CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The reason of defect or mostly shrinkage of plastic parts produced by the injection molding was due to uneven cooling channel in the mould itself. Uneven cooling distribution from the cooling channel cause uneven heat loss from the parts. The technician and engineer often struggled to find the optimum parameters. A lot of time being wasted just to find the optimum parameters that will create least defect. All the parameters here refer to injection pressure and speed, holding time and pressure, part temperature etc.

1.2 Objectives

The Objectives for this project are:

- To compare the different cross-sectional cooling channels for better heat dissipation
- To select the new cross sectional cooling channels for better heat dissipation

1.3 Background of Study

Injection molding (British English: **moulding**) is a manufacturing process for producing parts from thermoplastic materials. Material is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the mold cavity. After a product is designed, usually by an industrial designer or an engineer, molds are made by a mold maker (or toolmaker) from metal, usually either steel or aluminium, and precision-machined to form the features of the desired part. Injection molding is widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars. Injection molding is the most common method of production, with some commonly made items including bottle caps and outdoor furniture.

The basic injection cycle is as follows: Mold close – injection carriage forward – inject plastic – metering – carriage retract – mold open – eject part(s) Some machines are run by electric motors instead of hydraulics or a combination of both. The water-cooling channels that assist in cooling the mold and the heated plastic solidifies into the part. Improper cooling can result in distorted molding. The cycle is completed when the mold opens and the part is ejected with the assistance of ejector pins within the mold.

The cooling time is dependent greatly on the configuration of the cooling channel system that is used to remove heat from the injection mould. A reduction in the time spent on cooling the part before it is ejected would drastically increase the production rate and also reduce the costs. Normally, the cross-sectional of cooling channels is circular in injection molding. However, the Author tries to study the better cross-sectional of cooling channels injection molding for better heat dissipation has been called ‘D shape’.

1.4 Injection Molding Machine

Injection molding machines consist of a material hopper, an injection ram or screw-type plunger, and a heating unit. They are also known as presses, they hold the molds in which the components are shaped. Presses are rated by tonnage, which expresses the amount of clamping force that the machine can exert. This force keeps the mold closed during the injection process. Tonnage can vary from less than 5 tons to 6000 tons, with the higher figures used in comparatively few manufacturing operations. The required force is determined by the material used and the size of the part, larger parts require higher clamping force

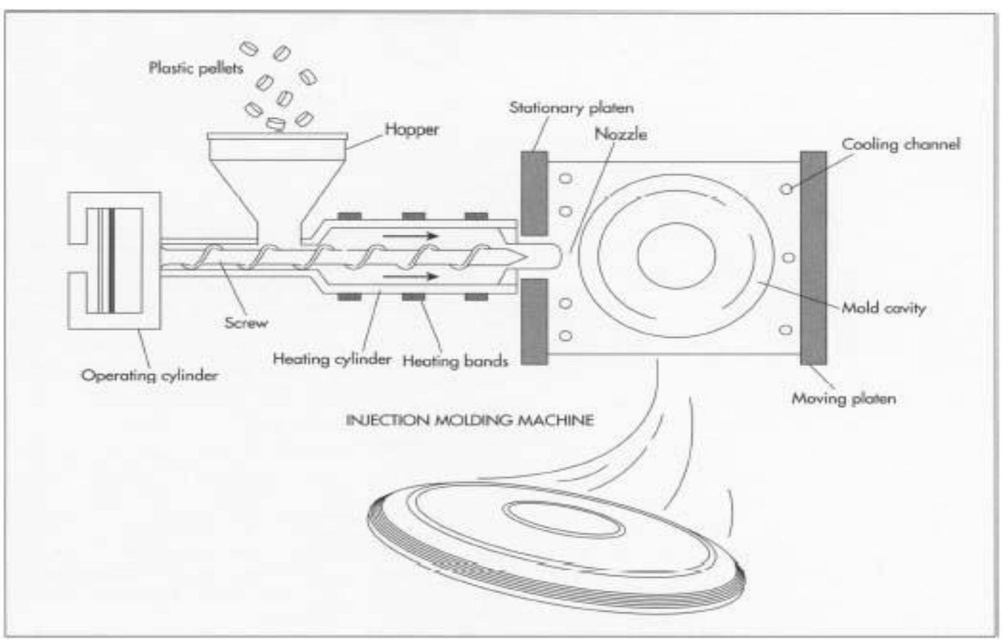


Figure 1.1: The process schematic of injection molding

CHAPTER 2
LITERATURE REVIEW

2.1 Heat Transfer

The heat transfer system has considerable influence on the cycle time and therefore on the efficiency on the whole process. Good process efficiency depends on the heat transfer of the mold. The heat transfer system has to provide both sufficient cooling efficiency and uniform cooling. The heat transfer has to be high enough to carry away the heat of the product in the cavity rapidly.

It is very important that the heat flow and temperature be uniform, so the channels for the heat transfer medium must be arranged such that there is an approximately uniform temperature profile along the cavity wall. The main parameters influencing the uniformity of the wall temperature are the distance of the cooling channels from the wall (*a* in Fig. 2.1) and the distance from one heat channels to the next (*b* in Fig. 2.1). With increasing *a* and decreasing distance *b* the temperature profile become more uniform

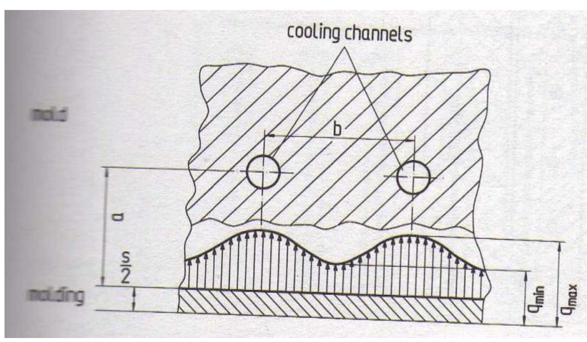


Figure 2.1: Heat flow profile

2.2 Heat Conduction

Conduction is the transfer of heat by direct contact of particles of matter. Metals (eg. copper, platinum, gold, iron, etc.) are usually the best conductors of thermal energy. This is due to the way that metals are chemically bonded: metallic bonds (as opposed to covalent or ionic bonds) have free-moving electrons which are able to transfer of thermal energy rapidly through the metal. In physics, thermal conductivity, *k*, is the property of a material that indicates its ability to conduct heat. It appears primarily in Fourier's Law for heat conduction. Figure 2.2 shows the detail of thermal conductivity.

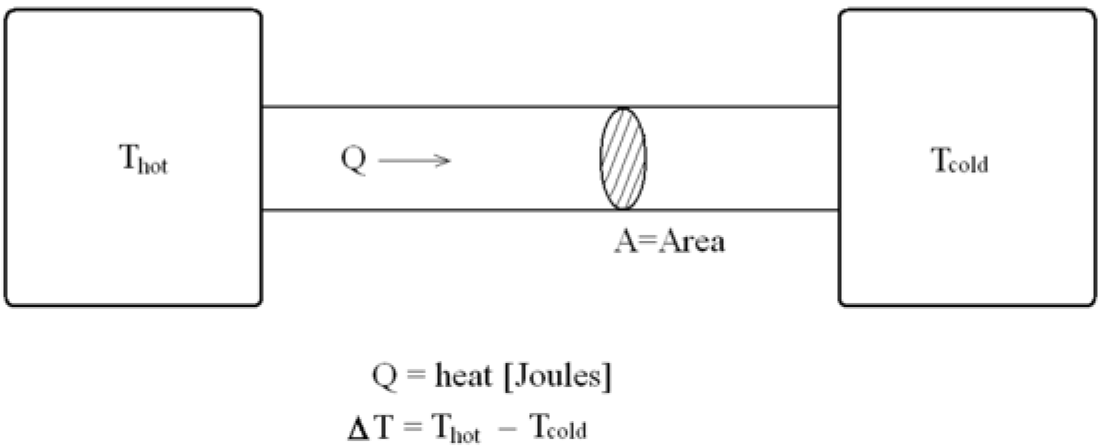


Figure 2.2: The detail of thermal conductivity

We define heat conduction by the formula:

$$H = \frac{\Delta Q}{\Delta t} = k \times A \times \frac{\Delta T}{x}$$

where $\frac{\Delta Q}{\Delta t}$ is the rate of heat flow, *k* is the thermal conductivity, *A* is the total cross sectional area of conducting surface, ΔT is temperature difference and *x* is the thickness of conducting surface separating the two temperatures.

2.3 Heat convection

Convection is the transfer of heat energy between a solid surface and the nearby liquid or gas in motion. As fluid motion goes faster the convective heat transfer increases. The presence of bulk motion of fluid enhances the heat transfer between the solid surface and the fluid. There are two types of Convective Heat Transfer:

- NaturalConvection:is when the fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid

- Forced Convection: is when the fluid is forced to flow over the surface by external source such as fans and pumps

The formula for Rate of Convective Heat Transfer:

$q = hA(T_s - T_b)$

A is the surface area of heat transfer. T_s is the surface temperature and while T_b is the temperature of the fluid at bulk temperature.

2.4 Design rules

The design rules presented here provide some guidelines for attaining proper and efficient mold cooling. Cooling channels should be of standard sizes in order to use standard machine tools, standard fittings, and quick disconnects. Based on the part thickness and volume, the mold designer needs to determine the following design variables when designing a cooling system:

- **Location and size of channels** of cooling channels.
- **Type** of cooling channels.
- **Layout** and connection of cooling channels.
- **Length** of cooling-channel circuits.
- **Flow rate and heat transfer** of coolant.

2.5 Wall Thickness

To maintain an economically acceptable cooling time, excessive wall thickness should be avoided. Required cooling time increases rapidly with wall thickness. This calculation is shown equation below

$$\text{Cooling time} \propto \frac{(\text{Heaviest wall thickness})^2}{(\text{thermal diffusivity of polymer melt})}$$

$$\text{Thermal diffusivity} = \frac{(\text{Thermal conductivity})}{(\text{Density})\,(\text{Specific heat})}$$

In other words, doubling the wall thickness quadruples the cooling time

2.6 Reynolds number and coolant flow

Whether or not the coolant flow is turbulent can be determined by the Reynolds number (Re), as listed in Table 2.1. The Reynolds number is defined as:

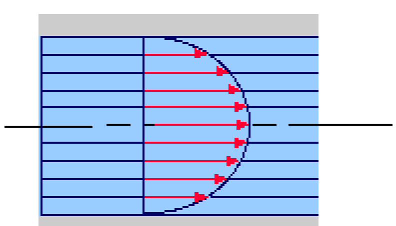
$$\text{Reynolds number (Re)} = \frac{\rho U d}{\eta}$$

Where ρ is the density of the coolant, *U* is the averaged velocity of the coolant, *d* is the diameter of the cooling channel, and η is the dynamic viscosity of the coolant.

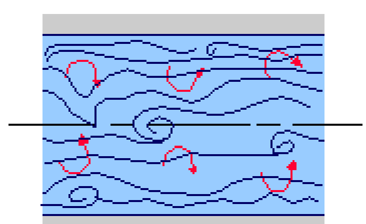
Table 2.1: Coolant flow types and corresponding Reynolds number ranges

Reynolds Number (Re)	Type of Flow
10,000 < Re	Turbulent Flow
2,300 < Re < 10,000	Transition Flow
100 < Re < 2,300	Laminar Flow
Re < 100	Stagnated Flow

The effect of heat transfer increases as the flow of coolant changes from laminar flow to turbulent flow. For laminar flow, heat can be transferred only by means of heat conduction from layer to layer. However, in turbulent flow, the mass transfer in the radial direction enables the heat to be transferred by both conduction and convection. As a result, the efficiency increases dramatically. The diagram below illustrates this concept.



Laminar Flow



Turbulent Flow

Since the increase of heat transfer will diminish as the coolant flow becomes turbulent, there is no need to increase the coolant flow rate when the Reynolds number exceeds 10,000.

Figure 2.3 below illustrates that once the flow becomes turbulent, a higher coolant flow rate brings diminishing returns in improving the heat flow rate or cooling time, while the pressure drop and pumping expenses are drastically increasing.

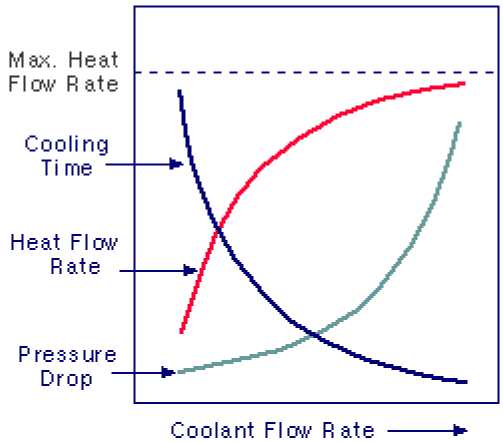


Figure 2.3: The relationship of heat flow rate, coolant flow rate and cooling time

CHAPTER 3

METHODOLOGY

3.1 Methodology

In author project, he has identified some software's that is needed in order to design and simulate the prototype properly. This is important to make sure his progress run smoothly and to avoid error during the simulation.

Software:

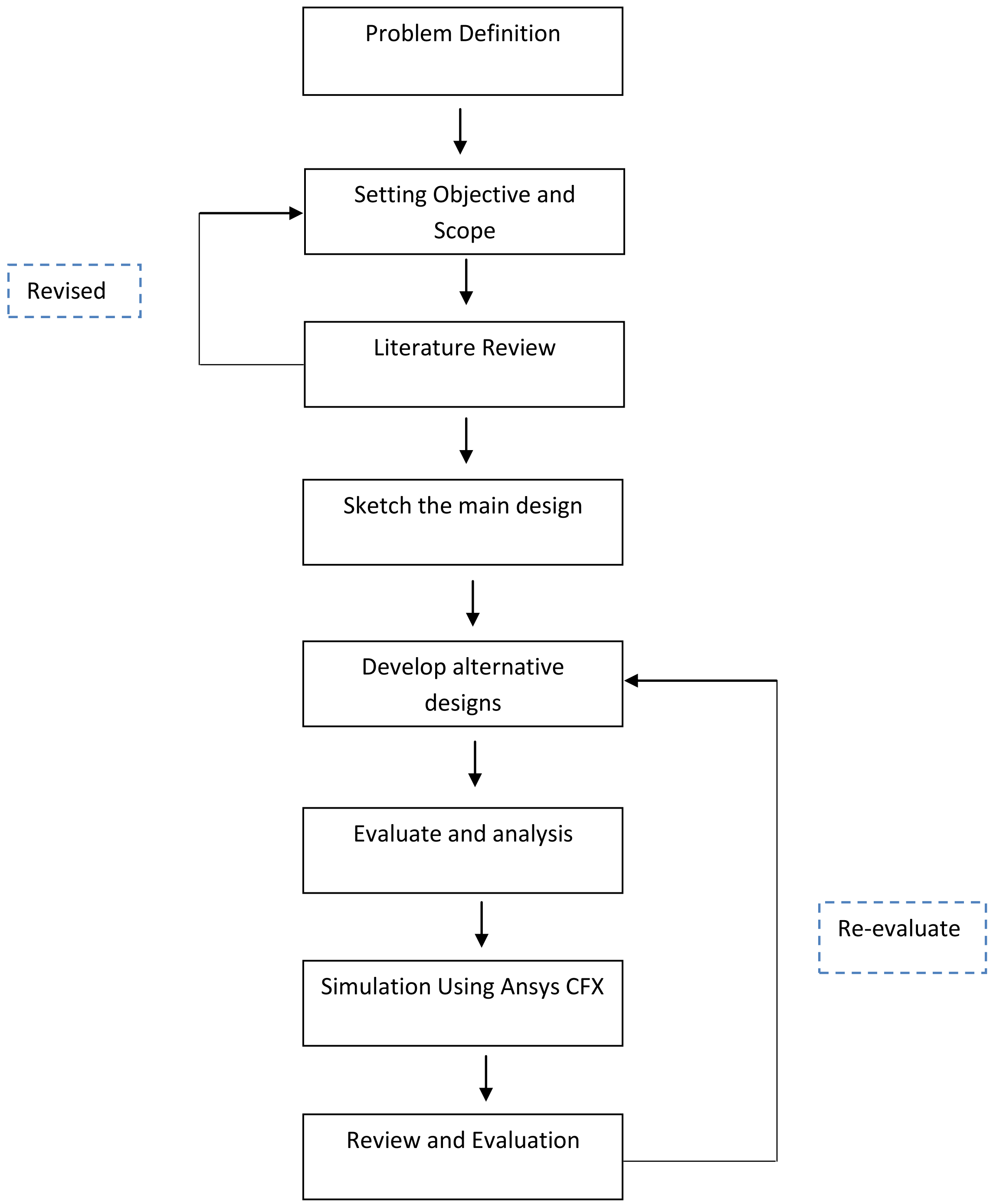
1. Solidwork

   This software is use in designing the prototype in 3D. All the measurement is stated in the technical drawing. This design will be export to Ansys 11.0 for simulation.

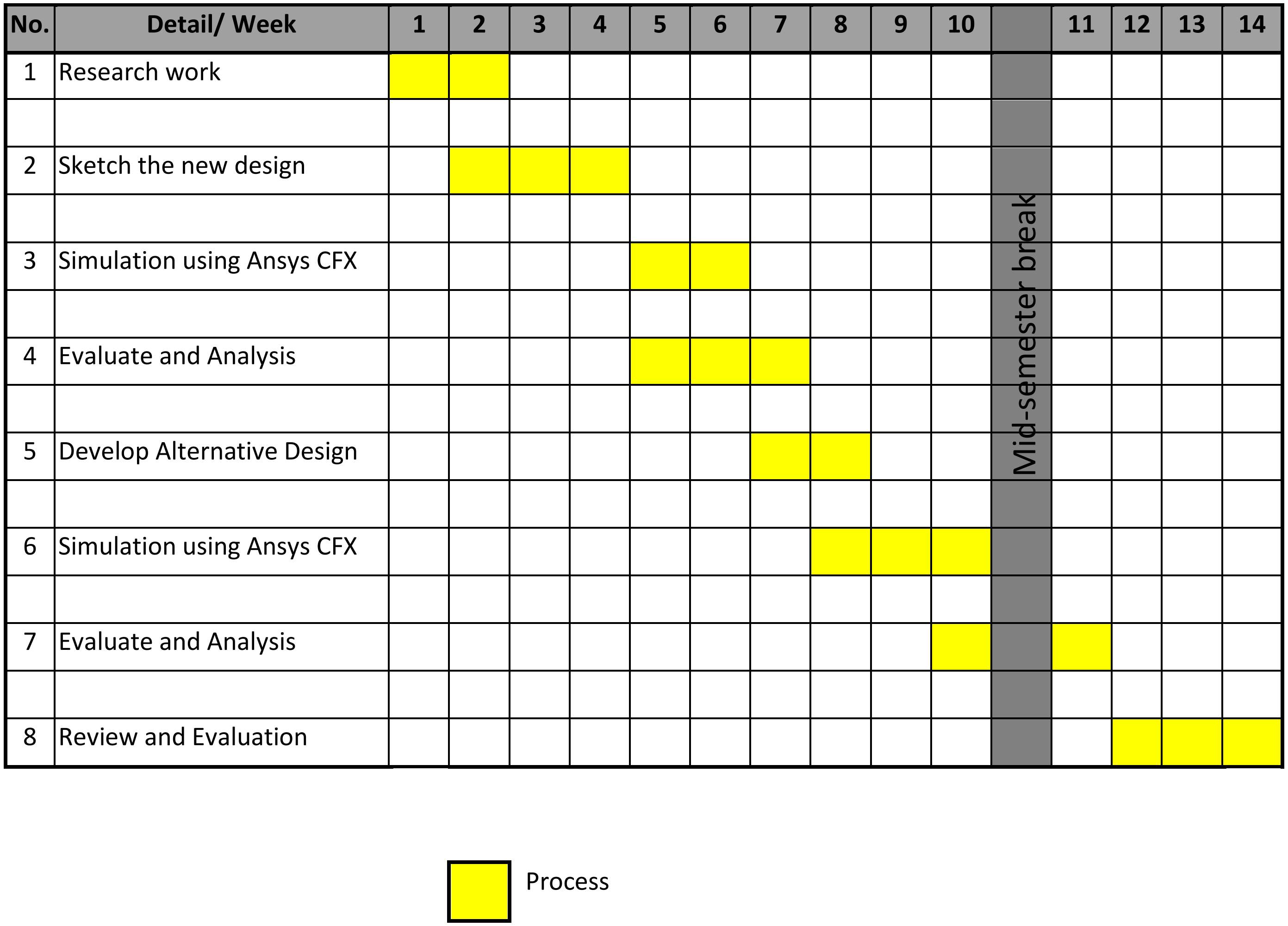
2. Ansys CFX

   CFX is a commercial Computational Fluid Dynamics (CFD) program, used to simulate fluid flow in a variety of applications. The ANSYS CFX product allows engineers to test systems in a virtual environment. The scalable program has been applied to the simulation of water flowing past ship hulls, gas turbine engines (including the compressors, combustion chamber, turbines and afterburners), aircraft aerodynamics, pumps, fans, HVAC systems, mixing vessels, hydrocyclones, vacuum cleaners, and more.

3.2 Project Activities



3.3 Gannt Chart



CHAPTER 4

RESULT & DISCUSSION

4.1 Design & Dimension suggestion

The 3D view for circular, square, 'D' shape, Ellipse Horizontal and Ellipse Vertical cross-sectional cooling channels has been designed using Autocad 2008 software.

