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Enhancement Of Gas Turbine Blade Cooling Using Rib Turbulators

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Abstract: The use of the Rib Turbulators is an effective technique to enhance the rate of heat transfer to gas flow in the gas turbine blades. A number of geometric parameters have been investigated on the heat transfer flow characteristics and pressure drop of internal blade cooling of gas turbine blade. In this paper, both with and without ribs are analyzed using ANSYS Fluent and to find that how the geometrical parameters will enhance the heat transfer rate and pressure drop in a gas turbine internal blade cooling.

Keywords—Rib Turbulators, Heat Transfer, Turbulent Flow and Aspect Ratio.

1. Introduction

Gas turbines are used for aircraft propulsion and in land based power generation or industrial applications. Thermal efficiencies and power output of gas turbine increase with increasing turbine rotor inlet temperature. The Rotor Inlet Temperatures (RIT) in gas turbine are far higher than the melting point of the blade material, therefore turbine blades need to be cooled. There are two types for cooling turbine blades air cooling and liquid cooling. Air cooling is done by extracted air from compressor of the engine. Since this extraction causes a penalty to the thermal efficiency, it is to be understood and optimized the cooling technique, operating conditions and turbine blade geometry.

It is widely accepted that the life of a turbine blade can be reduced by half if the temperature prediction of the metal blade is off by only 30°C. In order to avoid premature failure, designers must accurately predict the local heat transfer coefficients and local airfoil metal temperatures. By preventing local hot spots, the life of the turbine blades and vanes will increase. However, due to the complex flow around the airfoils it is difficult for designers to accurately predict the metal temperature. Figure 1 shows the heat flux distribution around an inlet guide vane and a rotor blade. At the leading edge of the vane, the heat transfer coefficients are very high, and as the flow splits and travels along the vane, the heat flux decreases. Along the suction side of the vane, the flow transitions from laminar to turbulent, and the heat transfer coefficients increase. As the flow accelerates along the pressure surface, the heat transfer coefficients also increase. The trends are similar for the turbine blade. The heat flux at the leading edge is very high and continues decrease as the flow travels along the blade; on the suction surface, the flow transitions from laminar to turbulent, and the heat flux sharply increases; the heat transfer on the pressure surface increases as the flow accelerates around the blade.

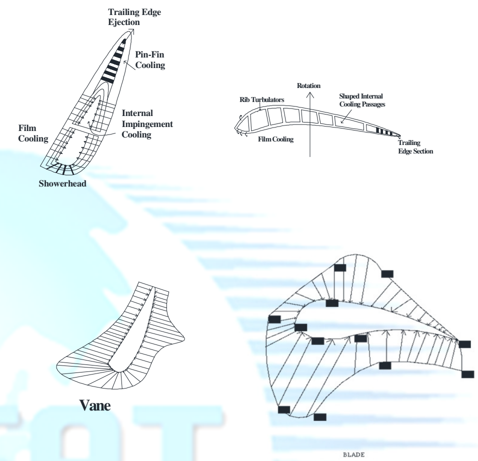
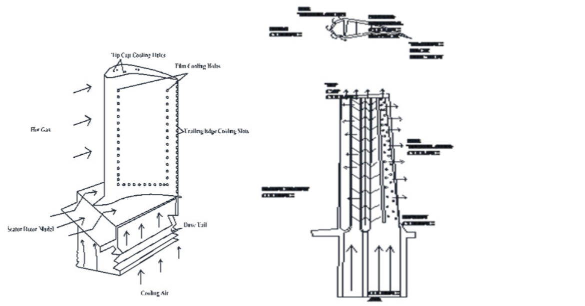


Fig.1.Cross-Sectional View and Heat Flux Distribution of a Cooled vane and blade.

During engine cooling, the maximum blade surface temperature and temperature gradients during operation are compatible with the maximum blade thermal stresses for the life of the blade. The engine cooling system must be designed to minimize the use of compressor blade air for cooling purposes to achieve maximum benefits of the high inlet gas temperature.

