CFD Analysis on Effect of Addition of Ribs in Water Jacket to Reduce Bore Distortion

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Abstract- *Cylinder block water jacket in a water cooled internal combustion engine is a structure through which water flows. Water enters from inlet, heat transfer takes place between, hot cylinder walls and colder water and water exits the cylinder block water jacket and moves to cylinder head water jacket. Bore distortion is a critical problem faced by internal combustion engine designers, it is expected that addition of ribs near combustion chamber will reduce bore distortion, following study is a comparison of cooling pattern and flow characteristics between the original water jacket and water jacket with ribs near combustion chamber.*

Keywords- Computational fluid dynamics, CFD, Water Jacket, Cooling, I.C. Engine, Automotive engine, Diesel Engine, Bore Distortion.

I. INTRODUCTION

Bore distortion in an internal combustion engine leads to high engine oil consumption.To reduce bore distortion, ribs connecting the outer surface of cylinder to the cylinder wallare added up to a depth of 35mm. This design is expected to reduce the bore distortion to a large extent.

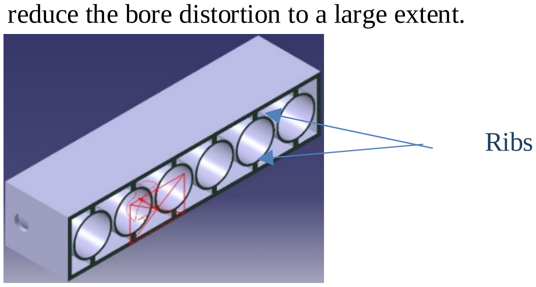


Fig 1.1: Addition of ribs

A computational fluid dynamic analysis was done for both original model (model A) and the new model with ribs (model B) to study the difference in flow behavior and cooling rate and pattern in the two models using ANSYS 15.0.The amount of temperature drop in both cases and flow characteristics like velocity, turbulence etc. was studied.The objective of this research was to find out whether the addition of ribs is justifiable or not.The model has one inlet on front and 12 outlets on top surface as seen in figure 2.2.

II. PROBLEM SETUP

A. Modeling and meshing

A standard 6 cylinder model with bore diameter 102mm and stroke length 120 mm is created in CATIA V5, once without ribs(model A) and then with ribs(model B). These models are saved in .iges format and then imported into CFX module of ANSYS 15.0. The model is an assembly of two parts, i.) Water jacket (material-iron) and ii.) Water (material-water). Mesh was generated using ANSYS 15.0, a fine global mesh isgenerated and local sizing of 0.01m is given to both water jacket and water. Inflation layer is generated at solid-liquid interface with 15 layers and total thickness is taken as inflation option.

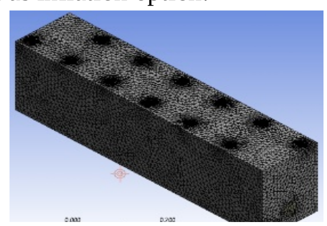


Fig 2.1: Meshed assembly

B. CFXPre-processor

Analysis type is taken as transient with time duration of 10 seconds and time-step of 0.05s. Water is assigned as material of fluid domain and iron is assigned as material of solid domain(water jacket). Water is initially at 298 K and water jacket at 1000K, with a constant temperature of 1000K at combustion chamber. Inlet has a mass flow rate of 3.333kg/s and exit port type is "opening" with a relative pressure of 25 psi. Convection takes place through side walls of the block and heat transfer coefficient is taken as 10 W/m^{2}K. Exterior temperature is taken as 298K.Residual target is taken as 0.001.

