MAE 560 – Applied Computational Fluid Dynamics, Fall 2021

Project – 1

Avinash Raj DGSK

1220420240

Name of the collaborator	
Task	Contribution
Anurudh Kamma	Task 2 - Graphs
	Task 3 - Contours

Task – 1 : Internal Flow with Thermal Convection

The task is to compute the temperature of the outflow of fluid from a cylindrical water heater at a steady state. The geometric parameters of the cylindrical water heater are as follows, diameter of the main cylindrical tank D =0.6 m, height of the tank H = 0.8 m, location of the inlet and outlet side tubes from the bottom surface of the tank Z1 = 0.6 m and Z2 = 0.2 m, the diameter of both inlet and outlet tube d = 0.06 m. The axial orientation of main cylindrical tank is along y axis and the inlet and outlet tube along x axis.

The mesh of the water heater was generated by setting the element size to 0.03m and the inflation setting is set to program controlled with 5 layers having growth rate of 1.2 at the wall.

All the surfaces of the water heater are thermally insulated except the bottom plate (surface) which is maintained at a constant temperature of 40 °C. Water is chosen as working fluid with viscosity, specific heat and thermal conductivity are set to the default values from the Fluent database.

The velocity of water inlet through the upper side tube is set to a constant of 0.05 m/s and the inlet water temperature is maintained at 10 °C. The bottom side tube is set to outflow conditions. Density of the water is set to Boussineq to simulate the effect of density variation with temperature. The operating density, $\rho = 997.04$ *Kg/m*^{3} and coefficient of thermal expansion $\beta = 0.0002573$ is calculated from the below equations obtained from "Jones, F.E. and Harris, G.L., 1992. ITS-90 density of water formulation for volumetric standards calibration. *Journal of research of the National Institute of Standards and Technology*, *97*(3), p.335". The temperature, T in calculating the operating density is the average of maximum and minimum temperature in the system.

T= (40°C + 10°C) / 2 = 25°C

$$\rho = 999.85308+6.3269\times10^{-2}\ T - 8.523829\times10^{-3}T^2 + 6.943248\times10^{-5}T^3 -3\ .821216\times10^{-7}\ T^4$$

$$\beta = -\frac{1}{\rho}\frac{\partial\rho}{\partial T}$$

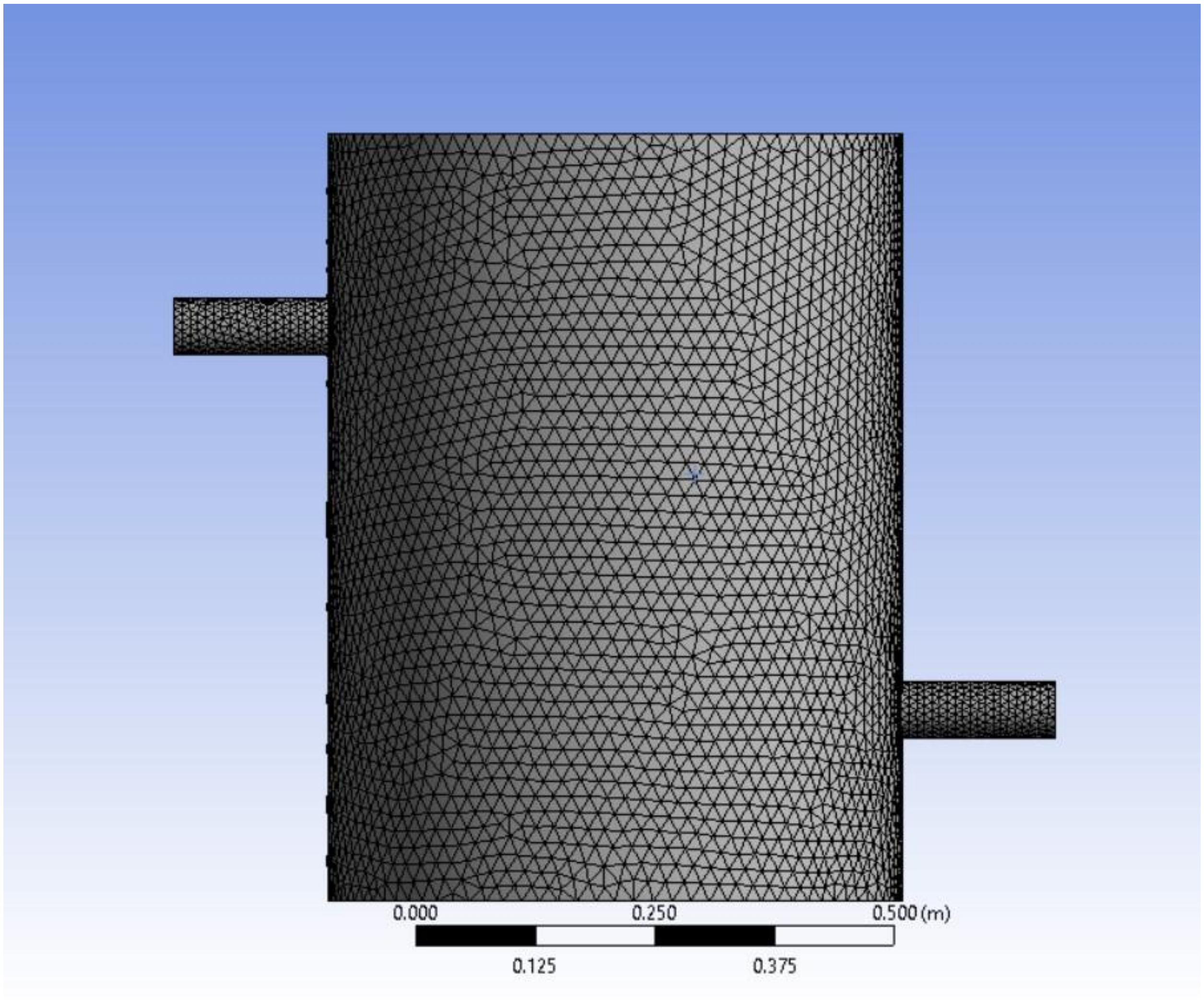
Task 1: Internal flow with thermal convection

