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Research Article

Improving Engine Cooling Performance through Slotted Fin Design: A Steady-State Thermal Analysis Study

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ABSTRACT

The engine fin is an essential component that significantly impacts the cooling system's effectiveness and overall performance. Although the engine fin is used to dissipate heat generated, an attempt to enhance the effective surface area for the fin needs to be addressed. This research aims to enhance the effectiveness of engine cooling systems through the fin design, which may involve incorporating slots to expand the surface area and improve overall efficiency. The analysis involved two fin geometries, rectangular and cylindrical fins, made of Aluminum 1100 material. The design models are created using the computer-aided design software PTC CREO Parametric 6.0., and steady-state thermal analysis and modal analysis were performed using ANSYS 2023 R1. The steady-state thermal analysis results indicate that the slotted cylindrical fin design demonstrated the highest heat transfer rate compared to the conventional fin design. The results from this study are expected to provide valuable performance in improving heat dissipation.

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1. Introduction

Engine fins play a crucial role in the cooling of internal combustion engines. These fins are affixed to the surface of the engine cylinder to accelerate the heat transfer process from the engine to the surrounding atmosphere. In the traditional design of engine fins, various parameters, such as the type of material used, the number of fins, the thickness of the fins, and the fin shape, significantly affect the thermal performance of the engine [1]. Over time, continuous exposure to high temperatures and thermal stress can cause engine fragility and decrease lifespan. Design modification plays a vital role in enhancing engine performance and cost reduction. The main problem with the current design and production method of engine fins is the limited options available for materials with high thermal conductivity. This results in low heat transfer rates and a decrease in engine efficiency. Another issue is the need for more consideration for optimizing the fin geometry, leading to a lack of optimal heat dissipation. Optimizing their geometry, material, and profile is one standard solution to improve engine fin performance [2]. It can be done through numerical simulations using computer-aided design (CAD) software and finite element analysis (FEA) tools. Determining the optimal design can provide the best balance between heat dissipation and weight reduction by testing various configurations. Another solution is to use materials with high thermal conductivity, such as

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Aluminum alloys, to enhance heat transfer. Incorporating innovative shapes can also increase surface area and enhance heat dissipation. Through the combination of these, we can improve the efficiency and lifespan of engine fins. The analysis of heat transfer and temperature variations is essential to understand the behavior of a system or material, and this method is commonly known as thermal analysis. It helps to predict how a system or material will perform under different thermal conditions. That information can then be used to modify the design and improve the performance of the system or material.

Several researchers worked in this area and reported their results. Dubey et al. [1] presented a work to increase an engine's heat dissipation rate by increasing the fin tip thickness, providing slots of different sizes, modelling the engine, and analyzingotherAluminum alloys such as 6061, C443, and 2014. The analysis shows that Aluminum Alloy 2014, with a slot width of 75 mm, has the highest thermal heat dissipation rate compared to other materials and slot widths. Shareef et al. [2] presented work on investigating the thermal properties of engine cylinders by varying the geometry, material, and profile of fins. Modelling was done for three geometrical shapes, and a numerical investigation was done using Ansys Workbench. The findings indicated that the angular profile fin decreased the weight by more than 60% compared to the original fin profile of the engine body while achieving the highest heat flux value and minimal possible temperature. Patil et al. [3] presented a work to identify the geometrical shape of a fin that dissipates more heat by varying geometry, material, and thickness of cylinder fins. Thermal analysis is done for the cylinder fins, and the heat dissipation rate of different geometries, materials, and thicknesses of the fins are compared. The analysis indicates that the step design fin is the most efficient in eliminating heat from the cylinder, resulting in a temperature reduction of 40.43°C compared to the standard design. Additionally, the wave design fin produced a temperature reduction of 13.17°C compared to the standard design. Sagar et al. [4] presented a work comparing aluminium alloy and magnesium alloy fins of different shapes (circular and rectangular) and thicknesses. The thermal analysis was conducted using a simplified case of stagnant air and an average internal temperature, with the film transfer coefficient used as the boundary condition. The Aluminium Alloy fin with 2mm thickness had the highest max temp (797.84°C) and shortest time to reach a steady state, conducting total heat flux than Magnesium Alloy fins. Increasing surface area increases heat flux while increasing thickness decreases it. Using ANSYS Workbench, Chaitanya et al. [5] analyzed the engine cylinder fins' thermal properties by varying their geometry, material, and thickness. The engine cylinder fin body was simulated, and a transient thermal analysis was performed to assess the temperatures and heat transfer over time. The findings revealed that implementing a circular fin made from Aluminum Alloy 6061, with a thickness of 2.5 mm, yielded superior heat transfer and reduced weight compared to the existing rectangular fin. Senthilkumar et al. [6] presented work on analyzing and comparing circular fins, axial fins, and circular fins with triangular profiles for their thermal performance in a two-stroke aluminium SI engine. The method uses FEA codes incorporating fluid mechanics to calculate the heat transfer coefficient and a simulation program for predicting and improving thermal performance. The utilization of triangle profile fins resulted in a decreased tip temperature distribution. In contrast, the elliptical fin was found to have better output in terms of overall thermal performance based on heat transfer analysis.

Sekhar et al. [7] presented work on the analysis of the heat dissipation of fins by varying its geometry and material composition. The 3D model was done for different geometries, analysis was conducted using ANSYS, and a thermal gradient was observed for each geometry and material composition. It was found that the triangular fins had a higher thermal gradient than rectangular fins, and the geometry and fin's cross-sectional area were the parameters that most contributed to the fin's efficiency. Devsingh et al. [8] presented the work on thermal analysis of 220cc engine cylinder fins to determine the heat dissipation through the cylinder. A parametric model of the piston bore fins was generated, and the analysis involved the variation of the fin body's manufacturing material, cast iron, with aluminium alloy 6082. The outcomes indicated that using aluminium alloy resulted in higher total heat flux, and it was established that cylindrical fins are better suited for implementation with aluminium alloy. Sagar et al. [9] presented a study on the effect of surface roughness on the heat transfer rate of a cylindrical body made of Aluminum alloy 6061. The study adopted a simulation approach using Thermal Analysis and performed body analysis. The findings demonstrate that an increase in body roughness from 240 to 400 microns corresponds to a rise in heat transfer rate and heat flux. This suggests that the heat dissipation rate is higher with increased roughness for the same area and volume. Kummitha et al. [10] presented a work on thermal analysis of cylinder block materials to find the best material that provides the best heat transfer rate while being lightweight and strong. A model of the Passion Pro bike cylinder block was done, and performed thermal analysis was done. The results indicated that grey cast iron and magnesium alloys were the most effective composite materials for heat transfer, but they were unsuitable for light vehicles due to their weight. Aluminium alloy A380 was determined to have the best heat transfer rate and strength compared to other alloys.

