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Optimization of Four Stroke SI Engine Fins Operated for CNG by CFD Analysis

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Abstract

Nowadays there is depletion in ozone layer and increase in global warming due to petroleum product so there is need of switch to alternative fuel. Today all Major automobile industry is on way to launch there CNG bike. In this 125cc bike four stroke SI engine was optimized for different fins material using CFD analysis. ANSYS Fluent15.0 show that aluminium alloy 6061 has more heat loss rate than that of cast iron. The all trial are performed on 450°C inner cylinder tempreture of Engine . In this we are taking CNG as fuel for two- wheeler four stroke SI engine and optimizing material for fins. We model engine piston cylinder block in CATIA V5 software. CFD analysis Two different material fins one of aluminium alloy 6061 and other of cast iron material performed in ANSYS 15.0 fluent Software to find heat transfer coefficient, heat flux and tempreture distribution over fins of piston cylinder of two-wheeler bike.

Keywords:*CNG,CFD,Heat Flux, Heat Transfer Coefficient, Heat Transfer, SI Engine*

1. Introduction

Fins are the extended surfaces provided on engines for enhancing rate of heat transfer. In IC engine due to combustion inside the cylinder high heat is generated. Due to this high heat there is knocking, melting of lubrication and Sezure of parts of engine takes place so to avoid this fins are provided on outer surface of cylinder to dissipate the heat. Due to combustion inside cylinder heat generated not 100% heat utilize to increase power of engine some heat is absorbed by piston and cylinder. The heating of engine parts is not desired as it will damage the engine parts and burn the lubricants. So, cooling must be done

This research is carried out for optimizing material for fins of CNG engine two wheeler bike. As we know that auto ignition teampreture of CNG gas 450°C [10]so combustion inside the CNG engine is take place at 450°C so high tempreture generated inside cylinder but in case of petrol engine combustion takes place at 150°C because auto ignition tempreture of petrol is 150°C. High heat is generated inside CNG engine as compare to petrol engine. In this project we did analysis of this CNG engine fins at this high tempreture of 450°C in combustion chamber to find heat flux, heat transfer coefficient,tempreture distribution for aluminium alloy and cast iron fins.

In this project we are not manufacturing any engine. Engine which we are analyse are available in the market. we are doing analysis of these fin at high tempreture of 723k and at velocity of wind 15km/hr to find how much heat transfer coefficient, heat flux dissipation and tempreture distribution over surface of fins. Normally in two-wheeler engine fins are made of aluminum alloy which is having good thermal conductivity and heat transfer rate as compare to cast iron. But in this case cost of aluminium alloy is seven times higher than that of cast iron. So it is necessary to do analysis of cast iron to find how much is the value of heat flux and heat transfer coefficient as compare to aluminium alloy for CNG engine. The purpose of this research paper is to provide CFD analysis of CNG engine fins to automobile industry.

2. Problem Statement

Many researchers did CFD analysis of four stroke engine with petrol as fuel but no one did CFD analysis of Fins of four stroke SI engine of two-wheeler with CNG as fuel. There is no specific research work for two wheeler four stroke SI engine fins which are made up of Aluminium alloy and Cast iron for CNG operation and many automobile industry is on way to launch there CNG bike so this research work is important for them. In this project we are using rectangular fins made up different material like cast iron and Aluminium alloy. We can find how much heat flux, heat transfer coefficient by use CFD analysis for Engine cylinder with cast iron fins and Engine cylinder with Aluminium alloy fins.

3. Objective

The objectives of this project are
To compare Heat Flux from fins made up of aluminium alloy and cast iron of CNG motorcycle engine and to analyzeCNG fuelEffect on different fin material.
To find rate of heat flux and Heat Tranfercoeffincientfor Al Alloy Fins and Cast Iron Fins at wind velocity of 15Km/hr and at ambient tempreture of 300K for CNG Engine of two wheeler.

4. Literature Review

E. Ramjee and K. Vijaya Kumar Reddy, Experimental investigations carried out on a single cylinder, four stroke, air cooled, Bajaj-Kawasaki petrol engine in the current study to evaluate the performance parameters and Emissions characteristics. In the present work, individual engine tests have been carried out in steady state and at full load condition for both fuels. Therefore, engine operation with CNG has been compared with petrol fuelled and the key observations made are: For all range of speeds, the volumetric efficiency is reduced and varies between 10-1 4%; Except thermal efficiency. The other performance parameters viz BMEP, Torque, Power and BSFC are decreased for CNG fuelled engine compared to petrol fuelled engine; Except NOx the other emission characteristics such as CO, CO_2, and HC are decreased.