D1) A plot of the mesh along the plane of symmetry, and a statement indicating the values of *operating temperature*, *operating density*, and *thermal expansion coefficient* used for the simulation.

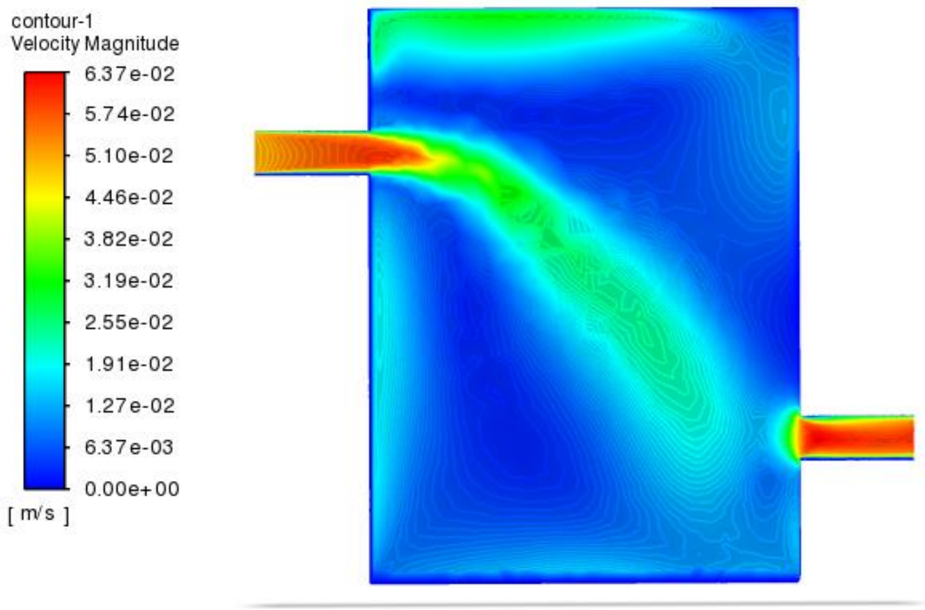
operating density, $\rho = 997.04$ *Kg/m*^{3}

coefficient of thermal expansion, $\beta = 0.0002573$

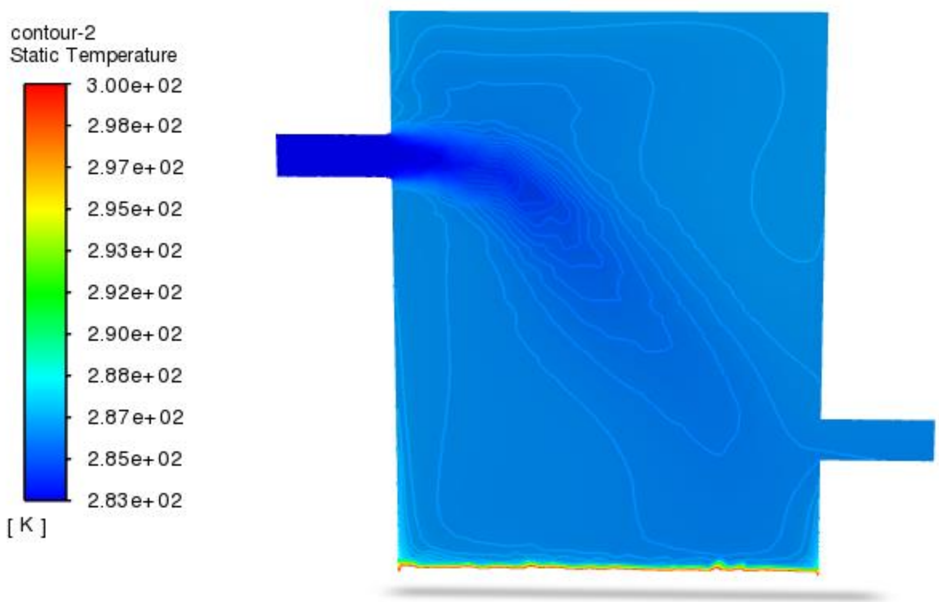
Operating temperature T = 25°C



(D2) A contour plot of the *y-velocity* (not to be confused with *velocity magnitude*) in the *plane of symmetry* for the steady solution. (See Fig. 1 for the definition of *y*-direction)

