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Designing and Analysis of Different Types of Fins in an Air-Cooled Engine

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Abstract

This paper is dedicated to the study of various shapes of extended surfaces, commonly known as fins, which are used on cylinder heads of internal combustion engines. Extended surfaces are used to improve heat dissipation from the object by increasing its effective surface area. Efficient heat dissipation is very important since proper cooling of an engine cylinder head helps to maintain optimal working temperatures, improves engine performance, increases service life, and prevents overheating. This means that the correct selection of extended surfaces for the engine is crucial for achieving optimal thermal conditions. In order to carry out investigations, various fin configurations are created with SolidWorks 2022 software. Created fin models are then exported to ANSYS Workbench 15 for thermal and computational fluid dynamics (CFD) analysis of fins. For the evaluation of thermal properties of various shapes of extended surfaces, a steady-state thermal analysis will be conducted. CFD analysis will also be performed using ANSYS Fluent software. The same boundary conditions will be set for all types of fins in order to compare their thermal characteristics. The main goal of the present study is to determine the fin configuration that will be optimal for heat transfer. Such criteria as temperature distribution, heat fluxes, thermal gradients, flow patterns, and cooling efficiency are considered and analyzed in the work. In addition, the influence of fin geometry on the speed of heat transfer is studied. The results of thermal and CFD analysis presented in the current paper can help to find out which fins perform better at heat transfer. It can be seen that fin geometry plays an important role in cooling efficiency. Some shapes are better than others because of more efficient heat transfer. The conclusions drawn in the paper can be helpful for engineers when designing the cooling system for cylinder heads.

Keywords: Extended surfaces (Fins), cylinder head cooling, heat transfer enhancement, thermal and CFD Analysis, cooling efficiency

INTRODUCTION

The heat produced on the inner walls of the cylinder in I.C. engines ranging between 1500°C and 2200°C can cause system failure, the explosion of the engine from detonation or burning of the fuel before its cycle period, higher waste, and less efficiency. We know that in an I.C. engine, air and fuel burn inside the engine cylinders, resulting in high-temperature gas generation. The gas does indeed have a temperature from 2100 to 4000°C. The oil film between moving components may be burned at this extremely high-temperature, which might lead to seizing or welding [1–5]. This temperature is therefore reduced to about 150–200°C, where the engine operates most efficiently. Therefore, any cooling system's goal is to keep the engine running as efficiently as possible at the temperature.

As it lowers thermal efficiency, excessive cooling is likewise undesirable. Remembering it, the cooling system is designed because the engine is very inefficient when cold. This allows the engine to warm up and prevent cooling down until maximum efficiency operation reaches the temperature, then begins to cool down. Heat is

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transferred to the surroundings to avoid overheating and adverse effects. As the power output and density of I.C. engines have gradually increased, the engine cooling system's performance has consistently improved [6]. Heat (above a certain level) should be removed and vented to the atmosphere as soon as possible that would be right. It can be said that a cooling system is a temperature control system. It is necessary to remember that heat deprivation from working fluid by cooling engine components is a direct thermodynamic loss [7–9].

I.C. engines are a factor in the global economic system's economic advancement. It gives way to a generation of large, gas-powered vehicles like vans, trucks, and buses. Internal combustion engines are utilized in both passenger and heavy-duty civil engineering vehicles; even when those engines are working, they produce an inordinate degree of heat. Air- cooled, oil-cooled, and water-cooled engine systems all use fins to help dissipate heat [10].

The fins are particularly important for the cooling of engines, and it is described as:

- Air-cooled engines
- Oil-cooled engines
- Water-cooled engines

Air-Cooled Engines

Both compression ignition engines and spark ignition engines make use of these types of engines. It consists of fins surrounding the combustion cylinder; as a result of direct air contact, the cylinder is cooled with the intervention of the fins.

Oil and Water-Cooled Engines

Oil-cooled and water-cooled engines with fin configurations are phrases used to describe the mild distinction between the cooling systems.

Oil Cooling

The majority of the thermal efficiency switch is made up of the fins on the engine block; thus, technically, an oil-cooled engine is an air-cooled engine with oil cooling assistance. Compared to liquid-cooled engines, air-cooled engines are typically more fuel-efficient, more affordable, and require less engine space. Compared to air-cooled engines, liquid-cooled engines cost more to maintain.

The simplest method to avoid any engine failure is to reduce the heat produced by transferring heat, i.e., heat transfer. Since the engine that is considered for the present study is air-cooled, the most suitable mode of heat transfer is convection.

An increment in convective heat transmission between solids and fluids depends on the surface area, the heat transfer coefficient, and the temperature differential. An adverse consequence of these tactics is increasing pressure. Finned surfaces, metal protrusions used to increase surface area, are often the primary contact area inside the fluid flow. These fins can be either cast, welded, or mechanically attached to the surface where the heat transfer is needed.

The fins can be of numerous designs, e.g., straight, triangular, circular, annular, constant areas, varying areas, etc. [11]. The most important component of the most advanced internal combustion engine is fluidly cooled, which is a very complicated structure. Putting such a structure on a bike engine significantly increases its weight and adds to its cost. In order to keep the price down, a bike known as an air-cooled framework uses a straightforward yet effective design (Figure 1).

To make this cooling form quick and practical, the engine body is extended with metal fins that form surface zones. The increased surface area improves air contact and heat removal rates. Technically, heat flows from the engine compartment to the metal fins by conduction 1, 2].

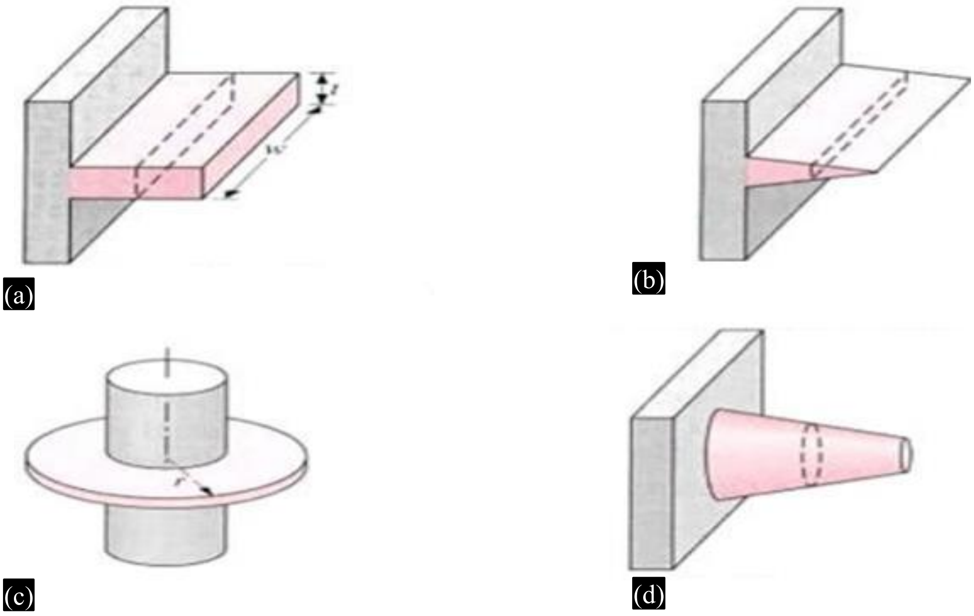

Figure 1. (a)–(d) Types of fins [6]. (a) Straight fin of uniform cross-section; (b) straight fin of nonuniform cross-section; (c) annular fin; (d) pin fin.

The engine packing is manufactured with either aluminum or carbon steel to reduce heat extension. Ingenious bike engines for standard motorcycles use aluminum fins. The use of combination materials provides an additional engine cooling measurement with significant effects on heat dispersion [3–5].

This paper proposes types of straight fin, rectangular fin, circular fin, wavy fin, triangular fin, and maze fin.

Air Cooling

Significant parts of the engine are usually left exposed to the atmosphere. For vehicles, while driving, the air hits the engine at a certain relative speed, sweeping away its heat. This manner of extorting heat from the air by natural convection is called natural air cooling. Engines installed in motorcycles are mainly cooled with natural air. It is necessary to enhance the engine's frontal cross-sectional area because heat dissipation depends on it. Engines with increased area are bulkier and have less power due to the weight relationship. To expand the frontal cross-sectional area of the engine as a substitute arrangement, ribs and fins are created. Sharp protrusions on the surface or head of the cylinder block are called fins (or ribs). In the space between the cylinder and the air, they increase contact with the outside world. Fins can be connected to the cylinder, but are typically cast as an inherent part of the cylinder.

Fins

A fin is a surface that extends from an object to increase the heat transfer rate to or from its surroundings. The amount of heat is determined by the amount of conduction, convection, and radiation of the object forward. Heat transfer can be increased in the following ways, as mentioned below.

- Convection heat increases as the temperature differential between the object and its surroundings widens.
- Heat transfer is accelerated by expanding the body's surface area or heat transfer coefficient. Not always economical.

These factors cannot be changed. However, adding fins to the object increases the surface area. It can be an economical solution to heat transfer problems. Circumferential fins around the motorcycle engine cylinder and fins attached to refrigerator condenser tubes are well-known examples.

1. Fins are extruded surfaces designed to increase heat transmittance for a specific surface temperature or decrease the surface temperature at a predetermined heat transmission rate.
2. Heat transfer occurs via convection between two surfaces; as a result, the surface area of fins is frequently increased during production.
3. To maintain the system's steady-state, heat conduction via solids, walls, etc., the boundary is the environment or the environment. In engineering applications, a tiny region must generate a lot of heat.
4. Fins improve each model's effective surface area, which boosts convectional energy transmission. Straight fins include triangular and rectangular shapes. Wavy fins are visually appealing and use a lot less space to transfer heat than rectangular slats. Due to cheap manufacturing, there is a maximum heat flow per unit mass; the fin's practical importance is significant.

Fins are used in the following applications:

- Automobile radiators.
- Economizers, heat exchangers, air-cooled I.C. engines, such as those found in scooters, bikes, and air compressors.
- Cooling systems for electric motors, transformers, electrical equipment, chips, and I.C. boards [7–11].

However, the following assumptions are assumed before investigating the fin:

- Continuous conduction without the creation of heat in the fin.
- The material is homogeneous and isotropic; thickness t is tiny compared to length L and breadth w; thermal conductivity k is constant.
- The constant heat transfer coefficient, h.
- Minimal radiation impact [12].

LITERATURE REVIEW

Researchers have presented a paper demonstrating heat transfer analysis for triangular and rectangular fins. Cylinders with surface temperatures ranging from 200°C to 600°C and lengths ranging from 6 cm to 14 cm are used in the analysis. The first set of metrics, including heat flow, heat flow per unit of mass, efficiency, and efficacy, is determined. By changing the fin length and keeping the base temperature at 600°C, the comparison is conducted with rectangular fins. The triangular fins have a larger heat flux than the rectangular fins do, and the rectangular fins have a higher heat flux rate per unit mass than the triangular fins, according to the results. In comparison to rectangular fins, triangular fins are more effective and have lower efficiency. For the same length of 10 cm and a fin base temperature range of 200°C to 600°C, the results are as follows: Triangular fins are less efficient than square fins, less effective than square fins, and more efficient than triangular fins [13].

Upon examining how heat is dissipated by fins of various geometries. The primary objective is to accelerate the fins' rate of heat transfer. By altering particular characteristics and shapes, this can be accomplished. CAD software parametric 2.0 was the modelling programme used. With ANSYS14.5, an analysis is performed. The triangular fins constructed of the aluminum alloy 6061 are superior, as can be shown by looking at the analytical findings. Due to their superior temperature drop and heat transfer coefficients compared to other fins, triangular fins are used in this way. Practical results from the software provide strong support for theoretical calculations for calculating fin heat loss, efficacy, and efficiency [14].

Research work studied fins of various materials in a pin fin apparatus for both natural and forced convection. The heat transfer characteristics can be improved, and the performance of fin efficiency can be investigated. The heat transmission of fins made of various materials was examined experimentally, and the results indicate that aluminum fins are more efficient than those made of brass and mild steel [15]. The comparison of different materials for their efficiency as a fin material is shown in Figure 2.

An experiment was performed with the goal of investigating how the performance of tiny, ribbed flat tube heat exchangers is affected by rib geometry. The three rib types are square-grooved, wavy, and smooth. This study shows that when compared to smooth corrugated fins, rectangular fins perform better in terms of heat transfer. Smooth fins provide the lowest heat transfer performance and the maximum efficiency. It turns out that applications where thermal performance takes precedence over hydraulic performance or efficiency are appropriate for rectangular fins [16]. The finding is shown in Figure 3, which shows the efficiency of different fins against Re.

A researcher's primary purpose is to compare materials with composites and study variable thermal conductivity. Also, assessed the response of copper, mild steel, and composite bars to the temperature distribution along the fin. As a result, it becomes mandatory to influence the performance of the slabs. Increasing and decreasing the thermal conductivity of metal with temperature depends on the material and the temperature range. Further away, experimental investigations and thermal analyses of nanoparticle copper coatings on cylindrical aluminum pin fins are performed [17].

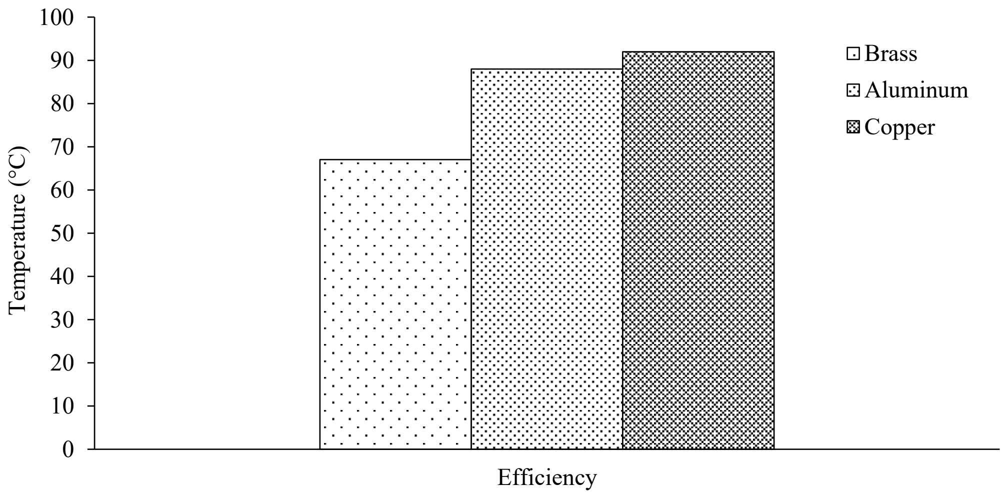

Figure 2. Efficiency of different materials fin [15].

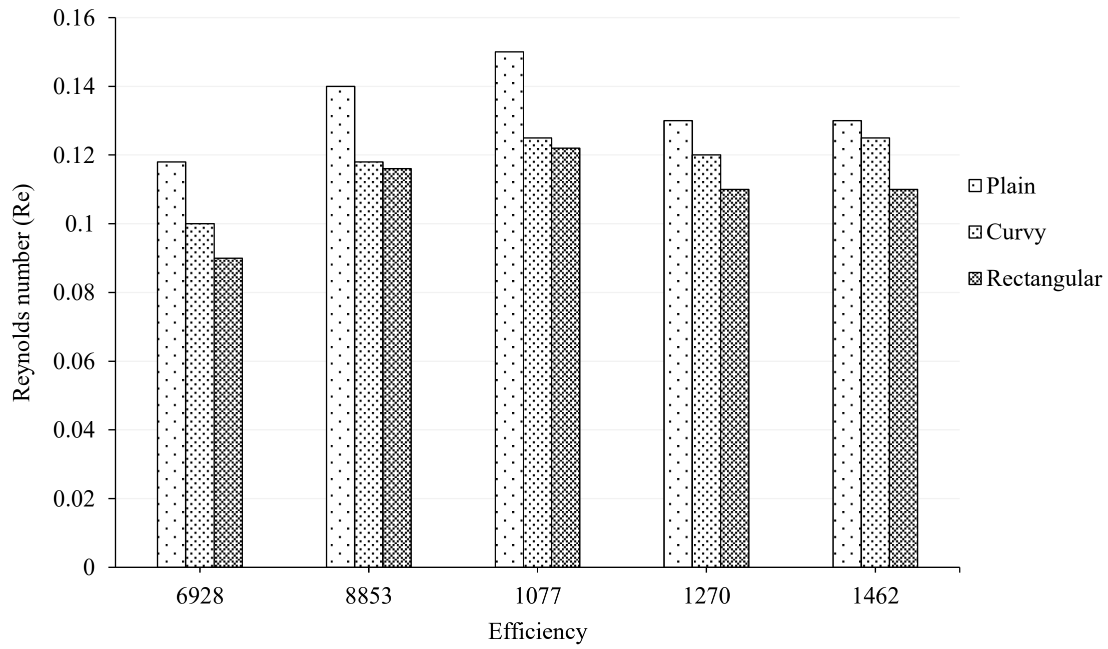

Figure 3. Efficiency of different fins against Re.

Conducted research for the investigation of convective heat transfer, aluminum 6063 bars were fabricated with three different surface roughnesses, thermal transmittance, and heat transfer coefficient were tested. Smooth aluminum 6063 rods have high heat transfer rates and coefficients when compared to aluminum rods with rough surfaces. More heat can be removed from the pin fin material by the transmission than by free and forced convention, in addition [18]. Figures 4(a–d) illustrate the variation of the heat transfer coefficient and rate of heat transfer under free and forced convection conditions. It is observed that forced convection exhibits a higher heat transfer coefficient and enhanced heat transfer rate compared to free convection, demonstrating the significant influence of fluid motion on thermal performance and fin heat dissipation efficiency [18].

An experimental investigation on thermal behavior and a finite element analysis of aluminum alloy 6061 engine cylinders with different rib thicknesses and shapes. Results from finite element analysis (FEA) and experiments demonstrate that the temperature distribution has the highest value for a rectangular fin cylinder with a fin thickness of 3.5 mm, and the minimum value is for 2.5 mm thick triangular fins [19].

A presented research paper shows the results of investigating and analyzing the heat transfer coefficient and pressure drop of various- shaped fins with rectangular channels, all having the same surface area. Rectangular and Circular are the two shapes of fins used in the analysis.

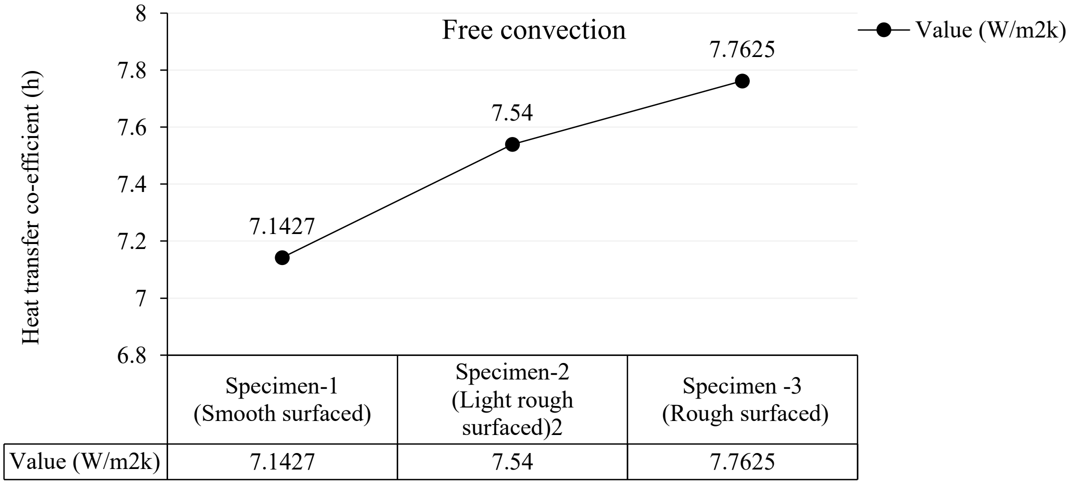

Figure 4. (a) Heat transfer coefficient for free convection [18].

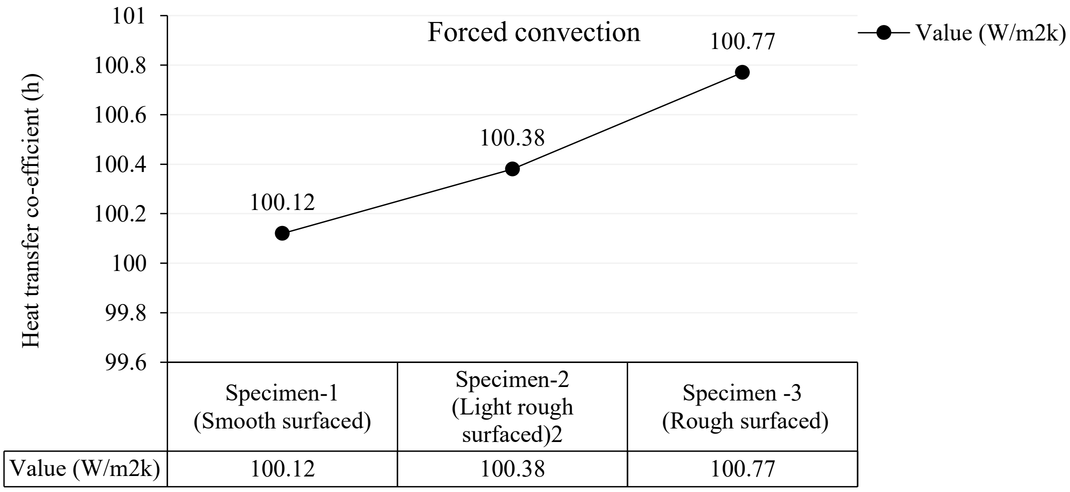

Figure 4. (b) Heat transfer coefficient for forced convection [18].

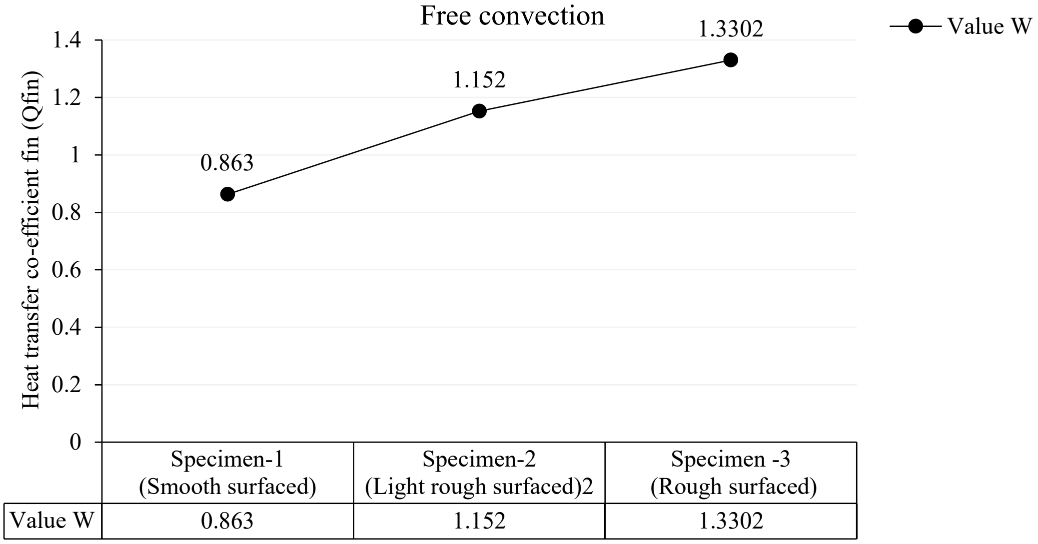

Figure 4. (c) Rate of heat transfer for a fin for free convection [18].

