FLOW ANALYSIS OF GAS TURBINE BLADE FOR OPTIMUM COOLING

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ABSTRACT

The aim of the paper is to evaluate the need in the gas turbine industry for a systematic validated computational methodology for heat transfer problem to give the optimum cooling. In order to raise thermal efficiency of a gas turbine, higher turbine inlet temperature (TIT) is needed. Various techniques have been proposed for the cooling of blades and one such technique is to have axial holes along the blade span. Cooling of blades has been a major concern since they are in a high temperature environment. In a high temperature gas turbine, turbine blade cooling designs require key technologies. Computational fluid dynamic (CFD) is used to analyze flow performance due to changing the material properties of like Nickel-Chromium alloy and Titanium-Aluminum Alloy. Three different models with different number of holes (6,8,12) were analyzed in this paper to find out the optimum number of holes for good cooling rate. In computational fluid dynamic (CFD), flow analysis is carried out. Graphs are plotted for velocity, pressure and temperature distribution for existing design. 3D model of the blade is shown. When the numbers of holes are increased in the blade, the temperature distribution falls down. Our calculations were compared adequately well with published experimental data as well as our own fundamental test data. Attention is focused on the accuracy using commercially available numerical methods, computational fluid dynamic (CFD) for fluid flow, temperature distribution for number of holes are analyzed.

***Keywords** – Gas Turbine, Blade cooling, CFD, Flow analysis, Number of holes*

I. INTRODUCTION

A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. The number of turbine stages can have a great effect on how the turbine blades are designed for each stage. Many gas turbine engines are twin spool designs, meaning that there is a high pressure spool and a low pressure spool. Other gas turbines use three spools, adding an intermediate pressure spool between the high and low pressure spool. The high pressure turbine is exposed to the hottest, highest pressure air, and the low pressure turbine is subjected to cooler, lower pressure air. That difference in conditions leads the design of high pressure and low pressure turbine blades to be significantly different in material and cooling choices even though the aerodynamic and thermodynamic principles are the same.

II. LITERATURE

The existing literature contains many experimental and numerical investigations on flow field in and around turbine blade tip models. Studies by R Yadav [9] and S.Gowreesh[1] have contributed to the general understanding of tip leakage flow patterns. S.Gowreesh concluded that the growth of a vortex, which forms as the flow separates on the pressure side wall and exits through the tip gap causing an increase in the secondary flow, results in large aerodynamic losses.

Han et al [3] worked on the topic of "Conjugate Heat Transfer Analysis Of Internally Cooled Gas Turbine Airfoils "performed two and three-dimensional conjugate analysis of a radically cooled gas turbine blade: the only thermal boundary conditions they imposed were the HTC on the surfaces of the internal coolant flow passages.

Laskowski and Felten research first stage gas turbine blades by means of computational fluid dynamics simulations, and the effect of cooling fluid on the blades of the next stage of the study [2]. John D Denton's research focuses on the limitations of computational fluid dynamics and numerical analysis of errors that may be considered and studied [3]. Saqib Hameed and Manarvi Research study predicts the location of damage in gas turbine blades by the finite element method for computational fluid dynamics is discussed, as a reference for non-destructive testing used [4].

The purpose of turbine technology [1] are to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time. Since the allowable temperature on the turbine blade dependents on the hot gas temperatures from the combustion chamber, preliminary design is been taken from the optimized dump gap design study carried out by Gowreesh.et.al [1]. The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several ring of fixed and moving blades to get a high pressure of order 4 to 10 bar of working fluid which is essential for expansion. Blade metal temperature distribution and temperature gradients are the most important parameters determining blade life. Therefore, accurately predicting blade heat transfer parameters is essential for precisely predicting blade life. As mentioned above, one of the most important loads for calculating blade life is temperature distribution. In cooled turbines, in order to calculate blade temperature precisely, internal coolant, external hot gas, and metal conduction should be simulated simultaneously by conjugate heat transfer (CHT) method. There have been increased research efforts in applying the CHT methodology to simulate gas turbine blade heat transfer Although three-dimensional (3-D) modeling of vanes and blades with complex cooling passages is time-consuming, there are some studies [8–11] which used 3-D solver and CHT method to calculate the temperature distribution of vanes and blades with more complex internal cooling passages.