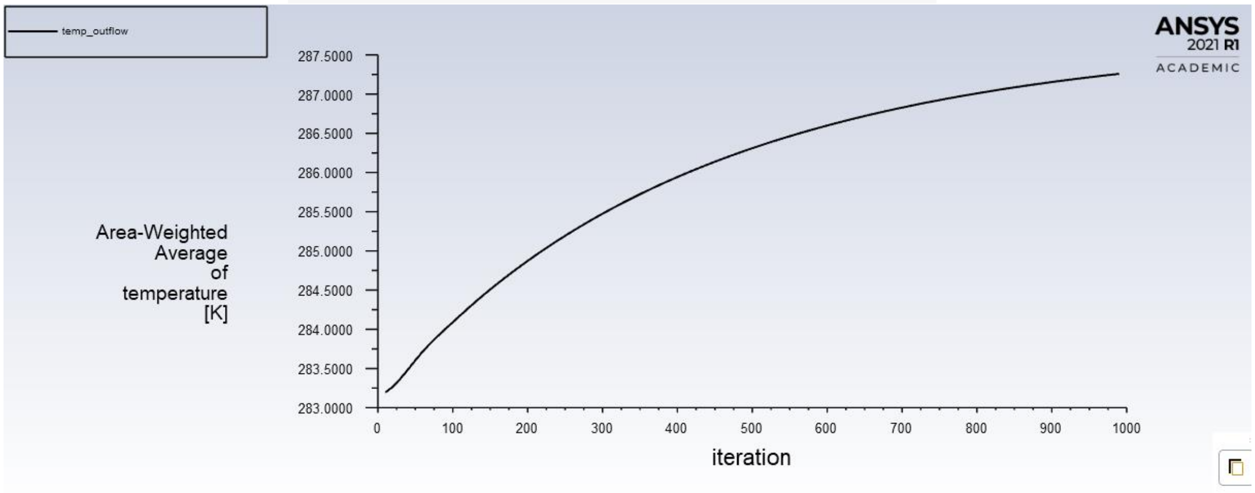


(D3) A contour plot of *temperature* in the *plane of symmetry* for the steady solution. [Note: Since there is always a tight temperature gradient near the bottom, in order to clearly show the key feature of the "cool waterfall" coming down from the inlet it is recommended that the contour intervals be manually adjusted.]



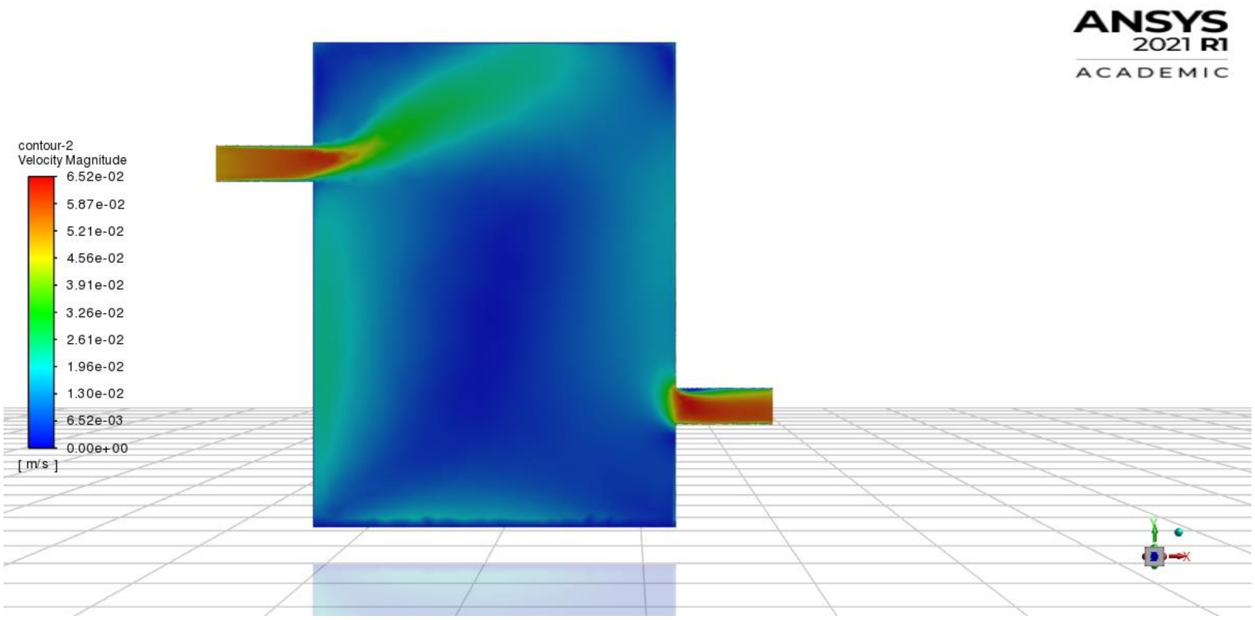
(D4) The value of *outlet temperature* (T_{out} as defined in Eq. (1)) at the steady state. This number must be clearly written out. In addition, *a line plot of the outlet temperature, T_{out}, as a function of the number of iterations*.

```
                  Area-Weighted Average
                     Static Temperature                   [K]
-------------------------------- --------------------
                               outflow          286.75991
```