- The value of cross-sectional area for each channel is **25 pi** (78.54 mm^2). The designs are below:

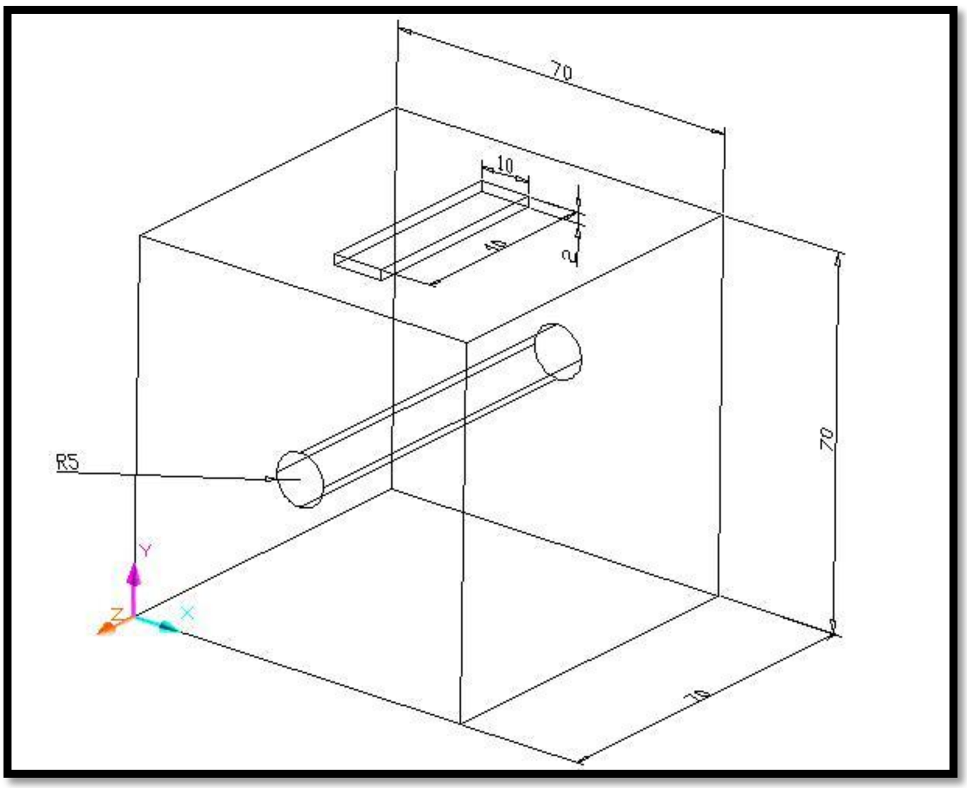


Figure 4.1: 3D view for Dimension of circular shape cross-sectional cooling channels

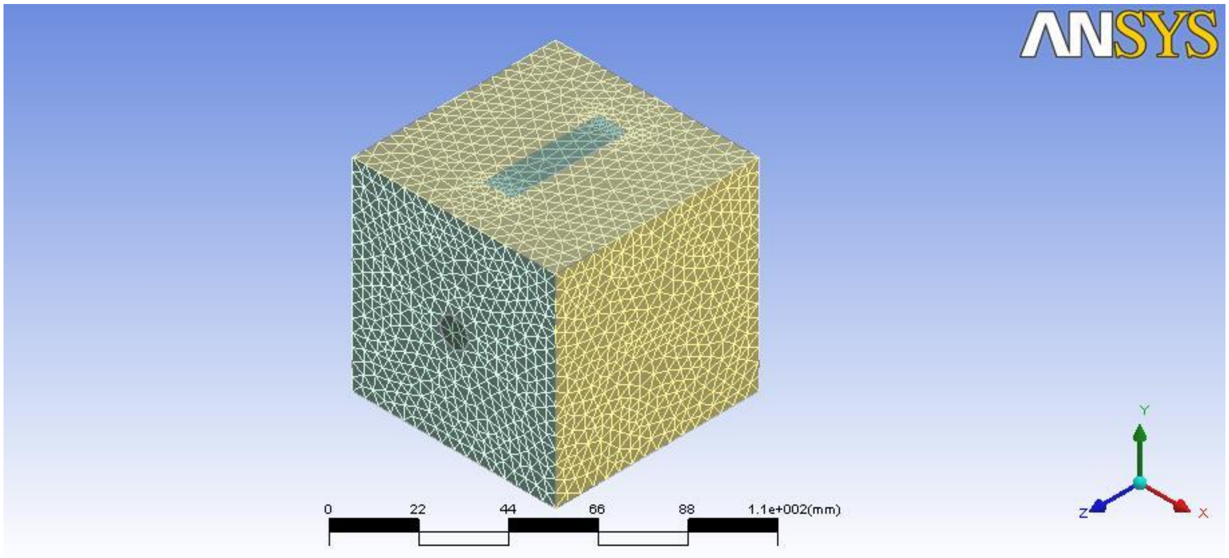


Figure 4.2: 3D view for Meshing of circular shape cross-sectional cooling channels

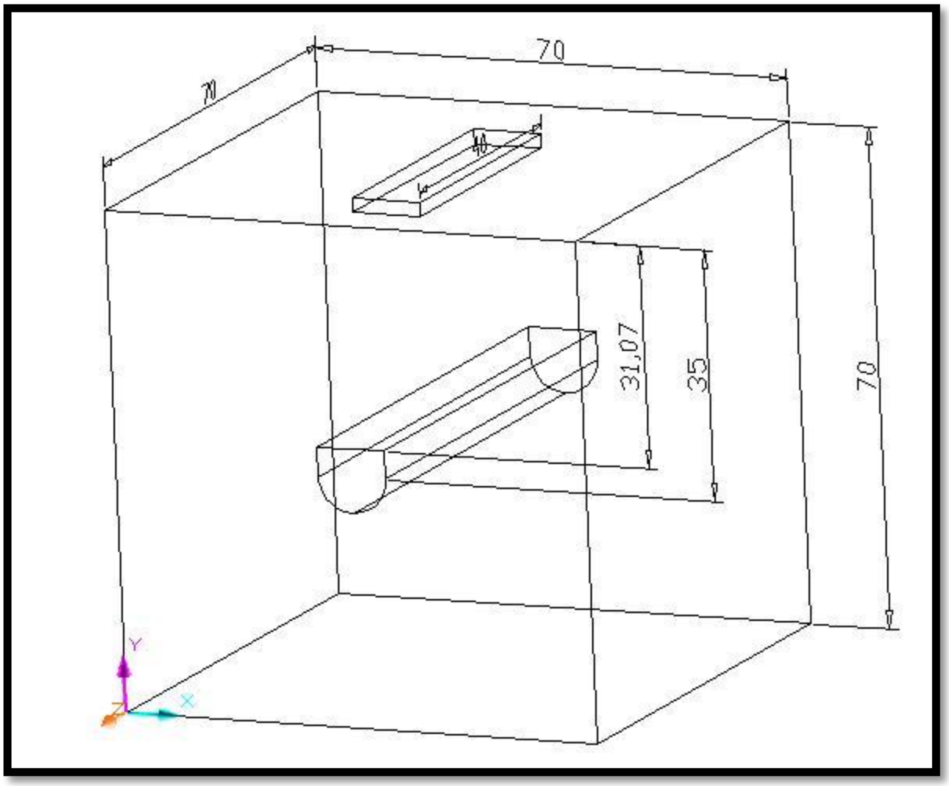


Figure 4.3: 3D view for Dimension of 'D' shape cross-sectional cooling channels

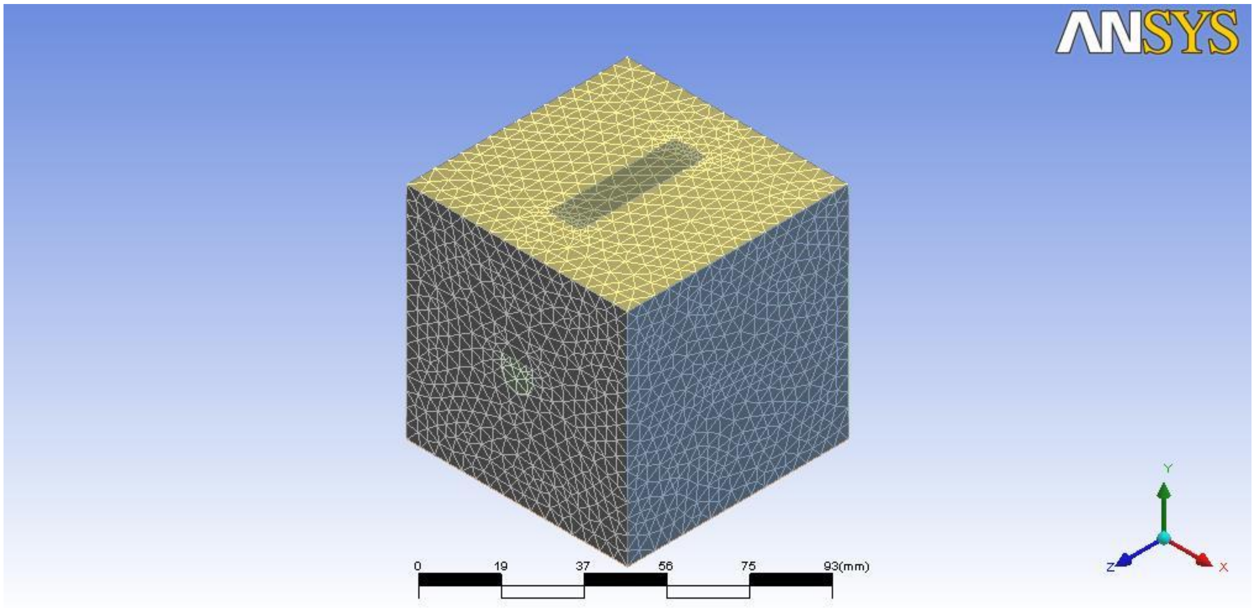


Figure 4.4: 3D view for Meshing of 'D' shape cross-sectional cooling channels

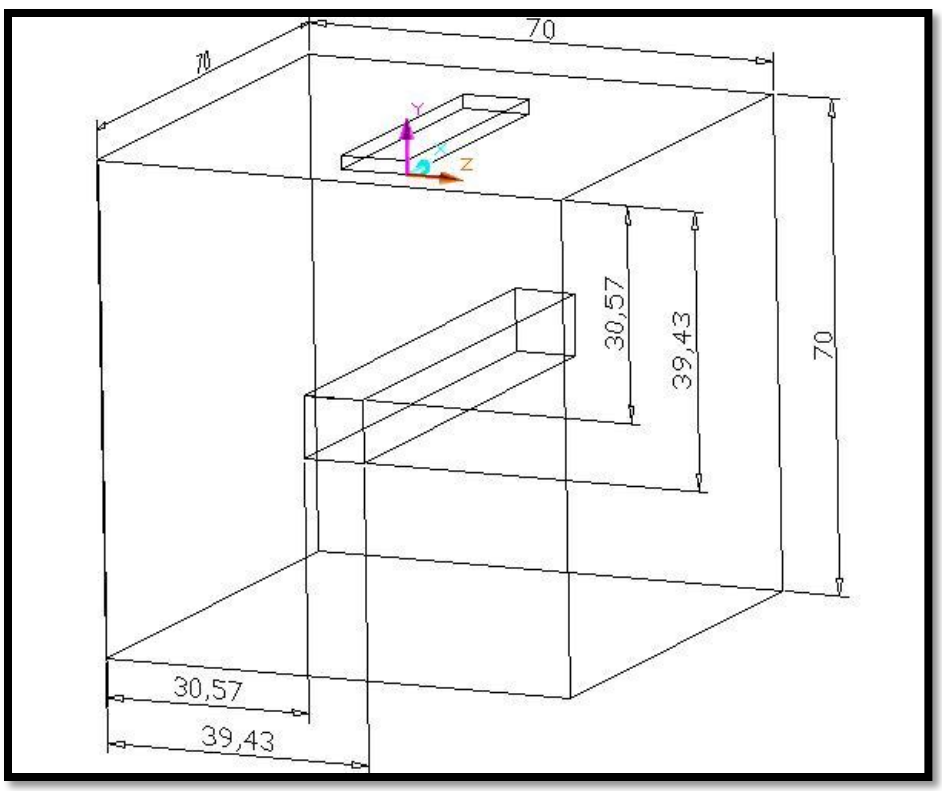


Figure 4.5: 3D view for Dimension of Square shape cross-sectional cooling channels

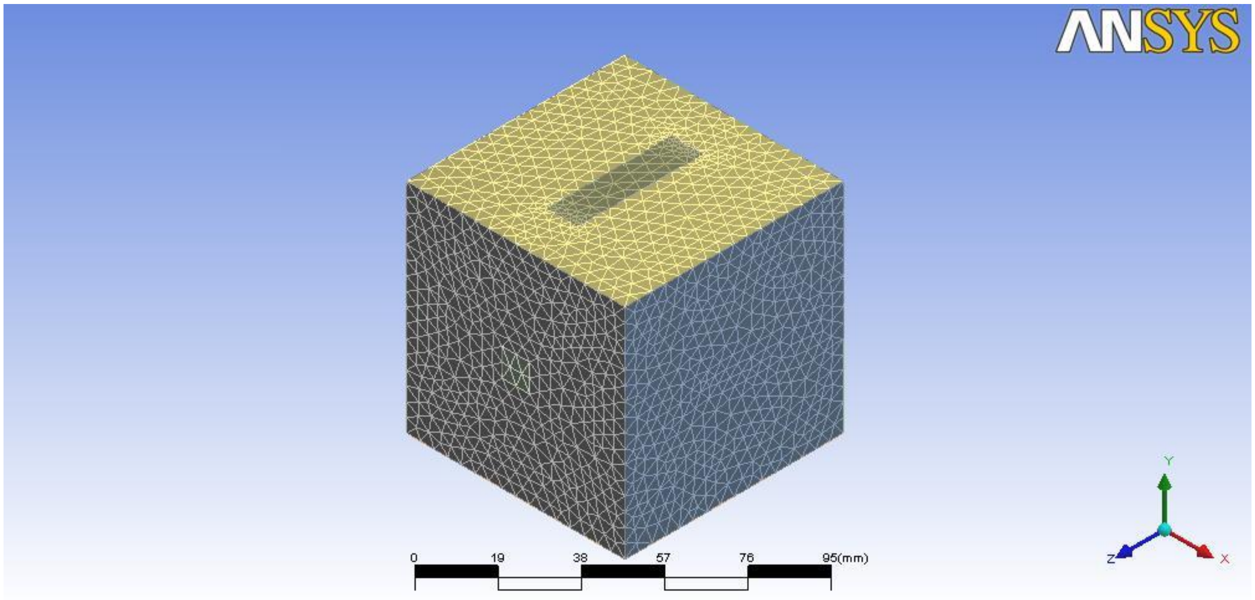


Figure 4.6: 3D view for Meshing of Square shape cross-sectional cooling channels

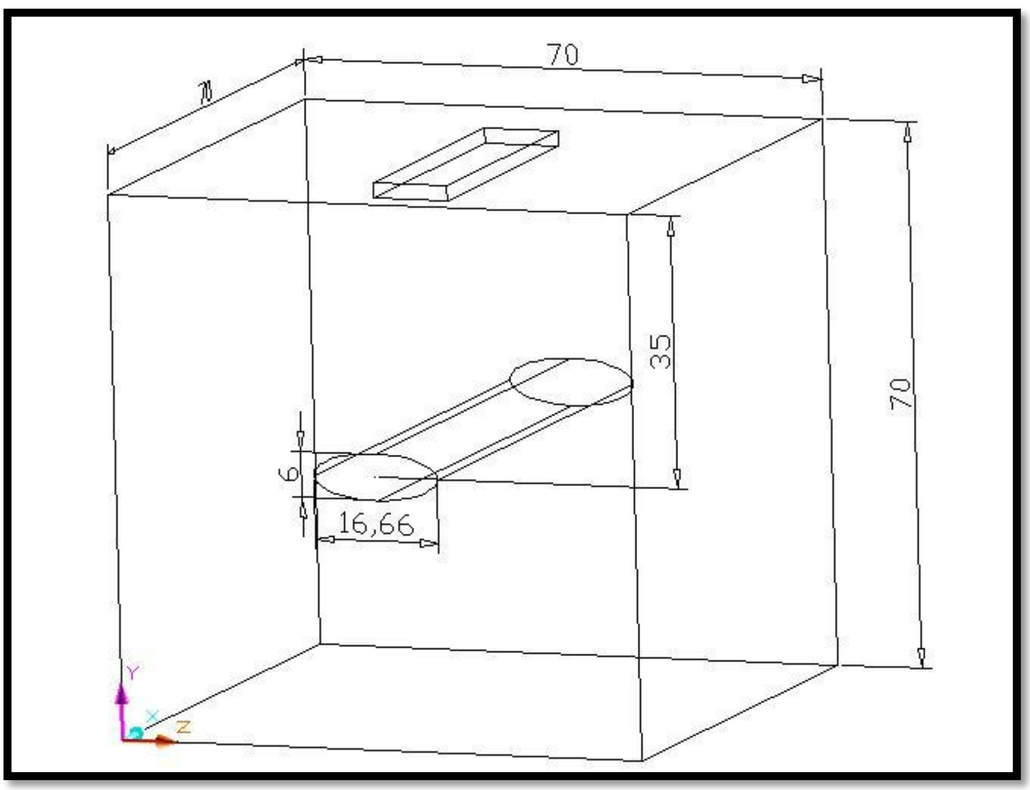


Figure 4.7: 3D view for Dimension of Ellipse Horizontal shape cross-sectional cooling channels

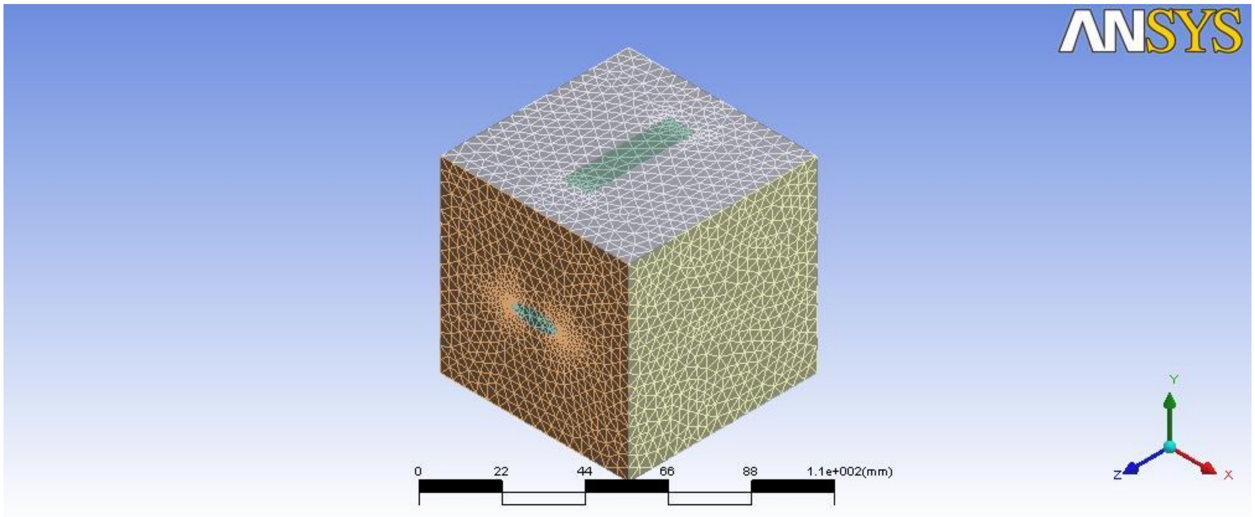


Figure 4.8: 3D view for Meshing of Ellipse Horizontal shape cross-sectional cooling channels

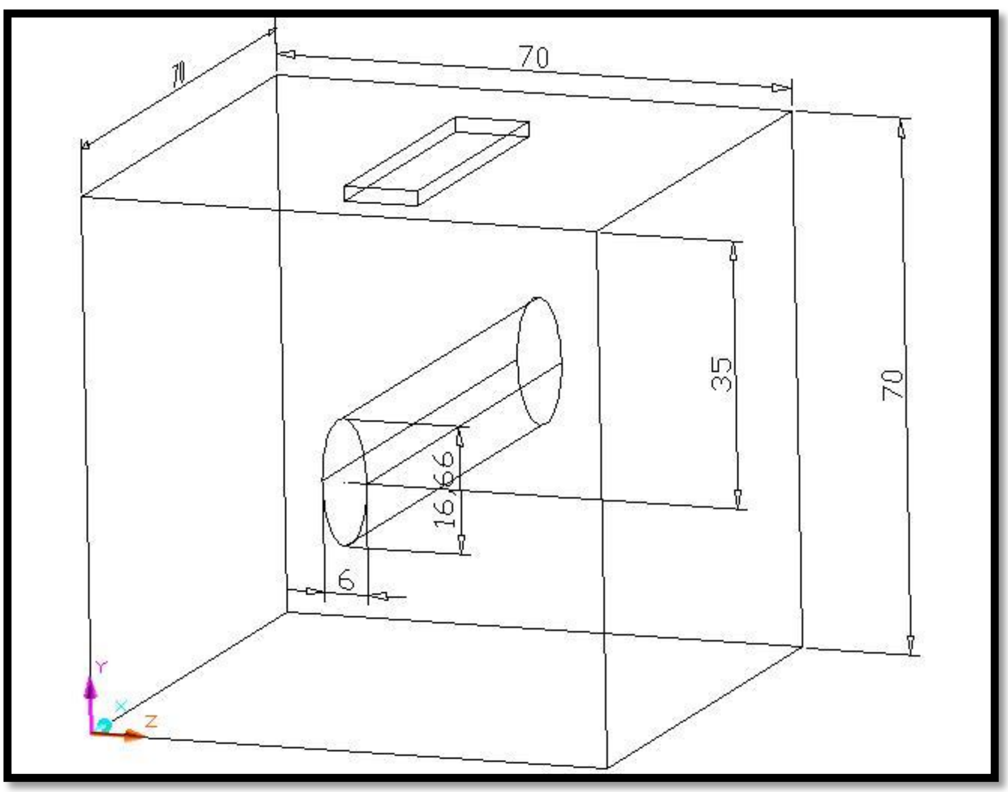


Figure 4.9: 3D view for Dimension of Ellipse Vertical shape cross-sectional cooling channels

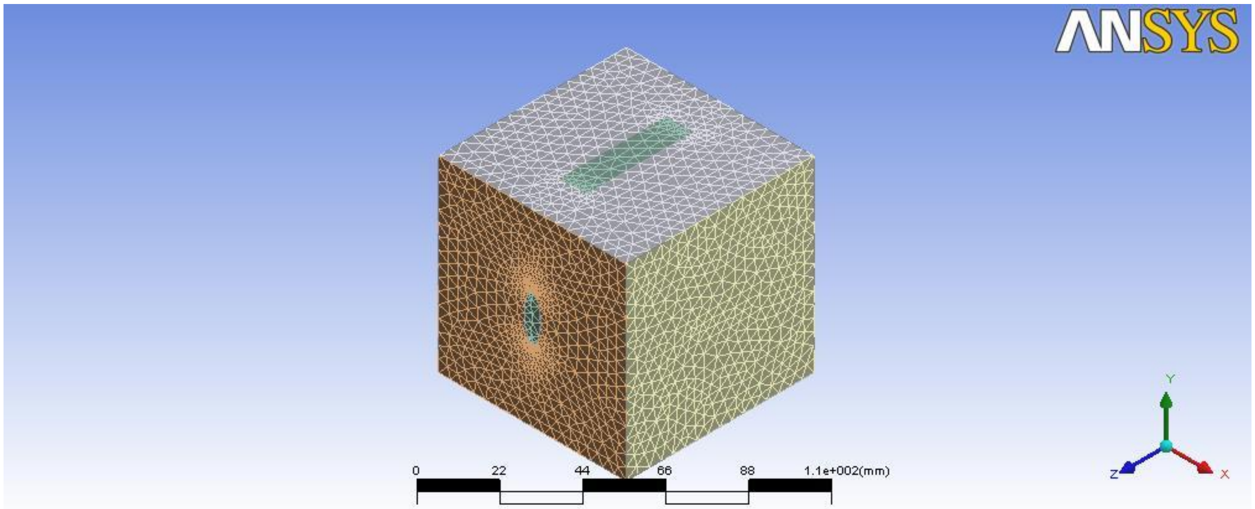


Figure 4.10: 3D view for Meshing of Ellipse Vertical shape cross-sectional cooling channels

➢ The value of cross-sectional area for each channel is **36 pi** (113.10 mm^2). The designs are below:

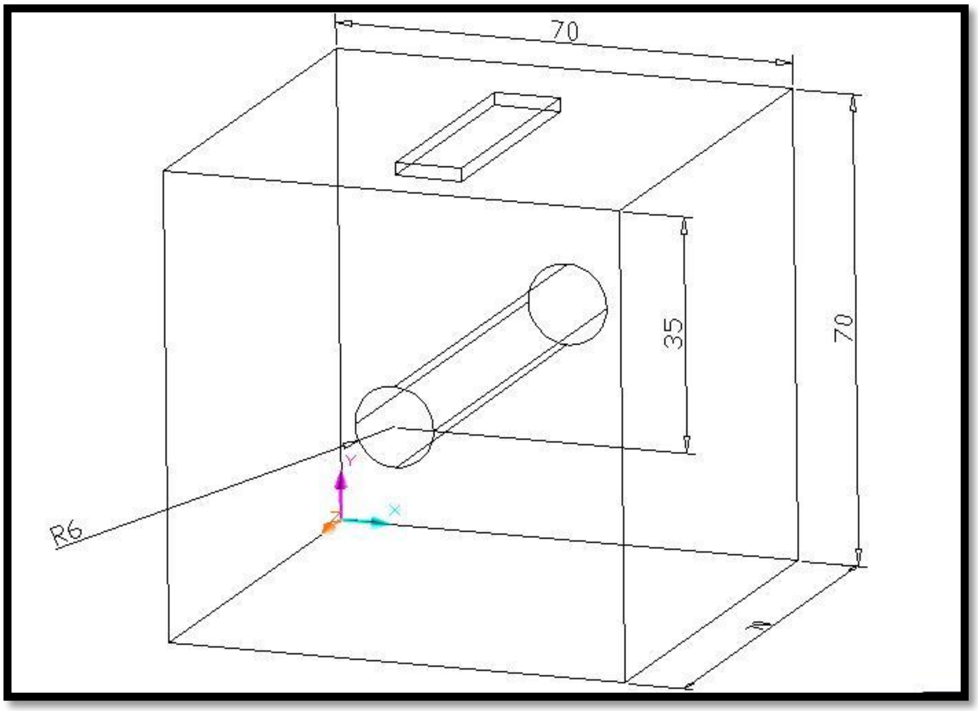


Figure 4.11: 3D view for Dimension of Circular shape cross-sectional cooling channels

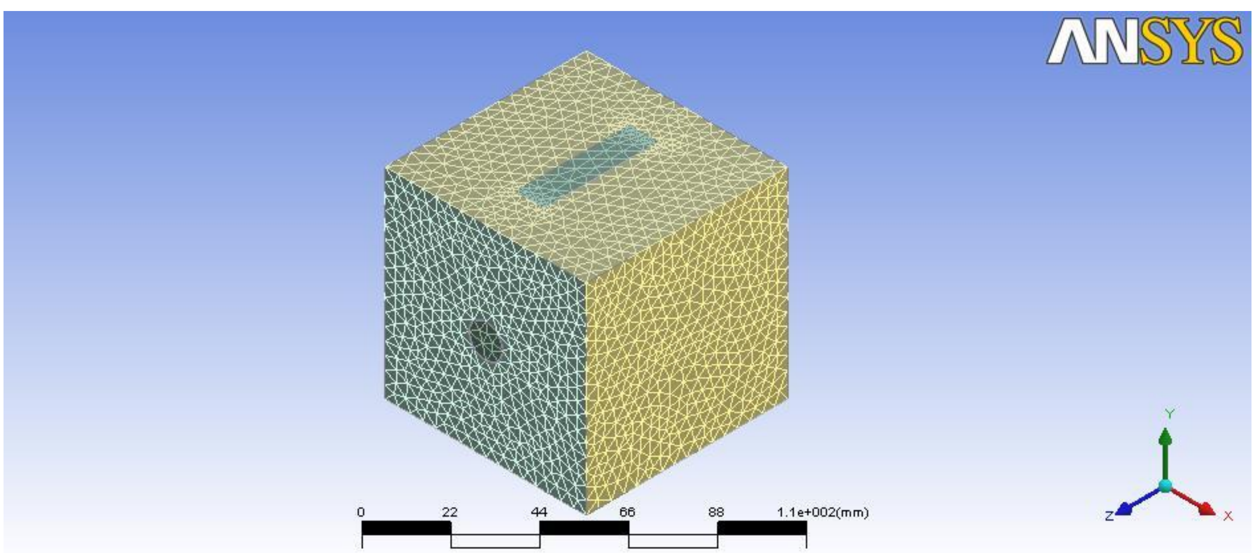


Figure 4.12: 3D view for Meshing of Circular shape cross-sectional cooling channels

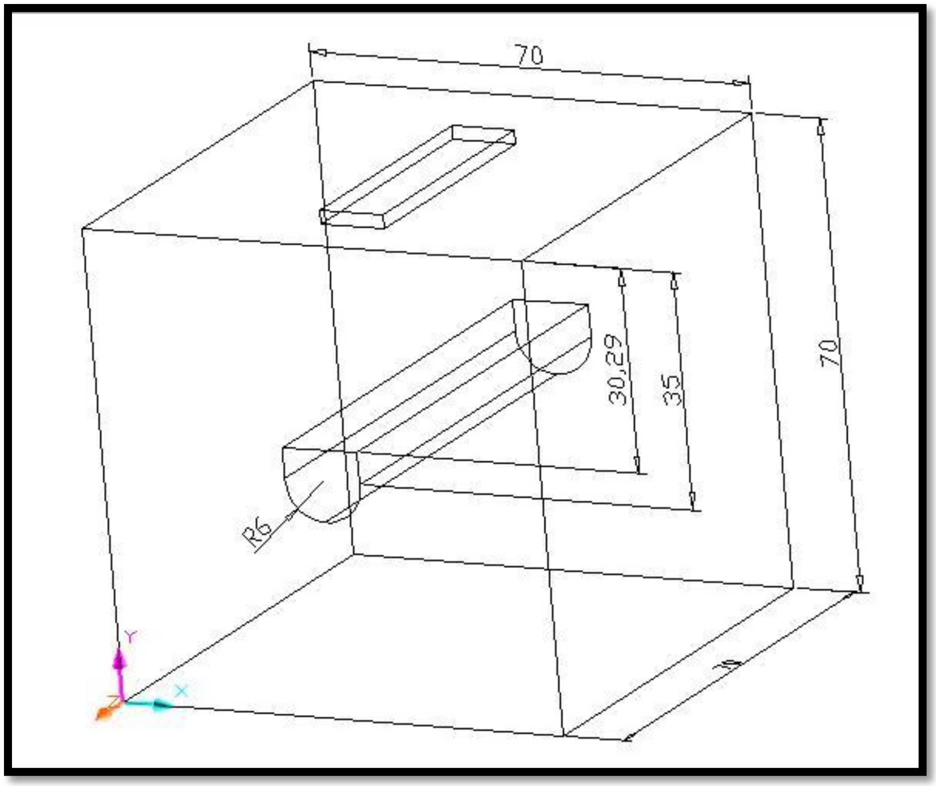


Figure 4.13: 3D view for Dimension of 'D' shape cross-sectional cooling channels

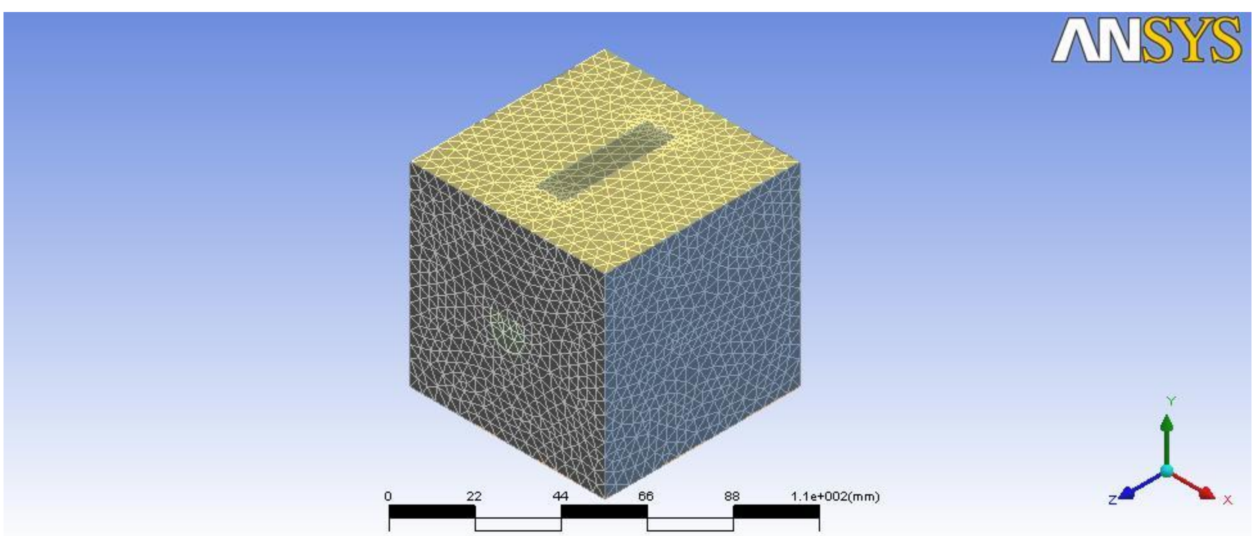


Figure 4.14: 3D view for Meshing of 'D' shape cross-sectional cooling channels

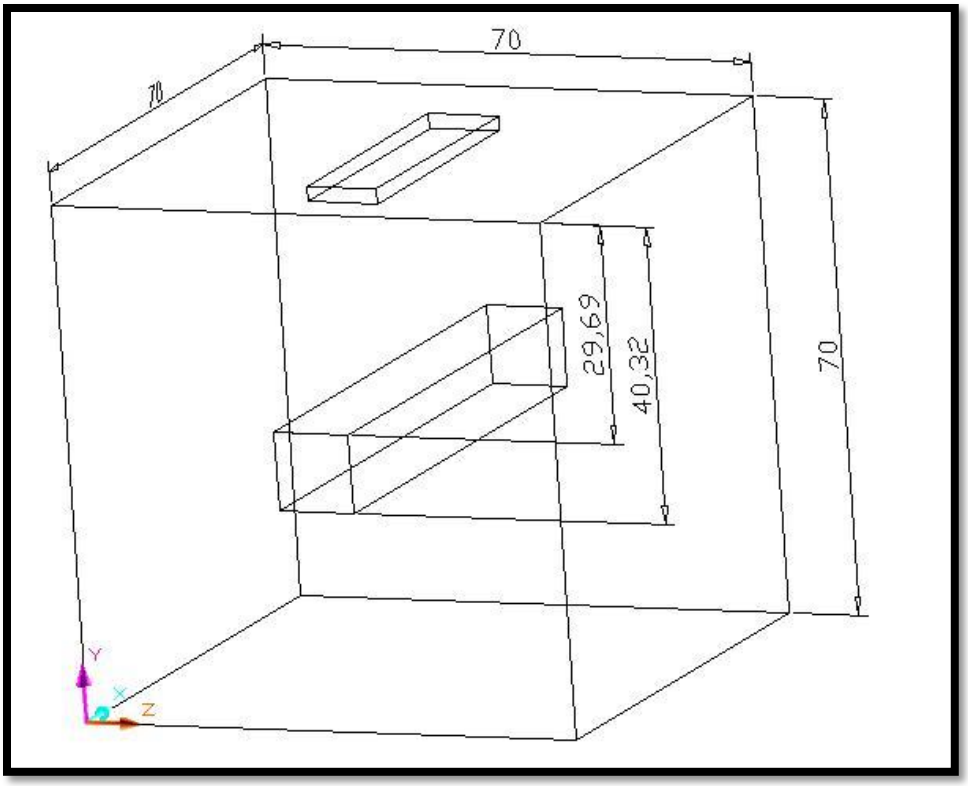


Figure 4.15: 3D view for Dimension of Square shape cross-sectional cooling channels

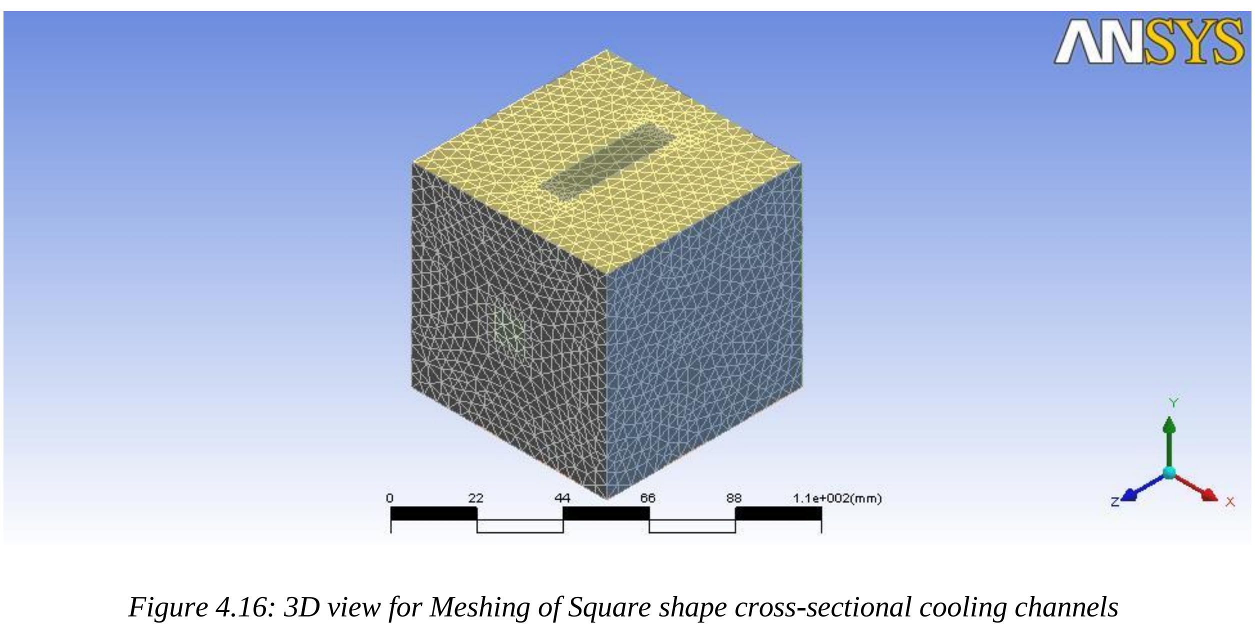


Figure 4.16: 3D view for Meshing of Square shape cross-sectional cooling channels

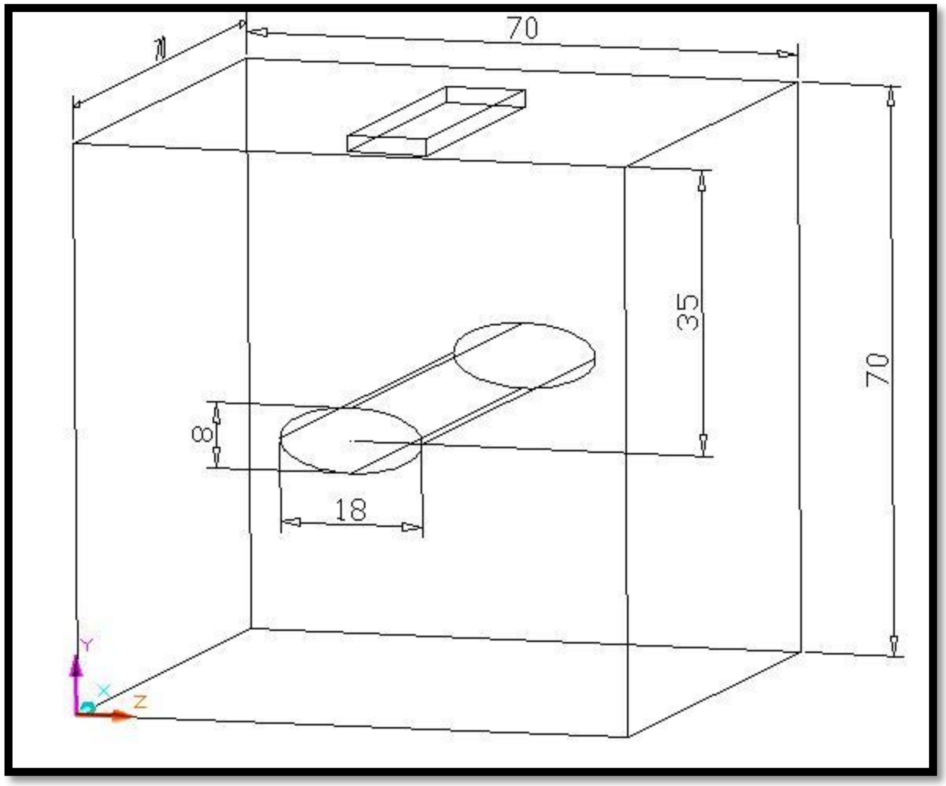


Figure 4.17: 3D view for Dimension of Ellipse Horizontal shape cross-sectional cooling channels

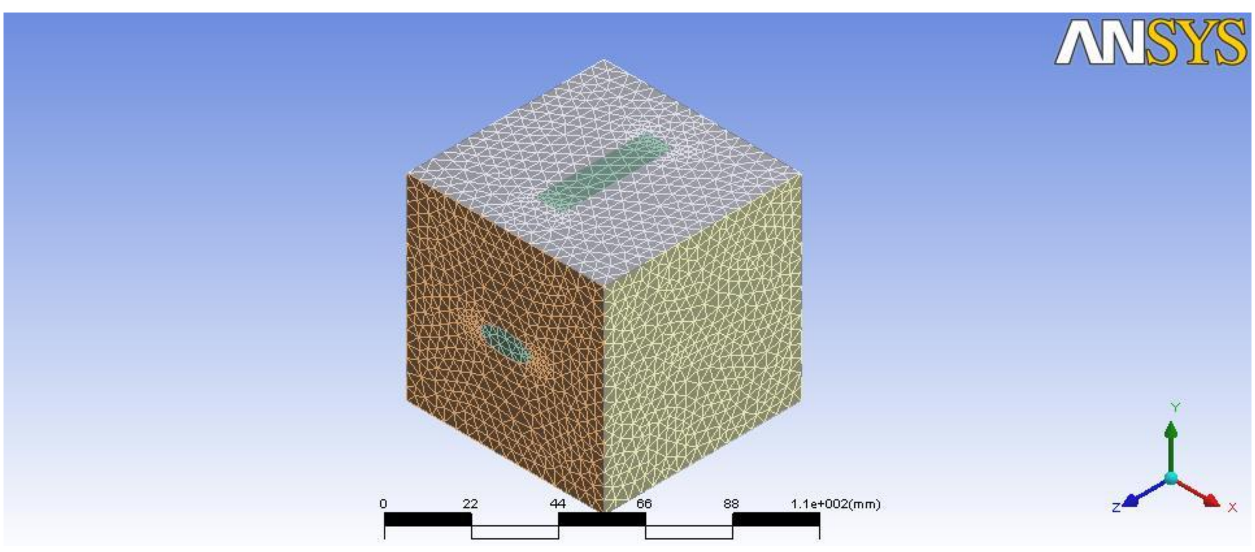


Figure 4.18: 3D view for Meshing of Ellipse Horizontal shape cross-sectional cooling channels

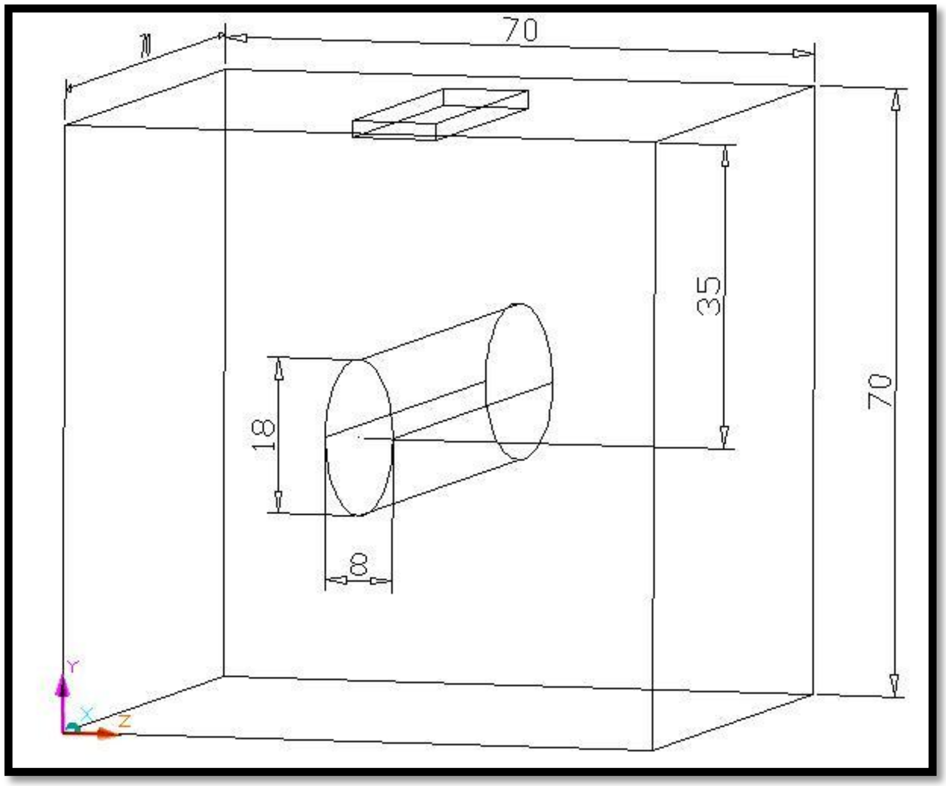


Figure 4.19: 3D view for Dimension of Ellipse Vertical shape cross-sectional cooling channels

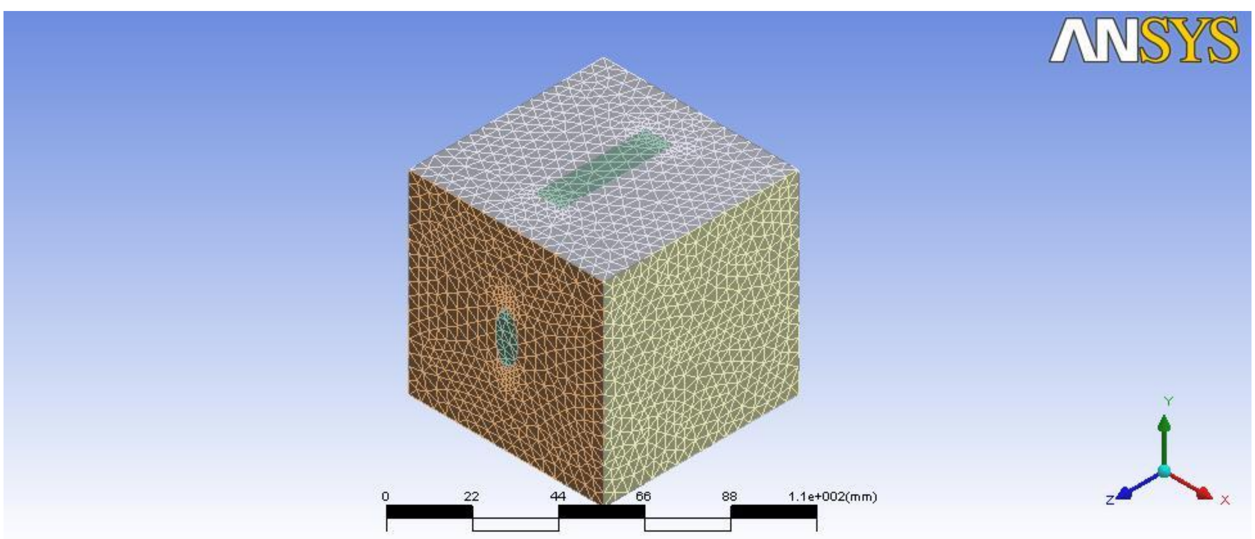


Figure 4.20: 3D view for Meshing of Ellipse Vertical shape cross-sectional cooling channels

