Technical Report

ME 412

Numerical Thermo-Fluid Mechs

First Ansys Project

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Submitted to:
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February 12, 2022

0.1 Problem Description

Natural Convection occurs because of density changes. Low density fluid rises, and heavy fluid settles to bottom due to gravity. A number of very interesting convection patterns occur depending on geometry, wall heating, convection parameter, fluid properties, etc. Simulate Natural convection in an equilateral triangle, side = 1, bottom wall heated, other two cold walls. Simulate with two grids containing 1000 elements and 8000 elements. Converge to steady state if it exists (some flows can be always unsteady. Use constant properties. Simulate for two Rayleigh (Ra $= 1.0 \times 10^5$ and Ra $= 1.0 \times 10^4$). Plot streamlines, residuals (of continuity, energy and momentum), temperature contours, and velocity vectors for the two cases. Write a short report on observed flow patterns and temperature distributions

0.2 Setup Procedure

0.2.1 Geometry Creation

During this project, first it was defined the geometry as an equilateral triangle of side 1. Both Fig. 1 and Fig. 2 show the constrains settled during it.

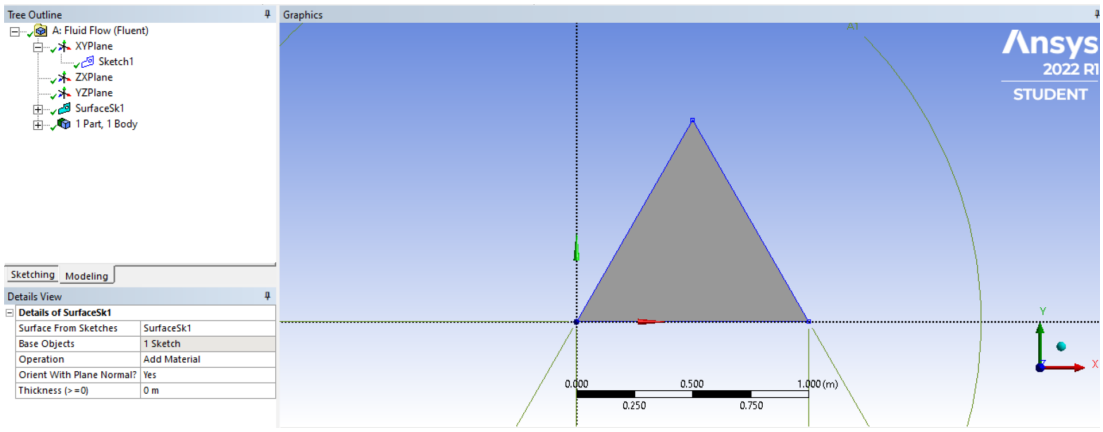


Figure 1: Triangle geometry

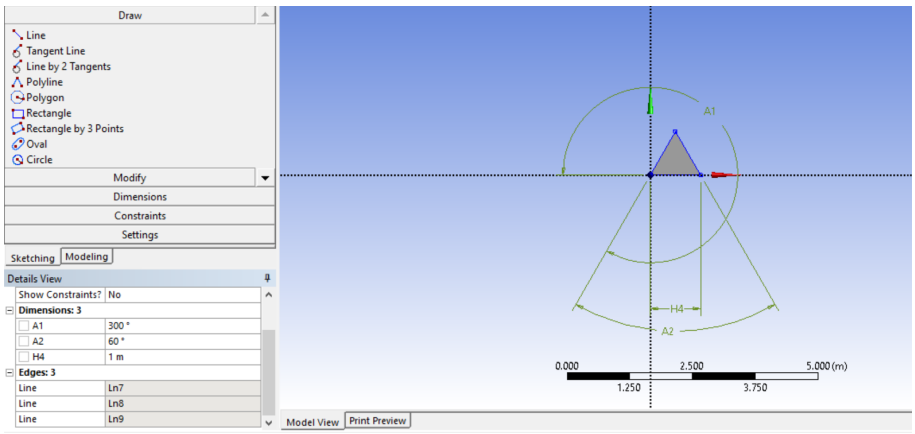


Figure 2: Geometry's constrains

0.2.2 Mesh

As the next step, it started to create the mesh for the body to be simulated. There are some considerations to elucidate during this step of the project. It is important to point out that it was not possible to find any option that allowed to chose the exact number of elements that would fill the mesh.To address this issue, it was performed some tests considering different element sizes in

order to get the closest to the need. As seen in in Fig. 3, using a quadrilateral mesh conformation, the mesh had 1014 elements.

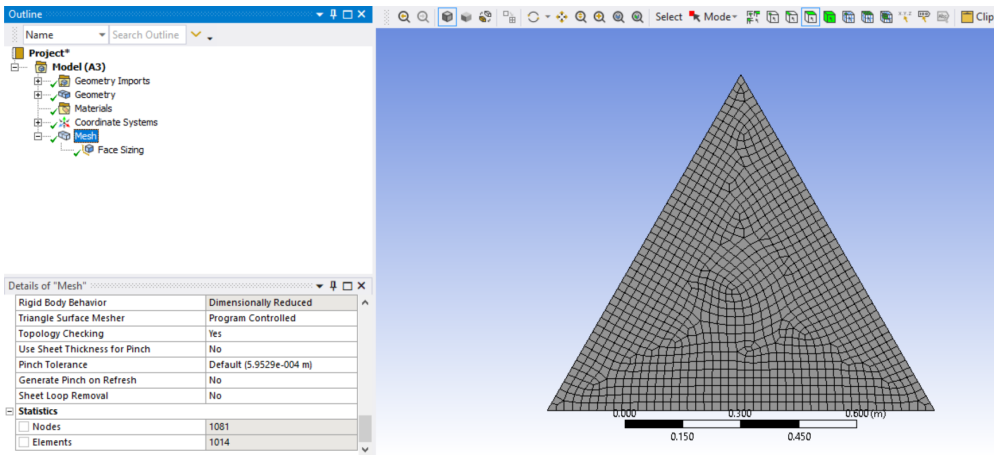


Figure 3: Quadrilateral mesh conformation

However, during this process,it was possible to realize that could be interesting to change to another grid shape. Therefore, for both 1000 and 8000 elements test were used a triangular mesh conformation as it is possible to verify in the Fig. 4 and Fig. 5