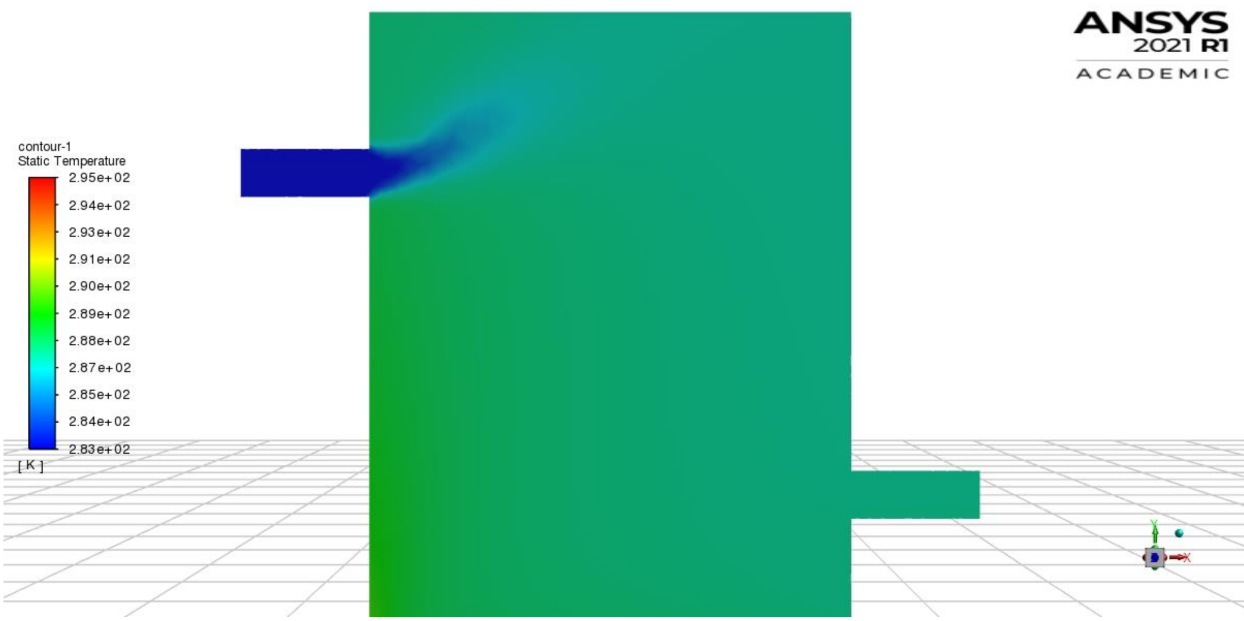


Task 1a: Vertically oriented tank

(D5) A contour plot of the *x-velocity* (not to be confused with *velocity magnitude* or *y-velocity*) in the *plane of symmetry* for the steady solution.

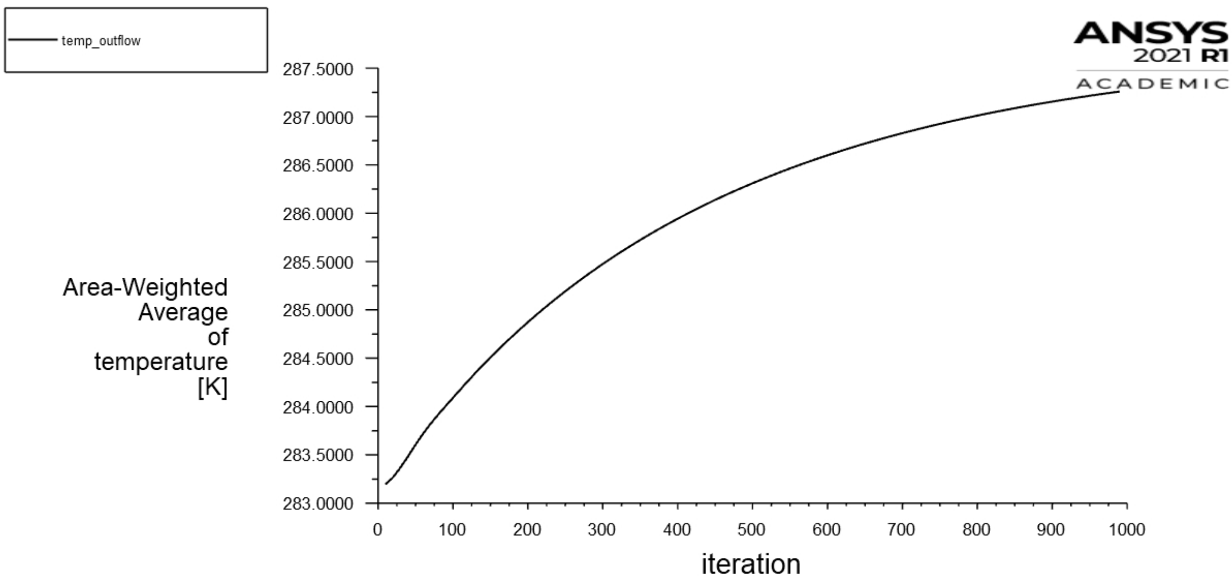


(D6) A contour plot of *temperature* in the *plane of symmetry* for the steady solution. [See the remarks after D3 on proper adjustments of the contour interval.]