➢ The value of cross-sectional area for each channel is **49 pi** (153.94 mm^2). The designs are below:

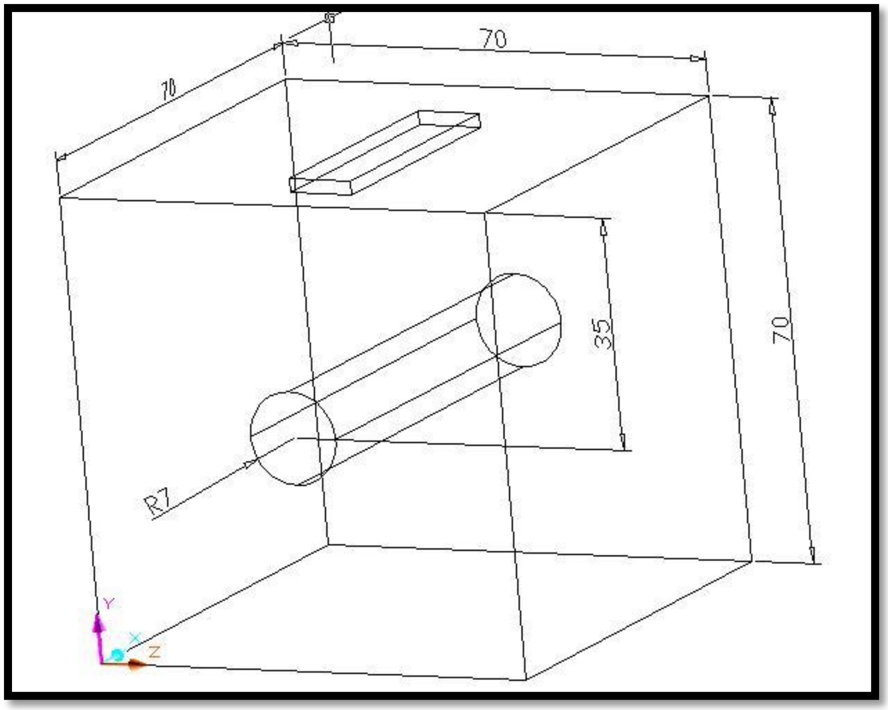


Figure 4.21: 3D view for Dimension of Circular shape cross-sectional cooling channels

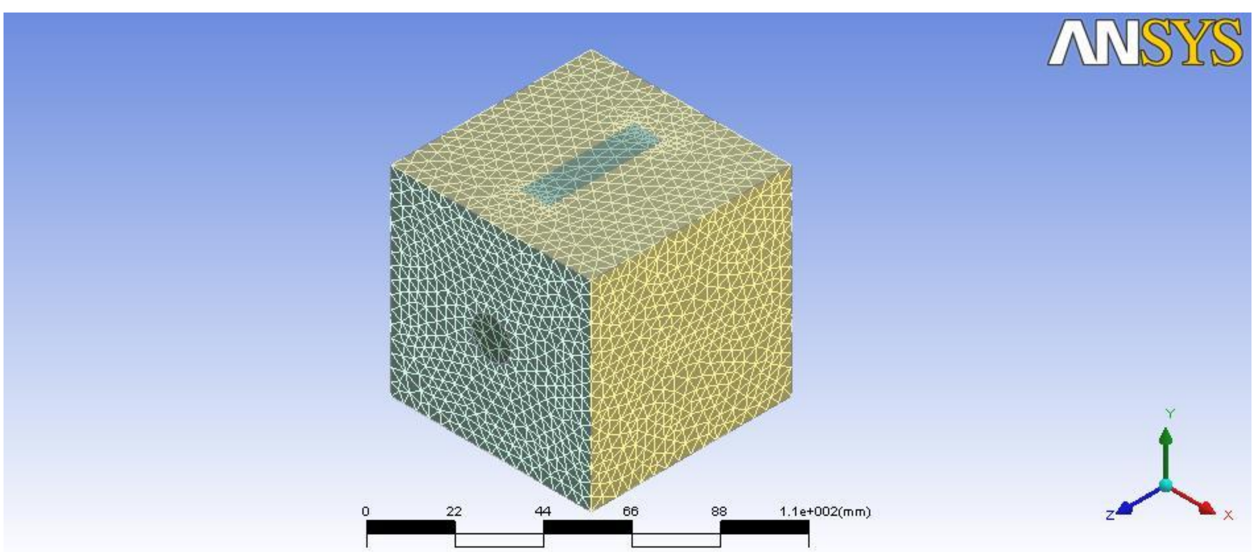


Figure 4.22: 3D view for Meshing of Circular shape cross-sectional cooling channels

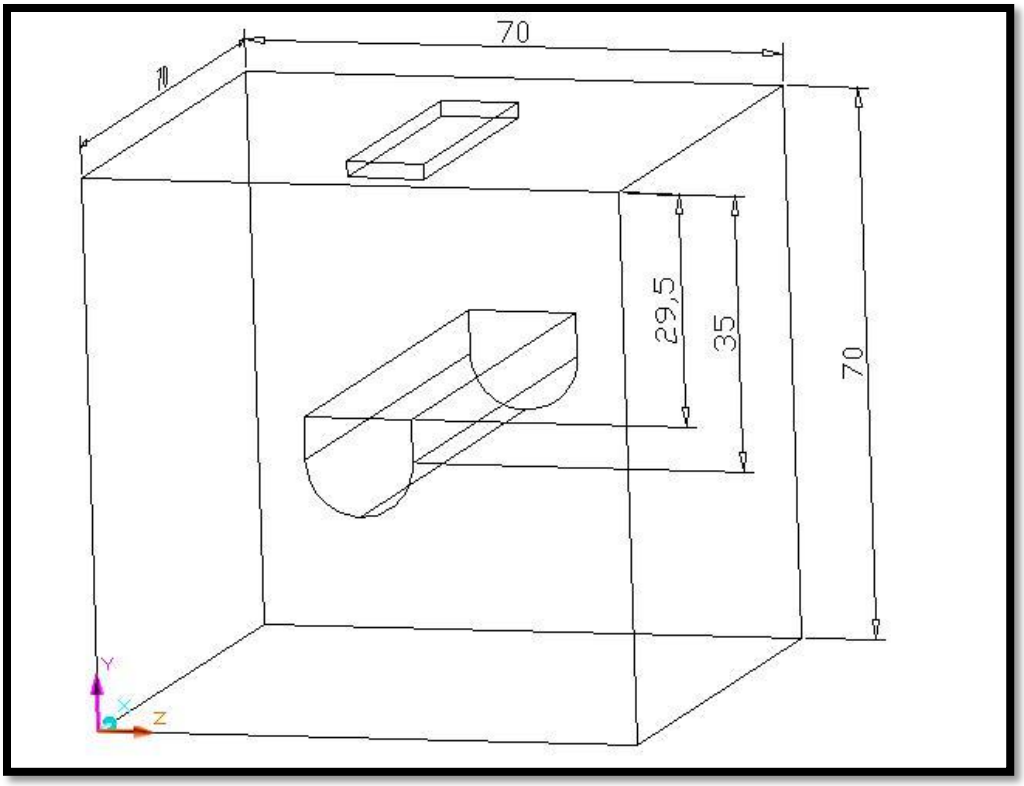


Figure 4.23: 3D view for Dimension of 'D' shape cross-sectional cooling channels

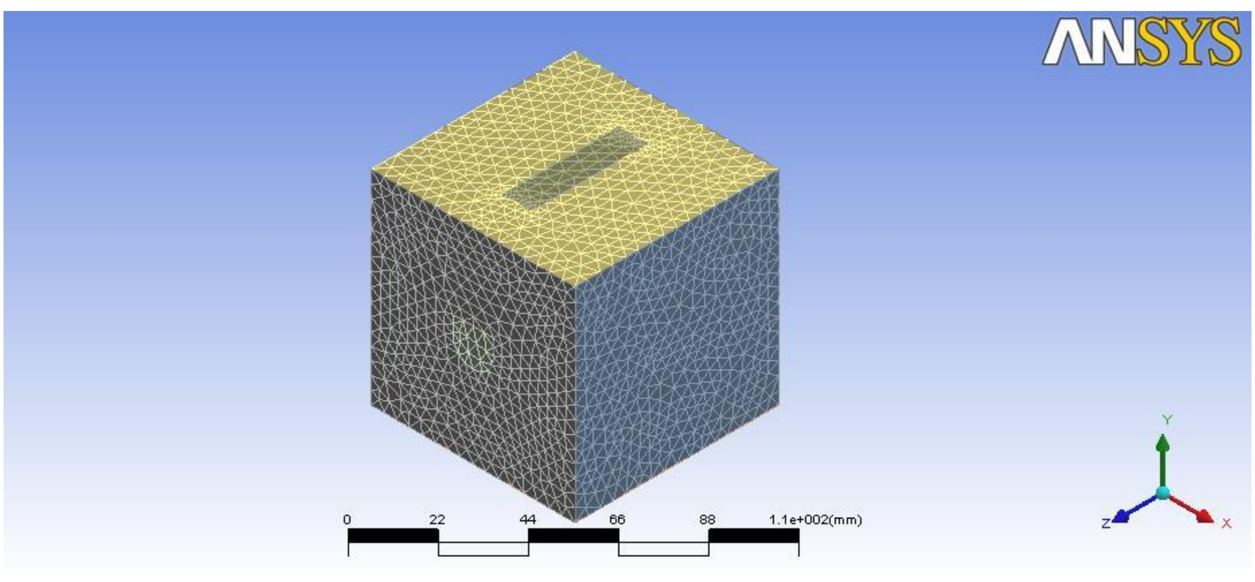


Figure 4.24: 3D view for Meshing of 'D' shape cross-sectional cooling channels

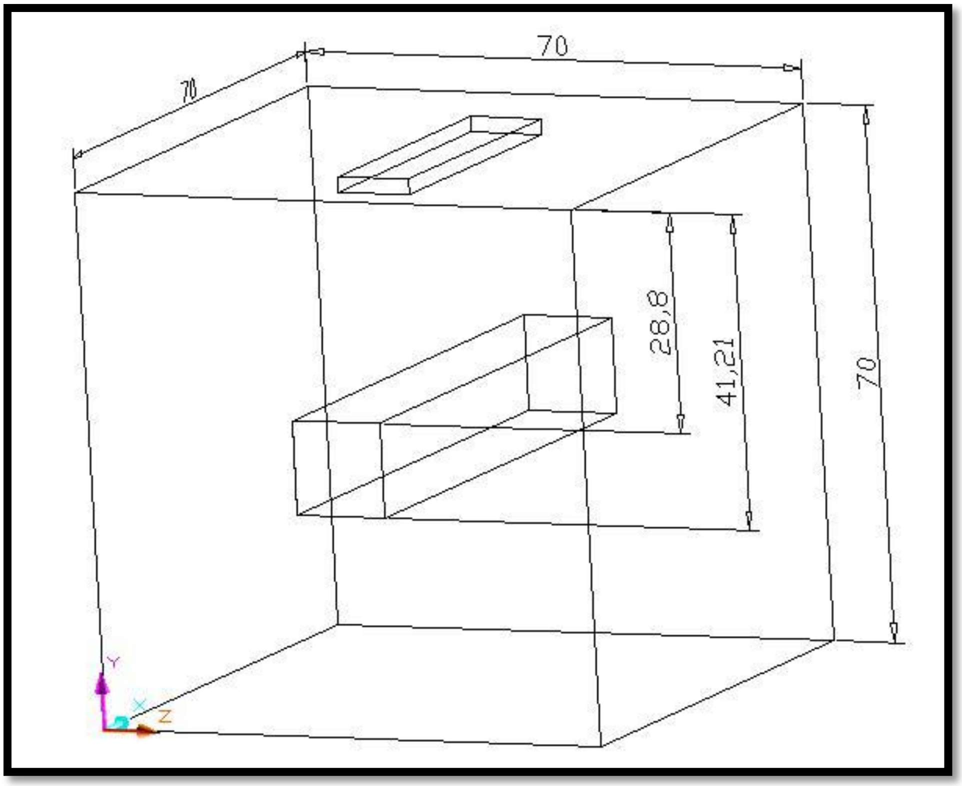


Figure 4.25: 3D view for Dimension of Square shape cross-sectional cooling channels

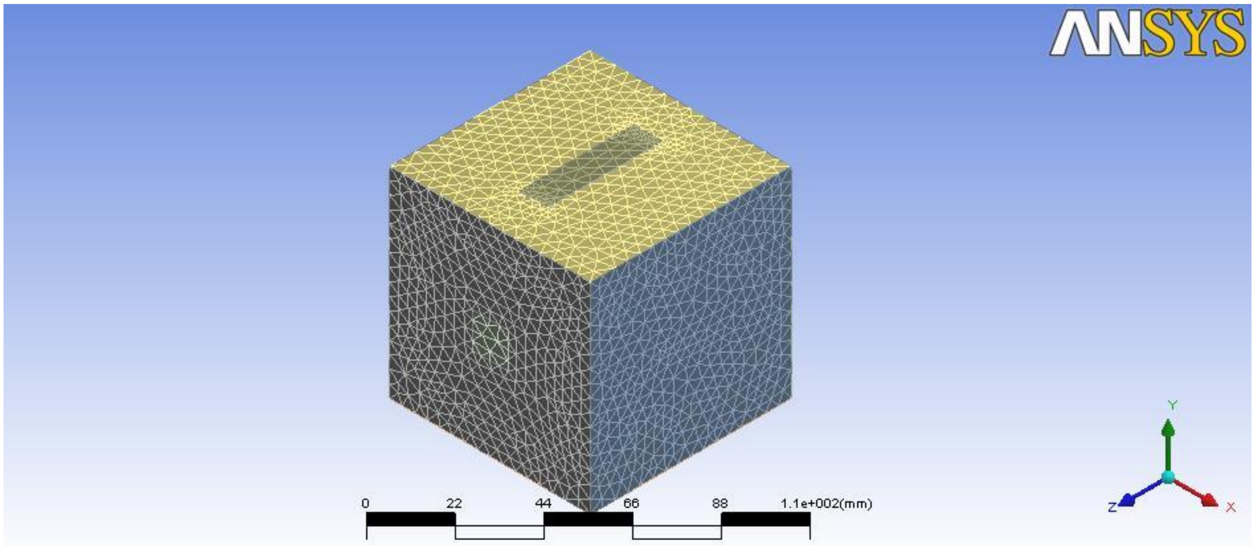


Figure 4.26: 3D view for Meshing of Square shape cross-sectional cooling channels

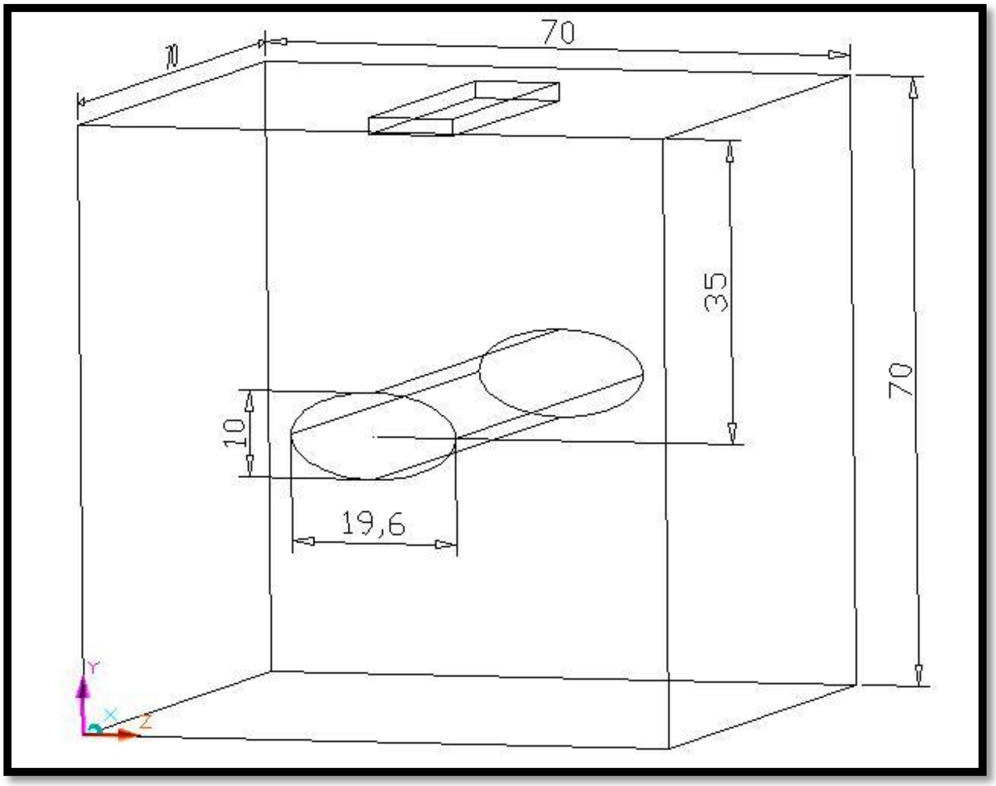


Figure 4.27: 3D view for Dimension of Ellipse Horizontal shape cross-sectional cooling channels

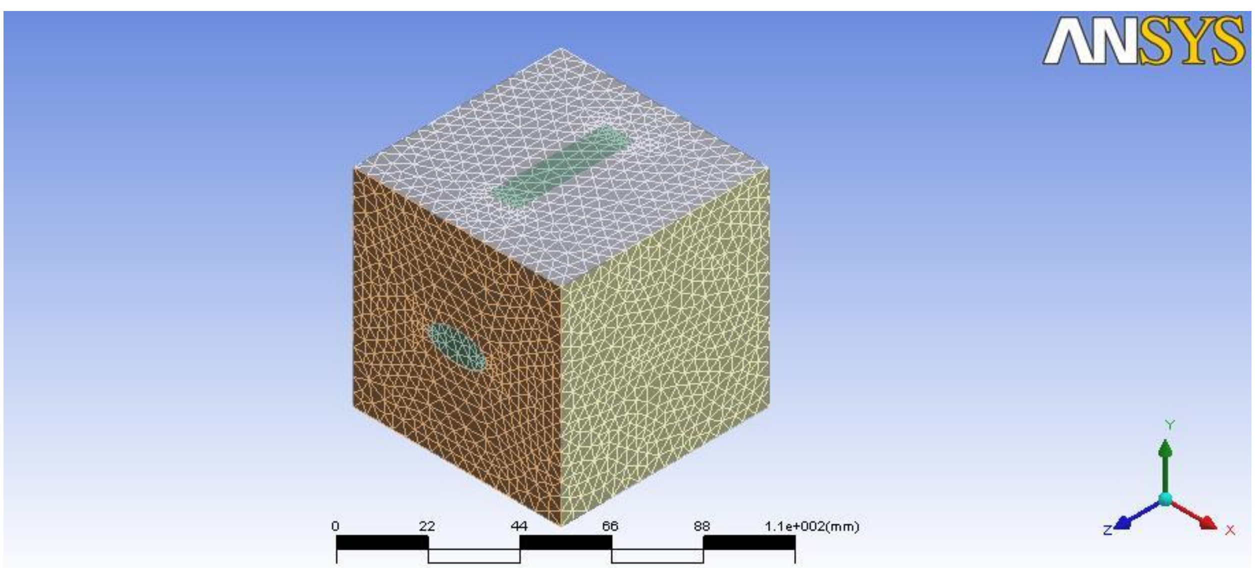


Figure 4.28: 3D view for Meshing of Ellipse Horizontal shape cross-sectional cooling channels

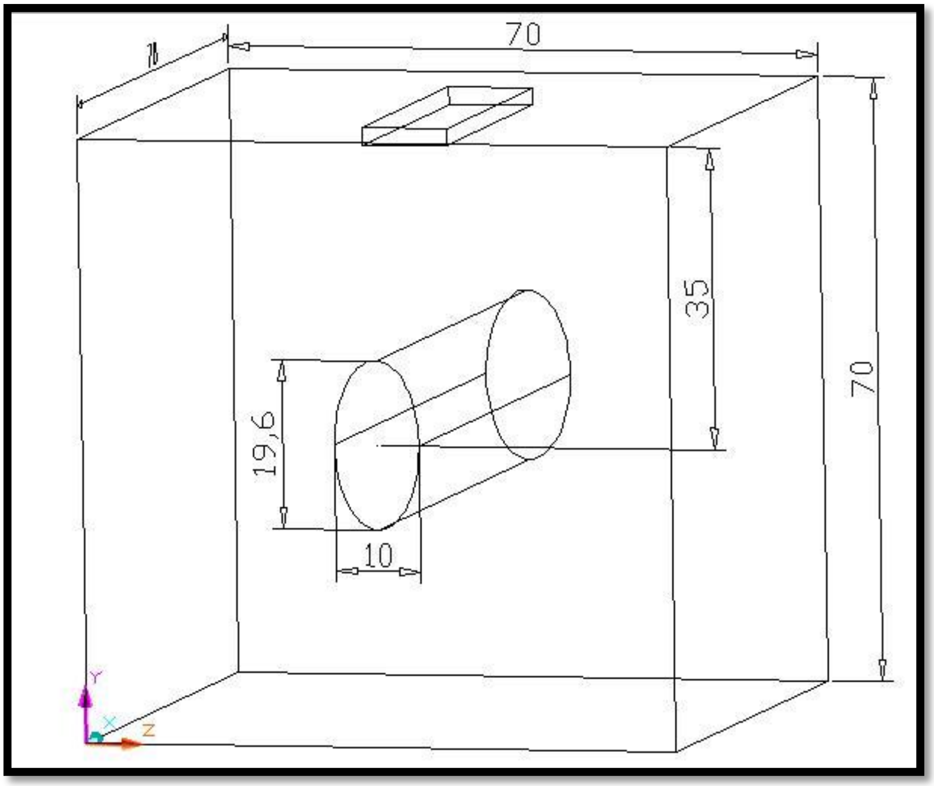


Figure 4.29: 3D view for Dimension of Ellipse Vertical shape cross-sectional cooling channels

