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Design and Analysis of the Heat Transfer Characteristics of Engine Cylinder Fins

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ABSTRACT

An SI engine is one in all the important elements of each automobile. Thermal energy in the form of heat generated due to the ignition of the fuel which is partly being used for work done and rest part is dissipated to the atmosphere. During internal combustion, the engine material sense quick temperature changes. Heat dissipation must be so fast in order to enhance the performance and its efficiency. Heat dissipation capacity of the engine is difficult as the surface area exposed to the atmosphere is not more. So, the extensive portions called fins assist in escalating the surface area thereby help in reducing the heat generated in the ignition chamber to the atmosphere. Using new alloy metals, heat dissipation performance of the fins have increased more without compromising other structural factors. The structural model of the engine with dissimilar fins is designed using design Software SOLIDWORKS. Using ANSYS Fluent Version 16.0 the thermal properties and thermal analysis are carried out.

Keywords: Dissipation, CFD, Fins, Heat, Transfer rate, Thermal Conductivity

1. INTRODUCTION:

IC engines work on the principle of energy conversion. When the fuel is burnt, heat is produced. This heat energy is converted into the useful work. Roughly 30% of the heat energy is changed over into valuable work, and remaining 70% must be expelled from the engine to prevent the failure from distortion of parts. Due to this engines are equipped with heat dissipation mechanisms. Some heavy engines operating at high pressures and temperatures require liquid cooling systems while most of the single cylinder motorcycle engines are air-cooled because liquid cooling systems use much space and add more weight to the engine. Heat produced during the ignition in IC engine is maintained at a higher level to increase the efficiency of an engine. But the excess heat should be removed to prevent the parts from thermal failure. In air-cooled engines, Fins are extended surfaces attached to the boundaries of the engine block to raise the heat transfer by increasing convective surface area. Fins are used in a several applications ranging from coffee cups to flood lights in cricket stadium. Optimization of heat transfer from the engines leads to the improved efficiency of the engine and saving the power. A combined conduction convection system with an extended solid surface is known as Fin. Inside a solid, heat is transferred by the process of conduction while for a fin surface the process of convection takes place in the direction which is perpendicular to conduction's direction. As a result of it there is a heat loss in the surroundings as well. With the increase of surface area Fin increases the rate of heat transfer without increasing primary surface area. The convection resistance is lost due to the increased surface area as a result of which the transfer rate of heat increases economically. Fin function is to maximize the surface area and to increase the heat transfer without even increasing the primary surface area. Conduction and convection both are included in the Fin for the transfer of heat. In the end some part of heat is lost to the surrounding atmosphere.

The process of transfer of heat can be done by making use of software known as ANSYS. In order to determine the relationship between velocities, heat transfer coefficient of fin engine, temperature the simulation is used. The comparison is made regarding efficient model engine fins block to find out which one is best to help engine block for heat maintenance. This is the main purpose of using two model engine fins. The distributed rate of heat transfer is dependent on some factors such as fin numbers, fins height, their geometry, wind velocity and pitch etc. For an efficient operation, there is an optimal cooling rate of an engine. In this project the target is to investigate the association between coefficient of heat transfer and velocity. While running the engine, the rate of heat transfer which contributes depends on vehicle's velocity, geometry of a fin and the ambient temperature.

MATERIAL PROPERTIES:

Aluminium alloys are selected for fin material as the thermal conductivity of aluminium alloys are higher. Because of unique properties, Aluminium is the best material to manufacture many automobile components. It has excellent corrosion resistance and good machinability and it possess good strength and ductility.

Table 1 Material properties

Material	Thermal Conductivity K (W/mK)	Specific heat C_p (J/kg-K)	Density ρ (Kg/m^3)
Aluminium Alloy 6061	180	962	2700
Aluminium Alloy A204	120	920	2750
Aluminium Alloy 356	167	963	2685

MODELLING:

The fin models were designed in Solid Works. For designing, considered the parameters such as the geometry of fins, number of fins, Size of fins

Table 2 Geometrical parameters

SI No	Parameter	Forms
1	Geometry of fins	1) Rectangle 2) Three Stepped
2	Number of fins	1) 5 fins 2) 7 fins
3	Size of fin from cylinder head	1) 13mm 2) 16mm

