Analysis Of Heat Sink Performance with Alternative Pin-Fin Geometry Using Ansys

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***Abstract*— This paper presents a comprehensive thermal analysis of heat sink performance using different pin-fin geometries — circular, rectangular, and triangular — with two fin configurations (16 fins and 25 fins) for aluminium and copper materials. Steady-state thermal simulations were performed using ANSYS Workbench with Finite Element Analysis (FEA). The 3D parametric models were created using CATIA V5. The results demonstrate that triangular fin geometry consistently achieved the lowest temperature distribution and superior heat dissipation for both materials. Copper outperformed aluminium due to its higher thermal conductivity of 385 W/m·K. Increasing fin count from 16 to 25 yielded a marginal but consistent improvement in thermal performance across all geometries. The study concludes that triangular copper pin fins with 25 fins offer the best thermal performance among all configurations tested, making them suitable for electronic cooling and IC engine cooling applications where space and efficiency are critical.**

***Index Terms*—ANSYS, Aluminium, Copper, Extended Surfaces, FEA, Fin Geometry, Heat flux, Heat sink, Natural convection, Pin-fin, Temperature distribution, Thermal analysis.**

I. INTRODUCTION

Many industries face the problem of overheating in electronic components due to heat generation within them. Industries manufacture appliances with compact design and low cost, but the heat needs to be disbursed at a higher rate to maintain the temperature of the device within its working range. Therefore, devising efficient cooling is an answer to fulfil the cooling requirement in devices.

Heat transfer is the transfer of thermal energy from a heated body to a colder body. Exchange of heat occurs till the body and its surroundings reach the same temperature. According to the second law of thermodynamics, where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed down. Heat transfer is classified into three fundamental modes: conduction, convection, and radiation.

Conduction is defined as transfer of heat occurring through intervening matter without bulk motion of the matter. The thermal energy may be transmitted by means of electrons that are free to move through the lattice structure of the material. Convection is heat transfer due to a flowing fluid. In convection heat transfer, the heat is moved through bulk transfer of a non-uniform temperature fluid. Radiation is transmission of energy through space without the necessary presence of matter, governed by the Stefan-Boltzmann law.

To overcome the problem of overheating in thermal systems, fins are usually provided. Fins can be analysed in the design phase using Computational Fluid Dynamics (CFD) as a tool, assuming a uniform heat transfer coefficient model on their surface. However, research investigators prove that heat dissipation is not constant but varies along the fin length, mostly due to non-uniform resistance experienced by the fluid flow in the inter-fin region.

In order to dissipate high heat flux densities, the specified heat sink has to be properly designed. The inter-fin resistance can be decreased by adding perforations to the fins or by varying fin geometry. The fluid drift motion at the underside of the fin array may also be improved by adding perforations. This project investigates circular, rectangular, and triangular pin-fin heat sinks using ANSYS Workbench to identify the most efficient geometry and material combination.

A. Extended Surfaces and Fins

In heat transfer study, the surface that extends from an object is known as a fin. Fins are used to increase the rate of heat dissipation from or to the environment by increasing the rate of convection. The total amount of heat dissipated by a surface depends on the temperature difference between the object and the environment, the convection heat transfer coefficient, and the surface area. Fins increase the effective surface area and can often be the most economical solution to heat transfer problems.

B. Types of Fin Cross-Sections

Different shapes and designs of fins are used in different engineering situations: (1) Rectangular fin — uniform cross-section, easiest to manufacture and widely used; (2) Triangular fin — tapered profile with reduced weight but effective heat transfer; (3) Trapezium fin — tapered with flat tip offering a balance between rectangular and triangular; (4) Circular/pin fin — cylindrical profile suitable for three-dimensional heat dissipation. The choice of fin geometry depends on the application, available space, weight constraint, and required heat dissipation rate.

C. Materials for Heat Sink Fins

Aluminium is most widely used as fin material because it has good thermal conductivity (approximately 205 W/m·K), low density (2700 kg/m³), high corrosion resistance, and an excellent surface finish. Copper offers superior thermal conductivity (approximately 385 W/m·K) and is preferred for high heat flux applications where weight is not the primary constraint. Cast iron, though having lower thermal conductivity, offers high compressive strength and damping capacity.