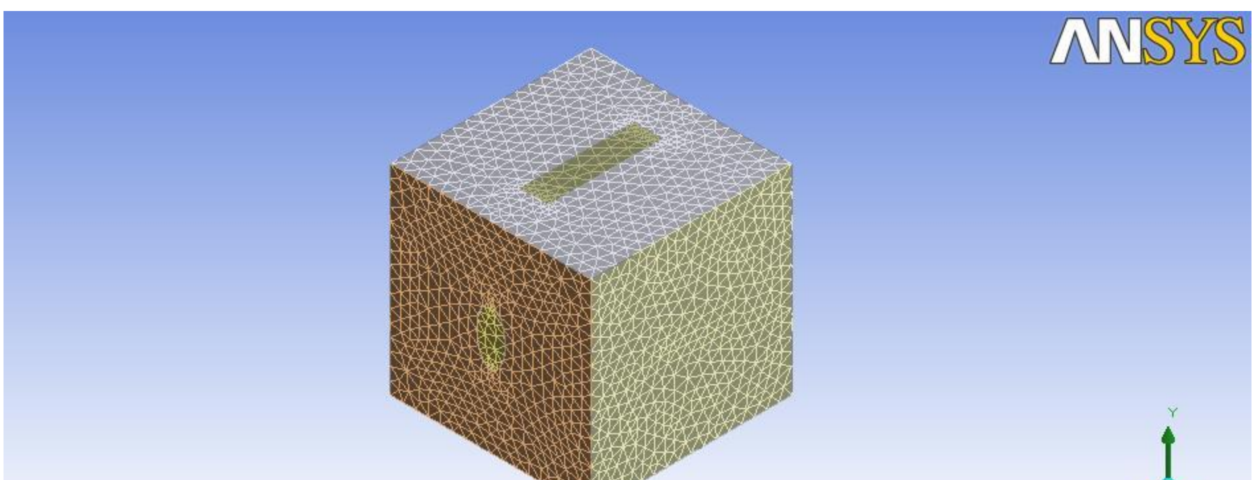


Figure 4.30: 3D view for Meshing of Ellipse Vertical shape cross-sectional cooling channels

4.2 Parameter of Simulation

<u>Block plate</u>

Temperature: 30°C (Room Temperature)

Material: Aluminum

<u>Product</u>

Material: Polystyrene

Temperature: 240°C

<u>Coolant</u>

Material: Water Flow Speed: 0.5 m/s

Temperature: 25°C

4.3 The coordinate for temperature taking during Simulation

After finish the simulation using Ansys CFX Software, the author got the result of temperature of the product. The node is 81 which is situated at 35, 68.5,35 coordinate. The simulation is about 60 seconds. The results are shown below:

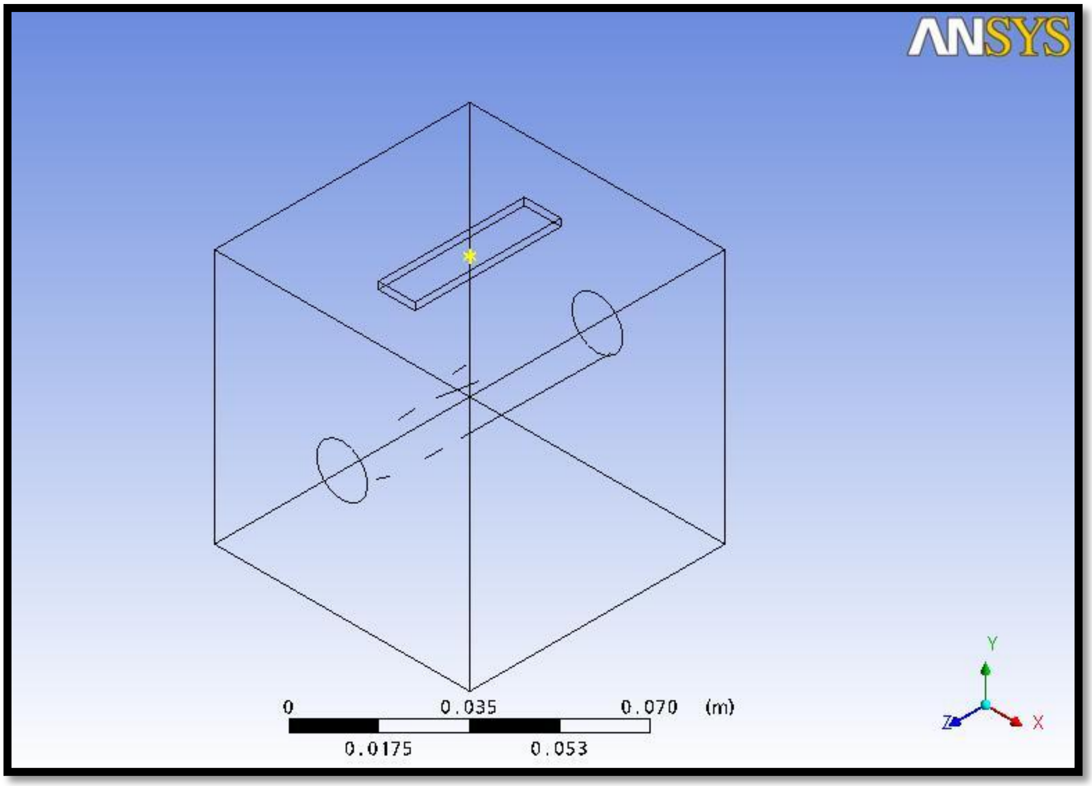


Figure 4.31: The coordinate for taking the temperature during simulation

4.4 Result of Simulation

4.4.1 The area for 25 pi

Circular (see appendix 1)

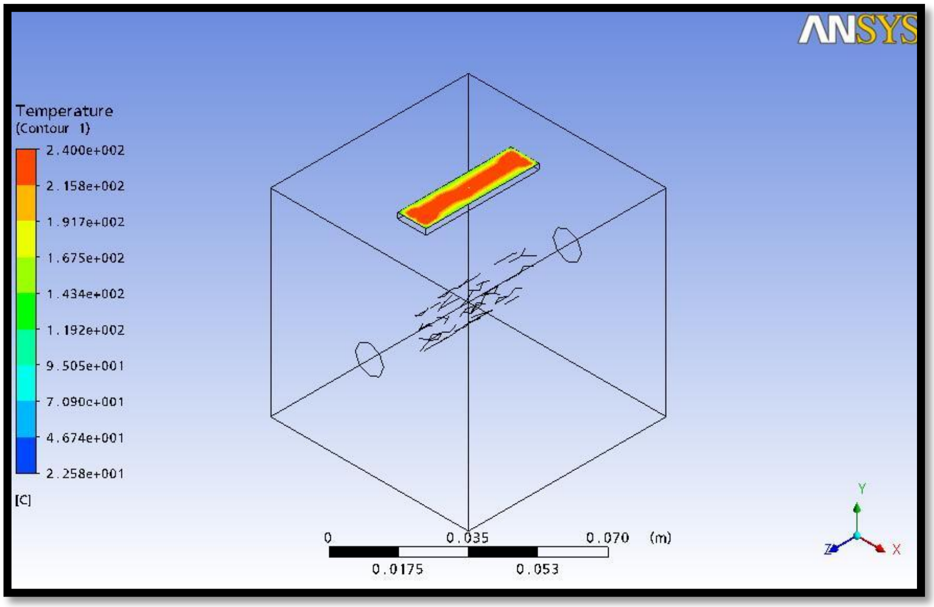


Figure 4.32: Starting time of the simulation for Circular shape cross-sectional cooling channel

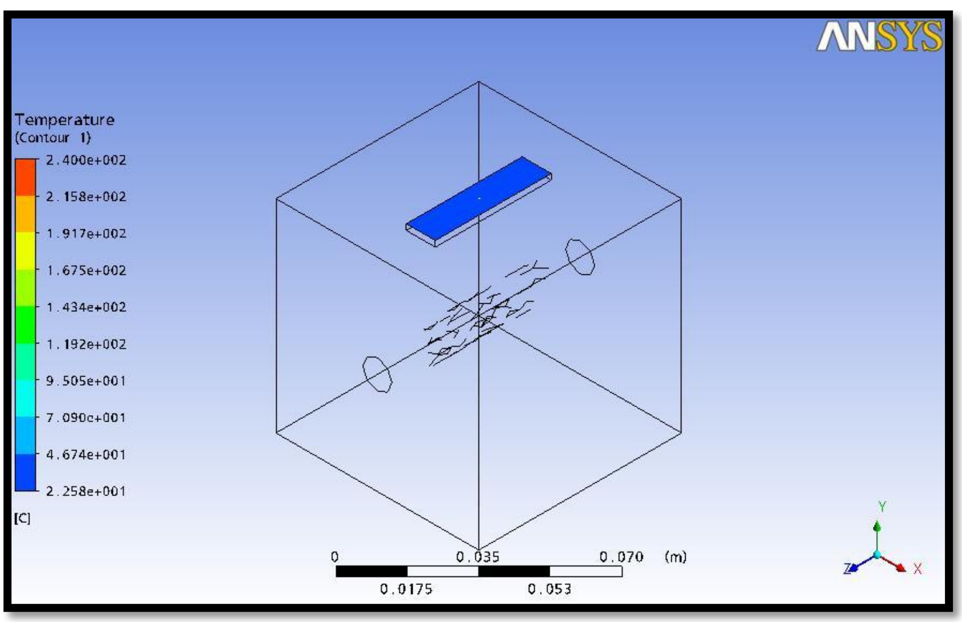


Figure 4.33: Finishing time (60th) of the simulation for Circular shape cross-sectional cooling channel

'D' Shape (see appendix 1)

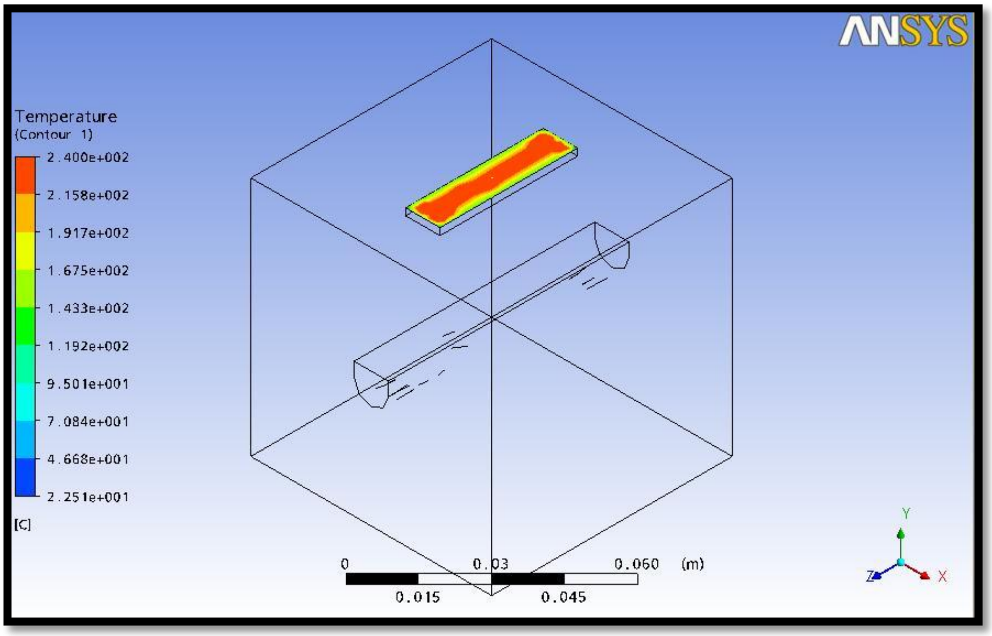


Figure 4.34: Starting time of the simulation for 'D' shape cross-sectional cooling channel

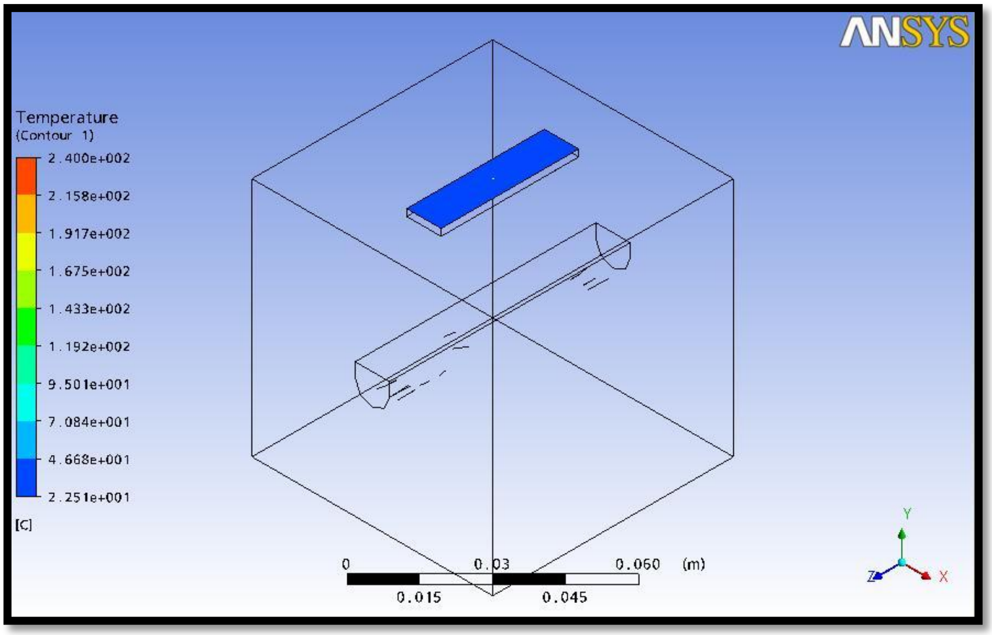


Figure 4.35: Finishing time (60^{th}) of the simulation for 'D' shape cross-sectional cooling channel

Square (see appendix 1)

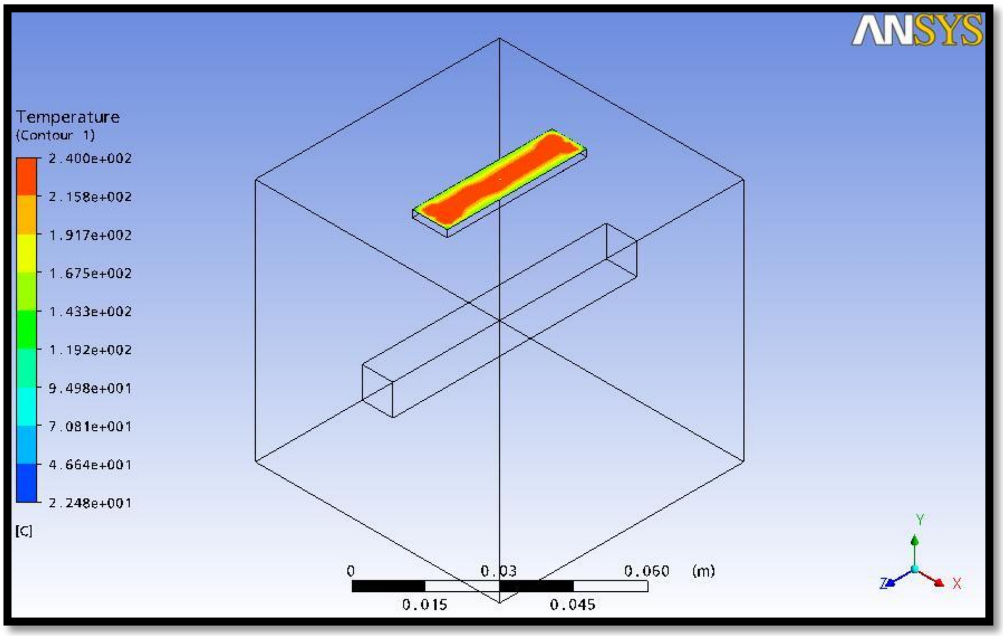


Figure 4.36: Starting time of the simulation for Square shape cross-sectional cooling channel

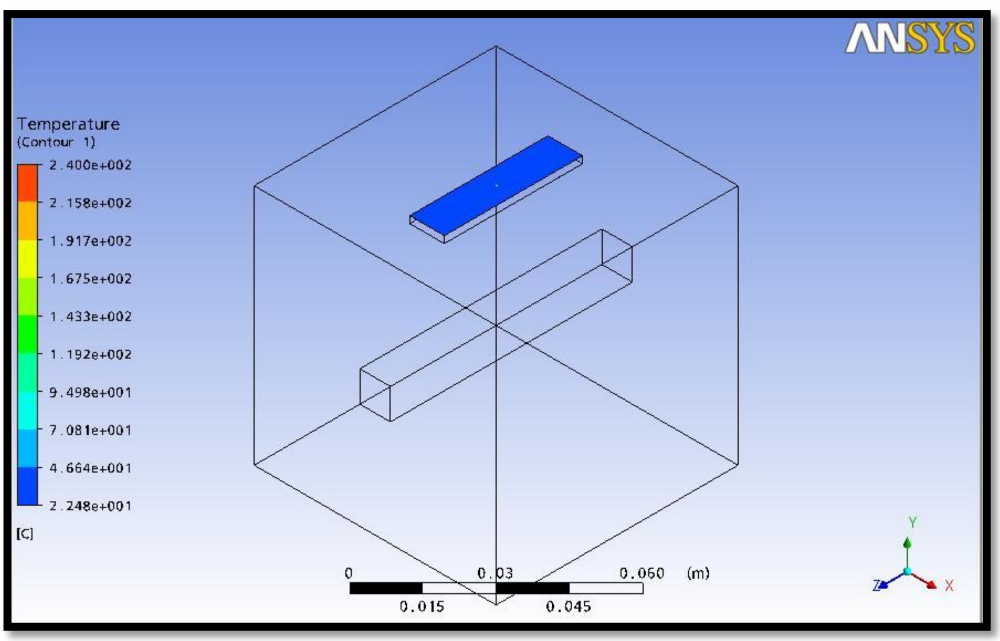


Figure 4.37: Finishing time (60th) of the simulation for Square shape cross-sectional cooling channel

Ellipse Horizontal (see appendix 1)

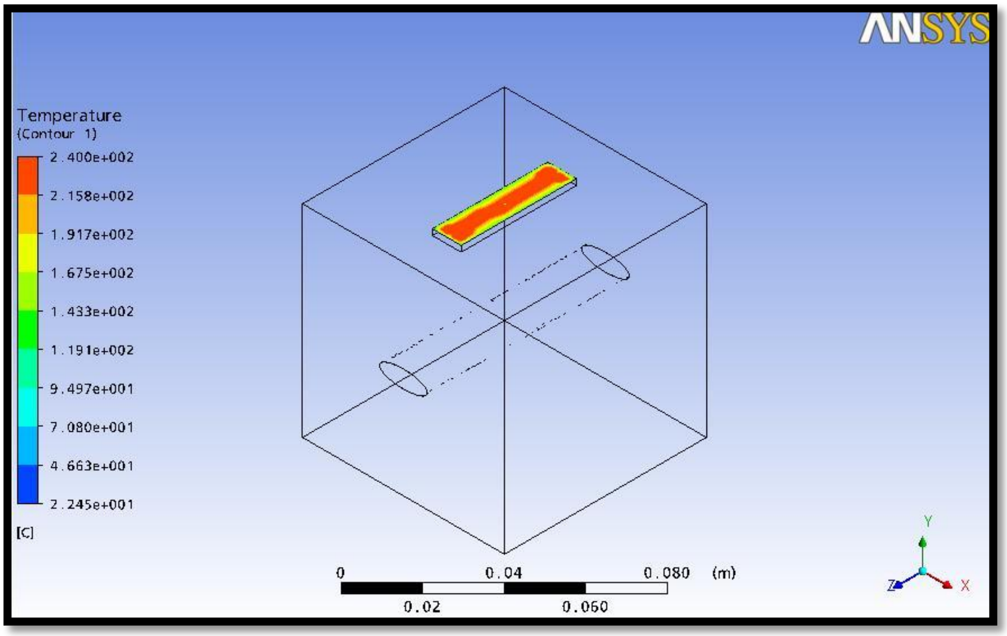


Figure 4.38: Starting time of the simulation for Ellipse Horizontal shape cross-sectional cooling channel

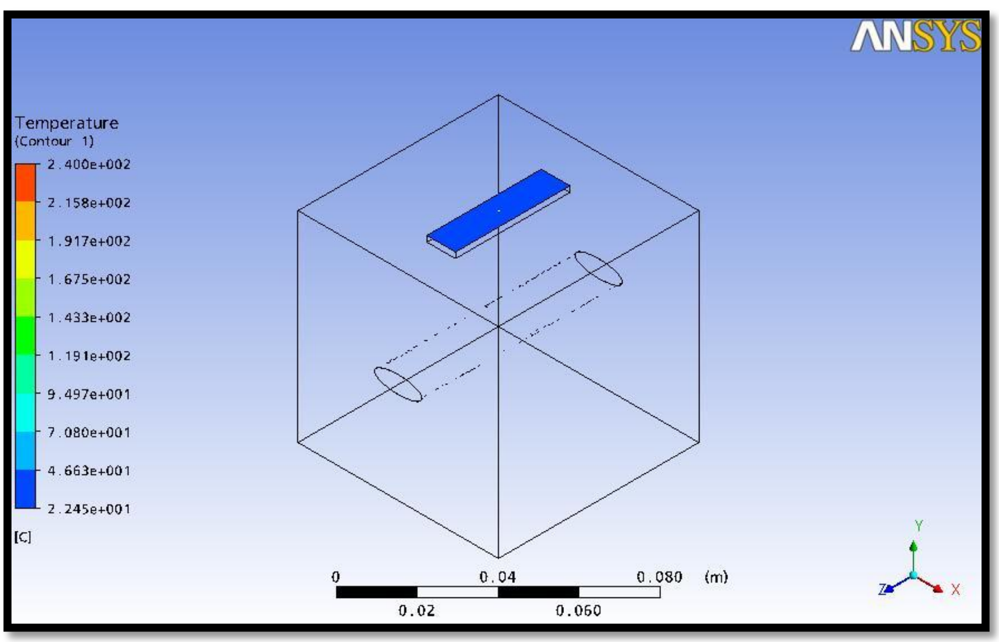


Figure 4.39: Finishing time (60th) of the simulation for Ellipse Horizontal shape cross-sectional cooling channel

Ellipse Vertical (see appendix 1)

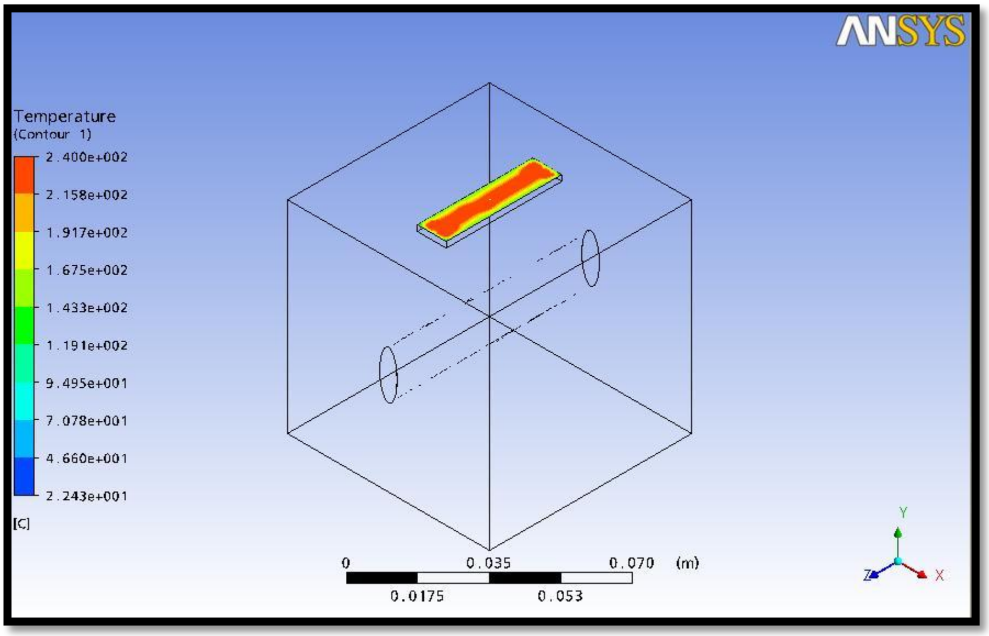


Figure 4.40: Starting time of the simulation for Ellipse Vertical shape cross-sectional cooling channel

