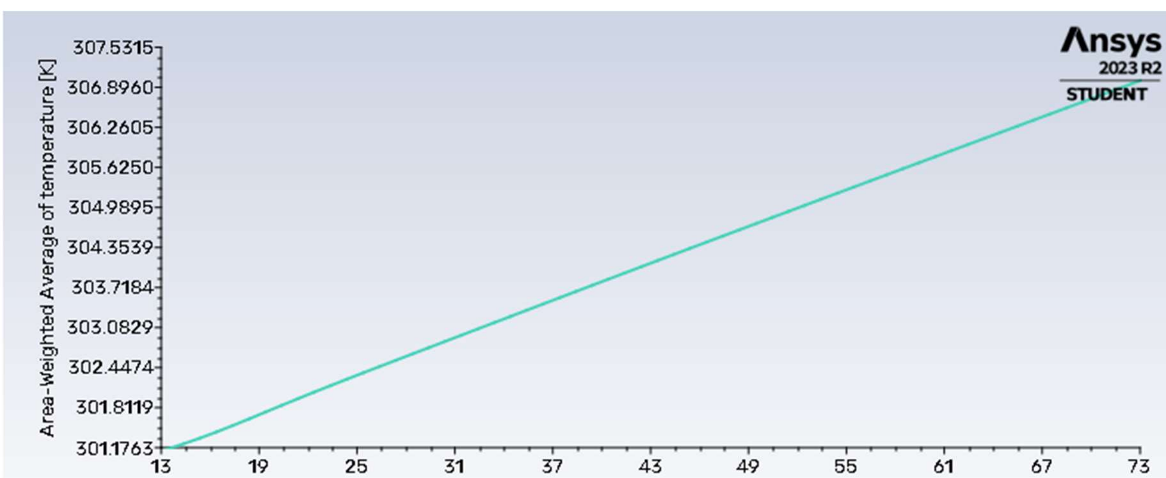
(D6)



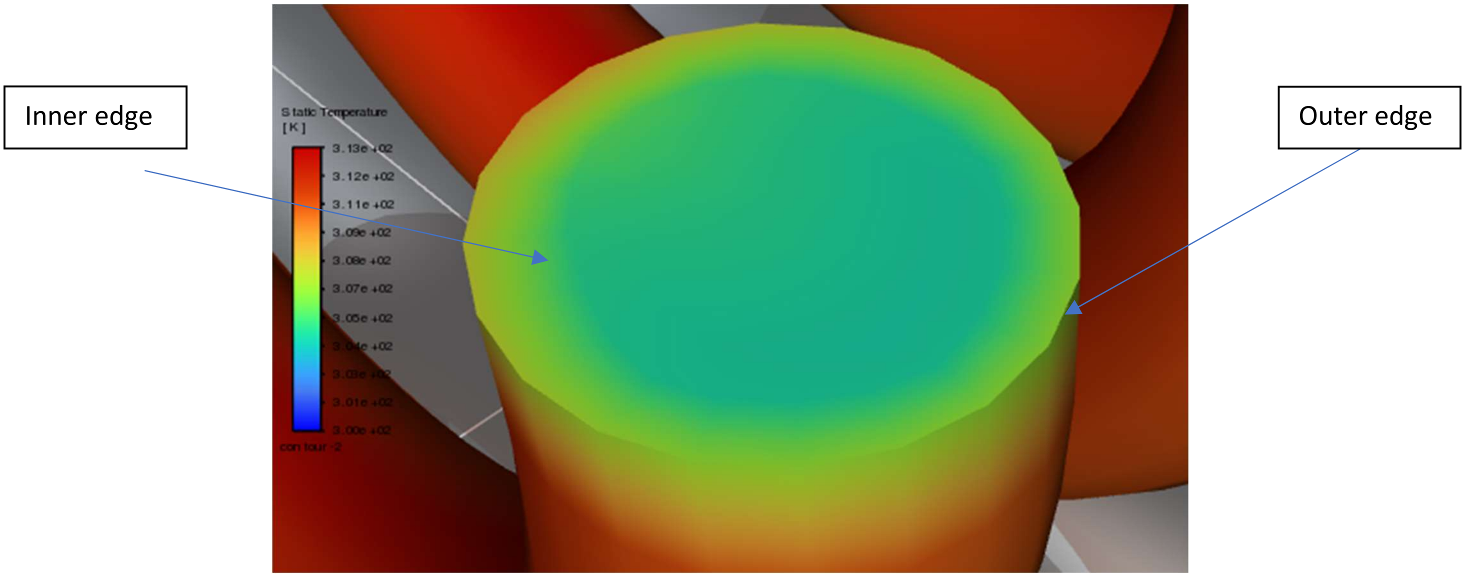
Velocity(m/s)	ΔT F(K)	ΔT H(K)
0.01	30	12.80
0.02	17	5.52
0.04	12	3.61
0.08	07	1.96

