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Design and analysis of water jacket in the inline six-cylinder engine

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ABSTRACT

A water jacket is a structure that allows water to pass through a cylinder block in a water-cooled internal combustion engine.Also designed and evaluated is a model with fins like projections around the cylinder outer wall that are in contact with the cooling fluid.This research compares the cooling pattern and flow properties of the three types (original water jacket, water jacket with ribs, and water jacket with fins).

Keywords: *CFD Analysis, Water Jacket, Cylinder Block, Bore Distortion*

1. INTRODUCTION

Automobiles play a significant role in our daily lives. They have a huge impact on our lives Engine heat management is a critical component of a car engine's efficiency. A temperature-controlled engine will perform better and more efficiently than a fuming heated engine. It's critical to keep the temperature in the right range for a smooth operation.

Bore distortion is a problem that occurs in automobiles when the engine bore becomes deformed as a result of high and continuously variable cylinder heating.Bore distortion can be caused by a variety of factors, including machining tolerance (zero and first order distortions), forces generated by tightening head bolts (distortion order = number of head bolts), differences in liner cooling resulting in thermal expansion differences, and distortions caused by gas pressure.As a result, keeping the temperature low or using efficient cooling systems has the extra benefit of minimizing the risks of bore distortion and so extending the engine's life.

We equip the engine with more design features called Ribs and Fins in this effort. Three models will be developed and analyzed in this section, i.e A standard inline six cylinder engine, an engine with fins and an engine with ribs.On the proposed models, various physical and thermal analyses will be performed, and we will determine which modification will provide the best cooling efficiency and thus successfully reduce the engine block temperature to the lowest possible level when compared to a standard inline six cylinder engine with no modifications.

1.1. Engine blocks

The engine block is a critical component of internal combustion engines, serving as the vehicle's powerhouse. Because the engine block is usually a solid cast that houses the cylinders and their components inside a cooled and lubricated crankcase, it is called a block.Pistons, camshafts, timing chains, rocker arms, and other pieces are common components found in engines. When the engine is completely stripped of all components, the cylinder block is visible. The cylinder block (also known as the engine block) is the most powerful component of an engine and houses many of the hundreds of pieces that make up a modern engine.The cylinders are commonly organized in a "V," inline, or horizontally opposed (also known as flat) layout, with the number of cylinders ranging from three to sixteen.

1.2. Water jacket in an Engine

The water jacket entirely covers all cylinders in the cylinder block along their entire length. Narrow channels are constructed between the cylinders within the jacket to allow coolant to circulate around them.Water passageways are also created around the valve seats and other hot cylinder block components. When the valves are positioned in the head, the water jacket covers the combustion chambers at the top of the cylinders and contains channels around the valve seats.The water jacket's channels are meant to regulate coolant circulation and ensure proper cooling throughout the engine. The pump directs coolant from the lower radiator tank connection into the cylinder block's forward part.Obviously, this form of circulation would cool the number one cylinder first, causing the rear cylinder to absorb coolant that had been gradually heated by the cylinders ahead.

1.3. Modifications performed in the Engine

The conventional inline six cylinder engine will be provided with two proposed design elements separately. They are as follows :
Ribs: Ribs, a new design element for the engine, will be added to it. It is placed in the combustion zone in the upper portion of the cylinder block, across the water jacket (in between inner walls). It measures 35 mm in length and 5 mm in thickness. They're designed to make the cylinder bore stronger and so lessen the risk of bore deformation.More importantly, they will produce turbulence in the coolant flow, which should increase the engine's cooling efficiency.
Fins : The engine will be provided with an additional design element called as Fins. They are added from the outer wall of the cylinder ,projecting towards the flow region. Fins are projected with a 5 mm thickness and 10 mm depth. Almost similar to an air-cooled engine, the fins are supposed to channel the fluid flow efficiently and also cause turbulence thereby improving the overall cooling efficiency of an engine compared to the conventional engine setup.

1.4. Performance analysis

Design and analysis of the three proposed designs i.e ((i.)basic inline six cylinder engine, (ii.)engine with ribs and (iii.) engine with fins) are performed using various technical software and the essential results of all the three models will be compared and critically analyzed to find out the most efficient design element of the both

2. ANALYSIS SETUP

Using CATIA V5 software, develop the needed standard inline six engine with a bore diameter of 102mm and a stroke length of 120mm. Model A is a regular model with no alterations. The model with ribs (Model B) has a 5mm width and a depth length of 35 mm. Then there's the type with fins (Model C), which has a 5 mm width and a 10 mm deep length. All of them were created with the use of software.

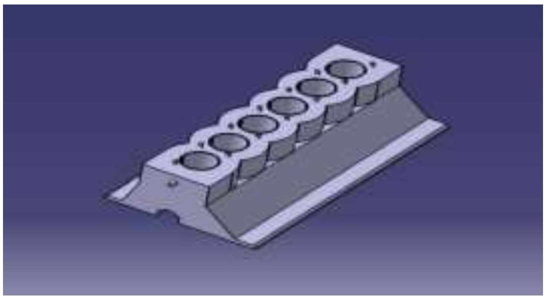
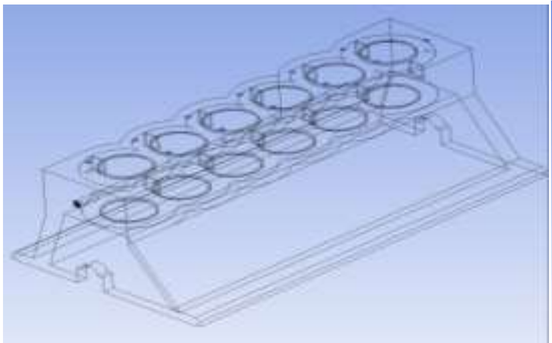


Fig 1: Basic model of cylinder block created using CATIA V5 software.