At present there are three methods employed for internal blade cooling. The first method is a jet impingement cooling technique, applied in the leading edge region of the rotor blade. The second method is pin-fin cooling technique applied in the blade trailing edge regions. It is found that to remove heat from leading and trailing edges is not much difficult than to remove heat at the Centre. There the middle portion of blade is cooled by serpentine rib roughened cooling passages which means repeated rib turbulence promoters. The Figure 2 shows the different cooling methods used in turbine blades to increase the heat transfer at the center. There have been many fundamental studies to understand the heat transfer phenomena by the flow separation caused by the ribs. In general ribs used for experimental studies are square in cross section with a typical relative rib height of 5-10% and p/e ratio i.e. pitch to height ratio varying from 7to15. Specific configurations that characterize a ribbed channel includes geometrical features like rib height, pitch and angle of attack.



a. Internal cooling   b. Cooling using rib turbulators

Fig.2 Cooling Methods

1. Rectangular Duct without Ribs

A rectangular duct without ribs has been analyzed using ANSYS Fluent to find out the heat transfer rate through convection. Where the model has been kept at certain temperature of 1200K and inlet velocity and temperature of air is given as 10m/s and 360K.

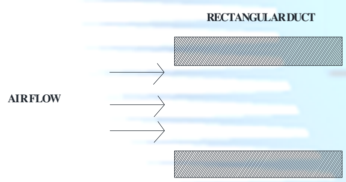


Fig.3 Rectangular Duct

1.1. Geometry and Preprocessing

A model of rectangular duct has been modeled in CATIA and to analyze the streamline flow pattern as well as to compute the results the model has been imported to ANSYS Fluent as shown in Fig. 4.

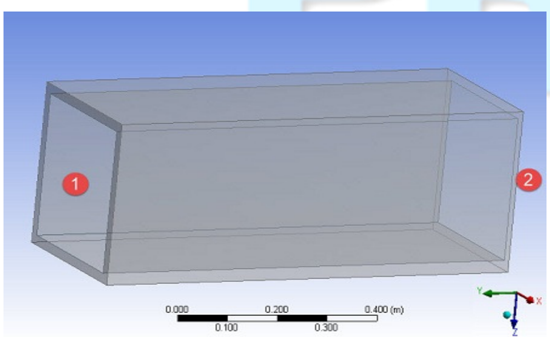


Fig.4 Geometry

2. Results and Discussion

2.1Flow inside the Rectangular Duct

Since the inlet condition is kept as 10 m/s the duct is analyzed for stream line flow pattern as well as vortices pattern and both are shown in Fig 5 & 6. below.

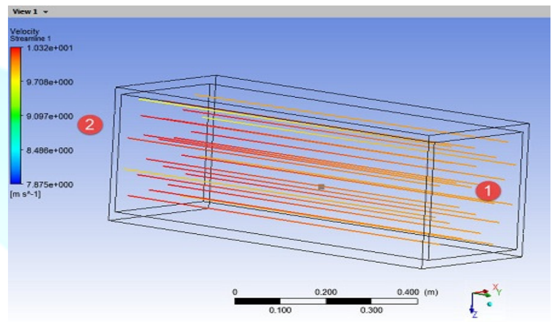


Fig.5 Streamline Pattern

From the figure of stream line pattern it is found that the flow remains steady throughout the flow along the duct. As well as the vortices produced in the duct as shown below have very less effect towards heat transfer.