II. LITERATURE REVIEW

Charan et al. (2018) analysed extended surfaces with perforations on the lateral surface of fins to enhance heat transfer rate effectively. From the research, it is evident that tip temperature is minimum for aluminium triangularly perforated fins with three perforations, and heat transfer is maximum for the same configuration. The Nusselt number increases for perforated fins when compared with non-perforated fins [1].

Sangaj et al. (2018) experimentally found the temperature distribution within pin fins of different materials and geometries and performed steady-state heat transfer analysis using ANSYS. The main aim was to optimize thermal properties by varying geometry, material, and thickness of fins. Their work concluded that copper circular hollow pin-fin and copper rectangular pin-fin are the most optimum configurations [2].

Beldar et al. (2017) performed steady thermal analysis using CFD software and conducted air flow analysis and pressure drop analysis with varying notch sizes (10%, 20%, 30%) and heat inputs (25W, 45W, 65W). They found that provision of notch at the central portion of the fin leads to change of flow pattern of natural air, increase in air velocity across the channel, and increase of heat transfer rate. Heat transfer was found to increase even when fin area was reduced due to notching [3].

Rajesh et al. (2017) analysed thermal properties by varying geometry and material (Cu and Al alloy 6082) and the distance between fins and thickness of cylinder fins. The fins models were created by varying geometry (circular) and also by varying thickness. Thermal analysis using ANSYS showed it is helpful to know the heat dissipation inside the cylinder [4].

Jain et al. (2017) analysed thermal heat dissipation of fins by varying geometry. Parametric models of fins were developed to predict transient thermal behaviour by varying geometry such as rectangular, circular, triangular, and fins with extension using CREO Parametric 2.0 and ANSYS 14.5. The study determined that geometry variation significantly impacts heat dissipation rate [5].

Kummitha et al. (2017) studied thermal analysis of cylinder blocks with various aluminium alloys. Passion Pro bike cylinder block was modelled using GAMBIT software and thermal analyses were performed using ANSYS. It was concluded that A380 has better heat transfer rate along with more strength as compared with other considered alloys [6].

Ravikumar et al. (2017) discussed geometric variables and design of heat sinks for enhancing thermal performance, making use of thermal evaluation for a computer using a 5W CPU. Round cylindrical pin fins and square plate heat sink fins layout with aluminium base plate were compared. An alternate model of heat fins was designed and analysed using ANSYS to increase heat dissipation [7].

Sandeep Kumar et al. (2017) studied heat transfer rate from the heating zone in IC engine through transient thermal analysis on actual design of Bajaj Discover 125CC single cylinder engine. The proposed design of the IC engine showed better performance and heat transfer rate from the heating zone [8].

Arefin (2016) introduced a modified pin design for pin fin heat sink where the pins have been expanded outward. Thermal analysis of the conventional pin fin heat sink and the modified pin fin heat sink was conducted numerically for natural convection, with the modified design showing better performance [10].

Balendra et al. (2016) performed experimental analysis and simulation for rectangular unnotched fins and worked on different forms of constant area inverted notched fins. The inverted triangular notched fin gave maximum heat transfer rate and the heat transfer rate was increased by almost 50.51% as compared to rectangular unnotched fin [11].

Kongre et al. (2016) analysed temperature distribution by varying geometry and thickness of cylinder fins using ANSYS workbench. By experimental work on array of perforated fins, it was observed that Nusselt number increases with increase in Reynolds number for both solid and perforated fins. Square perforations gave slightly higher percentage improvement compared to circular perforations [12].

Natrayan et al. (2016) analysed thermal properties by varying geometry of cylinder fins using ANSYS workbench. The 3D model of geometries was created using SOLIDWORKS 2016. The material used for manufacturing cylinder fin body was Aluminium Alloy AA 6061 with thermal conductivity of 160–170 W/m·K [13].

III. PROBLEM DEFINITION AND OBJECTIVES

In the present project, an investigation on thermal issues on fins was carried out. The investigation yields the temperature behaviour and heat flux of fins due to high temperature in the compressor chamber. ANSYS Workbench is utilized for analysis. The analysis is done for different models of fins that are commercially available and a comparison is established between them. The material and design are also varied to obtain better heat transfer rates.