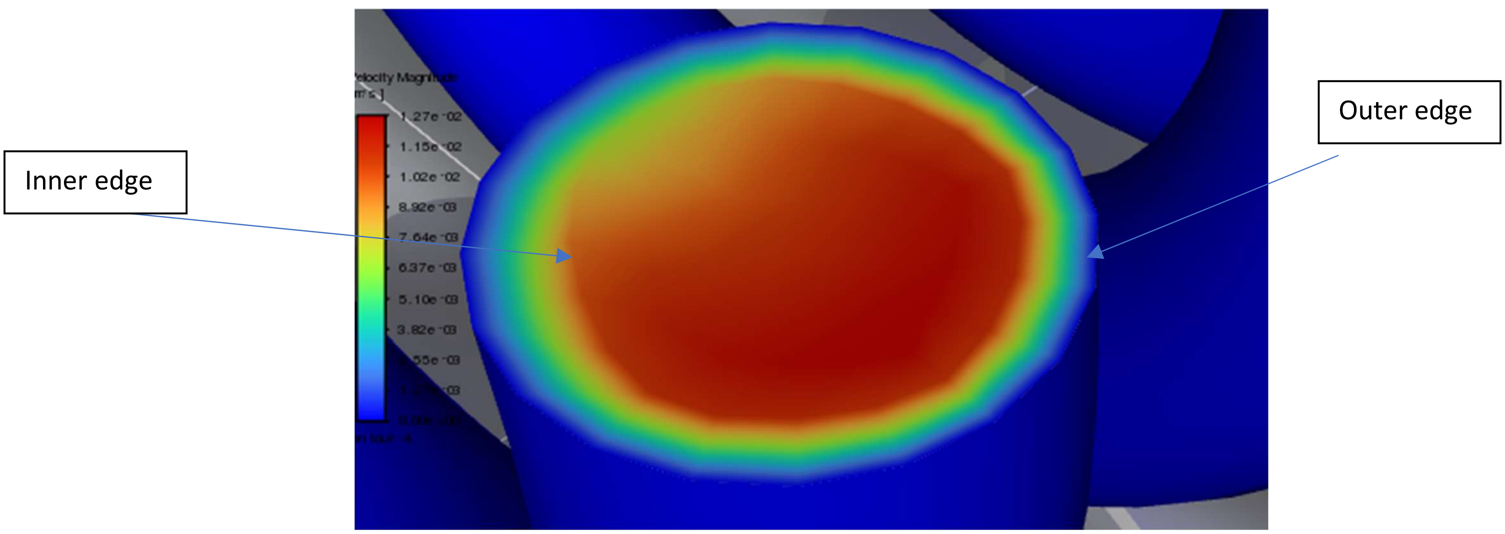


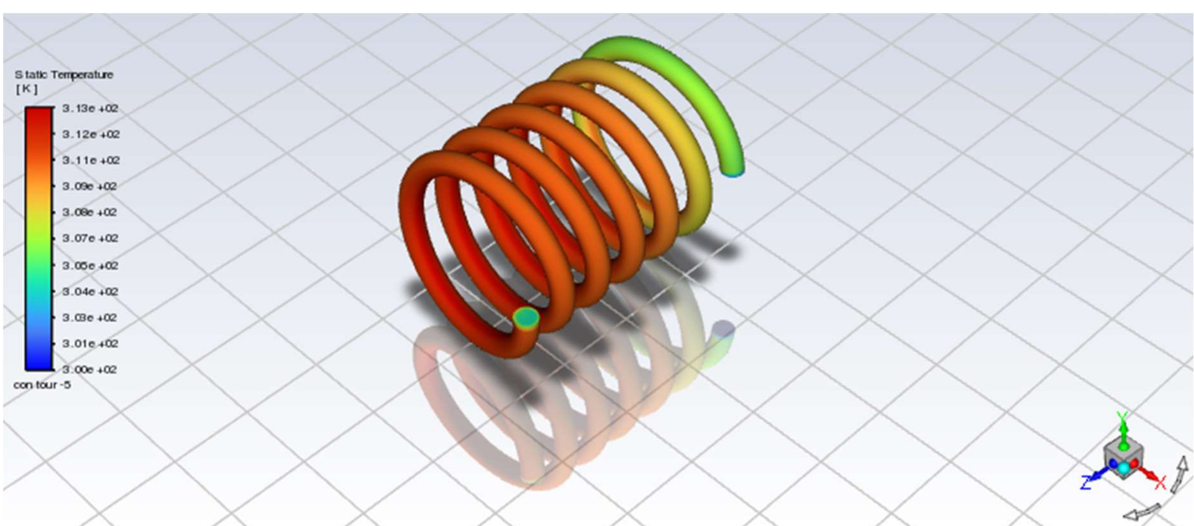
(D7) inlet velocity = 0.01 m/s



(D8) PTO

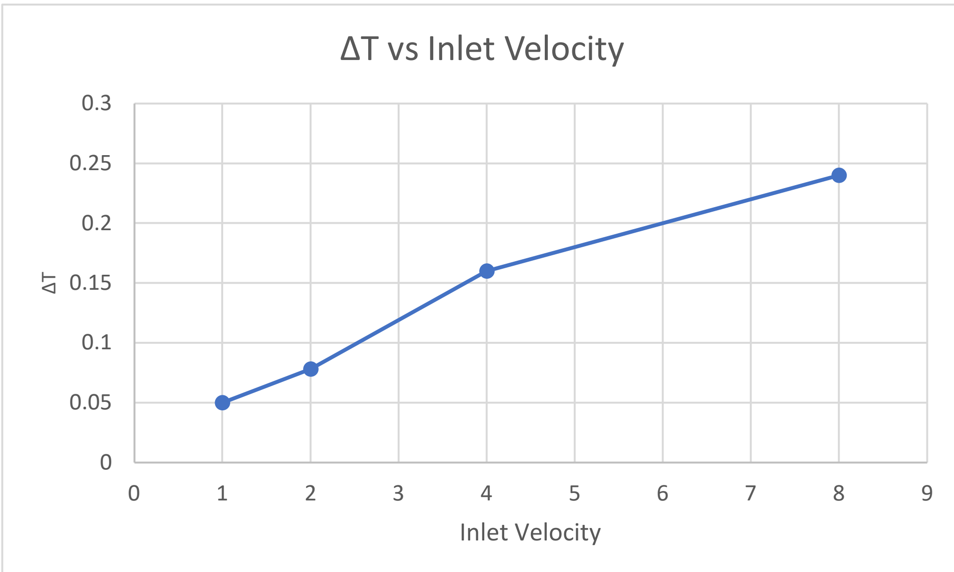

Inner edge
Outer edge
Static Temperature
[K]
3.13e+02
3.12e+02
3.11e+02
3.09e+02
3.08e+02
3.07e+02
3.05e+02
3.00e+02
contour-2


Outer edge
Inner edge
1.27e-02
1.15e-02
1.02e-02
8.92e-03
7.64e-03
6.37e-03
5.10e-03
3.82e-03


Static Temperature
[K]
3.13e+02
3.12e+02
3.11e+02
3.09e+02
3.08e+02
3.07e+02
3.05e+02
3.04e+02
3.03e+02
3.01e+02
3.00e+02
contour-5