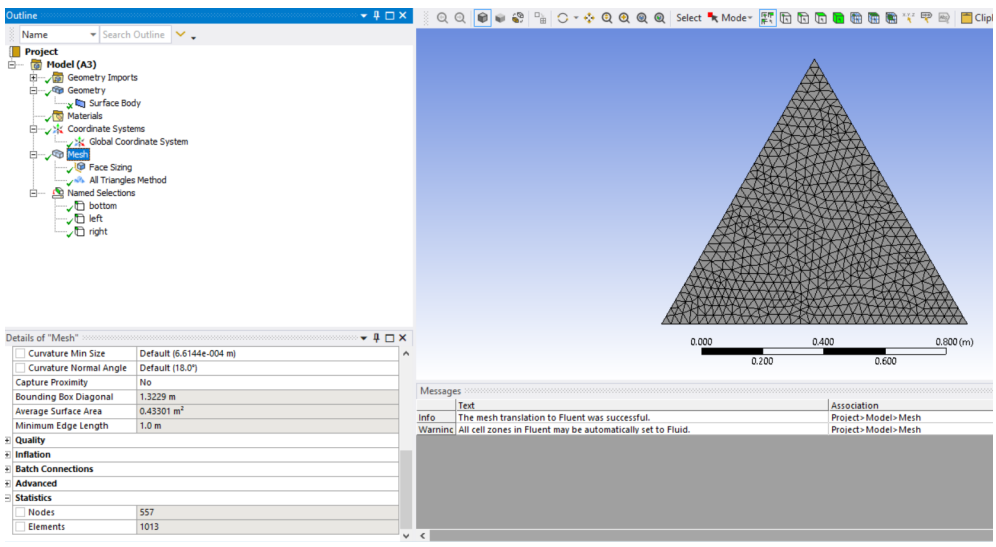


Figure 4: $\approx$ 1000 elements triangular mesh conformation

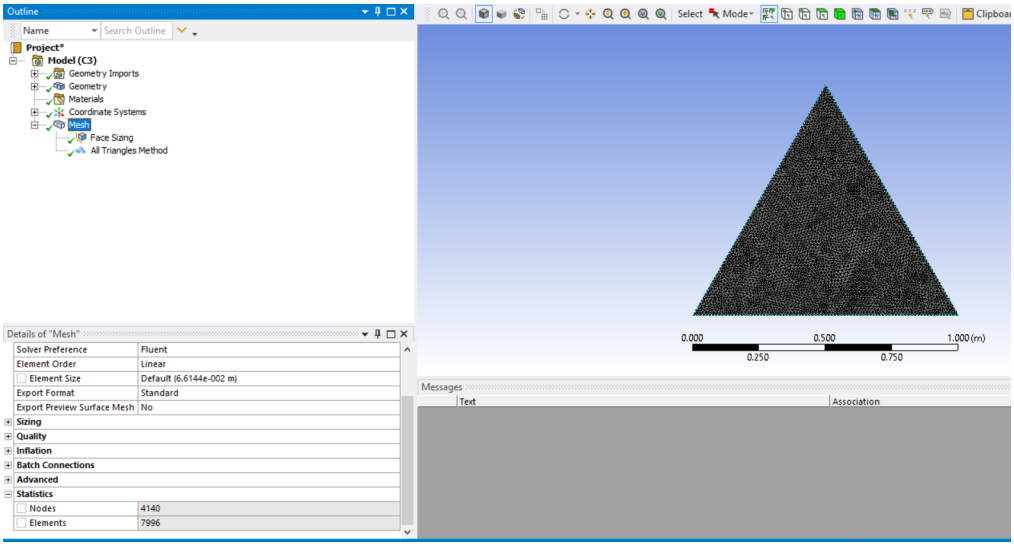


Figure 5: ≈ 8000 elements triangular mesh conformation

0.2.3 Set Fluent Physical Conditions

At this step, it had began the inputs of the problem's physical conditions to be simulated. First assumed gravity as ≈ -10 [m/s] on y direction once dealing with 2D approach. Apart from that, the Energy and Viscous options (both on Models label) were set to "On" and "Laminar" respectively. This can be seen in Fig. 6

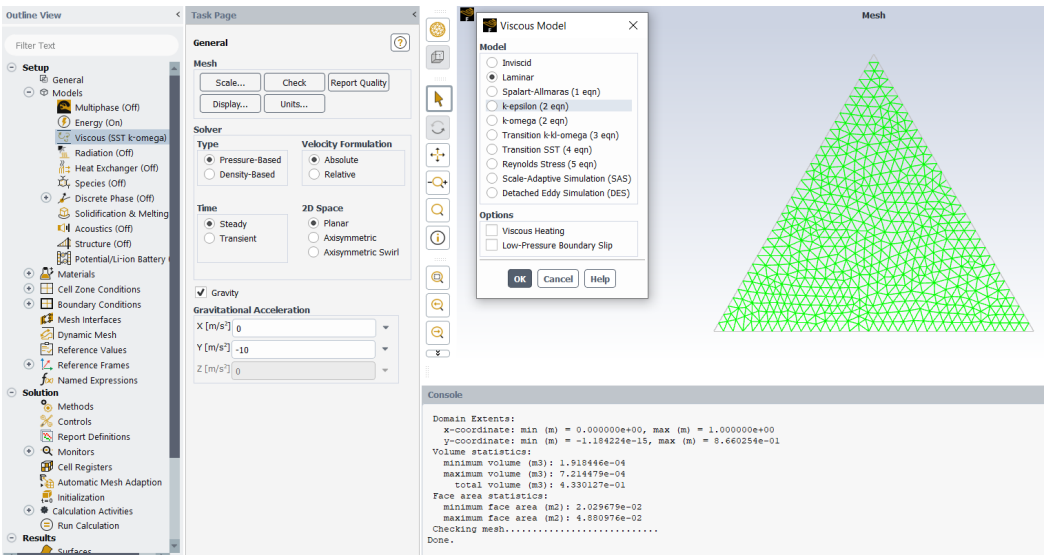


Figure 6: Gravity, Energy mode and Viscous defined

The triangle is made of aluminium. As for the fluid selected, it was chosen air with the following properties as show in Fig. 7 and Fig. 8. Important to mentioned that this part is crucial to determine the Rayleigh Number used in the simulation given by the formula:

$$Ra = \frac{g\beta\Delta T L^3}{\alpha\nu} \tag{1}$$

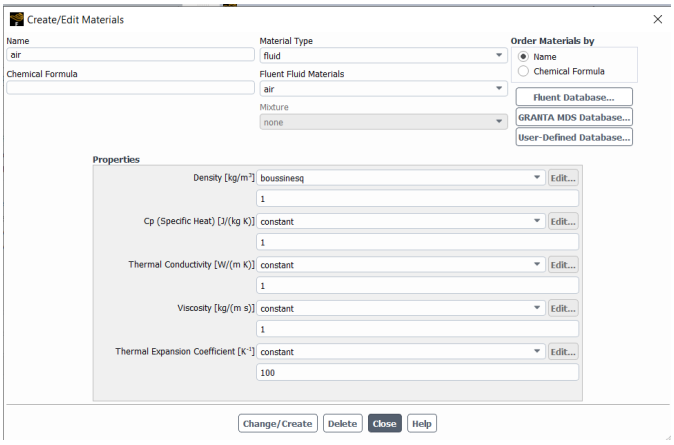


Figure 7: Air properties for Ra $= 1.0 \times 10^4$

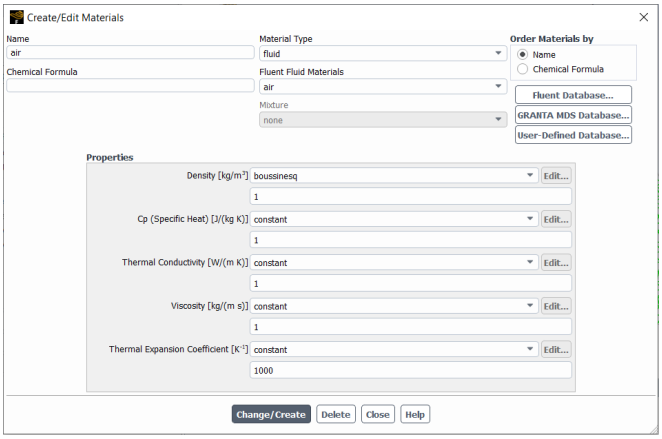
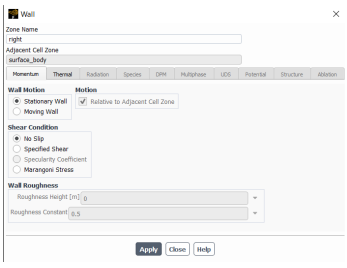
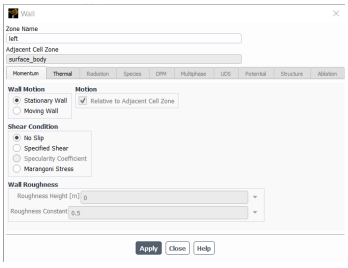


Figure 8: Air properties for Ra $= 1.0 \times 10^5$

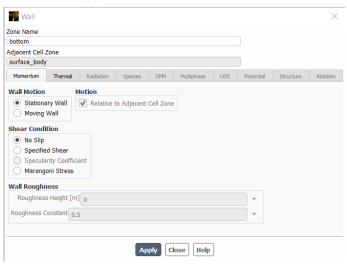
Figure 9 shows the Momentum Boundary conditions. All the walls (right, left, and bottom) were set as stationary ones considering the motion, as well as, no slip regarding shear condition.