The following are the main objectives of the present work:

1) To design cylinder with fins of different cross-sectional geometries (circular, rectangular, and triangular) using CATIA V5.
2) To determine steady-state thermal properties (temperature distribution and heat flux) of the proposed fin models using ANSYS Workbench.
3) To identify the most suitable material (aluminium or copper) for fabrication based on results obtained from finite element analysis.
4) To compare the effect of fin count (16 fins vs. 25 fins) on thermal performance for each geometry and material combination.
5) To identify the optimal heat sink design for electronic cooling and IC engine cooling applications.

IV. METHODOLOGY

The present work was carried out using the following methodology:

Step 1: Collecting information and data related to cooling fins, heat sink performance, and relevant literature.

Step 2: A fully parametric model of the cylinder with fins was created in CATIA V5 software for three geometries — rectangular, circular (pin), and triangular.

Step 3: Models were imported into ANSYS Workbench 14.5 and meshed using tetrahedral elements with an element size of 2.0 mm.

Step 4: Steady-state thermal boundary conditions were applied. Analysis was performed for both aluminium and copper materials, each with 16 fins and 25 fins configurations.

Step 5: Temperature distribution and heat flux results were extracted from ANSYS post-processor for all 12 configurations (3 geometries × 2 materials × 2 fin counts).

Step 6: Results were tabulated and compared to identify the optimal combination of fin geometry, material, and fin density.

V. CAD MODELLING USING CATIA V5

CATIA (Computer Aided Three-Dimensional Interactive Applications) is the most powerful and widely used CAD software. CATIA is owned and developed by Dassault Systems of France. The following best practices were followed in modelling:

A. Specification Tree Structuring

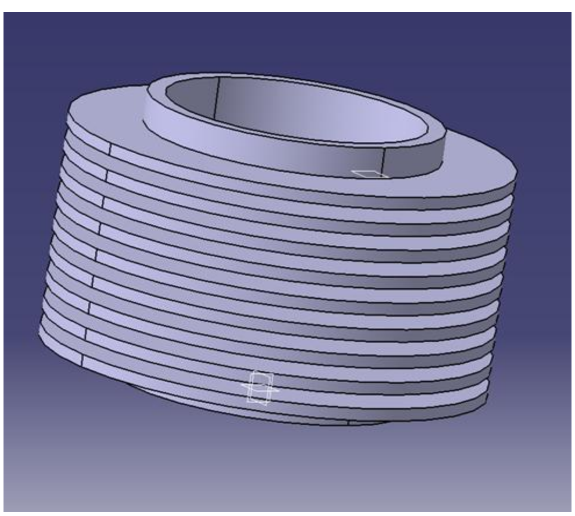
The specification tree captures the history of features modelled. It is structured in an organized manner in which machining body features are grouped under one body and base block features in another, with appropriate feature operations. Renaming of features and bodies helps in easy navigation for modifications.

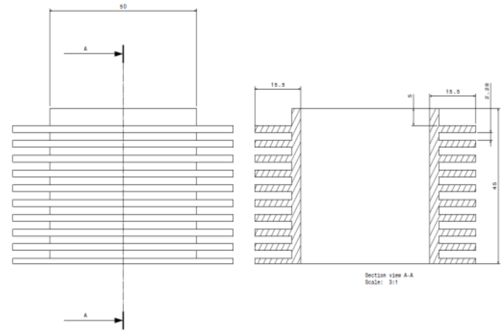
B. Dimensioning and Constraining in Sketches

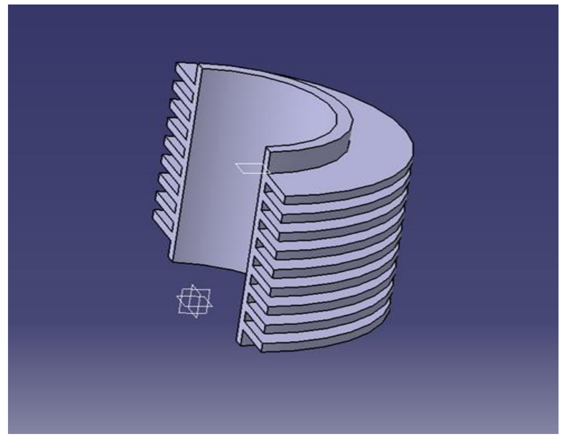
Planes were intersected in the sketches and made as construction elements, used as dimension references for geometries. Equivalent dimensions were used wherever possible to minimize modification time. Sketch analysis command was used at the end of every sketch build to diagnose and identify abnormalities.