Kawabata and Mori's, Studies were based on the principle of using squish motion to generate a series of jets directed towards the center of the chamber just prior to ignition. The chamber in this study referred to as the UBC squish jet. The faster burning rate of UBC chamber lead to an average three percent reduction in brake-specific fuel consumption, five percent increase in BMEP, and an increase in the lean limit of combustion.

Syed Kaleemuddin and G. Amba Prasad Rao, he study of experimental investigations carried and up gradation of 395 cc air cooled engine to dual fuel (CNG/Gasoline) application. The original 395 cc direct injection naturally aspirated, air cooled diesel engine was first converted to run on Gasoline by addition of electronic ignition system and reduction in compression ratio to suit both gasoline and CNG application. CFX software has been employed to calculate and improve the cooling capacity of engine with the use of CNG. Materials of major engine components were reviewed to suit CNG application. The engine was subsequently tuned with dual multi-mapped ignition timing for bi-fuel stoichiometric operation on engine dynamometer and then fitted on a 3-Wheeler vehicle. The vehicle was optimized on a chassis dynamometer to meet the proposed Bharat Stage-III norms

K.Shahrila, NurhayatiBinti, MohdKasim, and M.Sabri, This study is simulation of two type of engine block which is ModenasKriss 110 and Yamaha Lagenda 110z has been done accordingly to the requirement. The values of wind velocity have been determined to gain the heat transfer coefficients. This simulation is proving that the wind velocity is one important part that can affected the total of heat transfer and the value of heat transfer coefficient. Besides that, the design of motorcycle fins need to considered in order to measure total heat transfer, because fins are work to trap the air to maintain the heat of engine block, if the fins design are not too appropriate with the requirement, it can cause to overheating.

Sanjay Kumar SharmaandVikas Sharma, A reasonable comparison of various pin-fin geometries has been attempted. A three-dimensional conjugate problem has been studied with a three –dimensional CFD model .These were greatly simplified by assuming 1-column in-line pin-fins with axes perpendicular to the flow and isothermal heat transfer surfaces. At lower values of pressure drop and pumping power, drop shaped fins work best. At higher values, drop-shaped fins and Circular fins offer highest performance. For high Reynolds numbers, the fins thermal efficiency and effectiveness show same behaviour, but drop-shaped fins configuration always stand a little bit upper. Also its variation in different flow regimes is smoother, which means that the engine performance varies according the working load conditions.

MusthafahMohd. Tahir, M. S. Ali, M.A. Salima, Rosli A. Bakarb, A. M. Fudhaila, M.Z. Hassanc, Abdul Muhaimin M. S., Compressed natural gas (CNG) produced low performance compared to liquid fuel. The power of CNG when compared to liquid fuel is reduced to about 18.5 %. The main reason for the lack of power when using CNG is because of the volumetric efficiency. CNG's volumetric efficiency is lower than liquid fuel
due to its physical properties which is gas. the CNG have lower pressure than the liquid fuel at ignition stage. The pressure inside cylinder for liquid fuel at highest engine speed (4500 rpm) is nearly 40 bar. However, for CNG at the same engine speed, the pressure inside engine cylinder is only 32 bar. The lower pressure obtained by CNG is due to the low density of CNG itself compared to liquid fuel. The density is also resulting the low heat generated by CNG. The low heat generated is based on the temperature during combustion. The heat transfer rate to the wall by CNG is also lower compared to the liquid fuel. In the experiment, heat transfer rate for CNG at 4500 rpm is 20 kW at. However, the heat transfer rate by liquid fuel is higher (26 kW) at the same engine speed. Therefore, the performance of CNG is lower than liquid fuel, but in term of heat generated CNG give a better life span of the engine because of the low heat transfer rate to the wall

J.C. Sanders et.al. Carried out the cooling tests on two cylinders, one with original steel fins and one with 1-inch spiral copper fins brazed on the barrel. The copper fins improved the overall heat transfer coefficient from the barrel to the air 115 percent. They also concluded that in the range of practical fins dimensions, copper fins having the same weight as the original steel fins will give at least 1.8 times the overall heat transfer of the original steel fins.