Tekhre et al. [11] presented work on designing efficient cooling fins for a 150cc Honda Unicorn bike engine by improving the design and material. The cross-sectional area of the fin was increased by implementing various diameter holes on the fin, and the computational fluid dynamics (CFD) analysis was done. The outcomes revealed that utilizing Aluminum Nitride material and enlarging the diameter of holes in the cooling fins resulted in a decrease of up to 20% in the minimum engine temperature. Durgam et al. [12] presented work on the thermal analysis of engine cylinder fins for heat transfer enhancement. The method includes modelling a fin, evaluating different physical and thermal properties, and performing steady-state thermal analysis using Ansys fluent. The weighted point method was also applied to determine the best material. According to thermal analysis in ANSYS and the weighted point method, the result showed Aluminium alloy 356 to be the best material among aluminium alloys, gray cast iron, and copper alloys.

Alam et al. [13] presented a work to find the best material for a motorcycle's engine cylinder fin body to provide maximum heat dissipation while keeping weight minimum. Thermal analysis was performed on a cylinder fin body using three materials Cast Iron, Aluminum alloy 6082, and Copper. Parameters such as geometry, the distance between fins, and the thickness of fins were varied to study their effect on heat dissipation using ANSYS. The result showed that Aluminum alloy 6082 was the best for the engine cylinder fin body as it had the highest thermal flux and the lowest weight. Rupesh et al. [14] presented work on designing fins of circular and tapered shapes for a 2-stroke engine and analyzing their temperature distribution and heat dissipation. The methodology involved conducting steady-state thermal analysis using FEM (Finite Element Method) and comparing it with the existing fin's shape and material. The results indicated that using an annular-shaped fin made of Alusil was a superior material, as it reduced the fragility of the engine and increased its lifespan by improving the heat transfer rate from the engine cylinder to the atmosphere. Gupta et al. [15] presented a work to improve the engine performance and reduce its cost by analyzing the thermal properties of different materials for the fins with varying slot sizes. Using 3D modelling of the engine and performing steady-state analysis on ANSYS, it was found that the maximum heat transfer was achieved with 75 mm slotted fins made of Aluminum Alloy 2014. Heat transfer decreased as the slot size increased beyond 75 mm, making it the best option for cost reduction and maximizing heat transfer.

Reviewing various research papers related to the thermal analysis of engine fins identified some research gaps. Increasing the surface area of fins is a well-established method to enhance heat transfer, but there needs to be more optimal strategies to increase the surface area of engine fins to improve heat transfer. One potential solution to enhance heat transfer in engine fins could be to employ non-uniform spacing between fins, utilizing advanced materials such as aluminium alloys, and incorporate slots in the design. This approach can enhance the surface area and improve the heat transfer rate, resulting in a more efficient and effective cooling system for the engine.

2. Methodology

The methodology section comprised preliminary modelling and analysis, design calculation, modelling, and thermal analysis of the redesigned fin design.

2.1. Preliminary Analysis

The engine's outer body with the fin was modelled using PTC CREO (6.0.6), as depicted in Figs. 1 and 2. The CAD model was created with accurate dimensions and specifications of the existing rectangular and cylindrical engine fin as listed in Table 1.

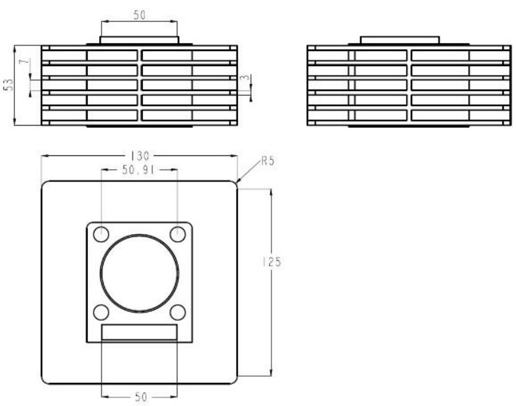


Fig. 1. Rectangular-shaped engine fin body

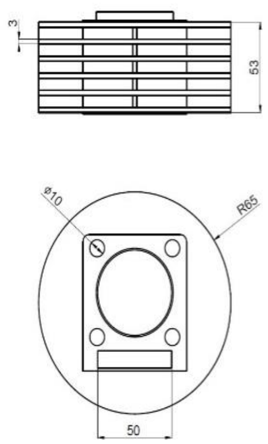


Fig. 2. Circular-shaped engine fin body

As illustrated in Figs. 1 and 2, the design consists of two different engine variants with fins. The CAD model was imported into ANSYS geometry to generate a finite element model. The model was divided into small elements to simplify the analysis process. Material properties and boundary conditions play a critical role in the accuracy of thermal analysis. The material properties, such as thermal conductivity and specific heat, are assigned to each element in the simulation model.

The boundary conditions are defined to simulate the real-world conditions of the system. For instance, the temperature at the inlet and outlet of the engine can be defined as boundary conditions that affect the heat transfer from the engine to the surrounding environment. The finite element model has meshed to convert the geometry into small, interconnected elements. Meshing helped to refine the analysis accuracy. The finite element model was used to conduct a thermal analysis to determine the temperature distribution on the outer body that included the fin. The study helped to find out the optimum geometry and slot width for better cooling of the engine. The results obtained from the thermal analysis were used to modify the geometry and slot width of the outer body with the fin. The modification helped to improve the cooling efficiency of the engine.

The modal analysis was performed for the existing and redesigned engine fin, and natural frequency was obtained for the component and corresponding mode shape. The mode shape forms with the combination of bending, twisting, etc. Based on the modal analysis results, it can be inferred that the natural frequency of the engine fin is within the acceptable range. The boundary conditions used in the modal analysis include fixed support constraints at the base of the fins and material. The modal analysis was performed to obtain natural frequency with the mesh size obtained from the mesh-independent study.

2.2. Design Calculations

The number of fins required to achieve the necessary heat dissipation is calculated assuming a certain heat transfer rate for an engine fin. It is assumed that the heat transfer rate is typically based on the preliminary design.

The rate of heat transfer from a rectangular fin with a uniform cross-section can be calculated using the formula

$$Q = h \times A_s \times \Delta t(n \times 2) \tag{1}$$

Required Heat transfer rate (Q) = 550 W

Temperature = 500°C

Film Coefficient (h) = 8.3e-006 W/mm^{2}K

Ambient Temperature = 25°C

Surface area of the fin (As) = 11935.4 × 2 mm^2

= 23870.8 mm^2

Number of fins (n) $= \frac{Q}{2h \times A_s \times \Delta t} = 5.844 \approx 6$

Space between fins = (w - (n x t)) / (n - 1)

= (53 – (6 × 3)) / 5 = 7 mm

2.3. Modeling of the Redesigned Engine Fin

The redesigned engine fin profile for rectangular and cylindrical shape engine bodies, with slots in the design, is shown in Figs. 3 and 4. The modelling is done using PTC CREO Parametric software (6.0.6).

