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Computational Fluid Dynamics

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Part 1: Heat Sink Design

Before the CFD analysis begins, one must calculate the thickness, height and width of the given problem as shown below:

$$t = \left(5 - \frac{76}{100}\right) mm = 4.24\, mm$$

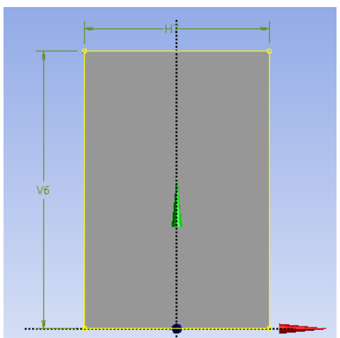
$$W = 4.24 \times 11 = 46.64\, mm$$

$$H = 4.24 \times 9 = 38.16\, mm$$

(Part 1):

Geometry:

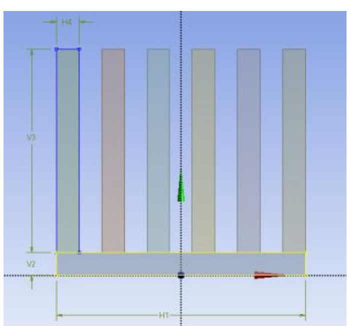
1. The following set of pictures shown below reveals the constructed model and geometry of the problem given using a 3D analysis. As a note the case was extruded 240 mm and the electronic chip and the fins are extruded 46.64 mm in the positive z direction:



Dimensions: 2

H7	80 mm
V6	120 mm

Figure 1: Computer Case with Dimensions Extruded 240 mm in positive Z direction



H1	46.64 mm
V2	4.24 mm
H4	4.24 mm
V3	38.16 mm

Figure 2: Electronic Chip and Fins with Dimensions Extruded 46.64 mm in positive Z direction

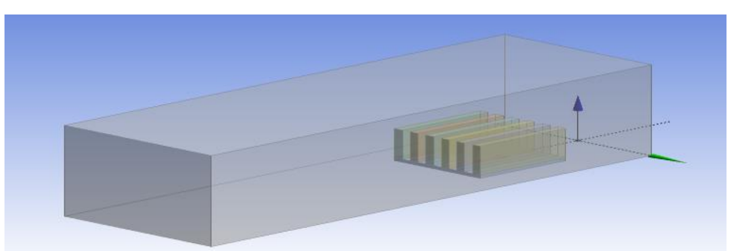


Figure 3: Isometric View Of Geometry

Boundary conditions:
2. The boundary conditions that were applied to the problem given are the following:

- At the inlet cross sectional area, there is a uniform inlet velocity of 1 m/s with air temperature of 25°C.
- At the exit of the outlet cross sectional area, the exit pressure is ambient and the air temperature of 25°C.
- There is constant heat generation from the electronic chip of 6.5×10^6 W/m^3.
- The walls of computer case and the wall under the electronic chip are stationary, fixed, insulated and with no slip condition.
- The walls of the fins and electronic chip have no slip condition, stationary and fixed.

Setup:
3. In order to determine the fluid flow regime (turbulent or laminar), one must calculate the Reynolds Number and compare the calculated value to the following criterion:

$$Re \leq 2300\ laminar\ Re > 4000\ Turbulent$$

The following equation was used to calculate the Reynolds Number:

$$Re = \frac{\rho U D}{\mu};\ \rho \sim Density; U{\sim}Velocity; D{\sim}Diameter;\ \mu \sim Dynamic\ Viscosity$$

The diameter was approximated using the hydraulic diameter as follows:

$$D_h = \frac{4A}{P} = \frac{4(0.08 \times .120)}{.080 + .080 + .120 + .120} = .096\ m$$

The calculated Reynolds number is the following using the air density and viscosity values given from Ansys fluent:

$$Re = \frac{1.224\ kg/m^3 (1 \frac{m}{s})(.096\ m)}{1.789 \times 10^{-5} \frac{kg}{m \cdot s}}$$

$$Re = 6568.14$$

The calculated Reynolds number from the previous equation resulted in the value of 6568.14 which is much larger than 4000 (Re >4000), therefore the flow regime is turbulent.

