Design Modification And Steady State Thermal Analysis Of Cylinder Fin Body With Different Cross-Sectional Fins Using Ansys Software

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Abstract
Thermal management is a critical aspect of air-cooled internal combustion engines because excessive heat generation during combustion can adversely affect engine performance, fuel efficiency, durability, and operational reliability. Cylinder fins are commonly employed to enhance heat dissipation by increasing the surface area available for convective heat transfer. However, conventional fin geometries often fail to provide optimal cooling performance under varying operating conditions. Therefore, the design optimization of cylinder fins has become an important area of research in automotive and thermal engineering applications.

This study investigates the design modification and steady-state thermal analysis of engine cylinder fin bodies with different cross-sectional fin geometries using ANSYS Workbench software. Four fin configurations, namely cylindrical, rectangular, aerodynamic, and curved fins, were modelled and analysed under identical thermal and airflow conditions. Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) techniques were employed to evaluate airflow characteristics, temperature distribution, heat transfer coefficients, and heat flux behaviour.

The simulation results indicate that fin geometry has a significant influence on thermal performance. Heat transfer coefficients of 681 W/m²K, 683 W/m²K, 688 W/m²K, and 696 W/m²K were obtained for cylindrical, rectangular, aerodynamic, and curved fins, respectively. The curved fin demonstrated the highest heat transfer capability due to enhanced airflow turbulence and improved air-fin interaction. Furthermore, heat flux increased consistently with increasing inlet air velocity, confirming the effectiveness of forced convection cooling mechanisms.

Comparative analysis revealed that modified fin geometries significantly outperform conventional cylindrical fins in terms of temperature reduction and heat dissipation efficiency. The aerodynamic fin exhibited improved airflow distribution and reduced flow resistance, while the curved fin achieved superior cooling performance by promoting turbulence generation around the fin surfaces.

The findings of this research demonstrate that optimized fin geometries can substantially improve engine cooling efficiency, reduce thermal stresses, and extend component life. The study also highlights the effectiveness of ANSYS-based simulation methodologies in evaluating and optimizing engine cooling systems prior to manufacturing. The proposed design modifications provide practical and economical solutions for developing advanced air-cooled engines with enhanced thermal performance and operational reliability.

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1. Introduction

Internal combustion engines convert chemical energy into mechanical power through the combustion of fuel-air mixtures. During this process, a considerable amount of heat is generated, and only a portion of this energy is transformed into useful work. The remaining heat must be dissipated effectively to maintain safe operating temperatures and ensure reliable engine performance. Excessive heat accumulation can lead to thermal stresses, lubricant degradation, component distortion, reduced fuel efficiency, and premature engine failure. Therefore, efficient cooling systems are essential for modern automotive and industrial engines.

Air-cooled engines employ external fins attached to the cylinder body to enhance heat transfer between the engine surface and surrounding air. These fins increase the available surface area for convection and improve cooling efficiency. The effectiveness of heat dissipation depends on factors such as fin geometry, fin spacing, airflow velocity, thermal conductivity of the material, and operating temperature conditions. Conventional cylindrical fins have been widely adopted due to their simple design and ease of manufacturing. However, recent studies indicate that alternative fin geometries can provide superior cooling performance.

Advancements in Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) have revolutionized thermal system design and optimization. Numerical simulation tools such as ANSYS Workbench enable engineers to analyse temperature distribution, airflow behaviour, heat transfer coefficients, and thermal stresses with high accuracy. These techniques significantly reduce experimental costs and development time while providing valuable insights into system performance.

Several researchers have investigated the influence of fin geometry on engine cooling characteristics. Modified fin structures such as rectangular, perforated, aerodynamic, and curved fins have shown promising results in improving convective heat transfer. The enhanced performance is primarily attributed to improved airflow distribution, increased turbulence generation, and greater surface interaction between the fin and surrounding air.

In this research, four different fin geometries are analysed using CFD and steady-state thermal analysis. The objective is to evaluate the thermal performance of cylindrical, rectangular, aerodynamic, and curved fins under identical operating conditions. The study focuses on temperature distribution, heat transfer coefficient, and heat flux behaviour to determine the most effective fin geometry for enhanced cooling applications.

The results obtained from this investigation contribute to the optimization of air-cooled engine systems and provide guidance for future thermal design improvements. By identifying efficient fin configurations, the study aims to improve engine performance, increase reliability, and reduce thermal-related failures in practical engineering applications.