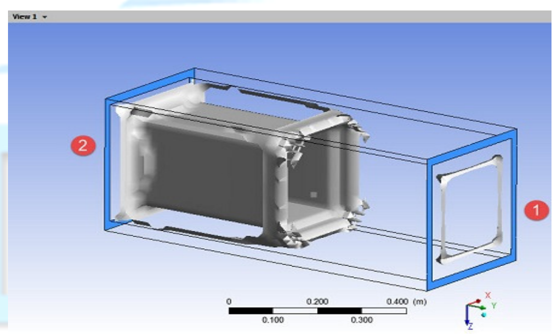


Fig.6 Vorticity Pattern

3. Pressure Contour

To find the variation of pressure inside the duct, it has been analyzed for pressure variation and the pressure contour for the duct is shown in Fig.7. It has been clearly shown that the pressure has been gradually increasing along the length of the duct.

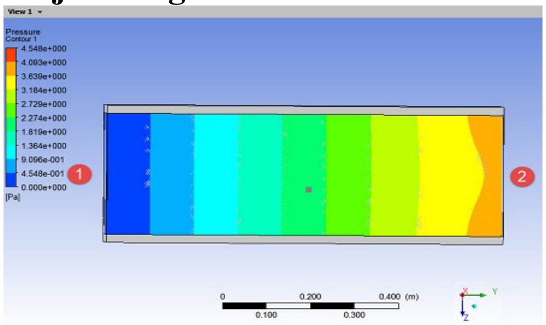


Fig.7 Pressure Contour

4. Temperature contour

Since the objective is to analyze the variation of heat transfer before and after the duct, as mentioned previously the duct has been kept at wall temperature of 1200K, and inlet velocity and temperature of air is 10 m/s and 360K respectively.

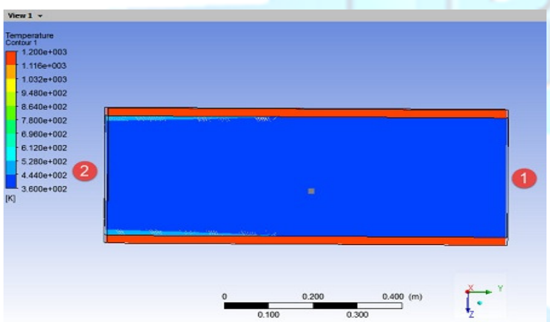


Fig.8 Temperature contour across the duct

After analyzing it has been found that the outlet temperature of air has increased to 410K i.e. giving a temperature gradient of 50K.The results are shown in the following Fig.9 below.

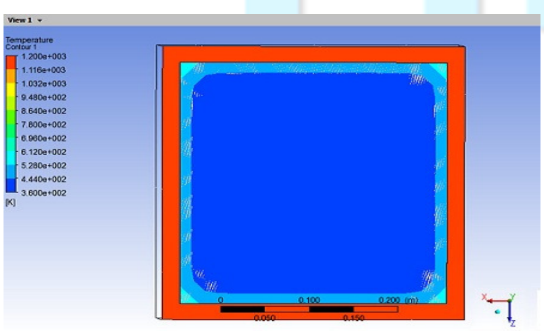


Fig.9 Temperature contour outlet

5. Plot

A graph has been plotted between temperature vs. time, which shows a steady increase in temperature across the duct

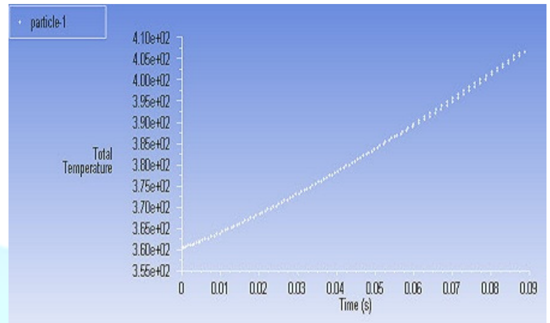


Fig.10 Plot of Temperature vs Time

4. Surface Heat Transfer Coefficient

On analyzing the surface heat transfer coefficient it has been found that there is a linear increase in heat transfer coefficient across the duct which is shown in Fig below ant value of heat transfer coefficient is of 37 W/m^{2}K