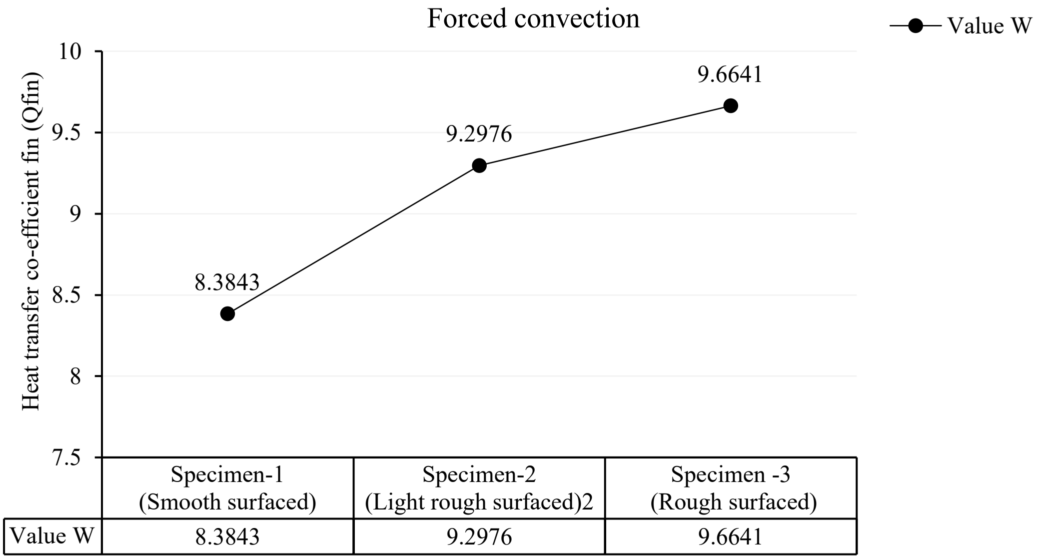

Figure 4. (d) Rate of heat transfer for forced convection [18].

The objective of this work is to establish the ideal sizes and configurations for circular pinned fins and rectangular vertical fins when lateral heat conduction is taken into account. The optimal dimensions of the fins stated above are also examined in this study, as well as the impact of varying heat transfer coefficients. The findings indicate that rectangular fins have the lowest heat transfer coefficient, while circular fins have the highest. Circular and rectangular fins in ducts have different pressure loss characteristics. The aforementioned information leads us to the conclusion that circular fins maximize heat transmission [20].

A paper presented an experimental analysis to determine effectiveness, efficiency, and heat transfer coefficient. They measure the heat transfer coefficient of three different-shaped pin fins of the same aluminum length. The real temperatures for all three fins are a little bit higher than the anticipated temperatures because of radiation heat loss. The free convective heat transfer coefficient has a maximum value for circular fins, followed by triangular fins, and a minimum value for square fins, but for forced convection, circular fins have the most significant value, followed by square fins, and the last one is triangular fins. Triangular fins have the highest efficiency in both free and forced convection [21].

A performance analysis using simulation and experimental techniques for the investigation of the heat transfer rate and temperature distribution of different fin geometries. They experimented with different heat inputs to accommodate different geometries. The results show that the heat transfer coefficient is high. The results also show that the heat transfer coefficient is higher when there is no insulating triangular fin, followed by an insulating triangular fin, a tapered pin rib, and a pin rib. In all conditions, it is ideal for the fin tip temperature to match the ambient air temperature. However, in practice, the temperature of the fins is not the same as the ambient temperature, and the heat transfer is expanded [22].

A project with the primary goal is to analyze thermal properties with different geometries and materials, and the thickness of the cylindrical rib. The model was created in Pro/ENGINEER, and the analysis was done in ANSYS. The material geometries used for the analysis are aluminum alloy 204, aluminum alloy 6061, a rectangular, curved shape, and circular magnesium alloy. The analysis reveals that the 2.5 mm thick aluminum alloy 6061 has circular fins and yields better results because of the better heat transfer. Theoretical calculations show that using circular fins results in higher heat loss and better efficiency, which is even more effective [23].

A presented paper demonstrating heat transfer analysis for triangular and rectangular fins. Cylinders with surface temperatures ranging from 200°C to 600°C and lengths ranging from 6 cm to 14 cm are used in the analysis. The first set of metrics, including heat flow, heat flow per unit of mass, efficiency, and efficacy, is determined. By changing the fin length and keeping the base temperature at 600°C, the comparison is conducted with rectangular fins. The triangular fins have a larger heat flux than the rectangular fins do, and the rectangular fins have a higher heat flux rate per unit mass than the triangular fins, according to the results. In comparison to rectangular fins, triangular fins are more effective and have lower efficiency. For the same length of 10 cm and a fin base temperature range of 200°C to 600°C, the results are as follows: Triangular fins are less efficient than square fins, less effective than square fins, and more efficient than triangular fins [24].

A trapezoidal and rectangular rib with variable rib cross-section research work. The temperature change in the experimental setup under various heat input settings and the temperature change throughout the length of the fin were used to measure it. Experiments have shown that the heat transfer coefficient of forced convection is greater than that of natural convection of both fins. They also observe a two times higher heat transfer coefficient compared to both fins. For both natural and forced convection, trapezoidal fins have higher heat transfer coefficients than rectangular fins . Figure 5(a) and (d) represent the change in temperature in relation to fin length in cases of rectangular fins and trapezoidal fins. Figure 5(b) and (c) represent the change in temperature concerning heat flux in cases of trapezoidal fins and rectangular fins. According to the graphs, trapezoidal fins possess higher thermal effectiveness than rectangular fins in natural and forced convection.

Figure 6 shows the variation in the temperature profile along the fin length. There is a steady drop in temperature along the fin length as a result of heat transfer to the surroundings.

Work on finding the best shape and material for the fins. For selecting geometries and materials for fabrication, the literature is reviewed. The manufactured model is attached to the base plate and heated with a heater for a certain period. The best form and material for the slats are then determined by measuring temperatures at various locations with the use of an infrared gun. From the experiments, we can conclude that the triangular shape is more suitable due to the better heat dissipation from the triangular fins, and copper is the most suitable material due to copper's more excellent heat dissipation. However, factors to consider for manufacturing include cost, weldability, density, and machinability of the material. Considering parameters such as cost and weight, aluminum can be used as an alternative material instead of copper. Transfer rates are slightly different .

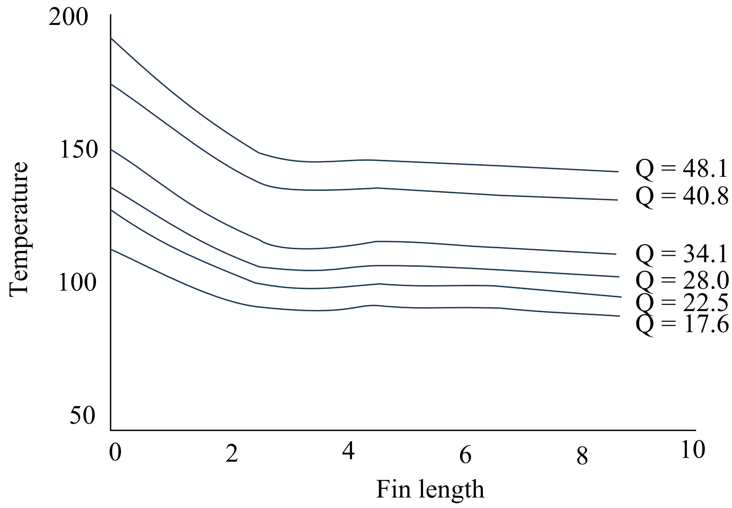

Figure 5. (a) Variation of temperature with rectangular fin, Fin length.

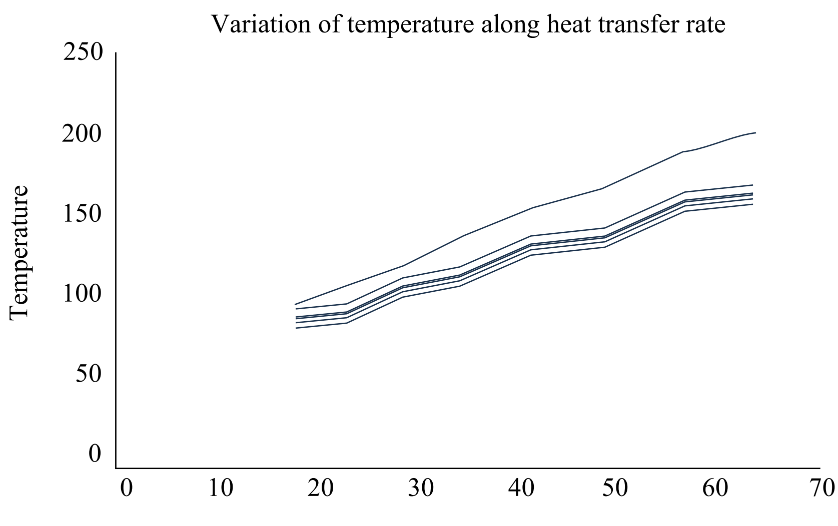

Figure 5. (b) Variation of temperature with heat flow in a trapezoidal fin.

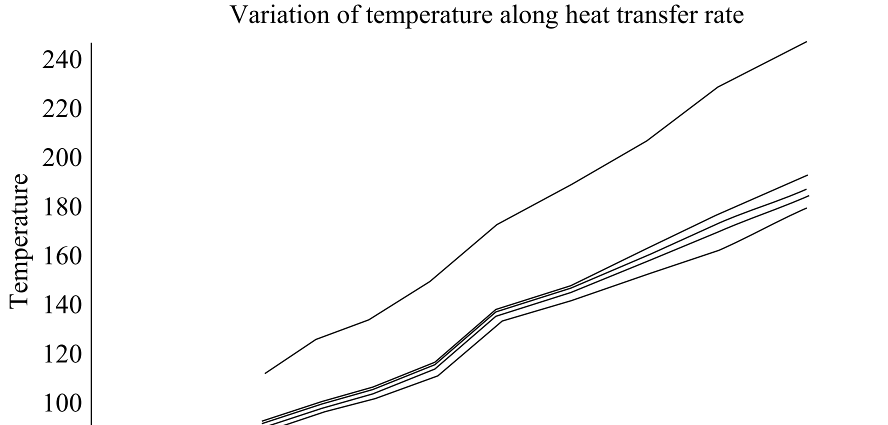

Figure 5. (c) Variation of temperature with flow in a rectangular fin [10].

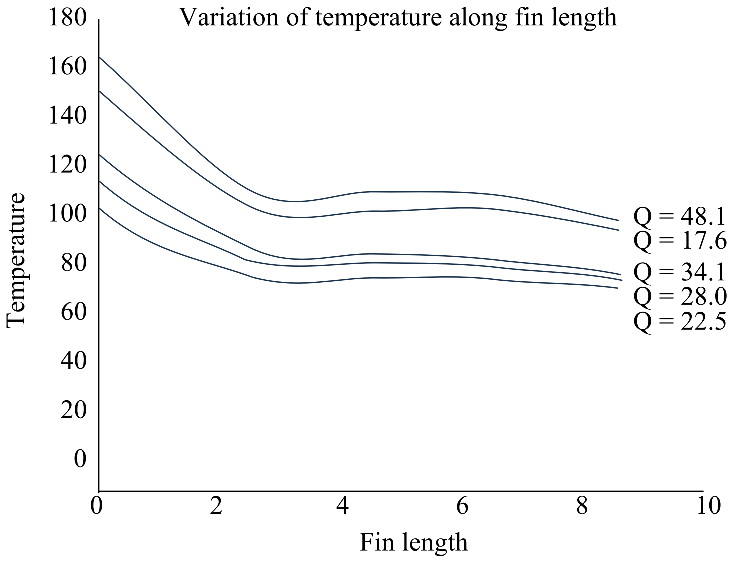

Figure 5. (d) Variation of temperature heat with trapezoidal fin, fin length.

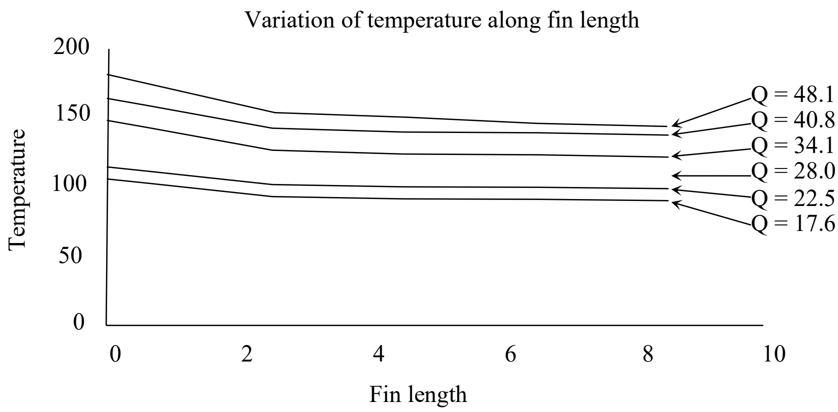

Figure 6. Temperature along fin length.

Using expanded surfaces known as fins might improve heat transmission from a condenser (a heat exchanger). The fin material, fin spacing, fin shape and size, and thermal conductivity all affect how quickly heat is transferred through the condenser. This experimental study focuses on the relationship between capacitor performance and its fin geometry. For different fin geometries, the condenser's heat transfer coefficient is computed. Comparing a rectangular condenser fin form to a circular condenser fin shape, the heat transfer coefficient via the condenser is more pronounced. Because rectangular fins have a bigger surface area than other rib forms, they have a higher heat transfer coefficient.

METHODOLOGY

Model Descriptions

Existing Design of Fins

The engine cylinders with rectangular fins and angular fins have been designed using SOLIDWORKS 2022, as shown in Figures 7(a), (b) and 8. The dimensions of the cylinder and the fins have been obtained from the research work of Pankaj Rao et al. [15].

Engine with New Design of Fins

One of the factors that influences the effectiveness of fins is to increase the ratio of circumference to contact area. The cylinder has been redesigned with a triangular, wavy, maze, and trapezoid fin. 3D model of this structure is shown in Figures 9, 10, 11, and 12, respectively.

Analysis of the Fins

The finite element method (FEM) is a reliable numerical method for engineering analysis of a draft. FEM replaces complex problems with simple problems; it breaks the model into many small parts. The percentage of items with simple shapes, called elements, and regular points called nodes. The behavior of these items is well recognized among all viable items, support, and cargo contingencies. Each movement of nodes is fully defined by their translations in the X, Y, and Z directions.

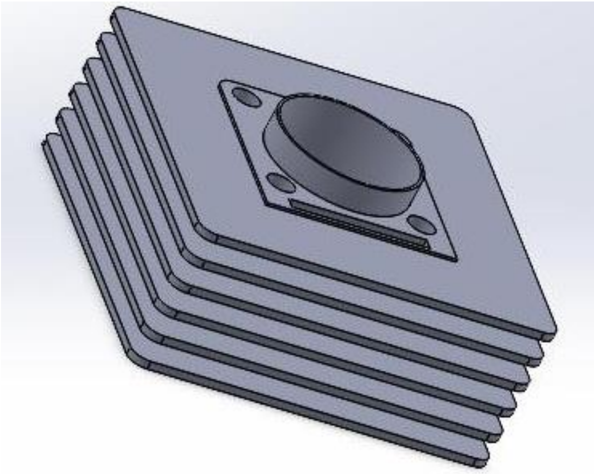

Figure 7. (a) Engine cylinder with rectangular fins designed in SOLIDWORKS.

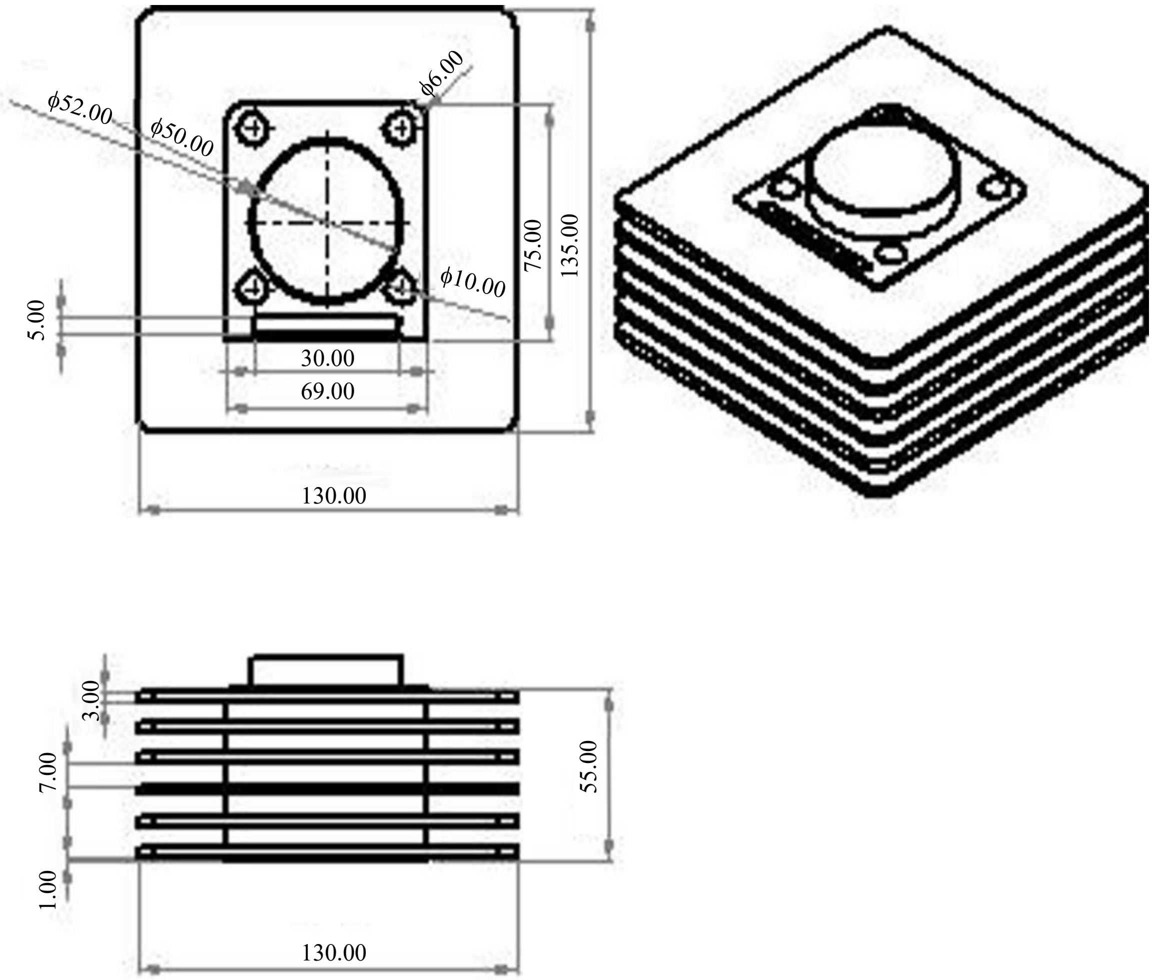

Figure 7. (b) Engine with the rectangular fin.

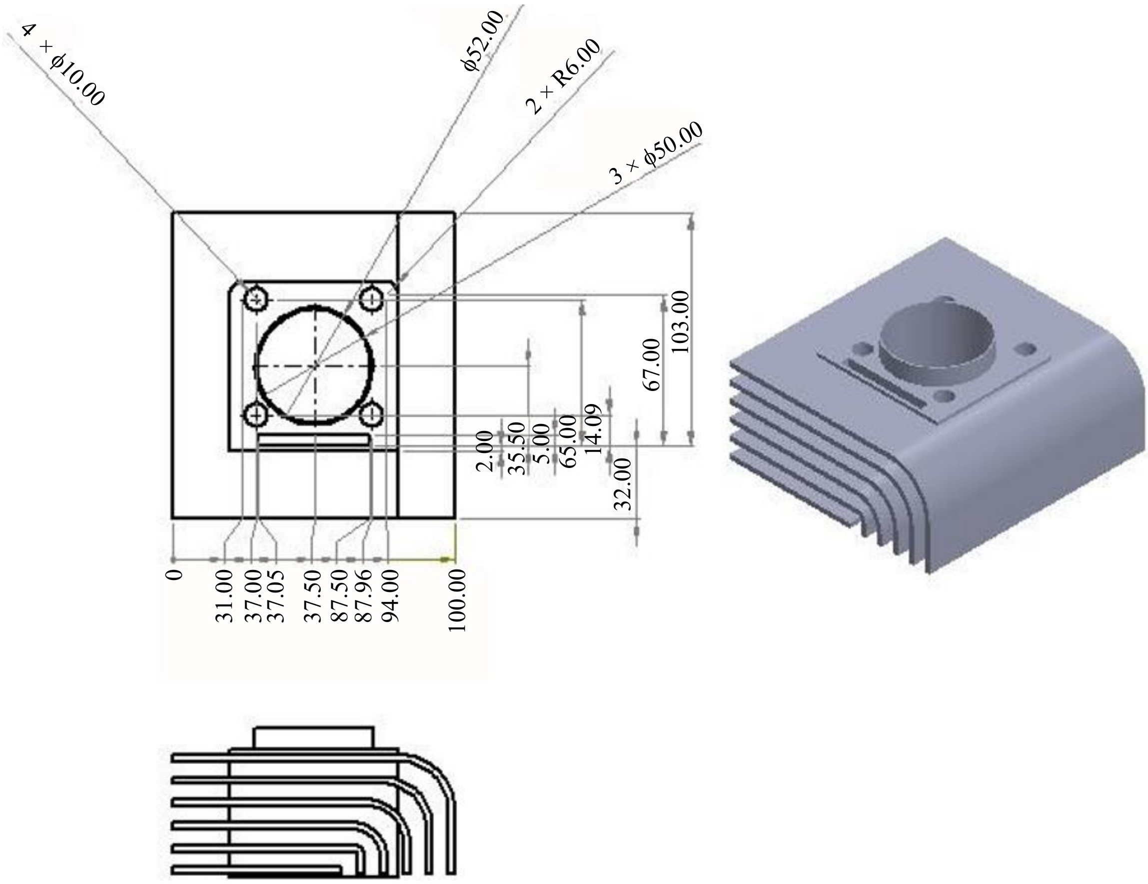

Figure 8. Engine with angular fin.