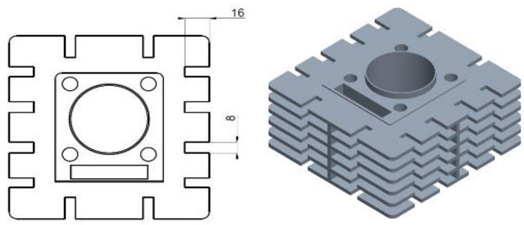


Fig. 3. Rectangular-shaped engine fin body with slot

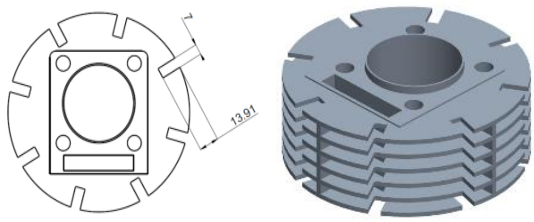


Fig. 4. Circular-shaped engine fin body with slot

Adding a slot to a surface can increase the available surface area for heat transfer, resulting in a higher heat transfer rate. This occurs as more heat can be transferred from the solid surface to the fluid or gas flowing over it. This effect is because heat is transferred from a hotter object to a cooler one through conduction, convection or radiation, and an increase in the more desirable object's surface area can boost the heat transfer rate.

Table 1. Design parameters

Parameters	**Shape of the Engine body**			
	Rectangular	Rectangular with slot	Circular	Circular with slot
Fin pitch	7	7	7	7
Fin thickness	3	3	3	3
Length	130	130	-	-
Width	125	125	-	-
Height	53	53	53	53
Diameter	-	-	130	130
Slot width	-	8	-	7
Slot depth	-	16	-	13.91
All dimensions are in mm				

2.4. Steady-State Thermal Analysis

This analysis considered two fin geometries: a rectangular fin and a cylindrical fin. The material chosen for the fins was Aluminum 1100, as illustrated in Table 2. The ANSYS 2023 R1 steady-state thermal analysis was performed, which allows for calculating temperature and heat flux distributions within the fins. The analysis involves adding material for the model of the fin geometry and applying thermal boundary conditions at the engine-fins interface and the fin-air interface. The model's thermal boundary conditions consider the engine's temperature at the interface with the fin and the heat transfer coefficient at the fin-air interface. The steady-state thermal analysis solution provides information on the fin's temperature distribution and heat flux. The comparison of the results for different fin geometries and materials allows for the determination of the optimal fin design for the specific engine application.

Table 2. Aluminium 1100 mechanical and thermal properties

S. No	**Property**	**Al 1100**
1.	Density (kg m-3)	2710
2.	Young’s Modulus (GPa)	69
3.	Poisson’s Ratio	0.33
4.	Thermal conductivity (W/mK)	222

The analysis assumes steady-state conditions, meaning that the temperature distribution within the fin remains constant with time. The material properties are supposed to be constant and isotropic.The heat transfer coefficient at the fin-air interface is assumed to be constant and uniform. The temperature of the engine is considered as 500°C. Table 3 presents the convention coefficient for different input temperature profiles. The ambient temperature was assumed to be 25^0 C.

Table 3. Convection coefficient table (Stagnant Air Horizontal cylinder)

Temperature (°C)	**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

2.5. Design Modification

In the design modification study, the objective was to increase the heat transfer rate of the engine fin by increasing the surface area in contact with air. To achieve this, a slot was introduced in the fin design to enhance the surface area exposed to the air stream. The slot size was selected based on an initial assumption and was further improved through a trial-and-error process. The final slot size was 7 x 14 mm, which increased surface area and heat transfer rate in contrast to the original design. The effect of the slot on the fin's thermal performance was evaluated by performing steady-state thermal analyses in ANSYS 2023 R1. The results were compared to the base fin design, which did not have a slot. This study on improvisation revealed that including the slot in the fin design increased the heat transfer rate, leading to lower temperatures of the fin and enhanced heat dissipation rates. As a result, the study proved the effectiveness of adding the slot to improve the surface area of the fin in contact with air and enhance the engine fin's thermal performance.

3. Results and Discussions

The result and discussion section comprised mesh independence study, modal analysis results, model validation, and steady-state thermal analysis.

3.1. Mesh Independence Study

The mesh independence study was conducted for different mesh sizes of the numerically developed model, and the natural frequency from the modal analysis was monitored. From Fig.5. it was found that a mesh size of 4 mm was sufficient to achieve converged results. Hence, the same mesh size of 4 mm was maintained throughout the analysis.

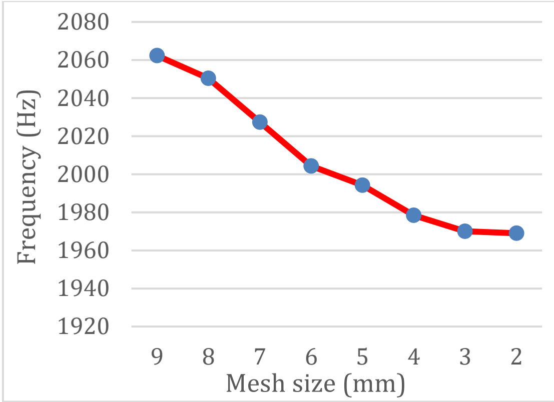


Fig. 5. Mesh independency study

3.2. Modal Analysis of the existing engine fin

Performing natural frequency helps to ensure that the fin does not vibrate excessively or undergo resonance, which can cause mechanical failure. Therefore, it is essential to perform model analysis and find the natural frequency to design fins that can withstand the thermal loads and vibrations induced during engine operation. It can be noted that the present study considers modal analysis for rectangular and circular-shaped engine fin bodies.