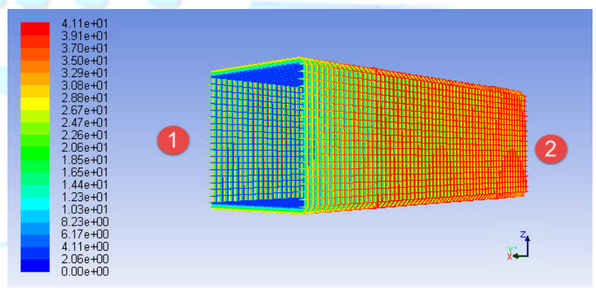


Fig.11 Surface heat transfer coefficient

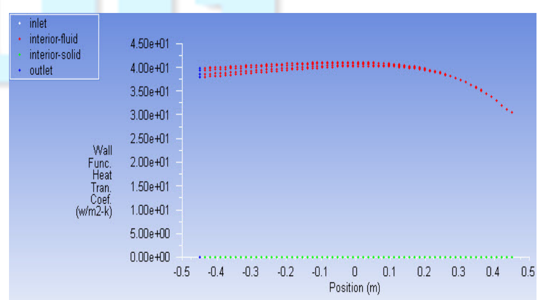


Fig.11.1 Variation of surface heat transfer along the duct

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5. Nusselt number

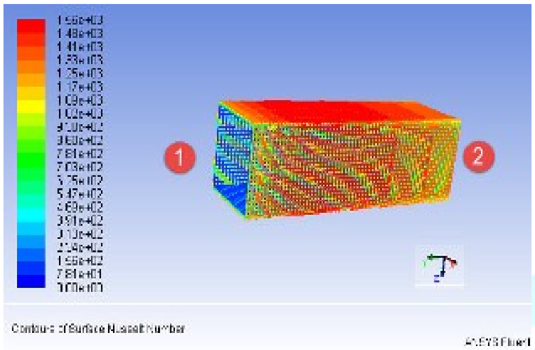


Fig.12 Nusselt number across the duct

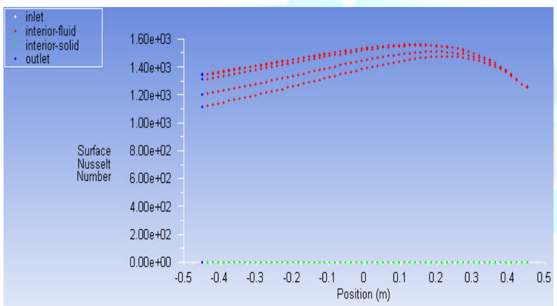


Fig.12.1 Variation of Nusselt number across the duct

6. Reynolds number

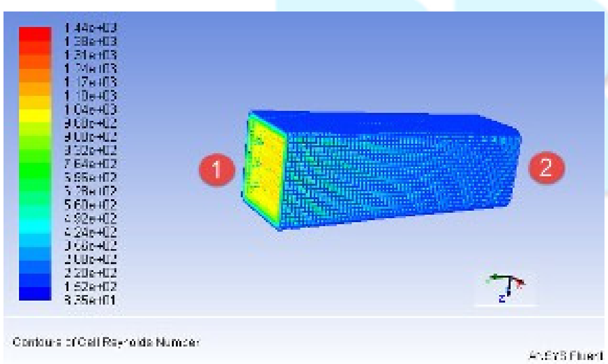


Fig.13 Reynolds number across the duct

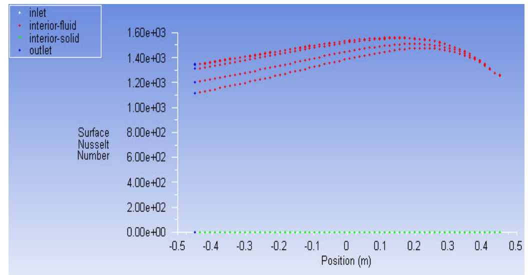


Fig.13.1 Variation of Reynolds number along the ribs

7. Arrangement of Transverse ribs

The Fig.14 shows a schematic of the flow pass on surface mounted ribs which indicates that a boundary layer separates upstream and downstream of the ribs.