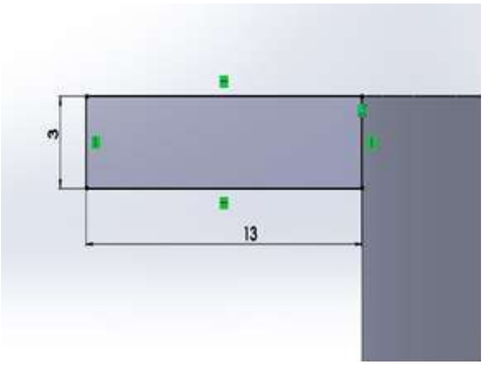

Figure 1 Rectangular fin with 13mm

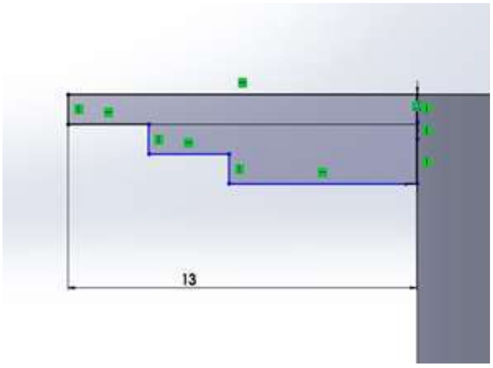

Figure 2 Three Stepped fin with 13mm

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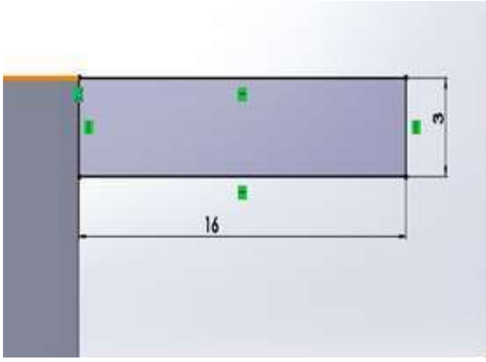

