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Transient CFD Analysis of Different Cross-Section Fins Under Free-Convection Conditions

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Abstract- **Manufacturers of aerospace and defense equipments are presently facing challenges related to both steady state and transient reliability of electronics systems; the continuing reduction in size of electronic components is resulting in higher power density due to which thermal management of electronic components is critical in electronic product development. Among heat transfer augmentation technique, passive cooling technique is more suitable than active cooling for specific applications. Also providing fins can regulate the temperature of the system at optimum levels by providing extended surface area of contact with surrounding cooling medium- air. In the present work, the Transient analysis has been carried out for three different cases to determine the transient performance considering different cross-sectional fins such as Tapered, Round and Rectangular configurations. The fins are subjected to free-convection cooling which are placed on plate with four heat sources each dissipating 100W power. Transient analysis is carried out using ANSYS CFD software for time step of 20 seconds and results obtained for different cross-section are compared for optimum temperature levels.**

Keywords: Fins, Tapered fin, Round Fin, Rectangular Fin, Transient analysis, ANSYS CFD, Free-convection.

1. INTRODUCTION

To increase the heat transfer rates by increasing the surface heat transfer coefficient or increasing the temperature difference between surface and surrounding medium sometimes becomes impossible at particular condition and application; hence at that situation fins can be used for increasing the heat transfer rates from the surfaces [17].
Fins are classified as straight fins with uniform (Fig. 1.1) and non-uniform thickness (Fig. 1.2), annular fins (Fig. 1.3) and spine of constant cross-section (Fig. 1.4) and non-uniform cross section (Fig. 1.5).

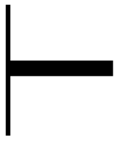
Fig. 1.1


Fig. 1.2

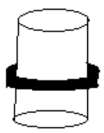
Fig. 1.3

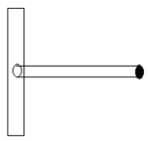
Fig. 1.4

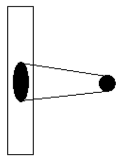
Fig. 1.5

The knowledge of temperature distribution along the fin is necessary for proper design of fins. Hence in the present work, Transient analysis is carried out using ANSYS CFD for understanding the temperature distribution and heat flow from different cross-section fins such as Tapered, Round and Rectangular fins.

2. LITERATURE SURVEY

Literature survey is carried out to understand the state of art in CFD transient analysis on natural convection cooling of fins. Here are some literatures as discussed below:
Santosh Kansal et.al., [1], [2015], This paper deals with a comparative study using CFD on Electronic enclosure consisting fins of different configuration. The overall performance of the six different heat sinks with different shaped pin-fin structures was studied in this paper for different velocities varying from 5, 10 & 12 m/s. The paper presents simulation and thermal analysis of different shape fins heat sink for an electronic system cooled by natural convection.
Aartee. S. Lokhande, [2], [2018], this article gives overall review on work carried out on Transient analysis fins with different shapes and briefs some of technical details on fins.
Only major journals are discussed in this section, remaining journals, articles and textbooks listed in References.

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3. METHODOLOGY

In the present work, Numerical approach is used to solve the conjugate heat transfer problem. Geometry, Meshing and Analysis are carried out using ANSYS CFD software. The details are given below.

Steps in the analysis involve:
1. Creation of Geometry
2. Meshing the Model
3. Apply Boundary Condition
4. Physical setup for analysis selecting appropriate Mathematical models
5. Result visualization and comparison

3.1 Geometry

The Geometry model of Tapered fin, Round fin and Rectangular fin is as shown in Fig. 3.1, Fig. 3.2 and Fig. 3.3. The fins are placed on a plate in an enclosure with Free-convection cooling. The plate is attached with four heat sources. The construction is maintained same for all the enclosures with different cross-section fins.