2.1 Wire frame model of block



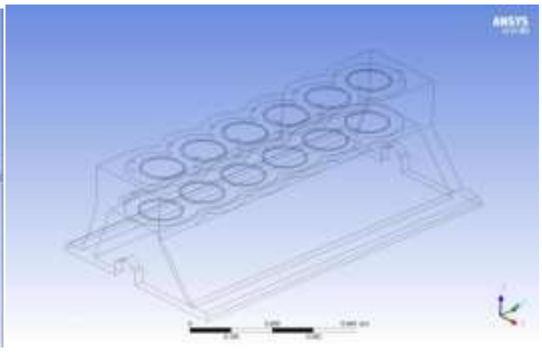


Fig 2: Wire frame model of Model A **Fig 3: Wire frame model of Model B**

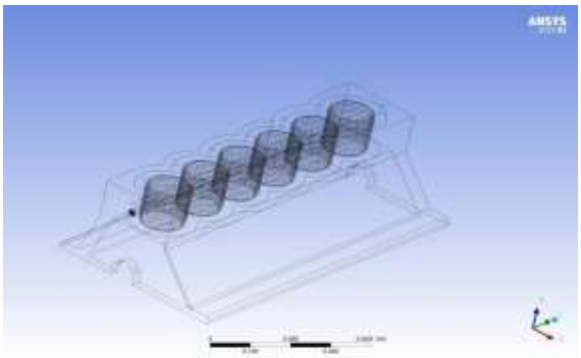


Fig 4: Wire frame model of Model C

Model having bore diameter 102 mm and stroke length of 120 mm is created (Model A)

In the 2nd model (Model B) a rib like structure is added as shown in the above figure 4.5.3 with a thickness of 5mm and length of 35 mm. It is added in the top portion of the cylinder block, across the water jacket (in between inner walls)near the combustion region .

In 3rd model (Model C) fins (extended surfaces) are added from the outer wall of the cylinder ,projecting towards the flow region .Fins are projected with a 5 mm thickness and 10 mm depth as shown in the figure 4.5.4.

2.2 Meshing

The three models created with the CATIA software are saved in .igs format.The data is then imported into the ANSYS 2019 R3 software's workbench module. ANSYS is then used to mesh the water domain, heating domain, and engine block model.In the fluid domain and cylinder block, tetrahedral meshing is employed, whereas in the heat domain, the Hex dominating meshing approach is used. For mesh generation, a software-based automatic mesh generating tool is used.

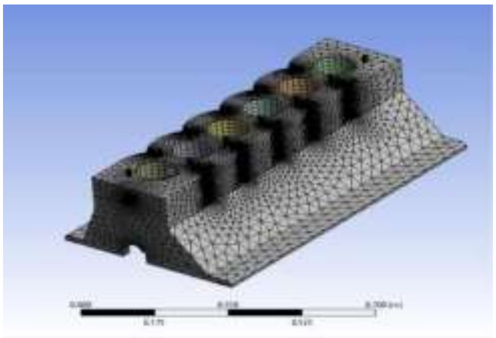


Fig 5: Meshing of cylinder block

2.3. CFD Pre processing

The steady state analysis type is used. The fluid domain's substance is water, while the solid domain's material is an aluminium alloy. The water is initially at 298 degrees Fahrenheit, and the water jacket is at 1000 degrees Fahrenheit, with a constant temperature of 1000 degrees Fahrenheit in the combustion chamber.The water jacket's inlet has a velocity of 2.6 m/s and a relative pressure of 25 psi. Convection occurs through the block's side walls, with a heat transfer coefficient of 10 W/m2K and an outside temperature of 298K.

2.4. CFD Post processing

The number of iterations is set to 100, and the K-epsilon turbulence model[1] is used in the analysis. We produced findings from the models by solving them on CFD FLUENT. We'll refer to the original model as model A from now on, and the proposed models as model B (with ribs) and model C. (model with fins).Cylinder 1 is closest to the inlet, and the remaining cylinders are 2,3,4,5, and 6. The distance along the longitudinal direction of the water jacket in the Y axis is represented by the X axis of the generated graph in Fluent(CFD post). Temperature, Velocity, and other types of contours are formed.

3. RESULT AND DISCUSSION

We got the findings by using the CFD solver. We'll refer to the original model as model A, the model with ribs as model B, and the model with fins as model C from now on. Cylinder 1 is nearest to the inlet, while the following cylinders are 2,3,4,5, and 6, correspondingly.The distance along the longitudinal direction of the water jacket is shown by the X axis of the graphs, with reference (Y=0) at the CG of the assembly. The temperature distribution graphs of the fluid travelling through the water jacket are also acquired, as are the temperature, velocity, turbulence kinetic energy, and eddy viscosity graphs of the fluid passing through the cylinder wall. The analysis produces the predicted outcomes.

3.1. Analysis of standard model (MODEL A)

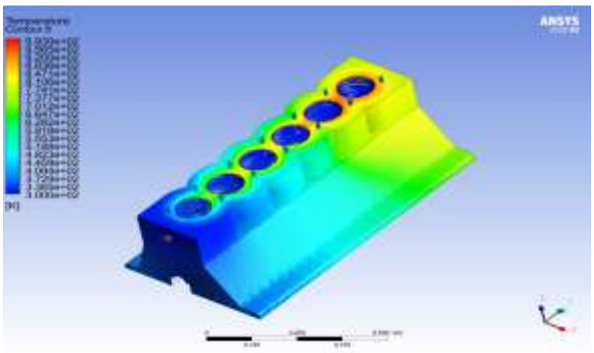


Fig 6: The isometric view of temperature distribution along the cylinder block.