(D7) The value of *outlet temperature* (T_{out} as defined in Eq. (1)) at the steady state. This number must be clearly written out. In addition, *a line plot of the outlet temperature, T_{out}, as a function of the number of iterations*.

```
         Area-Weighted Average
            Static Temperature                 [K]
-------------------------------- --------------------
                        outlet           287.26862
```



Task 2: Internal flow with heat transfer

Task 2a: Steady solution

(D8) The values of ΔT for the 4 cases, where $\Delta T = T_{out} - T_{in}$ is the difference between outlet and inlet temperature at steady state. Note that T_{in} = 300°K while T_{out} is defined by Eq. (1) (i.e., it is the area-weighted average of outlet temperature). In addition, a plot of ΔT vs. inlet velocity and a brief interpretation of the relation between the two variables.

```
         Area-Weighted Average                 [K]
-------------------------------- --------------------
                        outlet           328.78378

         Area-Weighted Average                 [K]
-------------------------------- --------------------
                         inlet                 300
```

$$\Delta T = 28.78378$$

```
         Area-Weighted Average                  [K]
-------------------------------- --------------------
                          outlet          314.58725

         Area-Weighted Average                  [K]
-------------------------------- --------------------
                           inlet                300
```

$$\Delta T = 14.58725$$

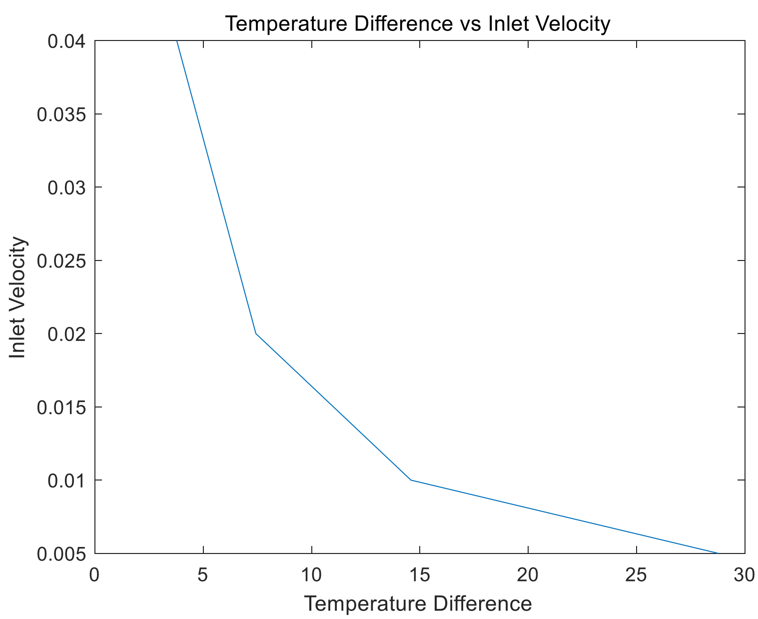
```
         Area-Weighted Average                  [K]
-------------------------------- --------------------
                          outlet          307.43008

         Area-Weighted Average                  [K]
-------------------------------- --------------------
                           inlet                300
```

$$\Delta T = 7.43008$$

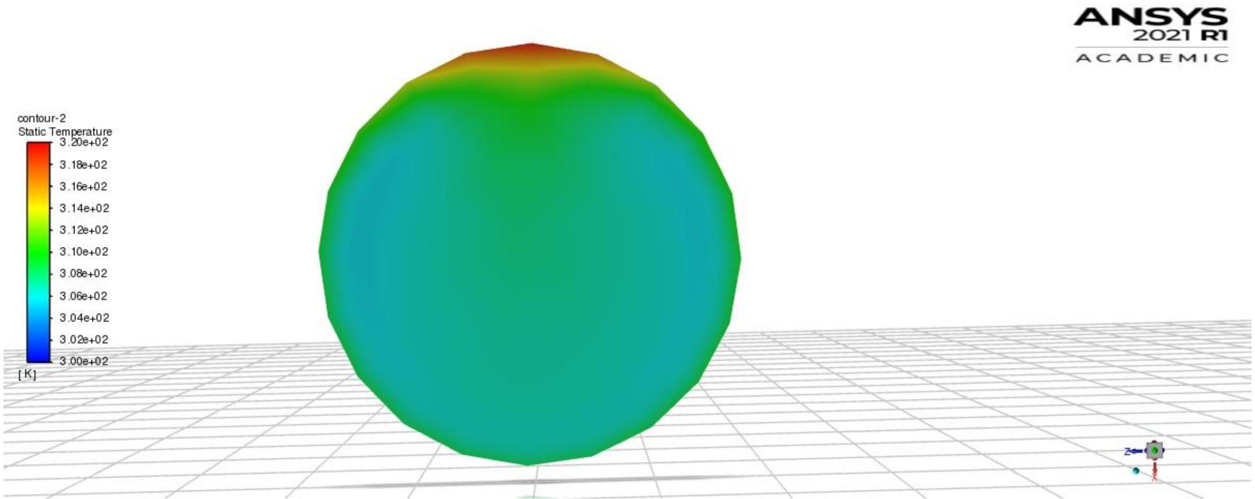
```
         Area-Weighted Average                  [K]
-------------------------------- --------------------
                          outlet          303.77597

         Area-Weighted Average                  [K]
-------------------------------- --------------------
                           inlet                300
```

