

Optimization of Gas Turbine Blade Cooling System

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Abstract:

In Aerospace Industry, Gas Turbine makes their roles very essential, significant for power generation, thermal efficiency, etc. Mainly it has been using for power generating and propulsion. The turbine inlet temperatures are very large extent and it fully based on performance and efficiency of gas turbine engine. The temperature of the combustion and fuel efficiency are bounded by heat transfer properties in the turbine blade. On account of that increase in hot gas temperature of a blade component at high pressure by the use of effective cooling method is too tedious to prevent the blade deformation, to increase the turbine inlet temperature and also increase the heat transferred to the blade, and holds an advantage on operating a temperature of the metal that would be able to cross the permissible temperature. In such case, the cooling efficient of turbine blade is insufficient so, the excessive thermal stress occur on the turbine blade it may be hazard to engine safe operations. Construction of cooling system in blades is the most important Process to increase Turbine Entry Temperature (TET), which induce the thrust of the engine. The Proposed methods for cooling the blades works with Impingement Cooling, Ribs Passages And Micro Pin Fin Cooling System . This cooling system will enhance the heat transfer with reduction of structural damage. Cooling air extracted from the compressor at 850K and Turbine Entry Temperature may be up to 1700K, flow in and around the turbine blades. This Paper mainly focusing on the internal and external cooling of blades without affecting the structure. Internal Cooling system is made by constructing the passage and external cooling are achieved by using film cooling. These are very essential for enhancing the heat transfer and pressure drop. Designing of the 3D Blades are developed using CATIA and analyzed using ANSYS.

Keywords: Turbine Entry Temperature (TET), CATIA, ANSYS, Gas Turbine, Cooling System.

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I. INTRODUCTION

Nowadays, the gas turbine plays a many role in generation of power, propulsion in aircraft and industrial application. The gas turbine is most powerful power plants, which generates large amount of energy for its weight to size ratio. It is compact, low weight and it is used as a various fuel application. By increasing TET which causes increase in performance and turbine output power. It is clear that, Brayton cycle states that to increase the efficiency of gas turbines with varying the pressure ratio and along with raise the temperature of the turbine. Most overall efficiency can improve by improving the pressure ratio at a certain temperature. Moreover, increase the pressure may causes certain ignition temperature can face the result in decreasing the full cycle efficiency. As the Turbine Temperature is high, the raising temperature transferred to gas turbine blades which also increase. The deviation in the heat encircling by the turbine blade substance should be imperfect to achieve feasible toughness targets. Additionally the heats are far away from the limited metal hotness because of such condition there is a need to cool down the component and operated in a protected condition. Consequently, the improvement of high temperature materials a complex cooling method ought to be improved by HP stage turbine blade for constant and safe functioning with higher efficiency.

II. OBJECTIVE OF THE WORK

- Altering the existing cooling system to increase the cooling effectiveness.
- Design and Analyzing the altered cooling system in order to boost heat transfer in the interior part
- Comparing the effectiveness with already existing system.

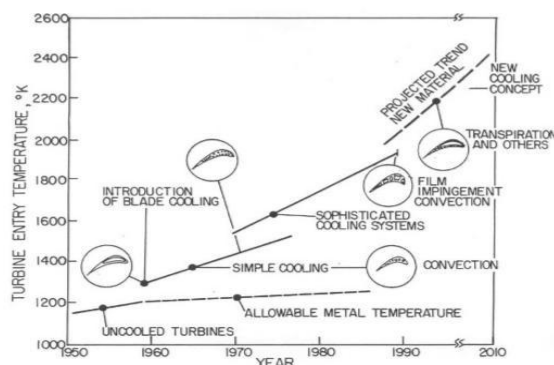


Fig 2.1 Turbine Inlet Temperature (Rolls Royce)

III. PROBLEM STATEMENT AND ASSUMPTION

Based on the timeline of design improvements, It is clear that the research and development work, mainly focused on the material optimization and cooling techniques without affecting the actual structural strength.

When compare to Material selection, Cooling systems in Turbine blades plays a prominent role in controlling the critical temperature and structural deformation due to thermal stress.

As a part, the project work solely deals with their modification of turbine cooling system for an improved efficiency.