S.S. Chandrakant et.al., conducted experiments for rectangular and triangular fin profiles for air velocities ranging from 0 to 11 m/s. Experimental and CFD simulated result proves that annular fins with rectangular fin profiles are more suitable for heat transfer enhancement as compared to triangular fin profiles. Surface temperature of triangular fin profile is higher than rectangular fin profile atdifferent air velocity. Heat transfer coefficient increase with increases with increases in velocity in both profiles. Incomparison of both profile rectangular fin profile have higher heat transfer coefficient than triangular fin profile. In comparison of both profile rectangular fin profiletransfer large amount of heat than triangular fin profile.

G. Babu and M. Lavakumar, Analyzed the thermal properties by varying geometry, material and thickness of cylinder fins. The models were created by varying the geometry, rectangular, circular and curved shaped fins and also by varying thickness of the fins. Material used for manufacturing cylinder fin body was Aluminum Alloy 204which has thermal conductivity of 110-150W/mk and also using Aluminum alloy 6061 and Magnesium alloy which have higher thermal conductivities. They concluded that by reducing the thickness and also by changing the shape of the fin to curve shaped, the weight of the fin body reduces there by increasing the efficiency. The weight of thefinbody is reduced when Magnesium alloy is used and using circular fin, material Aluminum alloy 6061 and thicknessof 2.5mm is better since heat transfer rate is more and using circular fins the heat lost is more, efficiency and effectiveness is also more.

PulkitAgarwal, MayurShrikhande and P. Srinivasan, CFD Analysis performed on two wheeler engine to develop realation between velocity of vehicle and heat transfer co efficient. They take different climatic condition with constant velocity of vehicle to find relation. They model engine cylinder in GAMBIT software and ANSYS Fluent software used by them for CFD analysis. They found that decrease in climate tempreture affect performance of engine.

5. Experimental set up

Fig. 1 – Experimental set up

Piston cylinder of aluminium alloy is shown in set up in front of Fan. Firstly we have to heat up cast iron inner cylinder of engine cylinder block by using heater up to high tempreture of 723k by using nichrome coil. After heating, create a wind of velocity 15Km/hr by using Fan and passes this over fins of cylinder . We can control speed of Fan by using dimmerstat as shown in set up and we can measure a wind velocity by using anemometer. All this experimention we did in ambient tempreture of 300k. After reaching tempretureof inner cylinder at 723k and creating wind velocity after we have to measure tempreture of fins by using k type thermocouple which is attached to digital meter which indicate tempreture of fins when thermocouple is placed on it. Measuring tempreture of fins, ambient tempreture, calculating heat transfer coefficient and fin effiectivness, we can find heat flux dissipation through fins by forced convection. Same procedure we have to do for cast iron fin block. At end compare heat flux value of cast iron and aluminium aluminum alloy fins.

5.1 Main Parts of Experimental set up are explain below

5.1.1 Engine Cylinder

BAJAJ Discover 125cc engine used in experimentation. It is having rectangular fins. It's fin pitch is 1cm, fin thickness is 3mm and bore diameter is 50cm, height of cylinder is 90mm and length of piston cylinder is 115mm. this engine speed speed is 5500RPM. It is standard piston cylinder of BAJAJ Auto.

Fig. 2- Piston Cylinder of BAJAJ 125cc bike

5.1.2 Anaemometer

Anaemometer used here for measuring wind velocity having accuracy of ±5% and also for measuring air tempreture having accuracy ±2%. Measuring range forwind velocity 0 to 30m/s and for tempreture -10 to 45°C.

Fig 3- Digital Anaemometer

5.1.3 Thermocouple

The thermocouple used here is K type. It's accuracy is $\pm 4°C$. Measuring range is 1 to 800°C

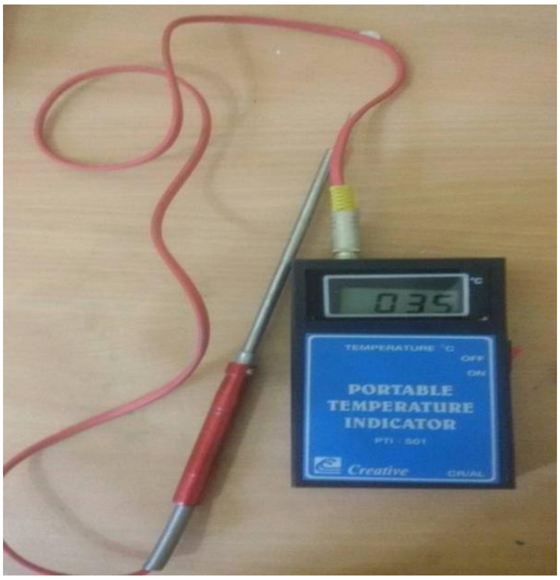


Fig. 4- Thermocouple with tempreture indicator

5.1.4 Heater

Heater we used is nichrome coil having melting point of 650°C. This nichrome coil is wound on circular ceramic rod as shown below. This ceramicrod covered with micathen placed inside cylinder to increase it'stempreture up to 450°C.

