Design and Analysis of Heat Transfer Rate from Gas Turbine Blade Using Film Cooling

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Abstract: Turbines are machines that give out power in a constant manner. In the present world, the development of gas turbines has at its peak however the energy crisis is alarming the world to create efficient machinery. Modern gas turbines blade work at extreme temperature results in melting of blade material. The best cooling system should be provided for the ceaseless safe operation of gas turbines so to achieve higher efficiency. In this project, we are dealing with the film cooling process and its effects on turbine blades.

The model of the blade is designed by the use of solid edge software and the analysis is done with the commercial CFD software fluent. Heat transfer analysis is carried with the INCONEL metal using different designs of film cooling mode of the gas turbine system. The internal passage in the blade may be circular or elliptical as needed. Cooling is carried out by the passage of cold air from the hub towards the blade.

KEYWORDS: Film cooling, INCONEL metal, heat transfer, internal passage.

DOI of the Article: https://doi.org/10.46501/GIETME02

Available online at: http://ijmtst.com/vol7si05.html

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To Cite this Article: E.Nirmala Devi ; Himalaya singh ; G.L.S.Bhaskar ; G.V.M.Reddy and M.Muralidhar[5]. Design and Analysis of Heat Transfer Rate from Gas Turbine Blade Using Film Cooling. *International Journal for Modern Trends in Science and Technology* 2021, *7*, pp. 5-12. https://doi.org/10.46501/GIETME02

Article Info. Received: 12 June 2021; Accepted: 16 July 2021; Published: 20 July 2021

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INTRODUCTION

Earlier the gas turbine was built in 1903 in Paris, Inimpulse turbine many subsequent improvements needed to be led to work on the gas turbine, which by 1932 could produce 82% of efficiency with an operating temperature of 550 ^{0}C. The working of the turbine blade is continuous there is a possibility of the generation of heat which causes a heat loss from the blades of the turbine and causes a thermal failure. Different cooling methods are available currently, which consist of;

Internal cooling:

1) Convection cooling method
2) Impingement cooling method

External cooling:

1) Transpiration cooling
2) Film cooling method
3) Cooling effusion
4) Pin fin cooling

These methods are used to extract the heat from the turbine blade which provides cooling to the blades which result in the better performance of the turbine blades. As we will know all the methods are used to cool the gas turbine blades, internal cooling consists of two major sub-method convection cooling & impingement cooling. In the convection cooling method, the turbine blade is cooled bypassing the cool air inside the internal passage of the blade. More area is required for this, it contains a large no of surface fins on the body. In this method, cooling is achieved by the passage of cooling air from the hub to the tip of the blades. Similarly, the internal cooling method, impingement cooling works by throwing the high-velocity air inside the inner surface of the blade. In this cooling system, there is heat load and maximum temperature on the leading edge and the cooling air enters towards the trailing edge from the leading edge.

The next cooling method is the external cooling method which consists of a different method, transpiration cooling is the one among them. The name itself indicates as on this method it is the same as compared to film cooling method where the air is passed through the porous shell rather as done on film cooling through holes. The passing of air is done through the struts of the body and later through the porous shell.

Film cooling method one of the external cooling methods in which the cool air is forced out of the holes in the blades which provide cooling to the blades. The layer of air on the blade surface creates the thin film on the surface of the blade however the holes can be designed in different ways as it has been designed in the figures presented. In this method, the cooling can be achieved by three different designs varying the no. of holes in the horizontal and the vertical direction.

Effusion cooling is one of the methods for cooling gas turbine blades with the help of a gas under pressure which is forced through the porous material. Thus the heat gets absorbed from the material and thereby leaving an insulating layer on the exposed surface. Pin fin cooling is generally done on the trailing edges of the blades where fins will increase the performance of the turbine blades. It carries the height to diameter ratio between 0.5to4 however it is associated with ejection cooling.

STRUCTURE OF THE PAPER

The present work is organized in the following order. In section 1, the introduction is provided with details of gas turbine cooling methods. In section 2, we detailed related work. In section 3, we have described the CFD analysis done on the gas turbine blade and its methodology. In section 4, we provided the complete heat transfer analysis in the gas turbine blade. Section 5, includes the result in tabular form. Section 6, includes the conclusion future scope, and references.