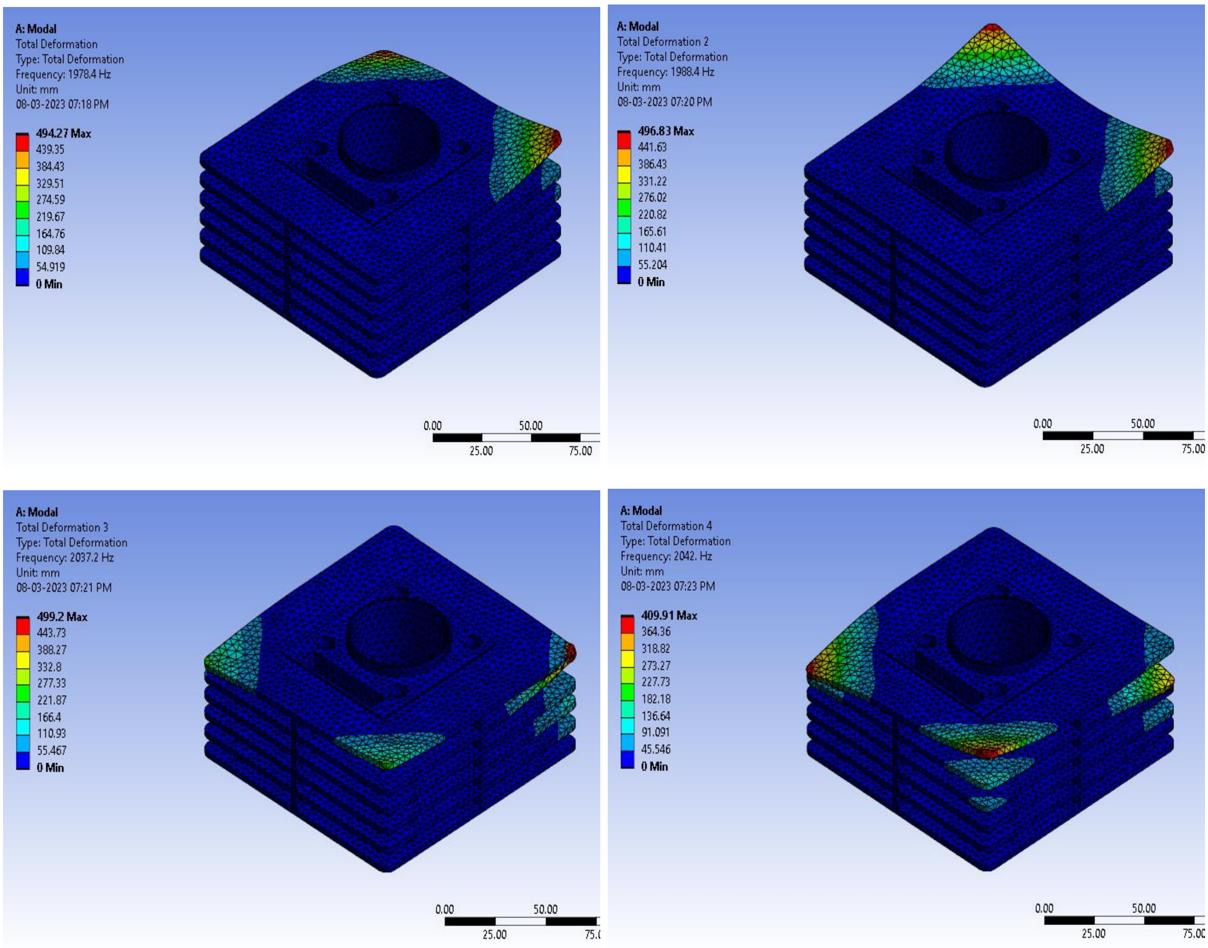


Fig. 6. Rectangular-shaped engine fin body –Mode Shapes 1, 2, 3, 4

Fig. 6 presents the different mode shapes for rectangular engine fins. It can be noted that the end corners of rectangular fins are mostly affected at the natural frequencies. The natural frequencies are given in Hertz (Hz) and can be used to understand the engine fin's behavior under different loading types. It is observed that the natural frequencies of the engine fin range from 1978.4 Hz to 2046.7 Hz. The lower natural frequencies (i.e., mode 1 and mode 2) represent the fundamental modes of the structure and correspond to large-scale deformations of the engine fin. The higher natural frequencies represent higher-order modes and correspond to smaller-scale deformations of the engine fin.

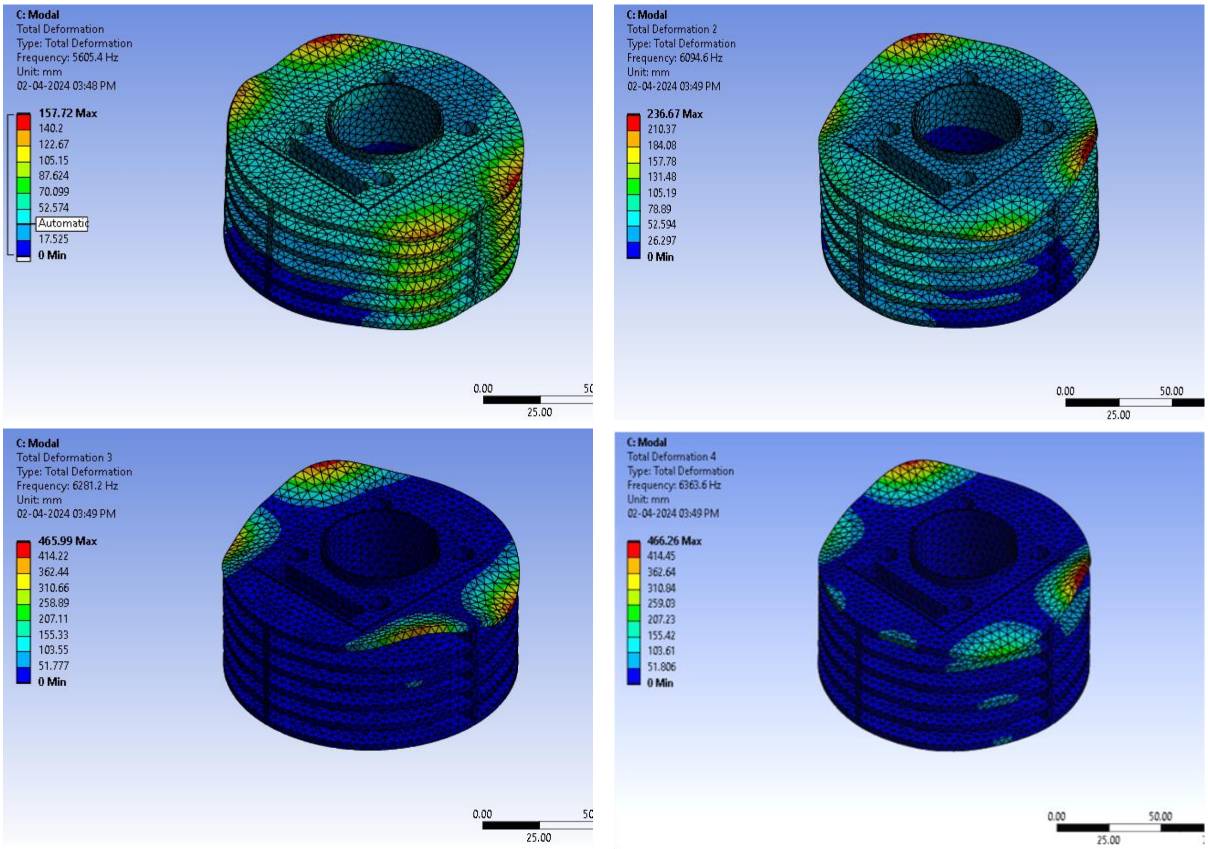


Fig. 7. Cylindrical-shaped engine body –mode shapes 1, 2, 3,4

Fig. 7 presents the different mode shapes for circular engine fins. It can be noted that curvature attached to bolt holes is mostly affected at the natural frequencies. It is observed that the natural frequencies of the engine fin range from 5605.4 Hz to 6519 Hz. The lower natural frequencies (i.e., mode 1 and mode 2) represent the fundamental modes of the structure and correspond to large-scale deformations of the engine fin. The higher natural frequencies (i.e., mode 3 and mode 4) represent higher-order modes and correspond to smaller-scale deformations of the engine fin.