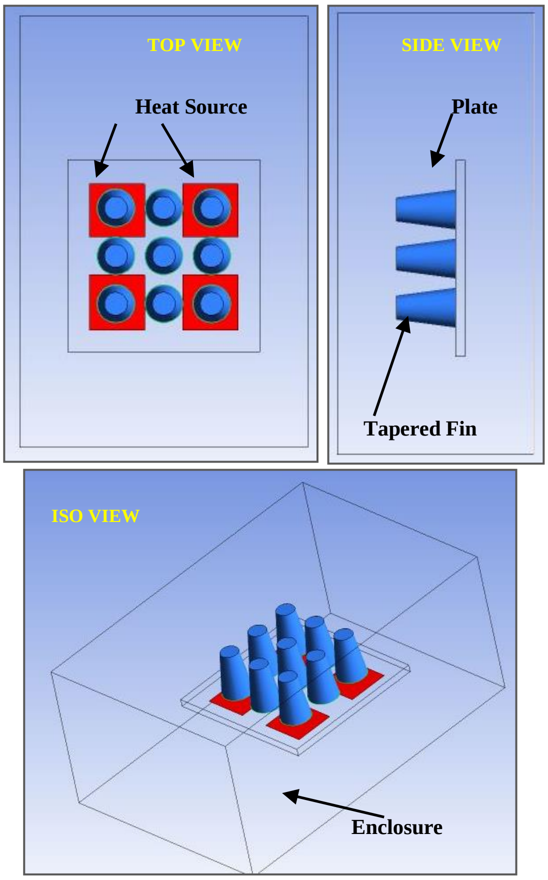

Fig. 3.1 Tapered fin model

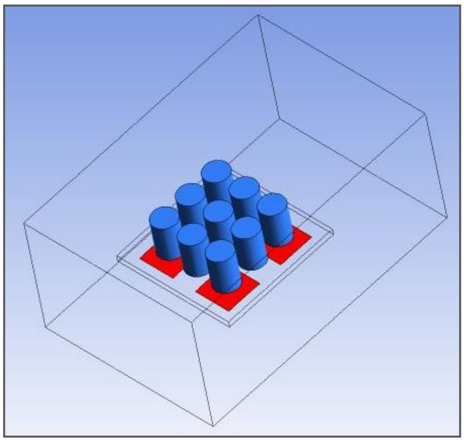

Fig. 3.2 Round fin model

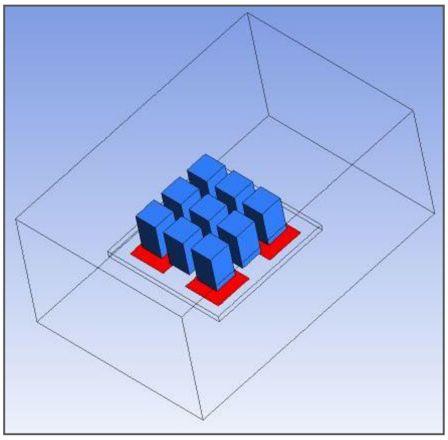

Fig. 3.3 Rectangular fin model

3.2Meshing

The cut plane mesh model of Tapered fin, Round fin and Rectangular fin is as shown in Fig. 3.4, Fig. 3.5 and Fig. 3.6. The Meshing parameters for three models are maintained same. The Models are meshed with Hexagonal elements.

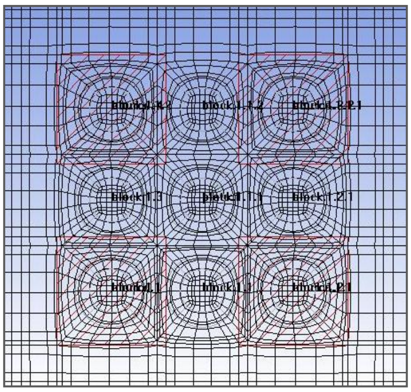

Fig. 3.4 Tapered fin meshed model

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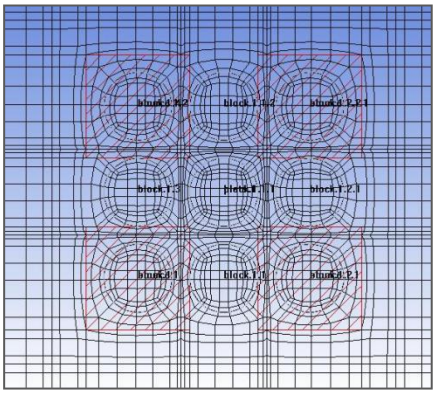