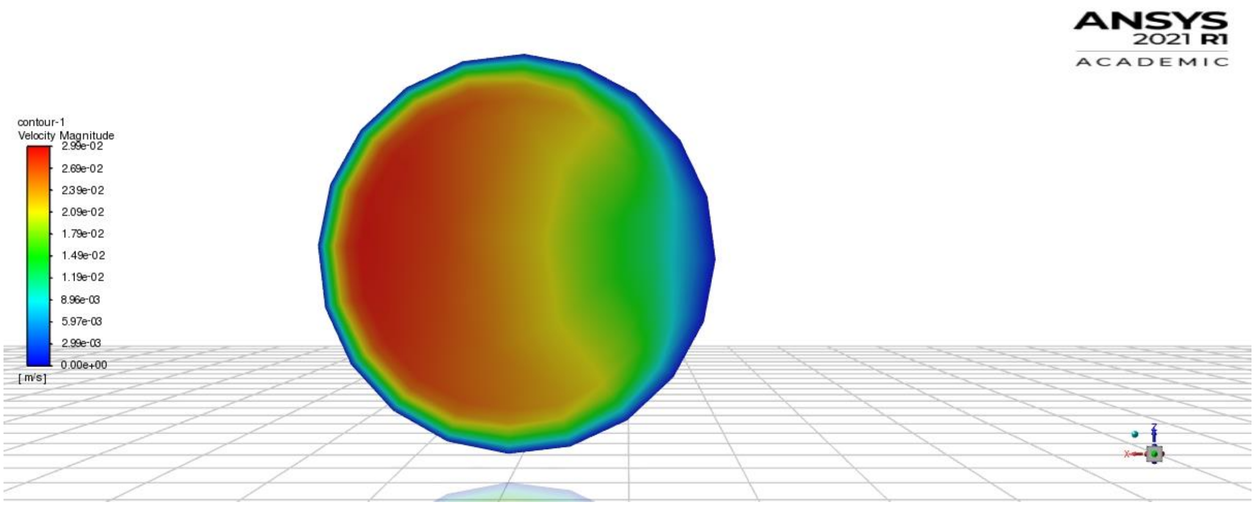
$$\Delta T = 3.77597$$

The graph for ***Δ***T and Inlet velocity is given below:



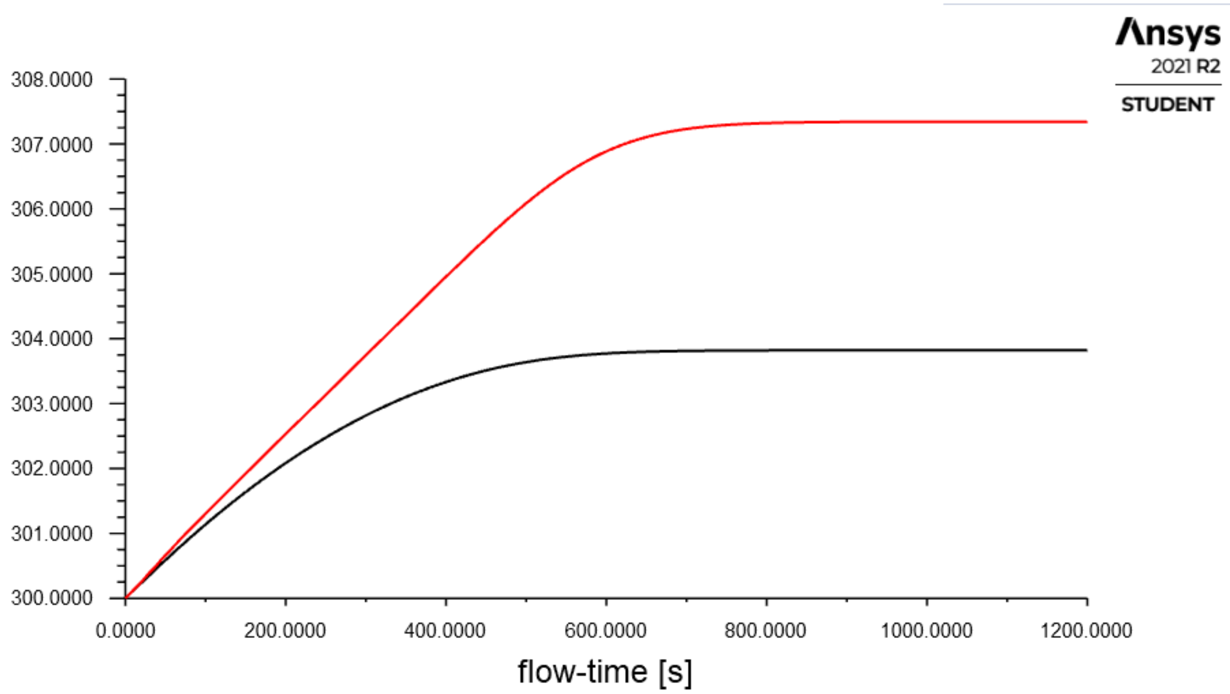
(D9) For the case with inlet velocity = 0.02 m/s only, contour plots of *temperature* and *velocity magnitude* over the circular opening of outlet. Please indicate the inner and outer edges of the pipe in the contour plots. Adjust contour intervals as needed to ensure clarity of the plot