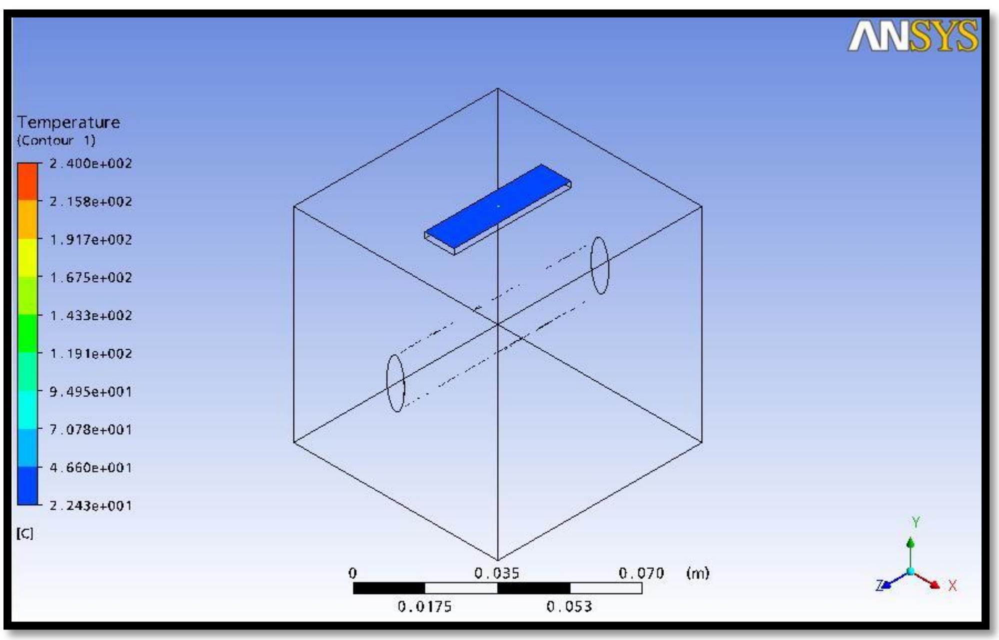


Figure 4.41: Finishing time (60th) of the simulation for Ellipse Vertical shape cross-sectional cooling channel

4.4.2 The area for 36 pi

Circular (see appendix 2)

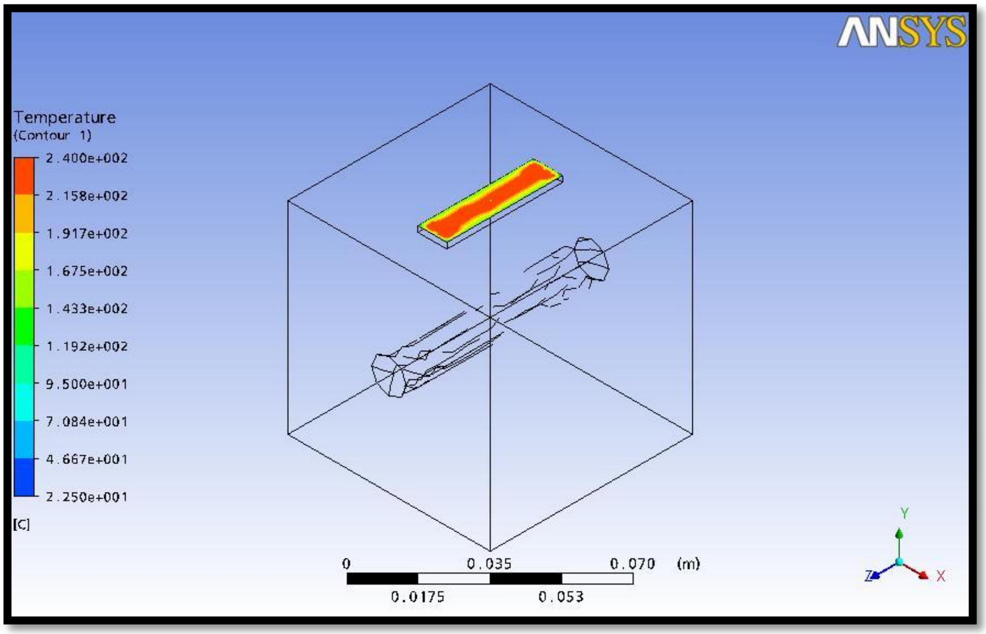


Figure 4.42: Starting time of the simulation for Circular shape cross-sectional cooling channel

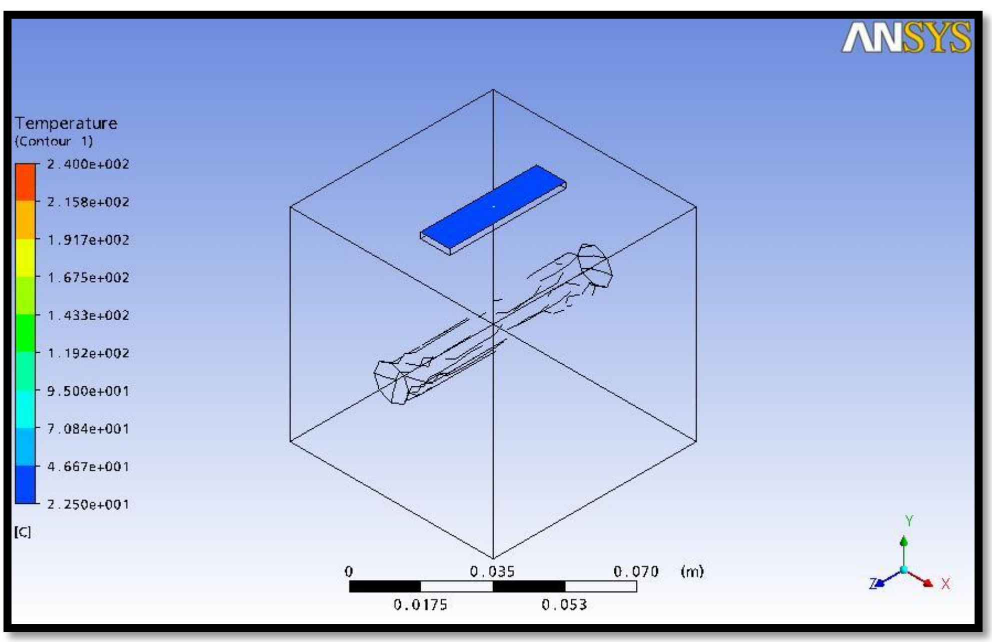


Figure 4.43: Finishing time (60^{th}) of the simulation for Circular shape cross-sectional cooling channel

'D' Shape (see appendix 2)

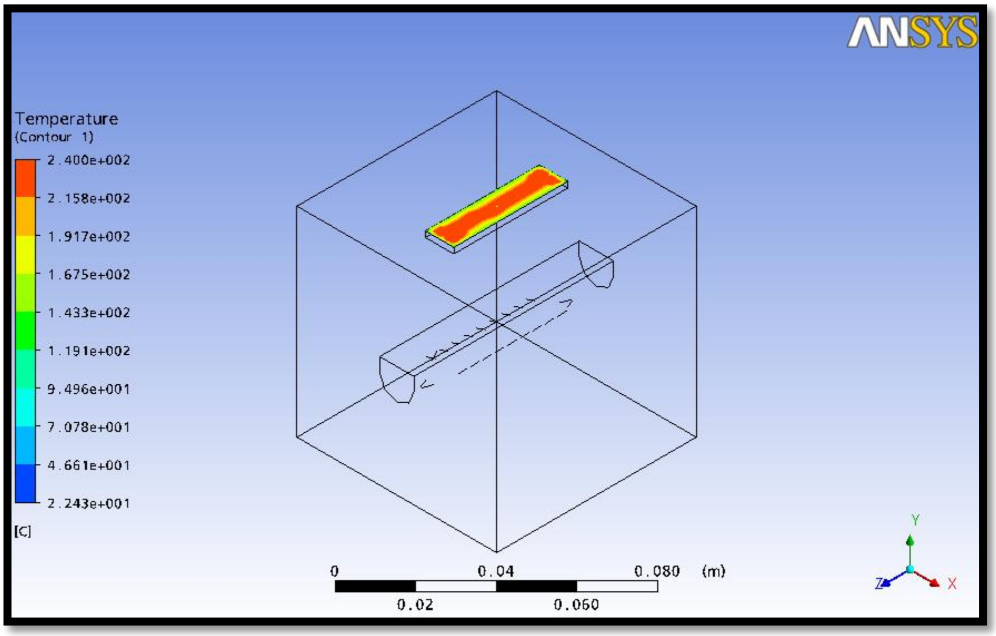


Figure 4.44: Starting time of the simulation for 'D' shape cross-sectional cooling channel

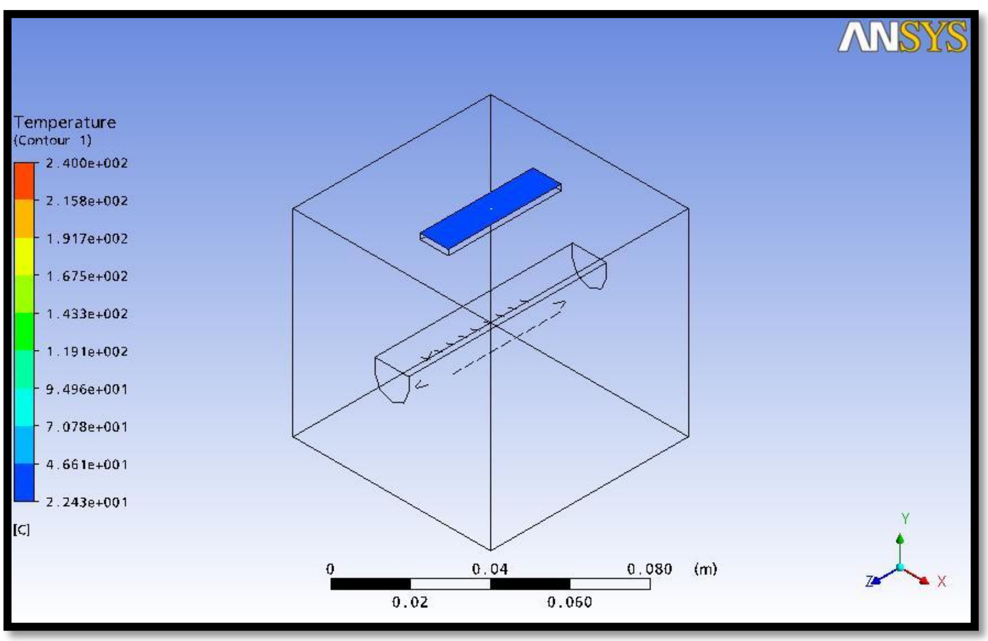


Figure 4.45: Finishing time (60th) of the simulation for 'D' shape cross-sectional cooling channel

Square (see appendix 2)

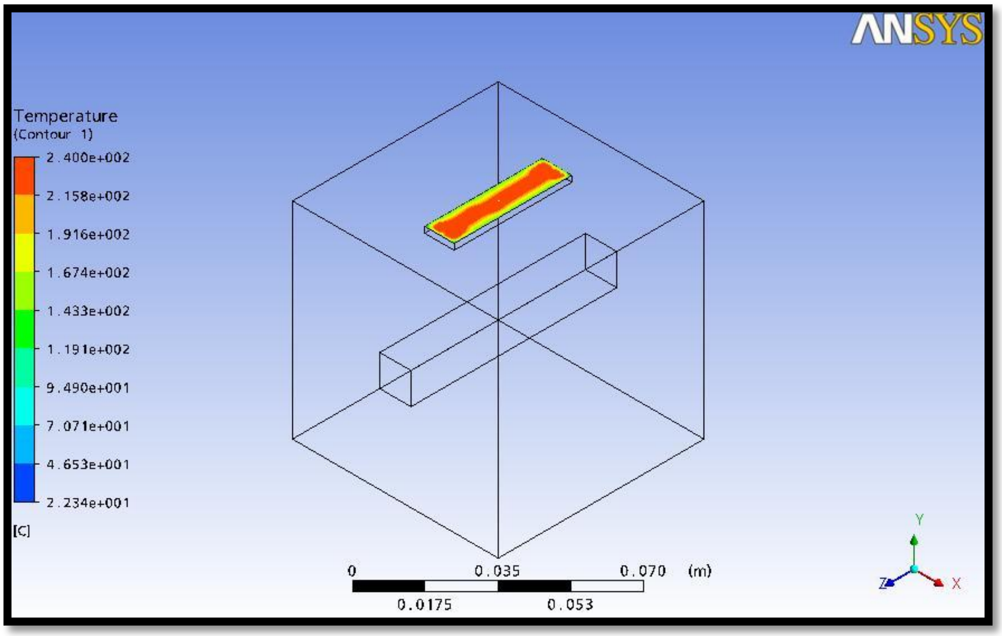


Figure 4.46: Starting time of the simulation for Square shape cross-sectional cooling channel

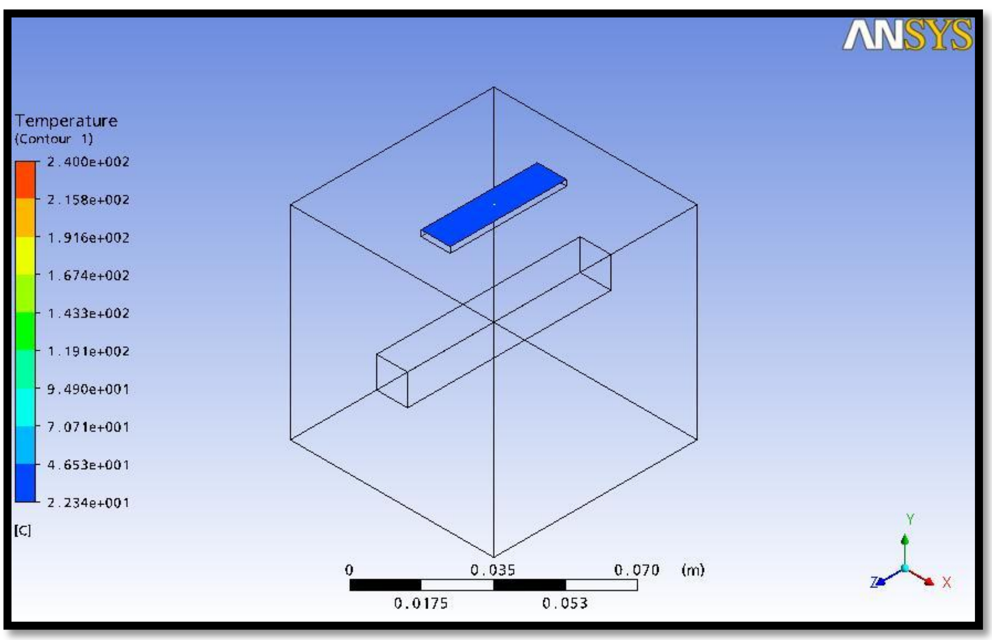


Figure 4.47: Finishing time (60^{th}) of the simulation for Square shape cross-sectional cooling channel

Ellipse Horizontal (see appendix 2)

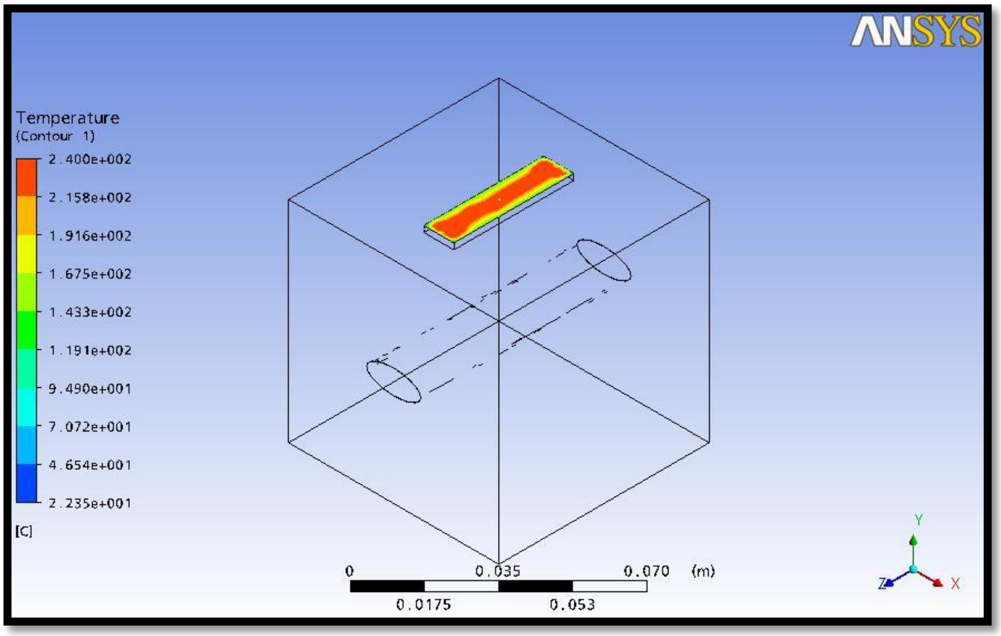


Figure 4.48: Starting time of the simulation for Ellipse Horizontal shape cross-sectional cooling channel

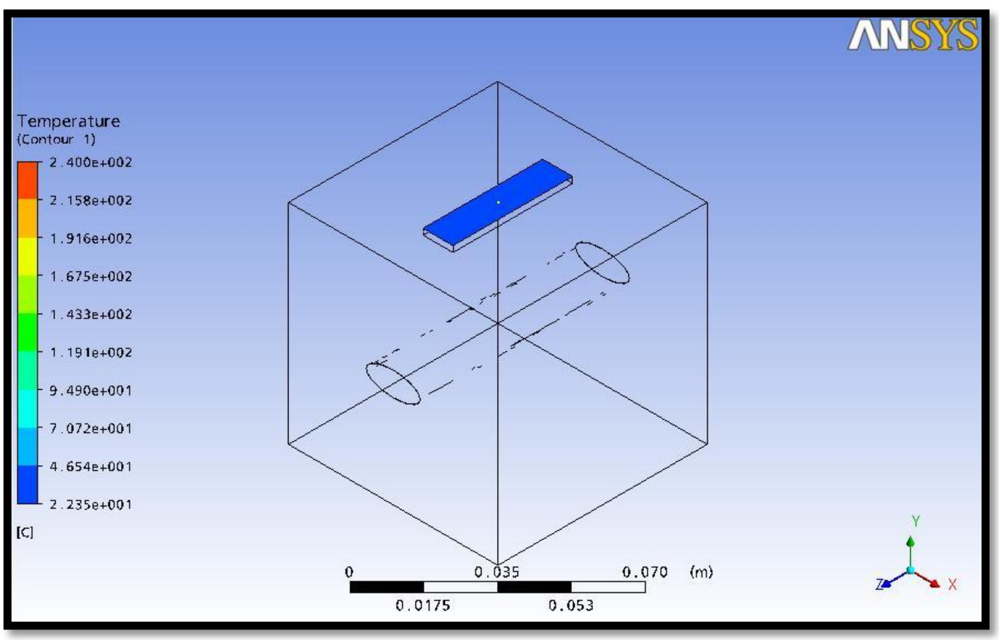


Figure 4.49: Finishing time (60^{th}) of the simulation for Ellipse Horizontal shape cross-sectional cooling channel

Ellipse Vertical (see appendix 2)

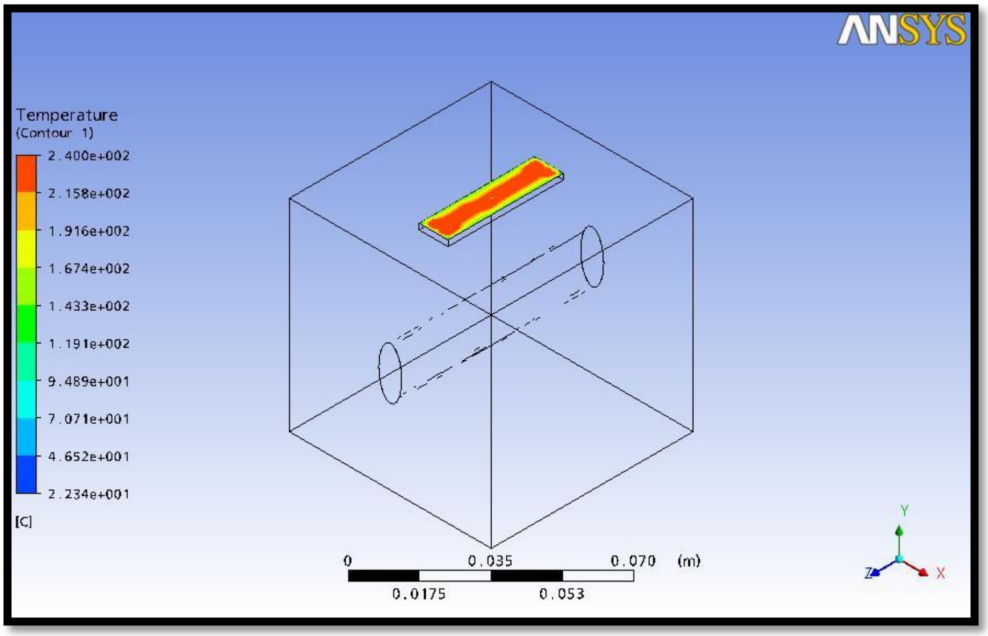


Figure 4.50: Starting time of the simulation for Ellipse Vertical shape cross-sectional cooling channel

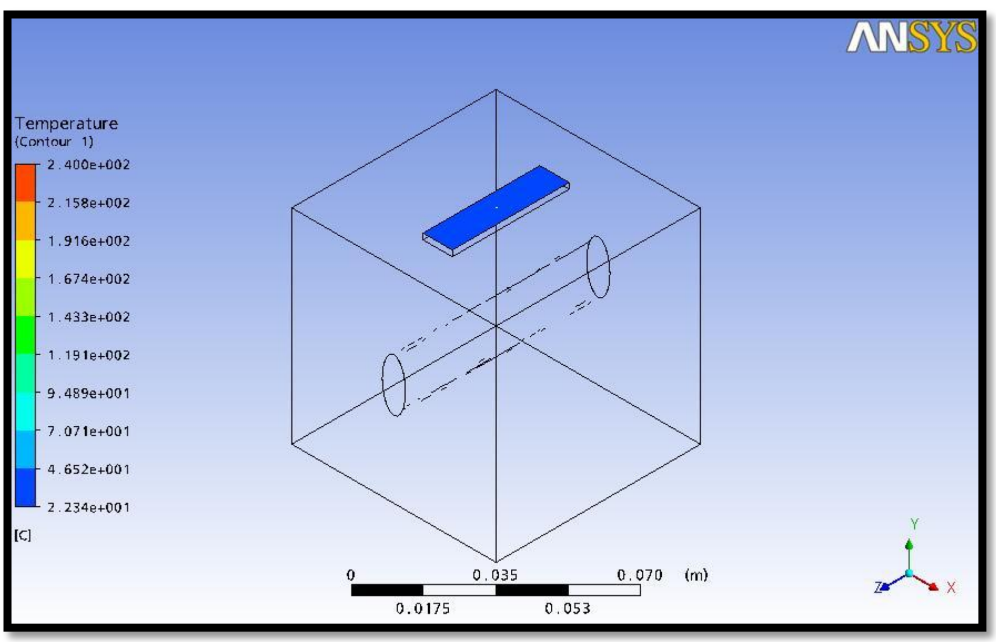


Figure 4.51: Finishing time (60th) of the simulation for Ellipse Vertical shape cross-sectional cooling channel