Fig. 3.5 Round fin meshed model

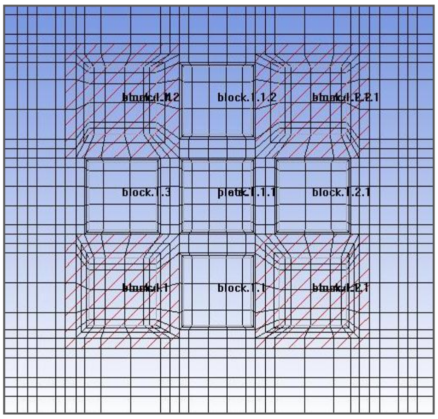

Fig. 3.6 Rectangular fin meshed model

The convergence plot for the Meshed models is as shown in Fig. 3.7. The Residual monitor or convergence criteria for flow and energy are maintained to be 0.001 and 1e-7. Iteration per time step is set for 20 seconds.

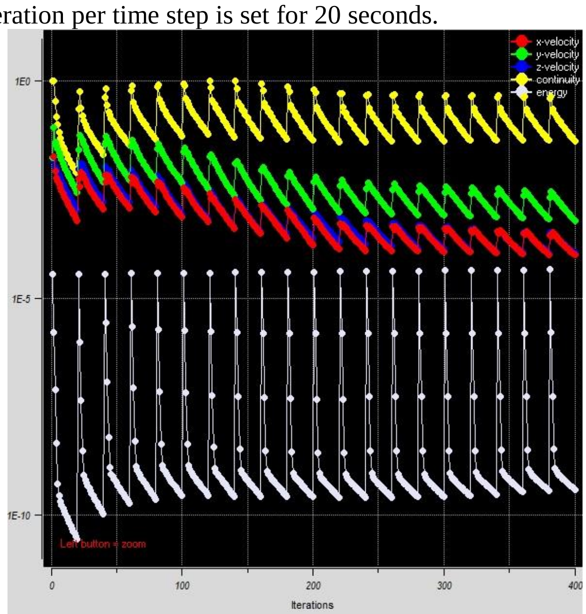

Fig. 3.7 Mesh convergence plot

3.3Solution Methodology

In the present analysis, the enclosure consist for four heat sources each dissipating 100W power, attached to a plate on which different cross-section fins are placed. The fins are subjected to free-convection cooling. The cycle time of 20 seconds is set for each heat sources which are with peak power of 100W. The variation of power is considered according to the equation of exponential curve [18], $P = b \times e^{at}$ where a and b are constants and t is time. The flow is considered to be laminar and at Tranient condition.

4. MATHEMATICAL MODELS

Conservation equations of mass and momentum for all flows are solved in ANSYS CFD and an additional equation for energy is solved for flows involving heat transfer. Flow inside a Electronic enclosure involves both fluid flow and fluid flow with heat transfer, hence governing equations [14] that are solved in ANSYS CFDare as listed below:

Mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = S_m \quad \text{………………………. (eqn. a)}$$

Momentum conservation equation:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla.(\rho \vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\tau}) + \rho \vec{g} + F \quad \text{………………………. (eqn. b)}$$

Where, the stress tensor, τ is given by

$$\bar{\tau} = \mu\,[\,(\nabla \vec{v} + \nabla \vec{v}^{T}) - \frac{2}{3}\nabla.\vec{v}\, I]$$

Energy conservation equation:

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\big(\vec{v}(\rho E + p)\big) = -\nabla.(\textstyle\sum_j hJ_j) + S_h \quad \text{……………………… (eqn. c)}$$

The above equations (a), (b) and (c) are a general form of governing equations and are valid for both compressible and incompressible flows.