Figure 3 Rectangular fin with 16mm

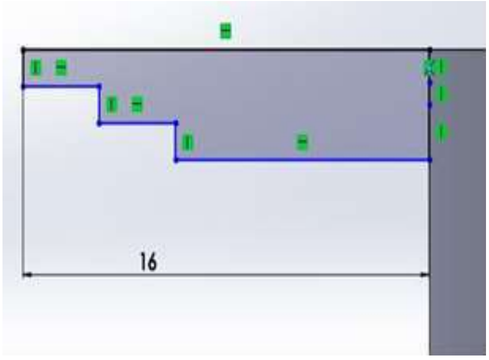

Figure 4 Three Stepped fin with 16mm

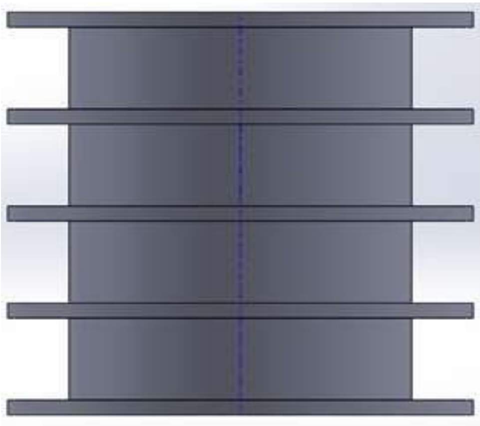

Figure 5 Rectangular Model with 5 fins

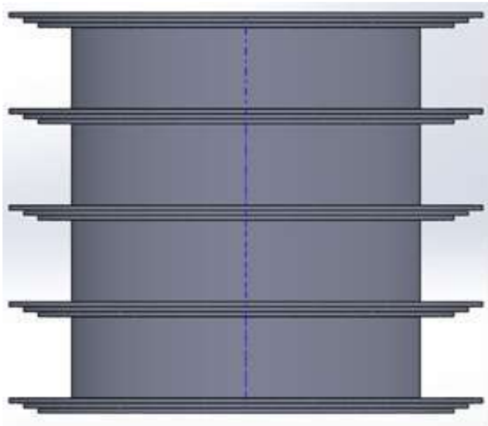

Figure 6 Three Stepped Model with 5 fins

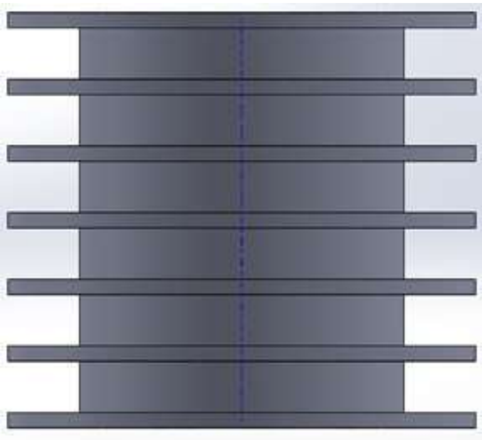

Figure 7 Rectangular Model with 7 fins

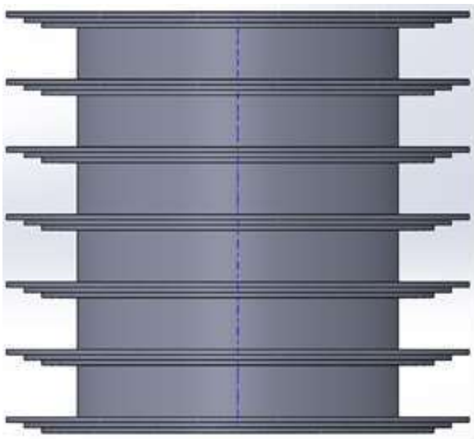

Figure 8 Three Stepped Model with 7 fins

MESHING:

Modelling of every model was done in Solid Works software. The Parasolid format of the model was imported to the Ansys Workbench and meshing was carried out.

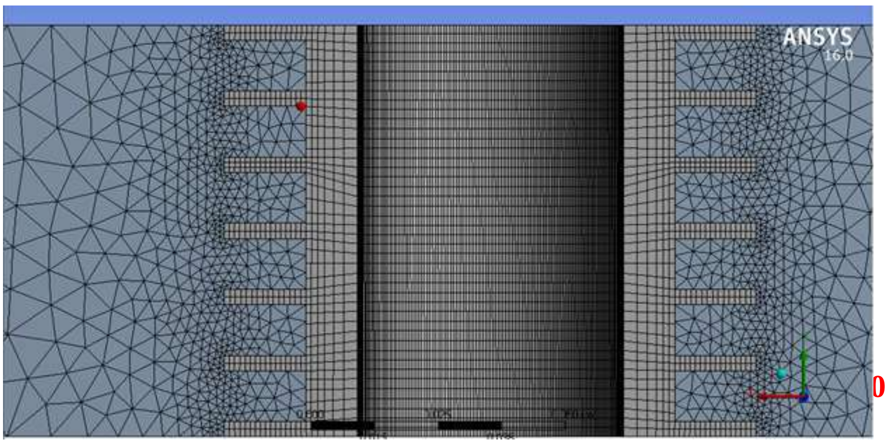

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Figure 9 Meshing of Rectangular geometry

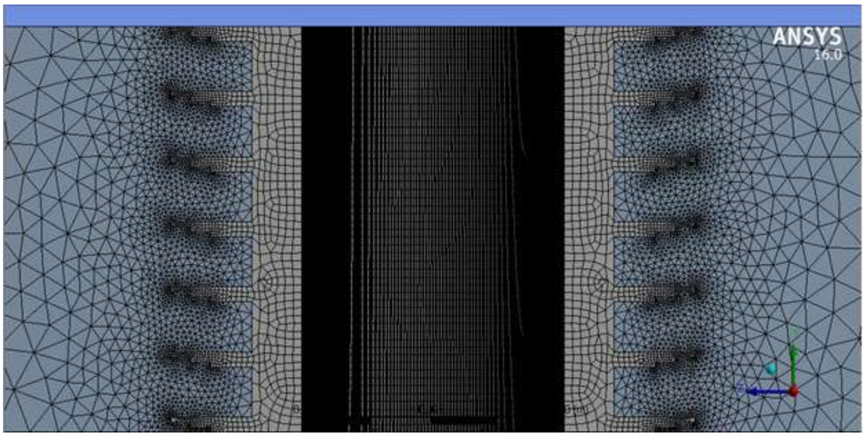
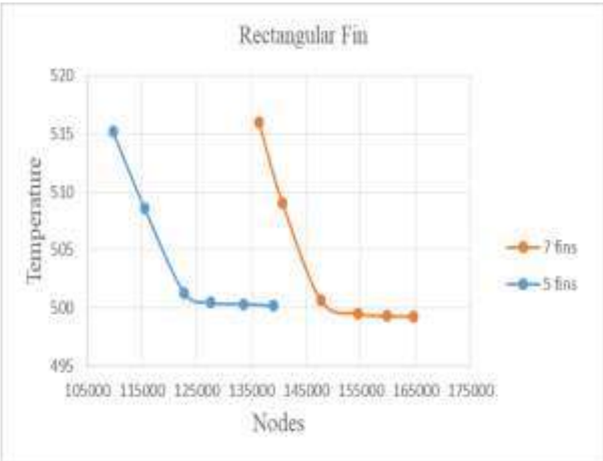