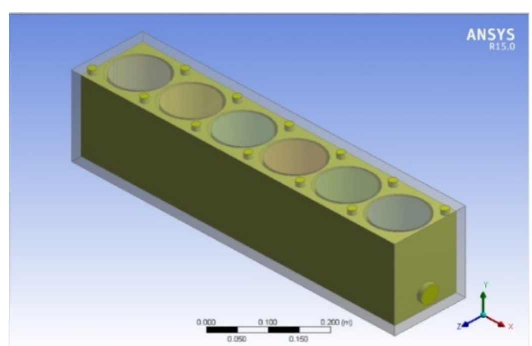


Fig 2.2: Original model

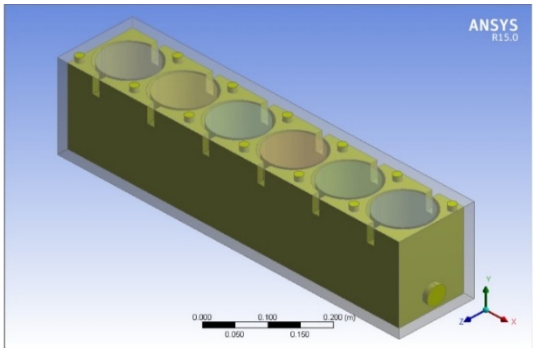


Fig 2.3: Proposed model

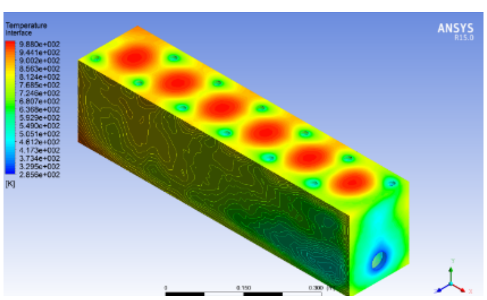
III. RESULT STUDY-CFX POST-PROCESSOR

On solving by using CFX serial solver with double precision, we got the results. From now on we will define original model(without ribs) as model A and proposed model (with ribs) as model B.The cylinder closest to the inlet is cylinder 1 and subsequent cylinders are cylinders 2,3,4,5 and 6 respectively. X axis of graphs represents the distance along the longitudinal direction of water jacket with reference(X=0) at C.G of the Assembly(Between cylinder 3 and 4). Left hand side refers to the left side when viewing in negative x direction.

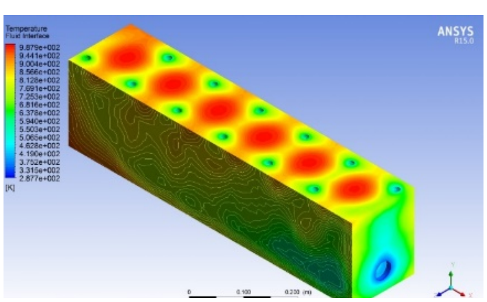
X[m] coordinates of centers of the cylinders:

Cylinder 1: 0.29625 Cylinder 2: 0.177.75
Cylinder 3: 0.05925 Cylinder 4: -0.05925
Cylinder 5: -0.177.75 Cylinder 6: -0.29625

A. Cooling pattern comparison

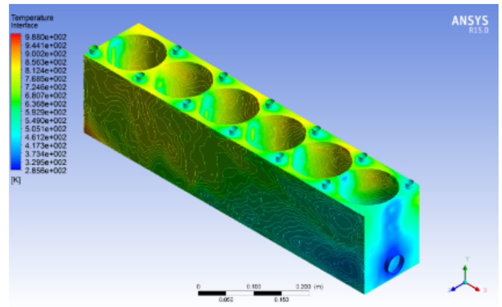


A: Original model (without ribs)

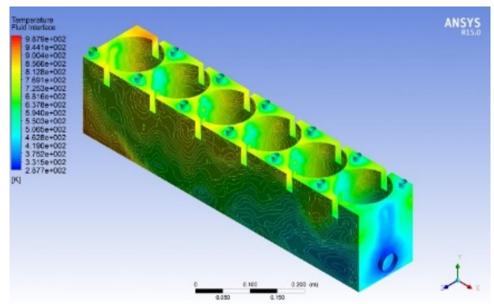


B: Proposed model(with ribs)

Fig 3.1: Isometric views: Outer block surface cooling pattern



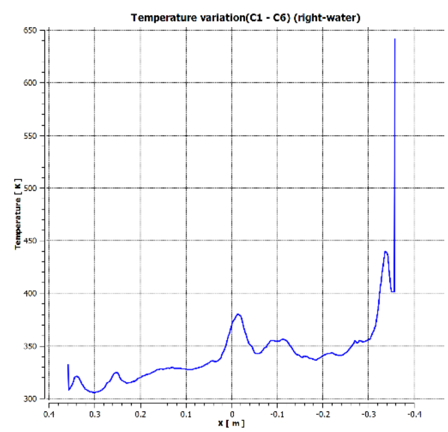
Model A: Original model (without ribs)



Model B: Proposed model (with ribs)

Fig 3.2: Isometric View: Interface cooling pattern(inner block surface)

B. Temperature variation



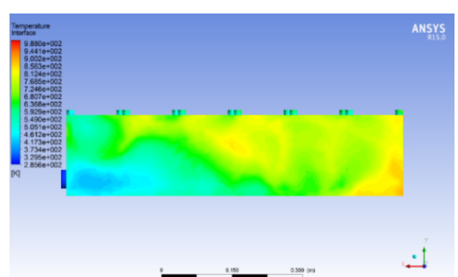


Fig 3.3: Temperature variation of water as we move from 1st to 6th cylinder(model A)