5. RESULTS AND DISCUSSION

The velocity and temperature contours results obtained from the Transient analysis on different cross-section fins are discussed in this section. The temperature distribution results obtained for Tapered fin model is dicussed in section 5.1, Round fin model disscssed in 5.2 and Rectangular fin model is discussed in 5.3.

5.1 Temperature contours/distribution for Tapered fin model

Fig. 5.1(a)and (b) shows the Temperature contour for Tapered fin model at the time step of 20 second. The maximum temperature of 37^0C was found at the source. The heat conduction takes place through the thickness of plate from the source. The temperature distribution in detail at different time step is shown in Table 5.1 and Plot 5.1.

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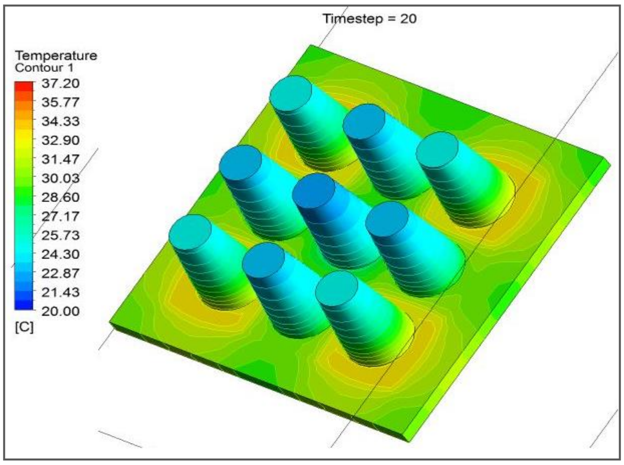


Fig. 5.1(a) Iso view of Tapered fin model

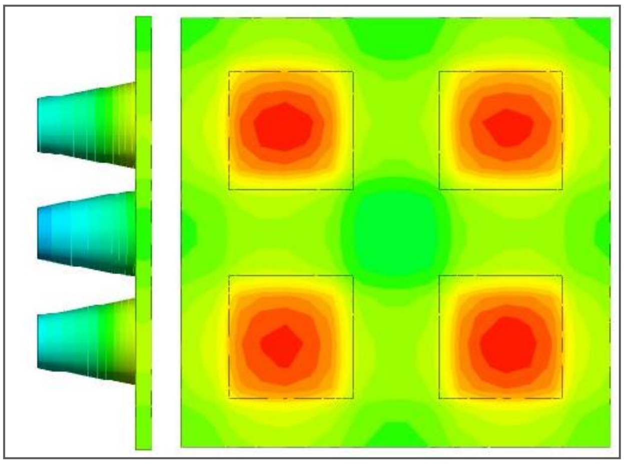
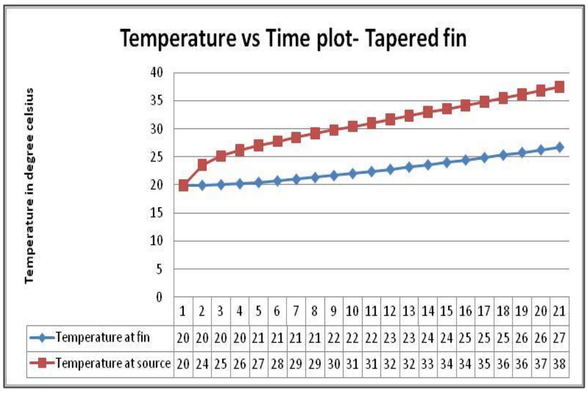