1.1 Research Objectives

- To model different cross-sectional fin geometries for engine cylinder applications.
- To perform CFD analysis using ANSYS Fluent.
- To conduct steady-state thermal analysis using ANSYS Workbench.
- To evaluate airflow distribution and heat transfer characteristics.
- To compare temperature distribution and heat flux among different fin geometries.
- To identify the optimum fin geometry for enhanced cooling performance.
- To improve thermal efficiency and reliability of air-cooled engines.

1.2 Problem Statement

Air-cooled internal combustion engines rely on cylinder fins to dissipate heat generated during combustion. Although conventional fin structures provide basic cooling functionality, they often fail to achieve optimal heat transfer under demanding operating conditions. Insufficient heat dissipation can result in elevated engine temperatures, reduced fuel efficiency, increased thermal stresses, and accelerated wear of engine components.

The thermal performance of cylinder fins is strongly influenced by their geometry. Traditional cylindrical fins may not effectively utilize airflow, limiting convective heat transfer rates. Consequently, there is a growing need to investigate alternative fin configurations that can improve cooling efficiency without significantly increasing manufacturing complexity or engine weight.

Experimental evaluation of multiple fin geometries is often expensive, time-consuming, and difficult to implement during the early stages of product development. Numerical simulation techniques such as Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) provide efficient alternatives for analysing thermal performance and optimizing fin design.

This study addresses the need for a comparative thermal analysis of different fin geometries under identical operating conditions. By evaluating cylindrical, rectangular, aerodynamic, and curved fins using ANSYS Workbench, the research seeks to determine which geometry provides the most effective heat dissipation. The findings will support the development of advanced cooling solutions capable of improving engine efficiency, reliability, and operational lifespan while minimizing thermal-related performance limitations.

2. Literature Review

Several researchers have investigated heat transfer enhancement techniques for air-cooled engines.

Karthikeyan et al. analysed rectangular fin arrays with perforations and extensions and reported improved heat transfer due to increased airflow interaction. Sajesh et al. studied heat transfer performance in rectangular fin structures and concluded that fin geometry significantly affects cooling efficiency.

Natrayan et al. investigated thermal behaviour of different fin geometries and reported that modified fin structures provide superior heat dissipation compared to conventional designs. Pardeep Singh et al. demonstrated that fin extensions enhance turbulence generation and improve convective heat transfer.

Recent studies using CFD techniques have shown that aerodynamic and curved fin geometries improve airflow distribution and reduce thermal resistance. Researchers have emphasized the importance of optimizing fin geometry to maximize heat transfer while minimizing material usage and manufacturing cost.

Although several studies have examined individual fin geometries, comprehensive comparison of cylindrical, rectangular, aerodynamic, and curved fins under identical operating conditions remains limited. This study addresses that gap through combined CFD and steady-state thermal analysis.

3. Objectives Of The Study

The objectives of the present work are:

1. To model different cross-sectional fin geometries.
2. To perform CFD analysis using ANSYS Fluent.
3. To conduct steady-state thermal analysis.
4. To evaluate temperature distribution and heat flux.
5. To compare heat transfer coefficients of various fins.
6. To identify the most effective fin geometry for enhanced cooling.

4. Methodology

The methodology adopted consists of the following stages:

1. Literature review and problem identification.
2. CAD modelling of cylinder fins.
3. Geometry imports into ANSYS Workbench.
4. Meshing of computational domain.
5. Application of material properties.
6. CFD simulation.
7. Steady-state thermal analysis.
8. Result comparison and interpretation.

Aluminium alloy was selected as the fin material due to its high thermal conductivity and lightweight properties.

5. Governing Equations

Heat transfer through fins involves conduction and convection mechanisms.

Conduction Heat Transfer:

$$q = -kA(dT/dx)$$

Convective Heat Transfer:

$$Q = hA(T_s - T_\infty)$$

Where:

q = Heat transfer rate
k = Thermal conductivity
A = Surface area
h = Heat transfer coefficient
T_s = Surface temperature
T_∞ = Ambient temperature
Q = Heat transfer rate

6. Cfd Analysis

CFD analysis was performed using ANSYS Fluent to study airflow behaviour around the fins.

Boundary Conditions:

- Inlet air velocity: 40, 60, and 80 km/hr
- Ambient temperature conditions
- Atmospheric outlet pressure
- Steady-state flow assumptions

The CFD simulations provided velocity contours, airflow distribution, turbulence intensity, and heat transfer coefficient values.