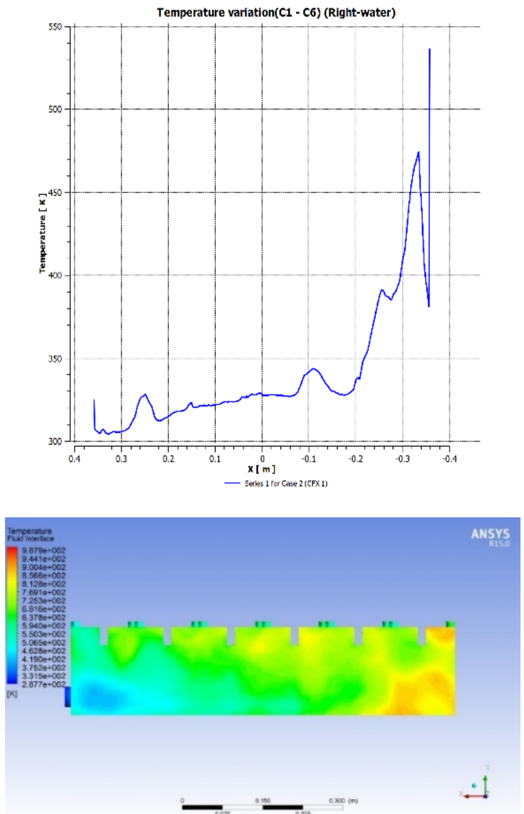


Fig 3.4: Temperature variation of water as we move from 1st to 6th cylinder(model B)

On the right side of the cylinders, there is a very similar temperature in both model A and B, except for a hype of temperature (380K) in between cylinder 3 and 4 in model A. When observation is made near the 6th cylinder, model A has a maximum temperature of 440K whereas model B has a temperature of 460K.Similar results were found at water on left hand side.

C. Turbulence Kinetic Energy Variation

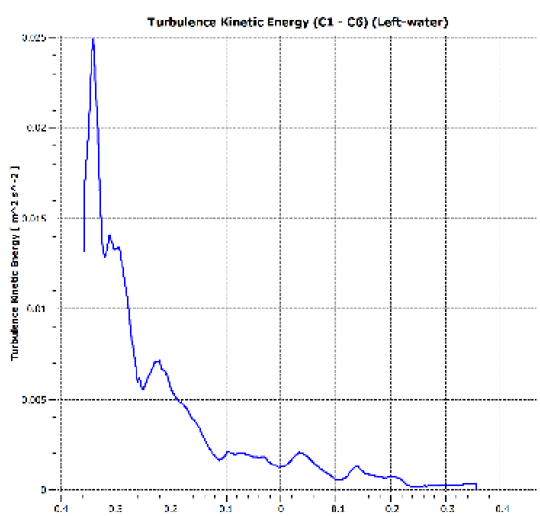


Fig 3.5: Turbulence kinetic energy in water in model A

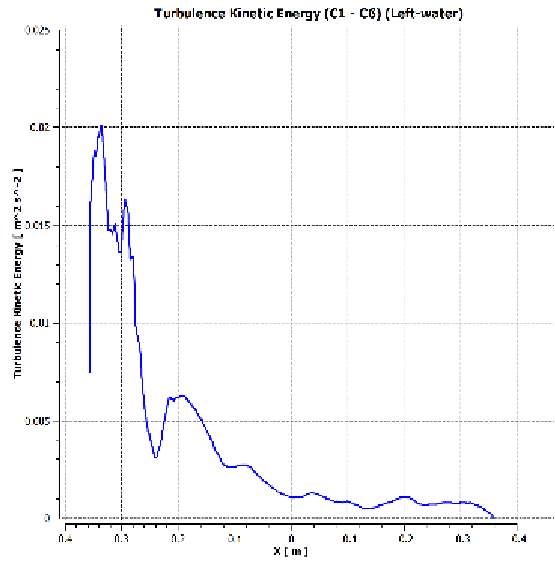


Fig 3.6: Turbulence kinetic energy in water in model B

On left side turbulence follows similar pattern in both models but maximum turbulence is actually higher in original model (model A), $0.025 m^2/s^2$ than in the model with ribs (model B), $0.02 m^2/s^2$.Similar results were found on right hand side.