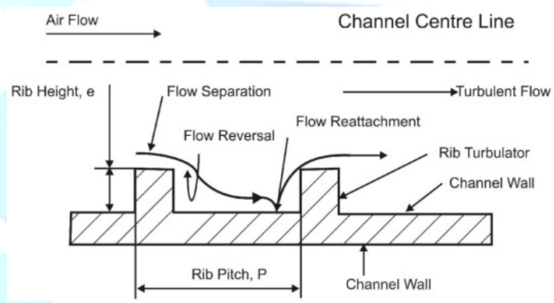


Fig.14 Transverse Ribs

By providing transverse ribs the heat transfer surface increasing the heat transfer coefficient. Ribs mostly disturb only the near wall flow and consequently the pressure drop penalty by ribs which are acceptable for blade cooling designs.

8. Arrangement of ribs

The high heat transfer coefficient is achieved by creating turbulent flow using ribs. The protruding ribs resulting in the formation of separated zones in the flow field, yielding substantially higher friction factors. Ribs are arranged inline.

9. Geometry and Preprocessing

A model has been modeled with a rectangular duct with four rectangular ribs of pitch to height ratio of ribs of 7 to 15. The model is done in CATIA. Then to analyze the streamline pattern of the model we have imported the model to ANSYS Fluent as shown in Fig.15.

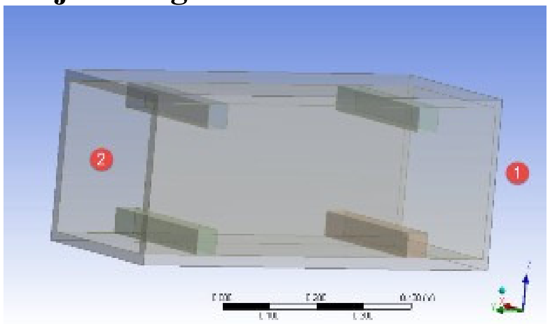


Fig.15 Geometry of rectangular ribs

10. Results and discussion

10.1 Flow over rectangular ribs

The inlet conditions as 10 m/s and we got a streamlines as well as vortices pattern as shown in Fig 16. and Fig.17. below. From the stream line pattern and vortices pattern it has been found that velocity is not steady across the duct as well as in the vortices pattern it produces strong vortices which shows the maximum possibility of increase in heat transfer.

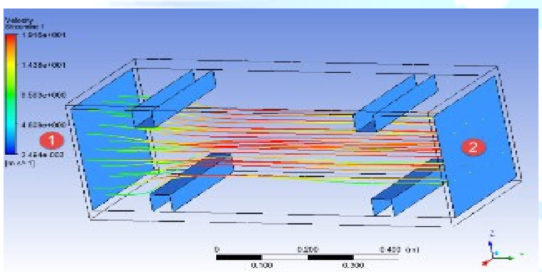


Fig.16.Streamline pattern over rectangular ribs

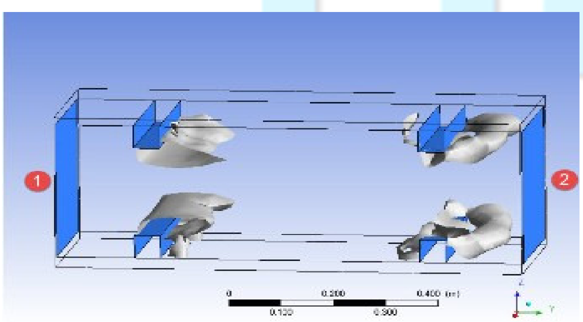


Fig.17 Vorticity pattern over ribs

11. Pressure contour

From the Fig.18 it is understood that pressure decreases gradually across the duct from 168.6N/m^2 to 28.12N/m^2.