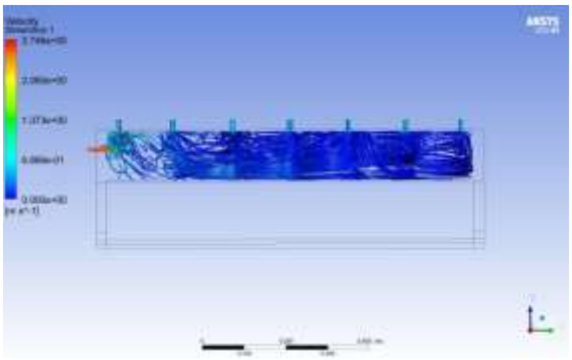


Fig 7: Streamline representation of coolant flow in Model A .

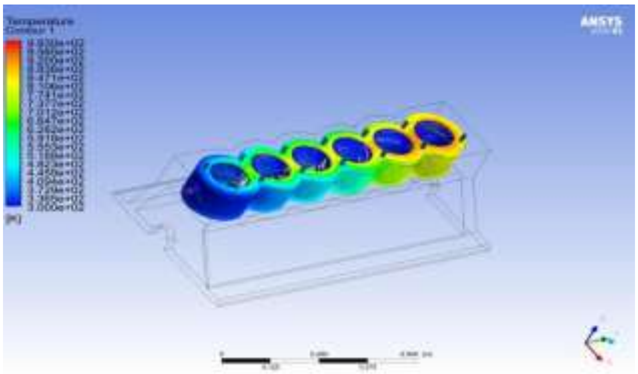
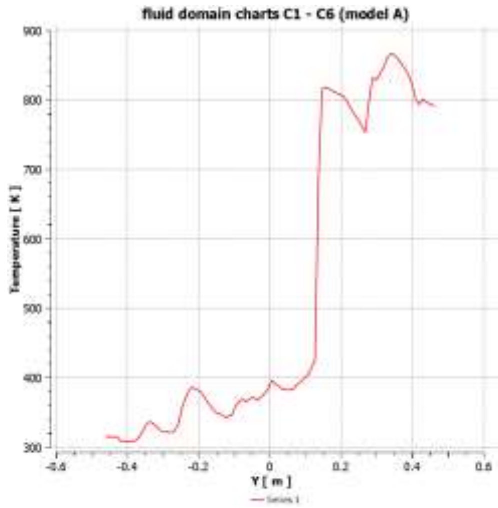
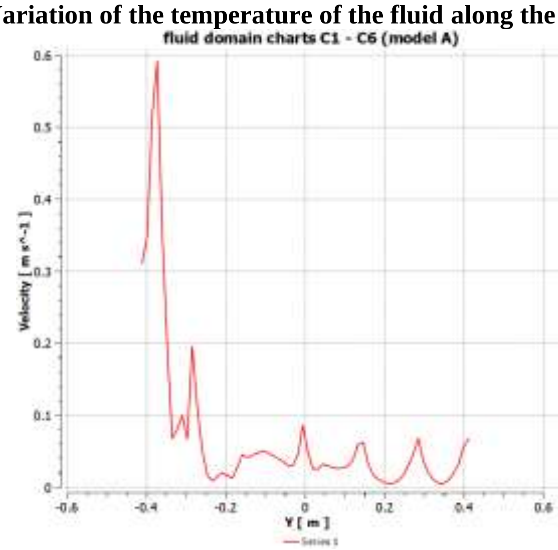


Fig 8 : Temperature distribution along the flow domain(Temperature absorbed from the cylinder block during flow by fluid)

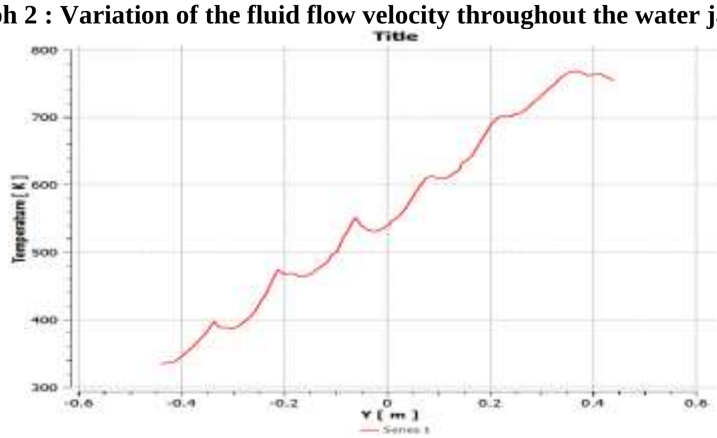
3.2. Graphs obtained as results on Model A



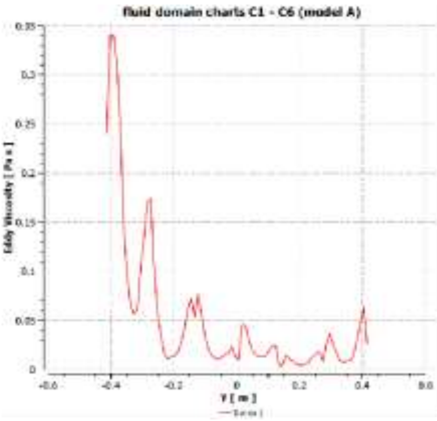
Graph 1 : Variation of the temperature of the fluid along the water jacket.