3.3. Model Validation

The natural frequencies obtained from the preliminary model were1978.4 Hz, 1988.4 Hz, 2037.2 Hz and, 2042 Hz. A previous study by Tandon et al. [16] showed that the natural frequencies were 2024 Hz, 2216 Hz, 2642Hz and 4400 Hz. Fig. 8 shows the comparison of the values of natural frequencies of both, the experimental and the simulation models showing closeness to each other for the respective modes. This dynamic behaviour model of the experiment and the simulation model as indicated by the values obtained in both cases point that the analysis could be a paramount tool for research purposes. Hence, the final model was validated and used for further analysis and improvement.

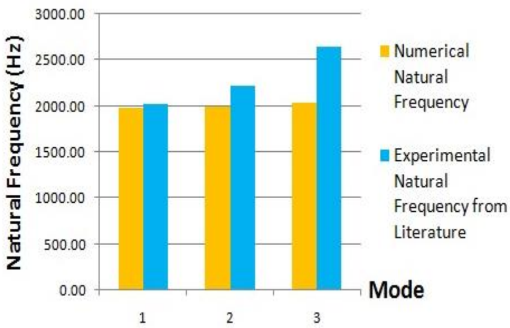


Fig. 8. Simulation model versus Experimental validation based on natural frequency

3.4. Steady-State Thermal analysis of existing and redesigned engine fin

Fig. 9 and Fig. 10 show the maximum and minimum temperatures and heat flux values for rectangular fin geometries, both with and without slots. The observation reveals variations in temperature gradients and heat dissipation between the two configurations.

Specifically, the heat transfer rate of an unslotted fin is observed as 0.2915 W/mm², while the presence of slots appears to enhance heat transfer with a value of 0.30558 W/mm², accompanied by a reduction in temperature differentials across the fin surface.

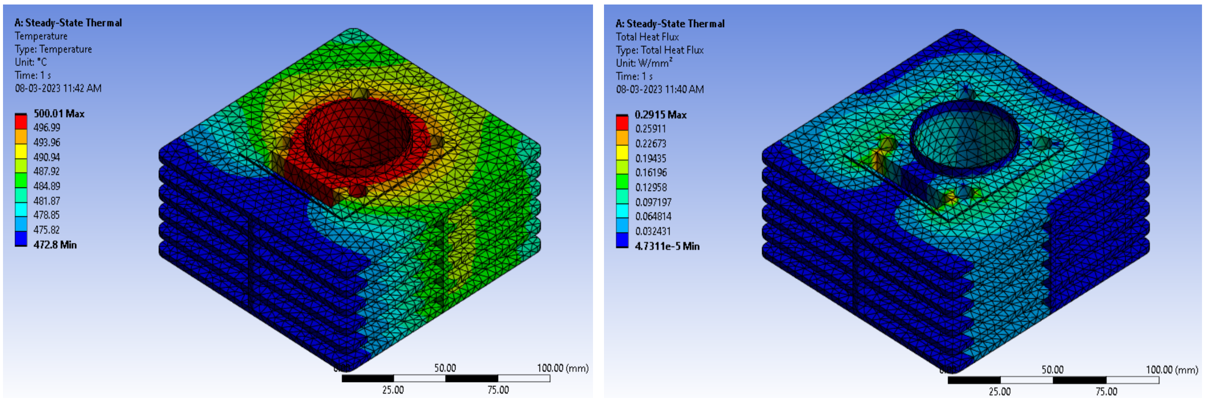


Fig. 9. Rectangular-shaped engine fin body a) Temperature variation; b) Heat flux variation

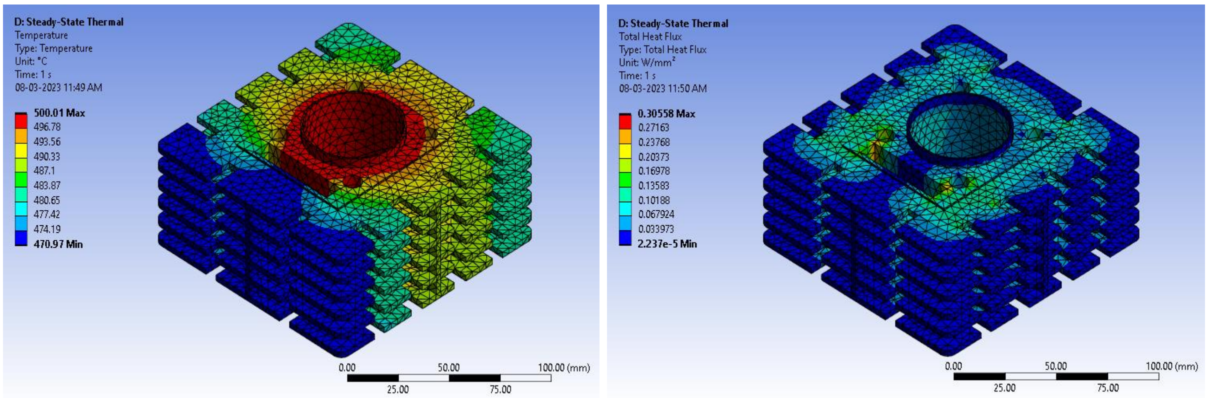


Fig. 10. Rectangular-shaped engine fin body with slot a) Temperature variation; b) Heat flux variation

Fig. 11 and Fig.12 show the maximum and minimum temperatures and heat flux values for circular fin geometries, both with and without slots. It is observed that the heat transfer rates are significantly higher compared to the unslotted rectangular fin, with values of 0.19891 W/mm² for the unslotted cylinder fin and 0.38041 W/mm² for the slotted cylinder fin. This indicates that the presence of slots in the cylinder fin configuration leads to a substantial enhancement in heat transfer, emphasizing the importance of slot design in improving the thermal performance of engine cooling systems.