Task 2b: Transient solution

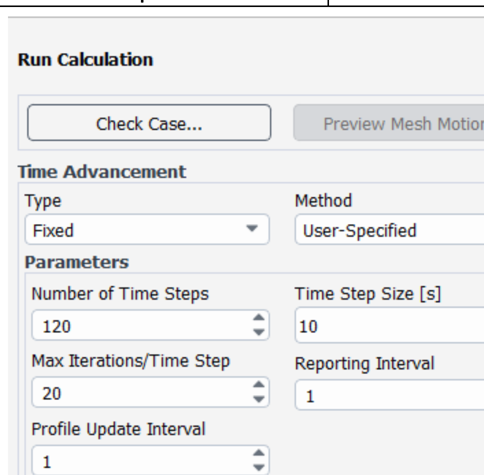
(D10) A plot of T_{out} and T_{vol} as a function of time for the transient solution over $0 \leq t \leq 20$ minutes. Here, T_{out} is the averaged outlet temperature as given in Eq. (1), and T_{vol} is defined in Eq. (5). The two curves should be put in the same plot.



(D11) A statement that indicates your setup of (i) *time step size*, and (ii) *number of iterations per time step*, for the transient simulation.

The setup used is given in the table below:

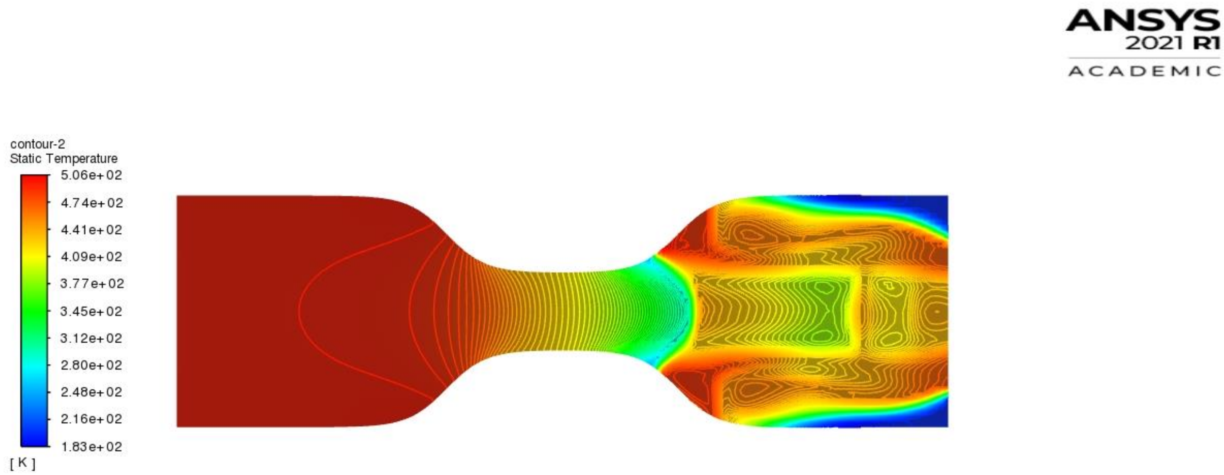
Time Step	120
Number of Iterations per time step	10