OBJECTIVES

The objective of this present work is to determine the heat transfer rate and the temperature distribution on the gas turbine blade with constant & varying velocity at cold inlet. Plain Holesare tested under this project which is designed using solid edge and analysis can be done using CFD software fluent, under which film cooling process is adopted.

RELATED WORK

The gas turbine comes into existence in the year of 1791 and was patented by John Barbar. Earlier the modifications were done in the gas turbine working model. Recent studies have focused more on work-efficient gas turbine engines. So the cooling of the gas turbine has been a big issue in the present gas turbine because the operating temperature is too high which can melt the blade material. So the previous paper has analyzed and studied based on the cooling of

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gas turbine blade and the heat transfer from the blade surface.

The study gives the concept of design of cooling holes which can vary accordingly, provides total heat transfer rate value is maximum and the temperature in the leading edge is minimum for the blade containing 13 holes. They are studiedtwodifferent materials that are Chromium steel and Inconel718werefound that the Inconel178 has ahigher thermal flux than chromium steel and the stress and strain are within the allowable limits so Inconel718 is better for blade material [1].

Thermal analysis of the aero gas turbine blade was studied the flow network to analyze the mass flow in 1D, 2D, & 3D. It is found that the temperature obtained is 1340 k for 2D and 1393k for 3D.The blade material temperature is 47 k less thanthemaximum allowable temperature so the cooling effect that is estimated in the two-dimensional analysis is 0.586[2].

Transient Thermal Analysis on Gas Turbine Rotor Blade by using Finite Element Analysis had been done and the result shows that the transient analysis was done using the different materials, found that aluminum alloy showed efficient heat flux as compared to the titanium & nickel alloy based on different timings and temperature distribution[3].

Experimental investigation on heat transfer augmentation in a two-pass channel featuring V-shaped ribs and cylindrical dimples,so on the study it was found that the heat transfer rate in the cross-stream direction on the ribbed wall on local variation V ribs is more significant than the W ribs. Also concluded that the heat transfer and the thermal-hydraulic performance of the V compound are better than other ribs[4].

A Review of Turbine Blade Tip and Heat Transfer on the study was found that in aerospace and power gas turbine focus is placed on the on high-pressure, high-temperature axial-turbine blade tips.the major cause of the increase in thermal stress is the secondary vortices that formed on the endwall[5].

Turbine blade cooling by air using Different methods, on the study it was found that the impingement and film cooling is the best method to cool the gas turbine blade. Whenever the increase in cooling air jet increases blade temperature so there is a reduction in temperature on using cooling methods[6].

Thermal Analysis of a Cooled Turbine Blade on the study found that the CFD analysis of gas turbine blade using different operation,asan increase in 6% of the gas side the heat transfer coefficient increases by 40^{0}C whereas increasing the gas temperature by 100^{0}C there is the increase in (50-100)^{0}c and on increasing the coolant temperature by 100^{0}c will result in 50^{0}c increase in blade metal temperature[7].

Computational Analysis of Turbine Blade Cooling using Cylindrical Coolant Channels on the study it was found that the four different models of the gas turbine containing 10, 12, 18, & 20 holes, the 18 holes turbine blade provides the most efficient cooling to the gas turbine blade. The temperature of 18 holes turbine is decreased by 7.85% and from 1100 k to 1013.627 k temperatureso with the cooling holes cooling effectiveness also increases [8].

State-of-the-art cooling technology for a turbine rotor blade on a study of the effectiveness of internal and external cooling is key to maintaining the blade material quality whereas the development of an internal cooling & external cooling concept for a state-of-the-art cooled turbine blade was studied in this journal[9].

Optimization of Turbine Blade Cooling Using Combined Cooling Techniques on a study it was found that the film cooling technique has some disadvantages including as this technique leads to some problems like low and non-uniform cooling effectiveness over the blade surface. The use of CICC and CIFC techniques will improve the cooling[10].