IV. COOLING TECHNIQUES

The environmental consciousness is grown and fuel costs become too high. Lately, they attempt strongly towards the improved performances for each and every automobile applications and Especially propulsion in aircraft applications, when compared to gas turbine, fuel consumptions plays a major role and also concentrate on the particular work in the result. The previous work is parallel to the inverse of the performance while it takes a time to measure the correct density of the turbine. Last decennium, particularly in stressed atmosphere the odd materials area unit worn, and that unit area is nay able to survive the demanded temperature with lacking of yielding to the cruel atmosphere. High strengthens material like cobalt and nickel alloys are become frail when the heat raises, and suppose the loads in a gyrate turbine are extremely high, and it may cause to fail the overall turbine structures, so necessary to taken the measure to avoid such failures.

V. INRODUCTION TO CATIA

The turbine blade is designed by using CATIA V5 software. The rotor plane is designed along with the shape by reference points. The key points are joined by connecting the spine curves to get a smooth curve. Then the smooth curve is converted into region and then volume was Constructed by extrusion. And also, the hub is developed similarly. These parallel volumes are merged and converted into single volume. The airfoil blade points are get from the NACA airfoil series. Then blade points are bringing in the EXEL sheet and to form coordinates X, Y and Z. These coordinates are import to the CATIA software.

VI. COMPUTATIONAL FLUID DYNAMICS

The proposed systems are completed by using ANSYS and CATIA software and for mesh generation and node collection. ANSYS 18.1 is used to design and analysis the structural modules; for the analyze of the rotor blade. Now, the rotational blades were totally checked for distribution of heat flow over the blades with different shape of mode. Then blade is checked repeatedly with thermal and structural analysis.

VII. MATERIAL SELECTION

The turbine blade material is high strength, to resist the heat gas and also withstands the oppressive temperature and the properties of the materials does not change. Those all parameters are considered. I had considered INCONAL 718 material.

VIII. RIB TURBULATED COOLING

The rib turbulence supporters are normally holding on the cooling passageways with two opposing walls. Commonly rib turbulated are technique to develop the heat transfer in the interior swivel cooling. Heat transfers from the pressure and suction surfaces to the blade walls, where it is converted into the cool turbine moving within the blade. The ribbed canal's ability to transmit heat is determined by the rib configurations,

channel aspect ratio, and Reynolds is a coolant flow. Many simple studies had been conducted in order to determine the cooling passage through a static rib system.