Fig. 5.1(b) Side view and Rear side view of plate attached to fin

Table 5.1 Temperature distribution for Tapered fin at different time step

Time steps	Fin temperature in ^{0}C	Source temperature ^{0}C
0	20	20
1	20.0466	23.6988
2	20.1581	25.2468
3	20.3312	26.2739
4	20.5551	27.1116
5	20.8187	27.8589
6	21.1131	28.5558
7	21.432	29.2225
8	21.7709	29.8707
9	22.1267	30.5078
10	22.4974	31.1386
11	22.8813	31.7666
12	23.2773	32.3942
13	23.6848	33.0232
14	24.103	33.6553
15	24.5314	34.2915
16	24.9698	34.9329
17	25.4177	35.5803
18	25.8749	36.2345
19	26.3414	36.8961
20	26.8168	37.5658



Plot 5.1 Temperature vs Time plot for Tapered fin

From the Table 5.1 and Plot 5.1, it is observed that the maximum temperature reached at time step of 20 second by fin was 26.81^{0}C and source was 37.56^{0}C.

5.2 Temperature contours/distribution for Round fin model

Fig. 5.2 shows the Temperature contour for Round fin model at the time step of 20 second. The maximum temperature of 36^{0}C was found at the source. The heat conduction takes place through the thickness of plate from the source. The temperature distribution in detail at different time step is shown in Table 5.2 and Plot 5.2.

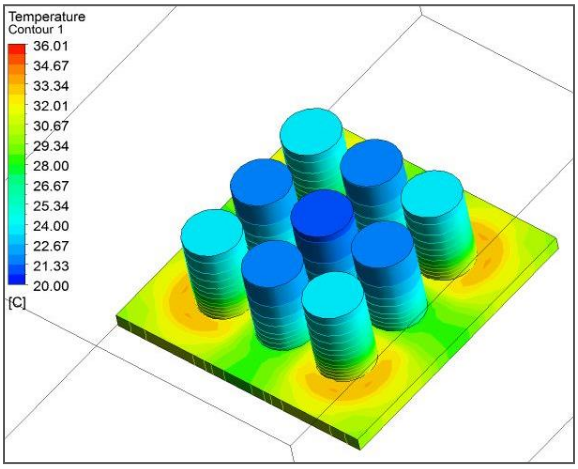


Fig. 5.2 Temperature contour of Round fin model

Table 5.2 Temperature distribution for Round fin at different time step

Time steps	Fin temperature in ^{0}C	Source temperature ^{0}C
0	20	20
1	20.0437	23.1916
2	20.1448	24.7165
3	20.2978	25.765
4	20.4919	26.6187
5	20.717	27.3703
6	20.9656	28.0602
7	21.2323	28.7102
8	21.5137	29.3336
9	21.8074	29.9389
10	22.1118	30.5321
11	22.426	31.1174
12	22.7494	31.698
13	23.0814	32.2762
14	23.4218	32.854
15	23.7703	33.4328
16	24.1267	34.014
17	24.491	34.5984
18	24.863	35.1871
19	25.2425	35.7809
20	25.6297	36.3803

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5.3 Temperature contours/distribution for Rectangular fin model

Fig. 5.3 shows the Temperature contour for Rectangular fin model at the time step of 20 second. The maximum temperature of 36^{0}C was found at the source. The heat conduction takes place through the thickness of plate from the source. The temperature distribution in detail at different time step is shown in Table 5.3 and Plot 5.2.