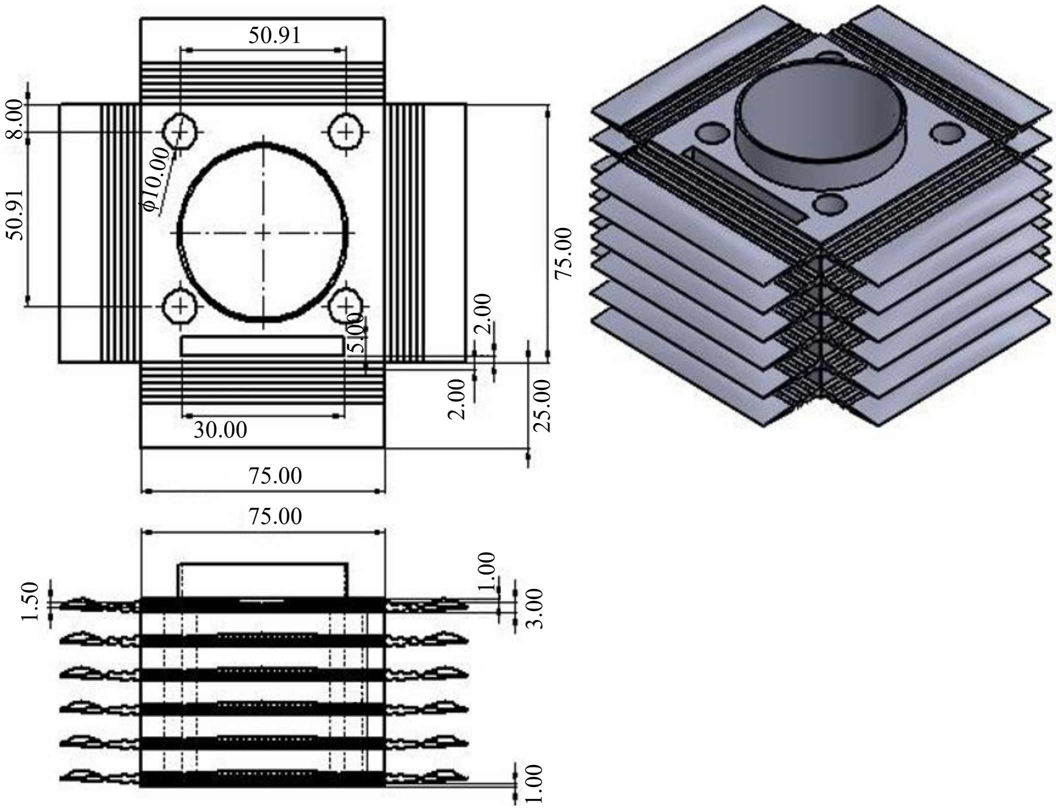

Figure 9. Engine with triangular fin.

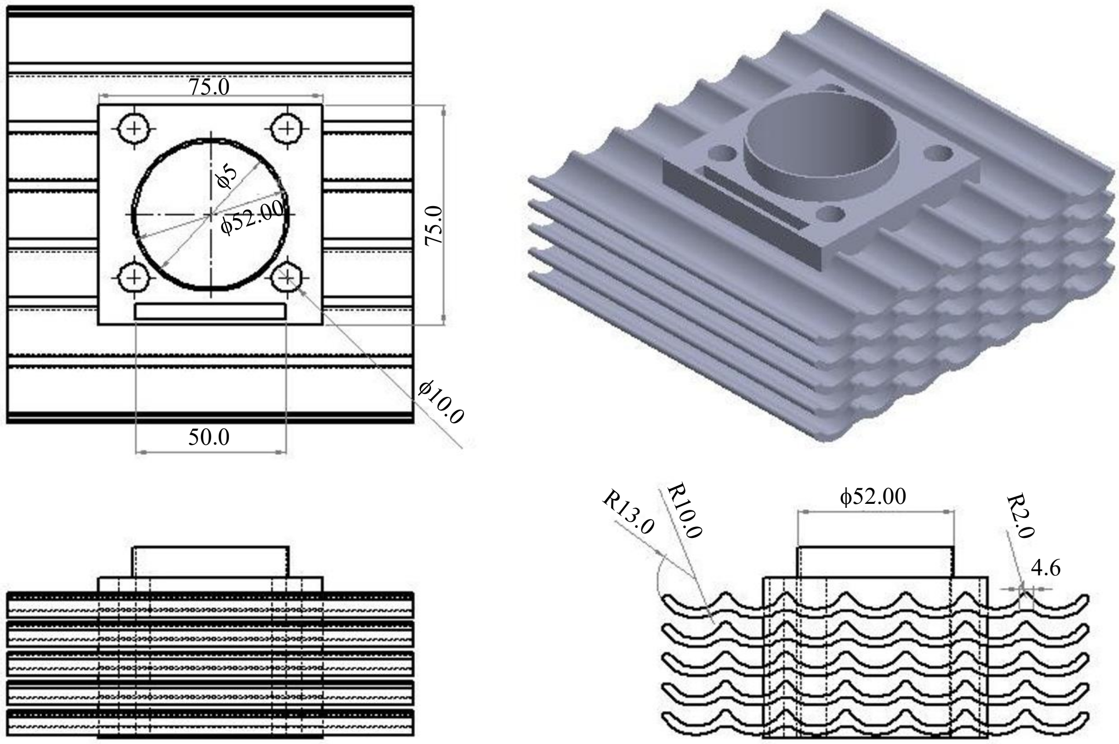

Figure 10. An engine with a wavy fin.

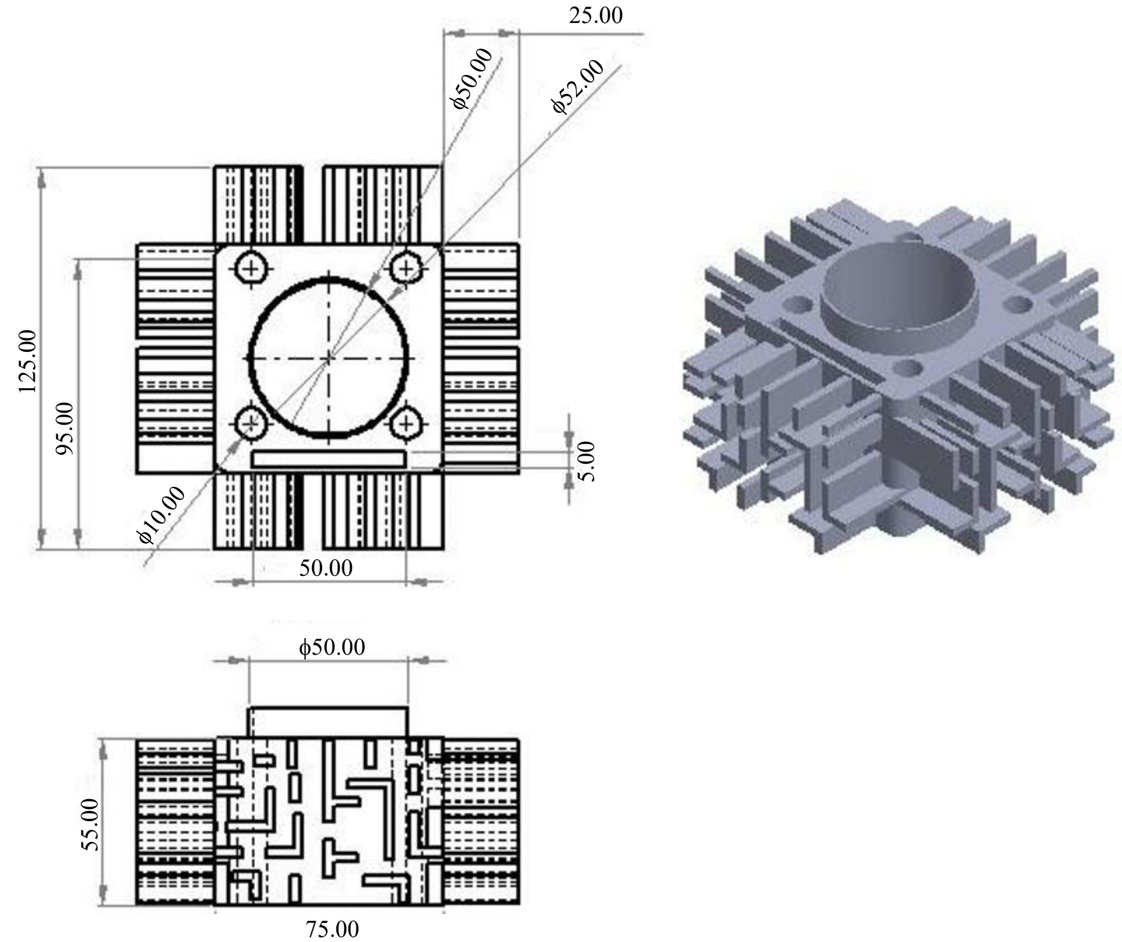

Figure 11. Engine with a maze fin.

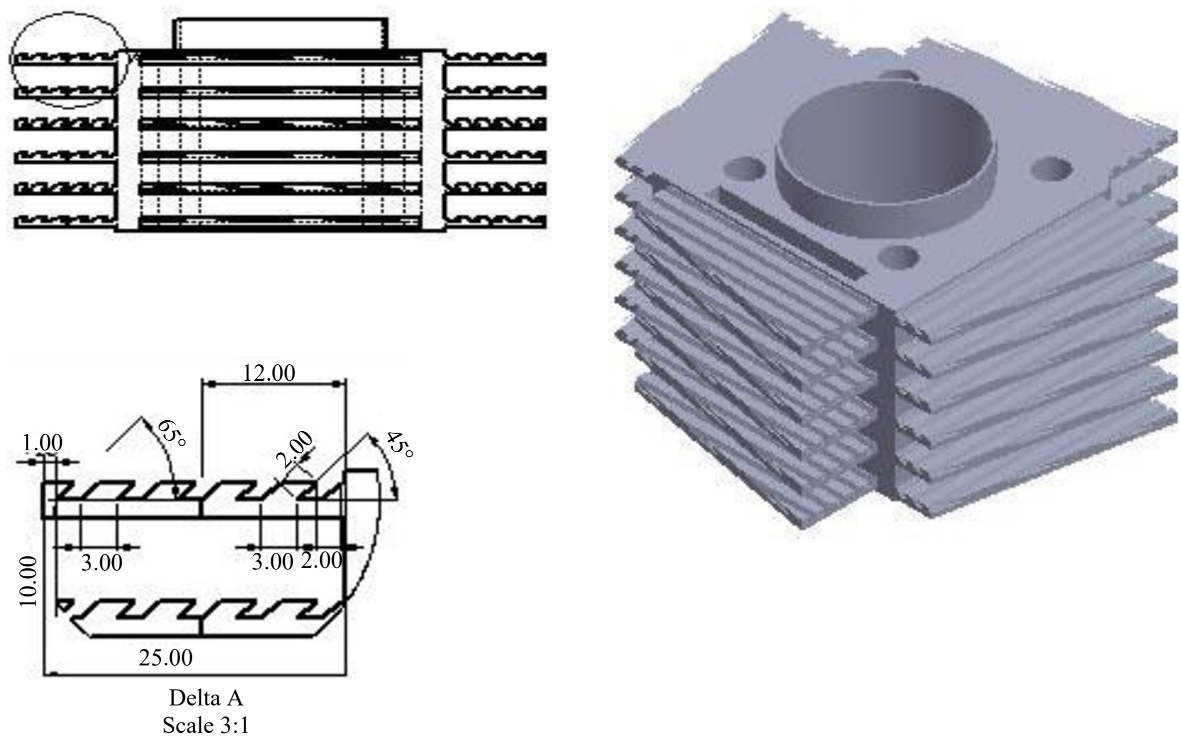

Figure 12. Engine with trapezoid fin.

Table 1. General description of analysis.

Object name	**Steady-state thermal (A5)**
State	Solved
Definition	
Physics Type	Thermal
Analysis	Steady-State
Solver Target	Mechanical APDL
Options	
Generate Input Only	No

These are helpful as a degree of freedom (DOF). Analyzing the use of FEM is called FEA. Geometry modelling can be done in ANSYS Workbench or using another CAD system. In this work, the geometry was modelled in SOLIDWORKS 2022 and imported into ANSYS for meshing and solving.

Steps to solve a problem:

- Define modelling goals
- Create model geometry
- Mesh generation
- Solver and physics model setup
- Solution calculation and monitoring different fins

The general settings used for steady-state thermal analysis are summarized in Table 1.

Steady-State Thermal Analysis of Different-Shaped Fins

The different shapes of air-cooled fins are analyzed. The analysis is performed using ANSYS software. Meshing, solvers, material selection, boundary conditions, etc., are performed step by step, and the results are analyzed.

Material Selection for Steady-State Analysis

Now, since the geometry exists, define the material library of the necessary materials that compose the object (or project) being modelled. This includes thermal and mechanical properties. The most suited material for the job that meets the entire criterion is general aluminum alloy (Fatigue properties come from MIL-HDBK-5H, page 3–277). The property of the material is as in Tables 2(a) and (b).

Meshing for Steady-State Analysis

The geometry is imported from SOLIDWORKS to ANSYS software and meshed in ANSYS WORKBENCH 15 with the following parameters, as shown in the table. The mesh parameters for angular, rectangular, wavy, maze, triangular and trapezoidal fins are summarized in Tables 3,4,5,6,7,8 respectively with the Figure 13 showing meshing of angular fin for steady-state analysis, Figure 14 showing meshing of rectangular fin for steady-state analysis, Figure 15 showing meshing of wavy fin for steady-state analysis, Figure 16 showing meshing of maze fin for steady-state analysis, Figure 17 showing meshing of triangular fin for steady-state analysis, Figure 18 showing meshing of trapezoidal fin for steady-state analysis.

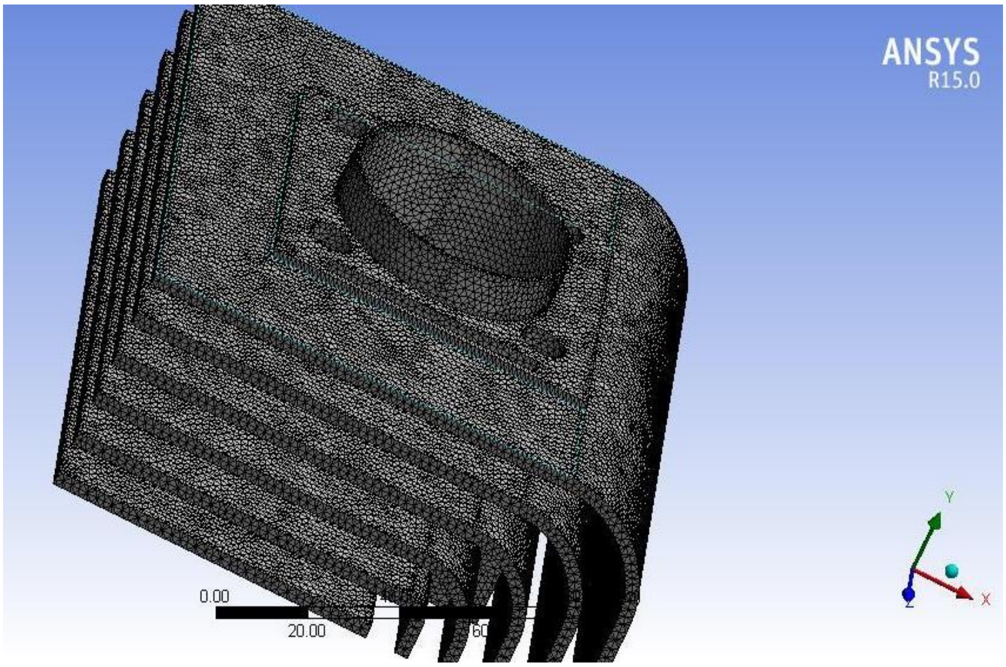

Figure 13. Meshing of the angular fin for steady-state analysis.

Table 2. (a) Mechanical property of the fin material.

Property	Value
Density (kg/m^3)	2.77e-006
Elastic modulus (MPa)	70300
Poisson's ratio	0.33
Tensile strength (MPa)	280
Ultimate strength (MPa)	310

Table 2. (b) Thermal property of the fin material.

Thermal conductivity W/mm °C	Temperature (°C)
0.114	-100
0.144	0
0.165	100

W/mm °C: Watts per millimeter per degree Celsius.

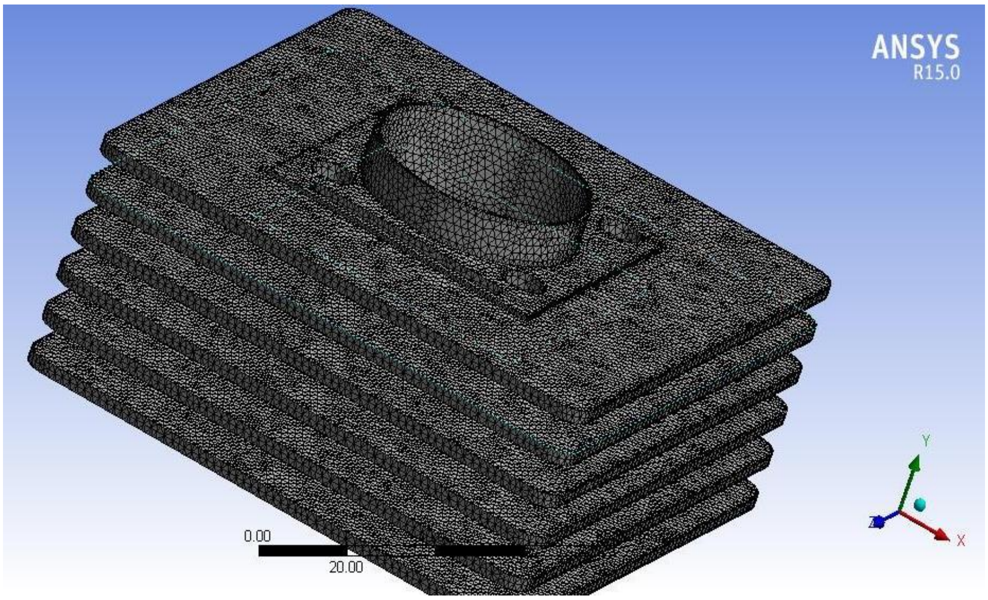

Figure 14. Meshing of rectangular fin for steady-state analysis.

Table 3. Meshing of the angular fin for steady-state analysis.

Physics reference	**Mechanical**
Element size	1.0 mm
Smoothing	High
Nodes	650631
Elements	373698
Mesh metric	None

Table 4. Meshing of rectangular fin for steady-state analysis.

Physics reference	**Mechanical**
Element size	1.0 mm
Smoothing	High
Nodes	704098
Elements	402571
Mesh metric	None

Table 5. Meshing of the wavy fin for steady-state analysis.

Physics reference	**Mechanical**
Element size	1.00 mm
Smoothing	High
Nodes	844351
Elements	481523
Mesh metric	None

Table 6. Meshing of the maze fin for steady-state analysis.

Physics reference	**Mechanical**
Element size	1.00 mm
Smoothing	High
Nodes	2543982
Elements	1670242
Mesh metric	None

Table 7. Meshing of the triangular fin for steady-state analysis.

Physics reference	Mechanical
Element size	1.00 mm
Smoothing	High
Nodes	706726
Elements	401754
Mesh metric	None

Table 8. Meshing of the trapezoid fin for steady-state analysis.

Physics reference	Mechanical
Element size	1.00 mm
Smoothing	High
Nodes	548136
Elements	305092
Mesh metric	None

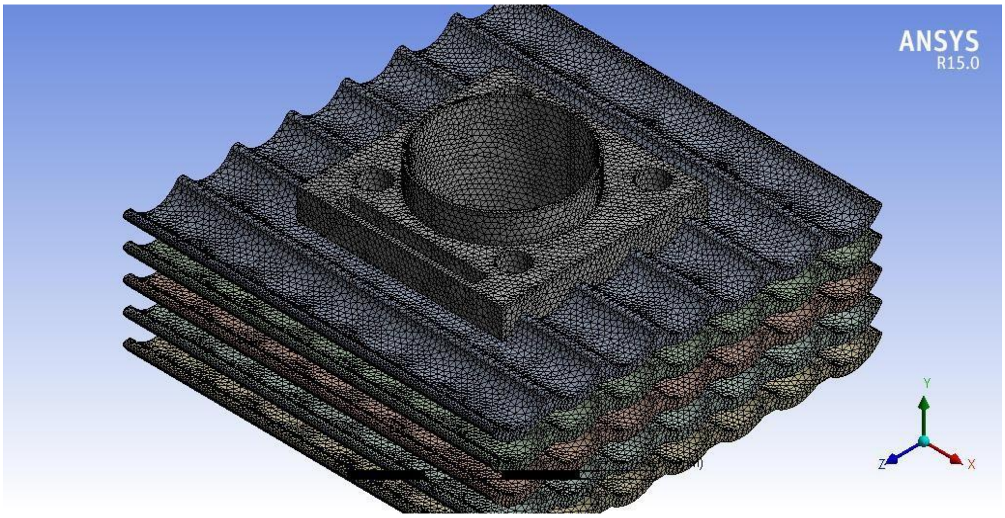

Figure 15. Meshing of the wavy fin for steady-state analysis.

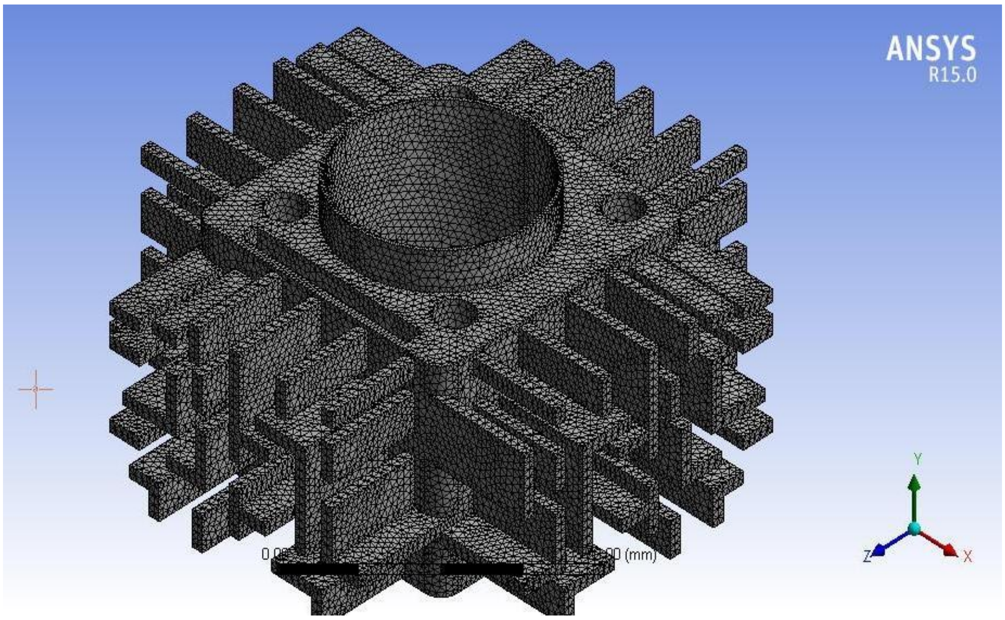

Figure 16. Meshing of the maze fin for steady-state analysis.