During gas turbine operation, each component has its own failure modes. For instance, vanes failure modes are thermal fatigue, low cycle fatigue and corrosion. In the case of blades, failure mechanisms are low cycle fatigue, high cycle fatigue, thermal fatigue, environmental attack and creep [17,18]. Consequently, life estimation of gas turbine hot section blades consists of two main parts; creep and fatigue calculation and environmental attack consideration. In most life estimation investigations, creep and fatigue lives are major parts of procedure and other failure mechanisms like corrosion are in second order of importance [19,20]. The critical part of a gas turbine that determines the hot section life is the turbine 1st stage blade [17–21]. Severe states of stress and temperature and corrosive condition in gas turbine 1st stage are the reasons for this claim.

III. MATERIALS & METHODOLOGY

There are many types of cooling used in gas turbine blades; convection, film, transpiration cooling, cooling effusion, pin fin cooling etc. which fall under the categories of internal and external cooling. While all methods have their differences, they all work by using cooler air (often bled from the compressor) to remove heat from the turbine blades.

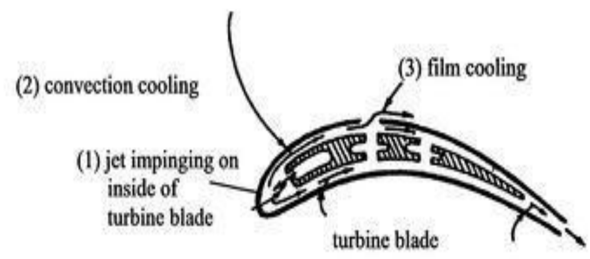

Fig.1 Types of cooling methods

The experimental techniques have their inherent problems viz. that they are equipment oriented, and they need large resources of hardware, time and operating costs. Their applications are also limited due to scaling considerations. Further theses involve certain measurement difficulties and handling of large quantity of data.

This approach forms the core of Computational Fluid Dynamics, commonly known as CFD. The popularity of CFD has been possible due to great developments in computing algorithms that have enabled fast Graphic User Interface that makes the interpretation and Visualization of the results easier.

Researchers around the world are trying to develop new materials which have high strength and stability at high temperatures to meet the demands of the turbine designers. Different alloy compositions have been developed which have a good stability to withstand the thermal stresses. These alloys have been modified to give good erosion-corrosion characteristics to the blades. Among the materials that have been found to be suitable for use in blades are steels, titanium alloys and nickel alloys. All the three types of alloys which are mainly used, have varying proportions of chromium and aluminum to improve the strength and corrosion at high temperatures.

Table 1 Material properties of Titanium-Aluminum alloy [2]

Property	Values
Density	4.51 $g.cm^{-3}$ at 20°C
Poisson's Ratio	0.3
Melting Point	1660 °C
Specific Heat	520.J/(Kg K)
Thermal Conductivity	7 W/m.K
Resistivity	42×10^{10} ohm.m

Table 2 Material properties of Nickel-Chromium alloy [7]

Property	Values
Density	8.9 $g.cm^{-3}$ at 20°C
Poisson's Ratio	0.325
Melting Point	1753 °C
Specific Heat	445.J/(Kg K)
Thermal Conductivity	17 W/m.K
Resistivity	699×10^{10} ohm.m

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IV. MODELING OF TURBINE BLADE

Using GAMBIT software, modeling is created with given dimensions as shown in the Fig.2.

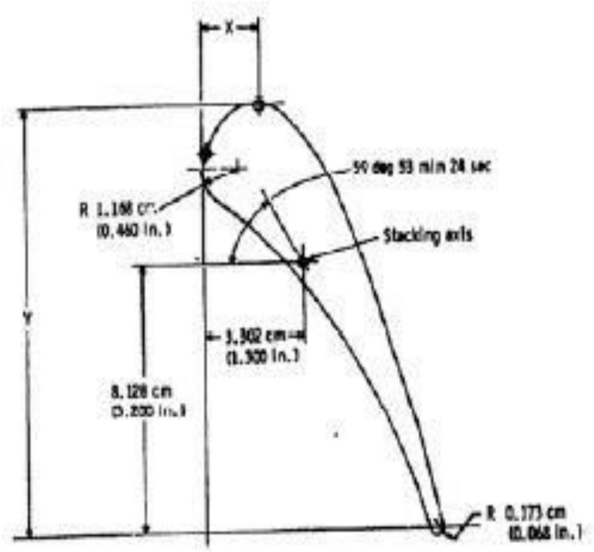

Fig.2 Schematic of the gas turbine blade

Three designs has been analyzed to observe the cooling pattern of turbine blades. The blade with holes of 6,8 and 12 were modeled using GAMBIT.