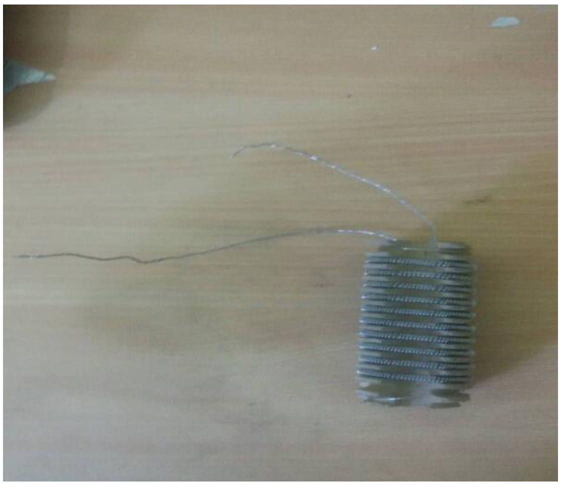


Fig. 5 – Heater of Ceramic and Nichorme coil

5.2Thermal Calculation

The heat transfer from fin surface to Atmospheric air by forced convection is given by
Q= $hA(T_f - T_{atm})$
Q- Heat flux from fin surface, h-heat transfer coefficient of fin , A- surface area of fins, T_f- Tempreture of fin surface, T_{atm} – Atmospheric tempreture.
For Alluminium alloy
Gibson[14], conducted experiments on cylinder cooling of two wheeler engine at relatively high velocities and derived an experimental equation for the fin surface heat transfer coefficient as follows:

$$h = 241.7\{0.0247 - 0.00148(l^{0.8}/p^{0.4})\}u^{0.73}$$

h-Heat transfer coefficient of fin surface (W/m^2°C), l-length of fin, P- Pitch of fin, u- wind velocity
l=75mm, p=10mm, u=15Km/hr
∴ h=22.14W/m^2°C
Q= $hA(T_{Al} - T_{atm})$
Tempreture of Aluminium alloy fin(T_{Al}) when inner surface sleeve tempreture is 450°C= 428°C
Area of Fin surface= length × breath
= 75mm×10mm
=750× 10^{-6}
Q/A = 22.14 × (428 − 27)
Q/A=9320W/m^2
For Cast Iron,
Tempreture of Cast Iron fin(T_{CI}) when inner surface sleeve tempreture is 450°C = 394°C
Q= $hA(T_{CI} - T_{atm})$
Q/A = 22.14 × (394 − 27)
Q/A = 8125.38 W/m^2

6. Methodology

6.1 Modelling and design

Engine cylinder with rectangular fins is modelled in CATIA V5 software having stroke volumn of 125cc. Piston cylinder consist of two parts one part is sleeve or liner and other part is aluminum alloy fins block mounted over sleeve

ANSYS FLUENT 15.0 software is used for preprocessing. Computation domain generated contains a fine mesh. Cut cell meshing is used here to generate the mesh. The computational domain consists of a rectangular volume of large dimensions containing the finned cylinder at its centre. It was focused on the fins and appropriate boundary conditions were applied at the domain ends to maintain continuity. The domain was made longer after the cylinder to allow for wake formation. A fine mesh has been created near the fins to resolve the thermal boundary layer which is surrounded by a coarse external mesh for better results, fast solution and accurate tempreture distribution.

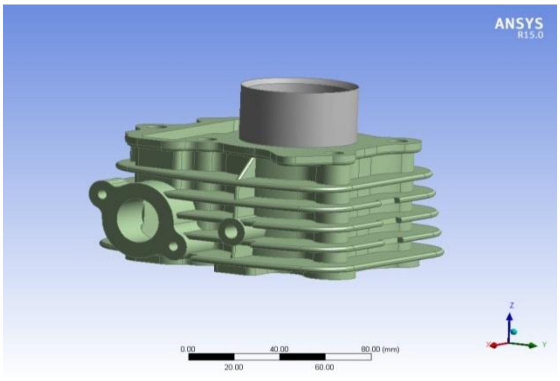


Fig 6 - Three diamensional Model of Piston cylinder with rectangular fin of two wheeler engine