DESIGNING AND METHODOLOGY OF CFD ANALYSIS ON GAS TURBINE BLADE

3.1 Designing details

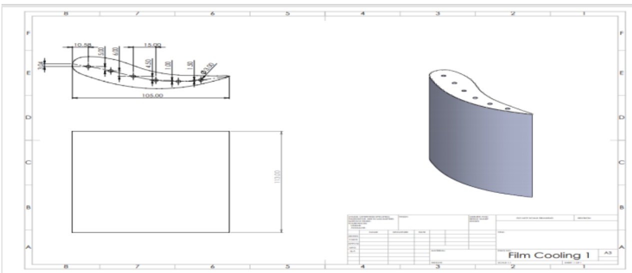
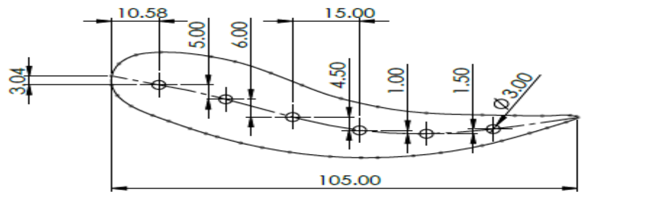


Fig 3.1 Blade design



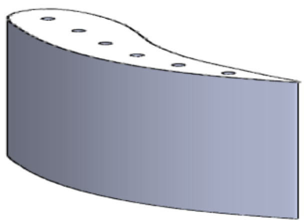


Fig3.2Through Holes cooling model

The Fig 3.2 represents the Cooling provision designed for the blade and surface holes with 15mm pitch in the Vertical direction The holes diameter of 5mm has been designed for air movement.The metal properties are shown in table 1.

Table 1.Physicalproperties of INCONEL

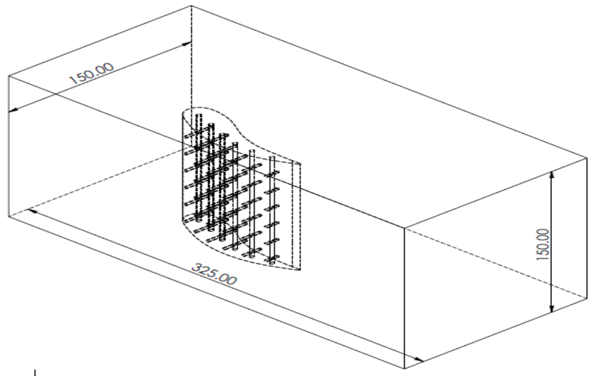
S.NO.	Properties	Inconel	Units
1	Density	8190	Kg/m³
2	Specific Heat	586	J/Kg-K
3	Thermal Conductivity	25	W/mK

3.2Methodology

Computational fluid dynamics is the process of analyzing the numerical way to analyze the complex problems which will have fluid-solid, fluid-fluid & fluid- gas combination. In this analysis, we are bringing the complex design using other software as we have gone through the solid edge for the designing purpose, and later the design is copied to the CFD where the design of the gas turbine blade is analyzed which is the fluid-solid interface. CFD is used in many fields like aerospace engineering, electronics manufacturing, HAVC engineering, metrology, polymer processing & many others. Therefore it constitutes the three processes under which the analysis is carried out:

1) Pre-processing
2) Processing
3) Post-processing

The pre-processing on the CFD is the first and the primary step of simulation where the design is to be defined in the geometry where it needs to be analyzed using CFD. This will define the geometry & parameters of the simulation accurately. Here we have to define the properties of the materials and setting the required conditions of meshing, & the boundary conditions.