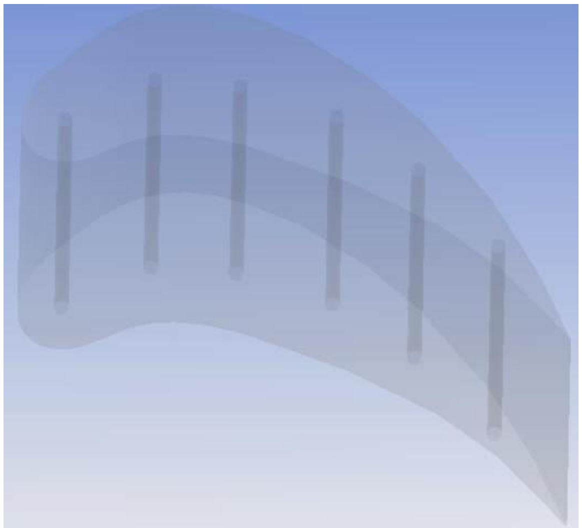

Fig. 3 Blade with 6 holes

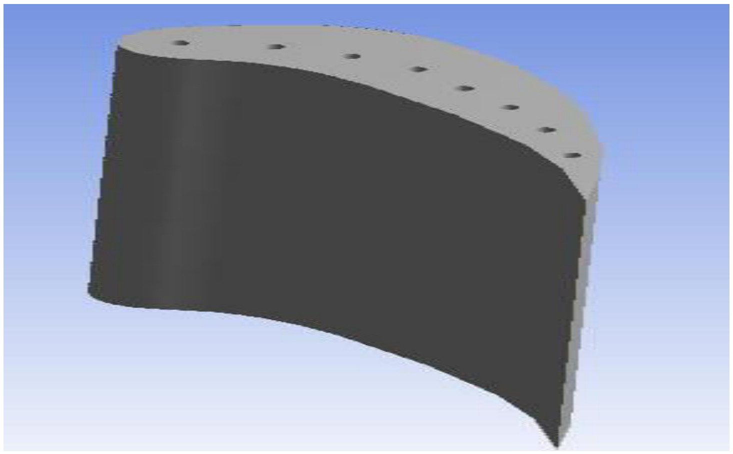

Fig. 4 Blade with 8 holes

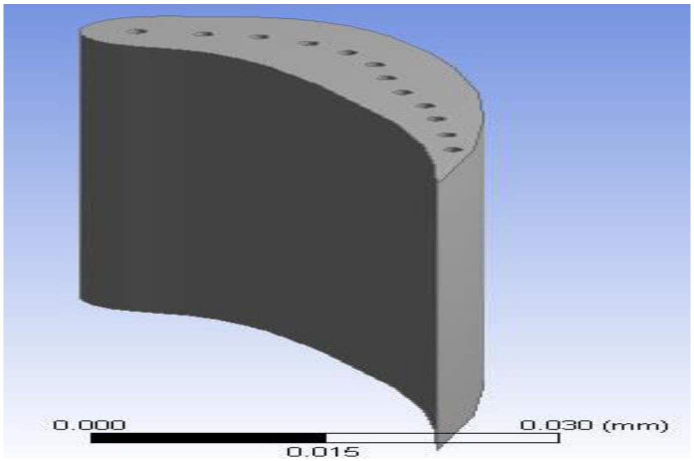

Fig. 5 Blade with 12 holes

CFD ANALYSIS

CFD Analysis has been performed using numerical flow simulation of FLUENT.

Meshing of gas turbine blade with different models

- The mesh is refined around the gas turbine blade to properly capture the boundary layer.
- Meshing is the process of discretization of space in which flow takes place.
- Meshing is the basic step in building a computer model for a flow problem. Depending on the discretization technique used, meshing procedure varies