C. Fin Geometries Modelled

Three distinct fin cross-sectional profiles were modelled: (1) Rectangular fin — flat blade profile with uniform rectangular cross-section throughout the fin height. This geometry is the simplest to manufacture. (2) Circular/Pin fin — cylindrical pin profile extruded from the base plate, allowing three-dimensional heat dissipation. (3) Triangular fin — tapered triangular profile with maximum thickness at the base and tapering to a point at the tip, reducing material while maintaining good heat transfer performance. Each model was created for both 16-fin and 25-fin configurations for aluminium and copper materials.







Cylinder fin cross section rectangular shape

VI. FINITE ELEMENT ANALYSIS USING ANSYS

FEA consists of a computer model of a material or design that is stressed and analysed for specific results. ANSYS is a general-purpose FEA software package that implements equations governing the behaviour of elements and solves them to create a comprehensive explanation of how the system acts. In practice, a finite element analysis consists of three principal steps: preprocessing, analysis, and postprocessing.

A. Preprocessing

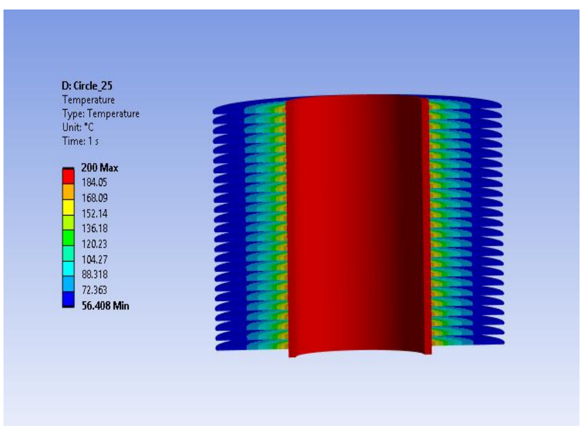
The user constructs a model of the part to be analysed in which the geometry is divided into a number of discrete sub-regions, or elements, connected at discrete points called nodes. Certain of these nodes will have fixed displacements, and others will have prescribed loads. The 3D CAD models created in CATIA V5 were imported into ANSYS Workbench 14.5 via the STEP file format. The geometry was verified and cleaned before proceeding to meshing.

B. Mesh Generation

Mesh generation is a critical step in the pre-processing of the finite element method. The SOLID92 tetrahedral element was selected for this analysis, with each unit having 10 nodes. The free meshing method was used with an element size of 2.0 mm. Table I shows the key meshing parameters used for all configurations.

Table I: Meshing Details

Parameter	Value
Element Type	Tetrahedral (Solid92)
Element Size	2.0 mm
Nodes	77,938
Elements	17,135
Bounding Box Diagonal	115.22 mm
Average Surface Area	978.41 mm²
Minimum Edge Length	0.02 mm
Smoothing	Medium
Mesh Quality Check	Standard Mechanical



C. Boundary Conditions and Loading

Steady-state thermal boundary conditions were applied to all models. A fixed temperature of 200°C was applied at the base surface of the cylinder to represent the heat source (engine/electronic component). Convective heat transfer with ambient air at 22°C was applied on all exposed fin surfaces, with a convection coefficient h = 10 W/m²·K for natural convection. The base of the cylinder block was constrained in the bolt hole positions along both axial and normal directions.