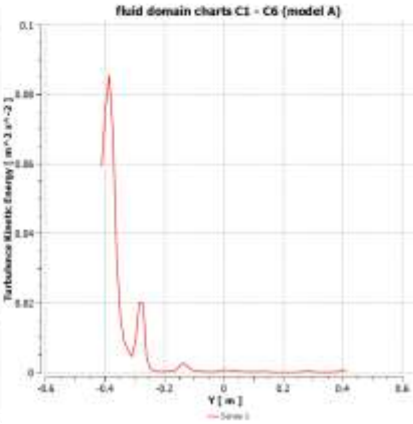
Graph 2 : Variation of the fluid flow velocity throughout the water jacket.



Graph 3 : Temperature variation of the cylinder block along its wall (y axis)



Graph 4 : Eddy viscosity variation in the fluid



Graph 5 : Turbulence Kinetic energy of the fluid

3.3. Analysis of Model with Ribs (MODEL B)

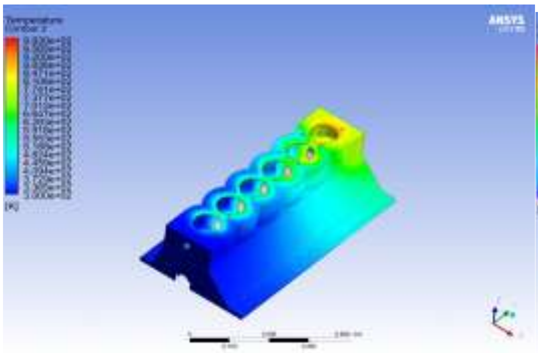


Fig 9 : The isometric view of temperature distribution along the cylinder block (Model B)

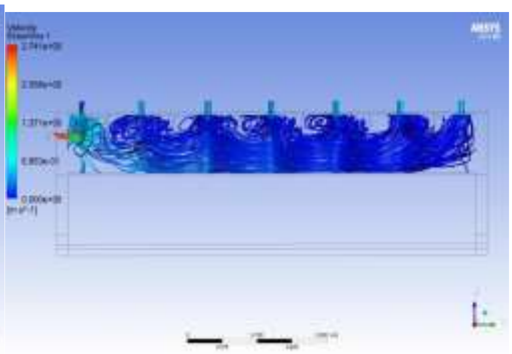


Fig 10 : Streamline representation of coolant flow in (Model B)

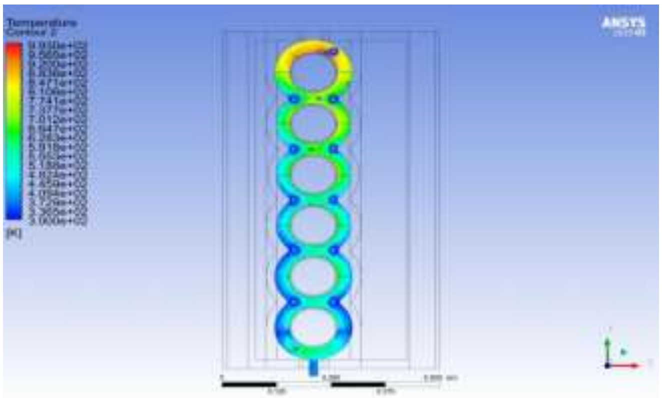
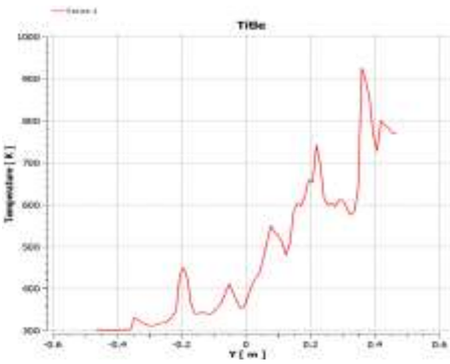
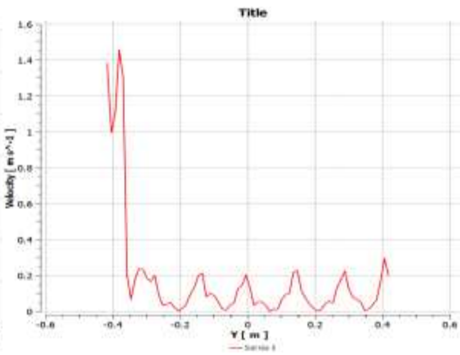


Fig 11 : Temperature distribution of the fluid along the water jacket.(Model B) (Temperature absorbed from the cylinder block during flow by fluid)

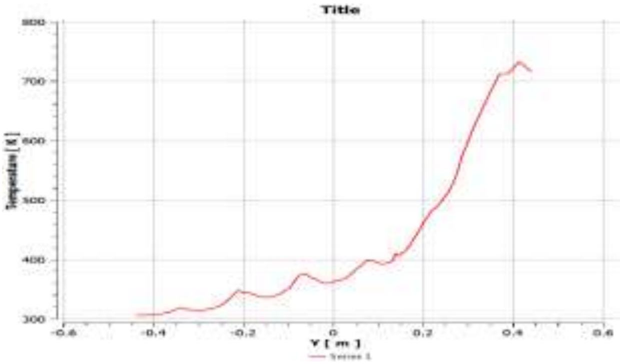
3.4. Graphs obtained as results on Model B



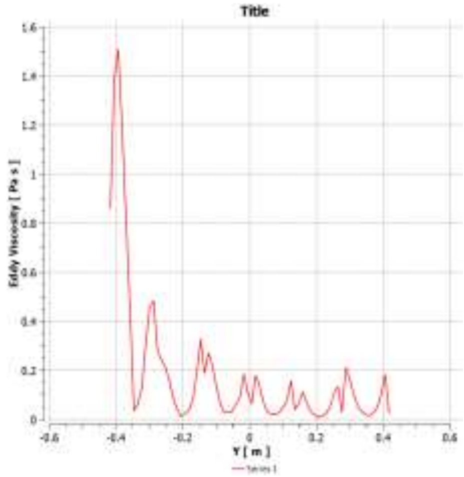
Graph 6 : Variation of the temperature of the fluid along the