Mesh Generation:
4. To perform a mesh dependency analysis, the following criterion must be met for the maximum temperature of the electronic chip:

$$|\mathrm{T}_2 - \mathrm{T}_1| \leq 1℃$$

This was achieved by running the calculation on fluent Ansys for 999 iterations, and noting down the number of elements, the body sizing (element size) used for the mesh sizing at the computer chip and the fins on which a solution was obtained and its maximum temperature at the computer chip. Note that all other mesh sizing was kept constant, and only the body sizing at the computer chip were changed for each mesh number. This process was done multiple times until the criterion mentioned was met. The following table summarizes the results:

Table 1: Mesh Dependency Study

Mesh Number	**Number of Elements**	**Body Sizing at The Computer Chip and Fins (Element Size)**	**Maximum Temperature °C**	$\mathbf{|T_2 - T_1| \leq 1}$℃
1	141130	0.002	378.9876 °C	N/A
2	603795	0.001	377.7024 °C	1.2852 °C
3	809757	0.0009	377.3324 °C	.3700 °C
4	1027177	0.0008	377.2004 °C	0.132 °C

As shown in table 1 for the mesh dependency, it could be seen that mesh number 1 (coarser mesh) has a difference in temperature that is 1.2852°C (greater than 1°C) with mesh number 2 (finer mesh) which is above the specified criterion. Another mesh analysis was done by increasing body sizing. The difference in temperature obtained between mesh number 3 (finer mesh) and 2 (coarser mesh) was .3700°C which satisfies the specified criterion. In order to reinforce the result another mesh analysis was done by increasing the body sizing. The difference in temperature between 3 (coarser mesh) and 4 (finer mesh) was 0.132 °C. Mesh number 4 has also satisfied the specified criterion, but in order to minimize the computational costs, mesh number 2 will be chosen with the corresponding body sizing of 0.001. The corresponding graph related to table 1 for mesh independency is shown below:

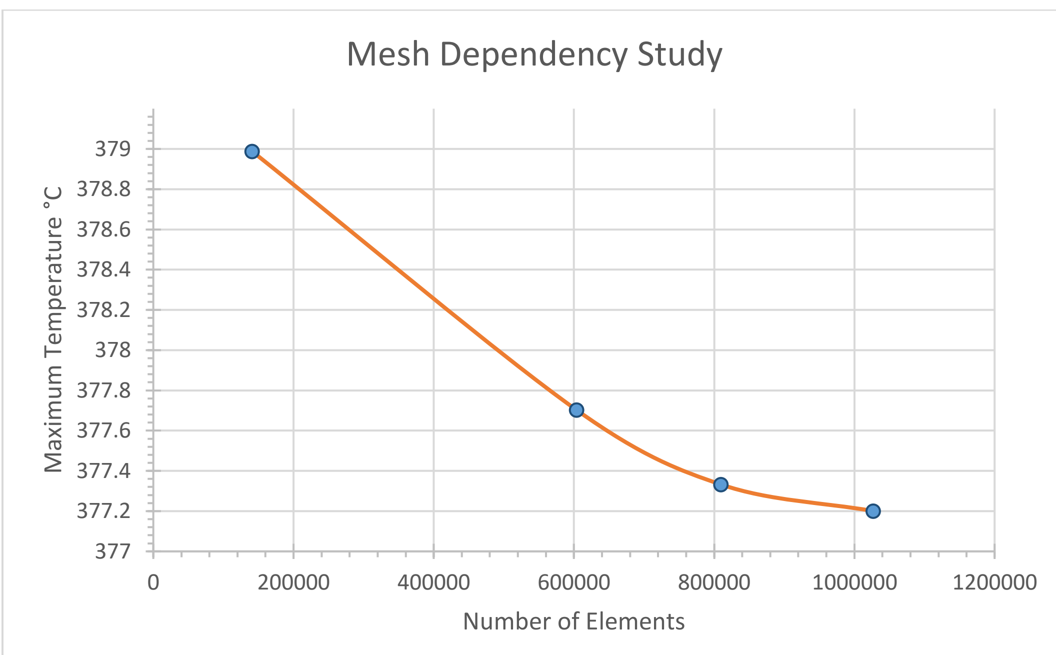


Figure 3: Plot of Mesh Dependence Study Maximum Temperature Vs Number of Elements

The graph above was plotted by recording the number of elements with is corresponding mesh sizing (body sizing) and then performing the mesh analysis using ANSYS: Fluent. Once the calculated maximum temperature at the computer chip was obtained for each mesh number, the difference between the temperatures based on the mention criterion was calculated and compared. It was concluded that mesh number 2 will be chosen with the corresponding number of elements and body sizing to be 603795, and 0.001, respectively to minimize computational costs.