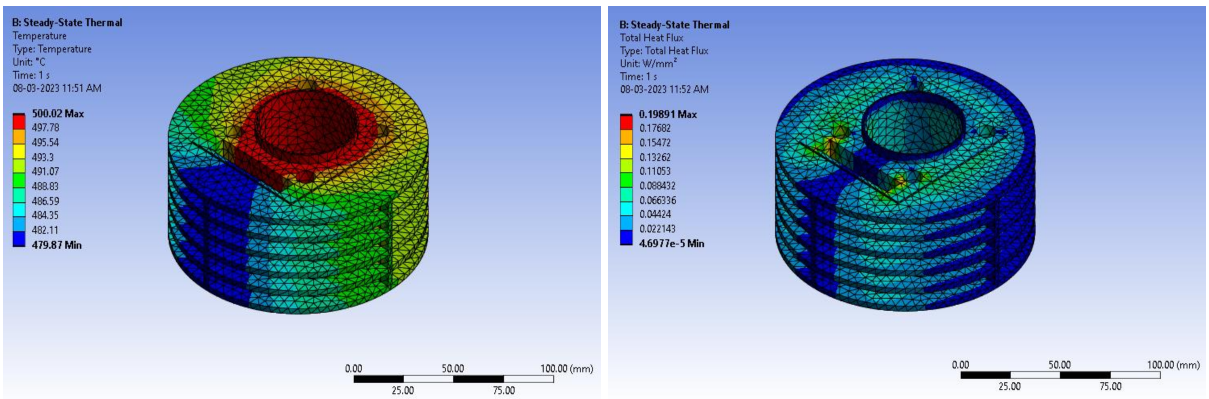


Fig. 11. Circular-shaped engine fin body a) Temperature variation; b) Heat flux variation

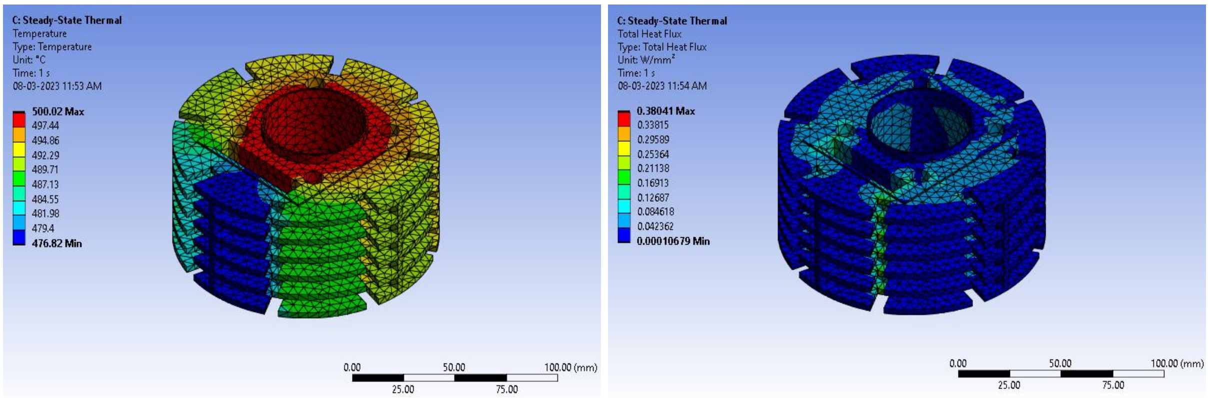


Fig. 12. Circular-shaped engine fin body with slot a) Temperature variation; b) Heat flux variation

Fig. 11 and Fig. 12 show the maximum and minimum temperatures and heat flux values for four fin geometries, both with and without slots. As depicted in Fig. 13., the rectangular slotted geometry exhibited the highest heat flux value and the lowest minimum temperature, suggesting the most efficient heat transfer performance. The cylindrical slotted geometry also has a high heat flux value but a slightly higher minimum temperature than the rectangular slotted geometry. Overall, the slotted geometries show improved heat transfer performance compared to the non-slotted geometries.

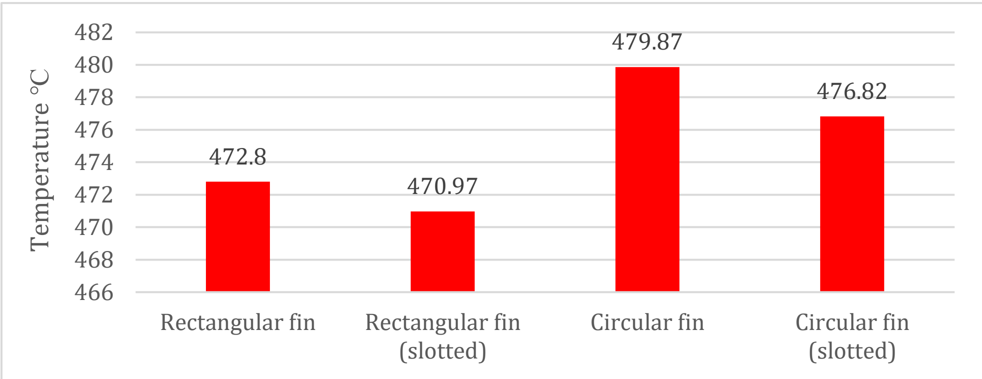


Fig. 13. Minimum temperature distribution comparison

3.5. Modal Analysis of the Existing and Redesigned Engine Fin

The results of the modal analysis are shown in Fig. 14, and it can be seen that the first mode occurs at a frequency of 1635.3 Hz, and the deformation at this frequency is maximum and occurs at the top fin's corners due to high-stress concentration, makes it lessstiffness at the end. The deformation is primarily due to bending in the first mode shape. In the case of the other three modes as well, bending is once again the dominant contributor to deformation. In the second mode, deformation occurs at the corner of the top fins, while in the case of the third and fourth modes, the deformation occurs at the corners of the middle fins. It can also be observed from the analysis that the deformation increases gradually to the maximum value at the tip of the fins. The deformation is maximum for the third mode for the modal frequency value of 1677.8 Hz, and the fin deformation occurs at two corners of the engine block. It can be inferred from the modes that the modal frequency increases from 1635.3 Hz to a maximum of 1679.3 Hz for the fourth mode, as shown in the figures and also listed in the table 4.

Modal analysis of the redesigned cylindrical engine fin is shown in Fig. 16, where the first mode occurs at a frequency of 5441.2 Hz, and the deformation at this frequency occurs at the fins, as shown in the figure, against the scale for deformation. The deformation is primarily due to bending in the first mode shape, which is again the dominant factor for deformation in the fourth mode. The second and third modes of the analysis indicate that the deformation is the result of twisting action. The deformation of the fins occurs as indicated in the figures, as seen against the scale for the deformation values. It can also be observed from the analysis that the deformation increases gradually to the maximum value at the tip of the fins like that in the rectangular engine fin design. The redesigned engine fin has the first natural frequency a little lower than that of the existing one due to the material reduction because the material reduction makes it less stiff. Hence, larger deformations and lower natural frequencies were observed in the modified design. The effective mass indicates more in Y directional vibration, and the participation factor is maximum in Y directional movement, as presented in Table 4. This is evident that the first mode is the dominant mode of vibration.

From Figure 14-17, the modal analysis results show the natural frequencies of the redesigned slotted engine fin. The data suggests that the redesigned fin has lower natural frequencies than the original design, indicating less stiff and prone to deformation under vibration. This reduction in stiffness can be attributed to the addition of the slot, which increases the surface area and enhances heat transfer with less than 3% compromising the mechanical strength of the fin. Overall, the modal analysis results suggest that the redesign has improved the dynamic performance of the engine fin. The effective mass and participation factor are maximum in twisting mode with respect to X-axis as presented in Table 5.