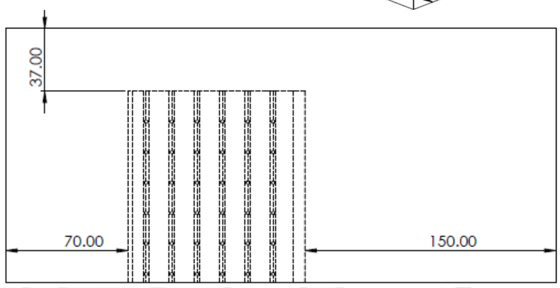


Fig 3.2.1 Domain Dimensions

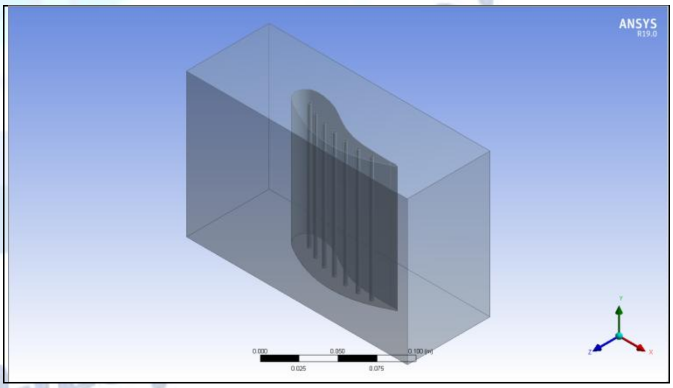


Fig 3.2.2 Final volume

The meshing of the turbine blade geometry results in dividing the geometry into no of small cells, Therefore the formation of nodes and elements will be there. So we have done meshing and got the data represented below:

Meshing Details	
Type	**Elements**
Plain Holes	1839203

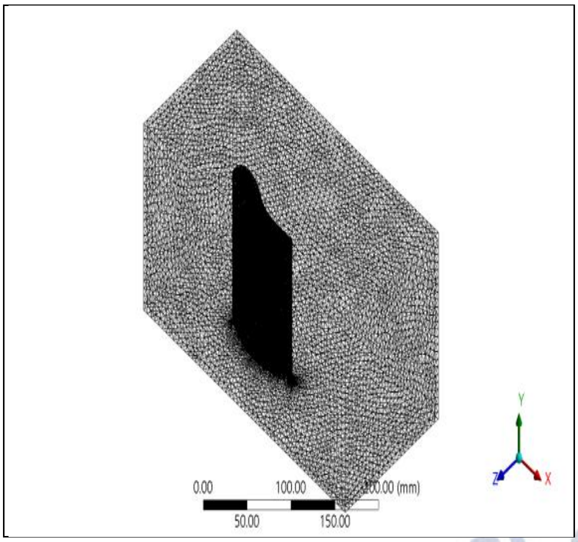


Fig 3.2.3 meshing

The Processing of the CFD analysis when there was the completion of the meshing, there we are analyzing the solutions in the given boundary conditions and the units will be in mm as we needed, the equations with consideration of material from material selection dialogue box INCONEL. For fluid, the air is added to the fluid database.

The required parameters are given with the boundary conditions for the fluid flow as shown in table 2.

Table 2.Boundary conditions

S.NO.	Boundary	Value
1	Hot Inlet	256 m/s
2	Cold Inlet	150 m/s
3	Hot Inlet Temperature	1250 K
4	Cold Inlet Temperature	300 K
5	Wall	No Slip.
6	Interface	Coupled Interface.
7	Viscous Model	K-omega
8	Inlet	Velocity Inlet
9	outlet	Pressure Outlet

On the last stage of CFD analysis, we are moving to do a post-analysis of the turbine blade which is under consideration. In this part we will get the results of the gas turbine blade which is shown in the figure below; temperature diagrams, velocity diagrams, and the heat transfer rates and include vector plots, line, and shaded counterplots, domain geometry, & in recent it comes with the dynamic result display.