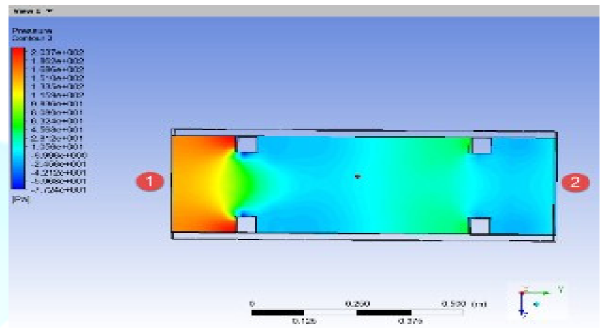


Fig.18 Pressure Contour across ribs

12. Scaled Residuals

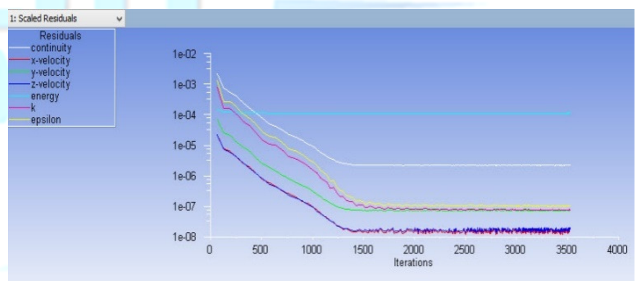
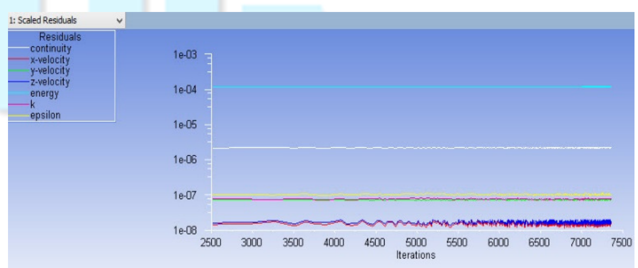


Fig.19.1 Scaled residuals



Fig,.19.2 Scaled residuals

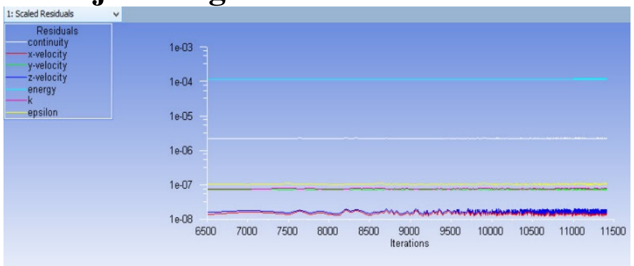


Fig.19.3 Scaled residuals

The Fig.19.1, 19.2, 19.3 are the Scaled residuals from ANSYS Fluent, which shows the convergence result of the Rib Turbulators.

Since the objective is to analyze how heat transfer increases before and after the duct. For that we have to keep the material at certain temperature condition of 1200K i.e. Turbine Inlet Temperature (TIT) and an inlet velocity of 10 m/s and inlet temperature of air is kept at 360K. After analyzing we have got a result of increase in the outlet temperature of 535.059K which is shown with the help of graph plotted temperature vs. time as shown in Fig.20. It clearly shows that the temperature difference of heat transfer has taken up to over 175.059K. Then, the internal surface of the turbine is reduced to 1090K, which is about 110K of the Turbine Inlet Temperature (TIT). Thus an increase in the heat transfer up to appreciable amount of temperature is achieved.