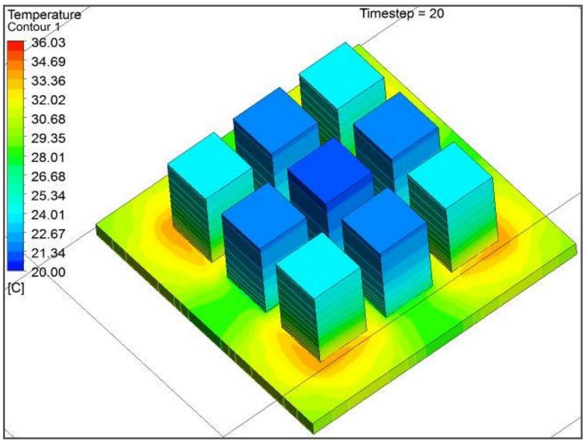

Fig. 5.3 Temperature contour of Rectangular fin model

Table 5.3 Temperature distribution for Rectangular fin at different time step

Time steps	Fin temperature in ^{0}C	Source temperature ^{0}C
0	20	20
1	20.0437	23.1916
2	20.1448	24.7165
3	20.2978	25.765
4	20.4919	26.6187
5	20.717	27.3703
6	20.9656	28.0602
7	21.2323	28.7102
8	21.5137	29.3336
9	21.8074	29.9389
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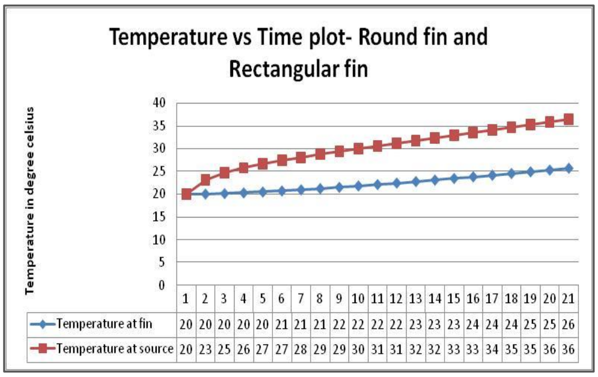
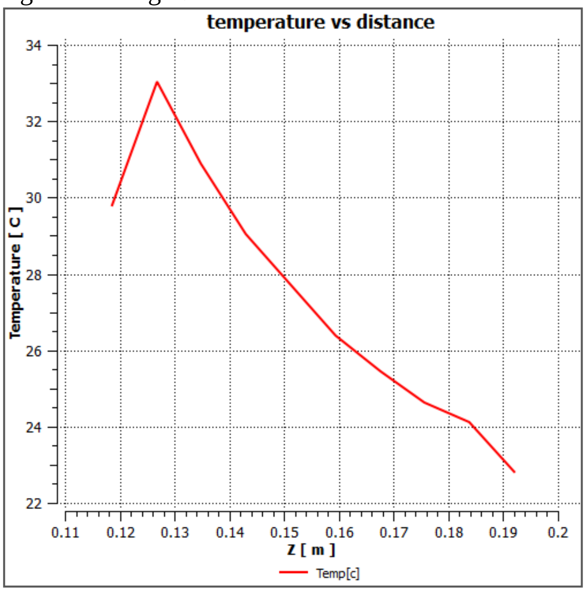
11	22.426	31.1174
12	22.7494	31.698
13	23.0814	32.2762
14	23.4218	32.854
15	23.7703	33.4328
16	24.1267	34.014
17	24.491	34.5984
18	24.863	35.1871
19	25.2425	35.7809
20	25.6297	36.3803

Comparing Table 5.2 and Table 5.3, the temperature distribution for Round fin and Rectangular fin is found to be same. Hence plotting the temperature distribution and is shown in plot 5.2.



Plot 5.2 Temperature vs Time plot for Round fin and Rectangular fin

Also the temperature distribution along the fin length is plotted for all the fin types and is as shown in plot 5.3. It is found that there is continuous reduction in temperature along the fin length.



Plot 5.3 Temperature vs. fin length plot

Comparing the Maximum temperature obtained for all the fin types, it is found that there is increase in temperature by 3% for Tapered fin compared to Round fin and Rectangular fin.

5.4Velocity streamline plots

Fig. 5.4, Fig. 5.5 and Fig. 5.6 shows the velocity streamline plots for tapered fin, round fin and rectangular fin. The maximum velocity achieved through free-convection is 0.2 m/s.