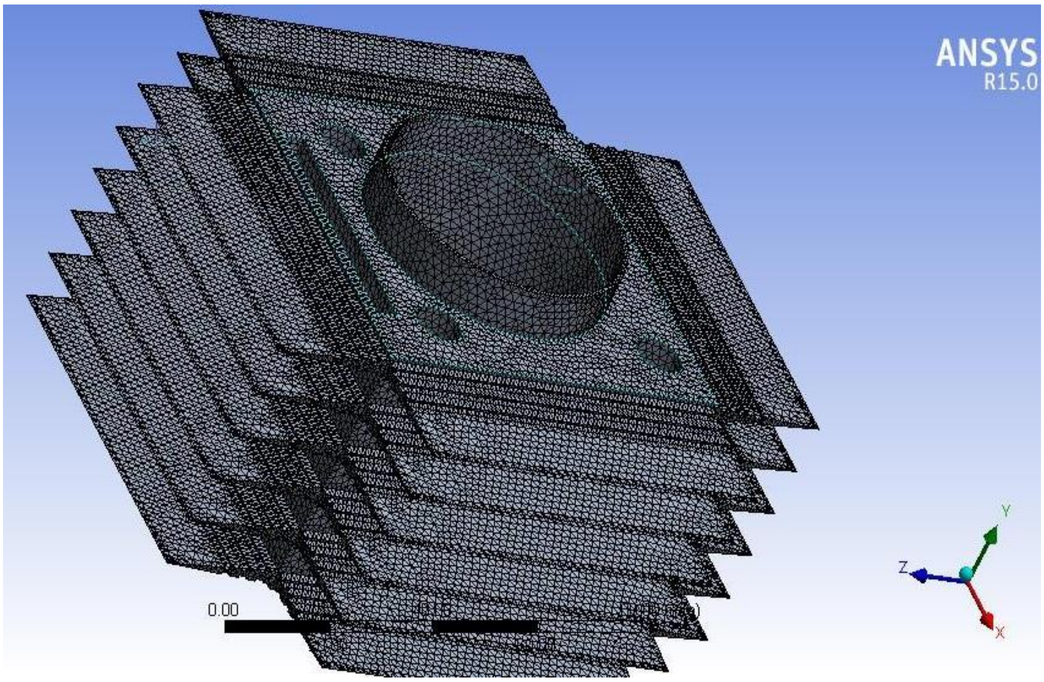

Figure 17. Meshing of the triangular fin for steady-state analysis.

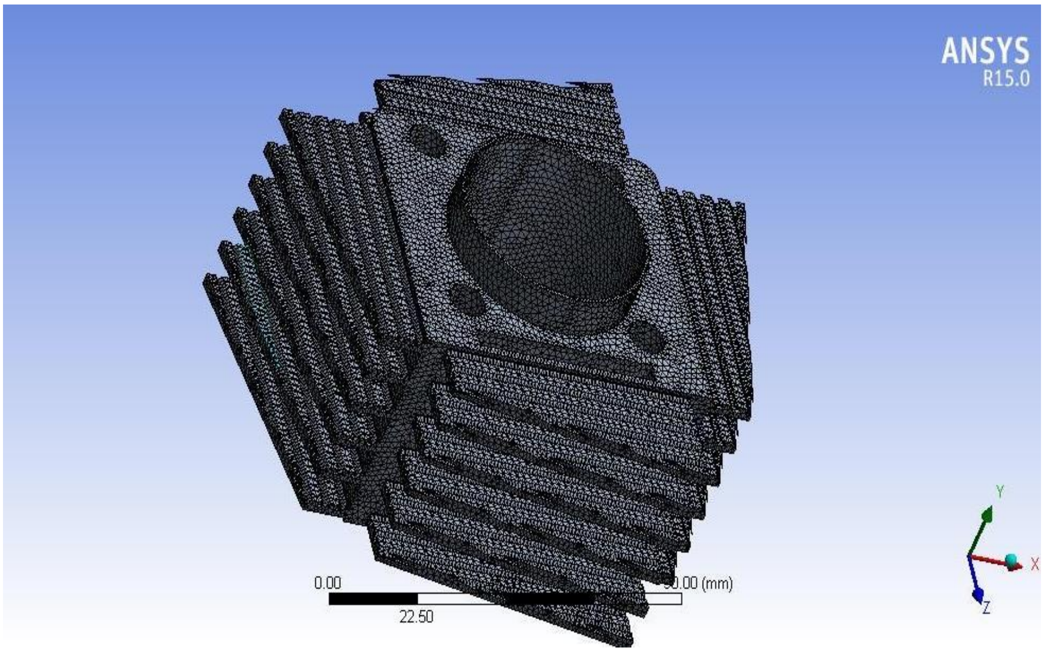

Figure 18. Meshing of the trapezoid fin for steady-state analysis.

Boundary Condition Setup for Steady-State Analysis

After the meshing is done to obtain more precise results, boundary conditions are loaded. Boundary conditions are applied to the geometry to test the object under real conditions; these constraints can be the loadings, fixed support, or heat. It is shown in Tables 9 and 10 and Figure 19, showing the properties of the air surrounding the engine. Tables 11–16 and Figures 20–25 present the steady-state thermal boundary conditions applied to the angular, rectangular, wavy, maze, triangular, and trapezoidal fin models in ANSYS. A constant base temperature of 1500°C and convection boundary conditions with tabulated film coefficients based on average film temperature and an ambient temperature of 30°C were imposed on the selected fin surfaces, ensuring consistent thermal loading for comparative heat transfer analysis among the different fin geometries.

Table 9. General setup of boundary conditions for steady-state analysis for all fins.

Object name	**Initial temperature**	
State	Fully Defined	
Initial Temperature	Uniform Temperature	
Initial Temperature Value	30°C	
Object name	***Analysis settings***	
State	Fully Defined	
Solver Type	1	
Object name	***Temperature***	***Convection***
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	109 Faces
Magnitude	1500°C	
Film coefficient		Tabular Data

Table 10. Property of the surrounding fluid (air).

Temperature [°C] of the air	**Convection coefficient [W/mm²°C]**
1	1.24e-006
10	2.67e-006
100	5.76e-006
200	7.25e-006
300	8.3e-006
500	9.84e-006
700	1.101e-005
1000	1.24e-005

Table 11. Steady-state boundary condition setup for an angular fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping method	***Geometry selection***	
Geometry	2 Faces	109 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		Tabular Data
Coefficient type		Average Film Temperature
Ambient Temperature		30°C (ramped)

Table 12. Steady-state boundary condition setup for a rectangular fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping method	***Geometry selection***	
Geometry	2 Faces	119 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		Tabular Data
Coefficient type		Average Film Temperature
Ambient Temperature		30°C (ramped)

Table 13. Steady-state boundary condition setup for wavy fin.

Object Name	Temperature	Convection
State	Fully Defined	
Scoping method	***Geometry selection***	
Geometry	2 Faces	339 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		Tabular Data
Coefficient type		Average Film Temperature
Ambient Temperature		30°C (ramped)

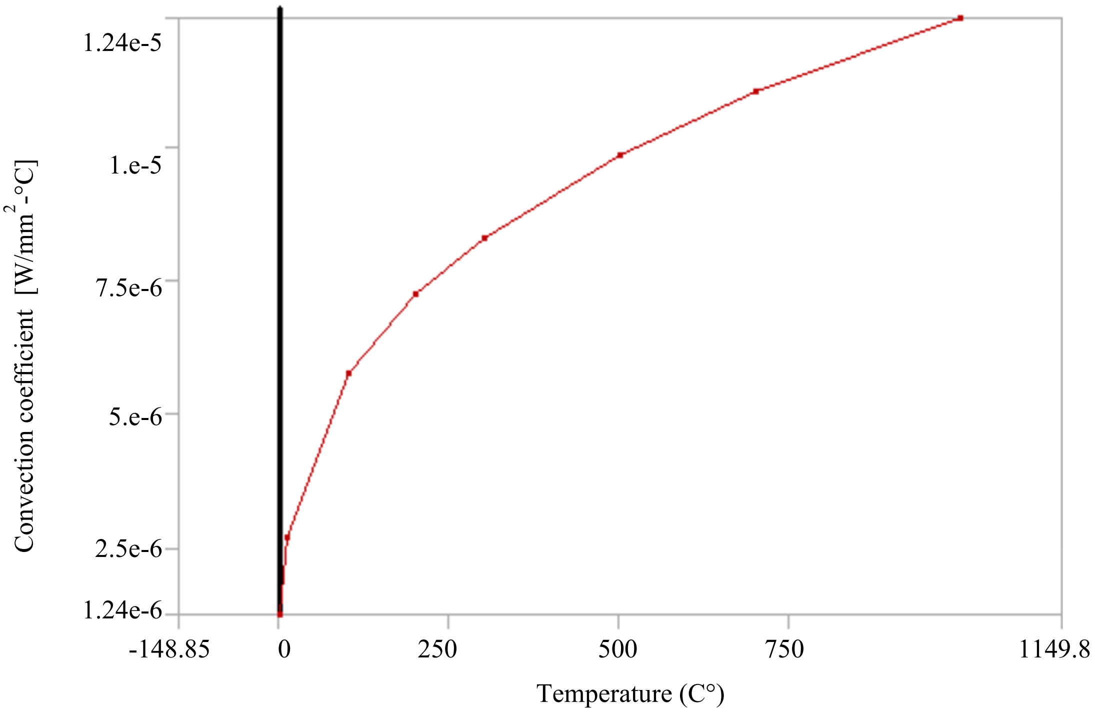

Figure 19. Property of the surrounding fluid (air).

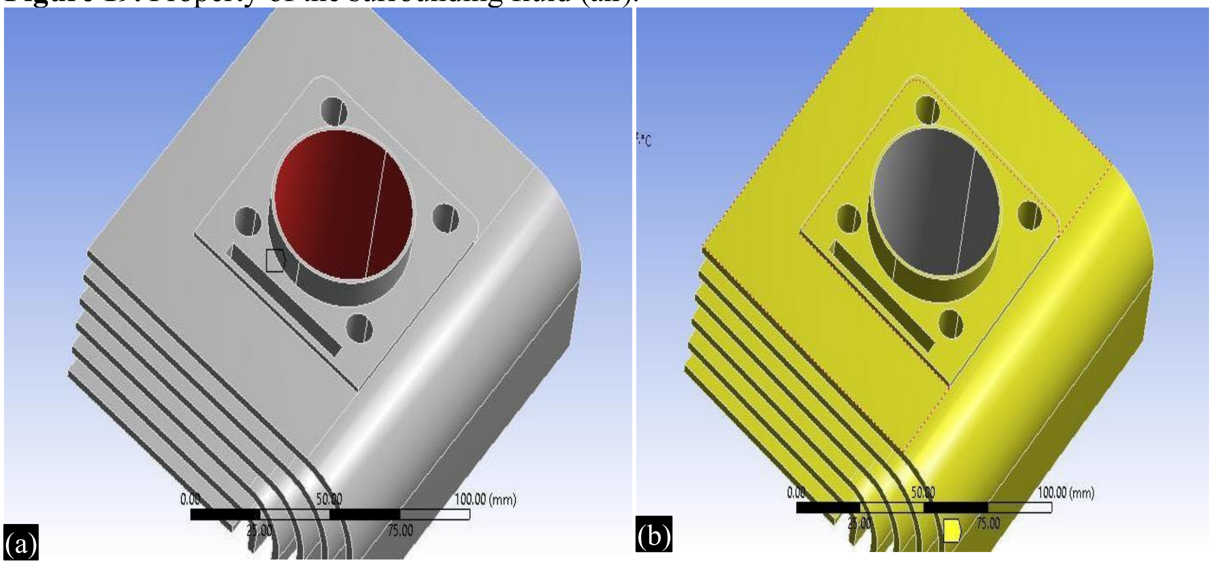

Figure 20. Steady-state boundary condition for angular fin (a) Temperature; (b) Convection.

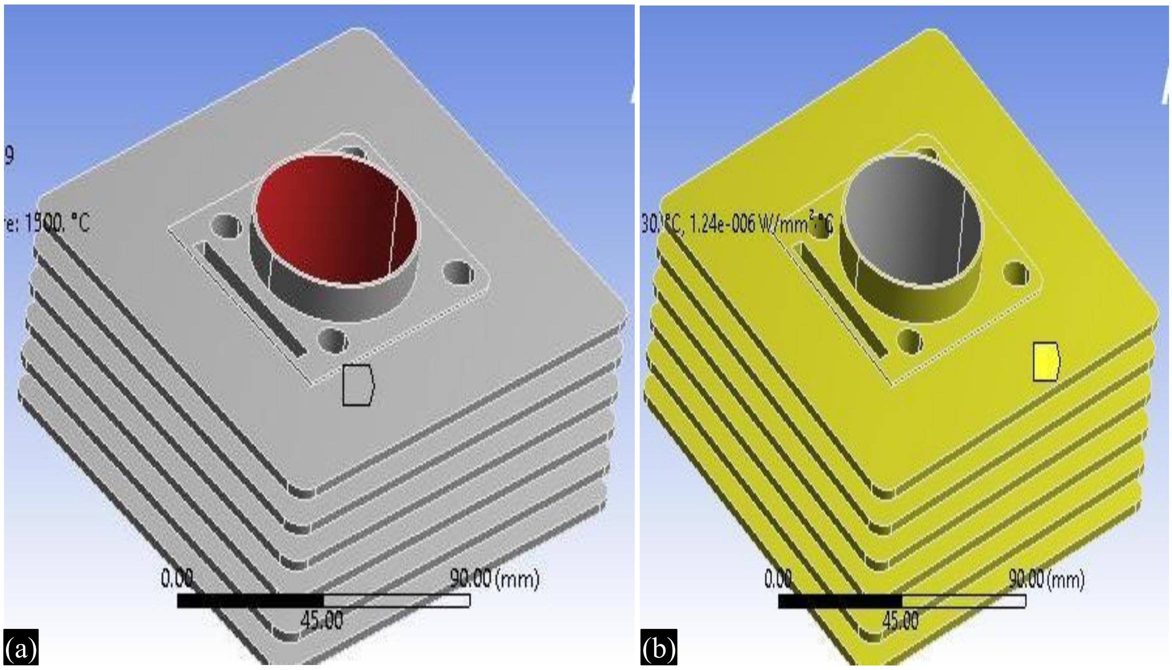

Figure 21. Steady-state boundary condition for rectangular fin (a) Temperature; (b) Convection.

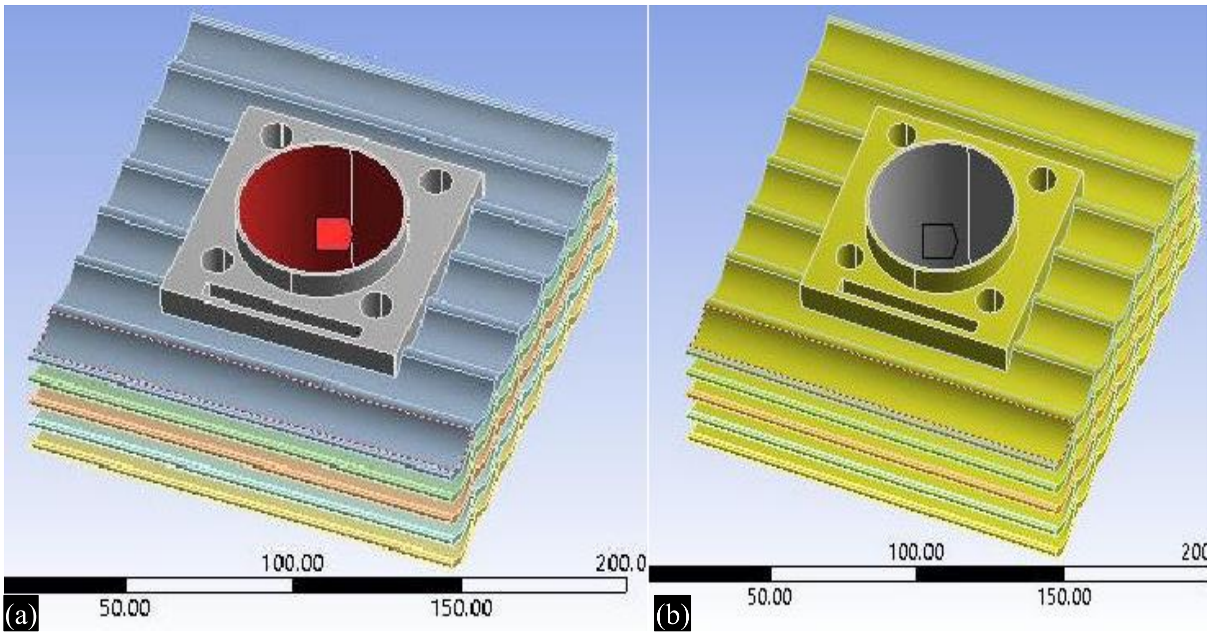

Figure 22. Steady-state boundary condition for wavy fin (a) Temperature; (b) Convection.

Table 14. Steady-state boundary condition setup for the maze fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping method	***Geometry selection***	
Geometry	2 Faces	462 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		Tabular Data
Coefficient type		Average Film Temperature
Ambient Temperature		30°C (ramped)

Table 15. Steady-state boundary condition setup for triangular fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping method	***Geometry selection***	
Geometry	2 Faces	717 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		Tabular Data
Coefficient type		Average Film Temperature
Ambient Temperature		30°C (ramped)

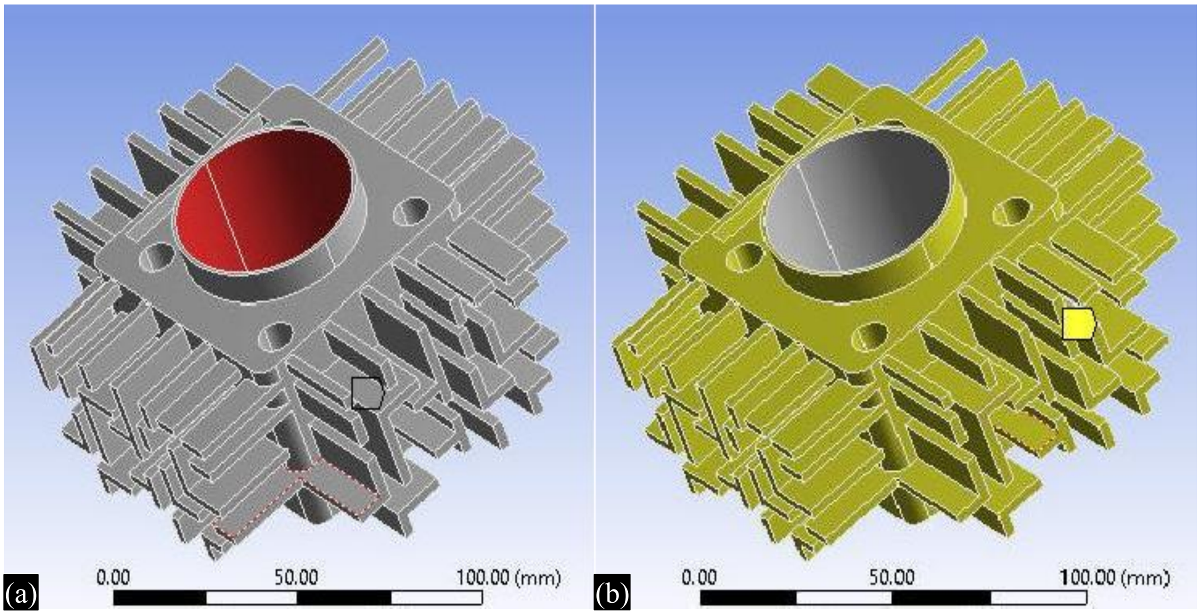

Figure 23. Steady-state boundary condition for maze fin (a) Temperature; (b) Convection

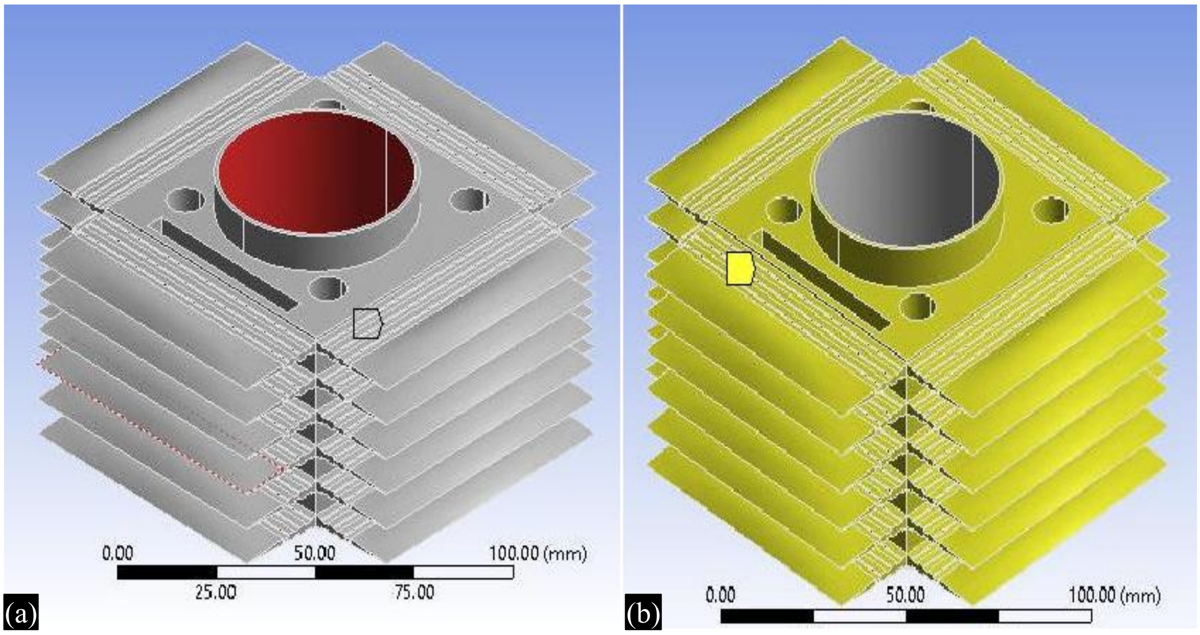

Figure 24. Steady-state boundary condition for triangular fin (a) Temperature; (b) Convection

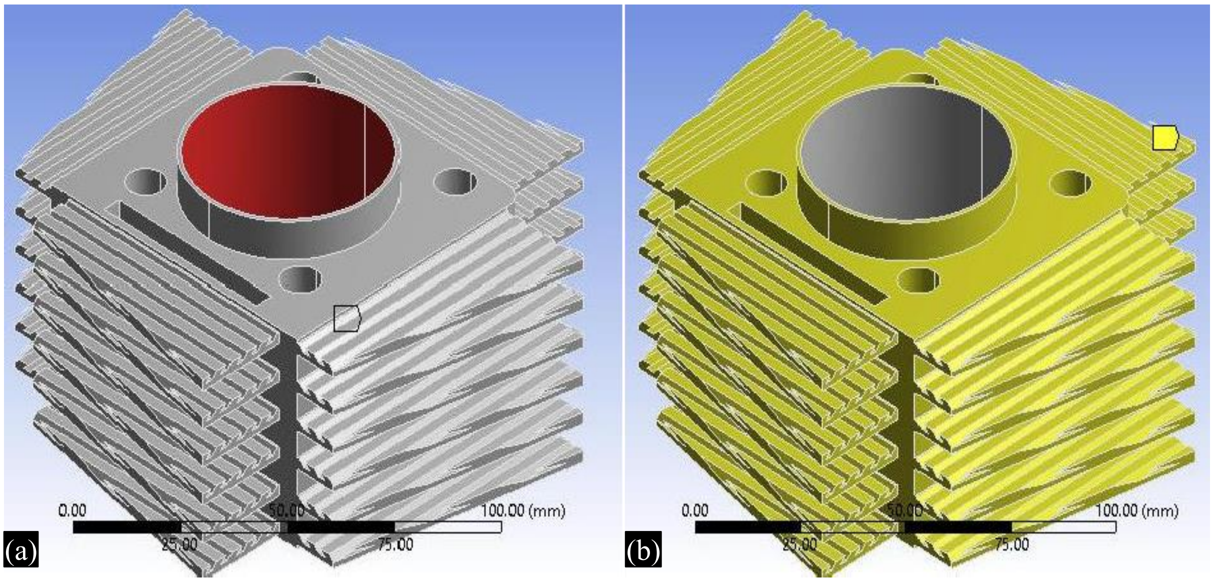

Figure 25. Steady-state boundary condition for trapezoid fin (a) Temperature; (b) Convection

Table 16. Steady-state boundary condition setup for trapezoid fin.