D. Eddy Viscosity variation

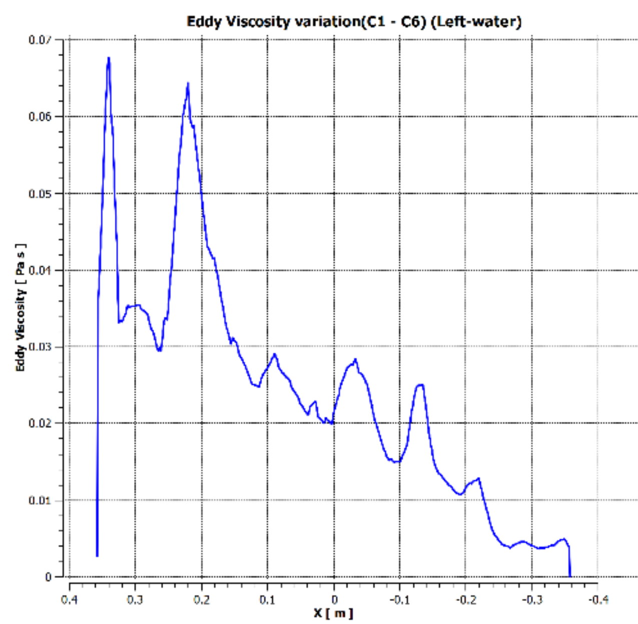


Fig 3.7: Eddy viscosity variation in water in model A (moving from cylinder 1 to cylinder 6).

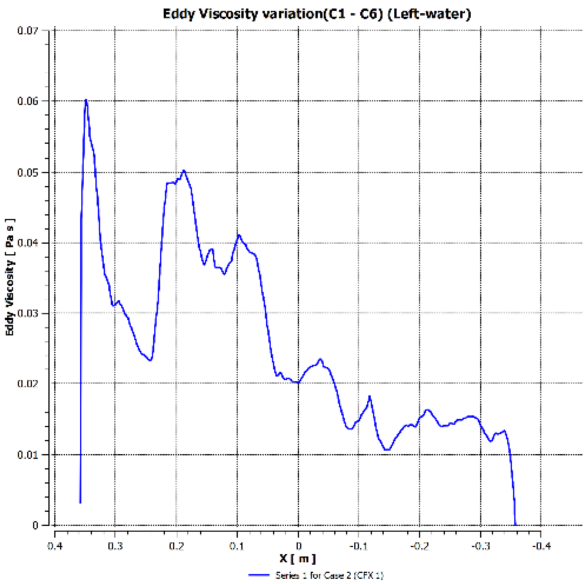


Fig 3.8: Eddy viscosity variation in water in model B (moving from cylinder 1 to cylinder 6)

We see a very similar variation of eddy viscosity in both the models, model A has a higher maximum viscosity os 0.068 Pas at inlet while model B has highest viscosity of 0.06. The difference is negligible.

E. Velocity Variation

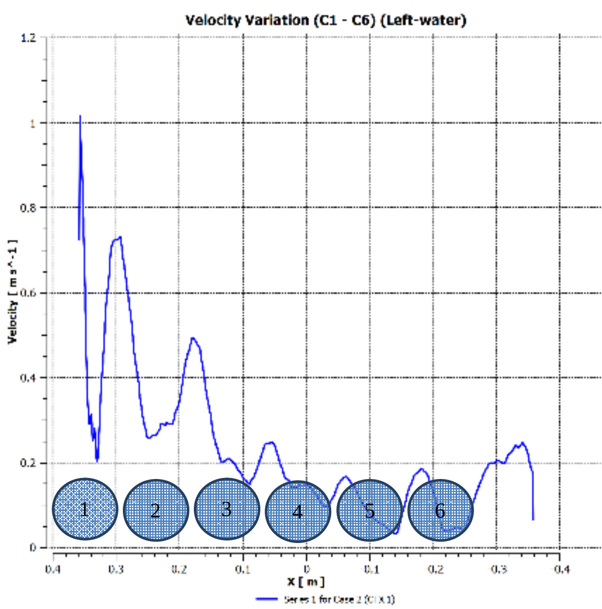


Fig 3.9: Velocity variation in water on left side of cylinders (moving from cylinder 1 to cylinder 6) of A

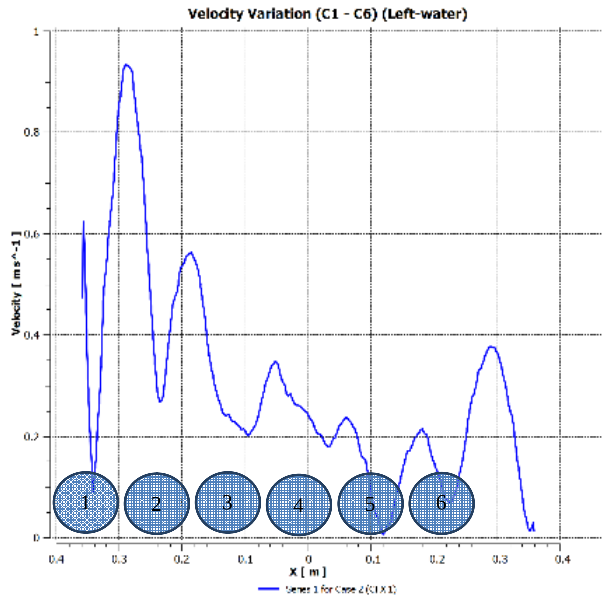


Fig 3.10: Velocity variation in water on left side of cylinders (moving from cylinder 1 to cylinder 6) of B