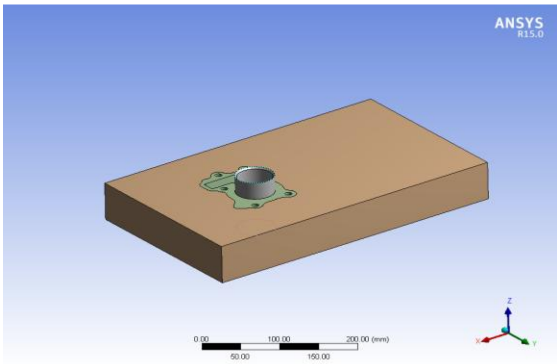


Fig. 7- Engine block fluid enclosure

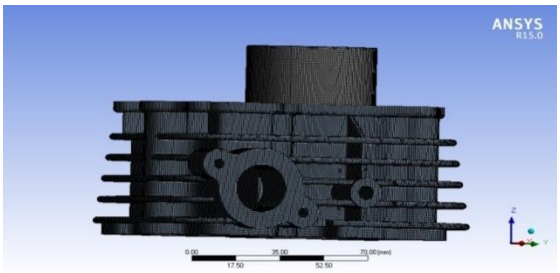


Fig. 8- Engine block surface After Meshing

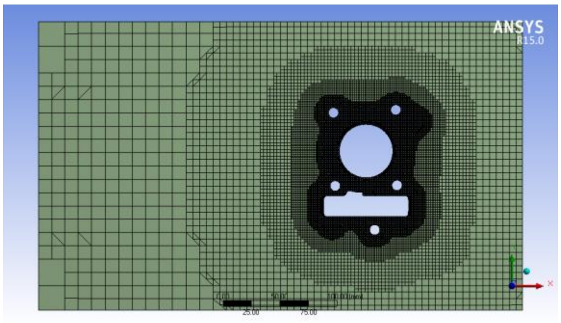


Fig 9- Top view engine block with fluid enclosure After Meshing

6.2Mathematical Model

The solver ANSYS CFD post software we are using for analysis is works on Finite Volumn Method(FVM) and Standard Navier Stroke Equation for fluid low is solved in three diamension to obtain value of velocity and pressure at node point. Below mention mass momentum conservation equation along with continuity equation is used in CFD to solve fluid flow.

$$\frac{\partial(\rho v)}{\partial(t)} + v\nabla.(\rho v) = \nabla P + \nabla.\tau + F + \rho g$$

For modelling Heat transfer, energy equation is solved in following form.

$$\frac{\partial(\rho E)}{\partial t} + \nabla.(v(\rho E + p) = \nabla.(k_{eff}\nabla T - \sum_j h_j J_j + (\tau.v) + S_h$$

Above equation is used to solve for tempreture at different point in fluid region. The three diamensional equation is solved as scalar transport equation to calculate tempreture at fin surface and cylinder surface for which above equation is reduced to

$$\nabla^2 T + \frac{q}{k} = 1/\alpha \frac{\partial T}{\partial t}$$

In this case, q=0 there is no internal heat generation in cylinder wall. Also $\frac{\partial T}{\partial t} = 0$ Owing to steady state assumption.

6.3 Problem set up in fluent

ANSYS Fluent software is used here for analysis. In this project we are taking two cases in first case we are using Piston cylinder having aluminium alloy fins and in second case we are using Piston cylinder with castiron fins with same boundry condition and turbulence model as Aluminium alloy 6061 fins block. In this piston cylinder there is sleeve which is made up of cast iron. On outer surface of sleeve there is rectangular block of aluminium alloy 6061 fins is present as shown in figure. For analysis boundry condition we have to give inlet velocity, outlet pressure, Air tempreture and inner tempreture of sleeve. Turbulence model is used here is Standard k-εModel with standard wall function. Solution method Decritiazation Technique for momentum, kinetic energy and Turbulent Dessipation rate is Second order Upwind Scheme and coupled scheme used for Pressure-velocity .