(a) Right wall



(b) Left wall



(c) Bottom wall

Figure 9: Momentum boundary conditions

Regarding the Thermal Boundary conditions (Dirichlet BC's) as shown in Figs. 10 and 11:

- Bottom wall had a fixed temperature of 305 K
- Both right and left walls also had a fixed temperature, however it was set 295 K

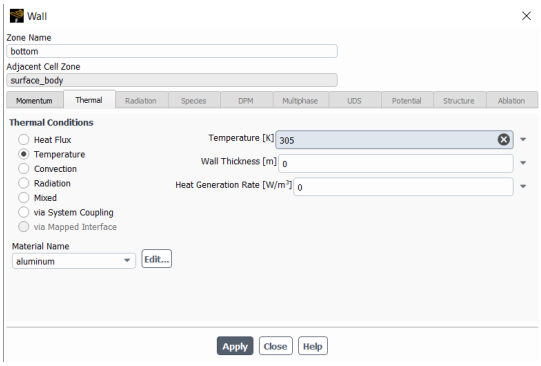
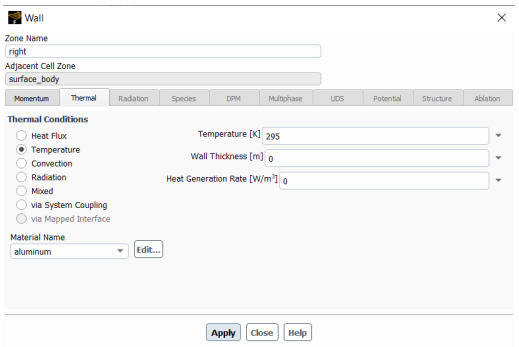
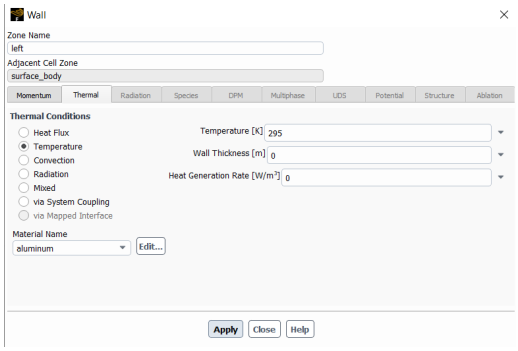


Figure 10: Thermal BC bottom wall



(a) Right wall



(b) Left wall

Figure 11: Thermal BC right and left walls

0.2.4 Set Solution Initialization and Methods

Figures 12 and 13 show the solution initialization and the methods used during the procedure. The initial temperature was set as 300 K. For the Methods it was used the SIMPLE Scheme and the other parameters were set as the default ones.

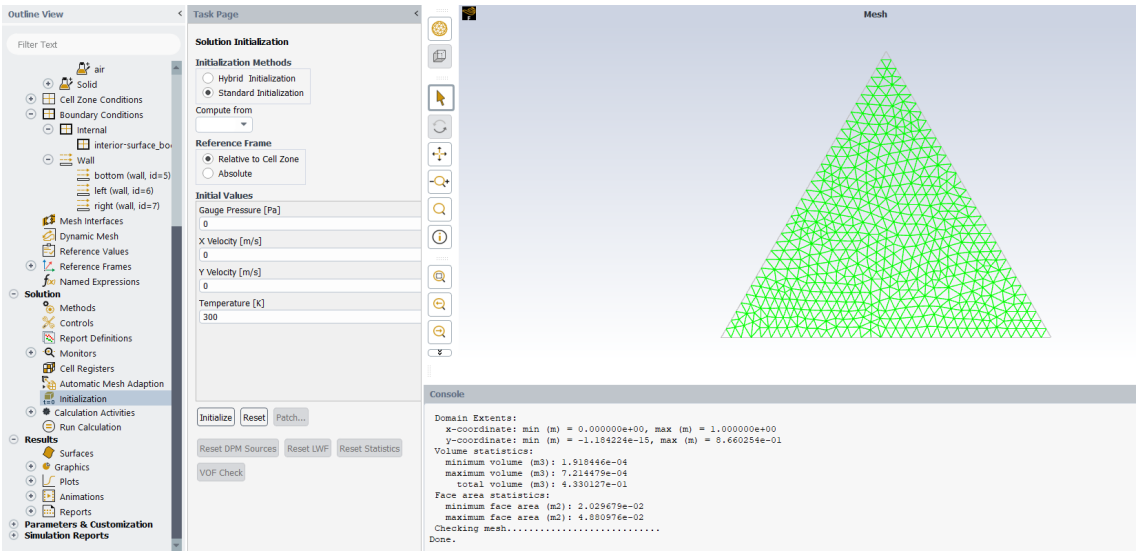


Figure 12: Solution Initialization

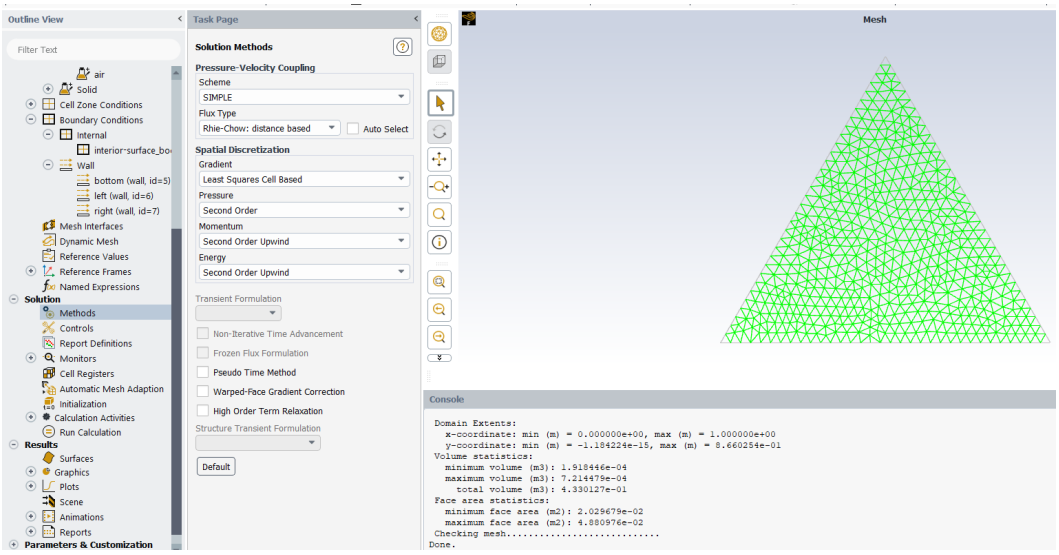


Figure 13: Solution Methods

Regarding the "Run Calculations" it was set the maximum number of iterations as 1000, what can be seen in Fig. 14.

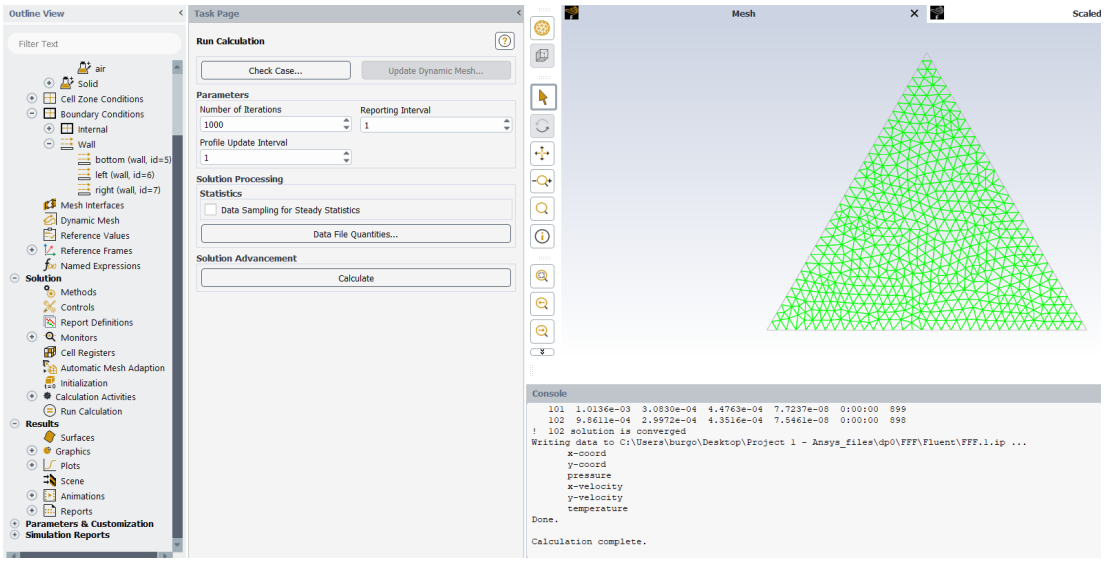


Figure 14: Run Calculations

0.3 Results and Discussion

Four simulations were performed. The first one with 1000 elements and Ra $= 1.0 \times 10^4$. The second with 1000 elements and Ra $= 1.0 \times 10^5$. The third with 8000 elements and Ra $= 1.0 \times 10^4$. Finally, the last considering 8000 elements and Ra $= 1.0 \times 10^5$.