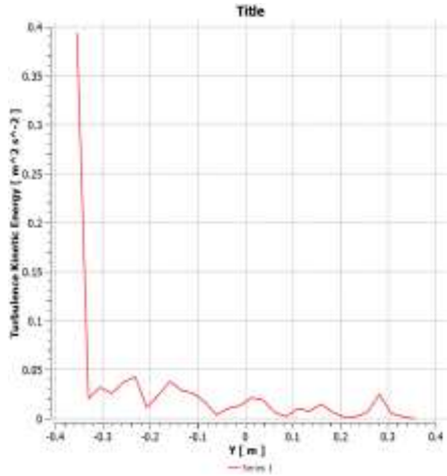
Graph 7 : Variation of the fluid flow velocity throughout the water jacket.



Graph 8 : Temperature variation of the cylinder block along its wall (y axis)

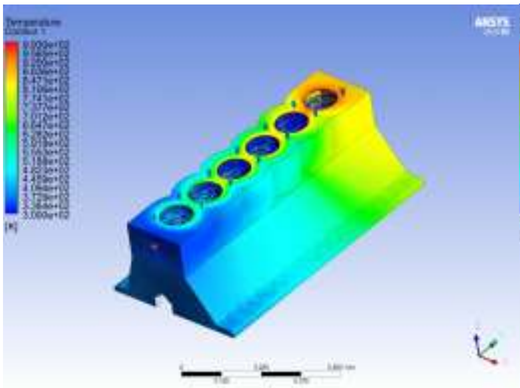


Graph 9 : Turbulence Kinetic energy of the fluid from cylinder 1 to 6



Graph 10 : Eddy viscosity variation in the fluid from cylinder 1 to 6

3.5. Analysis of Model with Fins (MODEL C)



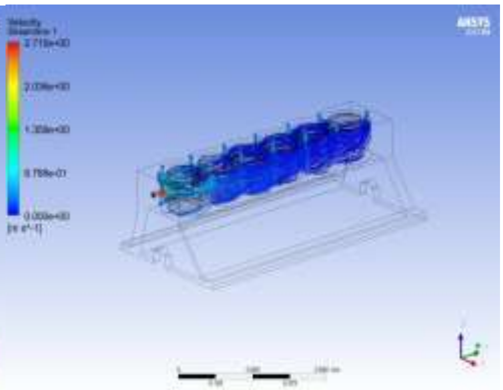


Fig 12 : The isometric view of temperature distribution along the cylinder block(Model C)

Fig 13 : The isometric view of velocity streamline along the cylinder block (Model C)

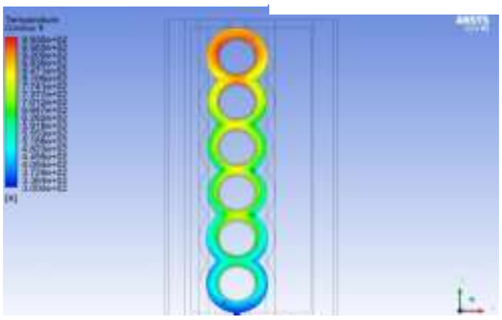
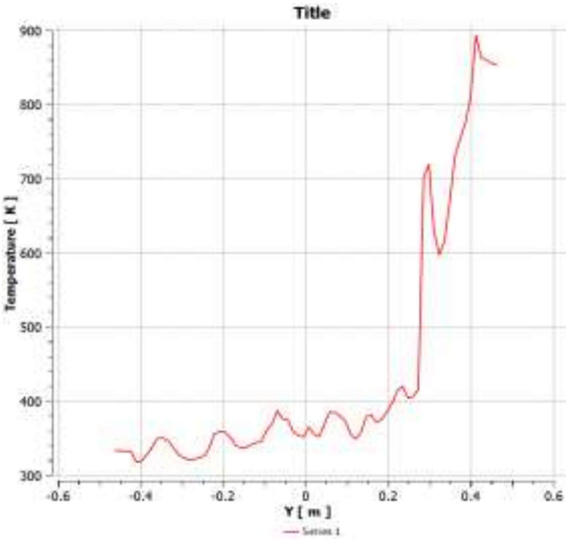
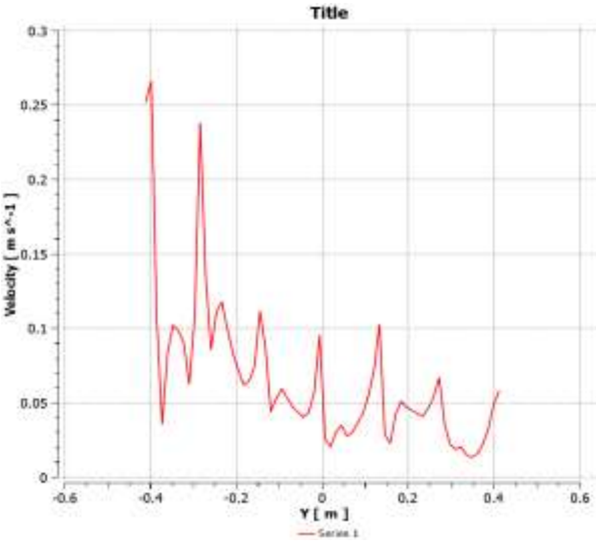


Fig 14 :Temperature distribution of the fluid along the water jacket.(Model C)