5. The following set of images will provide a clear picture of the mesh used in the CFD analysis:

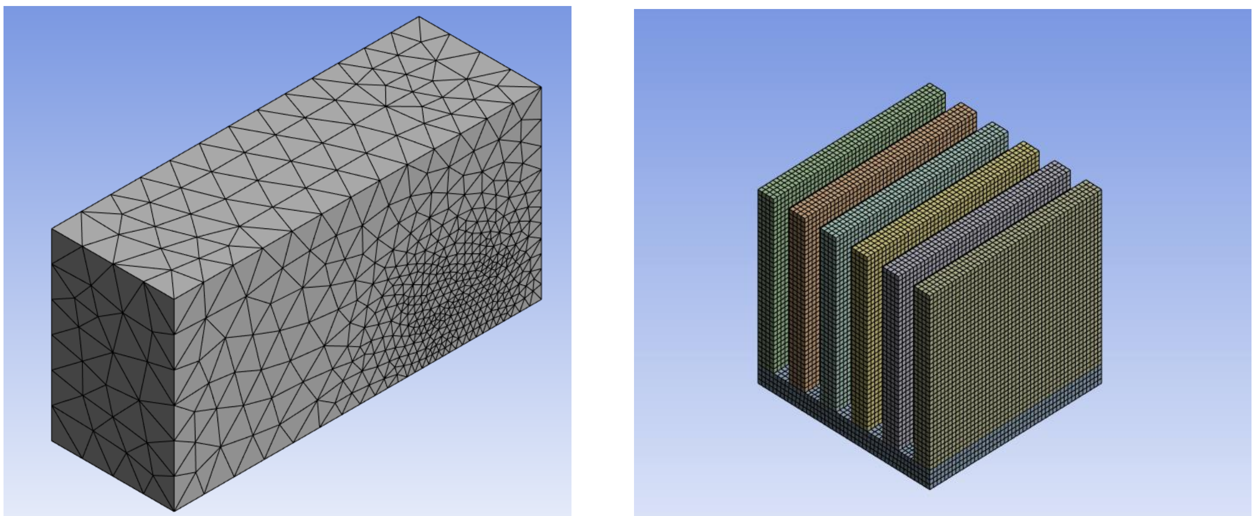
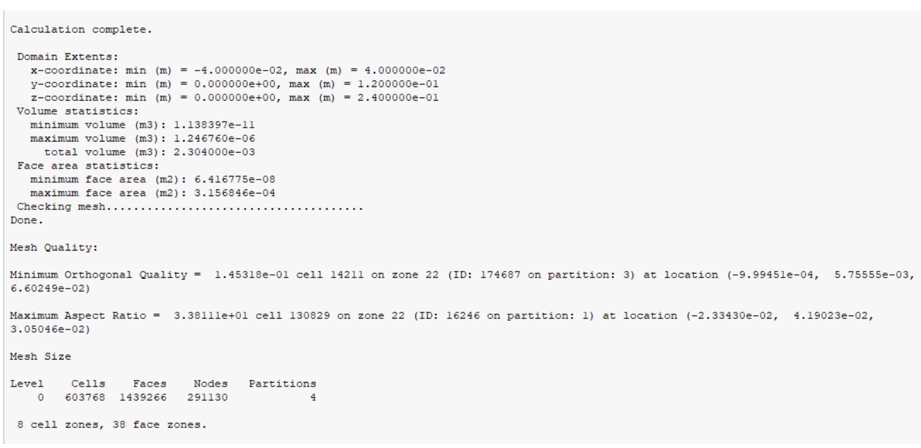