0.3.1 Residuals

Figures 15 to 18 show the residuals for continuity, energy and momentum (represented by x-velocity and y-velocity) over the number of iterations required to converge the solution. It is possible to verify two main aspects: first, all the residuals converged to small values and second during all the simulations despite 1000 as the maximum number of iterations no simulation required such amount of cycles as shown in the Tab. 1.

As expected, for 8000 elements the number of iterations was higher than the other case, since increasing the number of cells will also increase the computational cost. The same can be relatively

said with respect to the Rayleigh Number with one caveat: for 1000 elements case, it did not make too much of difference (where it is possible to consider that for this commercial software this amount of elements it is considered to have very low computational cost). However, for the 8000 case, the number of iterations increased considerably, what is in agreement with the expectations.

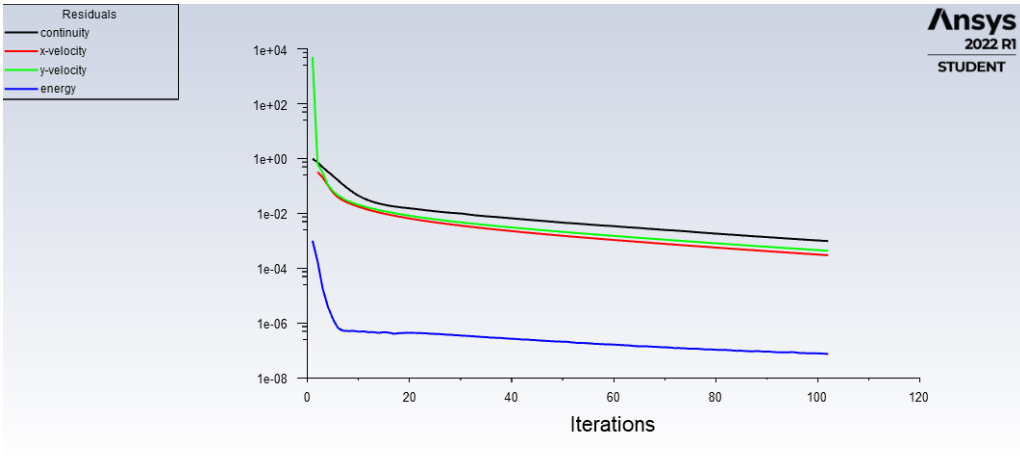


Figure 15: Residuals for 1000 elements and Ra $= 1.0 \times 10^4$

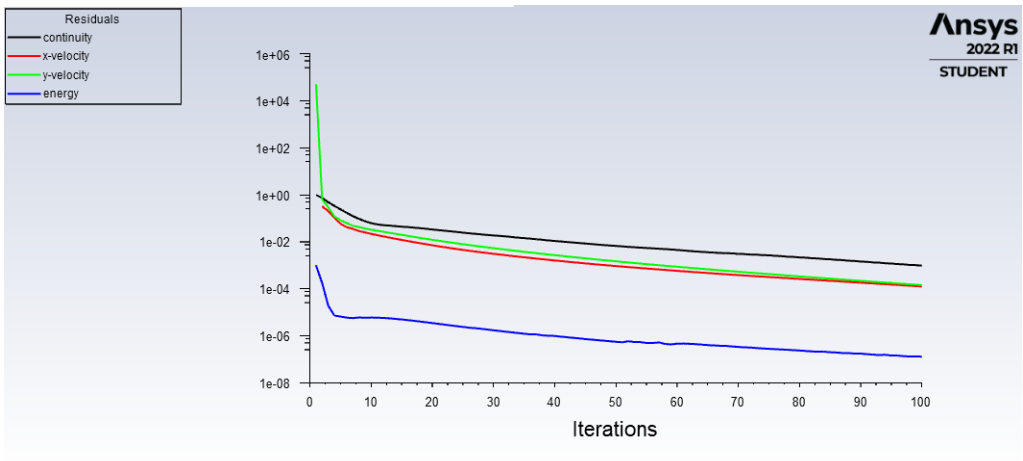


Figure 16: Residuals for 1000 elements and Ra $= 1.0 \times 10^5$

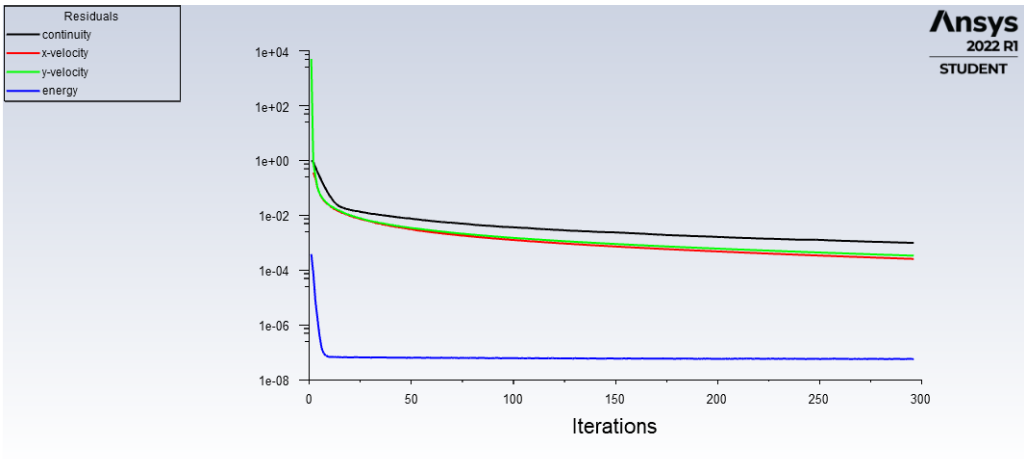


Figure 17: Residuals for 8000 elements and Ra $= 1.0 \times 10^4$

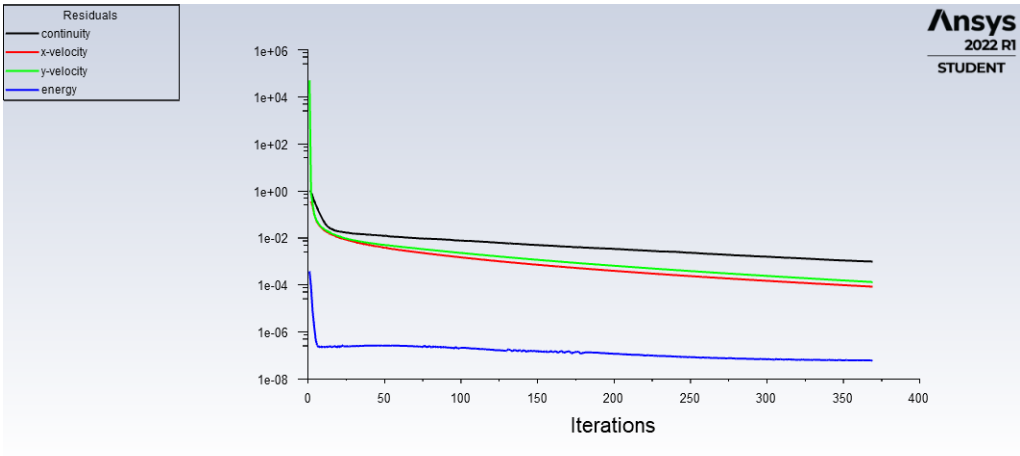


Figure 18: Residuals for 8000 elements and Ra $= 1.0 \times 10^5$

Table 1: Number of iterations needed to converge to the solution, applied on each simulation case varying number of elements and Ra number - those were acquired looking at the Console Log

Simulation	**Number of Iterations**
1000 elements and Ra $= 1.0 \times 10^4$	102
1000 elements and Ra $= 1.0 \times 10^5$	100
8000 elements and Ra $= 1.0 \times 10^4$	296
8000 elements and Ra $= 1.0 \times 10^5$	369

0.3.2 Temperature Contour

Figures 19 to 22 show the temperature contour of all previous simulations. The plots seem correct accordingly to the problem physics. Again, in this case, two aspects are visible and must be taken into account:

- Despite the different number of elements (mesh refinement) the temperature shape distribution, using the same Ra, are very much alike in format
- For the Ra $= 1.0 \times 10^5$ the solution converges to a temperature distribution where the "heat" is more spread towards the right and left walls when compared to the solution of Ra $= 1.0 \times 10^4$ for both mesh element numbers