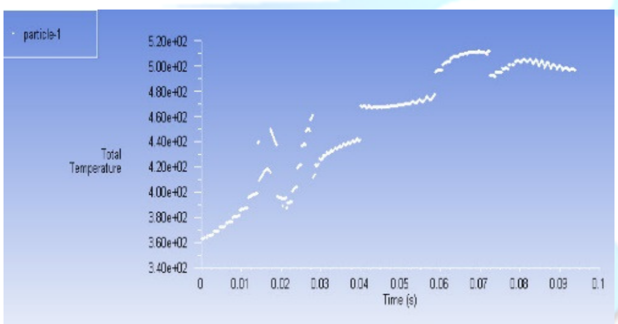


Fig.20 Graph shown Temperature vs. Time

15. Surface heat transfer coefficient

The surface heat transfer coefficient across the duct is found to be 48.4W/m^{2}K.

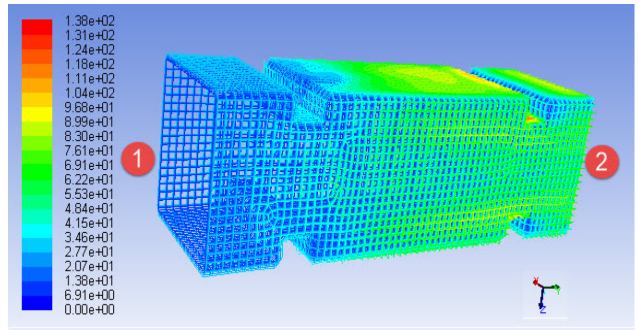


Fig.21 Variation of surface heat transfer

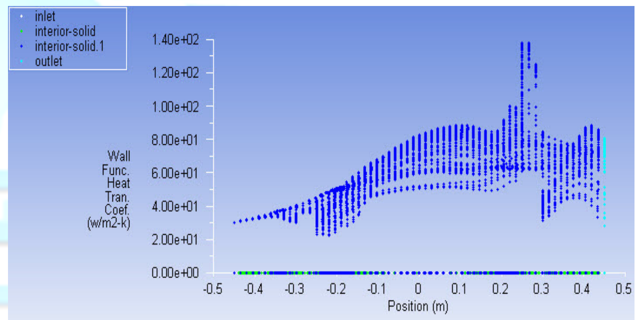


Fig.21.1 Variation of surface heat transfer across the duct

13. Nusselt number

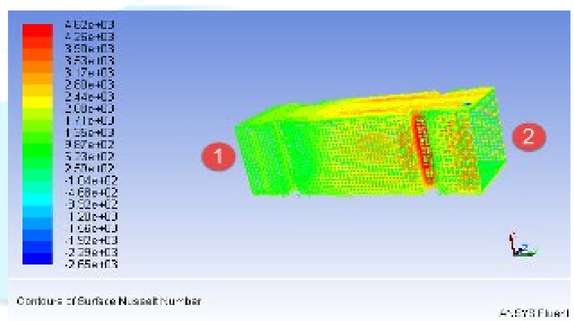


Fig.22 Nusselt number across the ribs

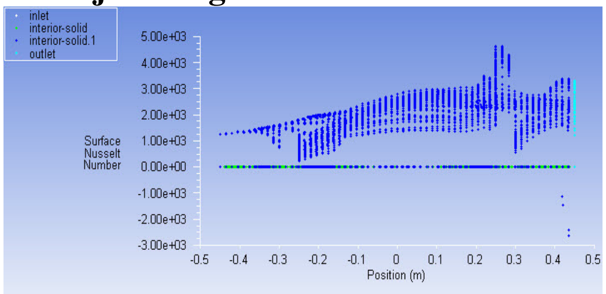


Fig.22.1 Nusselt number across the ribs

14. Reynolds number

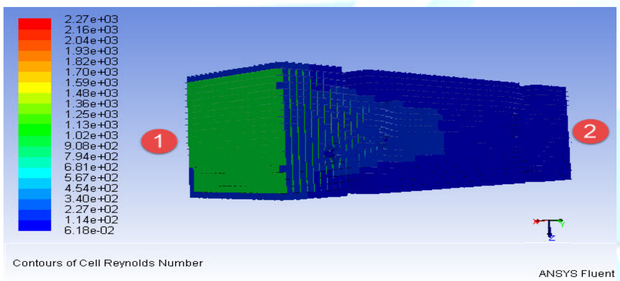


Fig.23 Reynolds number across the duct

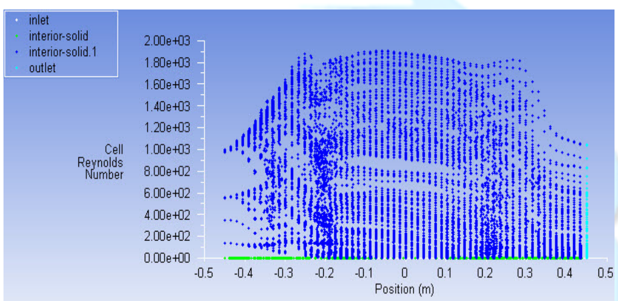


Fig.23.1 Reynolds number variation across the duct

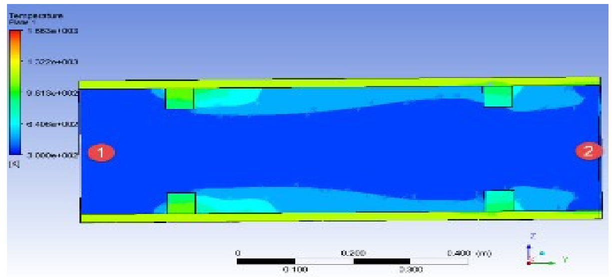


Fig.24 Temperature contour across the ribs

The Fig.24 shows the increase in temperature from 360K to 535.059K across the ribs and the turbine blade temperature has been reduced from 1200K to 1090K.