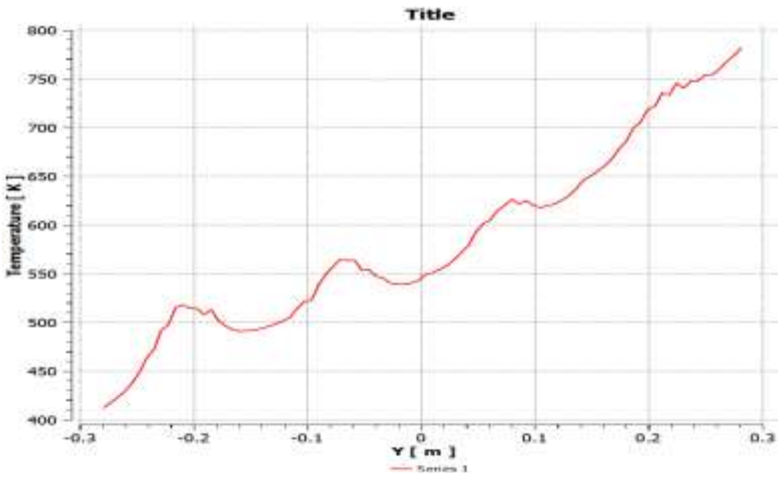
3.6. Graphs obtained as results on Model C



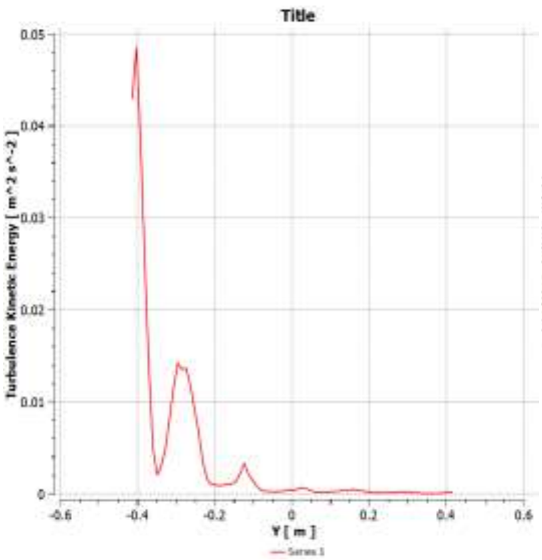
Graph 11 : Variation of the temperature of the fluid along the water jacket.



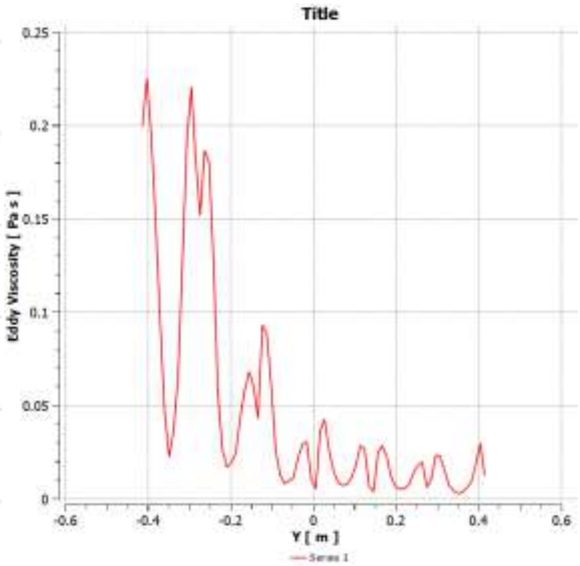
Graph 12 : Variation of the fluid flow velocity throughout the water jacket



Graph 13 : Temperature variation of the cylinder block along its wall (y axis)

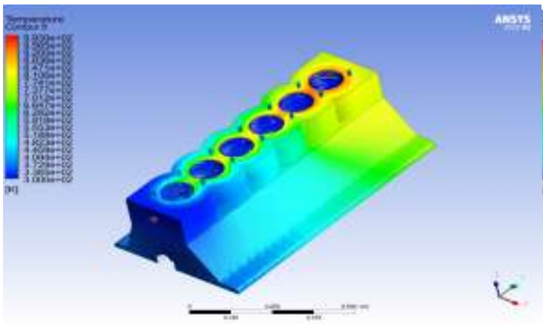


Graph 14 : Turbulence Kinetic energy of the fluid from cylinder 1 to 6

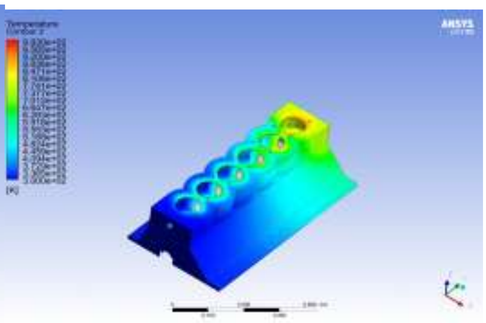


Graph 15 : Eddy viscosity variation in the fluid from cylinder 1 to 6

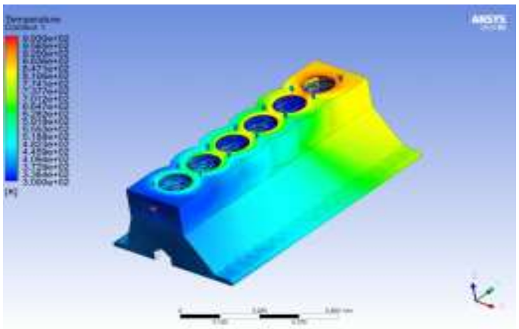
3.7. Comparison of temperature variation in block among the three models