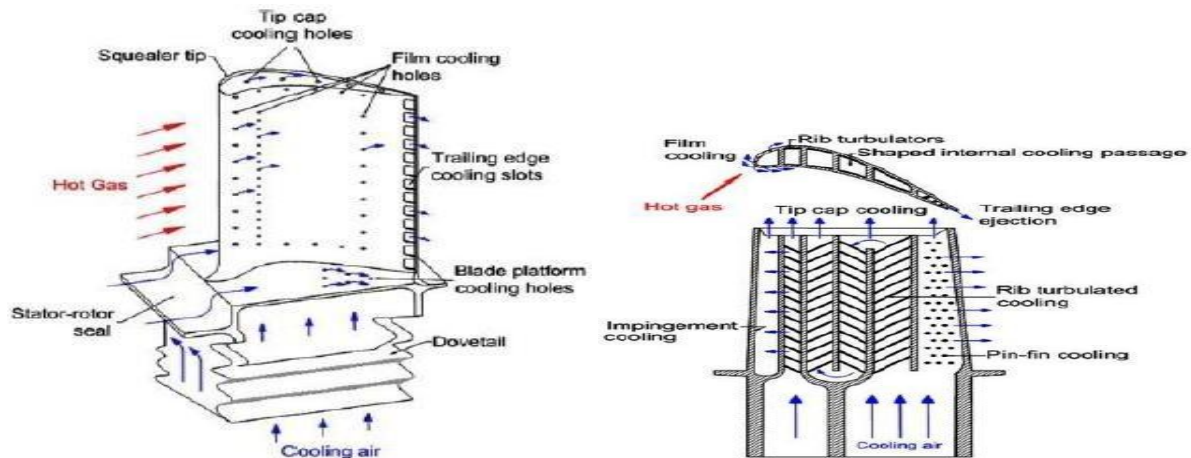


Fig 8.2 Rib Turbulated and Serpentine rib roughened cooling system

8.1 SERPENTINE RIB ROUGHENED COOLING SYSTEM

The temperature sent to the turbine blade increases as the temperature in the turbine blade rises. To achieve rational toughness targets, the variation and degree of heat inside the blade material, which causes thermal stresses, should be limited. The working temperatures are far higher than the metal's sufferable temperature. As a result, the cooling of blade is critical for a safe and stable operation. The engine turbine's compressor extracts and cools the air flowing through the turbine. Since this mining activity has an impact on the engine's output power and thermal efficiency, it's critical to locate and fix the cooling tools for specific turbine blades while the locomotive is in service. Turbine cooling is a long-lasting process that distinguishes locomotive brands. Aircraft impingement with film cooling is the primary edge, while serpentine rib-roughened passages with minimal film cooling freezes in the core portion, and pin fins with trailing edging insertion cools the rambling boundary.

8.1.1 SERPENTINE RIB ROUGHENED COOLING SYSTEM WITH PIN FINS ARRANGEMENTS

The serpentine rib roughened cooling system with pin fins idea are used to construct more capable to cooling the rotor blade materials which is assess with the serpentine rib roughened cooling system. The pin fins are worn to create additional turbulence in the middle section of the turbine blade. The 3D and 2D model were designed by CATIA V5 software.

IX. EXPERIMENTAL PROCEEDINGS

9.1 2D RIB TURBULATOR

Rib turbulator is one of the system using regularly to increase the heat transfer internally. These are positioned in the wall passages by opposite direction with some gap for flow. Changes of heat transfer depends on rib configuration, channel aspect ratio and Reynolds number for the flow. History says, the ribs are designed at the angle of 90° to increase the heat transfer, later angles are reduced to 45° to increase heat transfer. While placing the Ribs at 90°, reattachment helps to increase the heat transfer.

9.1.1 GEOMETRIC MODEL

2D turbulator is designed by using the ANSYS Geometry. At the angle of 45°, the design have been done and size of flow passage have reduced by increasing the area, it helps to reduce the boundary layer errors with enhancing heat transfer.

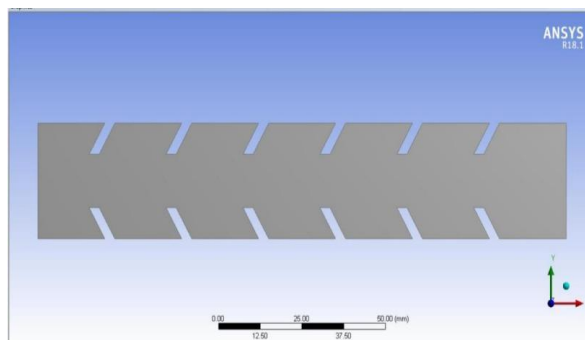


Fig 9.1.1.1 2D Rib turbulator

9.1.2 MESH GENERATION

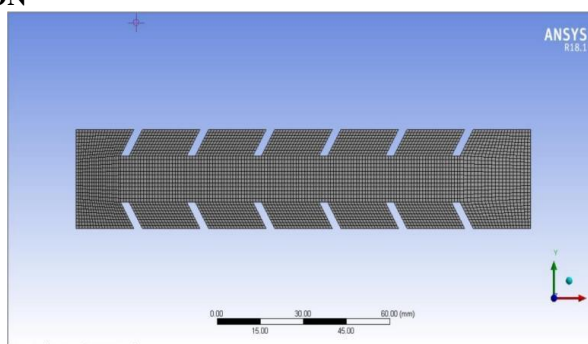


Fig 9.1.2.1 Meshing of 2D turbulator

9.1.3 FLOW SIMULATION BOUNDARY CONDITIONS

Solver type as Pressure-based and Velocity Formulation as absolute with Transient Time, change the viscous flow as laminar to SST k-omega (Model –k-omega and model constants) k-omega model to SST for better results. Material, Fluid as air (Material type- fluid, Fluent Fluid Material- air) and solid as INCONEL 718

- Thermal Properties of air
- Density- 0.54 kg/m³
- Viscosity-1.7894 kg/m-s
- Thermal properties of blade material.
- Density -8180 kg/m³
- Specific heat -446 J/kg C
- Thermal conductivity - 11.5 W/m C

To change the fluid use the fluid database and select Cell zone condition as airfoil Boundary condition, changing the inlet to velocity-inlet for flow field. Before changing inlet, change the Dynamic mesh for flow field conversion. Temperature as 1200K. Outlet as mass flow outlet. Reference values, Values are selected for flow purpose in steady flow and transient time.