Table 1- Engine Cylinder specification

Fin Material	Aluminium alloy 6061
No. of Cylinder	1
Engine Type	4-Stroke
Fin Pitch	10mm
Fin Thickness	3mm
Engine Displacement	125cc
Bore Diameter	50cm
Power	11Ps
Speed	5500RPM
Sleeve material	Cast Iron

Table 2– Boundary Conditions

Sr.	Physics	Values
1	Inlet Velocity	15Km/hr
2	Outlet Pressure	101.325kpa
3	Air Tempreture	300K
4	Sleeve Inner Wall Tempeture	723K

Table 3– Properties of alluminium alloy 6061

Sr.	Properties	Values
1	Density	2700Kg/m³
2	Specific heat (c_p)	900J/KgK
3	Thermal conductivity	200W/mK

Table 4 – Properties of Cast Iron

Sr.	Properties	Values
1	Density	6900 Kg/m³
2	Specific heat (c_p)	460 J/Kg K
3	Thermal conductivity	47.8W/mK

7. Result and Discussion

7.1 Flow Pattern Over Fins

Flow pattern over fin surface is shown in Fig. 4. Flow separation occurs at fin surface resulting in wake formation in leeward direction so there is increase in velocity of air after flow separation shown in yellow shade

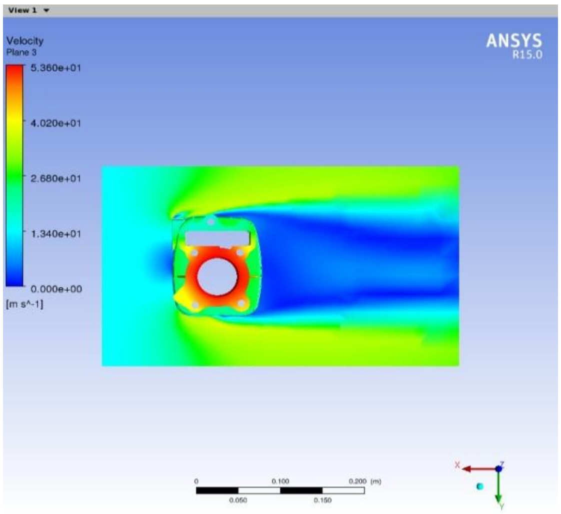


Fig 10– Velocity vector plot for fin surface at velocity of 15km/hr

7.2 Tempreture Distribution Across Fins

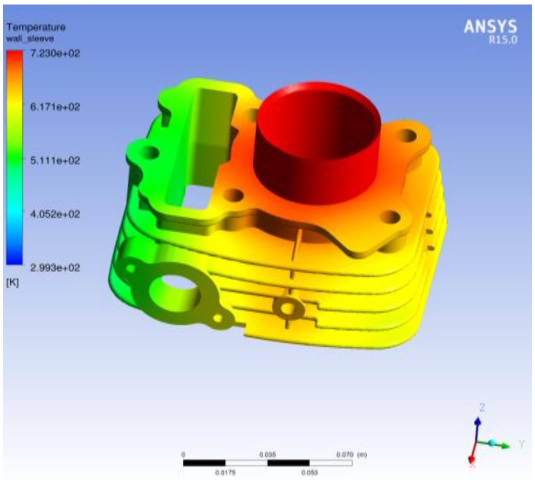


Fig 11– Contour plot of tempreture(K) for Aluminium alloy fins at wind velocity of 15Km/hr and tempreture 27°C

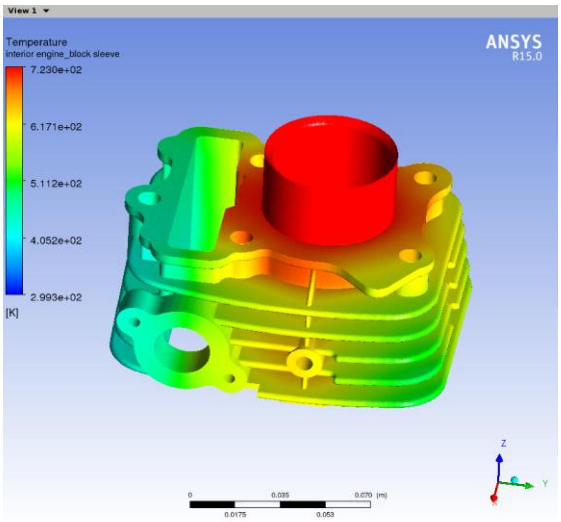


Fig 12- Contour plot of tempreture(K) for Cast Iron fins at wind velocity of 15Km/hr and tempreture 27°C

The figure shows variation of surface temperature along the fin surface. The wind is modeled to flow towards right and the area on the fin after the cylinder receives air at low velocity being the region of wake formation. Consequently, heat loss by forced convection is reduced and the surface temperature in this region is higher than that on the front side. Moreover, a comparison between the two figures indicates an increase in temperature on the fin surface with changing in material from increasing in temperature which results from decrease in heat transfer due to less temperature gradient.