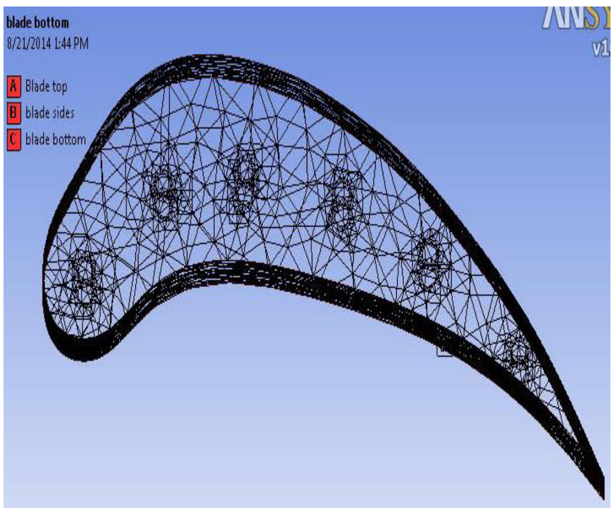

Fig. 6 Meshing of 6 holes gas turbine blade

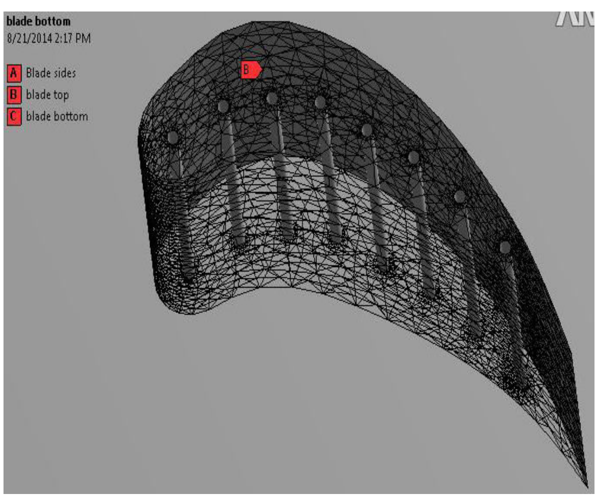

Fig. 7 Meshing of 8 holes gas turbine blade

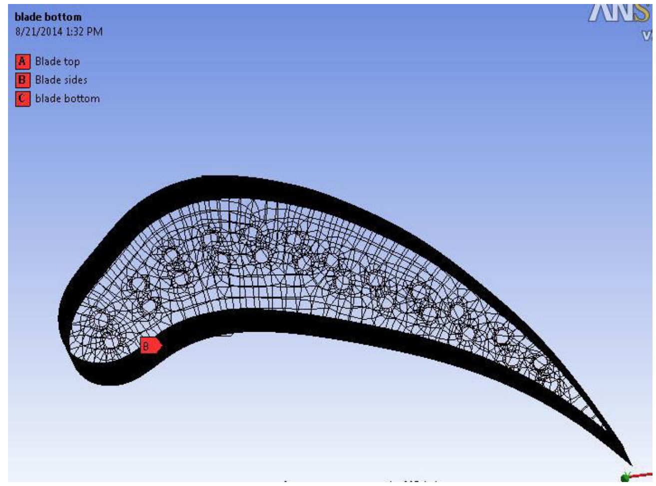

Fig.8 Meshing of 12 holes gas turbine blade

Table 3 Number of nodes and elements

Sl. No	Model Of Gas Turbine Blade	Number Of Nodes	Number Of Elements
1	6 holes	87950	131455
2	8 holes	296340	416570
3	12 holes	448982	632850

Boundary Conditions:

Table 4 Boundary conditions

Inlet pressure	160kPa
Inlet temperature	800° C
Inlet velocity	5m/s
Exit static pressure	110kPa
Inlet turbulence intensity	9%
Coolant temperature	300° C

V. RESULTS AND DISCUSSIONS

Contours of Nickel Chromium alloy with 6holes

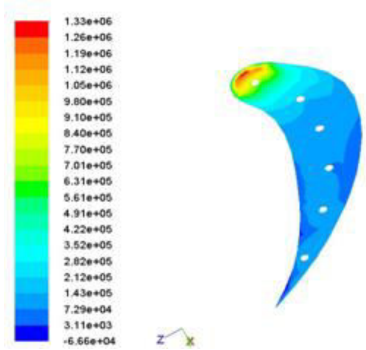

Fig. 9 Variation of static pressure of 6 holes Nickel alloy in Gas Turbine blade.

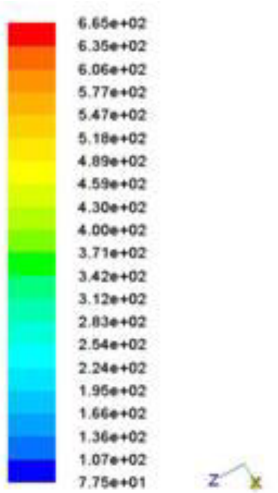

Fig. 10 Variation of static temperature of 6 Holes Nickel alloy in Gas Turbine blade.