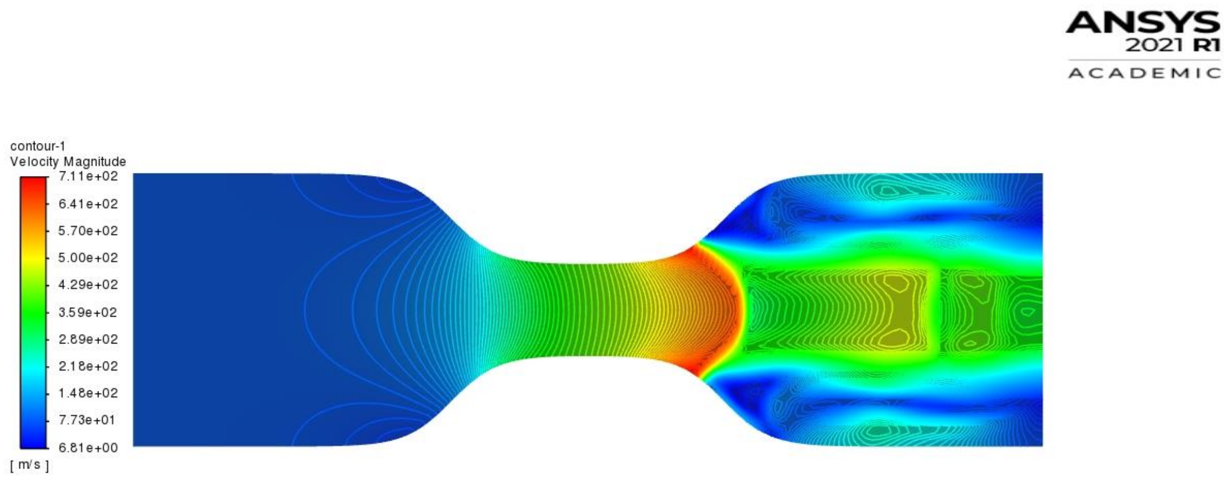


Task 3: Compressible flow

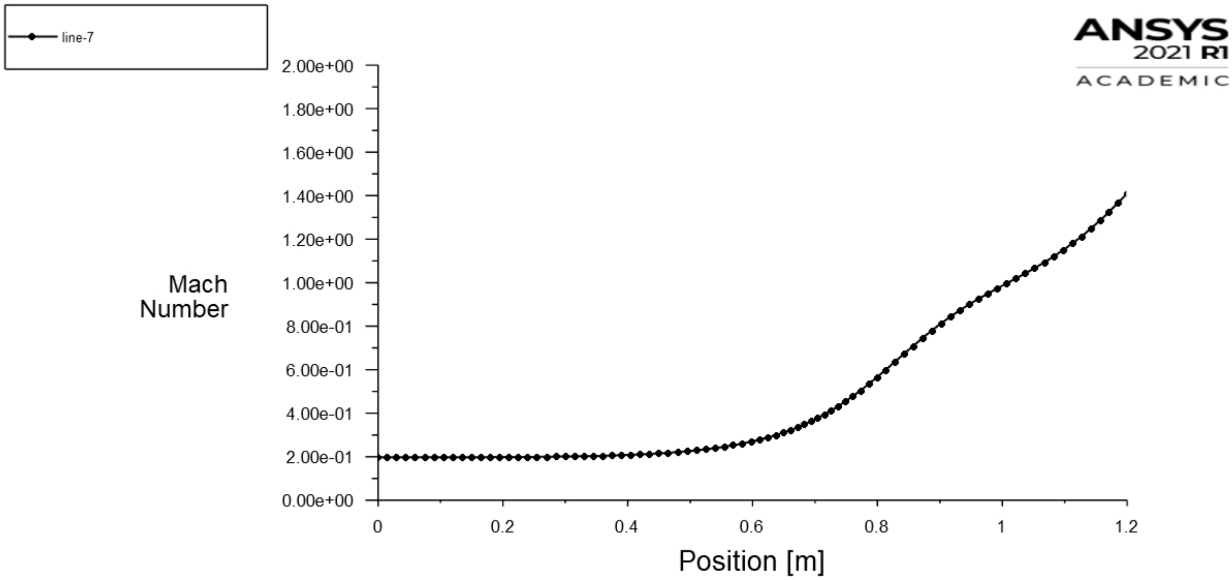
Task 3a: High-speed flow in a 2D nozzle

(D12) Contour plots of *x-velocity* and *static temperature*.



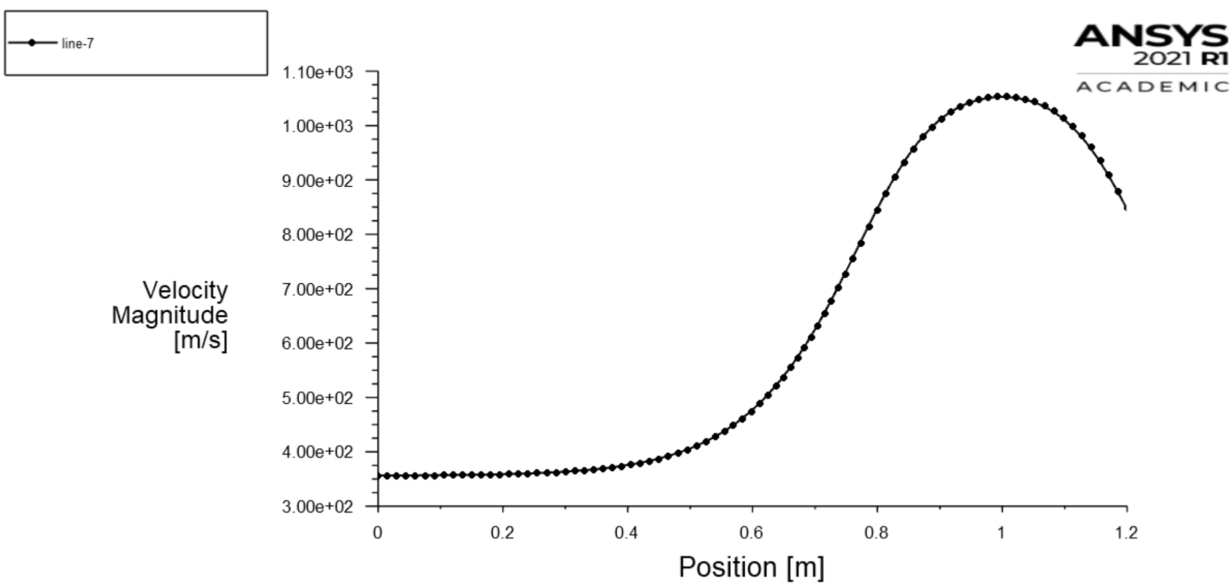


(D13) Line plots of *x-velocity* and *Mach number* along the *x*-axis (i.e., the axis of symmetry of the nozzle).



Task 3b: Demonstrating the effect of compressibility

(D14) A line plot of *x-velocity* along the *x*-axis (i.e., the axis of symmetry of the nozzle). In addition, a brief discussion on the difference in the velocity between the line plots in (D13) and (D14). Briefly explain why suppressing the effect of compressibility leads to the erroneous structure of velocity in



By suppressing the effect of compressibility, the difference is very high and can be seen from the 2 plots that we created. When ideal gas density is changed to constant, the results in the velocity are also changed.