We observe that there are hypes in velocity near the centers of cylinders, this was expected as the area of flow will be minimum at these locations. Velocity variation pattern is similar in both the models with a slightly lower velocities near all the cylinders in model B except for cylinder 6,here velocity is 0.365m/s in model B and 0.24 m/s in model A.

F. Temperature variation Top wall

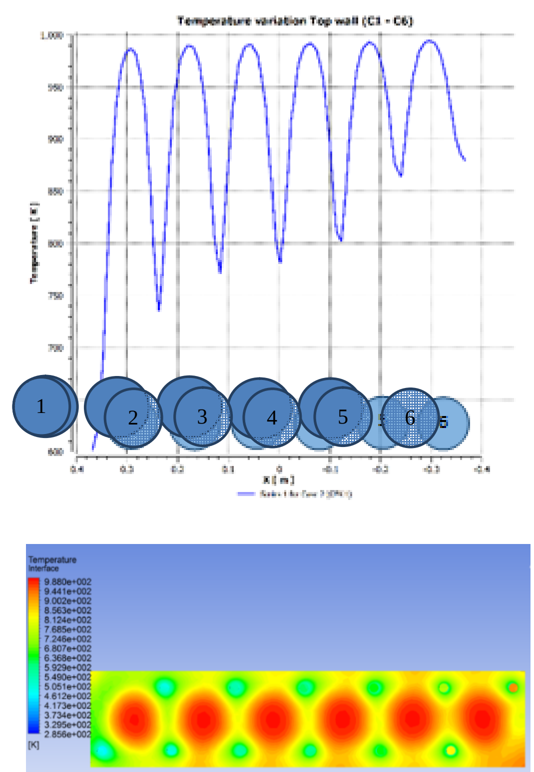


Fig 3.11: Temperature variation, top wall, model A

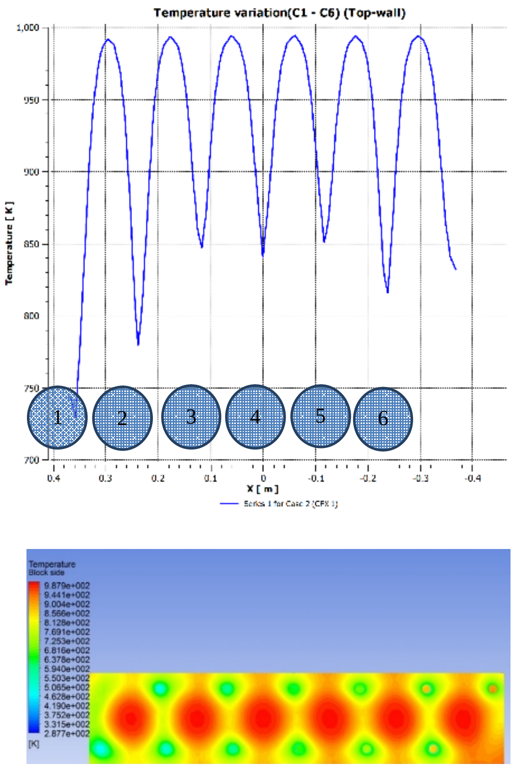


Fig 3.12: Temperature variation, top wall, model B

We observe that the pattern of temperature variation on the top wall is similar, but the amount of temperature drop is considerably larger in model A, here the temperature drops to up to 800K in inter cylinder regions and even up to 750 K at gap between cylinder 1 and cylinder 2, but in the inter cylinder gap between cylinders 5 and 6, we observe that the temperature drops only up to 860K. Now when temperature variation in model B is observed, we see that temperature drops only up to 850 K in between cylinders 2,3,4 and 5, but the drop is higher (to a temperature of 810K)in inter cylinder gap between cylinder 5 and 6 . So in model B, we get a better cooling of cylinder 6 and 5 but rest of the cylinders experience a 50K decrease in temperature drop if model B is used than if model A was used.