Figure 4: Mesh of Constructed Geometry

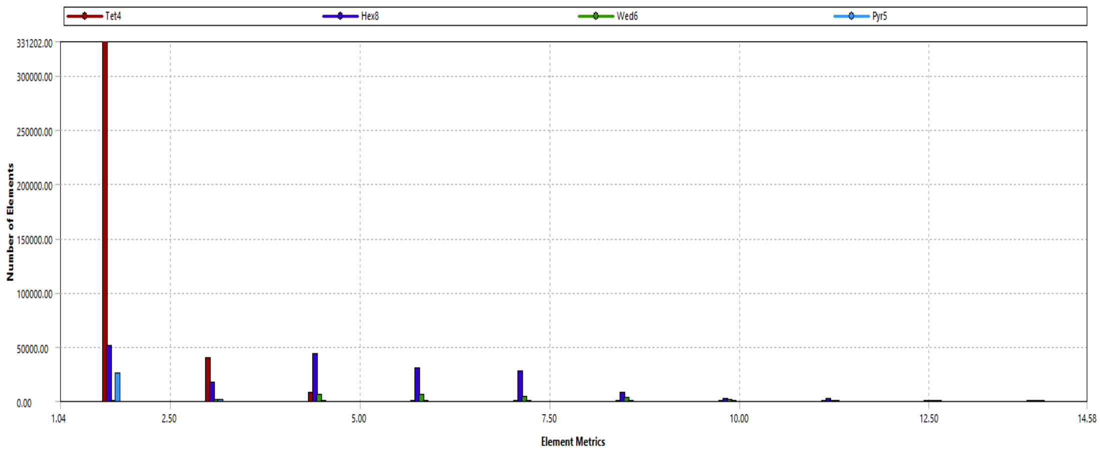
a) The mesh check and mesh size is shown in the following images below:



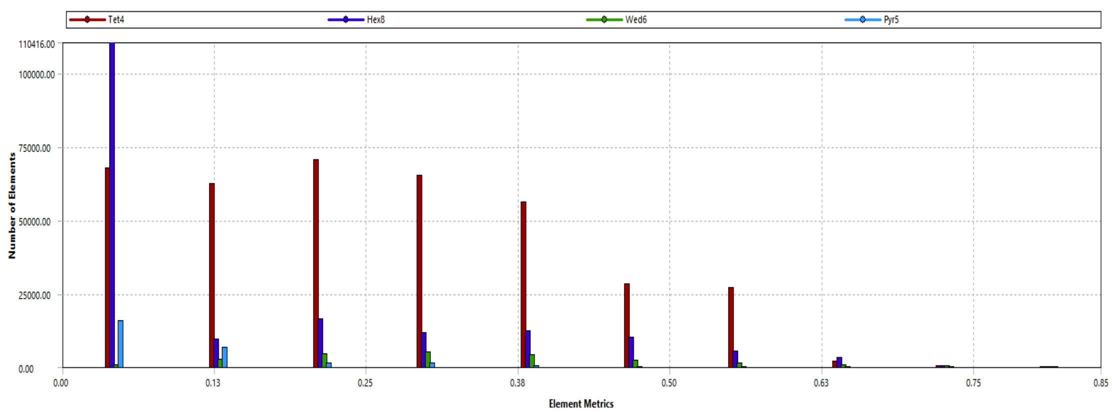
```
Calculation complete.

 Domain Extents:
   x-coordinate: min (m) = -4.000000e-02, max (m) = 4.000000e-02
   y-coordinate: min (m) = 0.000000e+00, max (m) = 1.200000e-01
   z-coordinate: min (m) = 0.000000e+00, max (m) = 2.400000e-01
 Volume statistics:
   minimum volume (m3): 1.138397e-11
   maximum volume (m3): 1.246760e-06
     total volume (m3): 2.304000e-03
 Face area statistics:
   minimum face area (m2): 6.416775e-08
   maximum face area (m2): 3.156846e-04
 Checking mesh....................................
Done.

Mesh Quality:

Minimum Orthogonal Quality =  1.45318e-01 cell 14211 on zone 22 (ID: 174687 on partition: 3) at location (-9.99451e-04,  5.75555e-03,
6.60249e-02)

Maximum Aspect Ratio =  3.38111e+01 cell 130829 on zone 22 (ID: 16246 on partition: 1) at location (-2.33430e-02,  4.19023e-02,
3.05046e-02)

Mesh Size

Level    Cells    Faces    Nodes   Partitions
    0   603768  1439266   291130            4

 8 cell zones, 38 face zones.
```

Figure 5: Mesh Check, Mesh Quality and Mesh Size

b) The mesh aspect ratio and skewness distribution could be seen in the following images:



a)