(D9) Task 2b: Viscous heating

Velocity(m/s)	Inlet T (K)	Outlet T (K)	ΔT
1	300	300.05	0.05
2	300	300.078	0.078
4	300	300.16	0.16
8	300	300.24	0.24



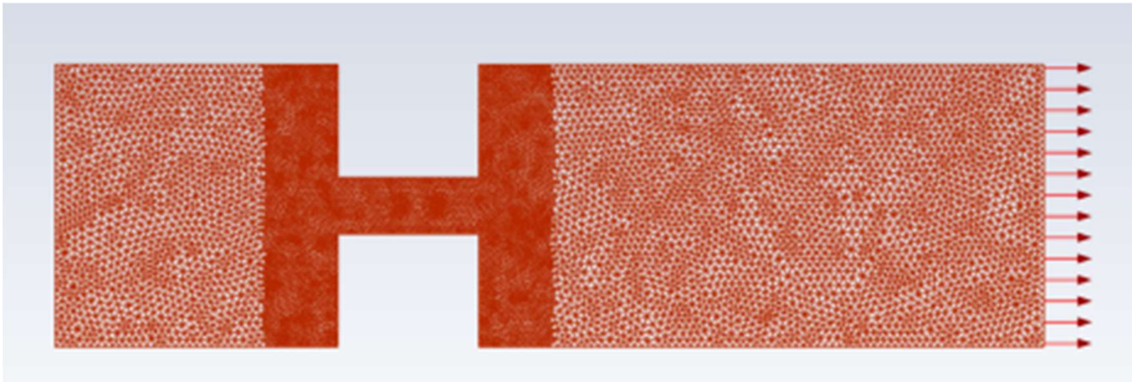
(D10)

In Task 2a, the higher inlet velocity leads to turbulent flow, which increases the heat transfer coefficient between the pipe wall and the fluid. This allows the fluid temperature to equilibrate faster with the pipe temperature before reaching the outlet. Therefore, increasing the inlet velocity reduces the temperature change ΔT in this case.

In contrast, in Task 2b, the higher inlet velocity means the fluid has less residence time in the pipe. This provides less time for heat transfer to occur before the fluid reaches the outlet. So even though the heat transfer coefficient may increase some with velocity, the dominant effect is the reduced residence time. This causes the temperature change ΔT to increase with increasing inlet velocity in this case.

Task 3: A simple compressible flow

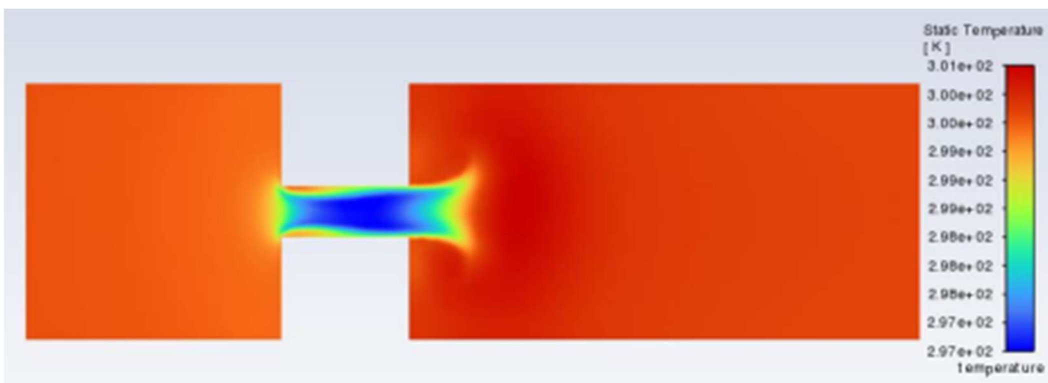
(D11)



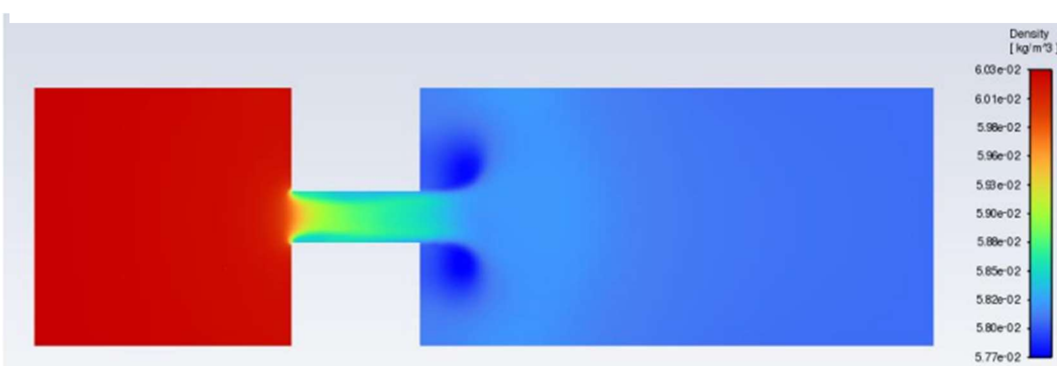
Plot showing the mesh along plane of symmetry by Varad Lad

The time step size is 0.001 and max iterations are 200

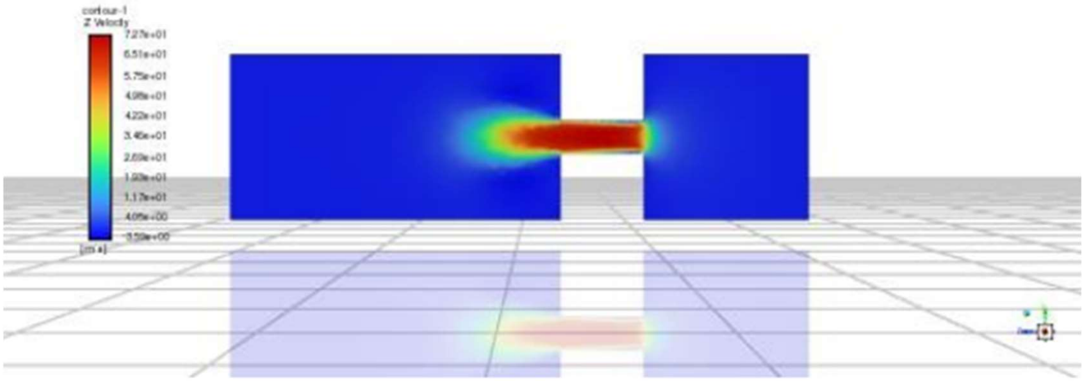
(D12)