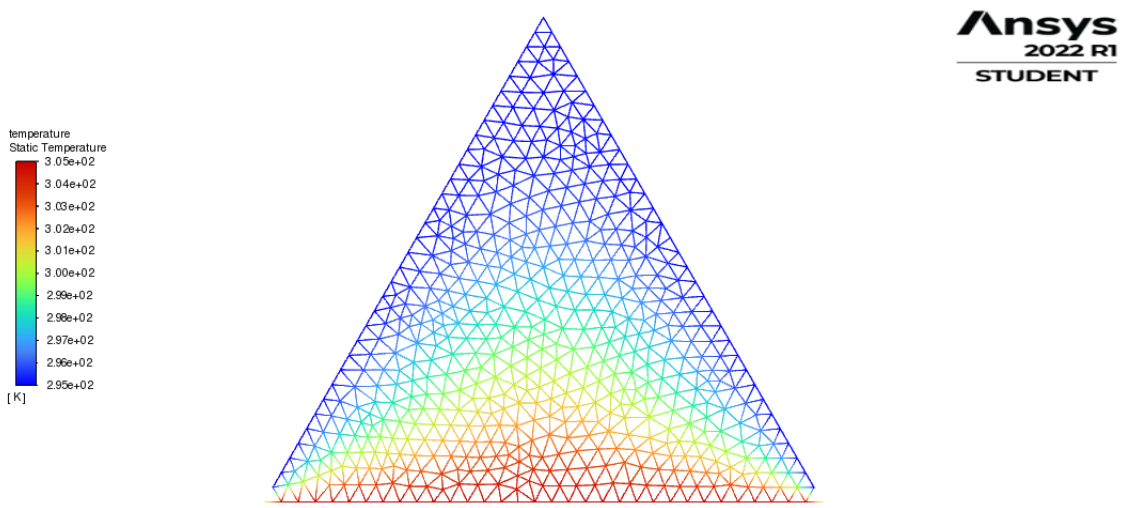


Figure 19: Temperature Contour for 1000 elements and Ra $= 1.0 \times 10^4$

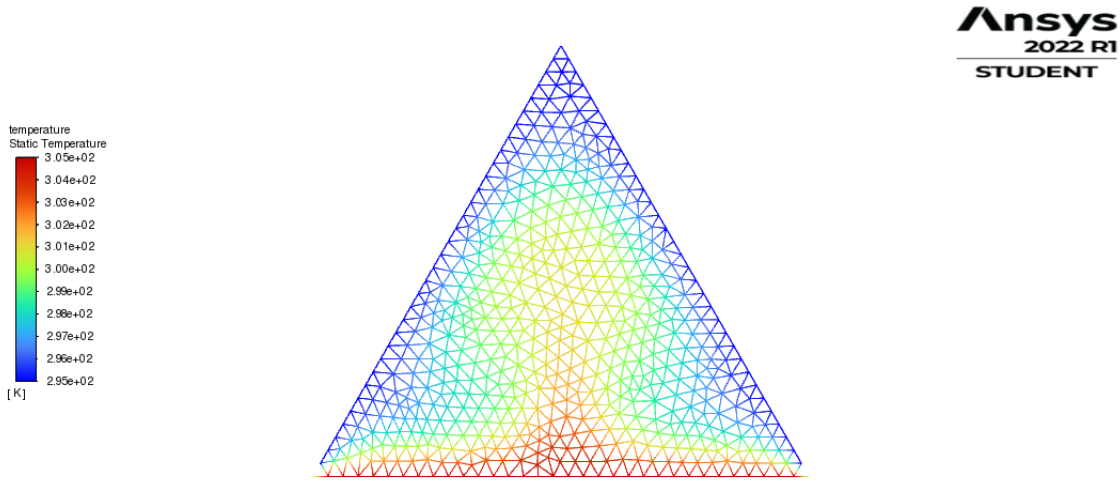


Figure 20: Temperature Contour for 1000 elements and Ra $= 1.0 \times 10^5$

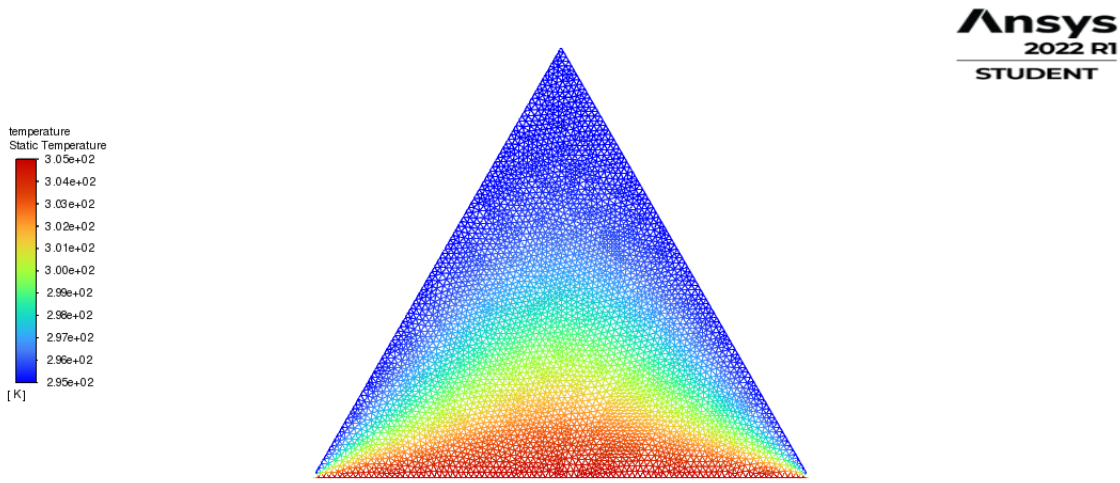


Figure 21: Temperature Contour for 8000 elements and Ra $= 1.0 \times 10^4$

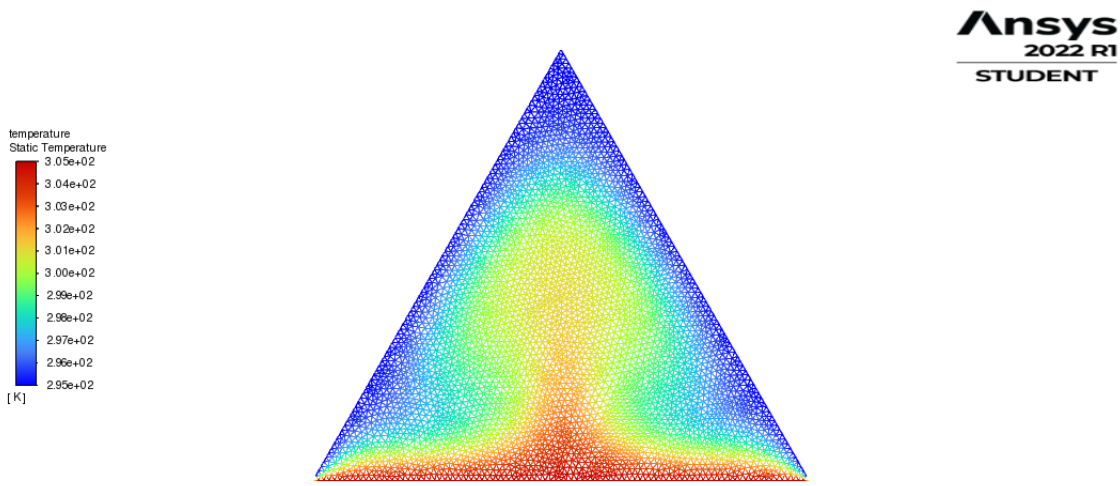


Figure 22: Temperature Contour for 8000 elements and Ra $= 1.0 \times 10^5$

0.3.3 Velocity

Figures 23 to 34 show the velocity vectors of all previous simulations. The plots seem correct accordingly to the problem physics. Again, in this case, two aspects are visible and must be taken into account:

- Despite the different number of elements (mesh refinement) the velocity shape distribution, using the same Ra, are very much alike in format

- For the Ra $= 1.0 \times 10^5$ the solution converges to velocity distribution where the "heat" is more spread towards the right and left walls when compared to the solution of Ra $= 1.0 \times 10^4$ for both mesh element numbers. This means that in the Ra $= 1.0 \times 10^5$ the velocity seem to be higher (this is visible in the bar-color cell) what justifies the more spread out heat.

Vx and Vy are in accordance with what is expected for the final Velocity Magnitude since they are the vector components of it. Apart from that, conformation of the velocity vectors that characterize the fluid flow seem to be in agreement with what is expected of a natural convection when the steady state is reached. In this there is a cyclical situation where the heat goes up and the cold goes down what is possible to verify in the temperature plots.