Contours of Titanium-Aluminum alloy with 6 holes

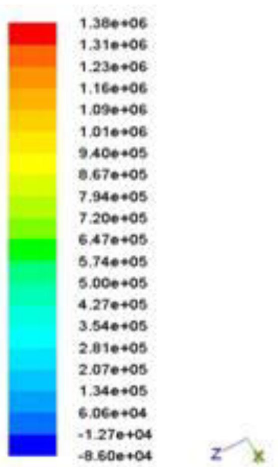

Fig. 11 Variation of static pressure of 6 holes Titanium alloy in Gas Turbine Blade.

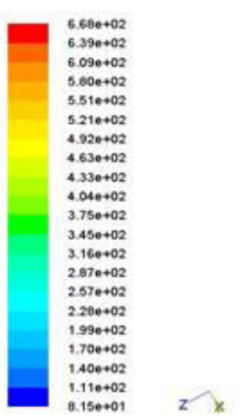

Fig. 12 Variation of static Temperature of 6 Holes

Contours of Nickel-Chromium alloy with 8 holes

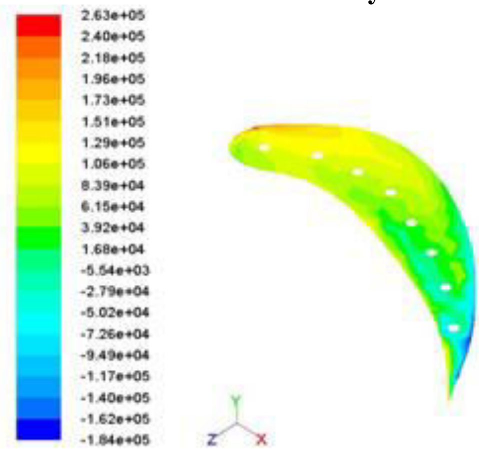

Fig. 13 Variation of static pressure of 8 holes Nickel

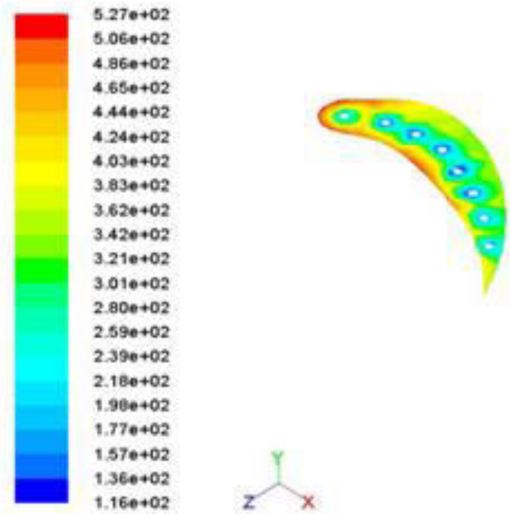

Fig. 14Variation of static temperature of 8 Holes Nickel

Contours of Titanium-Aluminum alloy with 8 holes

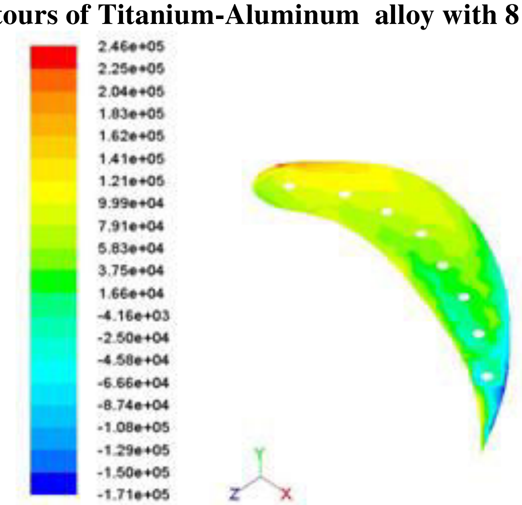

Fig. 15Variation of static pressure of 8 holes Titanium alloy in Gas Turbine Blade.