G. Temperature variation ribs- bottom

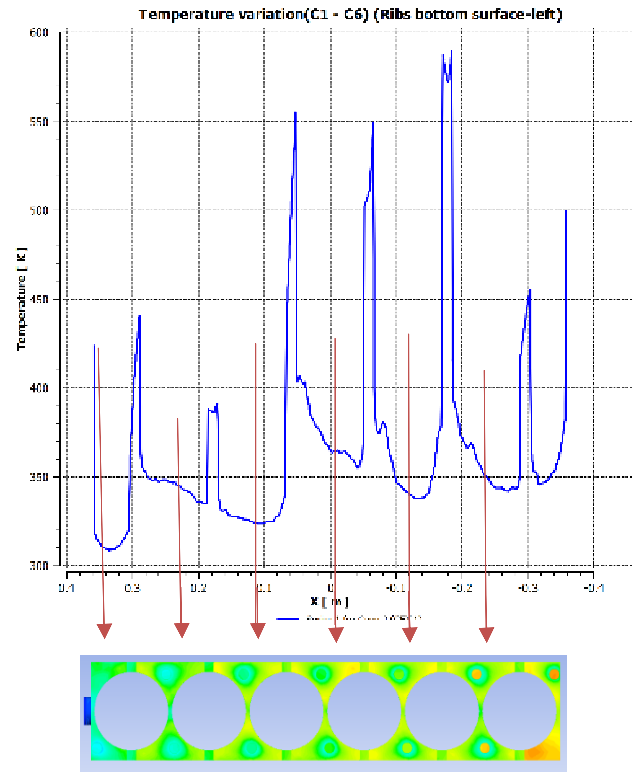


Fig 3.14: Temperature vaiation in model B in a line gazing bottom of the ribs (moving C1 to C6)

We observe that the maximum temperature reached at the bottom of ribs is 580K in model B. Ribs remain the coolest at cylinder 2 (390 K). 580 K temperature of ribs is still hoter than the water that would have been there if we had not used ribs.Fig 3.15 shows that if there were no ribs,at same location where there are ribs in model B. temperature is maximum 360K and minimum 310K.

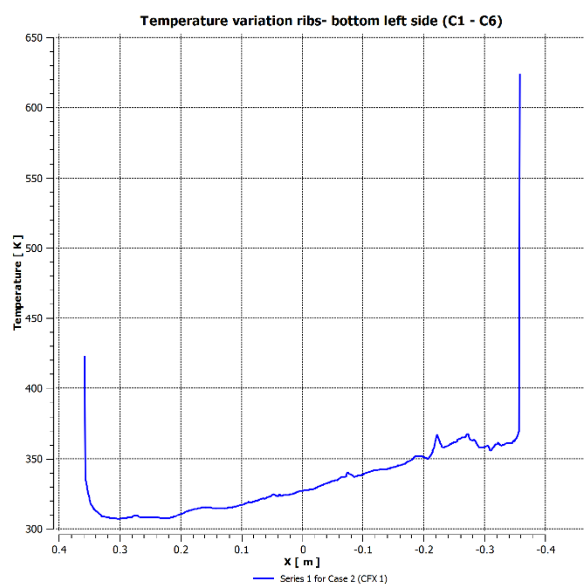
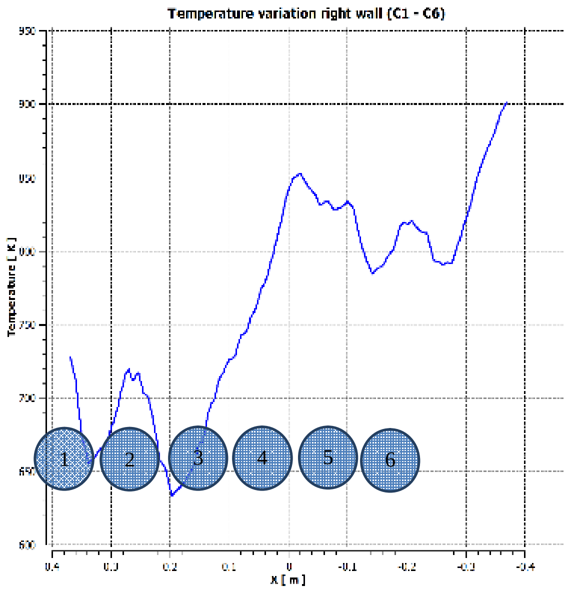


Fig 3.15: temperature variation of water in model A in locations where there are ribs in model B.