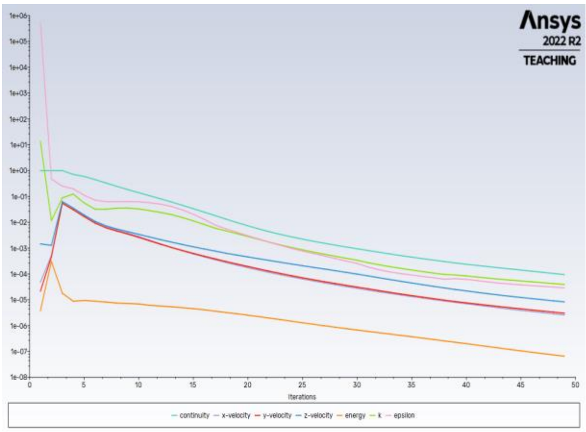
b)

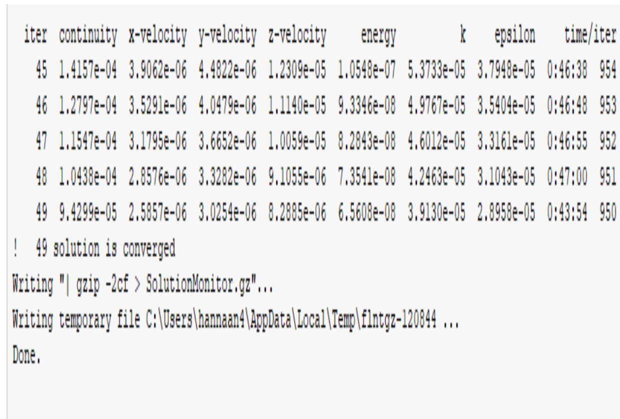
Figure 6: Mesh Quality a) Aspect Ratio b) Skewness

As shown in figure 6 above, the aspect ratio and skewness of the mesh chosen is displayed. The aspect ratio is defined as the ratio from the shortest length of the element to the longest length of the element, where a ratio of 1 is an ideal mesh. As shown in figure 6 a) most of the mesh elements are near 1 but slightly larger than 1. The mesh could be refined for a finer mesh at the computer case walls, finer at the computer chip and fins although this will raise the computational costs. Thus, the aspect ratio metrics was adequate for the CFD analysis. The skewness is defined as the deviation between the optimal cell sizes to the existing cell size. The range of skewness is between 0 and 1 in which a value of 0 indicates an equilateral cell (ideal) and 1 indicates completely degenerate cell (worst). As shown in figure 6 b) most of the elements lie below skewness range of 0.5 which is adequate and majority of the elements are near the ideal value of 0. As mentioned before refining the mesh at the computer case walls and finer mesh at the computer chip and fins will improve the quality of the skewness, but it will cost computational power. Thus, the mesh quality is adequate to run the CFD analysis.

Part 1: Heat Sink Design Continued

6. The plotted residual history with the corresponding number of iterations for the converged solution is shown below:



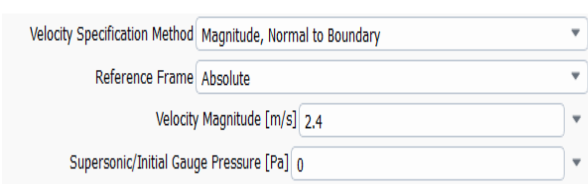


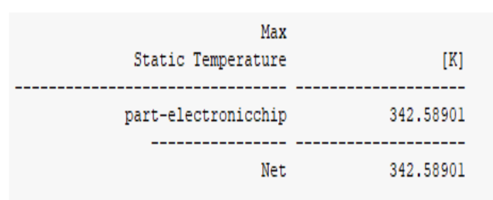
```
iter  continuity  x-velocity  y-velocity  z-velocity     energy          k    epsilon   time/iter
  45  1.4157e-04  3.9062e-06  4.4822e-06  1.2309e-05  1.0548e-07  5.3733e-05  3.7948e-05  0:46:38  954
  46  1.2797e-04  3.5291e-06  4.0479e-06  1.1140e-05  9.3346e-08  4.9767e-05  3.5404e-05  0:46:48  953
  47  1.1547e-04  3.1795e-06  3.6652e-06  1.0059e-05  8.2843e-08  4.6012e-05  3.3161e-05  0:46:55  952
  48  1.0438e-04  2.8576e-06  3.3282e-06  9.1055e-06  7.3541e-08  4.2463e-05  3.1043e-05  0:47:00  951
  49  9.4299e-05  2.5857e-06  3.0254e-06  8.2885e-06  6.5609e-08  3.9130e-05  2.8958e-05  0:43:54  950
!  49 solution is converged
Writing "| gzip -2cf > SolutionMonitor.gz"...
Writing temporary file C:\Users\hannaan4\AppData\Local\Temp\flntgz-120844 ...
Done.
```

a) b)