Contour plot of static temperature along symmetric plane at 0.005 seconds of transient simulation by Varad Lad

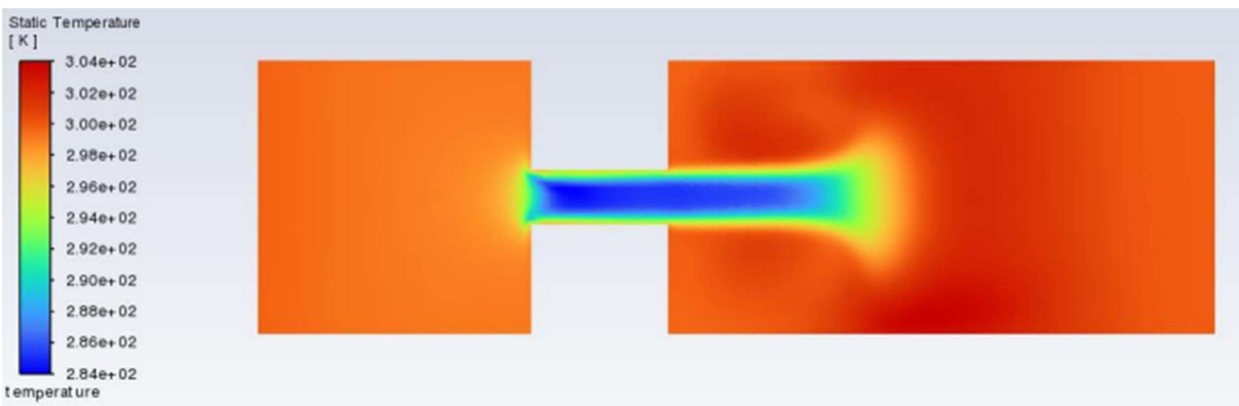


Contour plot of Density along symmetric plane at 0.005 seconds of transient simulation by Varad Lad

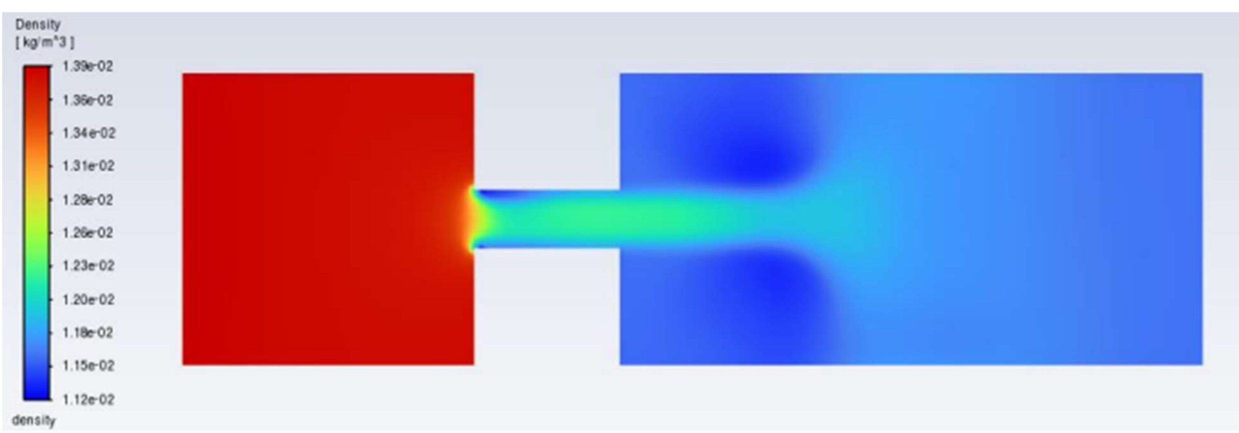


Contour plot of velocity along symmetric plane at 0.005 seconds of transient simulation by Varad Lad

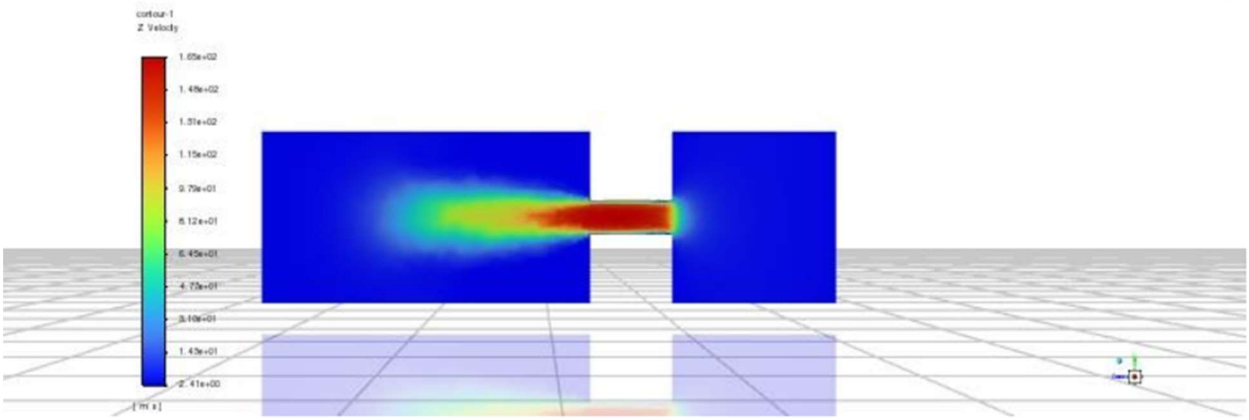
(D13)



Contour plot of static temperature along symmetric plane at 0.005 seconds of transient simulation by Varad Lad.