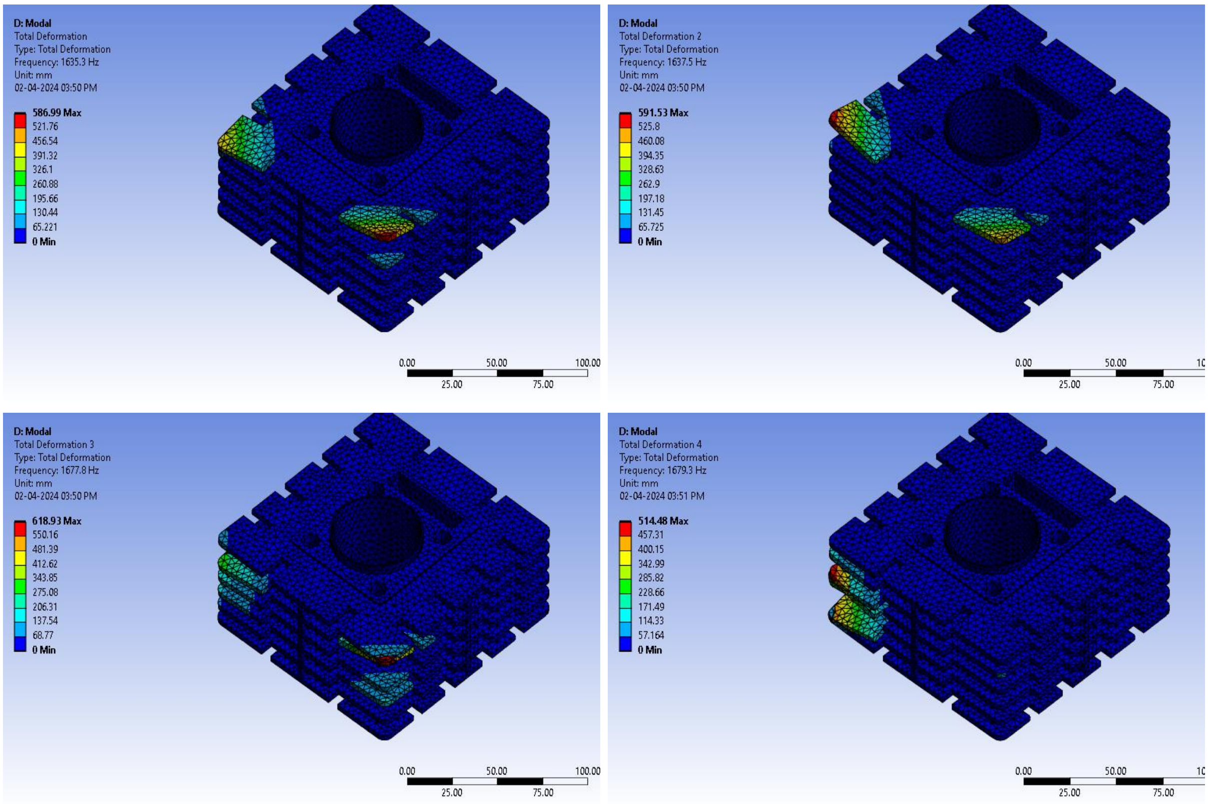
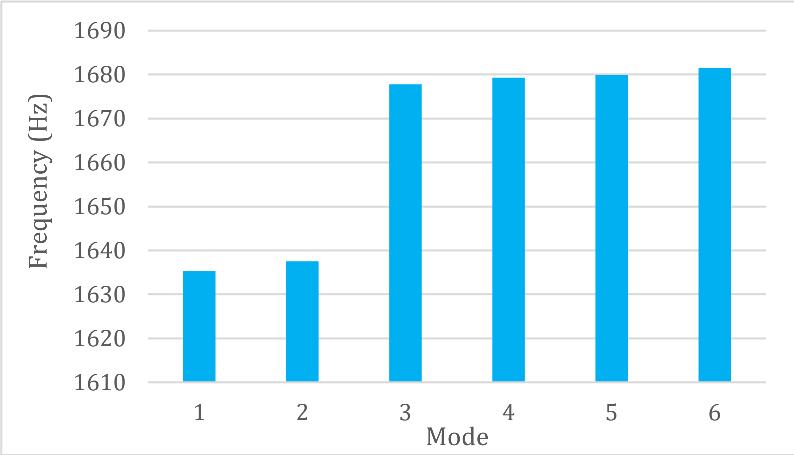


Fig. 14. Rectangular shape engine body (slotted) Mode shapes 1, 2, 3, 4

Table 4. Effective Mass and Participation Factor

DIRECTION	FREQUENCY	MODE	EFFECTIVE MASS	PARTIC.FACTOR
X	1677.79	3	0.493809E-07	0.22222E-03
Y	1637.49	2	0.184184E-04	0.42917E-02
Z	1679.88	5	0.512498E-07	0.22638E-03
Rotary X	1679.88	5	0.825001E-01	0.28723
Rotary Y	1677.79	3	0.723309E-05	-0.26894E-02
Rotary Z	1635.26	1	0.633788E-01	-0.25175