D. Material Properties

Two materials were considered for analysis. Aluminium: thermal conductivity ≈ 205 W/m·K, density 2700 kg/m³, specific heat 900 J/kg·K. It is preferred for its excellent strength-to-weight ratio, good thermal conductivity, and corrosion resistance. Copper: thermal conductivity ≈ 385 W/m·K, density 8960 kg/m³, specific heat 385 J/kg·K. It is preferred when maximum thermal conductivity is required, despite its higher weight.

E. Solution Method

The steady-state thermal analysis was solved using the h-method which can be used for any type of analysis. ANSYS calculates results separately for each load set included in the analysis. The Block Lanczos method was used for solving modal analysis. The h-method requires a finer mesh than the p-method; hence the 2.0 mm element size was selected to balance accuracy and computational efficiency.

VII. RESULTS AND DISCUSSION

The ANSYS steady-state thermal analysis was carried out to evaluate the performance of heat sinks using different pin-fin geometries (circular, rectangular, and triangular) with two fin configurations (16 fins and 25 fins) for both aluminium and copper materials. The performance was assessed based on temperature distribution and heat flux.

A. Individual Geometry Results

For circular fin geometry, the temperature distribution was from 200°C at the base to 164°C at the tip for aluminium material. The heat flow rate was 0.866 W/mm², representing the amount of heat transfer through the fin cross-sectional area. The circular profile allows uniform heat distribution along the fin perimeter, making it suitable for moderate heat flux applications.

For triangular fin geometry, the temperature distribution was from 200°C at the base to 164°C at the tip. The heat flow rate was 0.587 W/mm² for aluminium material. The tapered profile reduces material usage while maintaining effective heat transfer due to better airflow characteristics at the converging tip region.

For trapezium fin geometry, the temperature distribution was from 200°C at the base to 175°C at the tip, with a heat flow rate of 0.525 W/mm². For rectangular fin geometry, the temperature distribution was from 200°C at the base to 125°C at the tip, with a heat flow rate of 1.175 W/mm², indicating enhanced heat flux through the uniform cross-section.

B. Aluminium Heat Sink Results

Table II presents the complete steady-state thermal results for aluminium pin-fin heat sinks with all three geometries and both fin count configurations.

Table II: ANSYS Results — Aluminium Heat Sink

Fin Shape	No. of Fins	Temp (°C)	Heat Flux (W/m²)
Circular	16	56.97	1.0182
Circular	25	56.41	1.089
Rectangular	16	57.74	1.03
Rectangular	25	57.19	1.0878
Triangular	16	37.23	0.929
Triangular	25	37.07	0.9864

For the aluminium heat sink, the results show that rectangular fins exhibit the highest temperature values (57.74°C for 16 fins and 57.19°C for 25 fins), indicating relatively lower heat dissipation efficiency. The circular fins show slightly better performance with temperatures of 56.97°C and 56.41°C for 16 and 25 fins respectively. Triangular fins demonstrate the lowest temperature values (37.23°C for 16 fins and 37.07°C for 25 fins), indicating clearly superior cooling efficiency. In terms of heat flux, rectangular and circular fins show similar values (~1.08 W/m² for 25 fins), whereas triangular fins exhibit comparatively lower but consistent heat flux values, suggesting more effective heat spreading with reduced thermal resistance.

C. Copper Heat Sink Results

Table III presents the complete steady-state thermal results for copper pin-fin heat sinks.

Table III: ANSYS Results — Copper Heat Sink

Fin Shape	No. of Fins	Temp (°C)	Heat Flux (W/m²)
Circular	16	93.77	1.6146
Circular	25	92.93	1.7233
Rectangular	16	97.88	1.6127
Rectangular	25	94.04	1.7162
Triangular	16	64.34	1.4599
Triangular	25	63.94	1.5292

For the copper heat sink, overall performance is significantly improved due to its higher thermal conductivity. The rectangular fins again show higher temperature values (97.88°C for 16 fins and 94.04°C for 25 fins), whereas the triangular fins maintain the lowest temperatures (64.34°C and 63.94°C). The heat flux values are higher for copper in all cases, with circular and rectangular fins showing peak values (~1.72 W/m² for 25 fins), indicating enhanced heat transfer capability. Triangular fins show consistent heat flux performance at 1.53 W/m² for 25 fins, confirming effective heat spreading even with reduced cross-sectional area at the tip.