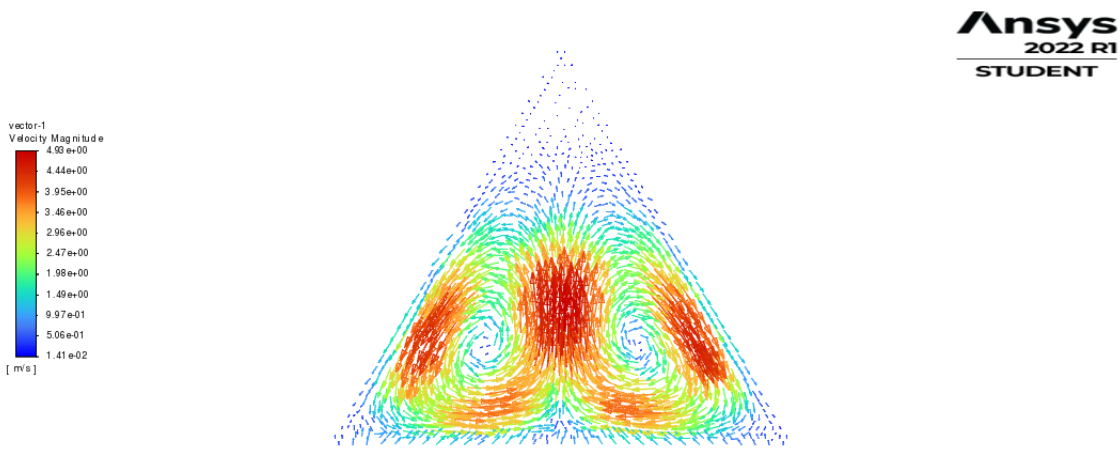


Figure 23: Velocity Magnitude for 1000 elements and Ra $= 1.0 \times 10^4$

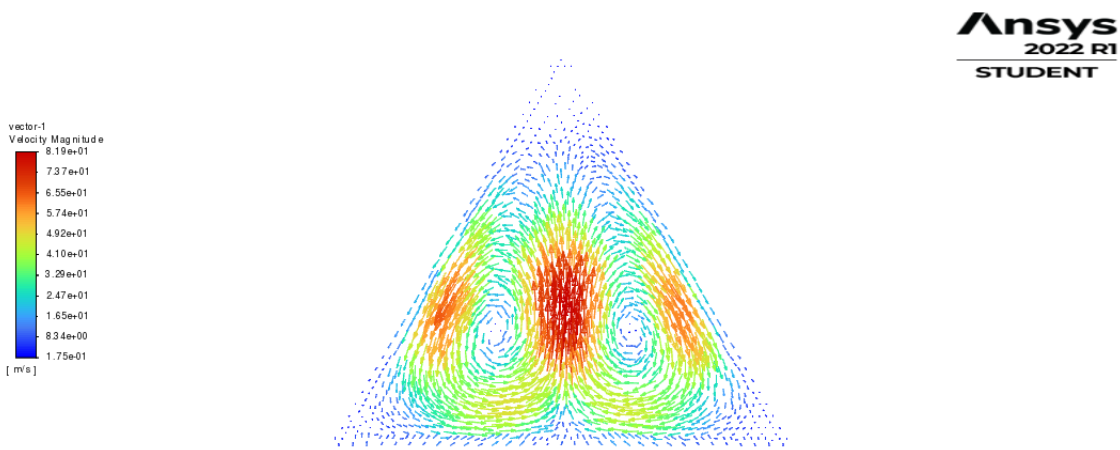


Figure 24: Velocity Magnitude for 1000 elements and Ra $= 1.0 \times 10^5$

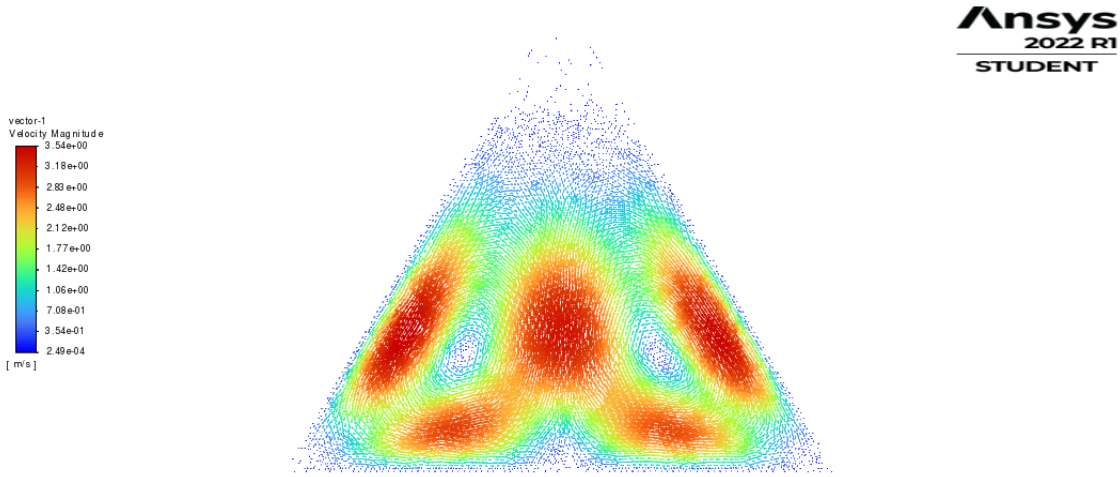


Figure 25: Velocity Magnitude for 8000 elements and Ra $= 1.0 \times 10^4$

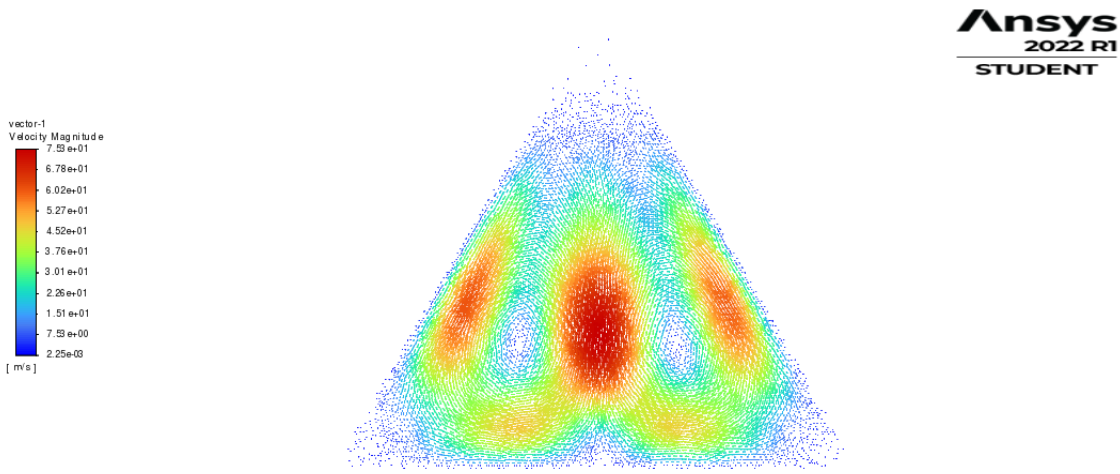


Figure 26: Velocity Magnitude for 8000 elements and Ra $= 1.0 \times 10^5$

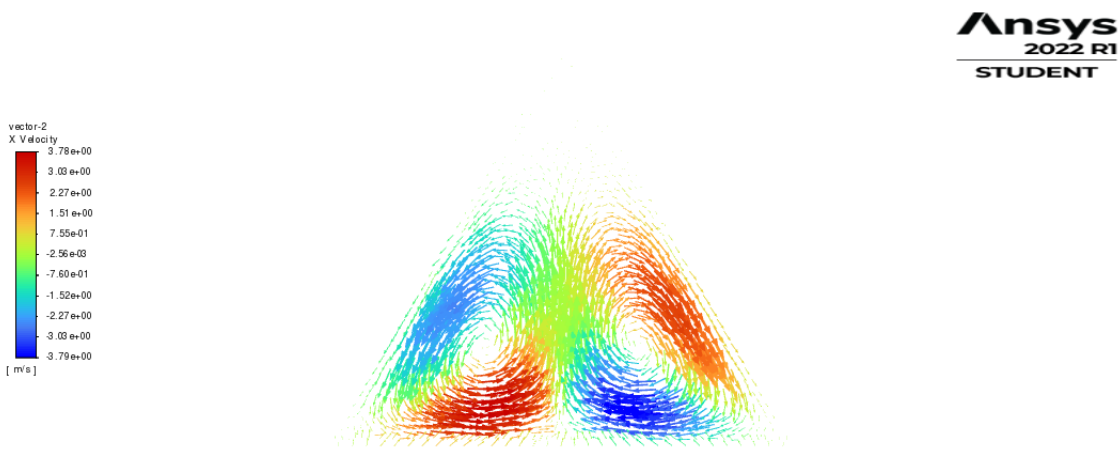


Figure 27: Velocity X for 1000 elements and Ra $= 1.0 \times 10^4$

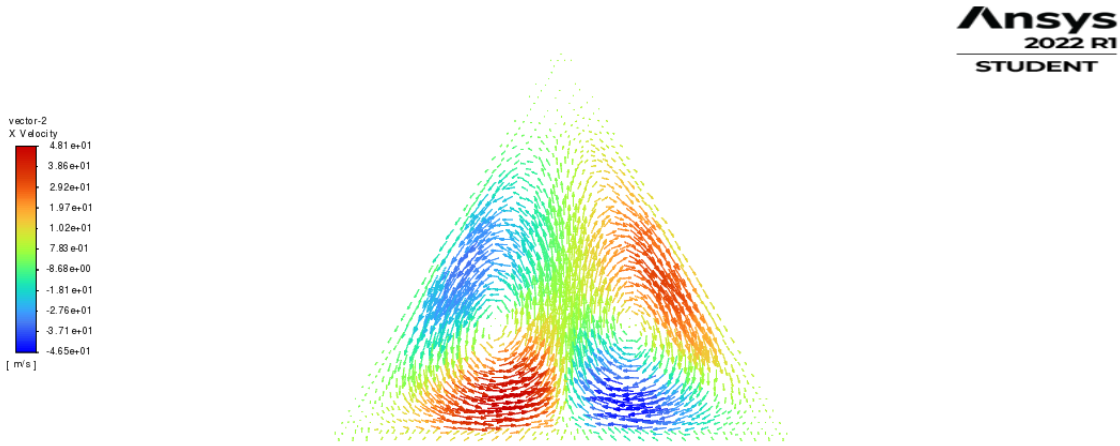


Figure 28: Velocity X for 1000 elements and Ra $= 1.0 \times 10^5$