Figure 7: a) Plot of Residual History, b) Number of Iterations for converged solution

7. In order to find the minimum required air velocity in order to satisfy the maximum temperature of 70 °C ~ 343.15°C was to run multiple fluent analysis calculations and analyze the maximum temperature at the computer chip. The analysis consisted of changing the fluid inlet velocity from 1 m/s and tuning the inlet velocity to observe what minimum velocity will find the maximum temperature of 70°C. Various inlet velocities were computed such as 1.5 m/s, 2 m/s, 2.1 m/s and after multiple iterations, the velocity was estimated to be about 2.4 m/s in order to maintain the maximum temperature of 70°C. The maximum temperature obtained at the computer chip for an inlet velocity of 2.4 m/s was 342.589 K ~ 69.439°C. The images below will reveal the maximum temperature obtained at the computer chip at the inlet velocity of 2.4 m/s:

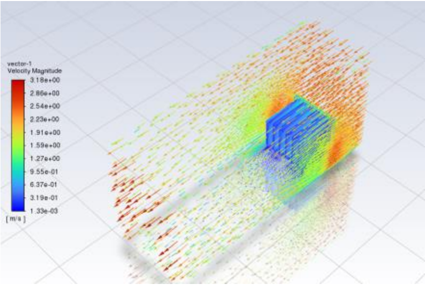




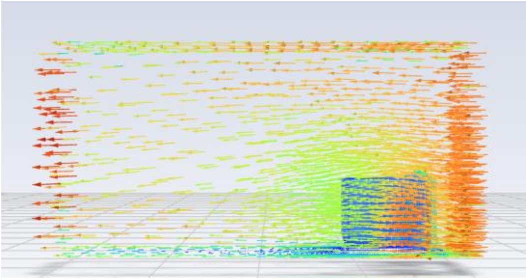
	Max Static Temperature [K]
part-electronicchip	342.58901
Net	342.58901

Figure 8: Maximum Temperature at the Computer Chip for Inlet Velocity of 2.4 m/s

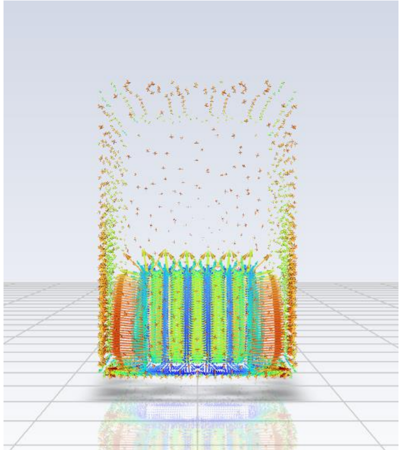
8. The following set of images display the plot of the velocity vectors for the entire domain:



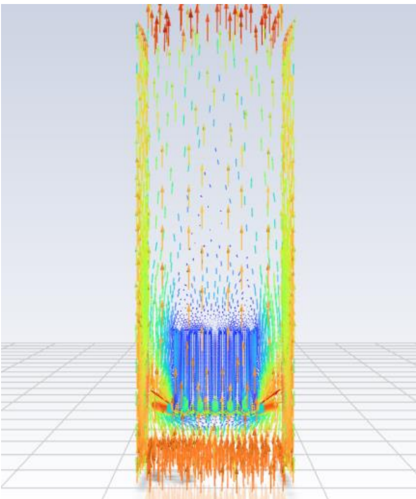
Isometric View



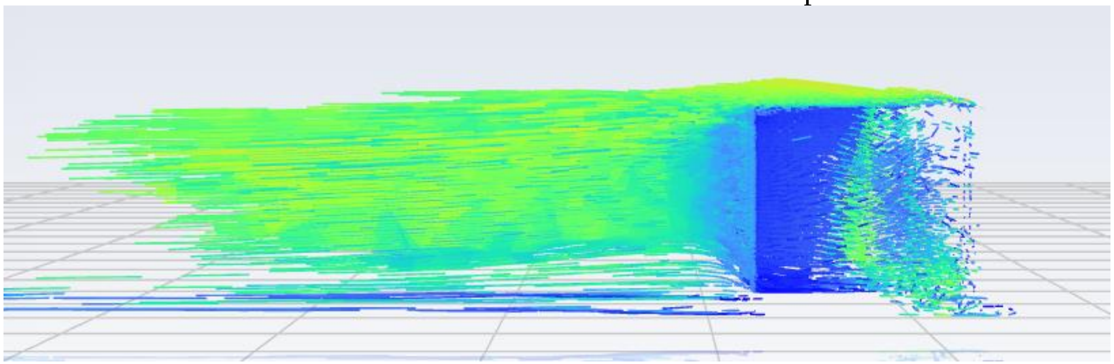
Front View



Right View (Inlet View)



Top View

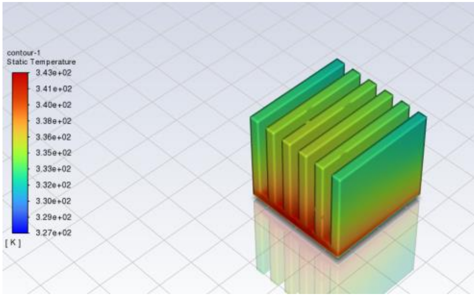


Pathline Plot Right View

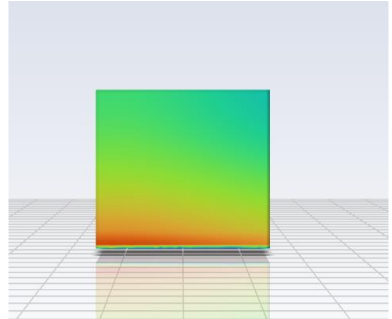
Figure 9: Plot of Velocity Vectors of the Whole Domain with Pathline Plot

As shown in figure 9, it could be observed that there are few vortexes forming at the bottom of the fins and at the computer chip. The vortexes could be forming due to the sudden height change from the computer chip toward the bottom computer case wall. Additionally, at the fins the velocity decreases due to flow separation, and reattaches further down the computer case. The resulting vortexes formed at the bottom of the computer chip and fins is due to the decrease in velocity at the fins resulted from flow separation and the sudden height change from the computer chip towards the bottom wall of the computer case. Thus the major phenomena observed in the CFD analysis is the formed vortexes.

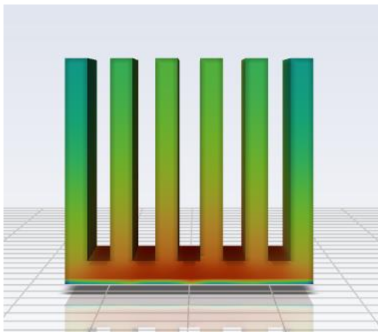
9. The following set of images display the temperature contours for the electronic chip and fins:



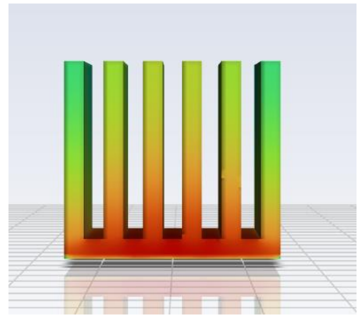
Isometric View



Front View



Right View (Inlet View)



Left View (Outlet View)

Figure 10: Temperature Contours for the Electronic Chip and Fins

As shown in figure 10 the temperature contours of the computer chip and fins are displayed. Inspecting the images, the temperature from the bottom of the computer chip toward the top of the fins gradually decrease in temperature from high temperature towards an intermediate temperature. This is due to the heat sink drawing heat from the computer chip toward its fins, where a fan blows cooler air through the fins to remove the excess heat from the fins. Thus the heat sink was effective in cooling the computer chip to its maximum temperature of 70 °C.