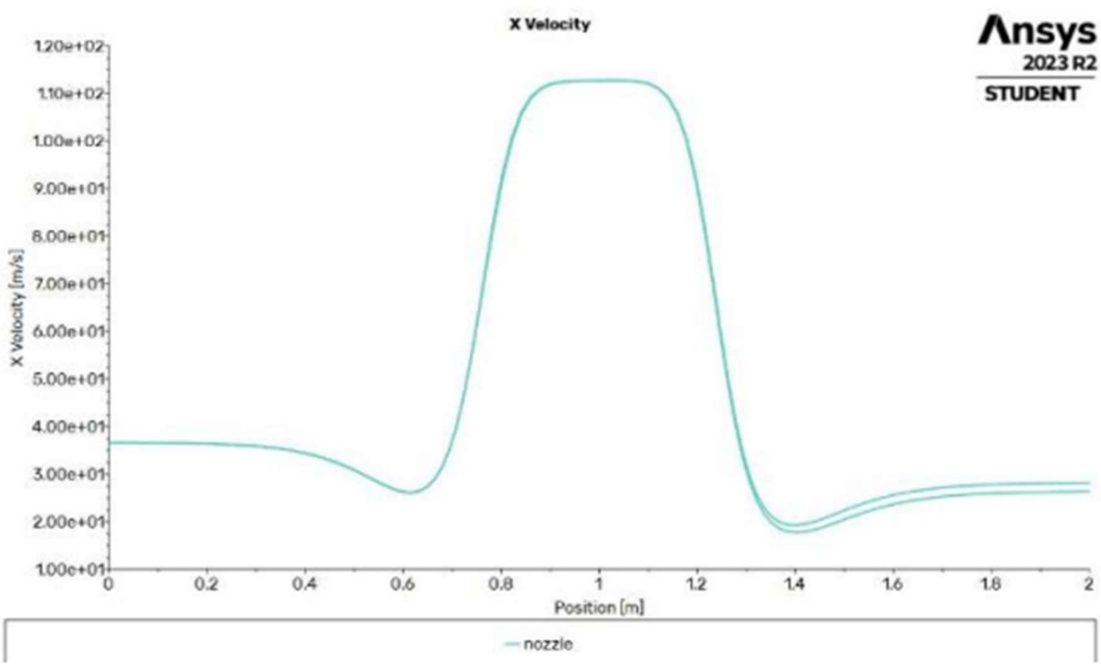
Contour plot of Density along symmetric plane at 0.005 seconds of transient simulation by Varad Lad



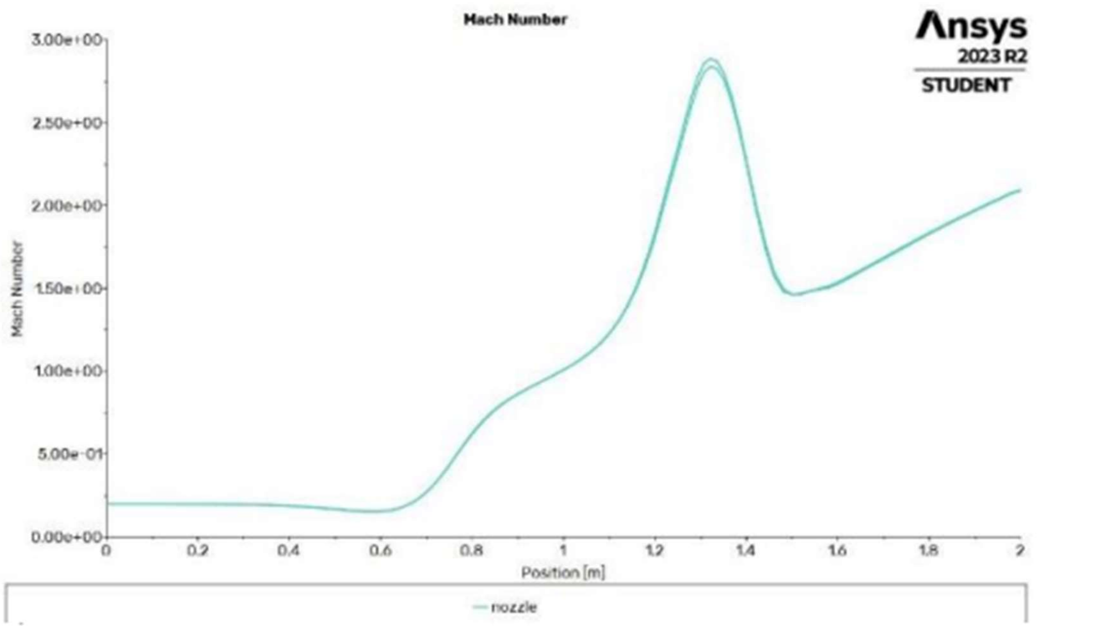
Contour plot of velocity along symmetric plane at 0.005 seconds of transient simulation By Varad Lad

(D14)

Case 1



Case 2



In light of the provided information, I anticipate that the Mach number will rise from the inlet to the outlet as the flow speeds up, though it will probably stay subsonic (not reach Supersonic) in both scenarios. The maximum Mach number should happen close to the outlet. Case 1 ought to generate overall higher Mach numbers versus Case 2 owing to the superior pressure variance propelling the flow. However, for the two cases, the flow plausibly does not attain supersonic velocities given the moderate pressure differences present.t