IV. HEAT TRANSFER ANALYSIS IN GAS TURBINE BLADES

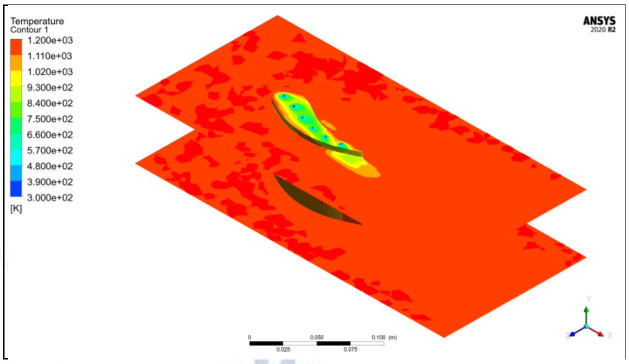


Fig 4.1 Temperature distributionThroughplainHoles

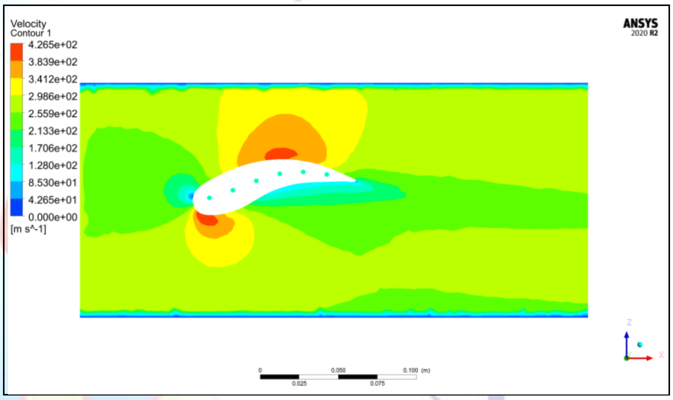


Fig 4.2 Velocity distribution Through plain Holes

Design	Maximum temperature	Minimum temperature
PlainHoles	1200 k	300 k

At the suction surface, the temperature is minimum whereas at the trailing and leading edges the temperature is maximum similarly on both the pressure surface and suction surface of the blade have reduced temperatures which turned orange suggests a decrease in temperature on the blade surface. In the picture minimum is blue and the maximum is red on trailing edges.The maximum velocity at the suction surface region is 426.5 m/sec whereas the minimum velocity at the pressure surface region is 46.25 m/sec.Now the velocity is changed at the cold inlet thus, we got the result as;

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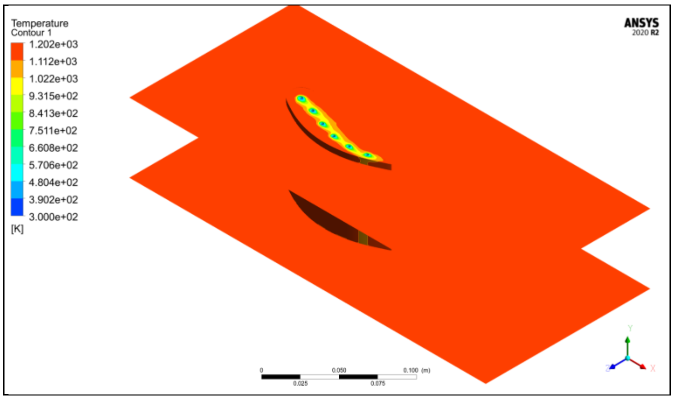

Fig 4.3 Temperature distribution at 50 m/sec

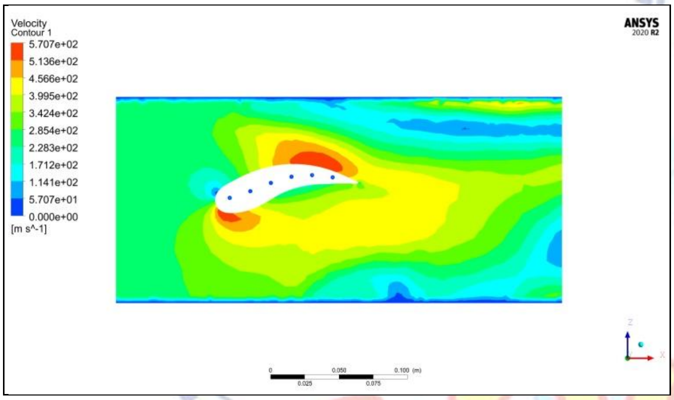

Fig 4.4 velocity profileat50 m/sec

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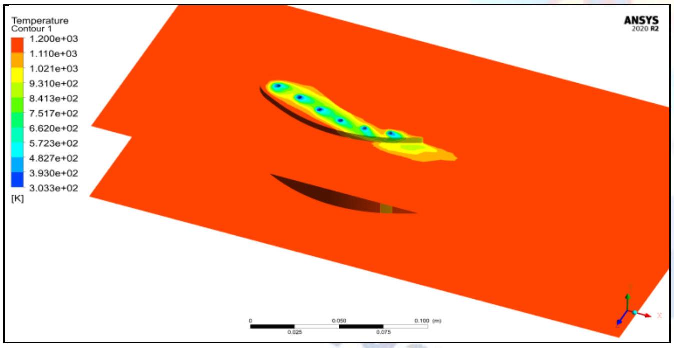