Mode	Frequency (Hz)
1	1635.3
2	1637.5
3	1677.8
4	1679.3
5	1679.9
6	1682.2

Fig. 15. Natural frequency plot for Rectangular slotted fin

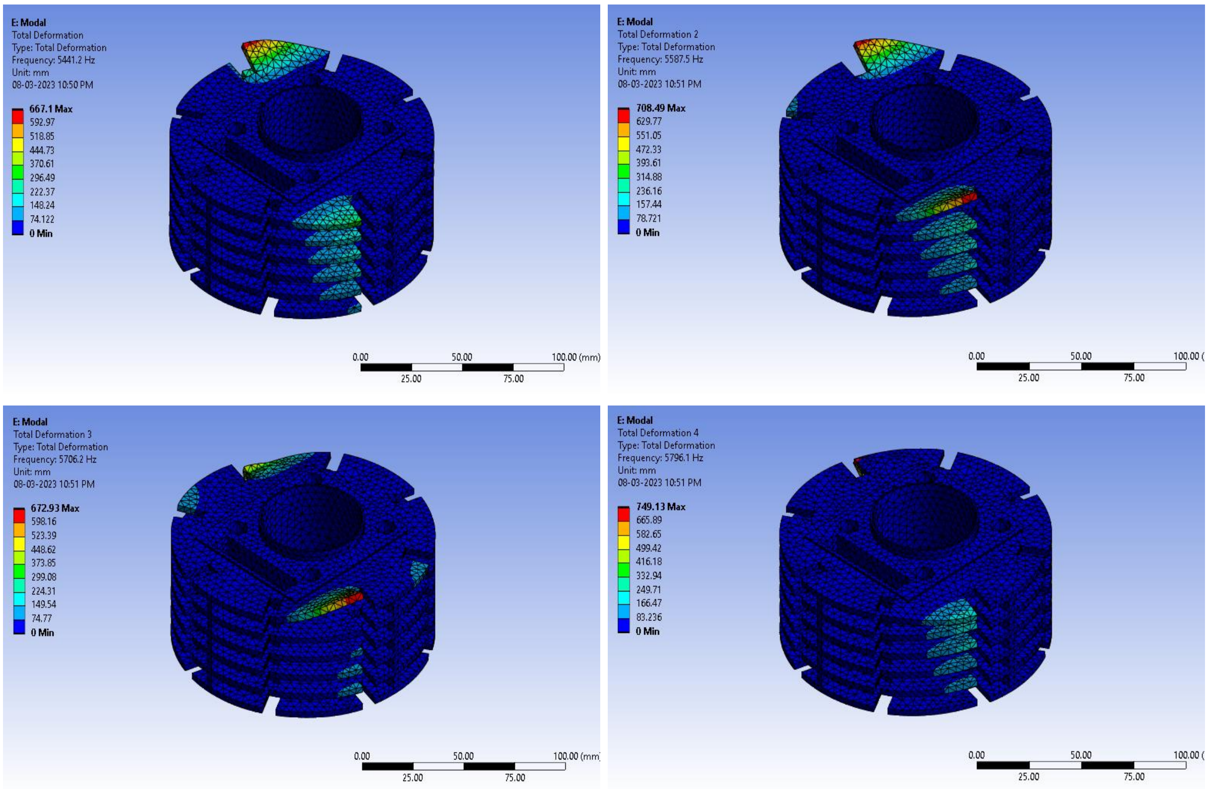
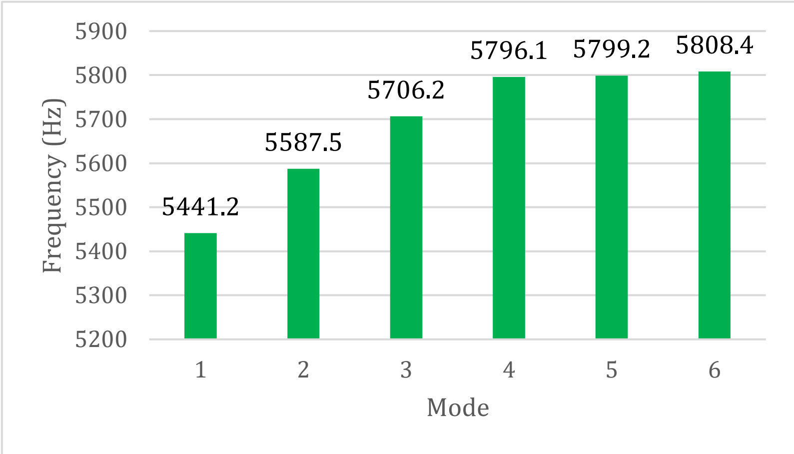


Fig. 16. Cylindrical shape engine body (slotted) Total deformation 1, 2, 3, 4.

Table 5. Effective mass and participation factor.

DIRECTION	FREQUENCY	MODE	EFFECTIVE MASS	PARTIC.FACTOR
X	5441.23	1	0.696044E-04	0.12162E-02
Y	5587.54	2	0.168098E-04	0.41000E-02
Z	5441.23	1	0.300070E-05	0.17323E-02
Rotary X	5441.23	1	0.458914E-01	0.21422
Rotary Y	5587.54	2	0.333256E-02	-0.57728E-01
Rotary Z	5441.23	1	0.569435	-0.75461



Mode	Frequency (Hz)
1	5441.2
2	5587.5
3	5706.2
4	5796.1
5	5799.2
6	5808.4

Fig. 17. Natural frequency plot for Cylindrical slotted fin

3.6. Results of the Improvement of Redesigned Engine Fin: Top of Form

The four types of design of the engine fin and the variation in the heat flux for each type of design were obtained, as shown in figures 9 – 12. The improvement result in Fig. 18 showed that the heat transfer rate was the highest for the slotted cylindrical fin design at 0.38041 W/mm^{2}compared to the other designs. This was attributed to the additional surface area provided by the slots that facilitated efficient heat transfer. The slotted cylindrical fin design was also found to have the lowest material cost when compared to the other designs. Based on these results, it can be inferred that the slotted cylindrical fin is the optimal design for the specific engine application considered in this study. However, it should be noted that the optimal fin design may vary depending on the particular application and requirements. The graph illustrates the variation in heat flux for different fin geometries, indicating that the slotted cylindrical fin had the highest heat flux value, followed by the rectangular slotted fin.

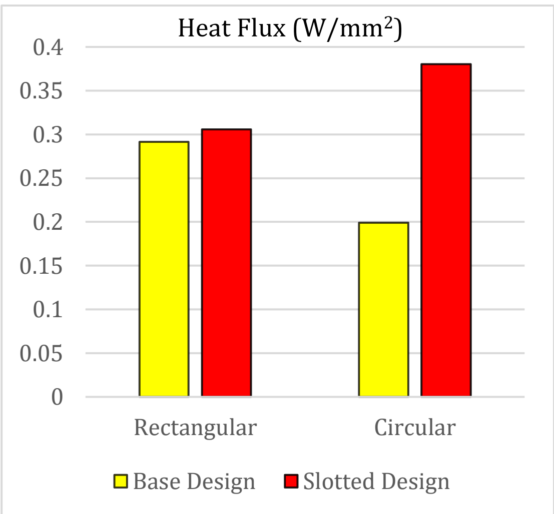


Fig. 18. Comparison of Heat flux of different profile

4. Conclusions

The optimal fin design was determined based on the steady-state thermal analysis conducted using theANSYS Workbench 2023 R1. The analysis involved two fin geometries, rectangular and cylindrical fins, made of aluminium 1100 material.

- Initially, a modal analysis of the designed engine fins was conducted. The modal analysis provided the mode shapes and the totaldeformation corresponding to the natural frequencies. To validate the accuracy of the results of the analysis, a mesh independency study was done.
- Steady-state thermal analysis results as indicated in figures 9 – 12 in the Model Validation depict clearly that the slotted cylindrical fin design has the highest heat transfer rate of 0.38041 W/mm^2 amongst the designs evaluated in this paper, representing a 91.5% improvement over the cylindrical fin design without slots, which had a heat flux value of 0.19891 W/mm^2. Similarly, the slotted rectangular fin design exhibited a lower heat transfer rate of 0.30558 W/mm^2, showing a 4.6% improvement over the rectangular fin design without slots, which had a heat flux value of 0.2915 W/mm^2 and 53.5% improvement compared to the unslotted cylindrical fin design.
- In conclusion, results indicate that adding slots can increase the surface area for air contact, significantly enhancing the heat transfer rate. Therefore, the slotted fin design can be used to improve engine thermal performance.

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Conflict of Interest

The authors declares that there is no conflict of interest regarding the publication of this article.

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