Object Name	Temperature	Convection
State	Fully Defined	
Scoping method	***Geometry selection***	
Geometry	2 Faces	629 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		Tabular Data
Coefficient type		Average Film Temperature
Ambient Temperature		30°C (ramped)

Solution Condition in ANSYS

The general solution condition, which is program-controlled and common for all the analyses of different fins, is as follows.

Transient Thermal Analysis of Fins

Transient thermal analysis will show how the fins will react to the fixed boundary condition over a time period. The steps of the analysis are as follows:

- Create model geometry
- Mesh generation
- Solver and physics model setup
- Solution calculation and monitoring different fins

Material Selection for Transient Thermal Analysis

Now since the geometry exists, define the material library of the necessary materials that compose the object (or project) being modelled. This includes thermal and mechanical properties. The most suited material for the job that meets the entire criterion is general aluminum alloy (Fatigue properties come from MIL-HDBK-5H, page 3–277). Tables 17, 18 and 19 summarize the mechanical and thermal properties of the fin material employed in the transient thermal analysis, while Tables 20–25 and Figures 26–31 present the meshing configurations of the angular, rectangular, wavy, maze, triangular, and trapezoidal fins. Furthermore, Tables 26–31 and Figures 32–37 illustrate the transient thermal boundary conditions, where a constant base temperature of 1500°C, a convection coefficient of 5×10^{-6} W/mm²°C, and an ambient temperature of 30°C were applied uniformly to evaluate thetransient heat transfer characteristics of the various fin geometries under identical operating conditions. Table 32 shows the transient solution for all fins.

Table 17. General solution for all fins.

Object name	**Solution**
State	Solved
Adaptive mesh refinement	
Max Refinement Loops	1
Refinement Depth	2
Information	
Status	Done

Table 18. Mechanical property of the fin material.

Property	**Value**
Density (kg/m^3)	2.77e-006
Elastic Modulus (MPa)	70300
Poisson’s Ratio	0.33
Tensile Strength (MPa)	280
Ultimate Strength (MPa)	310

Table 19. Thermal property of the fin material.

Thermal conductivity W/mm °C	**Temperature °C**
0.114	-100
0.144	0
0.165	100
0.175	200

Table 20. Transient analysis meshing for an angular fin.

Physics reference	**Mechanical**
Element Size	1.00 mm
Smoothing	High
Nodes	531481
Elements	301719
Mesh Metric	None

Table 21. Transient analysis meshing for a rectangular fin.

Physics reference	**Mechanical**
Element Size	1.0 mm
Smoothing	High
Nodes	975113
Elements	331433
Mesh Metric	None

Table 22. Transient analysis meshing for wavy fin.

Physics reference	**Mechanical**
Element Size	1.0 mm
Smoothing	High
Nodes	975113
Elements	975113
Mesh Metric	None

Table 23. Transient analysis meshing for the maze fin.

Physics reference	Mechanical
Element Size	0.50 mm
Smoothing	High
Nodes	1889699
Elements	1116727
Mesh Metric	None

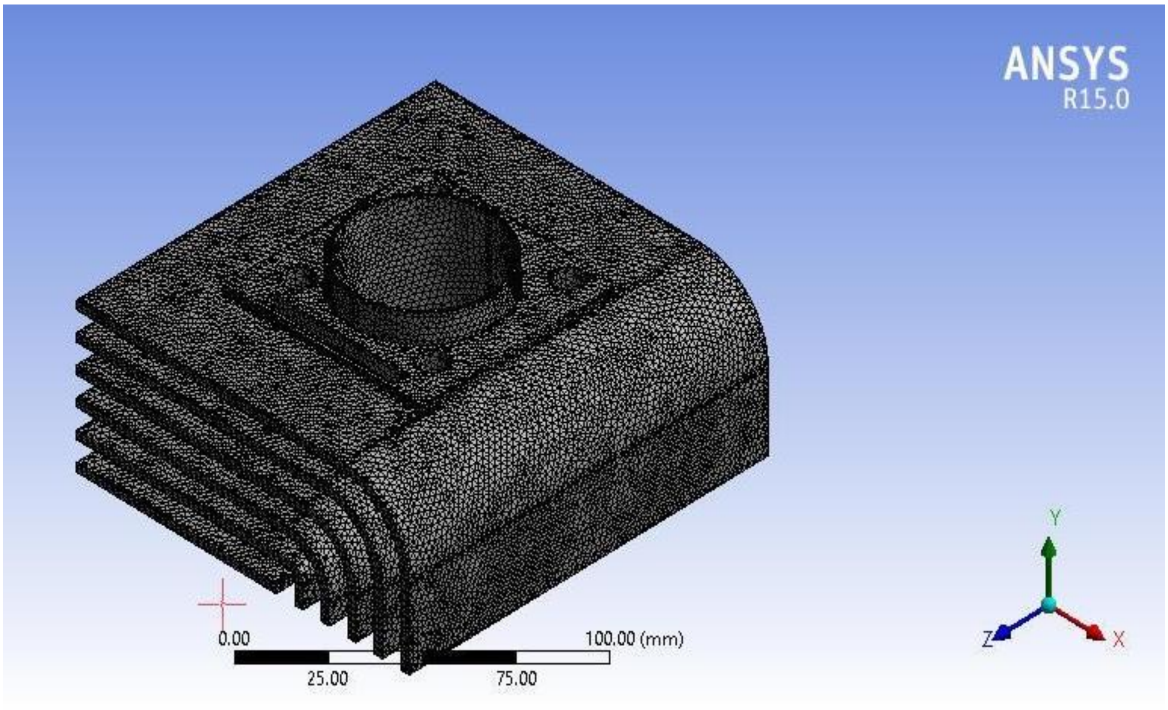

Figure 26. Transient thermal analysis meshing for an angular fin.

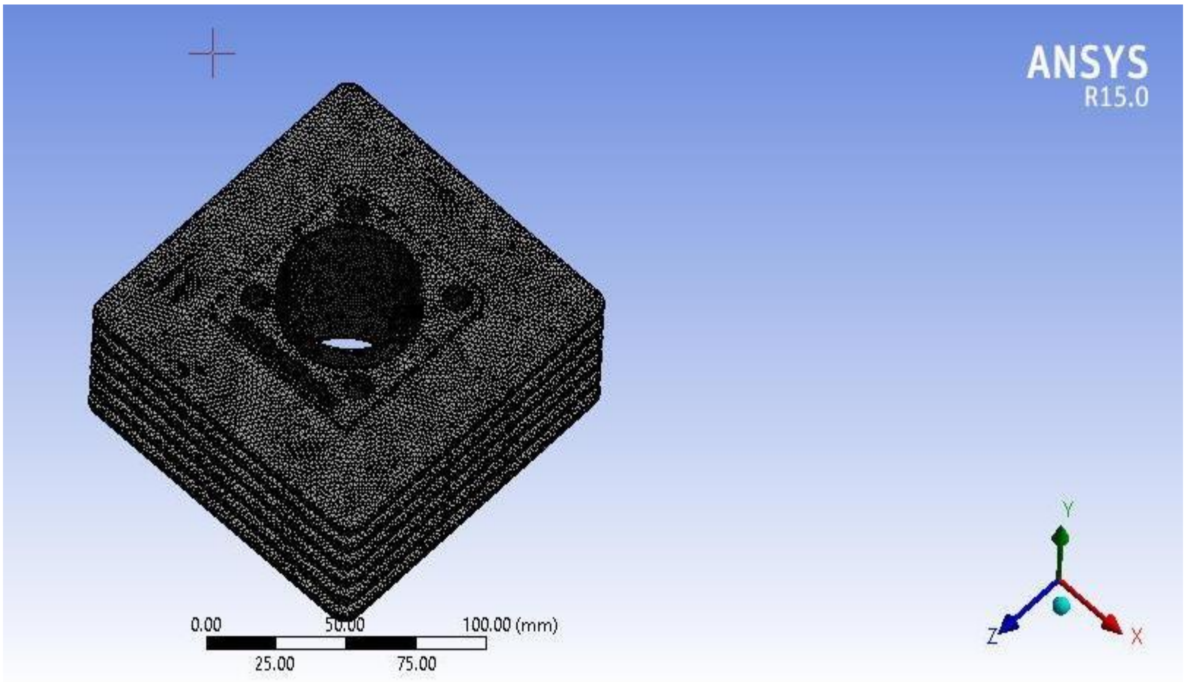

Figure 27. Transient thermal analysis meshing for a rectangular fin.

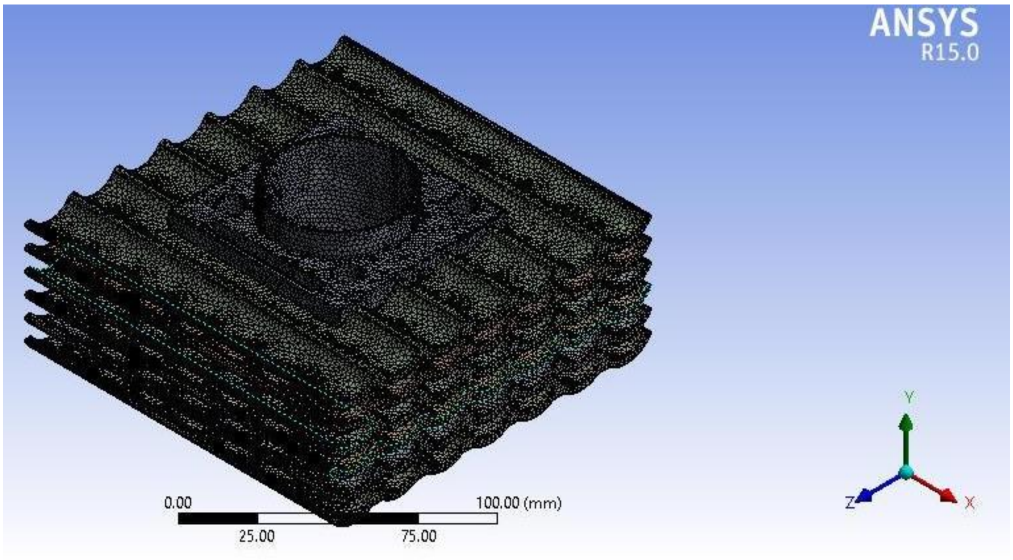

Figure 28. Transient thermal analysis meshing for a wavy fin.

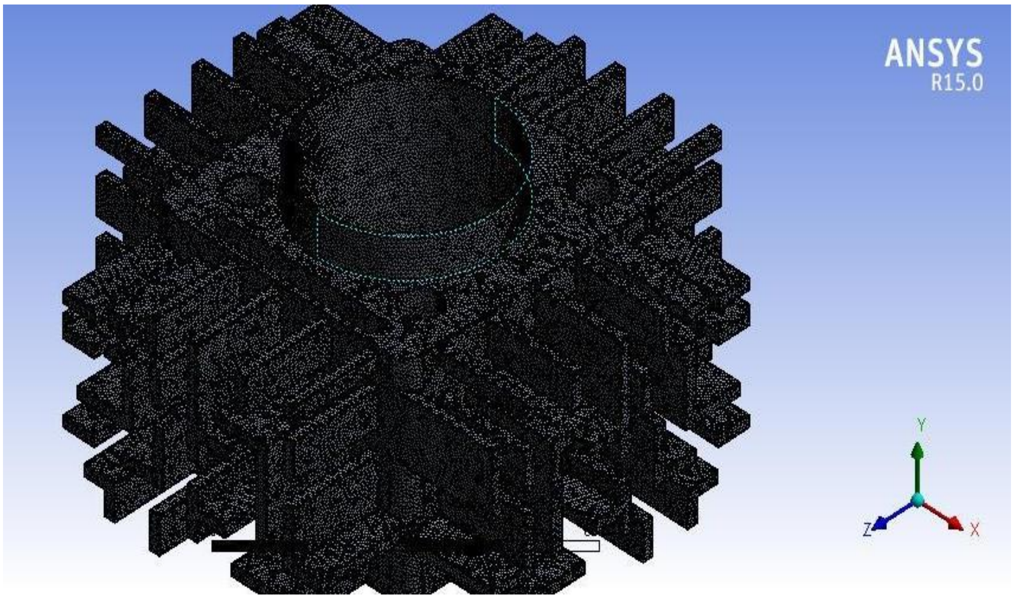

Figure 29: Transient thermal analysis meshing for maze fin.

Table 24. Transient analysis meshing for triangular fin

Physics reference	**Mechanical**
Element Size	1.00 mm
Smoothing	High
Nodes	757614
Elements	428687
Mesh metric	None

Meshing for Transient Thermal Analysis

To achieve accurate transient thermal modeling of the geometrical model, the geometry was discretized into a finite number of finite elements. A finer mesh density was used in regions where larger (>3°C) temperature gradients occurred. Regions identified as critical to transient thermal performance were modeled using finer meshes or were conformed to the actual geometry to maximize computational efficiency.

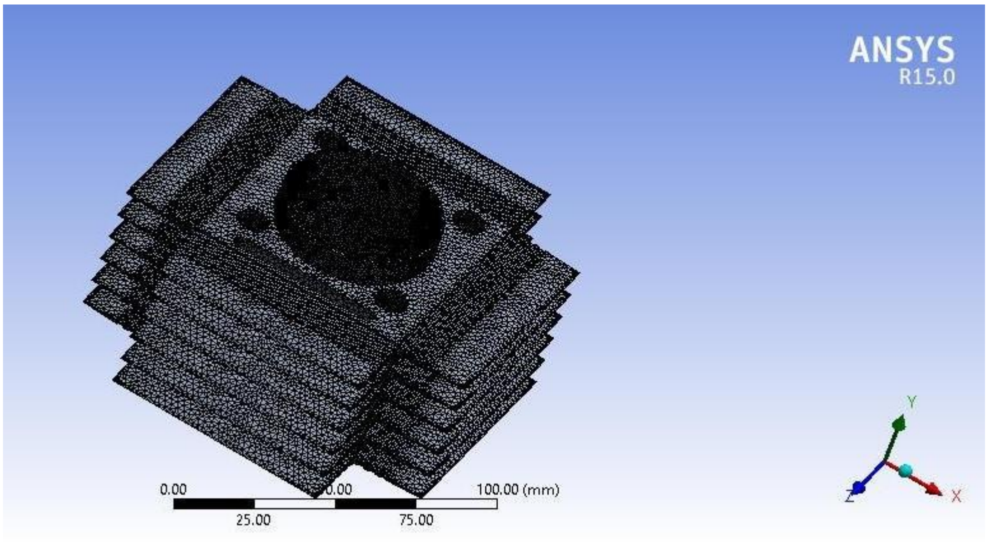

Figure 30. Transient thermal analysis meshing for a triangular fin.

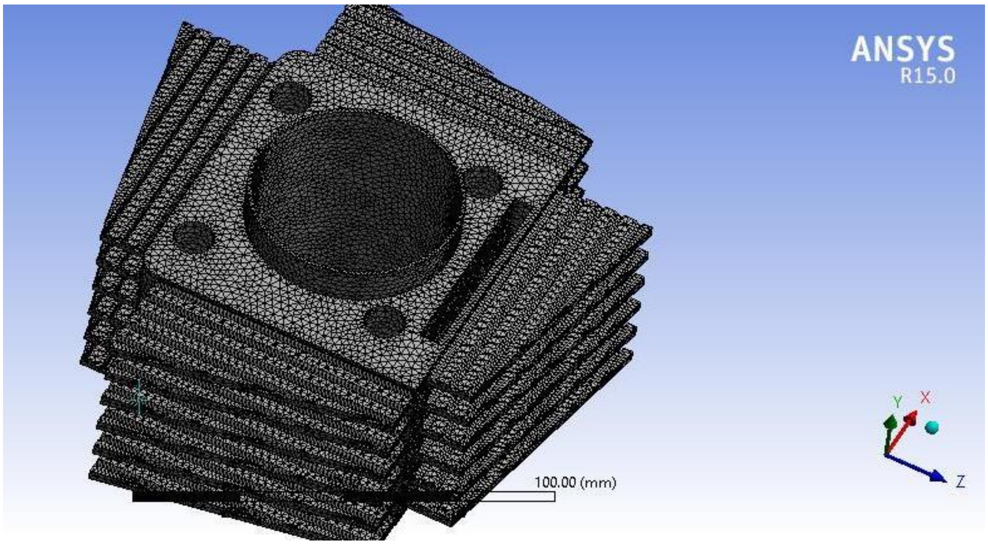

Figure 31. Transient thermal analysis meshing for an angular fin.

Table 25. Transient analysis meshing for trapezoid fin.

Physics reference	Mechanical
Element size	1.00 mm
Smoothing	High
Nodes	475885
Elements	259441
Mesh metric	None

The use of refined finite-element meshes allowed transient heat-transfer temperature gradients to be accurately represented, thereby enabling accurate heat-transfer calculations throughout the analysis. The finite-element mesh model developed for the transient thermal analysis is presented in Figures 26–31. The finite-element mesh model was tested to ensure good convergence and that the thermal results obtained from the analysis would be sufficiently reliable.

Boundary Condition Setup for Transient Thermal Analysis

To model the transient thermal response of the model under operational conditions, suitable boundary conditions were applied. A starting temperature for the component was defined and a time-variable thermal load was applied to represent the time-dependent temperature variation. In addition, the ambient temperature and heat transfer coefficients were defined to model convective heat transfer from the exterior surfaces of the component. Where applicable, heat flux, and thermal constraints were also defined to properly model the physical environment. The complete setup of the boundary conditions for the transient thermal analysis is shown in Table 26,27,28,29,30,31 and Figure 32,33,34,35,36 respectively.

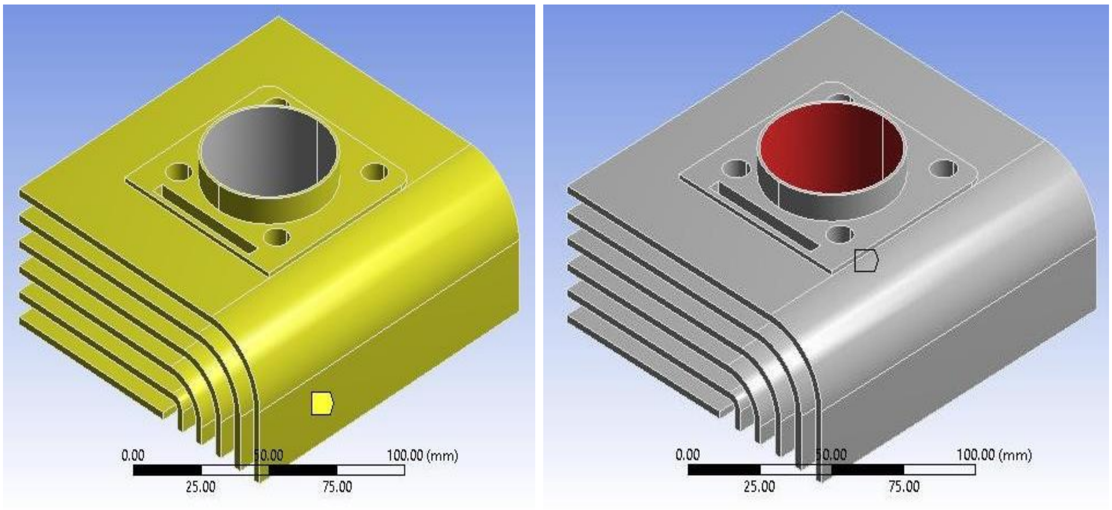

Figure 32. Transient thermal setup for angular fin (a) Temperature; (b) Convection.

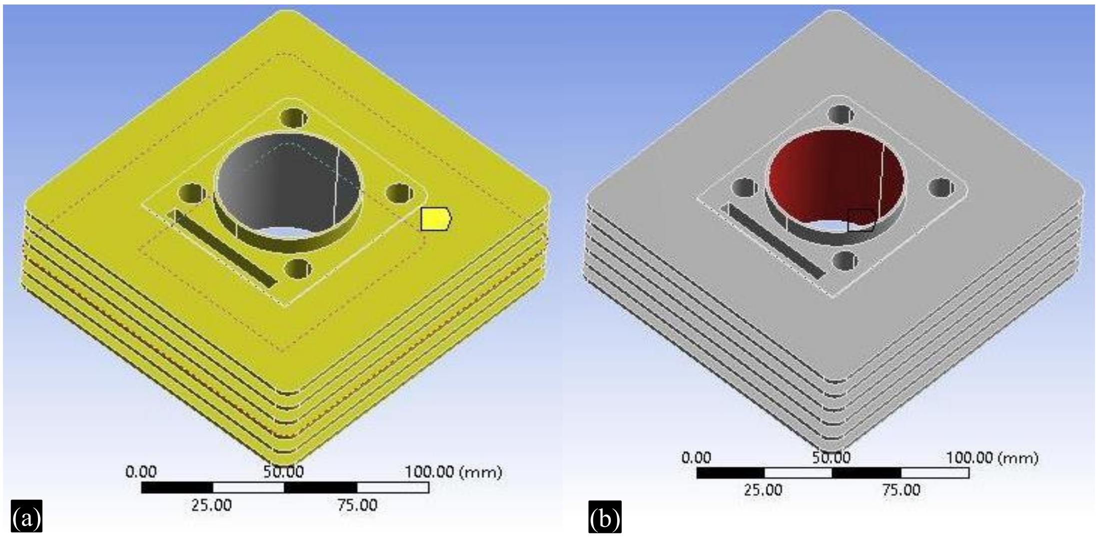

Figure 33. Transient thermal setup for rectangular fin (a) Temperature; (b) Convection.