Values are

- Density-0.54 kg/m³
- Length- 4 mm
- Temperature- 1200K
- Velocity- 240 m/s
- Viscosity- 1.7894e-0

Solution Methods, Scheme should be as SIMPLE Spatial Discretization

Gradient –Least Squares cell based

Pressure –Second order

Momentum –Second order upwind

o Turbulent kinetic Energy –Second Order upwind

o Specific Dissipation –Second Order Implicit

Steps are used for Pressure-velocity Coupling Solution Initialization and Calculation Activities

Set the values for the auto save every as zero for Calculation activities. Also set the Standard solution Initialization, reference frames as relative to cell zone and initialize the value for Gauge pressure, X-velocity, Y-

velocity, Z-velocity, Turbulent Kinetic energy and specific dissipation rate. These are used for setting the output in constant line. The Calculated values are displayed by using of graph. With the help of graph, get the values of x-velocity, y-velocity, z-velocity, kappa, omega, by running the solution and setup values. For getting the values of pressure, velocity, turbulent kinetic energy etc.

9.1.4 RESULTS AND DISCUSSION

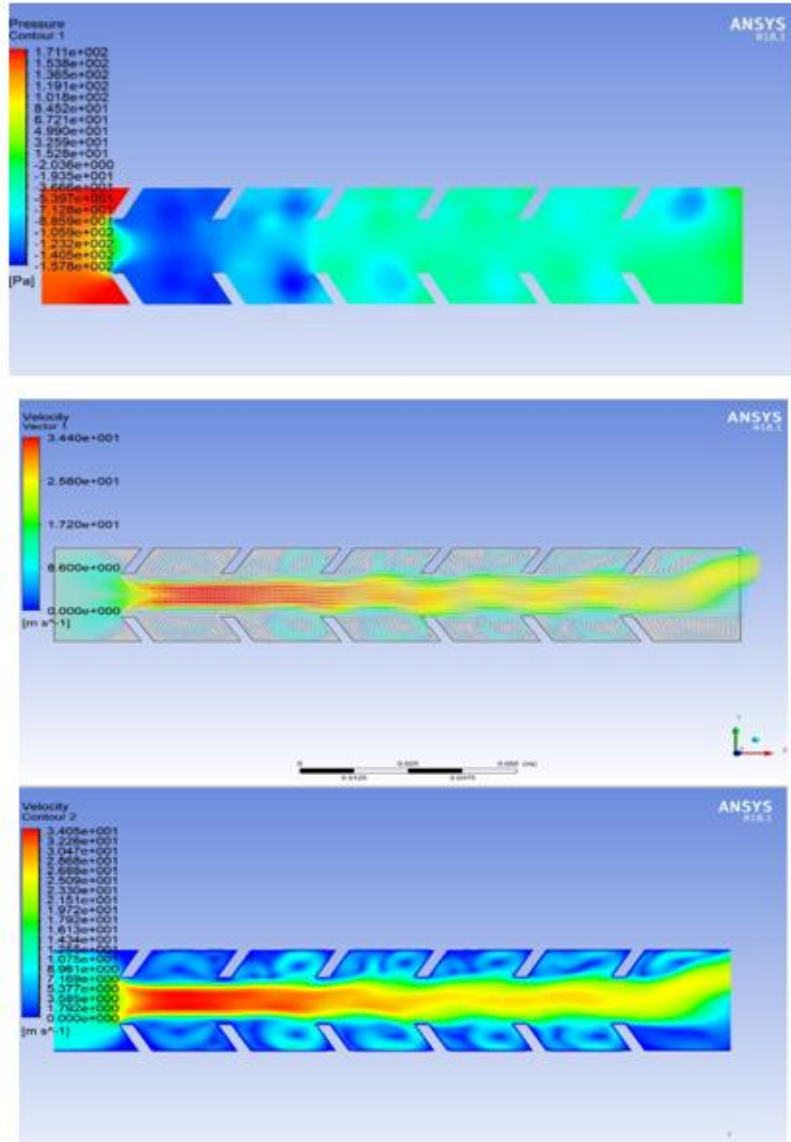


Fig 9.1.4.1 Pressure Contour
Fig 9.1.4.3 Velocity Contour

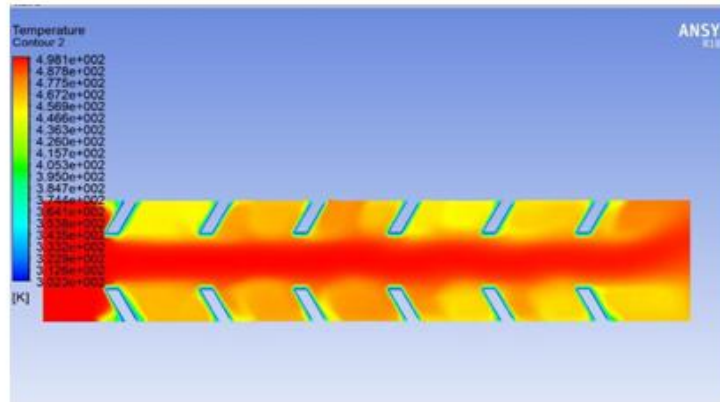


Fig 9.1.4.1 Temperature Contour

X. 3D RIB TURBULATOR

Rib turbulator is one of the systems using regularly to increase the heat transfer internally. These are positioned in the wall passages by opposite direction with some gap for flow. Changes of heat transfer depends on rib configuration, channel aspect ratio and Reynolds number for the flow. History says, the ribs are designed at the angle of 90^0 to increase the heat transfer, later angles are reduced to 45^0 to increase heat transfer. While placing the Ribs at 90^0 , reattachment helps to increase the heat transfer. Now a days, the most of the gas turbines performed high thermal efficiency with high entry temperature. So, the ribbed turbine blade was analyzed by Ansys fluent. To found the different variation of cooling effects with mass flow rate and then