D. Effect of Fin Count

Increasing fin count from 16 to 25 fins resulted in a consistent reduction in temperature across all geometries and materials, confirming that higher fin density improves heat dissipation due to increased total surface area. For aluminium circular fins, temperature reduced from 56.97°C to 56.41°C (a reduction of 0.56°C). For aluminium triangular fins, temperature reduced from 37.23°C to 37.07°C (a reduction of 0.16°C). For copper circular fins, temperature reduced from 93.77°C to 92.93°C (a reduction of 0.84°C). The improvement is marginal across all cases, suggesting that beyond a certain fin density, adding more fins yields diminishing returns due to restriction of airflow in the inter-fin channels.

E. Comparison of Aluminium vs. Copper

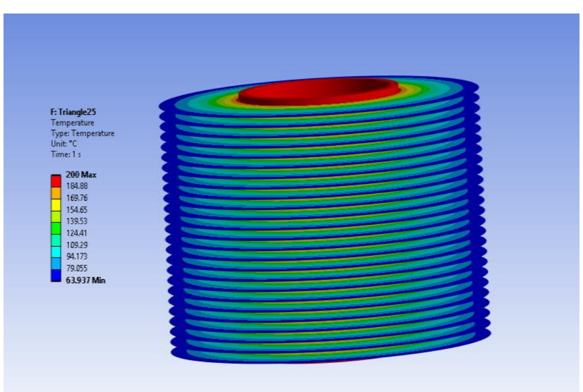
Comparing the two materials across all fin configurations, copper consistently achieves higher heat flux values due to its superior thermal conductivity (385 W/m·K vs. 205 W/m·K for aluminium). However, copper heat sinks also show higher absolute temperatures, which appears counterintuitive but is explained by the fact that copper's high conductivity allows more heat to flow through the fin, resulting in a larger temperature gradient and higher fin-tip temperatures relative to the boundary condition. Aluminium, being lighter in weight (2700 kg/m³ vs. 8960 kg/m³ for copper), is preferred where weight is a constraint, such as in aircraft and automotive applications, while copper is chosen for maximum heat removal in stationary electronic systems.

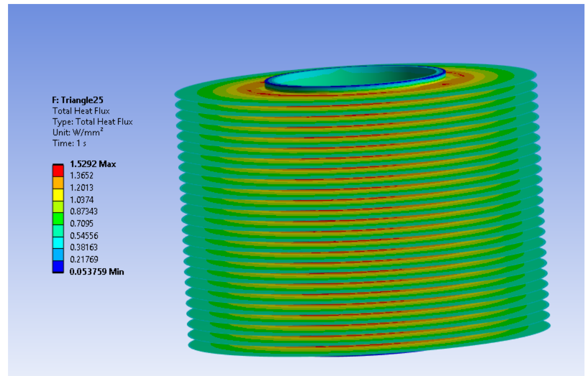
VIII. CONCLUSION

The thermal analysis of the heat sink with different pin-fin geometries using ANSYS Workbench clearly demonstrates that both fin shape and material significantly influence heat dissipation performance. Among the three geometries studied, triangular fins consistently showed the lowest temperature values for both aluminium and copper materials, indicating superior cooling efficiency due to better airflow distribution and reduced thermal resistance at the tapered profile.

When comparing materials, copper exhibited better thermal performance than aluminium in all configurations because of its higher thermal conductivity (385 W/m·K), resulting in greater heat flux values across all geometries. The increase in the number of fins from 16 to 25 resulted in a noticeable but marginal improvement in performance, as the additional surface area enhanced heat transfer. However, the improvement is not very significant beyond a certain fin density, suggesting that airflow limitations begin to offset the benefits of increased surface area.

Overall, the study concludes that a heat sink with triangular pin fins made of copper and having 25 fins provides the best thermal performance among all tested configurations. This combination ensures efficient heat removal and can be effectively used in thermal management applications such as electronic cooling systems, IC engine cylinder cooling, and heat exchangers. Future work may explore perforated fin geometries, hybrid aluminium-copper configurations, and advanced materials such as graphene composites for further improved thermal management.





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