4.4.3 The area of 49 pi

Circular (see appendix 3)

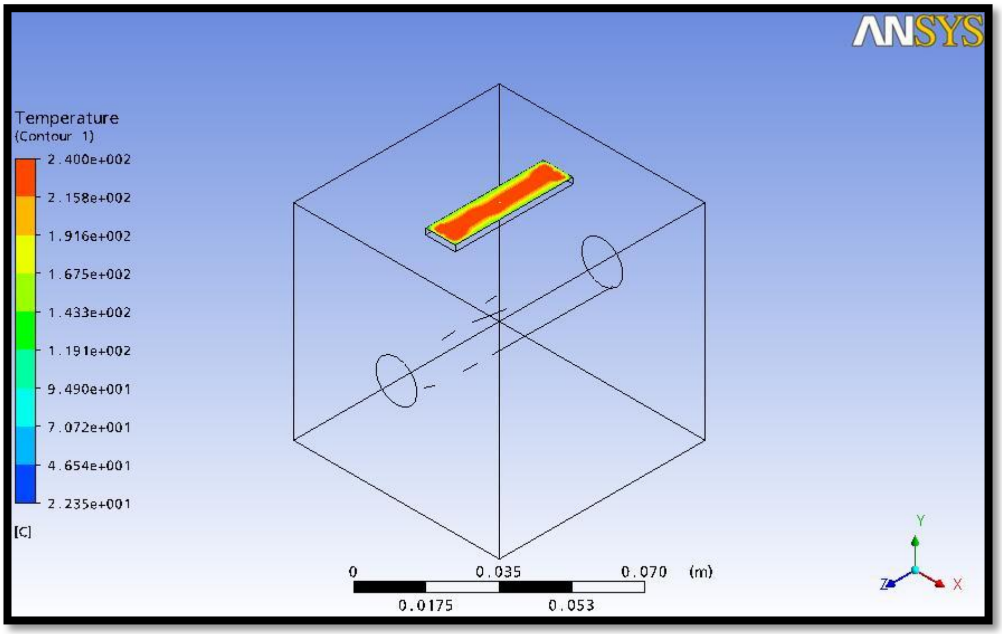


Figure 4.52: Starting time of the simulation for Circular shape cross-sectional cooling channel

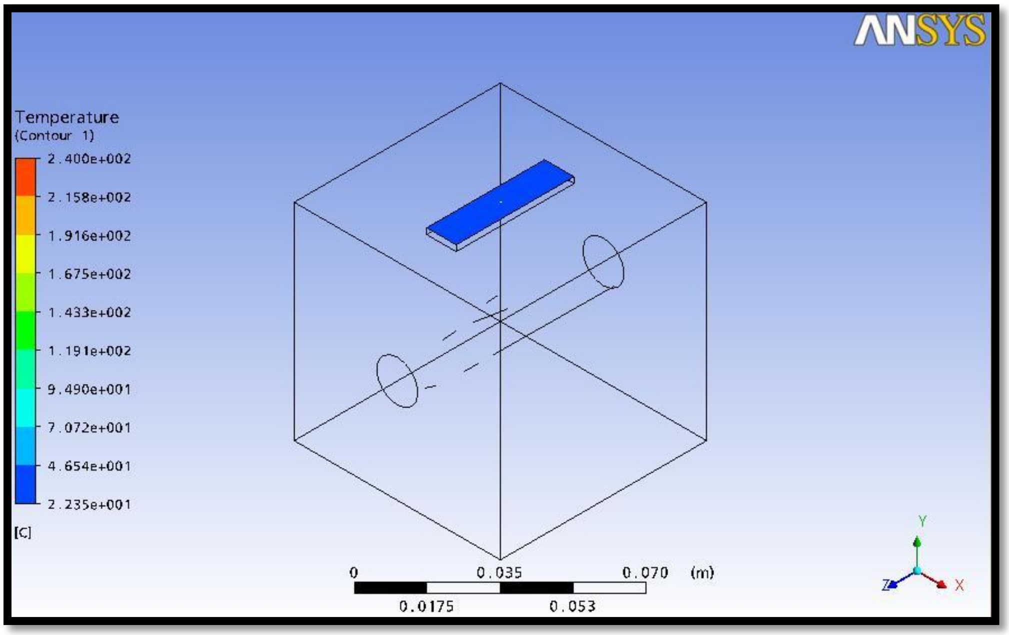


Figure 4.53: Finishing time (60th) of the simulation for Circular shape cross-sectional cooling channel

'D' Shape (see appendix 3)

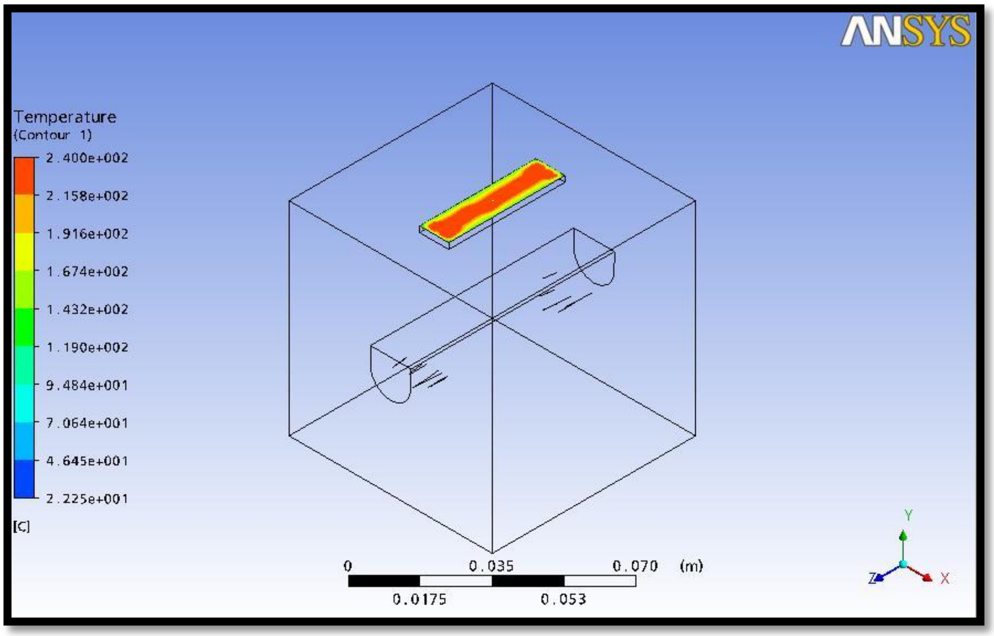


Figure 4.54: Starting time of the simulation for 'D' shape cross-sectional cooling channel

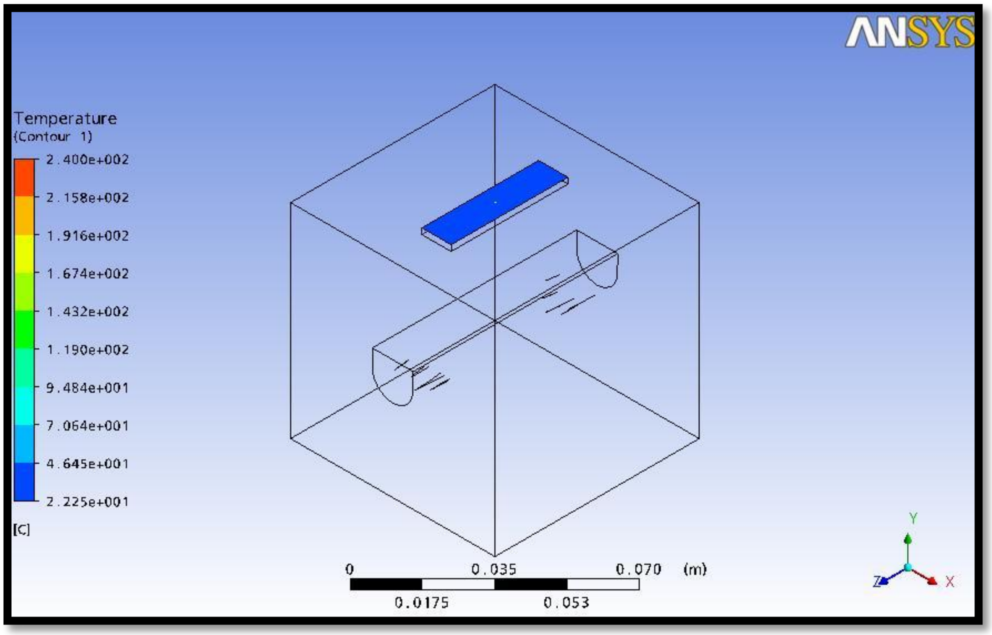


Figure 4.55: Finishing time (60th) of the simulation for 'D' shape cross-sectional cooling channel

Square (see appendix 3)

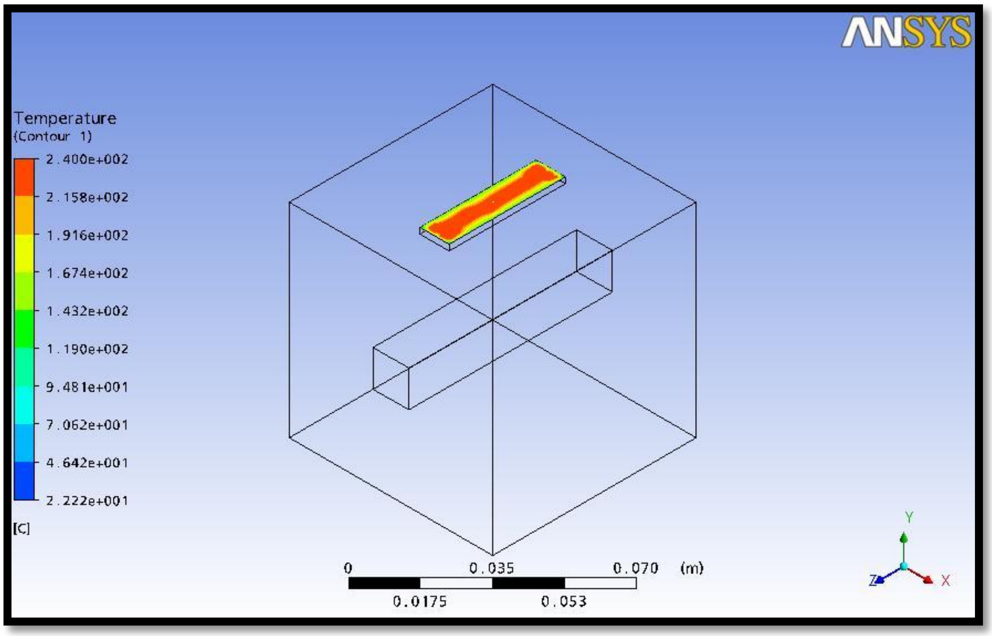


Figure 4.56: Starting time of the simulation for Square shape cross-sectional cooling channel

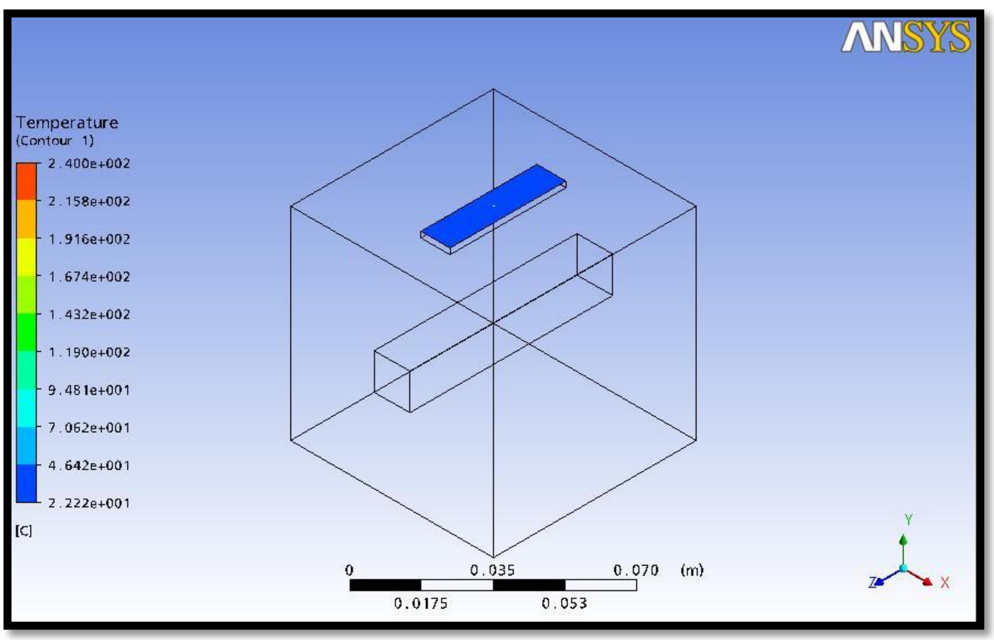


Figure 4.57: Finishing time (60^{th}) of the simulation for Square shape cross-sectional cooling channel

Ellipse Horizontal (see appendix 3)

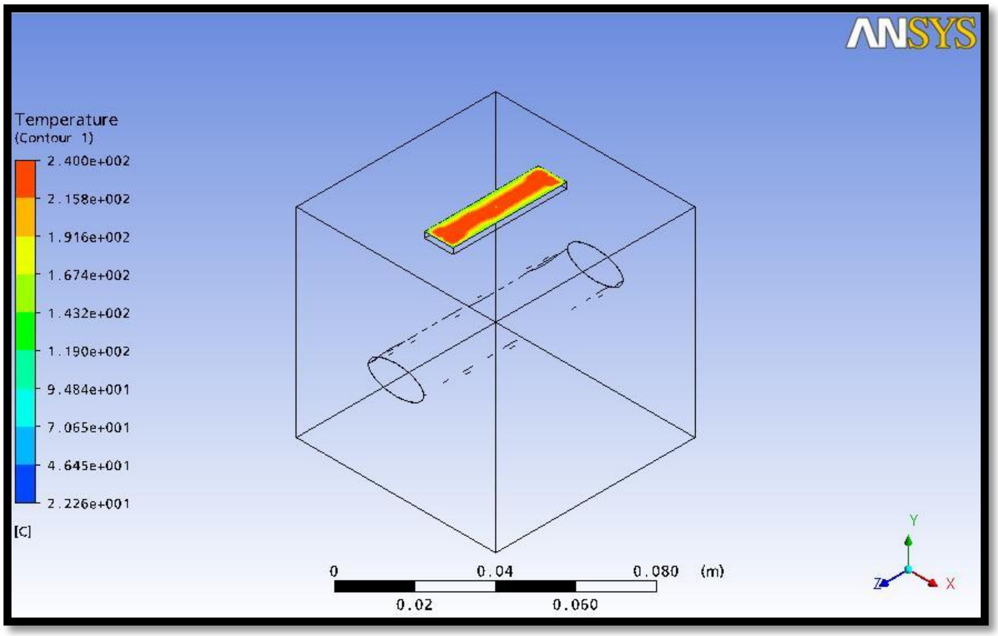


Figure 4.58: Starting time of the simulation for Ellipse Horizontal shape cross-sectional cooling channel

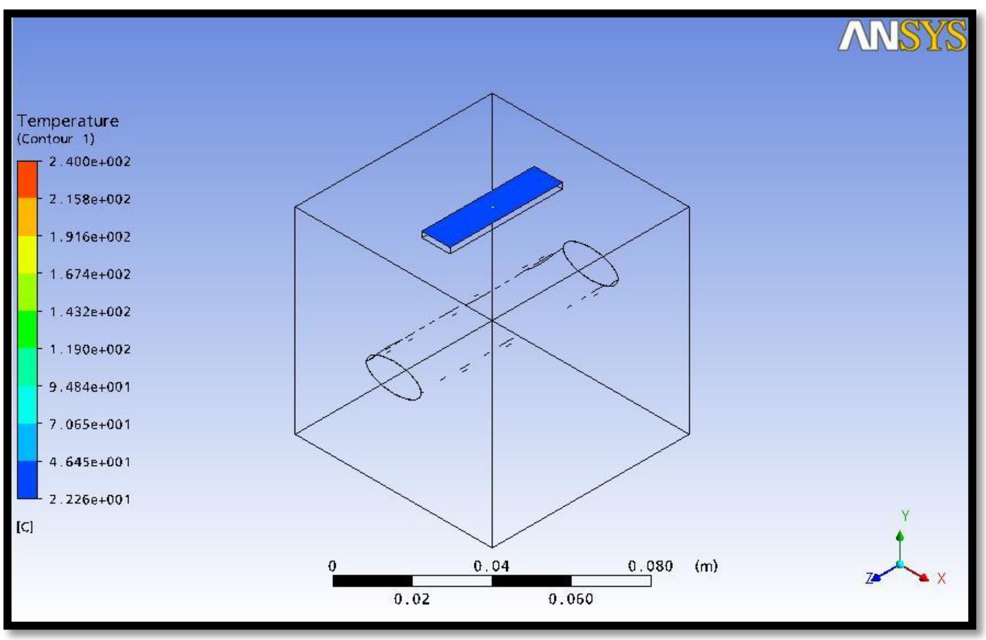


Figure 4.59: Finishing time (60^{th}) of the simulation for Ellipse Horizontal shape cross-sectional cooling channel

Ellipse Vertical (see appendix 3)

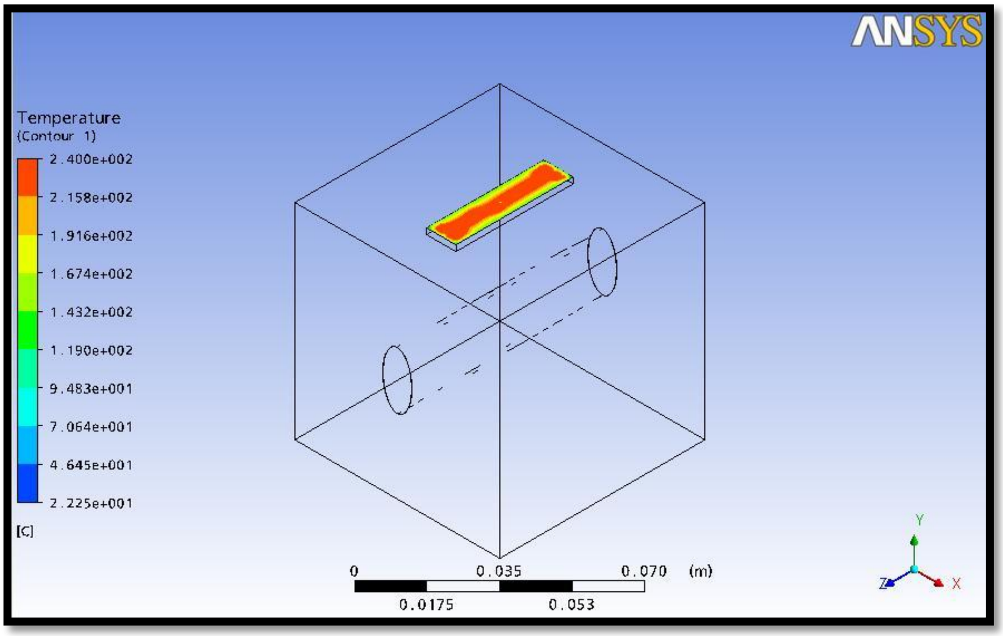


Figure 4.60: Starting time of the simulation for Ellipse Vertical shape cross-sectional cooling channel

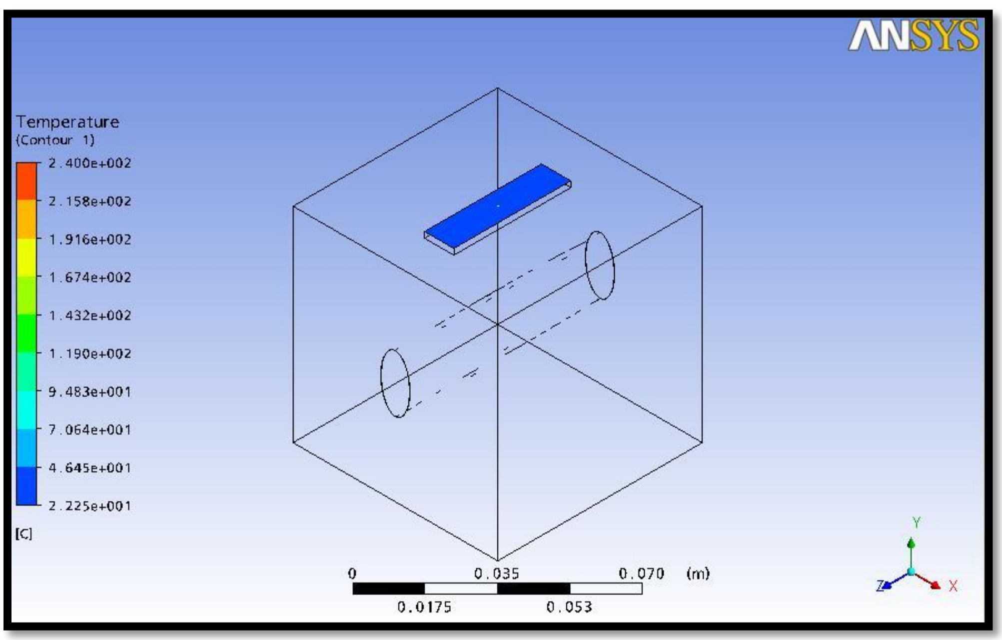


Figure 4.61: Finishing time (60^{th}) of the simulation for Ellipse Vertical shape cross-sectional cooling channel