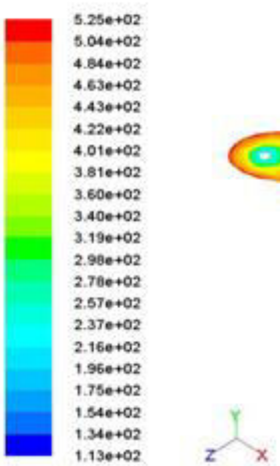

Fig.16Variation of static temperature of 8 holes

Contours of Nickel-Chromium alloy with 12 holes

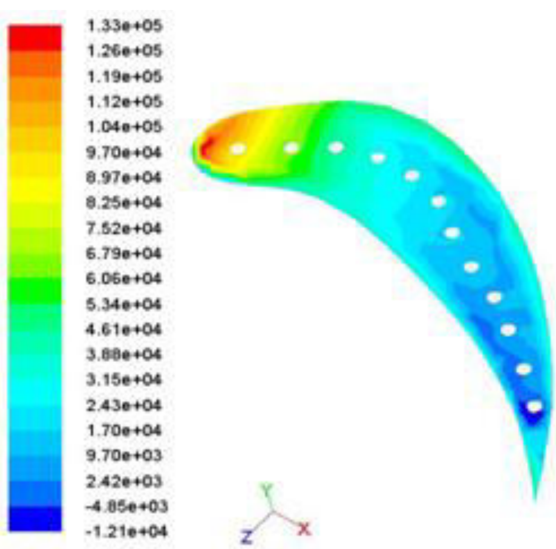

Fig.17 Variation of static pressure of 12 holes Nickel alloy in Gas Turbine Blade.

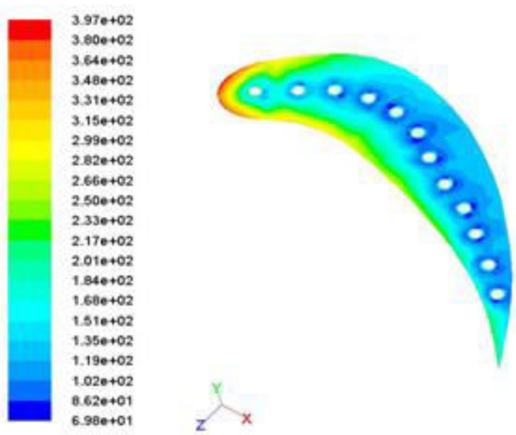

Fig.18 Variation of static temperature of 12 Holes Nickel alloy in Gas Turbine Blade.

Contours of Titanium aluminum alloy with 12 holes

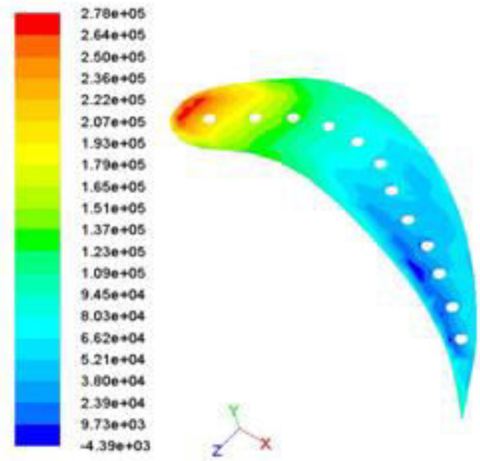

Fig.19 Variation of static pressure of 12 holes Titanium alloy in Gas Turbine Blade.

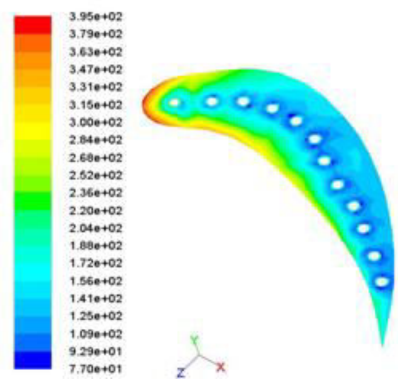

Fig.20 Variation of static temperature of 12 holes

Table 4 Variation of Pressure and Temperature distribution

No. of Holes	Pressure(Pa)		Temperature(◦C)	
	Titanium alloy	Nickel alloy	Titanium alloy	Nickel alloy
6	2.76e6	9.80e5	6.68e2	6.65e2
8	2.46e6	2.63e5	5.25e2	5.06e2
12	1.38e6	1.33e5	3.95e2	2.64e2

From the above results it is observed, when the number of holes increases pressure decreases, Nickel alloy gives the minimum pressure because Nickel alloy is better material than Titanium alloy. Pressure distribution depends on the material used for the blade and strength of the blade. Nickel alloy gives the minimum temperature because Nickel alloy is better material than Titanium alloy. Temperature depends on the material strength.

VI. CONCLUSION

- Using CFD analysis as a tool, the flow analysis is carried out sequentially.
- The blade with different no. of holes 6,8 and 12 were used for analysis. It was found that the blade with 8 holes has the moderate cooling rate for both materials of the blade when the coolant temperature was 300ºC.
- The placement of cooling holes in the blades which resulted in increased turbine efficiency.
- The overall cooling rate is 20% from the both materials with 6 and 12 holes models.

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