Table 26. Transient thermal analysis boundary condition for an angular fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	109 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		5.e-006 W/mm²℃
Coefficient type		Average Film Temp.
Ambient Temperature		30°C (step applied)

Table 27. Transient thermal analysis boundary condition for rectangular fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	119 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		5.e-006 W/mm^2°C
Coefficient type		Average Film Temp.
Ambient Temperature		30°C (step applied)

Table 28. Transient thermal analysis boundary condition for wavy fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	339 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		5.e-006 W/mm^2°C
Coefficient type		Average Film Temp.
Ambient Temperature		30°C (step applied)

Table 29. Transient thermal analysis boundary condition for maze fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	462 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		5.e-006 W/mm^2°C
Coefficient type		Average Film Temp.
Ambient Temperature		30°C (step applied)

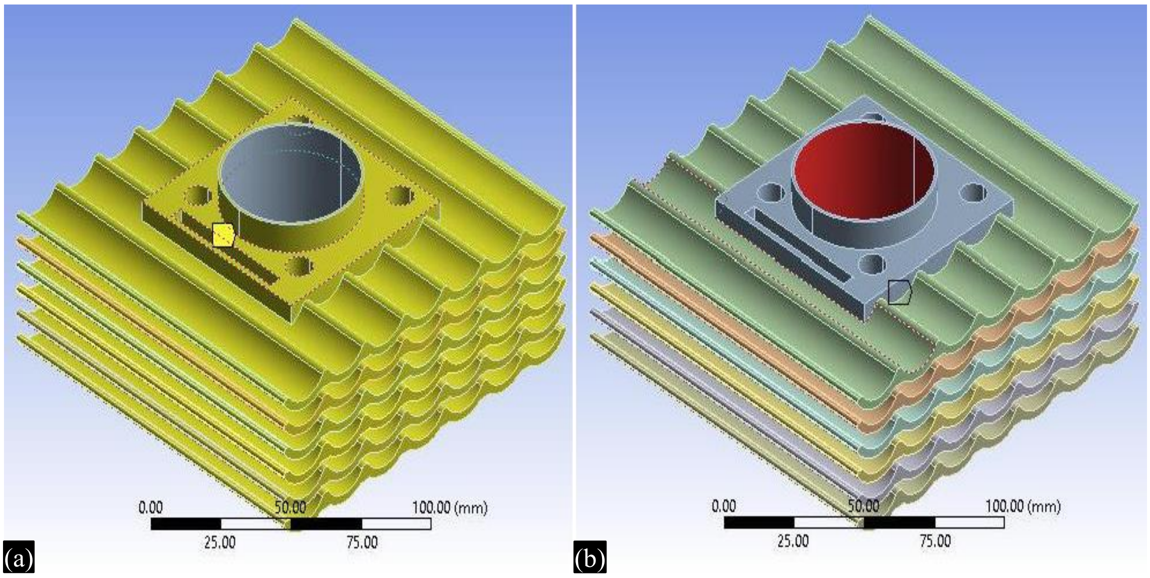

Figure 34. Transient thermal setup for wavy fin (a) Temperature; (b) Convection.

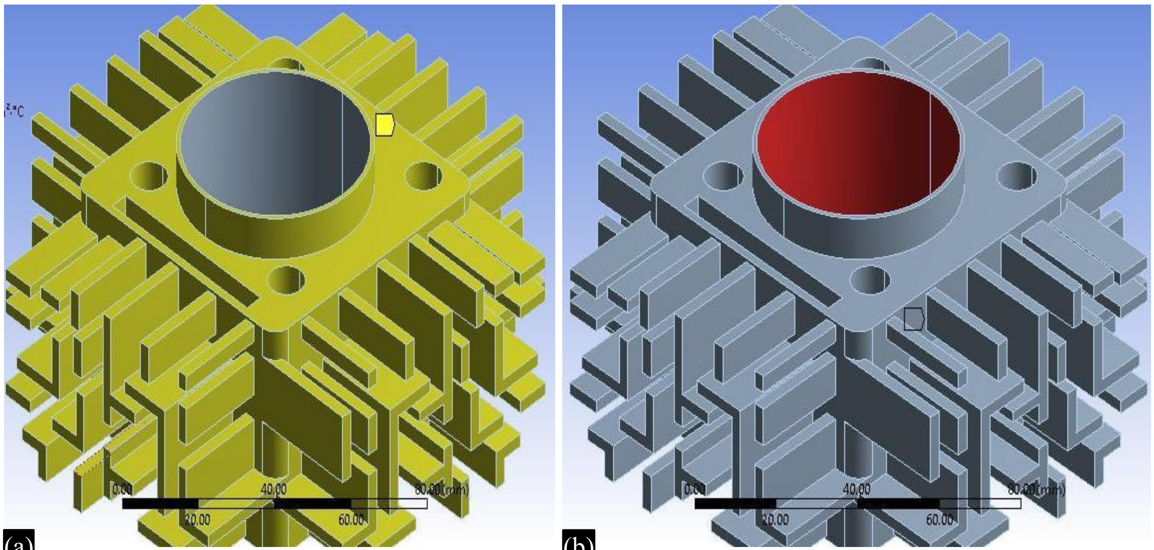

Figure 35. Transient thermal setup for maze fin (a) Temperature; (b) Convection

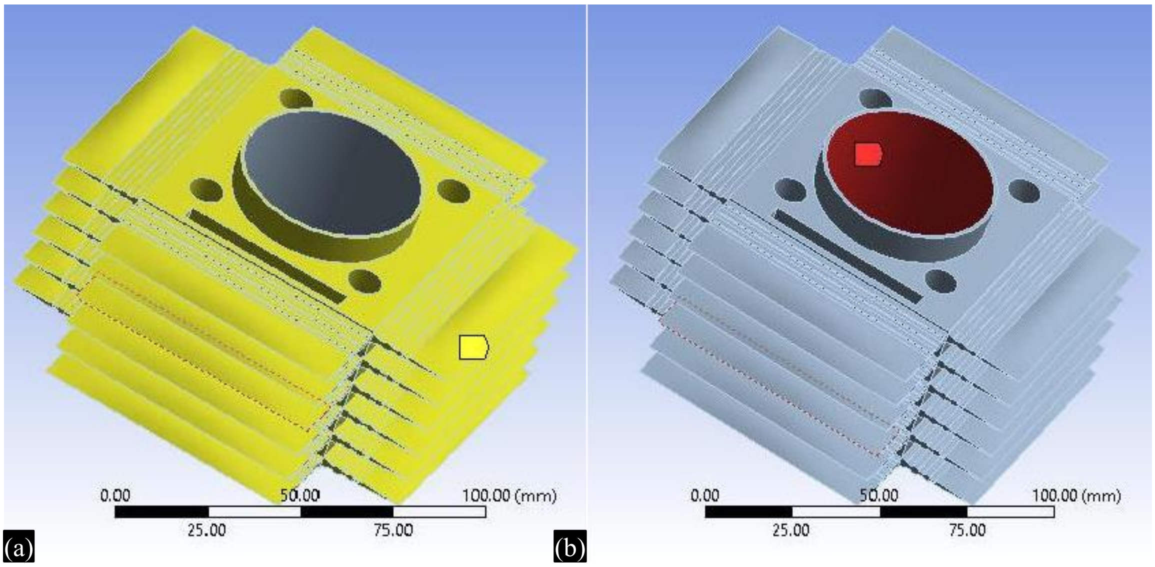

Figure 36. Transient thermal setup for triangular fin (a) Temperature; (b) Convection

Table 30. Transient thermal analysis boundary condition for triangular fin.

Object name	**Temperature**	**Convection**
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	712 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		5.e-006 W/mm²°C
Coefficient type		Average Film Temp.
Ambient Temperature		30°C (step applied)

RESULTS and DISCUSSION

In this chapter, results obtained through analysis of different-shaped fins of an air-cooled I.C. engine are presented. The heat transfer characteristics, temperature variation, and heat flux are discussed, with the help of ANSYS results. Finally, all results will be compared.

Table 31. Transient thermal analysis boundary condition for trapezoid fin.

Object name	Temperature	Convection
State	Fully Defined	
Scoping Method	Geometry Selection	
Geometry	2 Faces	629 Faces
Type	Temperature	Convection
Magnitude	1500°C	
Film Coefficient		5.e-006 W/mm^2℃
Coefficient type		Average Film Temp.
Ambient Temperature		30°C (step applied)

Table 32. Transient solution for all fins.

Object name	Solution
State	Solved
Max refinement loops	1.
Refinement depth	2.
Status	Done
Solution output	Solver output
Update interval	2.5 s
Display points	All
Draw a connection attached to	All nodes
Line color	Connection types
Display type	Lines

Table 33. Angular fin steady-state result.

Object name	Temperature	Total heat flux
State	Solved	
	Results	
Minimum	1294.4°C	1.8819e-003 W/mm^2
Maximum	1500°C	1.9303 W/mm^2
	Minimum value over time	
Minimum	1294.4°C	1.8819e -003 W/mm^2
Maximum	1294.4°C	1.8819e -003 W/mm^2
	Maximum value over time	
Minimum	1500°C	1.9303 W/mm^2
Maximum	1500°C	1.9303 W/mm^2

Steady-State Thermal Analysis Results

A steady-state thermal analysis shows the effects of steady-state heat loads on a system or component. Analysts often run a steady-state analysis to assist in adjudging initial conditions before running a transient analysis. Table 33 shows the angular fin steady-state result.

The temperature distribution through angular fins is depicted in the above Figures 38 (a) and (b). The temperature distribution ranges from 1294°C at the least to 1500°C at the maximum. Furthermore, the greatest total heat flux through it is 1.9303 W/mm^2, whereas the minimum total heat flux is 3.5835e-003 W/mm^2. Table 34 shows the rectangular fin steady-state result. The temperature distribution through rectangular fins is depicted in the above Figures 39 and 40. The temperature distribution ranges from 1353.9°C at the least to 1500°C at the maximum. Furthermore, the greatest total heat flux through it is 2.1192 W/mm^2, whereas the minimum total heat flux is 1.7753e-003 W/mm^2. Table 35 shows the wavy fin steady-state result.

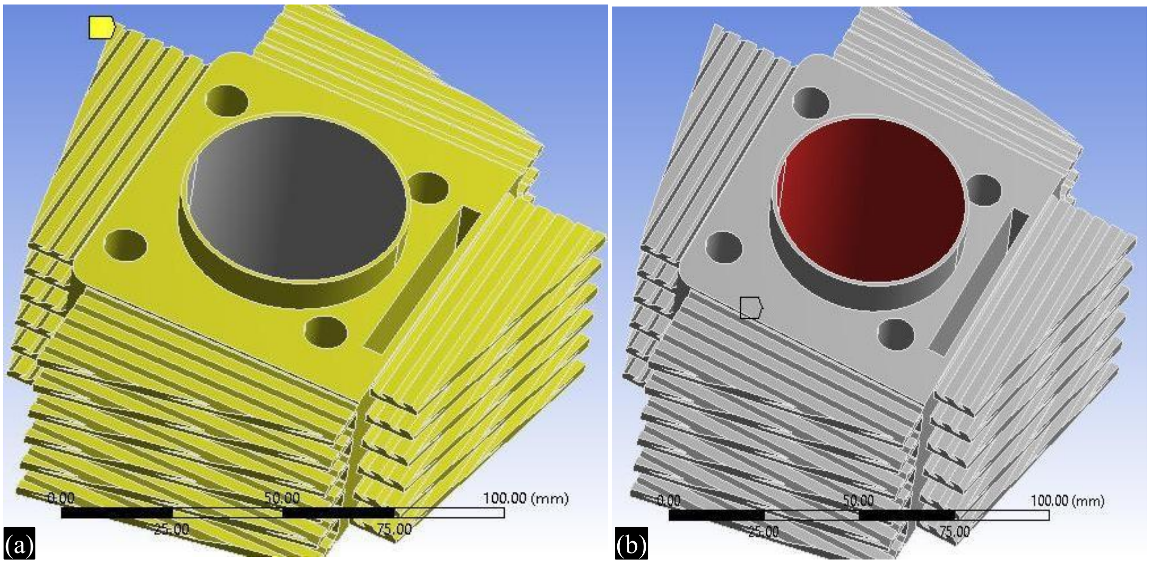

Figure 37. Transient thermal setup for trapezoid Fin (a) Temperature; (b) Convection

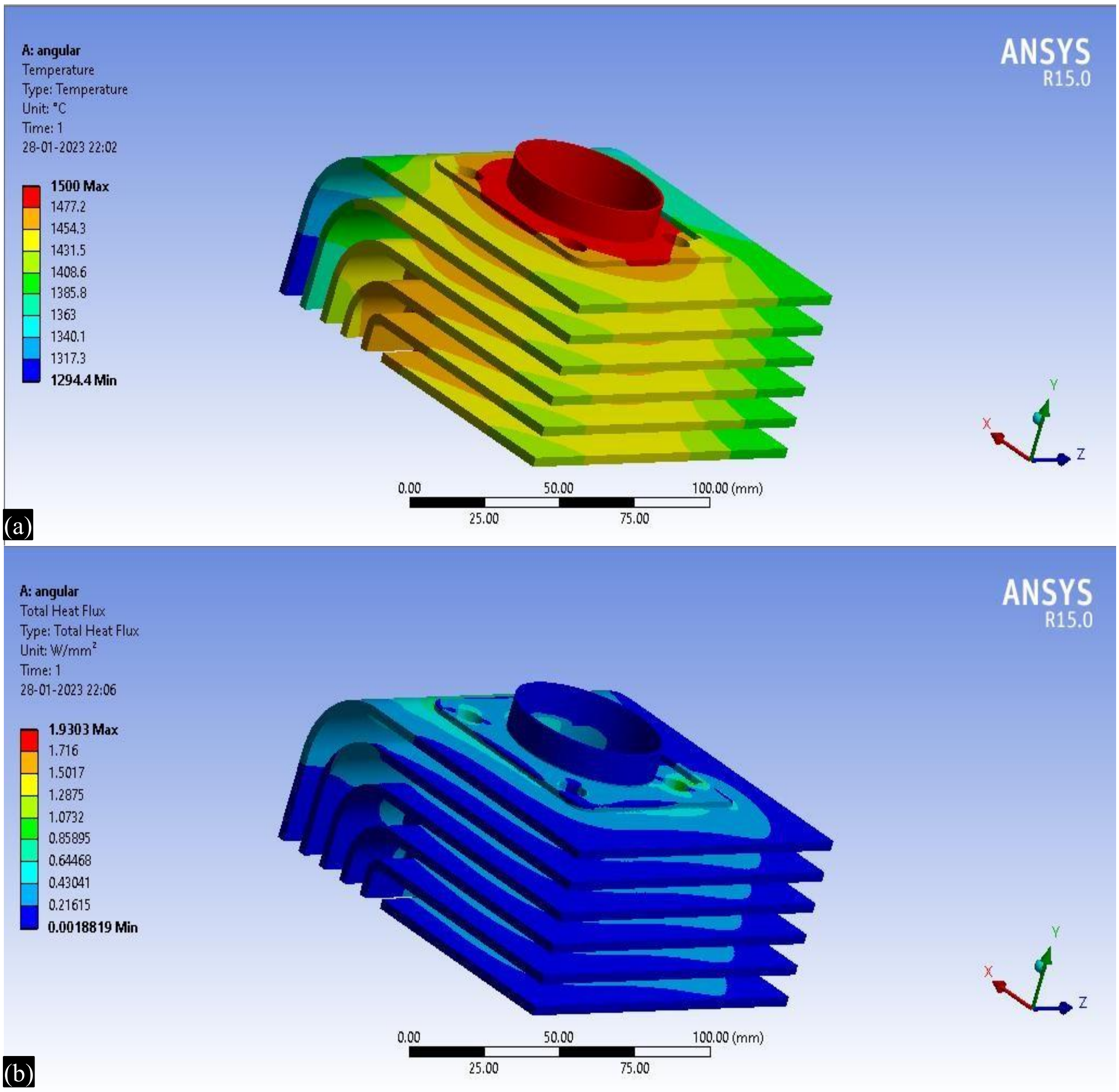

Figure 38. Steady-state thermal analysis of angular fin (a) Temperature; (b) Heat flux.

Table 34. Rectangular fin steady-state result.

Object name	**Temperature**	**Total heat flux**
State	Solved	
Results		
Minimum	1373.7°C	9.9168e-004 W/mm^2
Maximum	1500°C	1.7538 W/mm^2
	Minimum value over time	
Minimum	1373.7°C	9.9168e-004 W/mm^2
Maximum	1373.7°C	9.9168e-004 W/mm^2
	Maximum value over time	
Minimum	1500°C	1.7538 W/mm^2
Maximum	1500°C	1.7538 W/mm^2

Table 35. Wavy fin steady-state result.

Object name	**Temperature**	**Total heat flux**
State	Solved	
	Results	
Minimum	1100.5°C	2.161e-003 W/mm^2
Maximum	1500°C	1.8958 W/mm^2
	Minimum value over time	
Minimum	1100.5°C	2.161e-003 W/mm^2
Maximum	1100.5°C	2.161e-003 W/mm^2
	Maximum value over time	
Minimum	1500°C	1.8958 W/mm^2
Maximum	1500°C	1.8958 W/mm^2

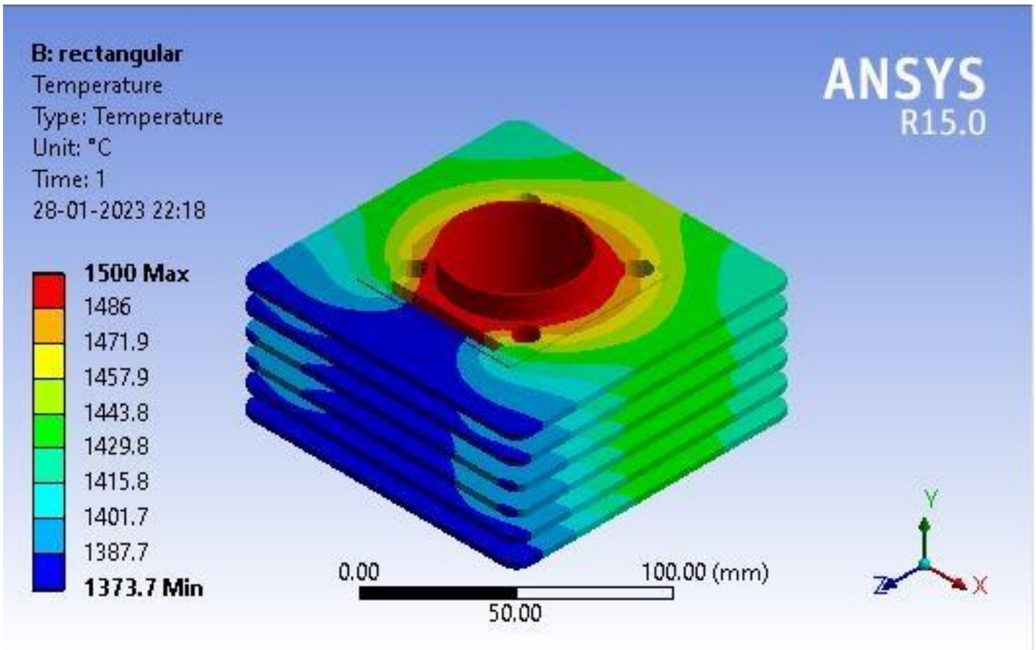

Figure 39. Steady-state thermal analysis of rectangular fin, temperature.

The temperature distribution through wavy fins is depicted in the above Figure 41. The temperature distribution ranges from 1100.5°C at the least to 1500°C at the maximum. Furthermore, the greatest total heat flux through it is 1.8958 W/mm^2, whereas the minimum total heat flux is 2.161e-003 W/mm^2. Table 36 shows the maze fin steady-state result.

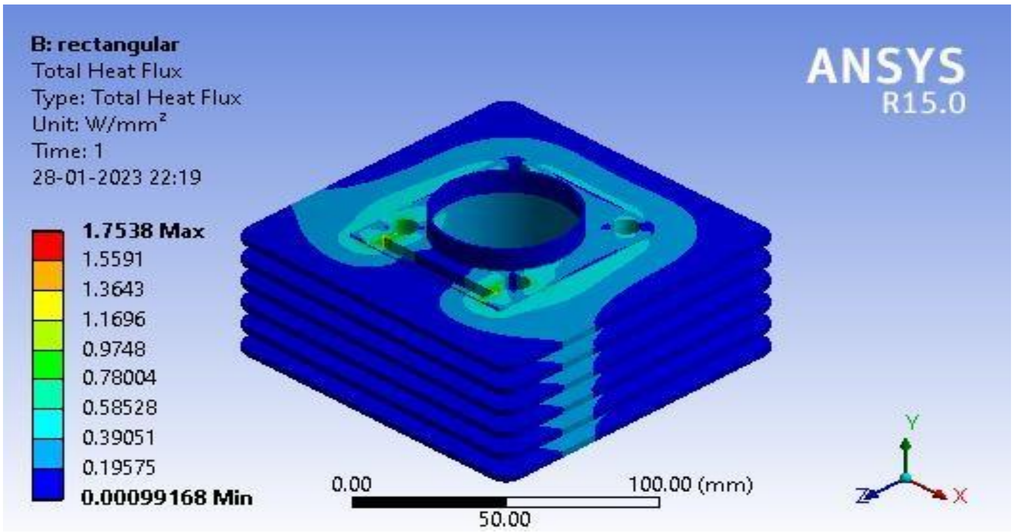

Figure 40. Steady-state thermal analysis of rectangular fin, heat flux.