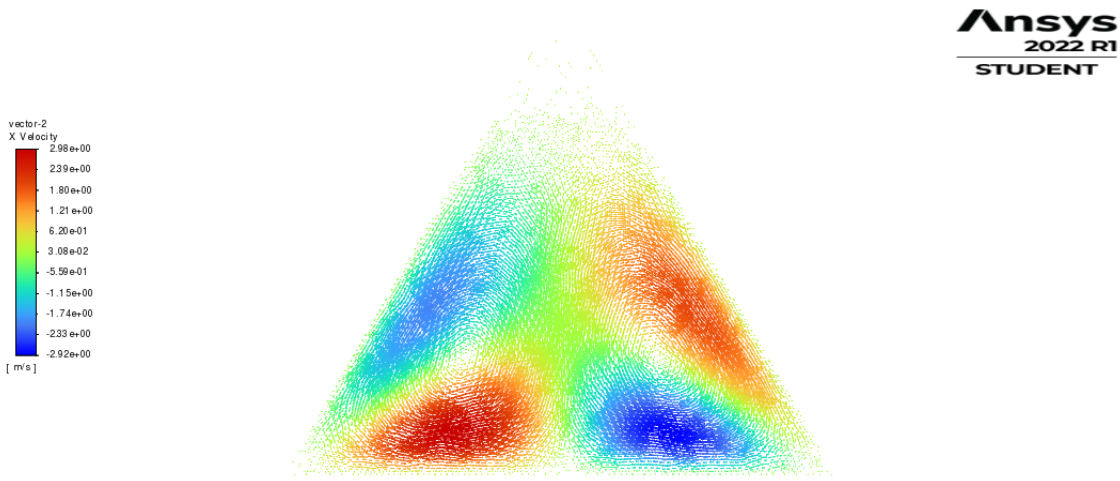


Figure 29: Velocity X for 8000 elements and Ra $= 1.0 \times 10^4$

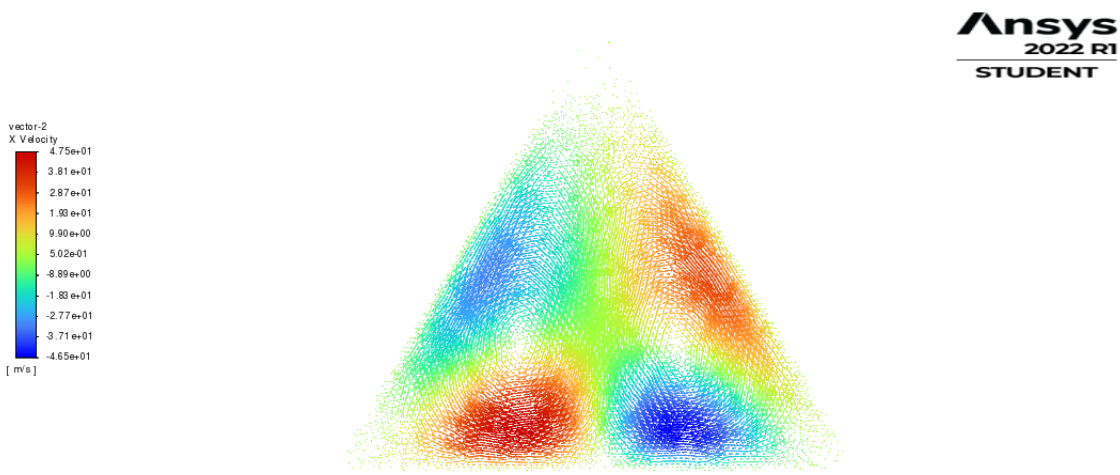


Figure 30: Velocity X for 8000 elements and Ra $= 1.0 \times 10^5$

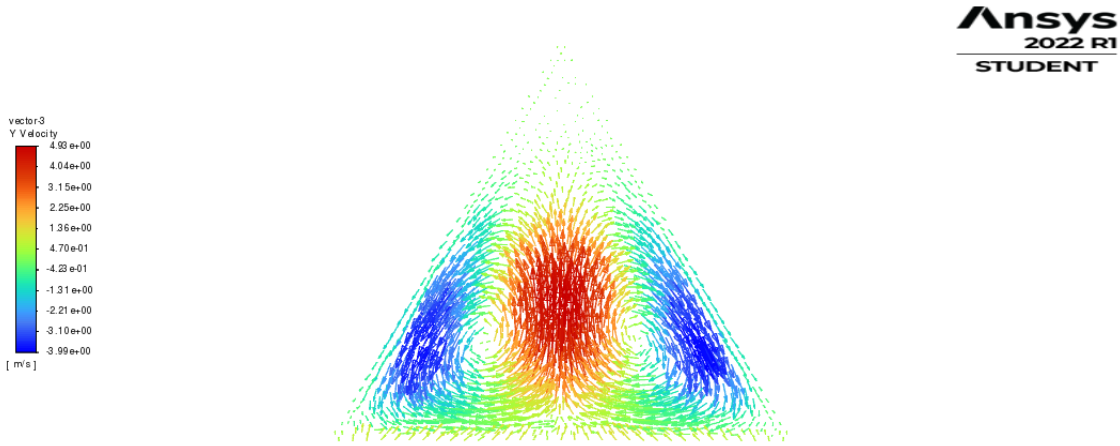


Figure 31: Velocity Y for 1000 elements and Ra $= 1.0 \times 10^4$

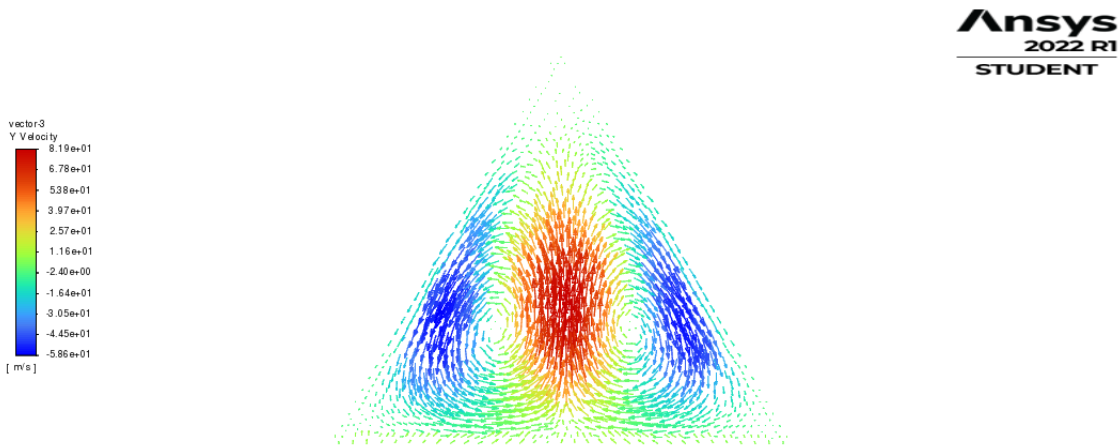


Figure 32: Velocity Y for 1000 elements and Ra $= 1.0 \times 10^5$

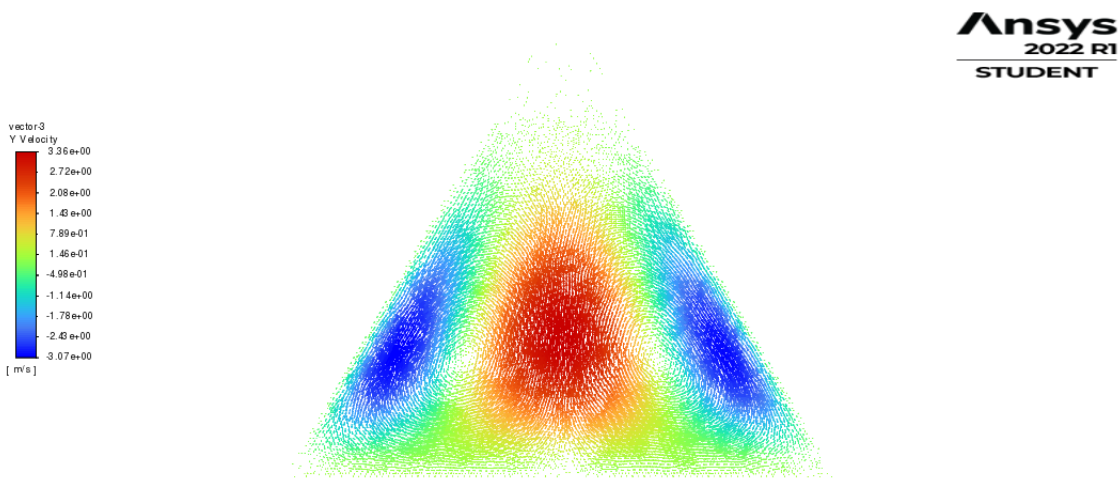


Figure 33: Velocity Y for 8000 elements and Ra $= 1.0 \times 10^4$

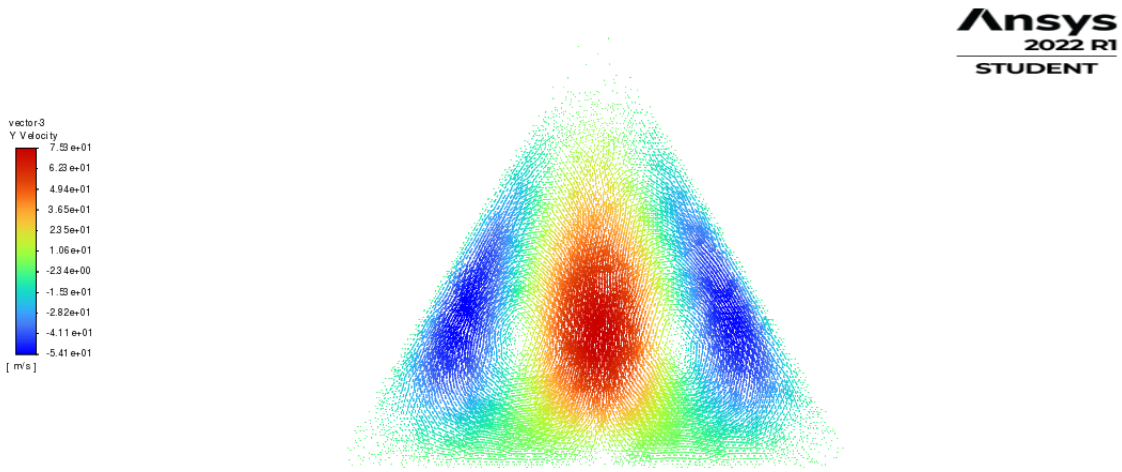


Figure 34: Velocity Y for 8000 elements and Ra $= 1.0 \times 10^5$