results were compared. And noted that the effect of cooling will improve with high mass flow rate, due to friction when the pressure loss increases and hence this technique is not feasible to have increase mass flow rate for turbine blade cooling. In experimental studies ribs are used in majority with different cross section and also concentrated on rib channels with more blockages for cooling effective. Ribs are used to form rounding effect on the surface with high aspect ratio. However, it slightly affected the rounded edge in the square rib. So, to increase the effective blockage on ribs and also increase the heat transfer co- efficient. Therefore, may be heat loads are maximum and the frictional loss were high and also it can be tolerated, the additional heat enhancement would beneficial.

10.1 GEOMETRIC MODEL

3D turbulator is designed by using the ANSYS Geometry. At the angle of 45^0 , the design have been done and size of flow passage have reduced by increasing the area, it helps to reduce the boundary layer errors with enhancing heat transfer.

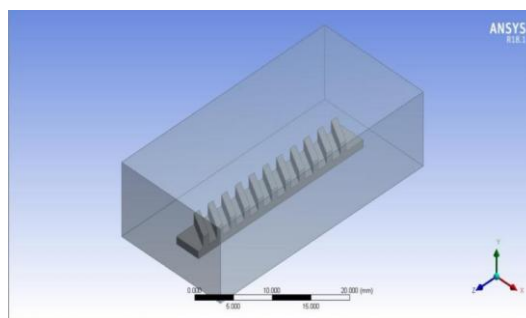


Fig 10.1.1 3DRib turbulator

10.2 FLOW SIMULATION BOUNDARY CONDITIONS

Solver type as Pressure-based and Velocity Formulation as Absolute with a Transient time. Models, change the viscous flow as laminar to SST k-omega (Model –k-omega and model constants) k-omega model to SST for better results. Material, Fluid as air (Material type- fluid, Fluent Fluid Material- air) and solid as INCONEL 718 Thermal Properties of air

- Density- 0.54 kg/m³
- Viscosity-1.7894 kg/m-s

Thermal properties of blade material.

- Density -8180 kg/m³

- Specific heat -446 J/kg C
- Thermal conductivity - 11.5 W/m C

To change the fluid, use the fluid database and select Cell zone condition as airfoil

Boundary condition, changing the inlet to velocity-inlet for flow field. Before changing inlet, change the Dynamic mesh for flow field conversion. Temperature as 1200K. Outlet as mass flow outlet. Reference values, Values are selected for flow purpose in steady flow and transient time.