7.3 Heat loss from fins

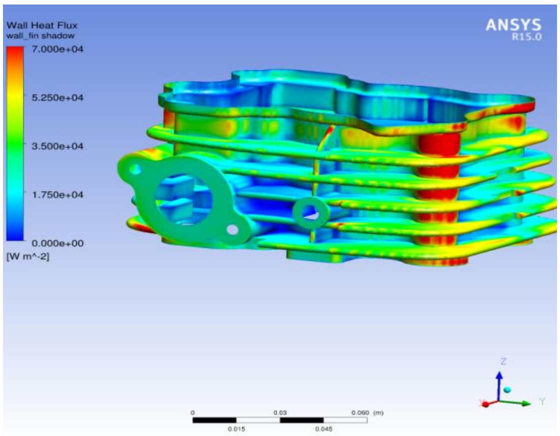


Fig 13- Heat loss from Aluminium Alloy fin surface at wind velocity of 15Km/hr and tempreture 27°C

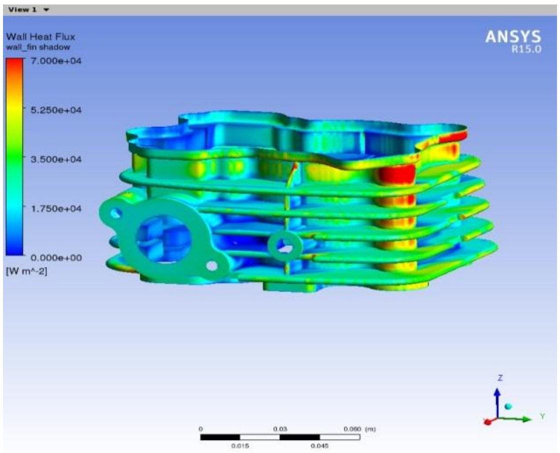
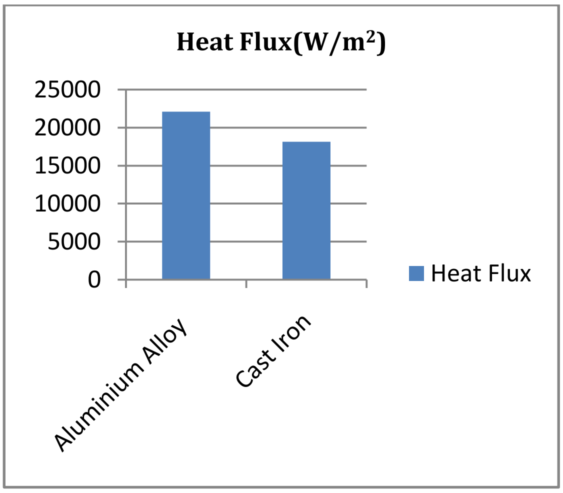


Fig 14- Heat loss from Cast Iron fin surface at wind velocity of 15Km/hr and tempreture 27°C

The figure shows the variation heat flux over fin surface. Front surface showing less heat flux as compare to side surface due to flow separation sudden increase in velocity of wind due to this more heat loss takes place from side fins. Alluminium Alloy minimum heat flux are 359.073W/m^2 and max heat flux are 107499.07W/m^2. For Cast iron min heat flux are 517.08W/m^2 and max heat flux are 78141.992W/m^2

Table 5-Heat Flux difference between two material

Material	Parameter	Min.	Avg.	Max.
Al. Alloy	Heat Flux(W/m^2)	359.073	22081.88	107499.07
Cast Iron	Heat Flux(W/m^2)	517.08	18154.312	78141.992



Graph 1 –Material Vs Heat Flux

7.4 *Heat transfer coefficient of the fin surface*

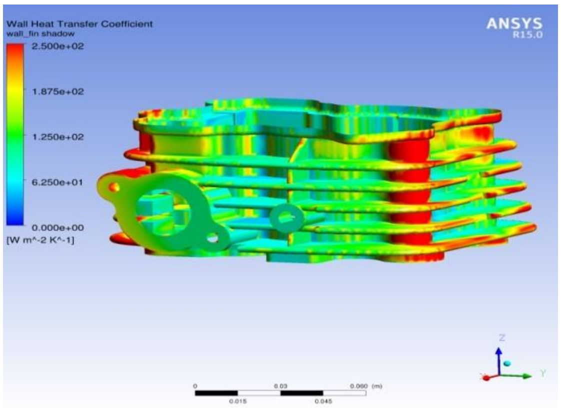


Fig 15 - Heat transfer coefficient of Aluminium Alloy fin surface at wind velocity of 15Km/hr and tempreture 27°C