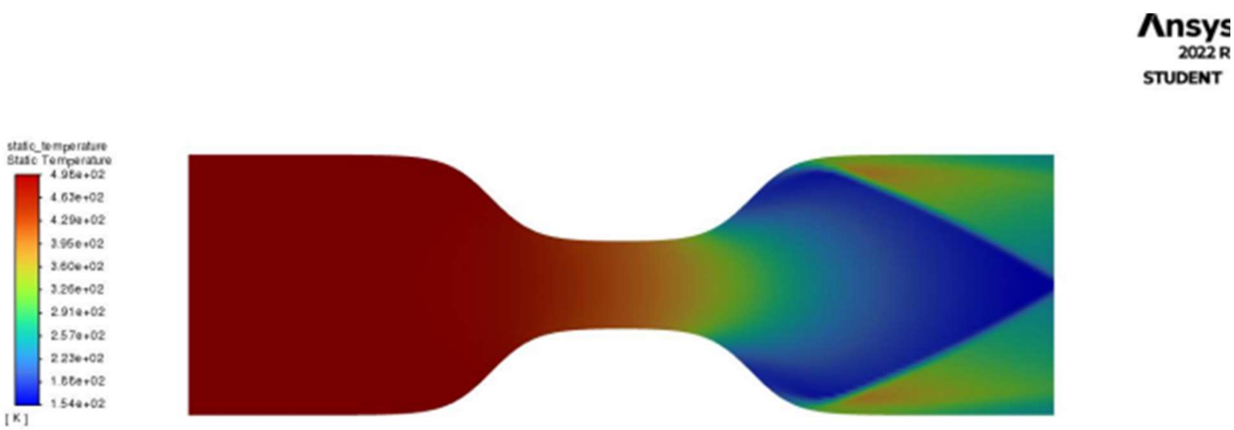
(D15)

Looking at the provided details, Case 2 could actually generate faster air jet speed versus Case 1, even with an inferior overall pressure variance. This is unintuitive, but can be clarified as follows: The inlet pressure for Case 2 is lower (1200 Pa) compared to Case 1 (5200 Pa). According to Bernoulli's principle, for incompressible flow, lower pressure is associated with faster velocity. At the inlet, the speed for Case 2 should be quicker owing to the lower inlet pressure. As the flow speeds up further via expansion, the velocity difference gets bigger. Therefore, despite Case 2 having a smaller driving pressure variance, the lower inlet pressure gives it a "jump start" in velocity. Regarding temperature, the preceding rationale stands - Case 2 will produce more intense cooling due to its larger total pressure decrease from inlet to outlet. The lower inlet pressure signifies the flow begins cooler, and expands more, amplifying the cooling effect. The first law declares that the change in internal energy of a system equals the heat supplied to *the system minus the work performed by the system. For an ideal gas going through adiabatic (no heat transfer) expansion, the change in internal energy connects to the temperature change: ΔU = mCpΔT Where m is the gas mass, Cp is the specific heat at constant pressure, and ΔT is the temperature change. In Case 2, the gas expands from a higher initial pressure (1200 Pa) to a lower ambient pressure (1000 Pa). This expansion does more work on the surroundings versus Case 1. Since no heat is supplied (adiabatic process) and more work is performed, the change in internal energy ΔU must be more negative by the first law. A more negative ΔU matches a larger temperature decrease ΔT for the ideal gas. Therefore, Case 2 yields a lower temperature for the jet owing to increased adiabatic cooling from greater expansion work, as governed by the first law of thermodynamics*

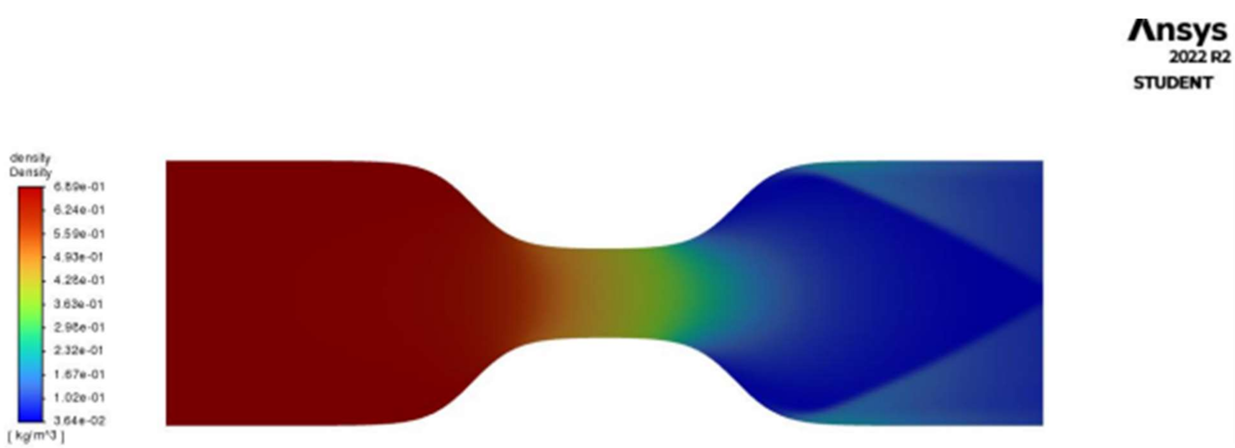
Task 4: Compressible flow through a nozzle

Task 4a

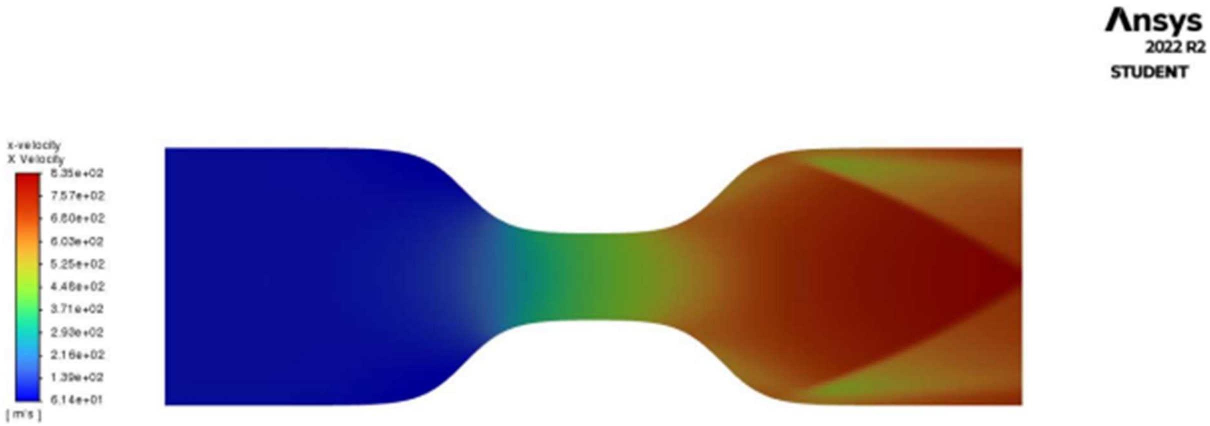
(D16)