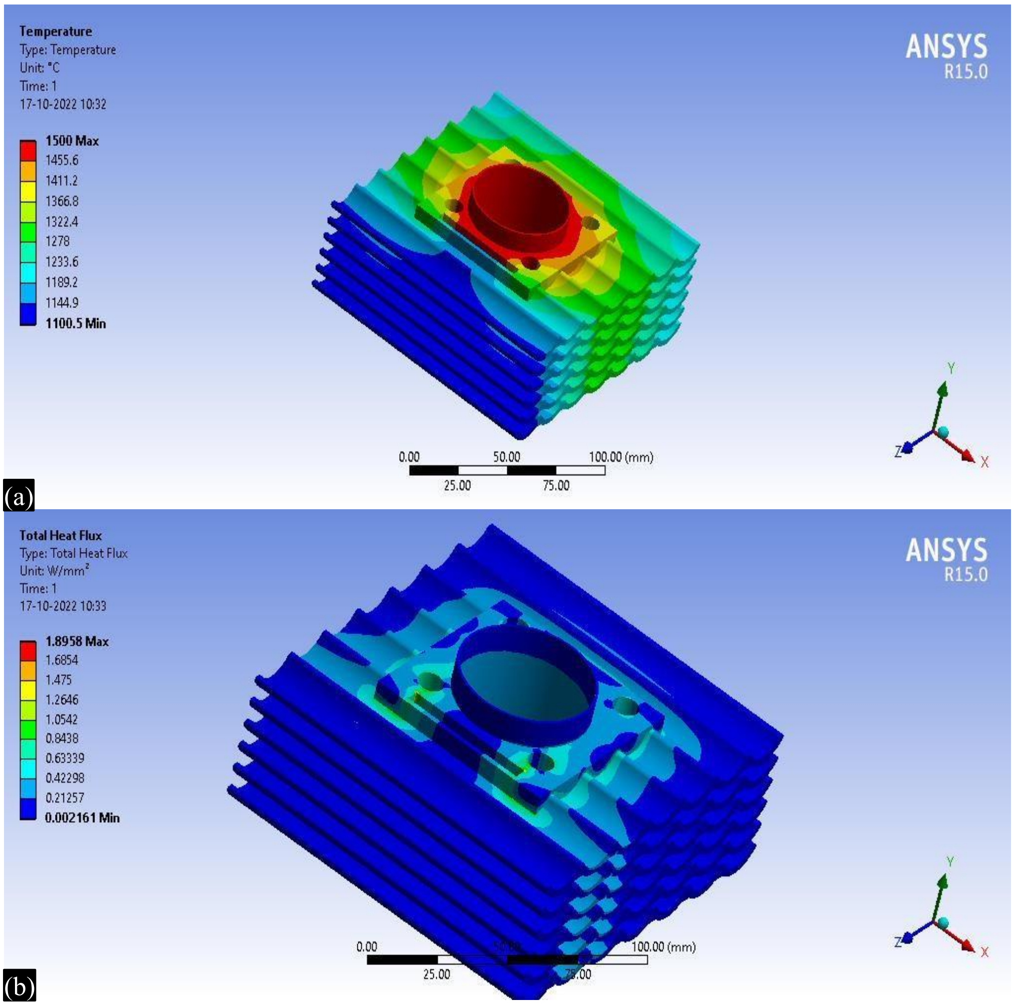

Figure 41. Steady-state thermal analysis of wavy fin (a) Temperature; (b) Heat flux

The temperature distribution through the maze fins is depicted in the above Figure 42 and 43. The temperature distribution ranges from 1344.5°C at the lowest to 1500°C at the maximum. Furthermore, the greatest total heat flux through it is 2.4993 W/mm^2, whereas the minimum total heat flux is 2.551e-003 W/mm^2. Table 37 shows the triangular fin steady-state result.

Table 36. Maze fin steady-state result.

Object name	**Temperature**	**Total heat flux**
State	Solved	
	Results	
Minimum	1344.5°C	2.551e-003 W/mm^2
Maximum	1500°C	2.4993 W/mm^2
	Minimum value over time	
Minimum	1344.5°C	2.551e-003 W/mm^2
Maximum	1344.5°C	2.551e-003 W/mm^2
	Maximum value over time	
Minimum	1500°C	2.0093 W/mm^2
Maximum	1500°C	2.0093 W/mm^2

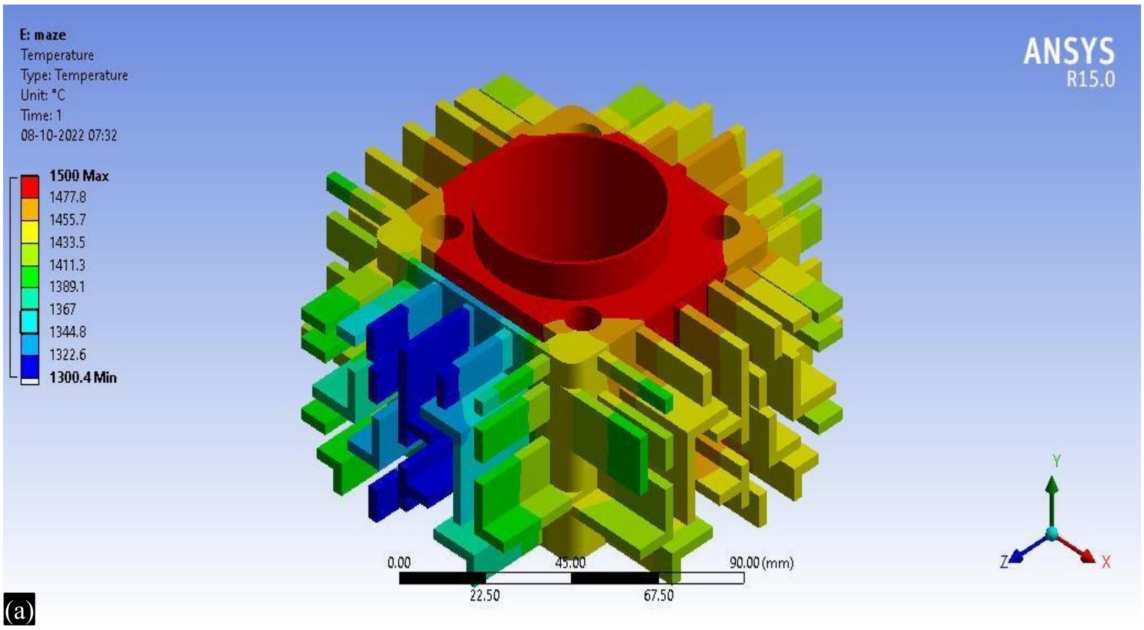

Figure 42. Steady-state thermal analysis of the maze fin, temperature.

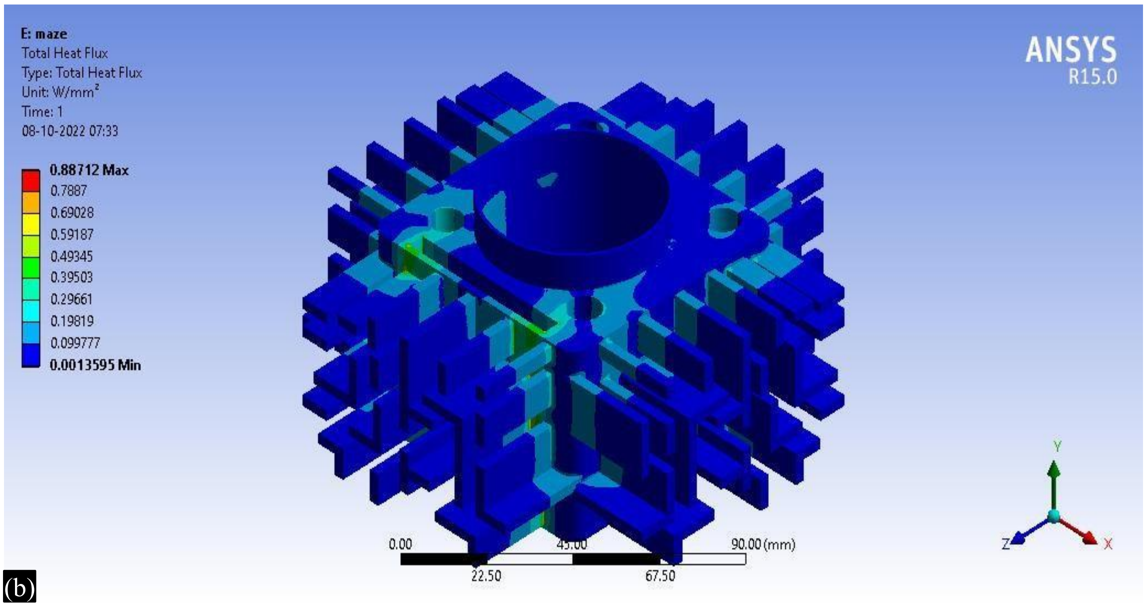

Figure 43. Steady-state thermal analysis of maze fin, heat flux.

Table 37. Triangular fin steady-state result.

Object Name	Temperature	Total Heat Flux
State	Solved	
Results		
Minimum	1361.7°C	3.1834e-003 W/mm^2
Maximum	1500°C	1.628 W/mm^2
Minimum value over time		
Minimum	1361.7°C	3.1834e-003 W/mm^2
Maximum	1361.7°C	3.1834e-003 W/mm^2
Maximum value over time		
Minimum	1500°C	1.628 W/mm^2
Maximum	1500°C	1.628 W/mm^2

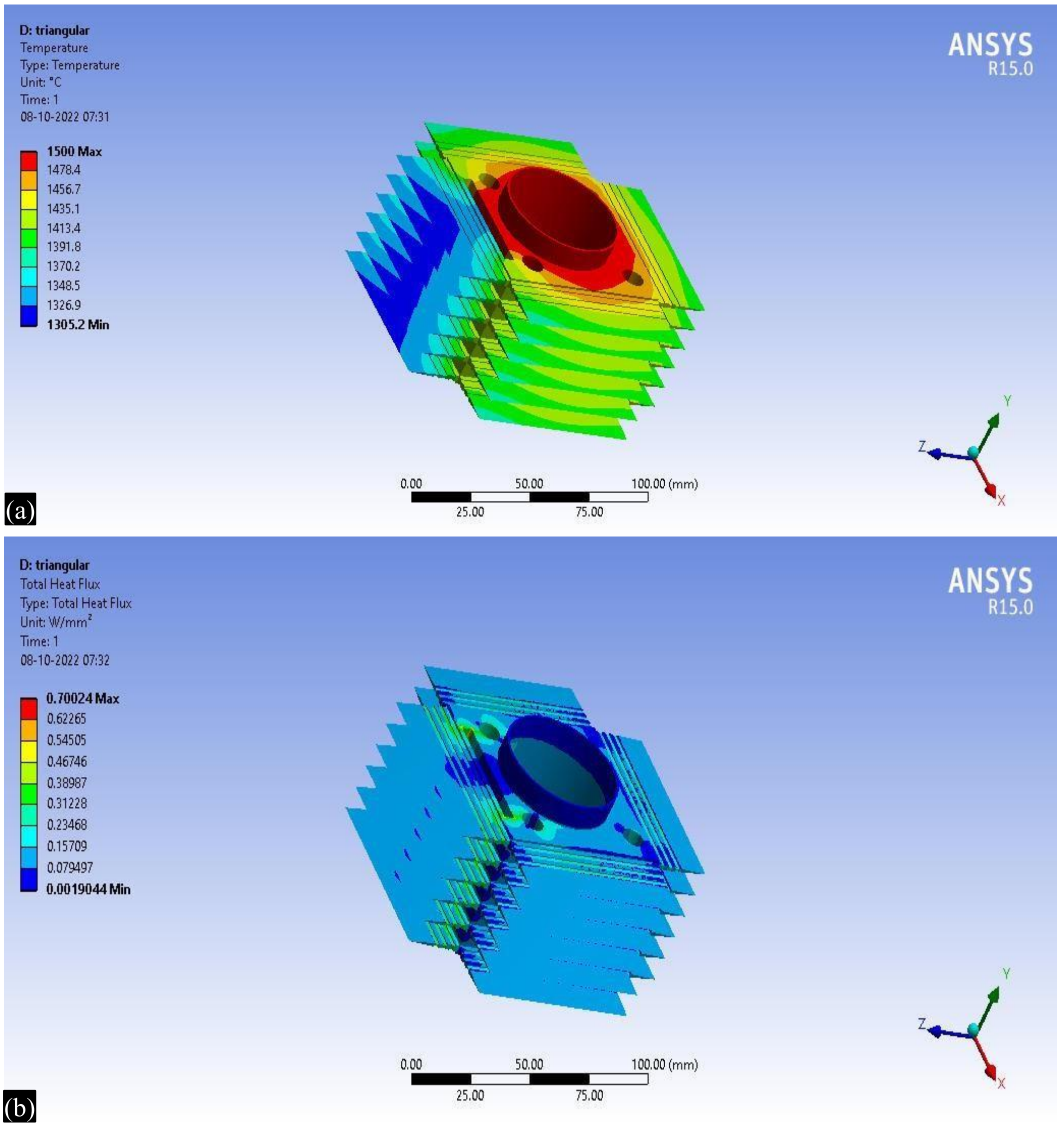

Figure 44. Steady-state thermal analysis of triangular fin (a) Temperature; (b) Heat flux

The temperature distribution through triangular fins is depicted in the above Figure 44 (a) and (b). The temperature distribution ranges from 1361.7°C at the least to 1500°C at the maximum. Furthermore, the greatest total heat flux through it is 1.628 W/mm^2, whereas the minimum total heat flux is 3.1834e-003 W/mm^2. Table 38 shows the trapezoid fin steady-state result.

Table 38. Trapezoid fin steady-state result.

Object Name	Temperature	Total Heat Flux
State	Solved	
Results		
Minimum	1356.7°C	1.9531e-003 W/mm^2
Maximum	1500°C	1.6206 W/mm^2
Minimum value over time		
Minimum	1356.7°C	1.9531e-003 W/mm^2
Maximum	1356.7°C	1.9531e-003 W/mm^2
Maximum value over time		
Minimum	1500°C	1.6206 W/mm^2
Maximum	1500°C	1.6206 W/mm^2

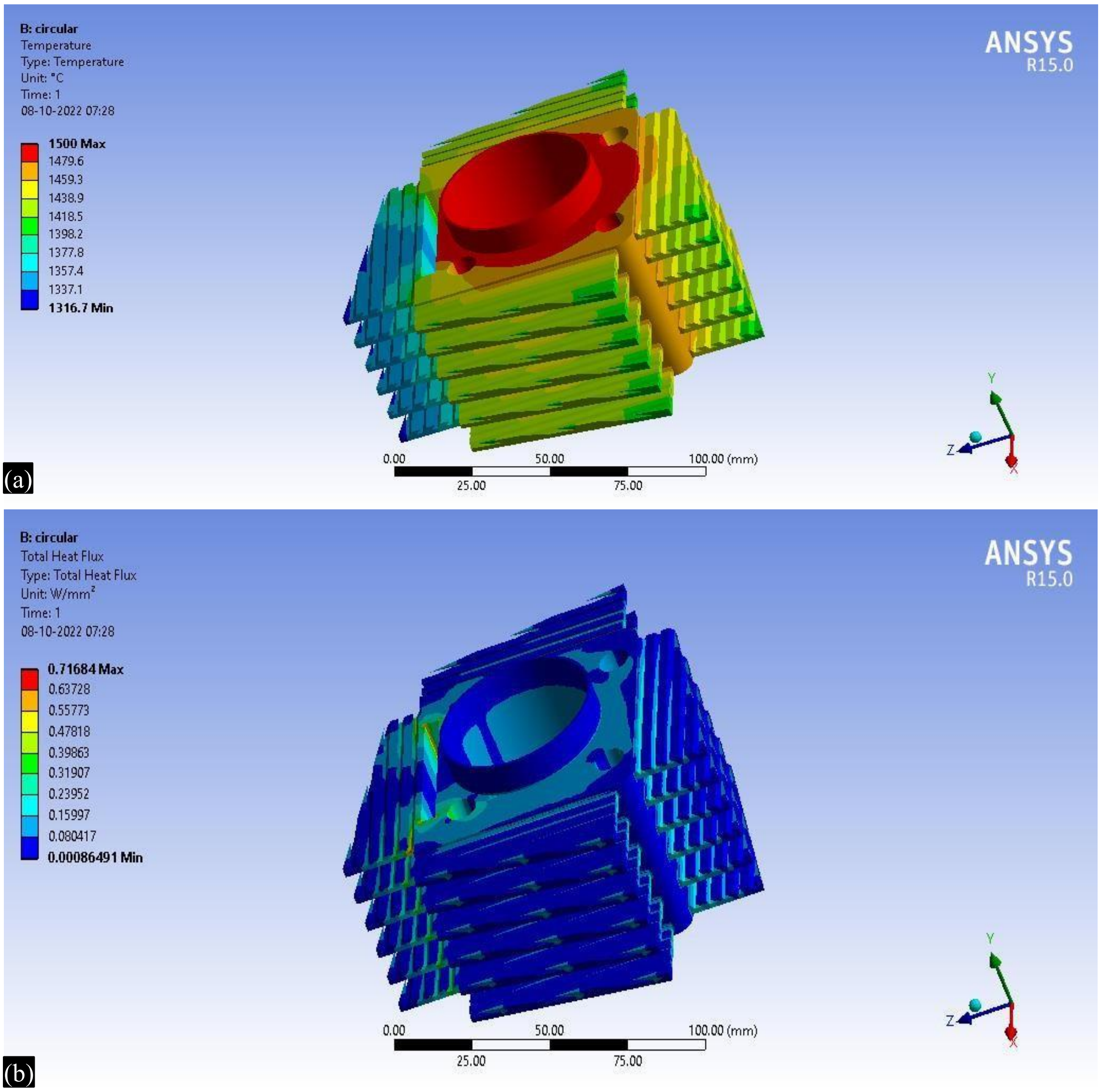

Figure 45. Steady-state thermal analysis of trapezoid fin (a) Temperature; (b) Heat flux

The temperature distribution through trapezoid fins is depicted in the above Figure 45 (a) and (b). The temperature distribution ranges from 1356.7°C at the least to 1500°C at the maximum. Furthermore, the greatest total heat flux through it is 1.6206 W/mm^2, whereas the minimum total heat flux is 1.9531e-003 W/mm^2. Figure 46 shows the comparison of temperature variation in different fins.

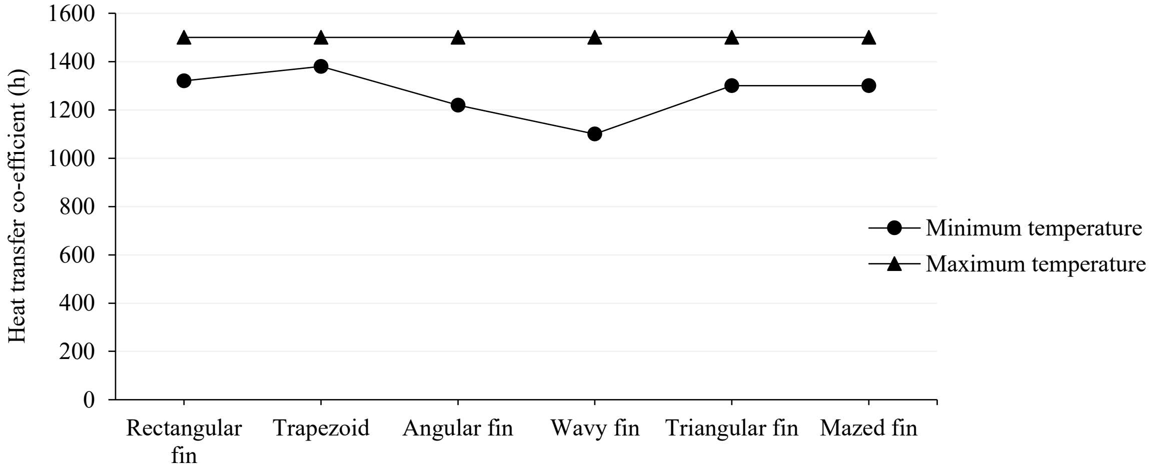

Figure 46. Comparison of temperature variation in different fins

Table 39. Angular fin transient thermal result.

Object name	Temperature	Total heat flux
State	Solved	
Results		
Minimum	29.984°C	3.5942e-006 W/mm^2
Maximum	1500°C	28.212 W/mm^2
Minimum value over time		
Minimum	-28.709°C	2.9191e-009 W/mm^2
Maximum	29.984°C	3.5942e-006 W/mm^2
Maximum value over time		
Minimum	1500°C	26.57 W/mm^2
Maximum	1500°C	324.63 W/mm^2

Table 40. Rectangular fin transient thermal result.

Object Name	Temperature	Total Heat Flux
State	Solved	
Results		
Minimum	30°C	1.1935e-008 W/mm^2
Maximum	1500°C	27.806 W/mm^2
Minimum value over time		
Minimum	5.5947°C	1.9696e-010 W/mm^2
Maximum	30°C	1.1935e-008 W/mm^2
Maximum value over time		
Minimum	1500°C	24.858 W/mm^2
Maximum	1500°C	327.77 W/mm^2

TRANSIENT THERMAL ANALYSIS RESULTS

A system's response to constant and changing boundary conditions is evaluated using transient thermal analysis. The time to attain the steady-state temperature and the amount of time the operating circumstances can be maintained before reaching the threshold temperature can both be calculated if the boundary conditions are fixed. A transient analysis can show the system's ensuing thermal response under boundary circumstances that change over time. Tables 39–44 and Figures 47–52 depict the transient temperature and heat flux distributions for different fin geometries, revealing the effect of fin shape on thermal response and heat dissipation characteristics under identical boundary conditions.

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Table 41. Wavy fin transient thermal result.