0.3.4 Streamlines

Figures 35 to 38 show the streamlines of all previous simulations. The plots seem correct accordingly to the problem physics.

Streamlines denote that heat has this cyclical behavior described in the previous section.

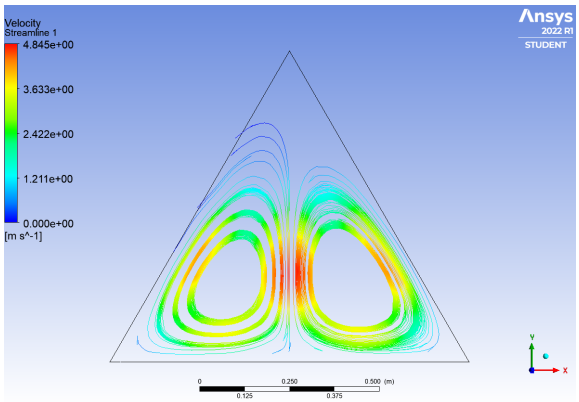


Figure 35: Streamlines for 1000 elements and Ra $= 1.0 \times 10^4$

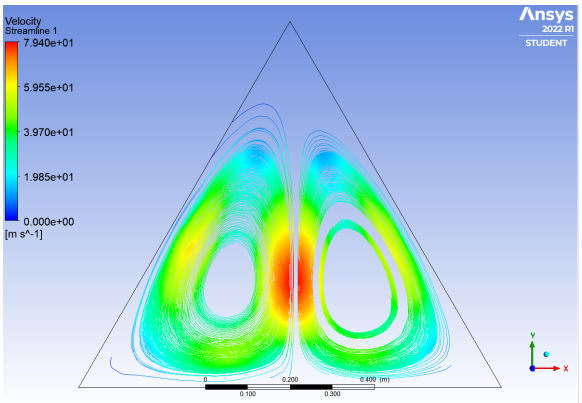


Figure 36: Streamlines for 1000 elements and Ra $= 1.0 \times 10^5$

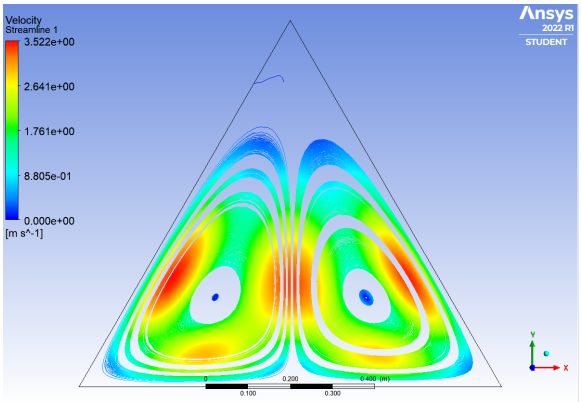


Figure 37: Streamlines for 8000 elements and Ra $= 1.0 \times 10^4$

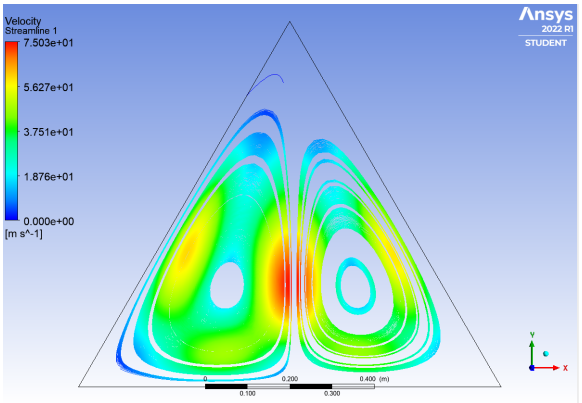


Figure 38: Streamlines for 8000 elements and Ra $= 1.0 \times 10^5$