Figure 10 Meshing of Three Stepped geometry

GRID SENSITIVITY



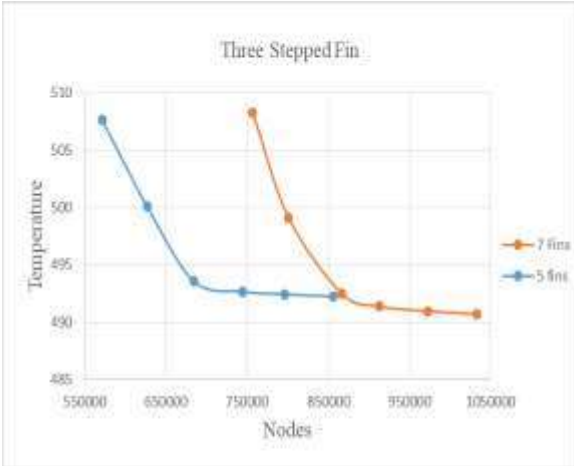


Figure 11 Grid Sensitivity for 13mm with 5 fins **Figure 12** Grid Sensitivity for 13mm with 7 fins

Even upon refining the mesh and increasing the number of nodes, the solution does not vary. The impact of the number of nodes on the temperature is negligible after any further increment in all of the four cases

GOVERNING EQUATIONS:

The following governing equations are considered which are suitable for the current model and simulations. The mass, energy, momentum are conserved in these equations which work by finite volume approach.

The Conservation equation of mass is given by

$$\frac{\partial y}{\partial x}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial x}+\frac{\partial(\rho w)}{\partial x}=0$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial x}+\frac{\partial w}{\partial x}=0$$

The Conservation equation of momentum in x, y, z directions of Cartesian co-ordinate system respectively is as follows

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial y}+v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial z}+v\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

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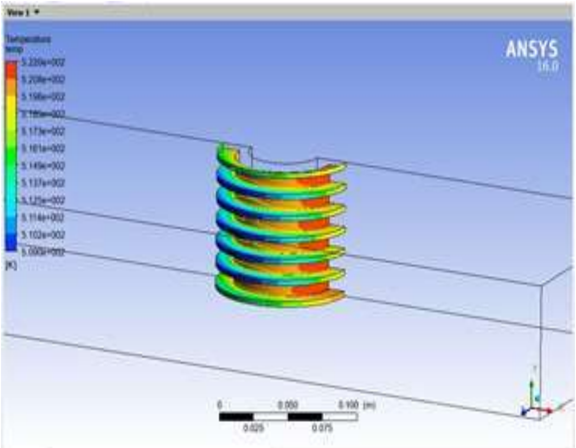
The Conservation equation of energy is given by

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \frac{k}{\rho C}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + q_g + \emptyset$$

$$\emptyset = 2\mu\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \mu\left[\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial w} + \frac{\partial w}{\partial y}\right)^2\right]$$

2. NUMERICAL SIMULATIONS:



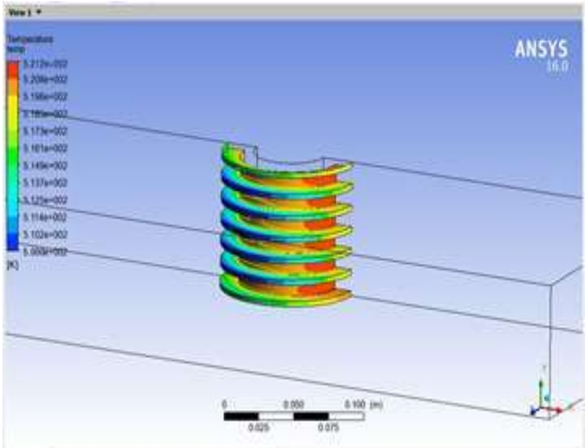
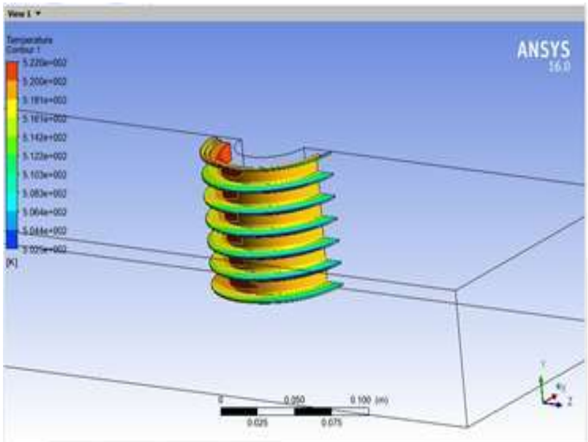