H. Temperature variation right wall



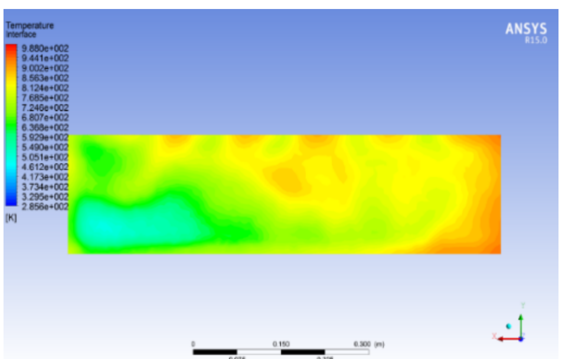
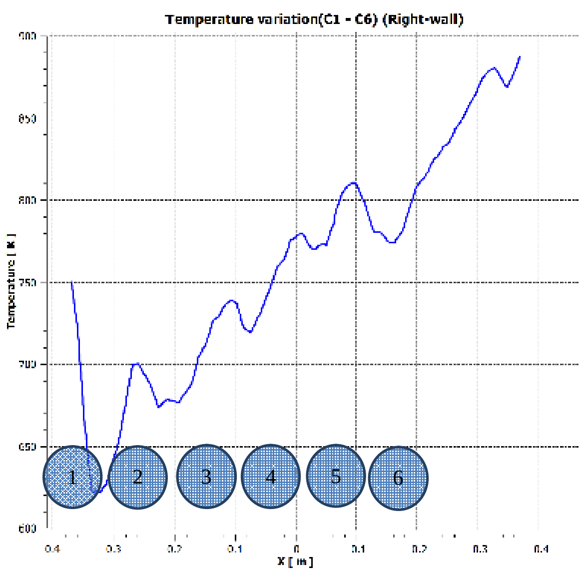


Fig 3.16: Temperature variation of side walls of model A



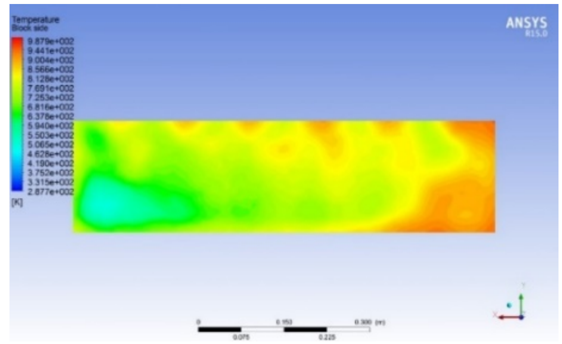


Fig 3.17: Temperature variation of side walls of model B

A very similar temperature variation is observed in right wall in both of the models. With a hype in temperature near cylinders 3 and 4 (850K) in model A. We observe that cooling is actually more uniform in model B and with similar temperature drops after 10 seconds. 6th cylinder in model A is cooled down to 825K after 10s of water flow through water jacket while 6th cylinder in model B is cooled only to 850K. 1st cylinder is also slightly less cooled in model A(720K) when compared to that in model B(700K). Thus it is observed that the cooling is similar in model B and even better for few cylinders

I. Cylinder outer wall

In this comparison, temperature along a line touching the outer surface of the 6 cylinders is compared in both the models at mid depth from the top, this will give us the actual idea of what temperature the cylinders in different cylinders are getting cooled down to in models A and B. The peaks in the graph represent the temperature of outer surface of cylinders 1 to 6 as X[m] increases.

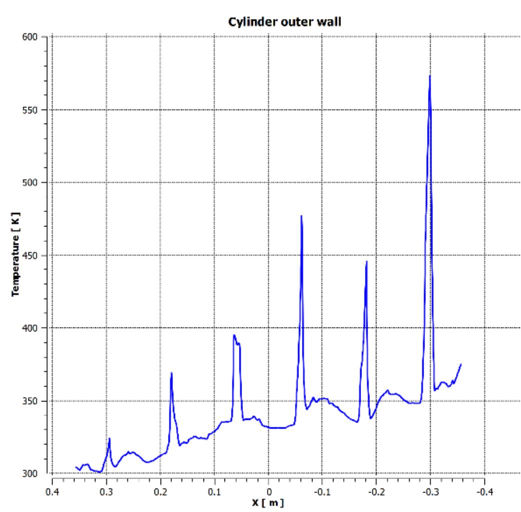


Fig 3.18: Cylinder outer wall temperature variation (model A)

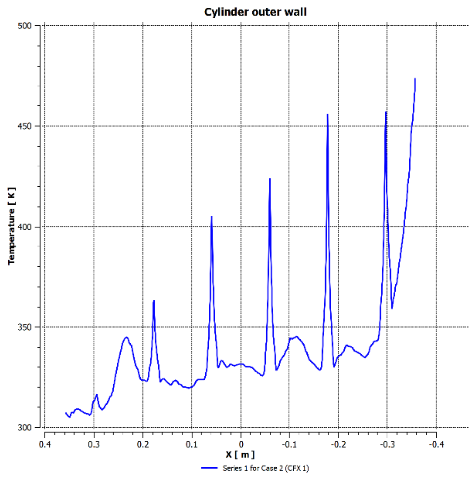


Fig 3.19: Cylinder outer wall temperature variation (model B)

Table 1: Comparison of temperatures of outer cylinder walls.