Contour plot of static temperature By Varad Lad

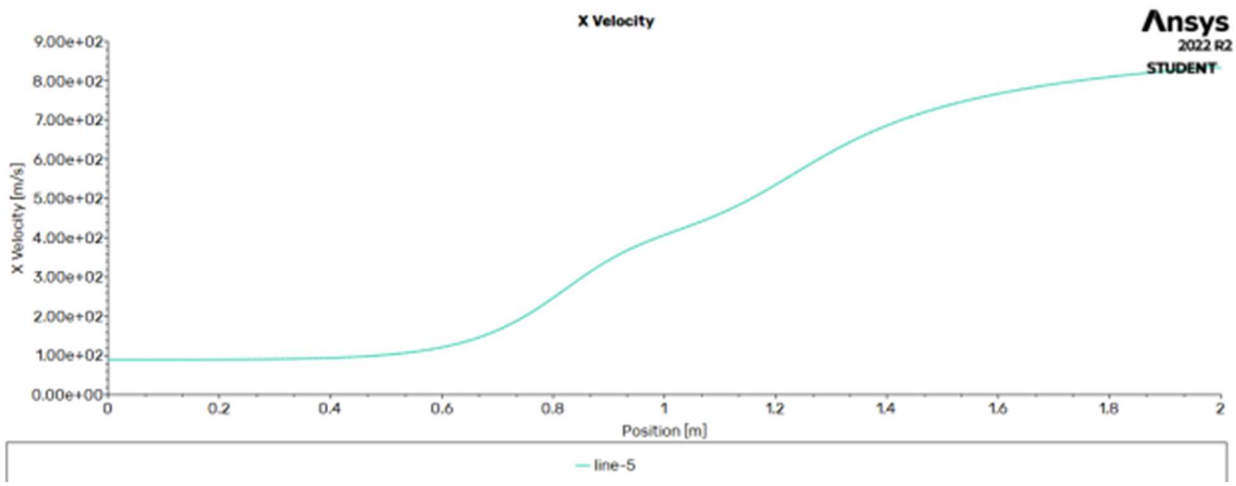


Contour plot of density By Varad Lad

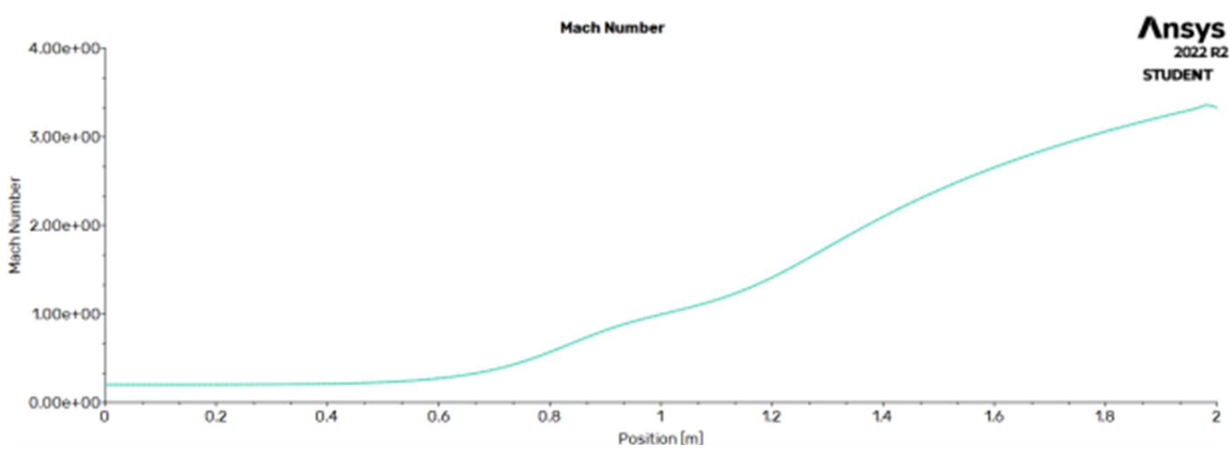


Contour plot of x-velocity By Varad Lad

(D17)