Values are

- Density- 0.54 kg/m³
- Length- 4 mm
- Temperature- 1200K
- Velocity- 240 m/s
- Viscosity- 1.7894e-05

Solution Methods, Scheme should be as SIMPLE. Spatial Discretization

- Gradient –Least Squares cell based
- Pressure –Second order
- Momentum –Second order upwind
- Turbulent kinetic Energy –Second Order upwind
- Specific Dissipation –Second Order Implicit

Steps are used for Pressure-velocity Coupling Solution Initialization and Calculation Activities. Set the values for the autosave every as zero for Calculation activities. Also set the Standard solution Initialization, reference frames as relative to cell zone and initialize the value for Gauge pressure, X-velocity, Y-velocity, Z-velocity, Turbulent Kinetic energy and specific dissipation rate. These are used for setting the output in constant line. The Calculated values are displayed by using of graph. With the help of graph, get the values of x-velocity, y-velocity, z-velocity, kappa, omega, by running the solution and setup values. For getting the values of pressure, velocity, turbulent kinetic energy etc.

10.3 RESULTS AND DISCUSSION

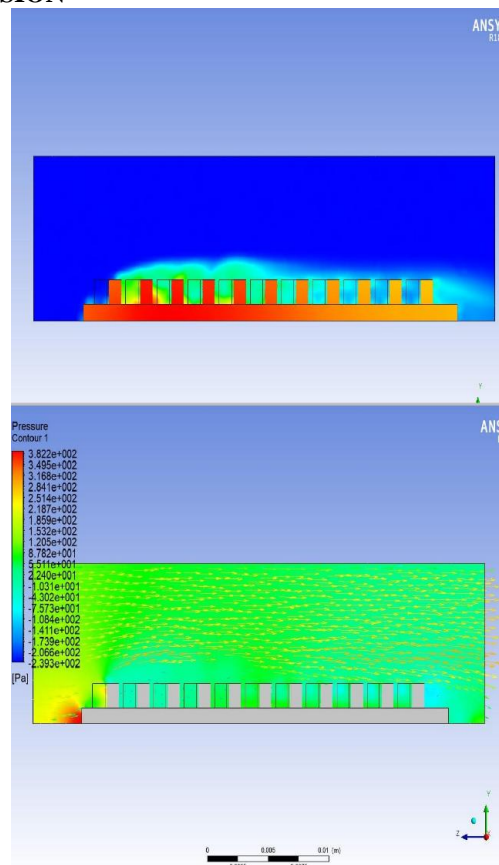


Fig 10.3.1 - Pressure Contours

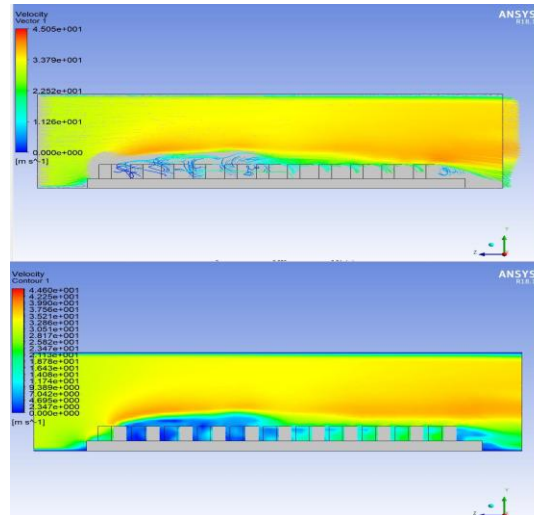


Fig 10.3.2- Velocity Contour

XI. RIB TURBULATED COOLING SYSTEM

11.1 DESIGN PROCEDURE

The Design work of typical Gas Turbine blade Cooling segment is carried out in CATIA V5 Surface Modelling workbench. The step by step procedure involved in the part are pinned:

- As an Initial step a Geometrical Set is inserted and named as Turbine Blade Framework in order to store the 2D Modeling capabilities.
- A reference Plane is Offset to specific distance and a Sketch for External Profile is created. It is then converted into a surface by using Fill command.
- Extrude the boundary up to the Element Main ZX Plane.
- In the next step, offset one more plane between Main ZX Plane and reference Plane 1. Create a Sketch to develop the integral surface.
- Once the surface is generated, the layout for the Circulation Wall is designed with specific dimensions so as not to collapse the Wall thickness.
- The profile is Extruded up to the Main Plane ZX.
- In order to create the Turbulence promoters, separate spline is invoked at designated angle between the walls for each of the passages.
- Once a Row of spline is formed, Reference Plane normal to each spline is provided and a semicircle is imposed to separate splines whose lower extremities are residing on the Circulation Walls and Integral surface.
- By using the Sweep command, the profile and Guide are modified into surfaces.
- Now the newly developed Rib structures are translated with relation to specific heights and number of Instances.
- The Split command is used next to this process to remove the unwanted surfaces that repose between the Internal Wall, Circulation Wall and Turbulence Promoters.
- The Gap between the Two surfaces (External & Internal) in the Upper and Lower End are closed using the Fill command.
- One the Work is done, the Entire structure is made Symmetric using Main ZX Plane as the Reference Element. Implement the Join command to make the Entity into a single Surface. Hereby the surface Modeling capability is completed.
- Step into the Part Design Workbench. The joined surface is forged into a solid part by means of Fill operation.
- Herewith the Design part is concluded and the model is directed towards Analysis Part.

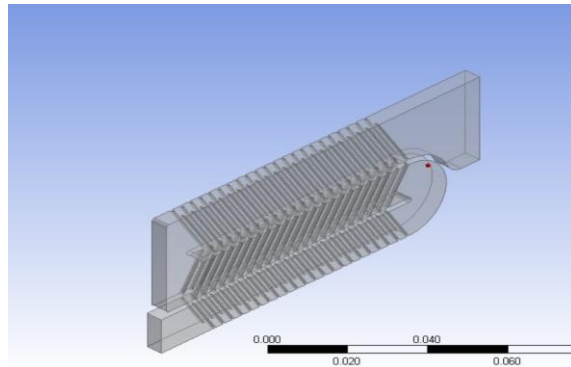


Fig 11.1.1 - Rib Turbulator cooling

11.2 MESH GENERATION AND FLOW SIMULATION BOUNDARY CONDITIONS

Solver type as Pressure-based and Velocity Formulation as Absolute with a Transient time. Models, change the viscous flow as laminar to SST k- omega (Model –k-omega and model constants) k-omega model to SST for better results. Material, Fluid as air (Material type- fluid, Fluent Fluid Material- air) and solid as INCONEL 718 Thermal Properties of air

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11.3 RESULTS AND DISCUSSION

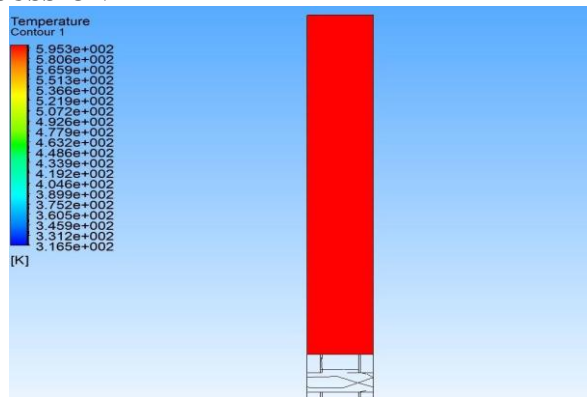


Fig 11.3.1- Temperature at Inlet

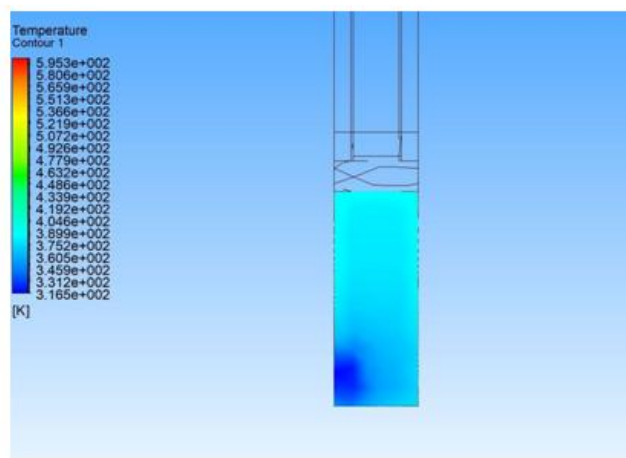


Fig 11.3.2 - Temperature at outlet

XII. WITHOUT COOLING SYSTEM

At Starting period, Turbine blades are constructed without any cooling systems, at that situations turbine entry temperature was 1000K approximately. Later internal and external cooling systems have used to increase the efficiency and reducing time consumption by increasing TET. It helps to rise the lifespan of the Blade to 50000hrs.