The results indicated improved airflow circulation around curved and aerodynamic fins, resulting in enhanced convective heat transfer.

7. STEADY-STATE THERMAL ANALYSIS

Thermal analysis was performed to determine temperature distribution and heat dissipation characteristics.
The cylinder base was subjected to thermal loading while convection boundary conditions were applied to exposed fin surfaces.
The temperature contours revealed that modified fin geometries reduced thermal concentration and improved cooling performance.

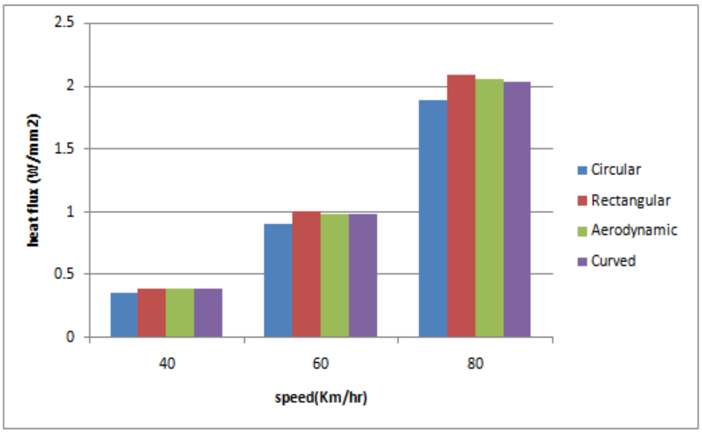

Fig 1: Inlet Speed v/s Outlet Heat Flux with Two various Fins

8. Results And Analysis

The performance of different cylinder fin geometries was evaluated using Computational Fluid Dynamics (CFD) and Steady-State Thermal Analysis in ANSYS Workbench. The objective of the analysis was to investigate the influence of fin geometry on heat transfer characteristics, temperature distribution, and cooling efficiency. Four different fin configurations, namely Cylindrical Fin, Rectangular Fin, Aerodynamic Fin, and Curved Fin, were considered under identical operating and boundary conditions.
The CFD simulations were performed to study airflow behaviour and heat transfer coefficients around the fin surfaces. Thermal analysis was conducted to determine temperature distribution and heat flux values generated under varying airflow velocities. The results obtained from both analyses were compared to identify the most efficient fin geometry.
The CFD results showed that airflow distribution and turbulence generation varied significantly with fin geometry. The conventional cylindrical fin exhibited relatively lower airflow interaction, resulting in a lower heat transfer coefficient. Rectangular fins provided improved cooling due to increased surface area. Aerodynamic fins allowed smoother airflow distribution and reduced flow resistance, while curved fins generated higher turbulence intensity, leading to enhanced convective heat transfer.
The heat transfer coefficient values obtained from the simulations are presented in Table 6.1.

Table8.1 Heat Transfer Coefficient for Different Fin Geometries

Fin Geometry	Heat Transfer Coefficient (W/m²K)
Cylindrical Fin	681
Rectangular Fin	683
Aerodynamic Fin	688
Curved Fin	696

The results indicate that the Curved Fin achieved the highest heat transfer coefficient of 696 W/m²K, followed by Aerodynamic Fin with 688 W/m²K. The increased turbulence and improved airflow circulation contributed to enhanced heat dissipation performance.
Steady-state thermal analysis was carried out at different airflow velocities corresponding to 40 km/hr, 60 km/hr, and 80 km/hr. The temperature distribution and heat flux results are summarized in Table 6.2.

Table 8.2 Thermal Analysis Results

Fin Geometry	Speed (km/hr)	Minimum Temperature (°C)	Maximum Temperature (°C)	Heat Flux (W/mm²)
Circular	40	130.10	270	0.35425
Circular	60	198.83	550	0.89968
Circular	80	289.77	1020	1.88750
Rectangular	40	127.43	270	0.39301
Rectangular	60	191.20	550	1.00100
Rectangular	80	277.34	1020	2.08670
Aerodynamic	40	126.39	270	0.39116

Aerodynamic	60	191.38	550	0.98417
Aerodynamic	80	277.49	1020	2.04860
Curved	40	127.55	270	0.38771
Curved	60	194.06	550	0.97666
Curved	80	284.69	1020	2.02910

The results demonstrate that heat flux increases with increasing airflow velocity for all fin geometries. At higher speeds, the enhanced convective heat transfer promotes efficient heat removal from the cylinder surface. Among the geometries analysed, Rectangular, Aerodynamic, and curved fins exhibited significantly better heat dissipation characteristics than the conventional cylindrical fin.
The temperature contour plots obtained from ANSYS Workbench revealed that Aerodynamic and Curved fins maintained a more uniform temperature distribution across the fin surfaces. Reduced thermal concentration near the cylinder body indicates improved cooling performance and lower thermal stress development.