Figure 13 Rectangle 13mm with 7fins at 35KMPH **Figure 14** Rectangle 13mm with 7fins at 85KMPH



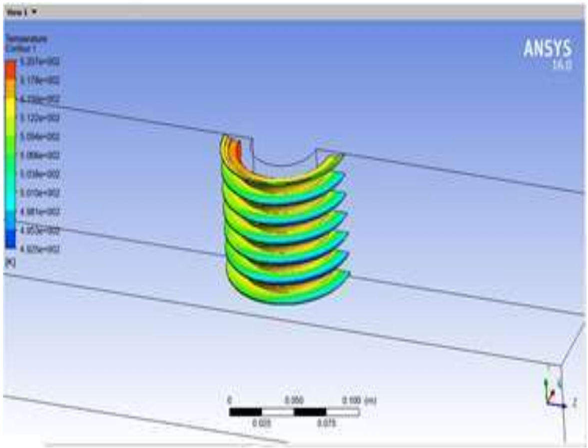
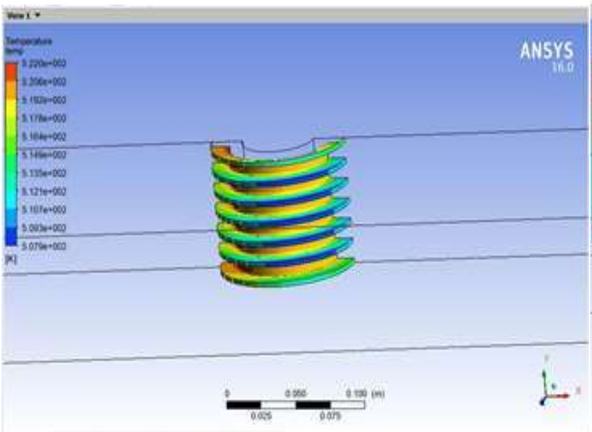


Figure 15 Three Stepped 13mm with 7fins at 35KMPH **Figure 16** Three Stepped 13mm with 7fins at 85KMPH



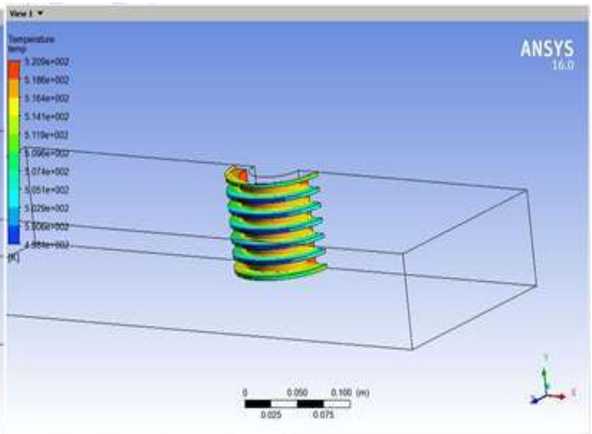


Figure 17 Rectangular 13mm with 7fins at 35KMPH **Figure 18** Rectangular 13mm with 7fins at 85KMPH