Fig 4.5 Temperature distribution at 100 m/sec

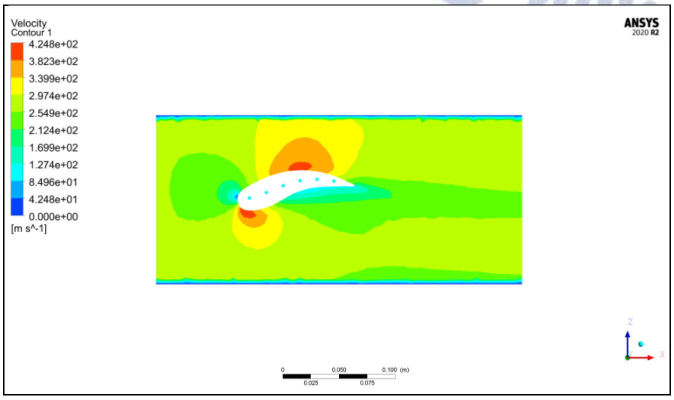

Fig 4.6 velocity profile at 100 m/sec

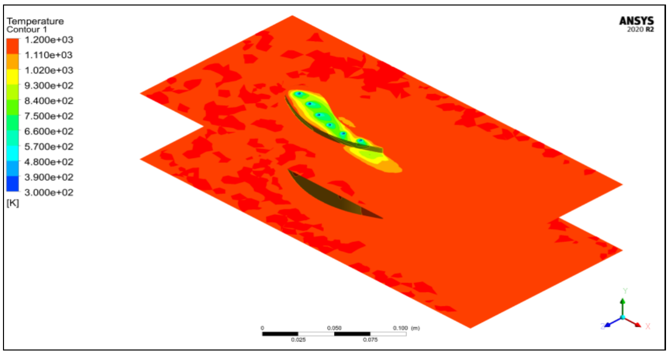

Fig 4.7 Temperature distribution at 150 m/sec

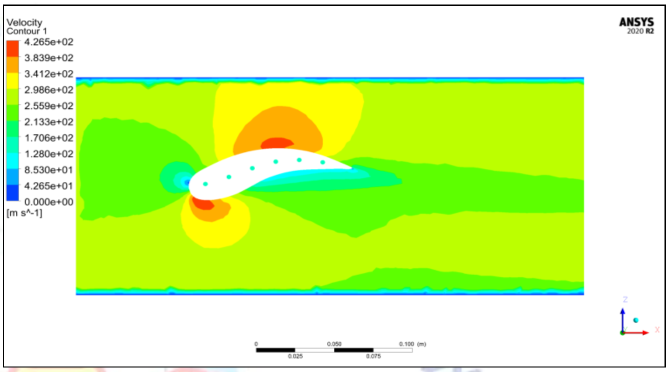

Fig 4.8 velocity profile at 150 m/sec

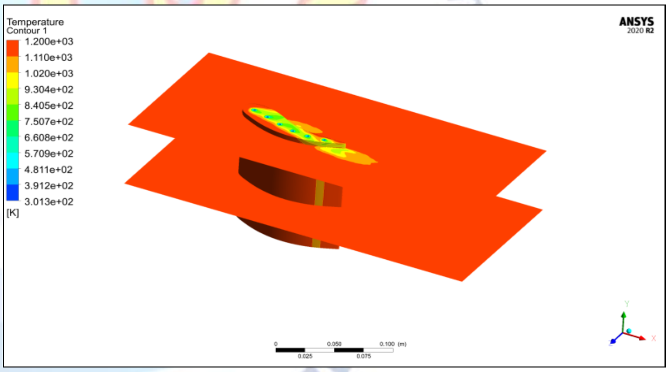

Fig 4.9 Temperature distribution at 200 m/sec

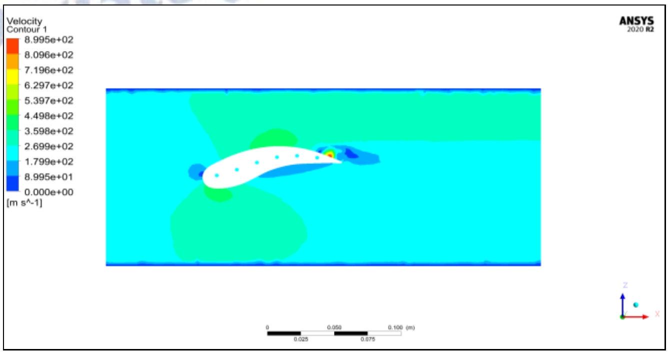

Fig 4.10velocity profile at 200 m/sec

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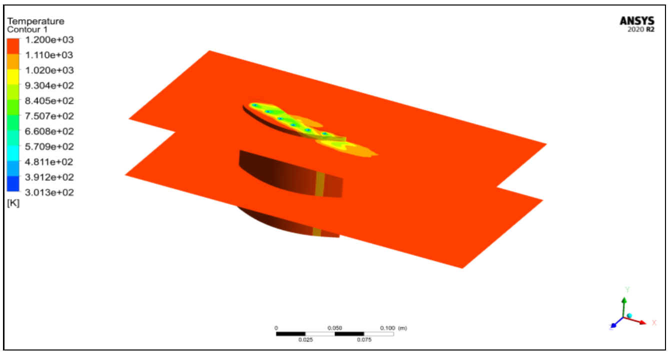

Fig 4.11 Temperature distribution at 250 m/sec

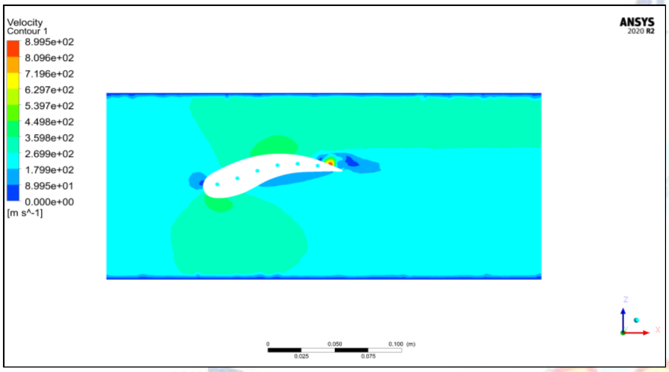

Fig 4.12velocity profile at 250 m/sec

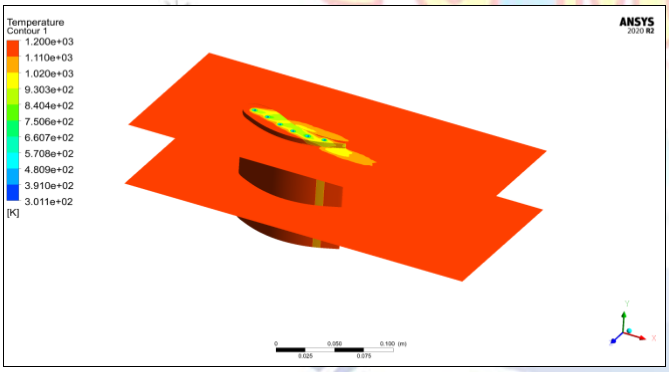

Fig 4.13Temperature distribution at 300 m/sec