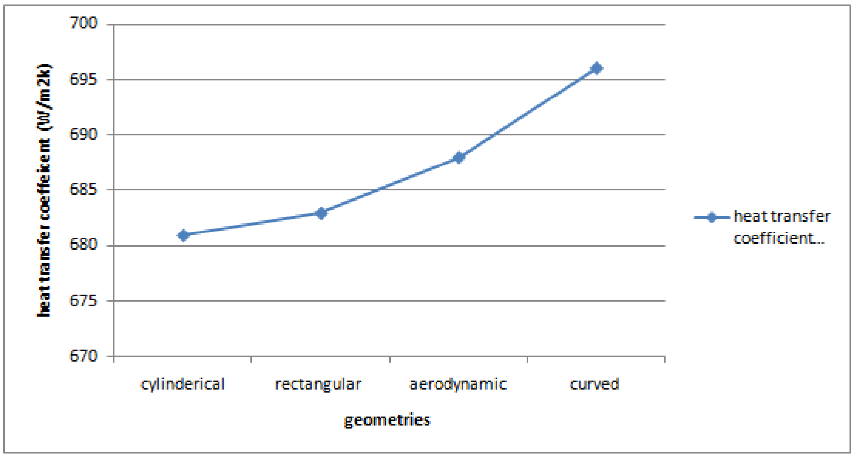

Fig 2: Heat Transfer Coefficient Geometrics Graph

9. Discussion

The present study investigated the thermal performance of four different cylinder fin geometries, namely Cylindrical Fin, Rectangular Fin, Aerodynamic Fin, and Curved Fin, using Computational Fluid Dynamics (CFD) and Steady-State Thermal Analysis in ANSYS Workbench. The primary objective was to evaluate the influence of fin geometry on heat transfer characteristics, temperature distribution, and cooling efficiency in air-cooled engine systems.
The simulation results clearly demonstrate that fin geometry plays a significant role in determining the heat dissipation capability of engine cylinder fins. Conventional cylindrical fins exhibited the lowest heat transfer coefficient among all geometries analysed. Although cylindrical fins are simple to manufacture and widely used in practical applications, their thermal performance is limited due to relatively lower airflow interaction and reduced turbulence generation around the fin surfaces.
Rectangular fins showed improved cooling characteristics compared to cylindrical fins. The larger surface area available for heat transfer enhanced convective cooling and increased heat flux values. At higher airflow velocities, rectangular fins demonstrated effective heat dissipation, making them suitable for moderate-performance engine applications. However, airflow separation near sharp edges reduced the overall thermal efficiency compared to more advanced fin designs.
Aerodynamic fins exhibited superior airflow behaviour due to their streamlined profile. The CFD analysis revealed smoother airflow distribution and reduced flow resistance around the fin surfaces. As a result, aerodynamic fins achieved a higher heat transfer coefficient of 688 W/m^2K. The temperature distribution was more uniform, indicating effective heat removal and reduced thermal concentration near the cylinder body. These characteristics make aerodynamic fins suitable for applications where both thermal efficiency and aerodynamic performance are important considerations.
Among all geometries studied, curved fins provided the best thermal performance. The curved profile generated higher turbulence intensity and improved air circulation around the fin surfaces. Increased turbulence enhanced the convective heat transfer coefficient, resulting in the highest value of 696 W/m^2K. The temperature contours obtained from thermal analysis showed lower thermal concentration and more uniform heat distribution. The curved fin geometry effectively maximized air-fin interaction, leading to superior cooling efficiency and improved thermal management.
The heat flux results further support these observations. As airflow velocity increased from 40 km/hr to 80 km/hr, heat flux increased for all fin geometries due to enhanced convective heat transfer. The modified fin structures consistently outperformed the conventional cylindrical fin, demonstrating the importance of geometric optimization in engine cooling applications.
Overall, the study confirms that advanced fin geometries can significantly improve engine cooling performance without increasing system complexity. The results suggest that curved fins offer the most efficient solution for

heat dissipation in air-cooled engines, followed closely by aerodynamic fins. The implementation of optimized fin structures can reduce engine operating temperatures, improve fuel efficiency, decrease thermal stresses, and extend engine service life.