MODEL A



MODEL B

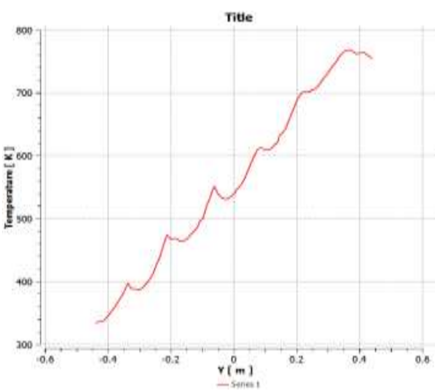


MODEL C

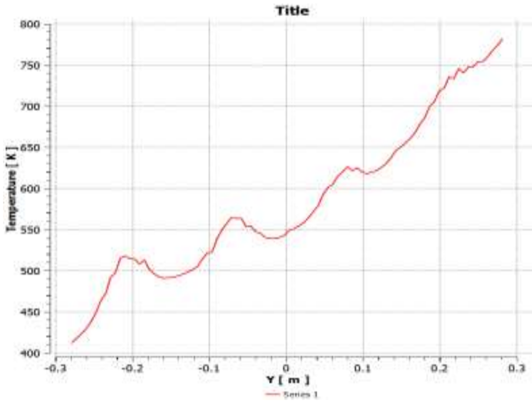
The temperature fluctuation can be seen clearly on the right side of the cylinder walls of models A, B, and C in the comparison above.The temperature varies from 320K to 750K in a consistent pattern in model A (standard model), with the temperature near the bore being somewhat greater than the outside wall temperature.Due to the high velocity at inlet, the temperature in cylinder 1 is around 350 to 370K.The mass flow rate at the intake is relatively lower than the region around cylinder 6 due to the lowest velocity drop at the inlet.When the fluid approaches via the water jacket at cylinder 6, the velocity is lowered, thus the heat lost to the fluid is more than in the intake regions (about 700K to 800K)The temperature distribution in Model B (with ribs near the combustion chamber) is significantly less than in Model A and C.The existence of ribs in the model causes the fluid travelling through that region to be blocked by the ribs, resulting in local turbulence.It provides us extra velocity and heat transfer.As a result of the extra heat and momentum transmission, the heat dissipation of the block rises.The isometric view of temperature distribution along the cylinder block in model B is shown above.

When comparing model A and model B, it is obvious that the temperature distribution over the cylinder block in model B is considerably better than in model A and model C.In model B, heat dissipation is rather high at the cylinder wall as well as on the top surface in the region around the combustion chamber. (in the ribcage area)In addition, there is a significant difference in temperature distribution across models A, B, and C, with model B having a more effective temperature distribution.The area of contact of the fluid flowing through the water jacket is enlarged in model C (with fins), resulting in greater heat dissipation of the fluid in contact with.As can be observed in the accompanying figures, the temperature distribution at the top surface and side wall of the cylinder block.The temperature distribution at the block's top surface is significantly more effective than the model A, but not as successful as the model B.Because the velocity of fluid flowing through the water jacket is decreasing at cylinder 6 (as seen in the graph of velocity of fluid domain), the temperature distribution across that portion of the block is high.The model B (with Ribs) appears to be more effective than the other tow versions based on an overall assessment of the three models (A,B, and C) (model A and C). As a result, it is advised that ribs be included in the cylinder block design for optimal heat dissipation.Because local stresses are created over that region, the suggested model's stability must be determined through careful study.Experiments on the models' practicality should also be carried out.

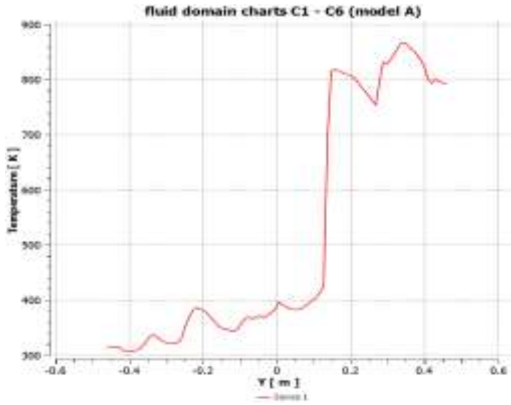
3.8. Comparison of temperature variation graphs of cylinder block (3 models)

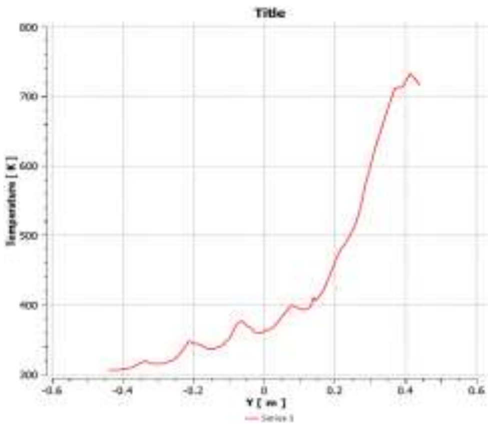


MODEL A



MODEL B

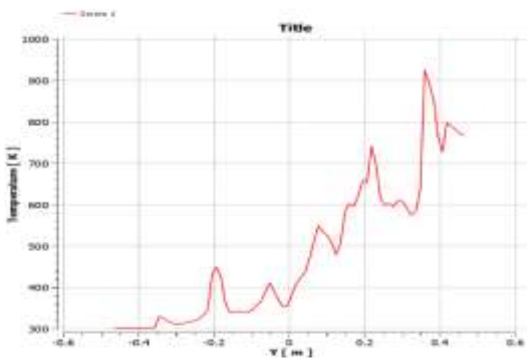




From comparing the graphs of model A ,model B and model C, we can find that the temperature distribution of model B is less than that of model A and C.The highest temperature acquired y the model A is about 760K,in model B temperature is up to 720K and in model C temperature is up to 780K, from this we can conclude that the model B is more effective .The variation of temperature is much more better than model A and C in model C,that is evident in graph of model B.