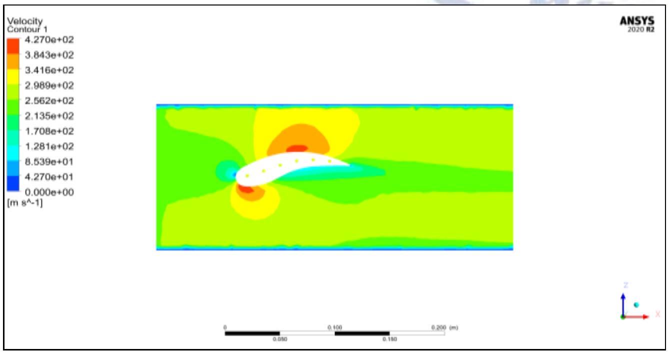

Fig 4.14velocity profile at 300 m/sec

Figure 4.3-4.14shows the result of the gas turbine blade when the cold inlet velocity is varied from 50 m/sec to 300 m/sec. It is found that the change in heat transfer rate as the temperature varies as there as the cold inlet velocity increases during the film cooling process

RESULTS

The below represented bar diagrams shows the results of plain holes velocity versus surface temperature (fig 5.1), plain holes velocity versus heat transfer coefficient(fig 5.2), plain holes velocity versus heat transfer rate(fig 5.3). The heat transfer rate at velocity of 150 m/sec is better as compared to others. It is found that the heat transfer rate is 22.1799W at the operational pressure of 101325pascal.