Table 9.1 Comparison of Thermal Performance of Different Fin Geometries

Parameter	Cylindrical Fin	Rectangular Fin	Aerodynamic Fin	Curved Fin
Heat Transfer Coefficient (W/m²K)	681	683	688	696
Cooling Performance	Moderate	Good	Very Good	Excellent
Airflow Distribution	Moderate	Good	Excellent	Very Good
Turbulence Generation	Low	Moderate	Moderate	High
Temperature Distribution	Non-Uniform	Improved	Uniform	Highly Uniform
Heat Dissipation Capability	Moderate	High	Very High	Maximum
Thermal Concentration	High	Moderate	Low	Very Low
Heat Flux at 80 km/hr (W/mm²)	1.8875	2.0867	2.0486	2.0291
Engine Cooling Efficiency	Average	Good	Very Good	Excellent
Overall Ranking	4	3	2	1

Table 9.2 Advantages and Limitations of Various Fin Geometries

Fin Geometry	Advantages	Limitations
Cylindrical Fin	Simple design, easy manufacturing, low cost	Lower heat transfer efficiency
Rectangular Fin	Larger surface area, improved cooling	Airflow separation near edges
Aerodynamic Fin	Smooth airflow, reduced drag, uniform cooling	Slightly complex manufacturing
Curved Fin	Highest heat transfer, enhanced turbulence, superior cooling	More complex geometry and fabrication

The comparative analysis clearly indicates that the Curved Fin geometry offers the best thermal performance among all configurations studied. Therefore, curved fins are recommended for high-performance air-cooled engines where efficient heat dissipation and thermal stability are critical requirements.

10. Conclusion

The present research focused on the design modification and steady-state thermal analysis of engine cylinder fin bodies with different cross-sectional geometries using ANSYS Workbench software. Efficient heat dissipation is essential for maintaining the performance, reliability, and service life of air-cooled internal combustion engines. Therefore, the study investigated the thermal behaviour of four fin configurations, namely Cylindrical Fin, Rectangular Fin, Aerodynamic Fin, and Curved Fin, under identical operating conditions to determine the most effective fin geometry for enhanced cooling performance.

Computational Fluid Dynamics (CFD) and Steady-State Thermal Analysis were successfully performed to evaluate airflow characteristics, temperature distribution, heat transfer coefficients, and heat flux values. The simulation results clearly demonstrated that fin geometry has a significant influence on thermal performance and cooling efficiency. The conventional Cylindrical Fin exhibited the lowest heat transfer coefficient and comparatively lower cooling capability due to limited airflow interaction and reduced turbulence generation. Although it remains widely used because of its simplicity and ease of manufacturing, its thermal performance was found to be inferior to the modified fin geometries.

The Rectangular Fin showed improved heat dissipation characteristics due to its larger surface area, resulting in higher heat flux values and better cooling performance. The Aerodynamic Fin provided smoother airflow distribution and reduced flow resistance, leading to enhanced convective heat transfer and more uniform temperature distribution. Among all the geometries analysed, the Curved Fin demonstrated the highest thermal performance. The curved profile generated increased airflow turbulence and improved air-fin interaction, resulting in the highest heat transfer coefficient of 696 W/m²K and superior cooling efficiency.

The thermal analysis results further revealed that heat flux increased with increasing airflow velocity for all fin geometries. The modified fin structures consistently outperformed the conventional cylindrical fin, highlighting the importance of geometric optimization in thermal management systems. The comparative evaluation confirmed that Curved and Aerodynamic fins are highly effective in reducing thermal concentration and improving overall engine cooling performance.

The study concludes that optimized fin geometries can significantly enhance heat dissipation, reduce operating temperatures, minimize thermal stresses, and improve engine reliability. The use of ANSYS-based numerical simulation techniques proved to be an effective and economical approach for evaluating thermal performance and optimizing fin designs before manufacturing. The findings of this research provide valuable insights for the development of advanced air-cooled engine systems and support the adoption of improved fin configurations in automotive and industrial applications. Future work may focus on experimental validation, transient thermal analysis, advanced materials, and optimization techniques to further enhance engine cooling efficiency.

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