	Model A (temp. in K)	Model B *(temp. in K)*
1	320	320
2	360	360
3	390	410
4	475	420
5	445	460
6	570	460

It is observed that cylinder 6 actually has a much lower temperature in model B (a difference of 110 K), cylinder 4 is also at lower temperature in model B (55K), cylinders 1 and 2 have been cooled down to the same temperatures and cylinders 3 and 5 are 10K and 5K hotter respectively in model B. We see that overall, a better cooling was found in model B.

J. Cylinder inner wall

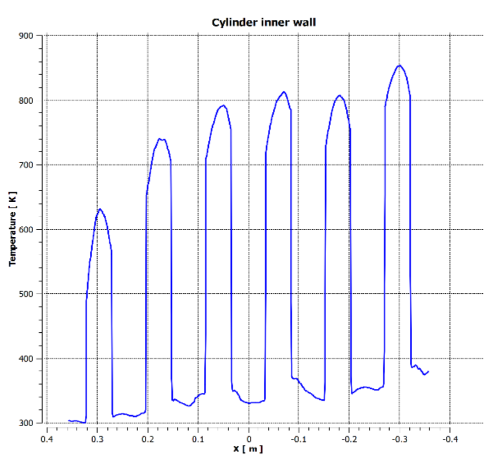


Fig 3.20: Cylinder inner wall temperature variation (model A)

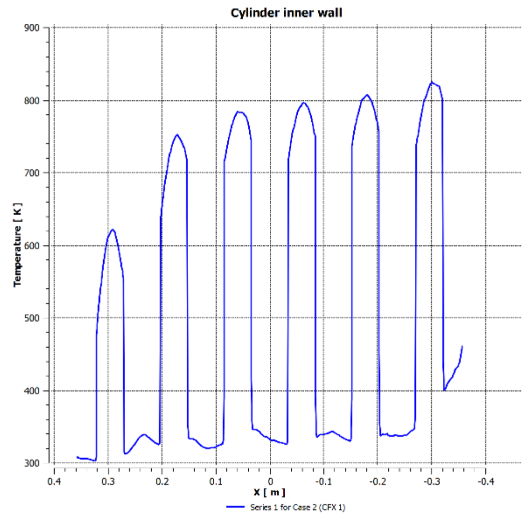


Fig 3.21: Cylinder inner wall temperature variation (model B)

It is found from Table 2 that the inner wall of all the cylinders are slightly better cooled in mode B. This will certainly lead to better engine performance and efficiency in model B.

Table 2: Comparison of temperatures of inner cylinder walls.

	Model A (temp. in K)	Model B *(temp. in K)*
1	630	620
2	740	740
3	790	780
4	820	795
5	810	810
6	840	820

K. Comparison of average values

Following average values have been calculated used CFX calculator.

Table 3: Comparison of average values

Average values	*Model A*	Model B
Velocity at inlet	2.62792 m/s	2.66111 m/s
Velocity at outlet	1.2491 m/s	1.31424 m/s
Temperature at inlet	298.715K	298.52
Temperature at outlet	370.022K	365.215K
Temperature at interface	495.583K	466.195K

Temperature at top surface	776.542K	786.508K
Temperature at side wall	737.782K	757.17K
Water temperature	388.188K	383.376K
Water jacket temperature	855.98K	845.55K
Turbulence kinetic energy	0.0038896 J/kg	0.0043522 J/kg
Velocity in water domain	0.50524 m/s	0.543396 m/s
Inner cylinder wall temperature	771.67K	760.83K
Outer cylinder wall temperature	426K	405K

It is observed that the average temperature drop is actually higher in model B except in the case of top and side walls. It should also be noted that average velocity at outlet is higher in case of model B.

IV. CONCLUSION

From the study of comparison of the cooling pattern and flow characteristics of the two models, we found a very similar results, in fact we found a better cooling of the cylinders in the proposed model. The only problem we found was that temperature drop near the combustion chamber is 50K less in the proposed model. This can be improved by increasing the mass flow rate of water at the inlet. The model with ribs will greatly reduce bore distortion and this will reduce the unnecessary engine oil consumption thus the research suggests that we should add ribs as in the case of model B.

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