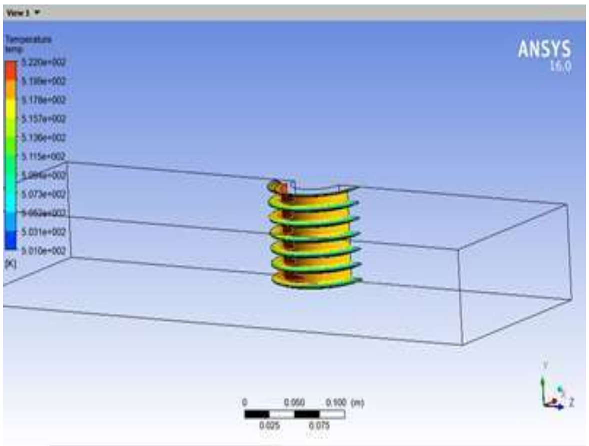


Figure 19 Rectangular 13mm with 7fins at 85KMPH

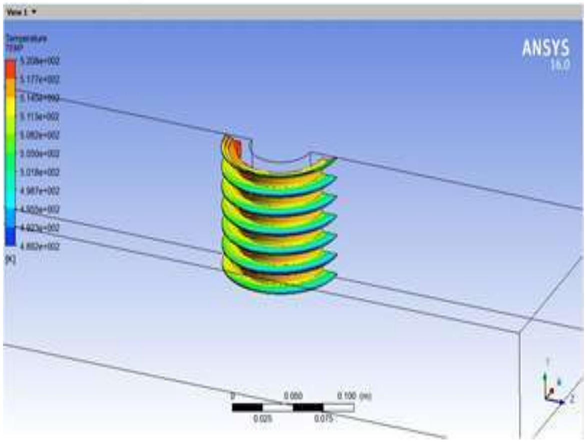


Figure 20 Three Stepped 13mm with 7fins at 85KMPH

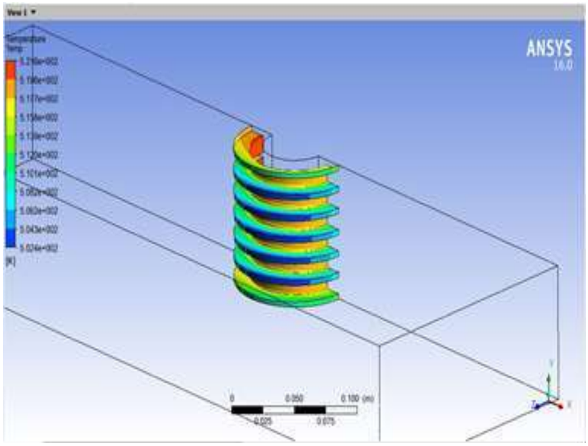


Figure 21 Rectangular 13mm with 7fins at 35KMPH

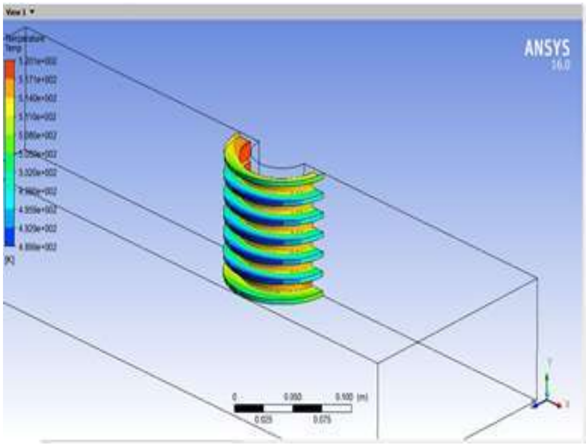


Figure 22 Rectangular 13mm with 7fins at 85KMPH

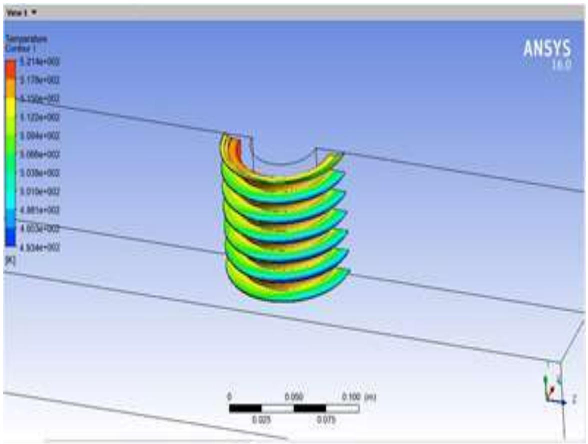


Figure 23 Three stepped 13mm with 7 fins at 35KMPH

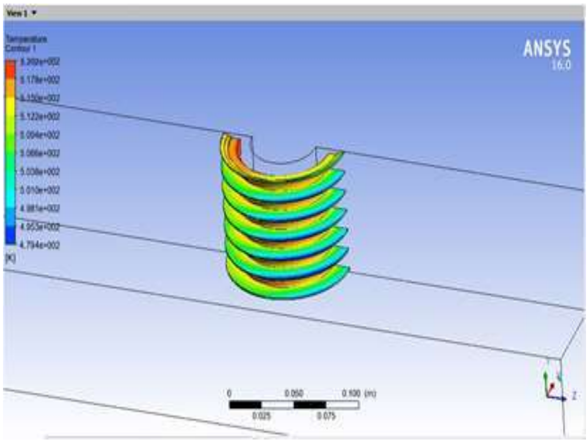


Figure 24 Three stepped 13mm with 7 fins at 85KMPH

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3. RESULTS

Table 3 Temperature distribution and Heat transfer coefficient of all simulations