4.5 Comparison of the result

4.5.1 Circular

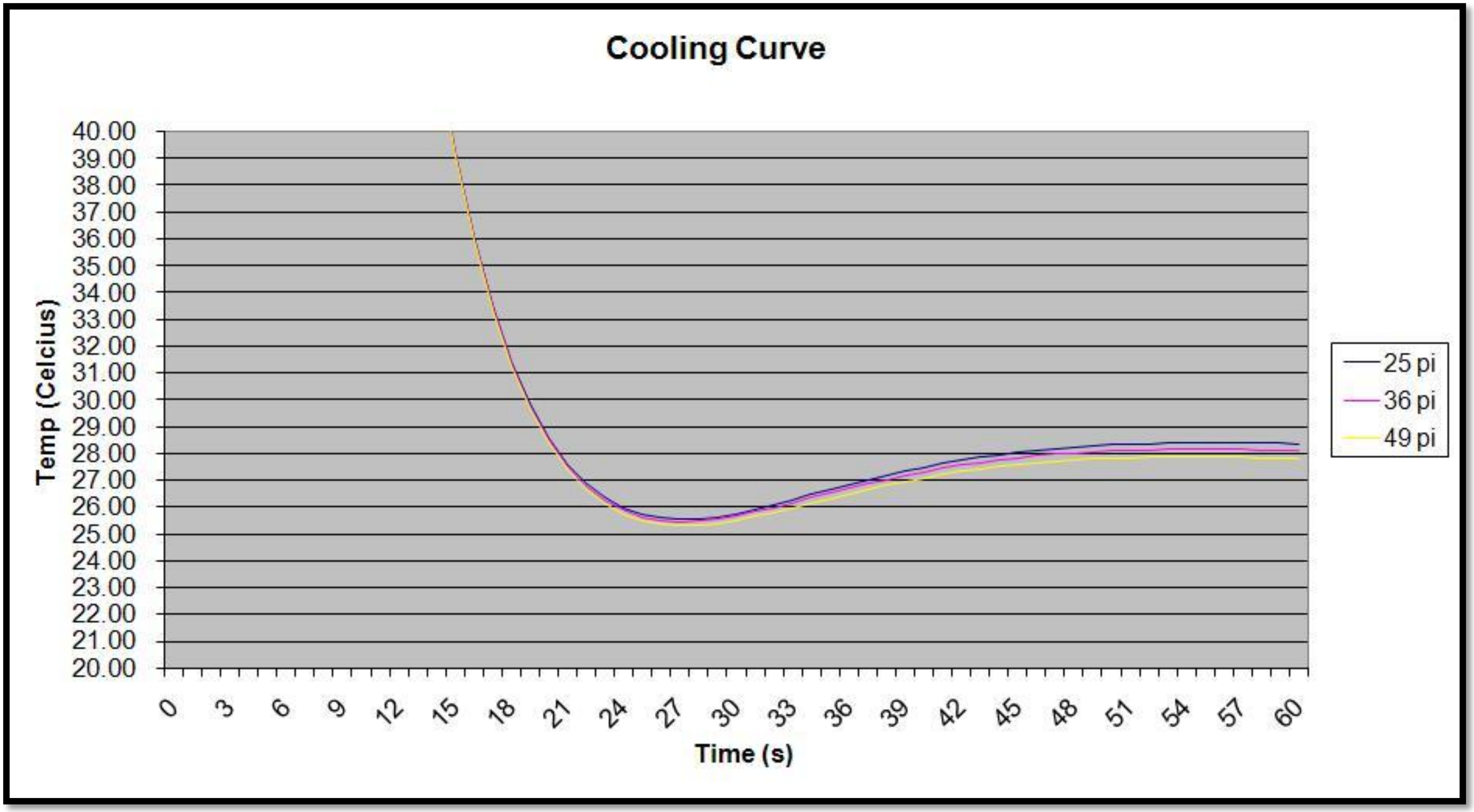


Figure 4.62: The comparison of cooling time after simulation for Circular cross-sectional cooling channel

According to the result on the graph, the author knows that the cooling time will be increase if the area of the cross-sectional cooling time increases. The area of 49 pi is better than the area of 36 pi and 25 pi. So, the author does the comparison using the data of area of 49 pi

4.5.2 The area of 49 pi

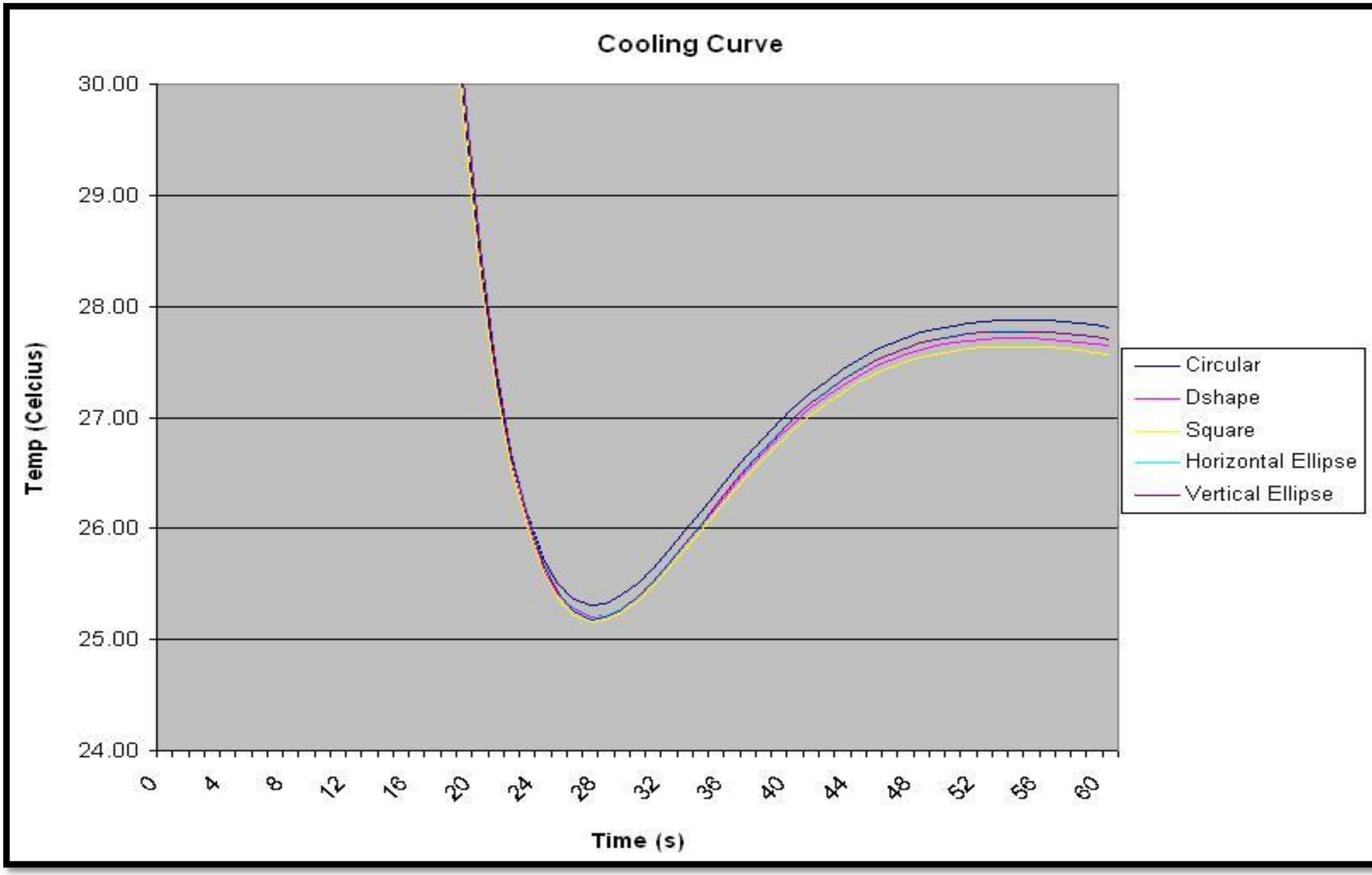


Figure 4.63: The comparison of cooling time after simulation for Circular cross-sectional cooling channel at the area of 49 pi

Table 4.1: The data for the area of 49 pi

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
0	240.00	240.00	240.00	240.00	240.00
1	212.69	212.69	212.69	212.70	212.70
2	187.33	187.34	187.34	187.36	187.36
3	164.53	164.54	164.54	164.54	164.54
4	144.33	144.34	144.34	144.31	144.30
5	126.58	126.58	126.58	126.52	126.51
6	110.97	110.96	110.96	110.98	110.97
7	97.35	97.34	97.34	97.46	97.45
8	85.55	85.54	85.53	85.74	85.74
9	75.37	75.35	75.34	75.63	75.62
10	66.62	66.59	66.59	66.94	66.93
11	59.14	59.10	59.10	59.49	59.48
12	52.77	52.73	52.72	53.15	53.14
13	47.38	47.34	47.33	47.77	47.76
14	42.85	42.80	42.79	43.24	43.23
15	39.07	39.02	39.00	39.45	39.44
16	35.93	35.88	35.86	36.30	36.29
17	33.36	33.30	33.28	33.70	33.69
18	31.28	31.21	31.19	31.59	31.58
19	29.66	29.58	29.56	29.89	29.88
20	28.39	28.31	28.29	28.54	28.53
21	27.41	27.33	27.30	27.49	27.48
22	26.67	26.58	26.55	26.69	26.68
23	26.12	26.03	26.00	26.10	26.10
24	25.74	25.65	25.62	25.69	25.68
25	25.49	25.40	25.37	25.42	25.41
26	25.36	25.29	25.22	25.27	25.26
27	25.31	25.20	25.17	25.19	25.18
28	25.33	25.22	25.18	25.22	25.21
29	25.40	25.29	25.25	25.28	25.28
30	25.51	25.40	25.35	25.39	25.38
31	25.65	25.53	25.49	25.53	25.52
32	25.80	25.69	25.64	25.69	25.68
33	25.97	25.85	25.80	25.86	25.86
34	26.15	26.02	25.97	26.04	26.03
35	26.32	26.20	26.15	26.22	26.21
36	26.49	26.37	26.31	26.39	26.39
37	26.66	26.53	26.47	26.56	26.56
38	26.82	26.68	26.63	26.72	26.72
39	26.96	26.83	26.77	26.87	26.86
40	27.10	26.96	26.90	27.01	27.00
41	27.22	27.08	27.02	27.13	27.13
42	27.33	27.19	27.13	27.24	27.24
43	27.43	27.29	27.22	27.34	27.34

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
44	27.52	27.37	27.31	27.43	27.43
45	27.60	27.45	27.38	27.51	27.50
46	27.66	27.51	27.44	27.57	27.57
47	27.72	27.57	27.50	27.63	27.62
48	27.76	27.61	27.54	27.67	27.67
49	27.80	27.64	27.57	27.71	27.71
50	27.83	27.67	27.60	27.74	27.73
51	27.85	27.69	27.62	27.76	27.75
52	27.86	27.71	27.63	27.77	27.77
53	27.87	27.71	27.64	27.78	27.77
54	27.88	27.71	27.64	27.78	27.77
55	27.87	27.71	27.64	27.77	27.77
56	27.87	27.70	27.63	27.77	27.76
57	27.86	27.69	27.62	27.75	27.75
58	27.85	27.68	27.60	27.74	27.74
59	27.83	27.66	27.59	27.72	27.72
60	27.81	27.65	27.57	27.70	27.70

Form the data and graph above, the author say that the better heat dissipation is square compare than Ellipse Vertical, Ellipse Horizontal, ‘D’ and circular shape cross-sectional. Because of this, the temperature reduces from 240°C until 25.17°C at 27 second. The second is Ellipse Vertical which the temperature reduces from 240°C to 25.18°C at 27 second. The percentage difference is 0.04%. The third is Ellipse Horizontal which the temperature reduces from 240°C to 25.19°C at 27 second. The percentage difference is 0.08%. The fourth is ‘D’Shape which the temperature reduces from 240°C to 25.20°C at 27 second. The percentage difference is 0.12%. The fifth is Circular which the temperature reduces from 240°C to 25.31°C at 27 second. The percentage difference is 0.56%.

These results occur because there have difference surface area between each cross-sectional channel. According heat convection equation,

$$q = hA(T_s - T_b)$$

Heat (q) is directly proportional to the surface area (A). So, if the value of surface area increases, the value of heat increases and the cooling time will be increases also. Mean that, the time to cool the product will be reduces. The surface area of each cross-sectional as shown in Table 4.2

Table 4.2: The surface area of the cross-sectional cooling channels

Cross-sectional cooling channels	**Surface Area (mm^2)**	**Percentage Difference (%)**
Circular	3078.76	11.40
D shape	3289.58	5.33
Square	3474.80	0
Ellipse Horizontal	3421.58	1.53
Ellipse Vertical	3421.58	1.53

The difference of decreasing temperature between Circular, ‘D’, Square, Ellipse Horizontal and Ellipse Vertical shape is very small. In industry field, the Circular shape cross-sectional cooling channel is normally used in injection molding process. So, the author decide that the circular shape cross-sectional is better compare than ‘D’, Square, Ellipse Horizontal and Ellipse Vertical shape for cooling channels in injection molding process.

CHAPTER 5

CONCLUSION

As the conclusion, the cooling time is dependent greatly on the configuration of the cooling channel system that is used to remove heat from the injection mould. A reduction in the time spent on cooling the part before it is ejected would drastically increase the production rate and also reduce the costs. The best design must be choose to get the better performance of the cooling channel. The Circular shape is better compare than ‘D’, Square, Ellipse Horizontal and Ellipse Vertical shape for cooling channels in injection molding process cause by the difference of decreasing temperature is very small.

CHAPTER 6

REFERENCES

There have a few references have been used:

1. Herbert Rees (2001), Injection Molding design, Hanser Publisher, Inc
2. Gerd Potsch and walter Michaeli (2001), Injection Molding An Introduction, Hanser Publisher, Inc
3. Michaeli, Greif, Kretzshmar and Ehrig (2001), training in Injection Molding, Hanser Publisher, Inc
4. http//:www.wikipedia.com
5. D.V. Rosato, D.V. Rosato and M.G. Rosato, Injection Moulding Handbook, 3rd ed (Boston: Kluwer Academic Publishers, 2003).
6. C. L. Li, A feature-based approach to injection mould cooling system design, Computer-Aided Design, 33
   (2001), pp 1073-1090
7. Saeed moaveni (2008), Theory and Aplication with ANSYS, third edition, PEARSON Prentice Hall

APPENDIXES

Appendix 1 (*Cooling time for the area of 25 pi*)

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
0	240.00	240.00	240.00	240.00	240.00
1	212.69	212.69	212.69	212.70	212.70
2	187.34	187.34	187.33	187.35	187.36
3	164.54	164.54	164.54	164.57	164.55
4	144.34	144.34	144.34	144.37	144.31
5	126.60	126.59	126.59	126.62	126.53
6	111.00	110.99	110.98	111.02	110.99
7	97.39	97.38	97.37	97.41	97.48
8	85.60	85.59	85.58	85.61	85.77
9	75.43	75.41	75.40	75.43	75.67
10	66.69	66.67	66.65	66.69	66.98
11	59.22	59.20	59.18	59.21	59.54
12	52.87	52.84	52.82	52.84	53.21
13	47.49	47.46	47.44	47.46	47.84
14	42.97	42.94	42.91	42.93	43.31
15	39.20	39.17	39.13	39.15	39.53
16	36.08	36.04	36.00	36.02	36.39
17	33.52	33.48	33.44	33.46	33.80
18	31.45	31.40	31.36	31.37	31.70
19	29.84	29.79	29.74	29.76	30.01
20	28.59	28.54	28.48	28.49	28.67
21	27.62	27.57	27.51	27.52	27.62
22	26.89	26.83	26.77	26.78	26.83
23	26.36	26.30	26.23	26.24	26.25
24	25.99	25.93	25.85	25.86	25.85
25	25.75	25.69	25.61	25.62	25.59
26	25.60	25.53	25.48	25.46	25.44
27	25.56	25.49	25.44	25.41	25.38
28	25.57	25.50	25.46	25.42	25.40
29	25.64	25.57	25.54	25.48	25.48
30	25.76	25.68	25.65	25.59	25.59
31	25.91	25.82	25.79	25.73	25.74
32	26.08	26.00	25.96	25.89	25.90
33	26.27	26.18	26.13	26.07	26.08
34	26.46	26.38	26.31	26.26	26.27
35	26.66	26.57	26.49	26.45	26.45
36	26.85	26.76	26.66	26.64	26.63
37	27.03	26.93	26.83	26.82	26.81
38	27.20	27.10	26.99	26.98	26.97
39	27.36	27.26	27.14	27.14	27.12
40	27.50	27.40	27.28	27.28	27.27
41	27.64	27.54	27.41	27.41	27.40
42	27.76	27.66	27.52	27.52	27.51
43	27.87	27.76	27.63	27.62	27.62

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
44	27.96	27.86	27.72	27.72	27.71
45	28.05	27.94	27.80	27.79	27.79
46	28.12	28.01	27.86	27.86	27.86
47	28.18	28.07	27.92	27.92	27.92
48	28.24	28.12	27.97	27.97	27.97
49	28.28	28.17	28.01	28.01	28.01
50	28.32	28.20	28.04	28.04	28.04
51	28.35	28.23	28.07	28.07	28.07
52	28.37	28.25	28.08	28.09	28.08
53	28.39	28.27	28.10	28.10	28.09
54	28.40	28.27	28.10	28.11	28.10
55	28.40	28.28	28.10	28.11	28.10
56	28.41	28.28	28.10	28.10	28.09
57	28.40	28.27	28.09	28.09	28.09
58	28.39	28.26	28.08	28.08	28.07
59	28.38	28.25	28.07	28.06	28.06
60	28.37	28.24	28.05	28.05	28.04

Appendix 2 (*Cooling time for the area of 36 pi*)

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
0	240.00	240.00	240.00	240.00	240.00
1	212.69	212.69	212.69	212.70	212.70
2	187.33	187.34	187.33	187.36	187.36
3	164.54	164.55	164.53	164.54	164.54
4	144.34	144.35	144.33	144.31	144.31
5	126.59	126.60	126.58	126.53	126.52
6	110.98	110.99	110.97	110.99	110.98
7	97.38	97.38	97.36	97.47	97.46
8	85.58	85.58	85.55	85.76	85.75
9	75.40	75.39	75.37	75.65	75.64
10	66.66	66.65	66.62	66.96	66.95
11	59.19	59.17	59.14	59.52	59.51
12	52.83	52.80	52.77	53.18	53.17
13	47.45	47.42	47.38	47.81	47.80
14	42.92	42.89	42.85	43.28	43.27
15	39.15	39.11	39.07	39.49	39.48
16	36.02	35.98	35.93	36.35	36.34
17	33.45	33.41	33.36	33.76	33.75
18	31.37	31.33	31.27	31.65	31.64
19	29.76	29.71	29.65	29.96	29.94
20	28.50	28.45	28.38	28.61	28.60
21	27.53	27.47	27.40	27.57	27.55
22	26.79	26.73	26.66	26.77	26.76

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
23	26.26	26.19	26.11	26.19	26.17
24	25.88	25.82	25.73	25.78	25.76
25	25.64	25.57	25.49	25.51	25.50
26	25.51	25.44	25.35	25.36	25.35
27	25.47	25.39	25.30	25.30	25.29
28	25.49	25.41	25.32	25.32	25.30
29	25.57	25.49	25.39	25.39	25.37
30	25.69	25.60	25.50	25.50	25.49
31	25.83	25.74	25.64	25.64	25.63
32	25.99	25.90	25.79	25.81	25.79
33	26.17	26.07	25.96	25.98	25.97
34	26.35	26.25	26.14	26.16	26.15
35	26.53	26.43	26.31	26.34	26.33
36	26.70	26.60	26.48	26.52	26.51
37	26.87	26.77	26.65	26.69	26.68
38	27.04	26.93	26.80	26.85	26.84
39	27.19	27.08	26.95	27.01	26.99
40	27.33	27.21	27.08	27.15	27.13
41	27.45	27.34	27.21	27.27	27.26
42	27.57	27.45	27.32	27.39	27.37
43	27.67	27.55	27.42	27.49	27.47
44	27.77	27.64	27.50	27.58	27.56
45	27.85	27.72	27.58	27.66	27.64
46	27.92	27.79	27.64	27.73	27.71
47	27.97	27.85	27.70	27.78	27.77
48	28.02	27.89	27.74	27.83	27.81
49	28.06	27.93	27.78	27.87	27.85
50	28.10	27.96	27.81	27.90	27.88
51	28.12	27.99	27.83	27.92	27.90
52	28.14	28.00	27.85	27.93	27.92
53	28.15	28.01	27.85	27.94	27.93
54	28.16	28.02	27.86	27.95	27.93
55	28.16	28.02	27.86	27.94	27.93
56	28.16	28.01	27.85	27.94	27.92
57	28.15	28.01	27.84	27.93	27.91
58	28.14	27.99	27.83	27.92	27.90
59	28.13	27.98	27.81	27.90	27.88
60	28.11	27.96	27.79	27.88	27.86

Appendix 3 (*Cooling time for the area of 49 pi*)

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
0	240.00	240.00	240.00	240.00	240.00
1	212.69	212.69	212.69	212.70	212.70
2	187.33	187.34	187.34	187.36	187.36
3	164.53	164.54	164.54	164.54	164.54
4	144.33	144.34	144.34	144.31	144.30
5	126.58	126.58	126.58	126.52	126.51
6	110.97	110.96	110.96	110.98	110.97
7	97.35	97.34	97.34	97.46	97.45
8	85.55	85.54	85.53	85.74	85.74
9	75.37	75.35	75.34	75.63	75.62
10	66.62	66.59	66.59	66.94	66.93
11	59.14	59.10	59.10	59.49	59.48
12	52.77	52.73	52.72	53.15	53.14
13	47.38	47.34	47.33	47.77	47.76
14	42.85	42.80	42.79	43.24	43.23
15	39.07	39.02	39.00	39.45	39.44
16	35.93	35.88	35.86	36.30	36.29
17	33.36	33.30	33.28	33.70	33.69
18	31.28	31.21	31.19	31.59	31.58
19	29.66	29.58	29.56	29.89	29.88
20	28.39	28.31	28.29	28.54	28.53
21	27.41	27.33	27.30	27.49	27.48
22	26.67	26.58	26.55	26.69	26.68
23	26.12	26.03	26.00	26.10	26.10
24	25.74	25.65	25.62	25.69	25.68
25	25.49	25.40	25.37	25.42	25.41
26	25.36	25.29	25.22	25.27	25.26
27	25.31	25.20	25.17	25.19	25.18
28	25.33	25.22	25.18	25.22	25.21
29	25.40	25.29	25.25	25.28	25.28
30	25.51	25.40	25.35	25.39	25.38
31	25.65	25.53	25.49	25.53	25.52
32	25.80	25.69	25.64	25.69	25.68
33	25.97	25.85	25.80	25.86	25.86
34	26.15	26.02	25.97	26.04	26.03
35	26.32	26.20	26.15	26.22	26.21
36	26.49	26.37	26.31	26.39	26.39
37	26.66	26.53	26.47	26.56	26.56
38	26.82	26.68	26.63	26.72	26.72
39	26.96	26.83	26.77	26.87	26.86
40	27.10	26.96	26.90	27.01	27.00
41	27.22	27.08	27.02	27.13	27.13
42	27.33	27.19	27.13	27.24	27.24
43	27.43	27.29	27.22	27.34	27.34

Time	Circular	Dshape	Square	Horizontal Ellipse	Vertical Ellipse
44	27.52	27.37	27.31	27.43	27.43
45	27.60	27.45	27.38	27.51	27.50
46	27.66	27.51	27.44	27.57	27.57
47	27.72	27.57	27.50	27.63	27.62
48	27.76	27.61	27.54	27.67	27.67
49	27.80	27.64	27.57	27.71	27.71
50	27.83	27.67	27.60	27.74	27.73
51	27.85	27.69	27.62	27.76	27.75
52	27.86	27.71	27.63	27.77	27.77
53	27.87	27.71	27.64	27.78	27.77
54	27.88	27.71	27.64	27.78	27.77
55	27.87	27.71	27.64	27.77	27.77
56	27.87	27.70	27.63	27.77	27.76
57	27.86	27.69	27.62	27.75	27.75
58	27.85	27.68	27.60	27.74	27.74
59	27.83	27.66	27.59	27.72	27.72
60	27.81	27.65	27.57	27.70	27.70