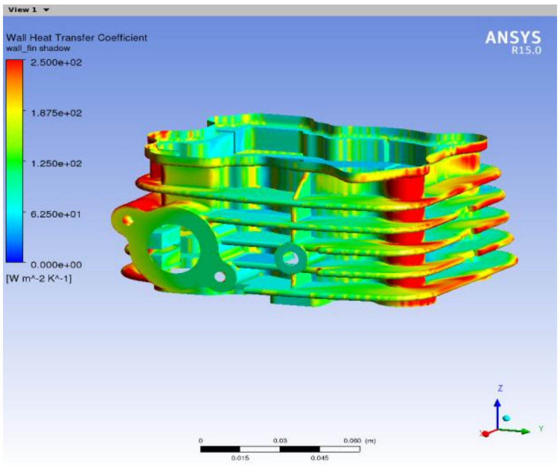
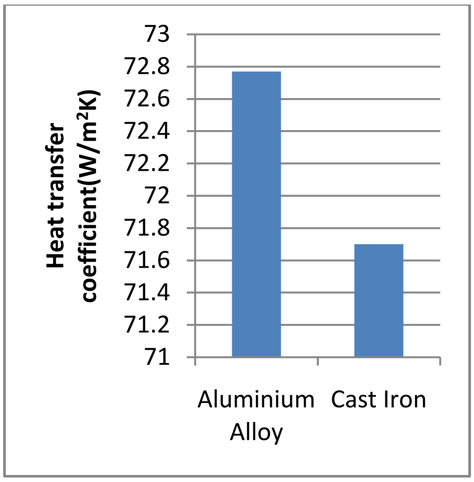


Fig 16 - Heat transfer coefficient of Cast Iron fin surface at wind velocity of 15Km/hr and tempreture 27°C

At different fin materials, the average heat flux was calculated for each of the fins. the average fin surface heat transfer coefficient was calculated for each case. The values of heat transfer coefficients obtained for different material verified to a very good agreement . Thus a correct benchmark for investigating the effect of different material on heat loss and heat transfer coefficient was obtained through CFD simulation.

Table 6– Comparision of materials

Materi al	Parameter	Min	Avg	Max
Al Alloy	Heat transfer co efficient (W/m²K)	0.95 4	72.77 9	457.4 6
Cast Iron	Heat transfer coefficient(W/m² K)	1.35 5	71.7	440.7 5



Graph 1 –Material Vs Heat transfer coefficient

8. Conclusion

Following conclusion are made from above project work

1. In this way BAJAJ Discover 125cc cylinder with rectangular fins is modelled in CATIA V5. Steady state CFD analysis is performed for two material Alluminium Alloy 6061 Fins cylinder and Cast Iron Fins cylinder.
2. By CFD Analysis, Tempreture distribution, Heat transfer coefficient and heat flux at wind velocity of 15Km/hr and Ambient tempreture of 27°C are found for Al alloy and Cast iron fins.
3. By Experimention, Tempreture distribution over fin surface, Heat transfer coefficient, heat flux are calculated for Al Alloy and Cast iron at wind velocity of 15Km/hr, Ambient tempreture of 27°Cand for inner surface tempreture of cylinder is 450°C
4. By Cfd Analysis For Alluminium alloy fins min heat flux are 359.073 W/m² and max heat flux are 107499.07 W/m². By Experimentation For Al Alloy fin cylinder heat flux are found to be 9320W/m² and it is in between cfd result 359.073 W/m² and 107499.07 W/m² so CFD result we got are validated.
5. By Cfd Analysis For Cast Iron fins min heat flux are 517.08 W/m² and max heat flux are 78141.992 W/m². By Experimentation For Cast Iron fin cylinder heat flux are found to be 8125.38 W/m² and it is in between cfd result for heat flux 517.08 to 78141.992 W/m² so CFD result we got are validated.
6. We also compare Cfd result with experimentation for validation of tempreture distribution. By passing air with velocity of 15Km/hr over fins when it's inner surface cylinder tempreture is 450°C . The measured tempreture on front surface of fins during experiment is nearly same as Tempreture obtained by CFD analysis By this paper we compare CNG engine fins of aluminium alloy and cast iron. It is found that Aluminium fin cylinder dissipate nearly 20% more heat flux than cast iron cylinder for CNG fuel engine.

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