Material	Fins	Speeds(km/hr)	Fin length(mm)	No of fins	Max temp(k)	Min temp(k)	Max HTC (W/(mK))
Al6061	Rectangular	35	13	5	522.202	509.828	218.522
				7	522.01	508.996	216
			16	5	522.032	505.85	211.612
				7	521	504.8	229
		85	13	5	521.44	501.276	295.008
				7	521.251	500.637	287.3
			16	5	521.076	494.733	278.379
				7	520.924	494.147	301.8
	3 stepped	35	13	5	522.134	504.207	443.015
				7	521.985	502.488	410.87
			16	5	521.872	457.654	414.878
				7	520.631	496.578	478.931
		85	13	5	521.21	493.568	497.587
				7	520.65	492.518	485.717
			16	5	520.969	431.966	490.235
				7	520.307	484.11	497.809
Al204	Rectangular	35	13	5	521.813	503.722	212.52
				7	521.563	502.42	211.559
			16	5	521.977	504.611	212.034
				7	521.912	506.646	229.414
		85	13	5	520.78	491.697	292.12
				7	520.081	489.897	294.555
			16	5	520.506	482.872	284.65
				7	519.9	480.9	307.837
	3 stepped	35	13	5	521.413	481.101	414.871
				7	521.4	493.4	411.285
			16	5	521.487	440.443	414.835
				7	519.5	485.78	462.8
		85	13	5	520.577	440.096	487.705
				7	520.2	479.4	492.12
			16	5	520.135	412.956	498.093
				7	516.737	468.072	490.788
Al356	Rectangular	35	13	5	522.081	508.817	206.442
				7	522	507.8	211.5
			16	5	521.952	504.607	220.069
				7	521.7	503.4	229.3
		85	13	5	521.324	499.733	288
				7	520.8	498.369	294.5
			16	5	521.161	492.873	284.572
				7	520.723	491.35	308.05

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	3 stepped	35	13	5	522.067	502.85	407.096
				7	521.983	501.045	411.242
			16	5	521.796	454.557	414.877
				7	521.771	494.896	464.943
		85	13	5	521.078	491.538	474.574
				7	520.82	489.158	485.446
			16	5	520.823	428.461	501.089
				7	520.133	480.711	489.49

GRAPHS:

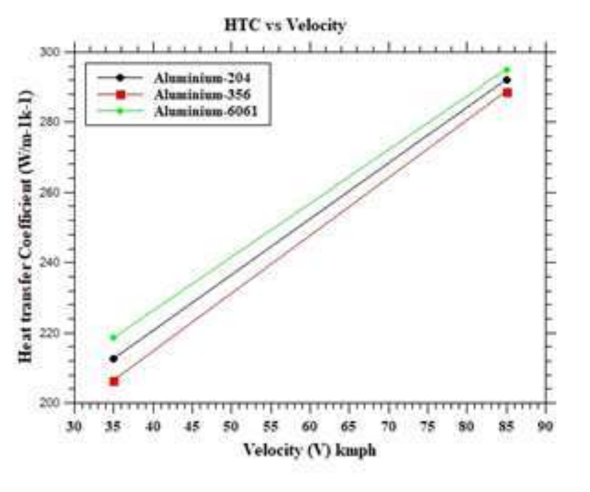

Figure 25 13mm 5 fins Rectangular profile Convective heat transfer coefficient vs Velocity

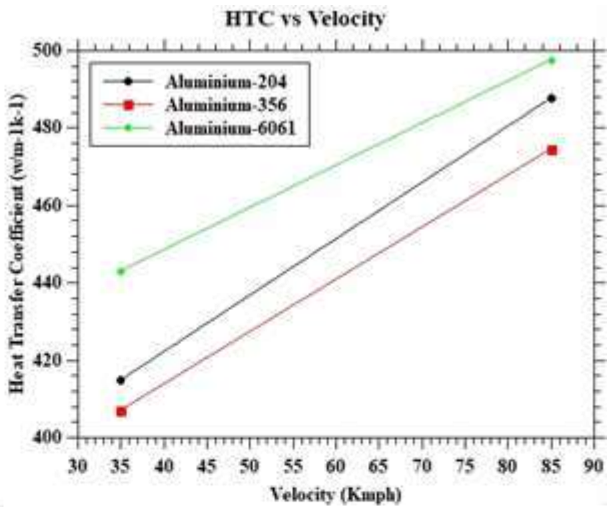

Figure 26 13mm 5 fins stepped profile Convective heat transfer coefficient vs Velocity