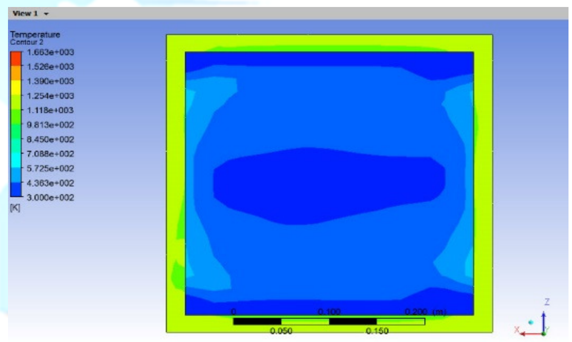


Fig.25 Outlet temperature variation

The Fig.25. shows the outlet temperature variation. The outlet temperature of the inlet air is found to be increased due to the ribs.

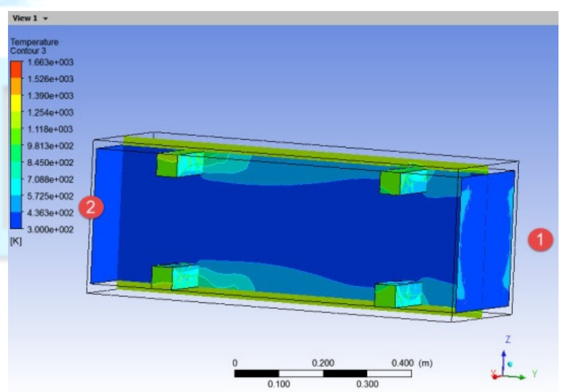


Fig.26 Overall temperature variation

The Fig.26. shows the overall temperature variation at the mid-chord region due to the introduction of ribs.

16. Conclusion

It is observed that the heat transfer rate is higher in case of the blade with ribs attached than that of without ribs. The effectiveness of using ribs for heat transfer for turbine blade is established by computational analysis using ANSYS Fluent and the various parameters such as heat transfer coefficient; Nusselt number, Reynolds number, and Temperature and pressure distribution have been compared for the case with ribs and without ribs. However the effect of different shapes, orientation and pitch of the ribs used can be analyzed further.

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