Whenever the cold inlet velocity changes from 50-300 m/sec the surface temperature changes for the blade design plain holes with change in heat transfer rate.
All belowrepresented bar diagrams shows coefficient of heat transfer and heat transfer rate & surface temperauature at velocity of 50 m/sec, 100m/sec, 150m/sec, 200m/sec, 250m/sec, & 300m/sec.

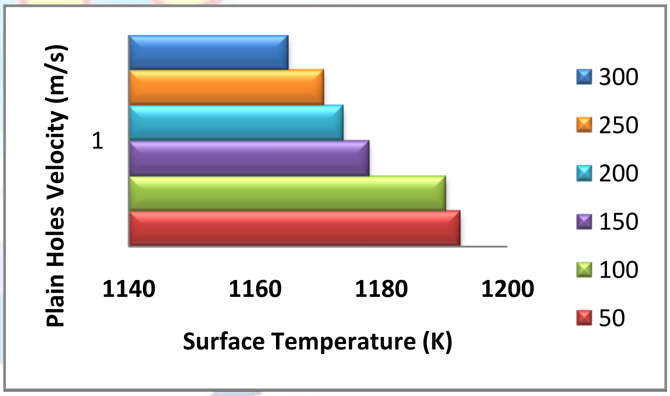

Fig 5.1 Velocity vssurfacetemperature

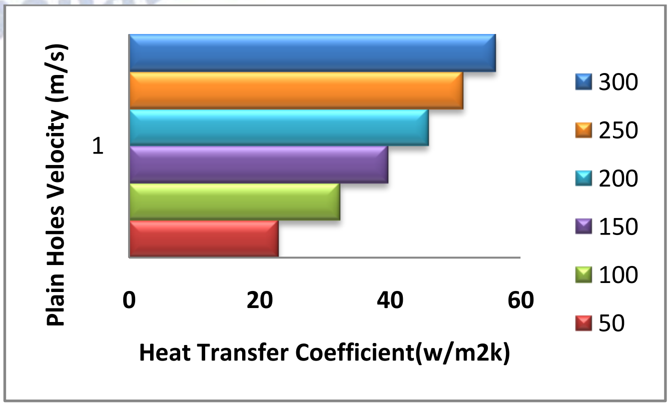

Fig 5.2 Velocity vsHeat Transfer coefficient

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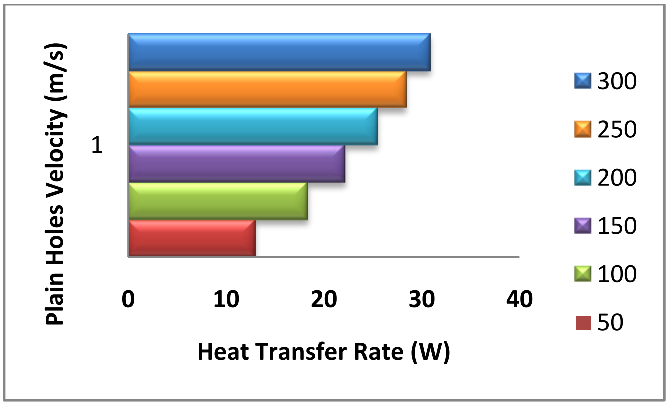

Fig 5.3 Velocity vs Heat Transfer Rate

FUTURE SCOPE AND CONCLUSION

The analysis on the gas turbine using film cooling with the suggested design will help in designing the turbine blade which provides more cooling on the blade material and helps to protect the material of the blade from melting. In Gas turbine heat transfer analysis will constitute in the working of the blades under high pressure and velocities, which provides clear information and idea to achieve the better performance & efficiency of the gas turbine. Some key applications are;

1) Aerospace
2) polymer processing
3) electronics manufacturing
4) HAVC engineering

From this paper, we lastly concluded that the film cooling using the suggested design of the gas turbine blades will improve the working and efficiency whereas protectingthe blade material from melting.The heat transfer rate in plain type holes found 22.1799W at the operational pressure of gas turbine blade 101325pascal.

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