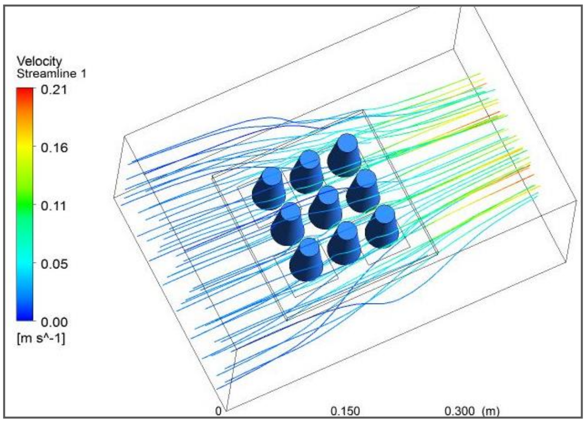


Fig. 5.4 Streamline plot for Tapered fin

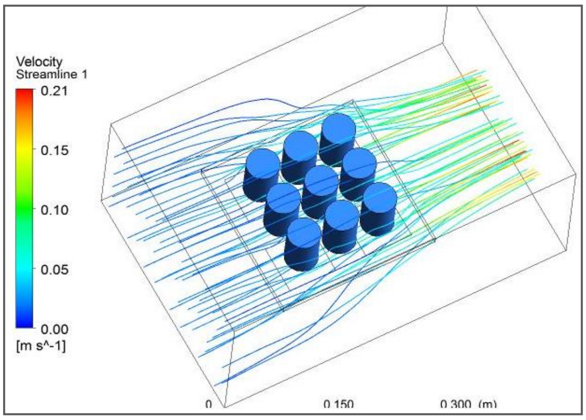


Fig. 5.5 Streamline plot for Round fin

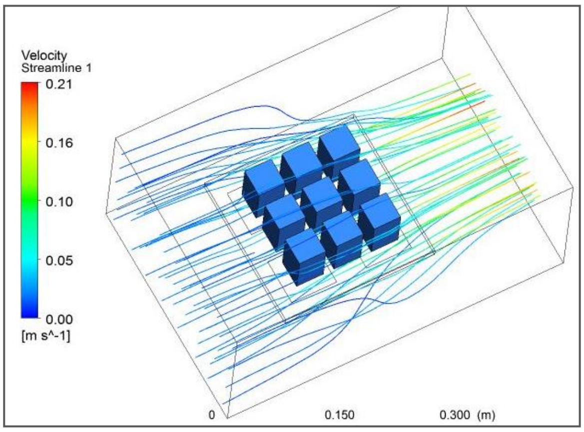


Fig. 5.6 Streamline plot for Rectangular fin

Streamline plots helps in identifying and studying the circulation zones and flow around fins.

6. CONCLUSION

Transient analysis is carried out on Electronic enclosure using commercial CFD software ANSYS. The Transient analysis carried out for time step of 20 seconds on Electronic enclosure for three different cases consisting different cross-section fins such as Tapered fin, Round fin and Rectangular fin attached to a plate with four heat sources each dissipating power of 100W. Cooling of fins is through free-convection. The following are the conclusions drawn from the analysis results are:

1. In determining Temperature distribution at varied time step in carrying out transient analysis, CFD technique is very much effective at minimum time and cost.
2. Analysis is carried out for different cross- section fins for finding optimum temperature level. It was found that there is increase in temperature by 3% by using Tapered fin compared to Round fin and Rectangular fin and hence tapered are recommended.
3. The results obtained through the analysis helps as ready reckoner for beginning Engineers in decision making in selection of fins among different cross-sections and understanding temperature distribution in fins.
4. This work showcases determining transient performance of heat sink under natural convection conditions. Further work on varying pitch of the fins can be taken up to optimize the flow.

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