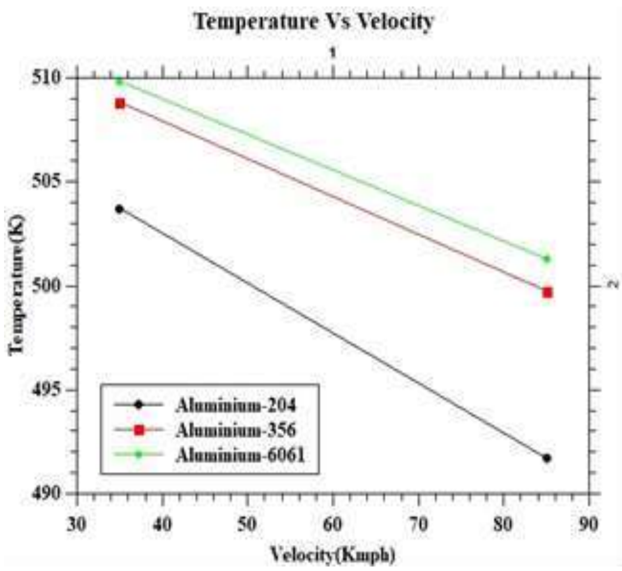

Figure 27 13mm 5 fins Rectangular profile Temperature vs Velocity

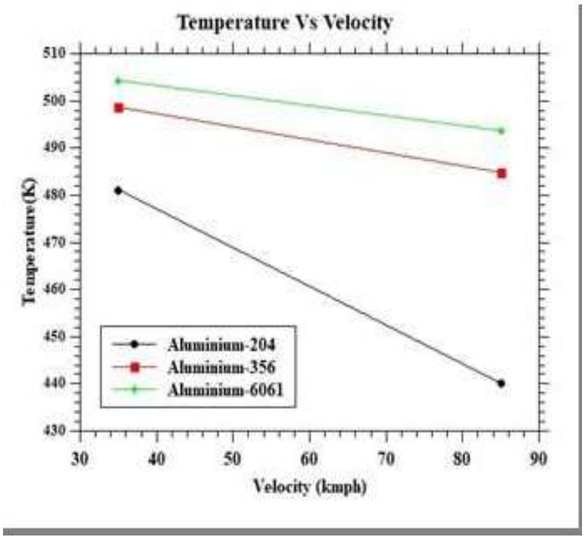

Figure 28 13mm 5 fins Stepped profile Temperature vs Velocity

Aluminium 6061 material showed better heat transfer rate than other two materials considering the certain parameters as constant such as length and number of fins because Al 6061 material has higher thermal conductivity (180 W/(m K)).

It can be observed that increase in the velocity resulted in increase of the heat transfer coefficient and decrease in the temperature. Aluminium material 204 has better temperature distribution among the other two materials.

PROPOSED CORRELATION:

Since, the temperature is a function of all these parameters. Therefore

$$\theta = f(Material, Shape\ of\ the\ fins, Velocity, Fin\ size, No\ of\ fins)$$

To generalize the discussion and for the reference of wide heat transfer community, a correlation is proposed for the maximum temperature of the heat source. It is evident from the discussion that maximum temperature of the heat source is better function of Velocity (V), Length of the fins (L), Thermal conductivity of the Material (K), Number of the fins (N) and Fin Profile (X).All the parameters are non-dimensionlized. The correlation is based on 48 data points and is given in equation. The correlation has a regression coefficient (R^2) of 0.78 and an RMS error of 11%.

Y = (-0.00779)*V+ (0.03544)*L + (0.00000077431)*K + (0.014415)*N+ (0.003838)*X+1.744044

This equation is valid for the following range of following parameters

0.411765 < V <1, 0.1382< L<0.1649, 4485.98<K<6728.971, 0.185< N <0.259 and

0.6730< X <0.7924.

4. CONCLUSION:

Upon simulating the various engine cylinder models considering various parameters like material, geometry, height of fins and the number of fins at certain velocities and concluded that

- Heat transfer through the fins of varying thickness in every material was more than their corresponding rectangular fin models.
- Fins with the length of 16mm showed better performance than their 13mm counterparts regardless of the other parameters.
- Number of fins also played an important role in our observation as the models with 7 fins proved to be more efficient than the models with 5 fins regardless of the other parameters.
- Increase in the velocity from 35kmph to 85kmph resulted in more heat transfer regardless of the other parameters.
- The data is exported to the data analysis software DATAFIT and non-linear regression analysis is done.
- The following inference is produced:
  1. The correlation coefficient came approximately ~0.80.
  2. The equation model can be used to better understand the effects of these parameters and to optimize the heat transfer rate across in the model.

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