Part 2: Design Heat Sink with a Much Smaller Fan

Before the CFD analysis begin, the calculations for the fan velocity, and fin modifications are presented below for the following investigation:

$$U_{new} = \frac{2}{3}U_{Q7} = \frac{2}{3}\left(2.4\frac{m}{s}\right) = 1.6\ m/s$$

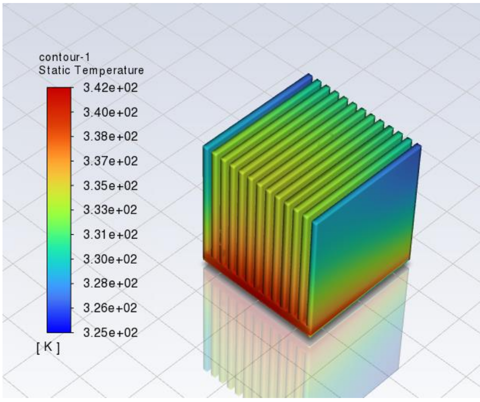
$$t_{new} = \frac{W_{old}}{25} = \frac{46.64\ mm}{25} = 1.8656\ mm$$

$$H_{max,part2} = 1.2H_{part1} = 1.2(38.16\ mm) = 45.792\ mm$$

Number of fins increased to 13 fins.

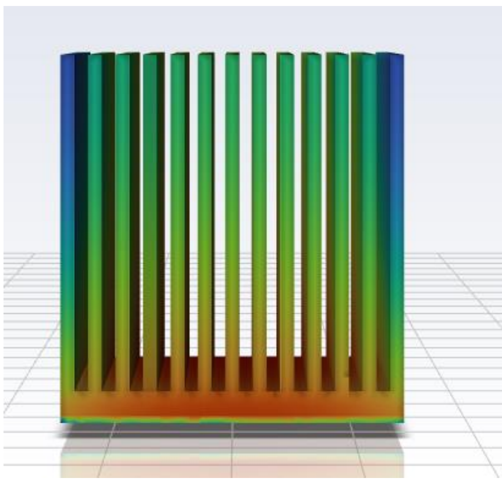
(Part 2):

10. The following set of images display the temperature contours for the electronic chip and fins:

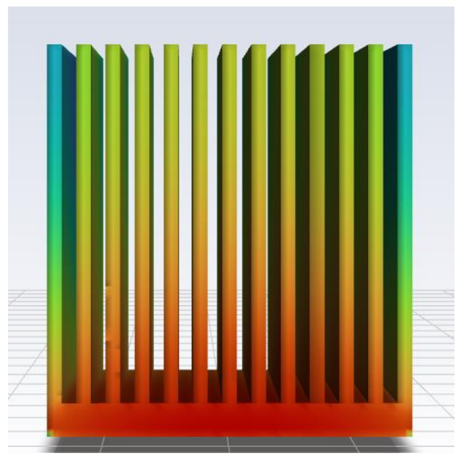


Isometric View

Front View



Right View (Inlet View)



Left View (Outlet View)

Figure 11: Temperature Contours for the Electronic Chip and Fins with Modifications

The modifications used in the design of the heat sink are as follows:

- Reduced the fan cooling speed from 2.4 m/s to 1.6 m/s
- Reduced the fins thickness from 4.24 mm to 1.8656 mm
- Increased the fins height from 38.16 mm to 45.792 mm
- Increased the number of fins from 6 to 13 fins

With the following modifications, the temperature was reduced to 341.74042 K which is around 68.59042°C. See the image below for the maximum temperature of the electronic chip:

```
Calculation complete.

                                 Max
                  Static Temperature                      [K]
-------------------------------- --------------------
                part_2-computerchip             341.74042
                    ---------------- --------------------
                                 Net             341.74042
```

Figure 12: Maximum Temperate of Electronic Chip with Modifications

As shown in figure 11 increasing the number of fins, reducing the thickness of the fins and increasing the height of the fins has improved in reducing the temperature of the electronic chip with reduced fan velocity from the previous heat sink design (compare with figure 10). Increasing the number of fins results in increased amount of surface area to allow for more heat energy to be dissipated when cooler air passes through the fins. Additionally, increasing the height of fins increases the surface area of the heat sink which allows more heat to dissipate from the electronic chip. Reducing the thickness of the heat sink allowed for more fin spacing and additional fins in order to provide adequate air flow through the fins (increasing convection heat transfer). Also reducing the thickness of the fins improves heat conduction from the electronic chip to the fins enhancing the heat transfer. Enhancing the heat transfer allows for increased quantity of thermal energy to be dissipated from the electronic chip due to the cooler air passing through the fins and dissipating the excess heat. Thus, reducing fin thickness, increasing number of fins, and increasing fin height will improve the heat transfer from the electronic chip to the fins which then dissipates the excess heat to the cooler air utilizing forced convection resulting in a reduced temperature on the electronic chip.