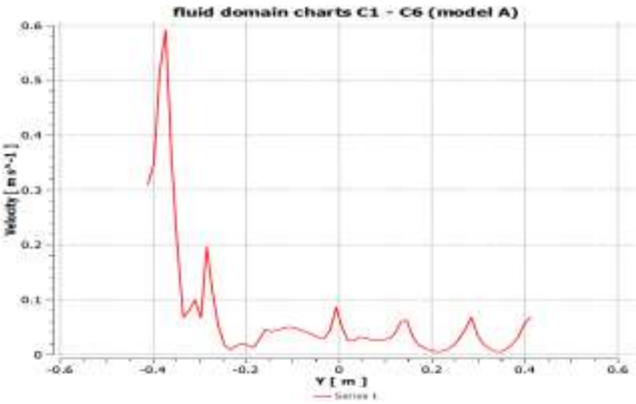
3.9. Comparison of variation of temperature of the fluid along the water jacket (3 models)

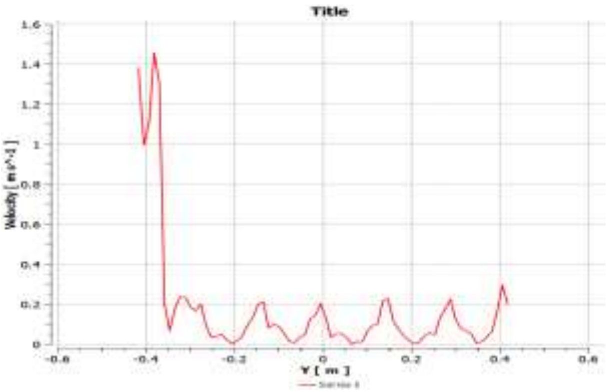
The variation of temperature absorption is much more regular in model B than model A and model C . Thus a better cooling pattern is obtained in model B compared to the other two models .



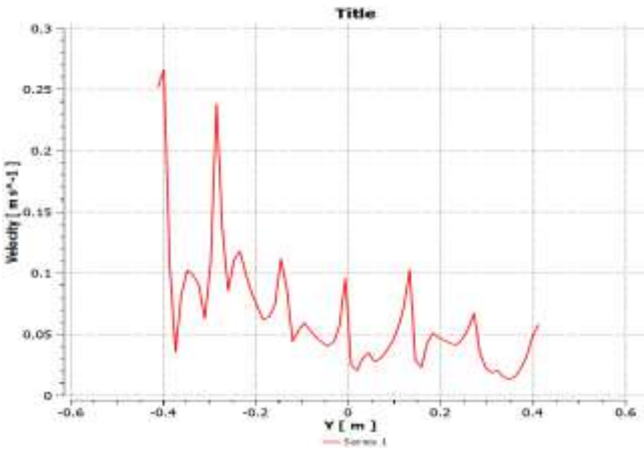
MODEL B

3.10. Comparison of variation of the fluid flow velocity throughout the water jacket (3 models)





MODEL A MODEL B



MODEL C

At the inlet portion the velocity is high and after impact wit the cylinder the temperature is dropped in all models .In model B a regular increase in the velocity at the portion of ribs is seen.In model A the velocity is decreasing along the flow path.The model C also more like model A ,that decreases the velocity along the flow through the water jack

Comparison of temperatures of outer cylinder walls of the three models

CYLINDER NO:	MODEL A (TEMP IN K)	MODEL B (TEMP IN K)	MODEL C (TEMP IN K)
1	318	306	338
2	411	353	382
3	476	379	458
4	580	493	532
5	755	586	676
6	796	712	828

The table shows the temperatures generated in the outer wall of 3 cylinder blocks (models).From the table it is clear that as compared to model A , the model B and model C are efficient in heat dissipation .The overall average values of temperature is less in model C and model B relative to model A. From the result we can strongly suggest the model B over the other two models for cylinder blocks to improve the heat dissipation.

4. CONCLUSION

From the study of comparison of cooling pattern and flow characteristics of three model,we found that the proposed models (Model B and C) have a better cooling pattern than the model A .Through the comparison and analysis of data generated model B and C have better cooling efficiency than model A. But in overall comparison the model B is more effective than the other two models because the temperature possessed by the model B having ribs is low as compared to the other models. From the analysis we can see temperature is slowly reducing at the cylinder 6.There are some irregular temperature distribution possessed in the model , this problem can be improved by increasing the mass flow rate of water at inlet from the water pump.Heat transfer rate of our design in ribs and fins have totally changed the temperature characteristics.The flow characteristics of our design produced better circulation of water inside the cylinder block.Thus water jacket of our design also gained better internal turbulence. The model with ribs (Model B) is expected that ,it will greatly reduces the bore distortion generated due to a long period running of engine .And also expected to reduce the unnecessary engine oil consumption and offers a long life and durability to engine block. There are advantages as well as disadvantages ,due to the addition of additional geometry in the model,the center of mass of the engine block will tends to vary ,it will cause the equilibrium state of the engine causes the generation of unbalanced forces . This can be rectified by proper structural analysis, vibration analysis etc. By the analysis and study carried out by this project the model with ribs (model B) and the model with Fins (model C) are more effective than the model A . But by comparing ribs and fins , the addition of ribs results more effectiveness.Thus the results suggest that we should add ribs as in the case of model B .

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