12.1 DESIGN

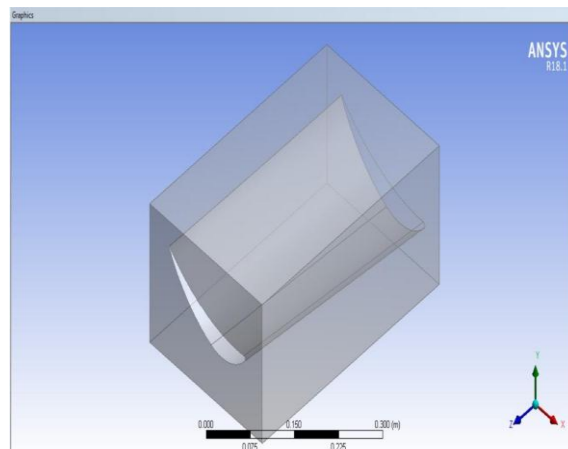


Fig 12.1.1 Without cooling system

12.3 RESULTS AND DISCUSSION

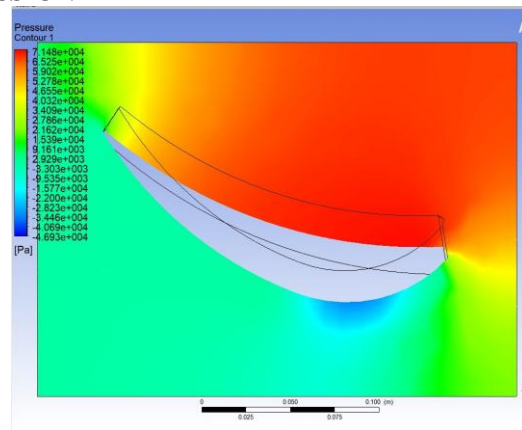


Fig 12.3.1 Pressure Contours

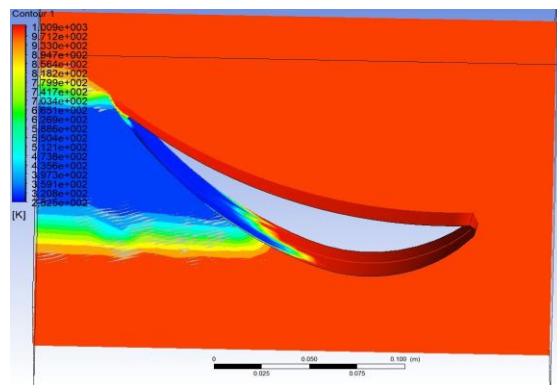


Fig 6.1.3.2 Temperature Contour

XIII. CONCLUSION

The component that is capable of withstanding the highest amount (1700K) of heat inside Gas powered Engines is Turbine Blade. As defined higher the Turbine Entry Temperature (TET) higher the Efficiency of Engine. If TET increases to 1%, efficiency increases to 2%. Gas Turbine Engines find wide range of Industrial applications such as Aviation, Marine, Power Generation Unit, Oil and Gas Production arena by driving and compensating the major energy requisites. In recent times, multiple research works have been carried out in optimized Block out and justified material selection for the Turbine blades in order to retain optimized higher efficiency and low emissive powerplants. In relation, the purpose of this project is to Design an optimized First Stage Gas Turbine Blade with better Heat Exchange characteristics and to render high temperature bearing capabilities. The progress path initiated from the 2D Rib Turbulated Model Design and Analysis with specific parameters. In continuation, the 3D model is developed in the Design Workbench and Analysis part is executed. Along the side a model without Cooling Platform and Existing Cooling Profile of typically similar geometry is made out and performed analysis individually. As a termination part, the Results from individual are compared and discussed to extract the Mean Efficiency Parameters. From the Results it is found that Rib Roughened Models with aggrandized Turbulence Promoters and Circulation passages with large area improves the Heat Exchange Rate and thus proficient to bide harsh combustion conditions

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