Object name	Temperature	Total heat flux
State	Solved	
Results		
Minimum	29.985°C	1.6771e-005 W/mm^2
Maximum	1500°C	27.849 W/mm^2
Minimum value over time		
Minimum	-0.38713°C	6.5067e-009 W/mm^2
Maximum	29.998°C	2.0063e-005 W/mm^2
Maximum Value over time		
Minimum	1500°C	25.532 W/mm^2
Maximum	1500°C	324.79 W/mm^2

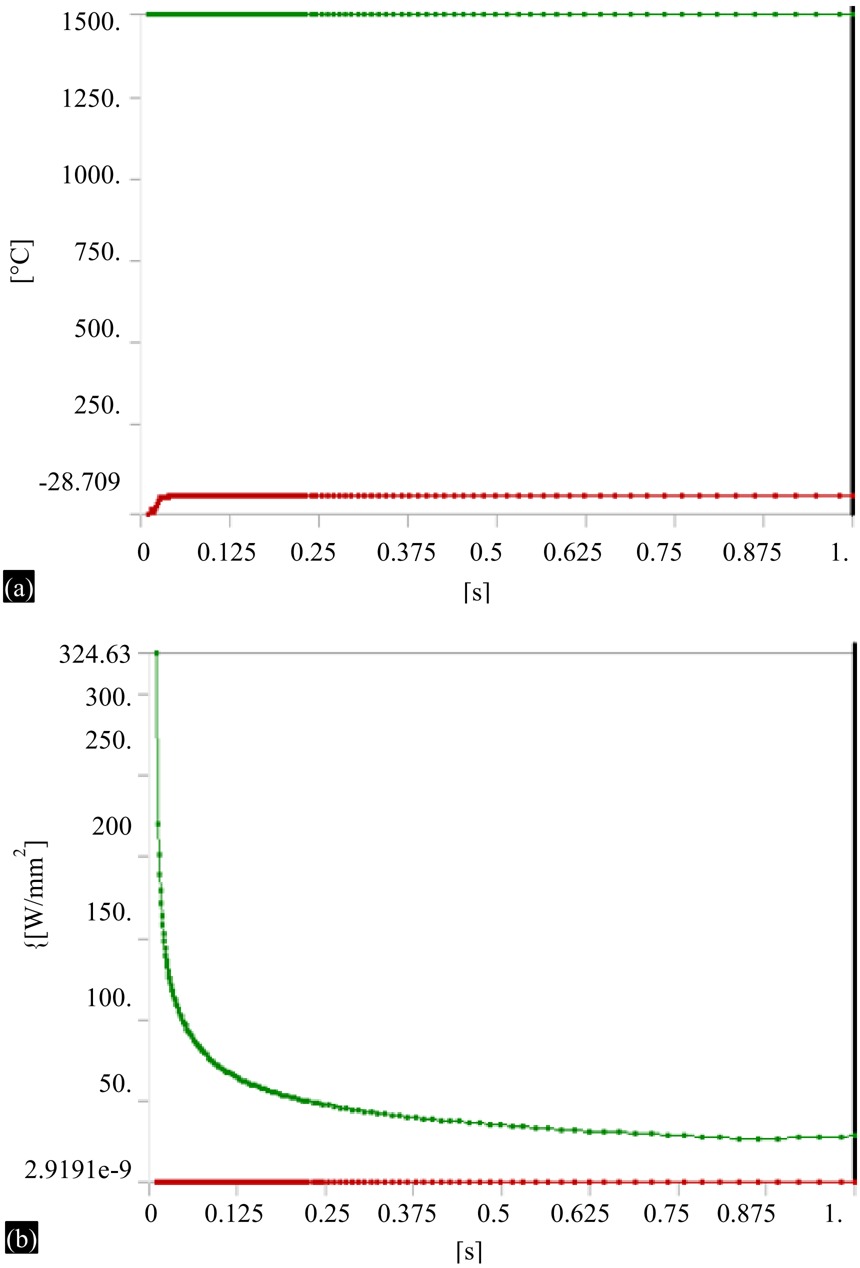


Figure 47. Transient thermal (a) Temperature; (b) Heat flux, variation in angular fin.

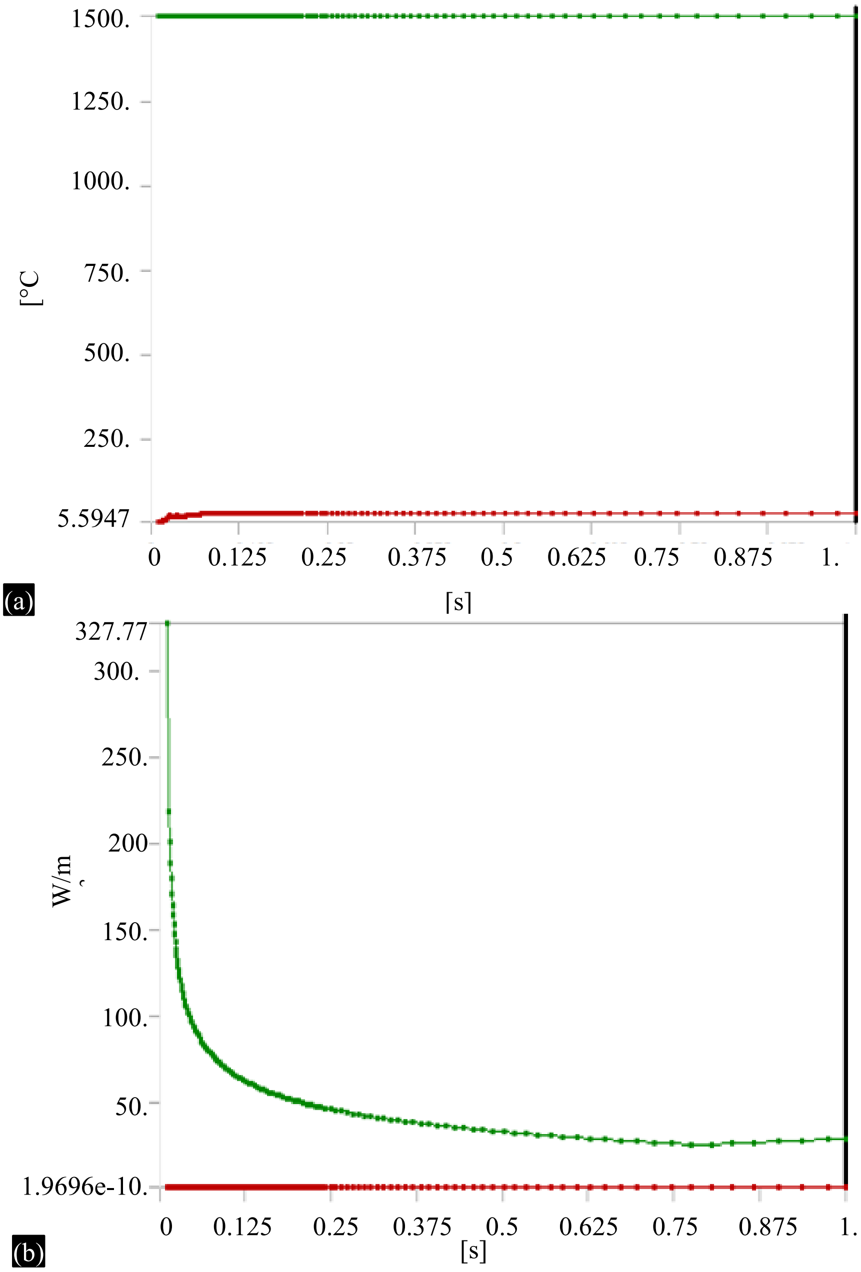
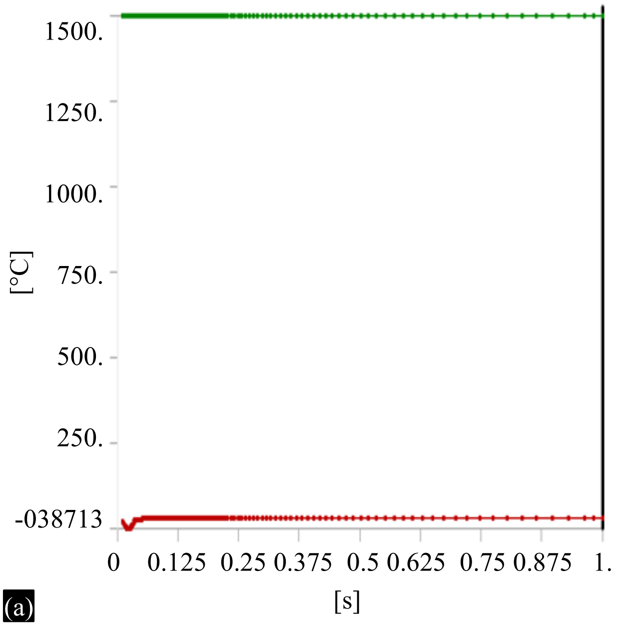


Figure 48. Transient thermal (a) Temperature; (b) Heat flux, variation in rectangular fin

Table 42. Maze fin transient thermal result.

Object Name	**Temperature**	**Total Heat Flux**
State	Solved	
	Results	
Minimum	30°C	4.2295e-010 W/mm^2
Maximum	1500°C	19.966 W/mm^2
	Minimum value over time	
Minimum	18.098°C	3.2431e-011 W/mm^2
30°C	30°C	7.6055e-010 W/mm^2
	Maximum value over time	
Minimum	1500°C	19.966 W/mm^2
Maximum	1500°C	210.28 W/mm^2



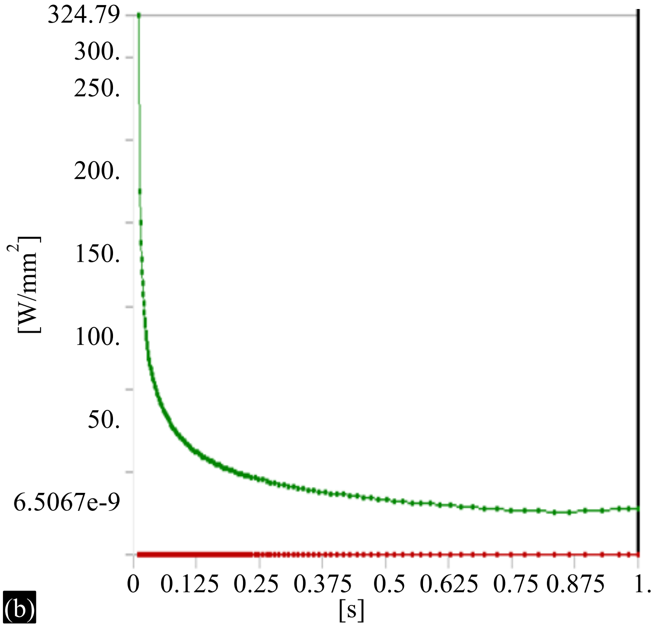


Figure 49. Transient thermal (a) Temperature; (b) Heat flux, variation in wavy fin

Table 43. Triangular fin transient thermal result.

Object Name	**Temperature**	**Total Heat Flux**
State	Solved	
	Results	
Minimum	29.993°C	1.5896e-009 W/mm^2
Maximum	1500°C	15.152 W/mm^2
	Minimum value over time	
Minimum	-10.923°C	4.2909e-011 W/mm^2
Maximum	29.997°C	1.5896e-009 W/mm^2
	Maximum value over time	
Minimum	1500°C	15.152 W/mm^2
Maximum	1500°C	209.71 W/mm^2

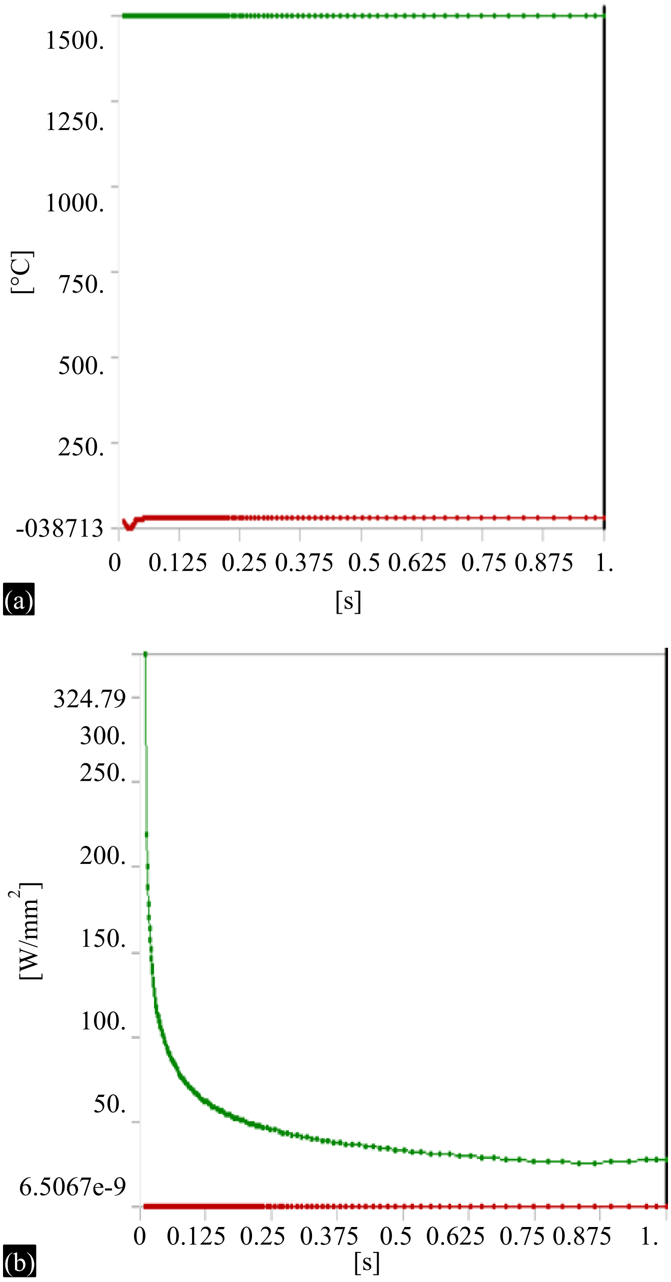


Figure 50. Transient thermal (a) Temperature; (b) Heat flux, variation in maze fin

Table 44. Trapezoid fin transient thermal result.

Object name	**Temperature**	**Total heat llux**
State	Solved	
Results		
Minimum	30°C	4.5185e-007 W/mm^2
Maximum	1500°C	27.132 W/mm^2
Minimum value over time		
Minimum	4.6783°C	2.404e-010 W/mm^2
maximum	30°C	7.7892e-009 W/mm^2
Maximum value over time		
Minimum	1500°C	25.227 W/mm^2
Maximum	1500°C	325.4 W/mm^2

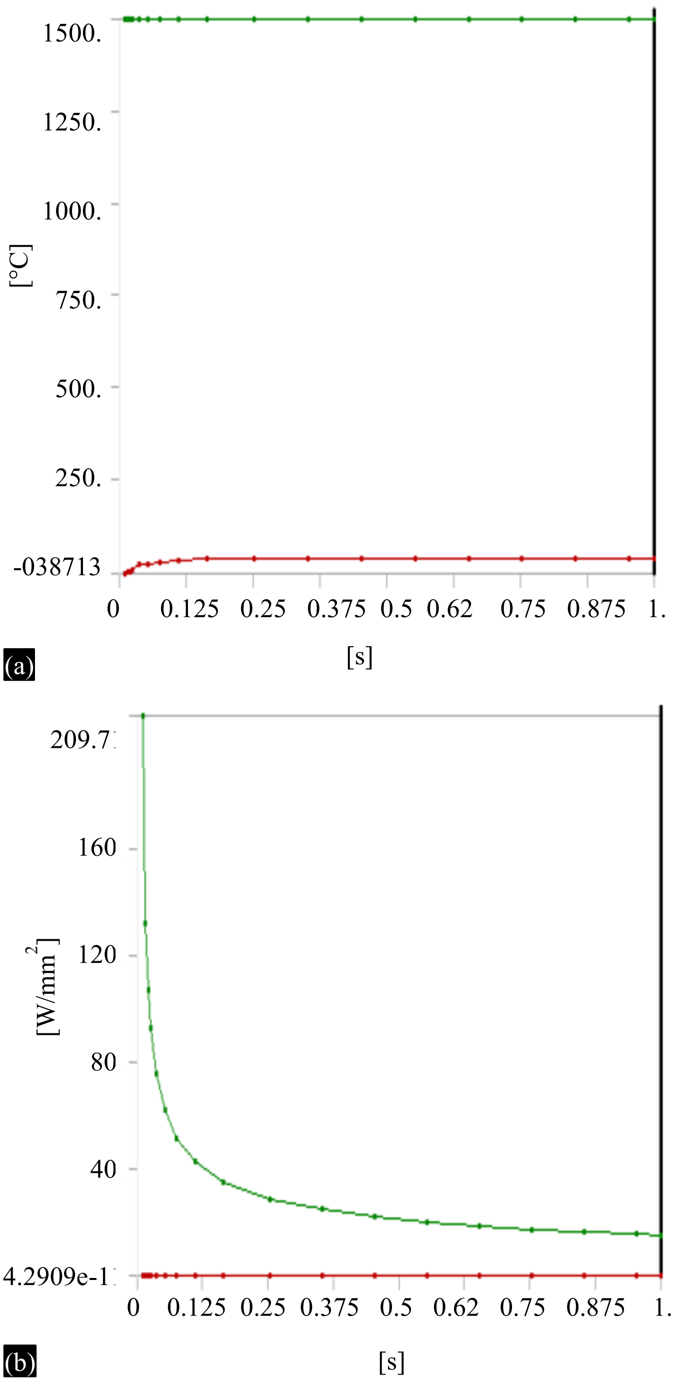


Figure 51. Transient thermal (a) Temperature; (b) Heat flux, variation in triangular fin

Fin Effectiveness

Fin effectiveness is the ratio of heat transfer from the fin to heat transfer without a fin.

$$\in = \frac{Qfin}{Q\ no\ Fin} \tag{1}$$

Actual heat transfer from the fin,
Heat transfer without a fin,
Where,

$$Q_{Fin} = \sqrt{(hPkA_c\theta_0)}\tan h\ (mL) \tag{2}$$

$$Q_{No\ Fin} = hA_c\theta_0 \tag{3}$$

$\theta_0 = (T_1 - T_2)$

Fin effectiveness,

if, mL ≅ 2.8

$$\in = \frac{\tan h\,(mL)}{\tan mL} \tag{4}$$

tanh(mL) = 0.98

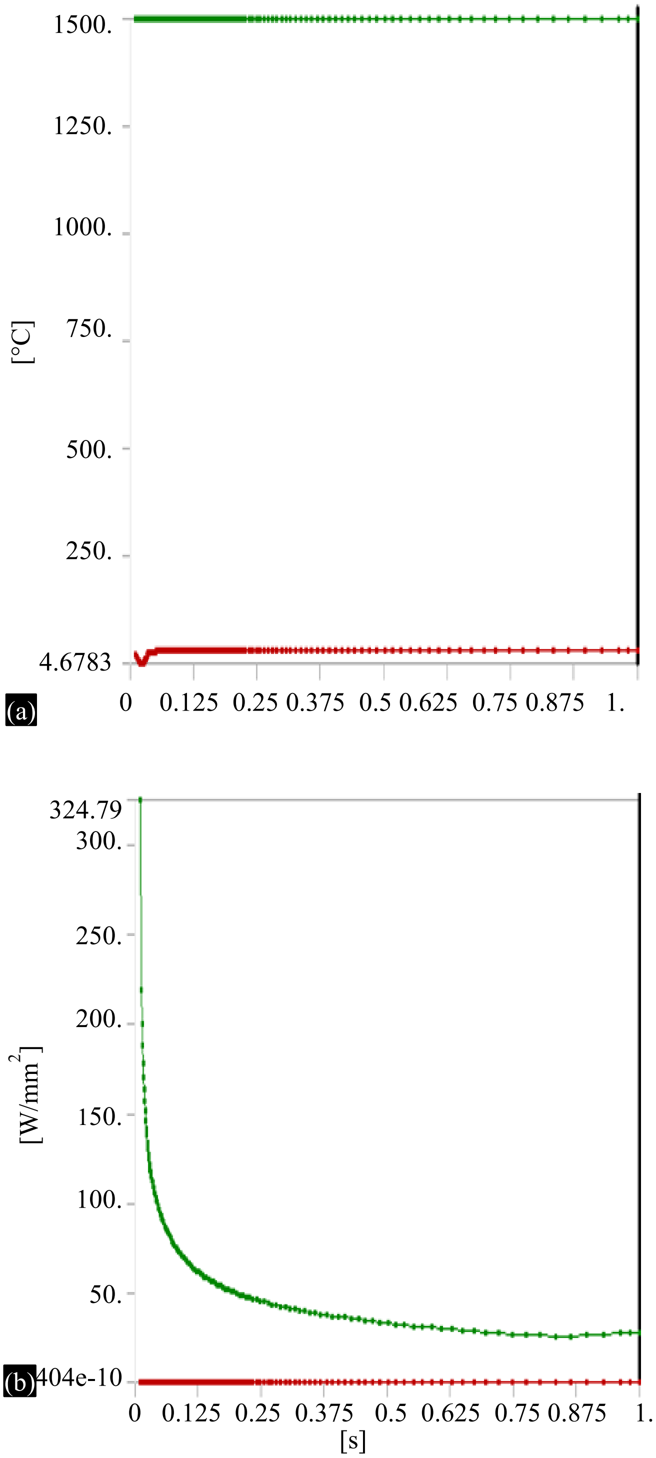


Figure 52. Transient thermal (a) Temperature; (b) Heat flux, variation in trapezoid fin

Table 45. Numerical calculation of different fins

	Angular	Rectangular	Wavy	Maze	Triangular	Trapezoid
Ac	0.01	0.01	0.01	0.01	0.01	0.01
P	6.1	6.86	5.67	5.26	1.84	2.44
mL	2.8	2.8	2.8	2.8	2.8	2.8
tanh(mL)	0.98	0.98	0.98	0.98	0.98	0.98
k	0.1	0.1	0.1	0.1	0.1	0.1
h	5	5	5	5	5	5
Ɛ	3.34	3.54	3.22	3.10	1.84	2.11

Table 46. Comparison of the minimum temperature achieved.

Fins	Angular	Rectangular	Wavy	Maze	Triangular	Trapezoid
For steady-state thermal analysis						
Temperature(°C)	1294.4	1373.7	1100.5	1344.5	1361.7	1356.7
For transient thermal analysis						
Temperature(°C)	29.98	30	29.98	30	29.99	30

Table 47. Comparison of fin effectiveness for different fins.

Fins	Angular	Rectangular	Wavy	Maze	Triangular	Trapezoid
Ɛ	3.34	3.54	3.22	3.10	1.84	2.11

The value of effectiveness indicates an increase in the rate of convective heat transfer from the body after the addition of fins; therefore, the value of effectiveness should be greater than 1. If the value of fin effectiveness is more than or equal to 2, then only the designed fin will be accepted. The value of the effectiveness of angular, rectangular, wavy, maze, and trapezoid fins is greater than two (Ɛ > 2); the fin for the desired output can be selected among these. The rectangular fin has maximum fin effectiveness, whereas the angular and wavy fins are in the series. But the triangular fin has a value of fin effectiveness less than 2; it is less desirable. Table 45 shows the numerical calculation of different fins.

CONCLUSION

A set of novel designs is examined for their potential to improve engine protection and heat transfer. The thermal performance of the six different fin geometries, viz., angular, rectangular, wavy, maze, triangular, and trapezoidal, was analyzed using different analyses. The objective was to find out which geometrical shape gives maximum heat dissipation and improved cooling for the engine.

- Comprising six fin profiles, the engine body was carried out in the present investigation, viz., angular, rectangular, wavy, maze, triangular, and trapezoid. The minimum temperature that was achieved in steady-state thermal analysis and transient thermal analysis is given in Table 46.
- In steady-state thermal analysis, the wavy fin has the lowest minimum temperature of 1100°C that is achieved, and the trapezoid fin has the highest temperature of 1356°C. The highest heat flux value is 2.4993 W/mm^2 for the maze fin because it has more surfaces.
- In transient thermal analysis, the maximum heat flux is for the maze fin, i.e., 4.2295e-010 W/mm^2. Whereas other fins have had very minimal heat flux. Table 47 shows the comparison of fin effectiveness for different fins.
- The fin effectiveness of the rectangular fin is 3.54, and it is considered the most effective for the use, indicating the best overall thermal performance among all the geometries considered. Although the Maze type fin produced the highest heat flux and the wavy type of fin achieved the lowest temperature, the rectangular fin provided the best balance between heat transfer capabilities and heat dissipation and overall effectiveness. Therefore, a rectangular fin is recommended as the optimal fin design for an air-cooled engine due to its superiority and reliability.

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