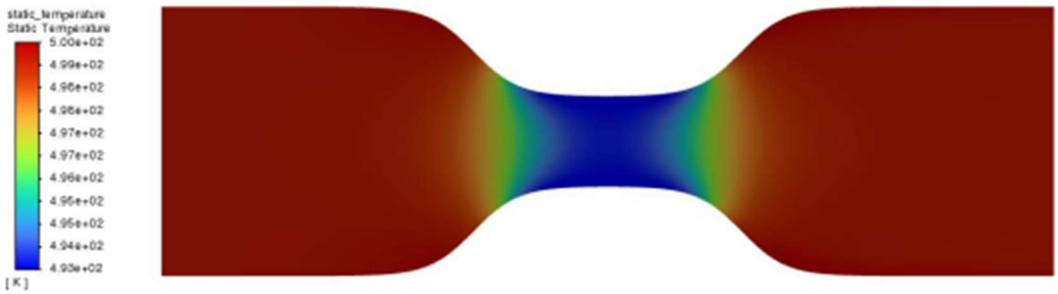
Line plot of x-velocity By Varad La



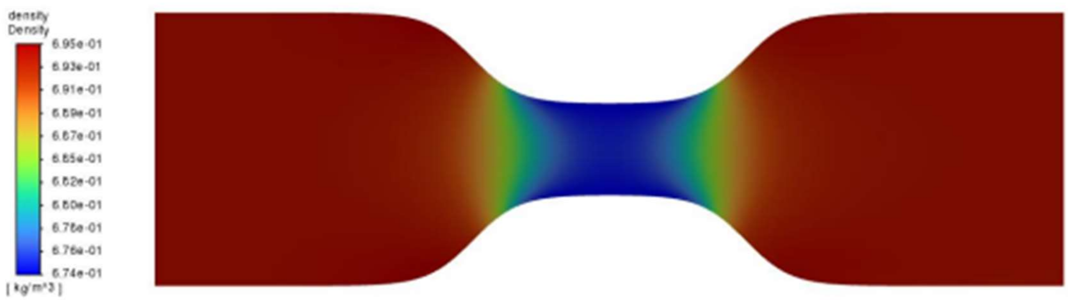
Line plot of Mach number By Varad lad

Task 4b

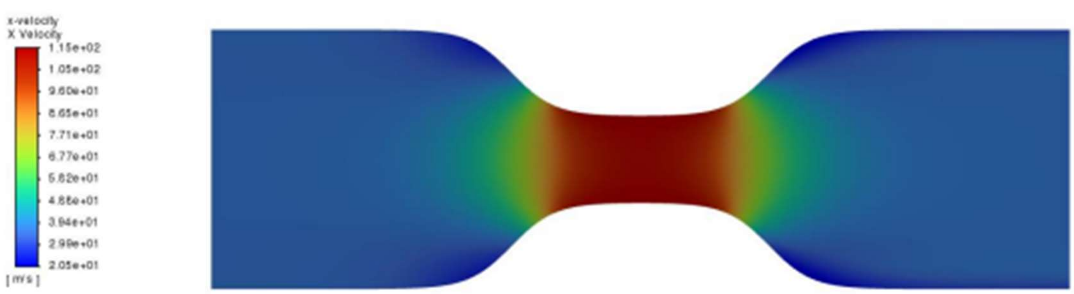
(D18)



Contour plot of static temperature By Varad Lad

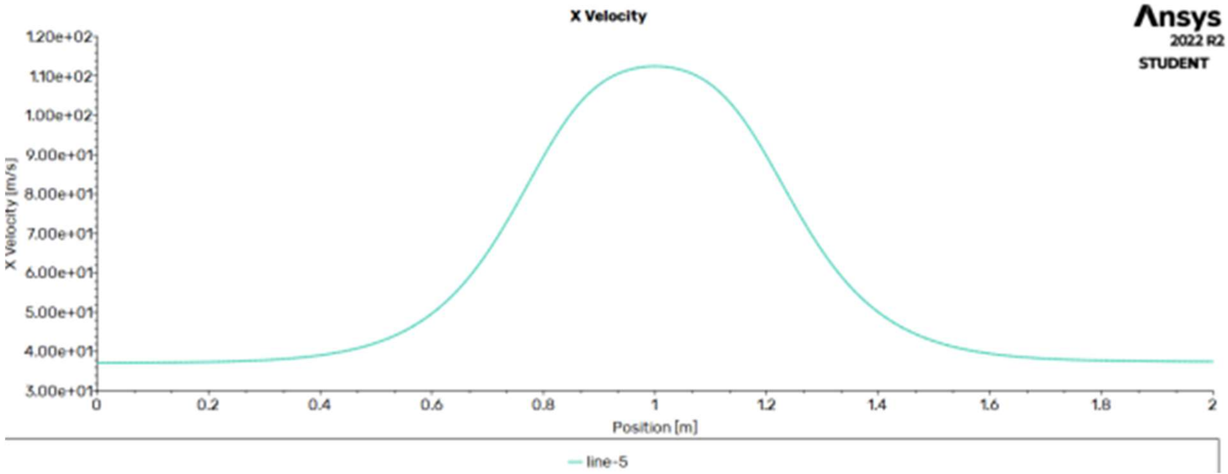


Contour plot of density By Varad Lad

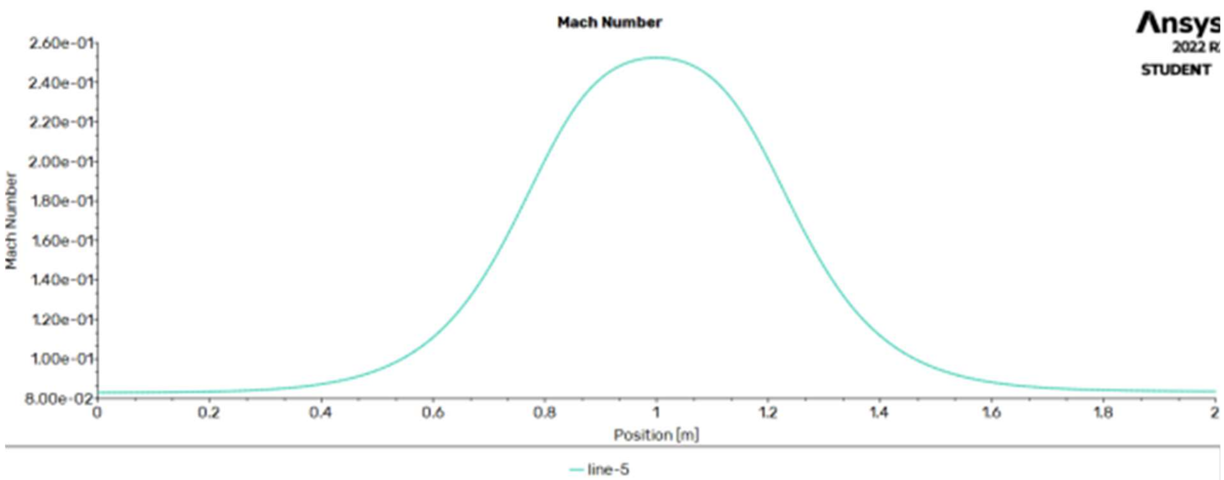


Contour plot of x-velocity By Varad Lad

(D19)



Line plot of x-velocity By Varad Lad



Line plot of Mach number By Varad Lad