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Computational Analysis of Turbine Blade Cooling using Cylindrical Coolant Channels

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Abstract - *A Turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. In a gas turbine engine, turbine blades are operated at extremely high temperatures. So, heat transfer from the blades play a vital role. Cooling of a gas turbine blade is a challenging task to ensure safe operation. Different methods can be adopted to improve cooling efficiency. This paper focusses on how to improve the heat transfer in the turbine blade by varying the number of coolant channels. The CFD analysis of the blade is done with four different models consisting of 10,12,14 and 18 coolant channels. The temperature distribution for the various models are analyzed and plotted. The turbine blade with 18 coolant channels delivered the maximum cooling effect. Compared to the other models, this model shows 7.85% reduction in temperature from the original isothermal blade temperature.*

***Key Words*: Rotary Mechanical Device, ANSYS Workbench, Cooling Effectiveness, Efficient, Heat Transfer, Channels.**

1. INTRODUCTION

Gas turbine engines are used as a prominent equipment in the aviation industry. The engines have gone through various advancements in the cycle of usage. The efficiency and power output of gas turbine powerplants is dependent on the efficiency attained in the cycle. The latest gas turbine engines operate at a temperature range between 1100K and 1300K. Due to the increase in temperatures of the hot gases, the heat transferred to the blades increase substantially leading to thermal failure of the blade. The developments in turbine blade cooling play a vital role in increasing efficiency and decreasing the chances of failure of the blade. Turbine Blade cooling is a method that is used to cool the turbine Blade due to high temperatures acting on the blade which can lead to disintegration of the blade. This can be done by various methods. The types of cooling methods that are being used are as follows: 1. Convection cooling, 2. Film cooling and 3. Transpiration cooling. All these methods use cold air for cooling which is taken from the compressor section as bleed air and is fed to the turbine for cooling. The method used in this paper is Film cooling. Film cooling is the ejection of coolant gas through channels in the airfoil body which results in a layer or film of coolant gas flowing closely to the external concave surface of the airfoil. The recent papers have studied the variation in the number of holes, the variation in hole size depending on the amount of cooling needed and the various hole shapes. The analysis has been carried out under steady state conditions using ANSYS software. Our study was conducted using different materials such as Titanium Alloy, Nickel and Inconel 718. Out of the three, Titanium Alloy gave extremely satisfying results and hence it was used for the Turbine blade material.

2 LITERATURE SURVEY

[1] **Aqeel Jomma Athab (August 2015)** investigated the heat transfer analysis of a gas turbine blade without holes and blade with three different models consisting of 4,8 and 12 holes. The analysis was done using the commercial CFD software FLUENT (a turbulence reliable k-ϵ model with enhanced wall treatment) has been used. On evaluating the graphs drawn for total heat transfer rate and temperature distribution, the blade with 12 holes is considered as optimum. Steady state thermal and structural analysis was done using ANSYS software with different blade materials Inconel 718, chromium steel and N-155. With comparison of these materials Inconel-718 had better thermal properties and induced stress is lesser than the chromium steel and N-155.

[2] **N.Nandakumar, N.Selva Moorthi (April 2015)** have studied high operating pressures and temperatures in the turbine blade. The analysis was carried out using the commercial CFD software FLUENT (a turbulence reliable k-ϵ model with enhanced wall treatment). The turbine blade was fixed with a single configuration of 4 holes. As the temperature is increased above the 1500K mark, cooling of turbine blades offers a practical approach with high performance. Investigation into the base of turbine blade

when coolant is ejected from the trailing edge at span-wise angle. The temperature reduction rate of the turbine blade without passages were analysed and it was compared to the blade with holes.

[3] **Prakhar Jindal, A.K.Roy, R.P.Sharma (October 2015)** have studied the performance of different hole shapes, cooling effectiveness was measured in terms of centre line and spatially averaged adiabatic film cooling. The analysis was carried out using the commercial CFD software FLUENT. For the validation of CFD results, the case of cylindrical holes is compared with that of experimental data. Various models, a cylindrical, ellipse and triangular were observed. Various inlet velocities are used for the analysis (M 0.33, M 0.5, M 0.67, M 1.0). Various hole shaped geometries have been presented and compared to each for better results in terms of centre line and spatially averaged film cooling effectiveness. Triangular hole shape gave the highest centre line film cooling effectiveness. Elliptical hole shape shows transitional results between other hole shapes.

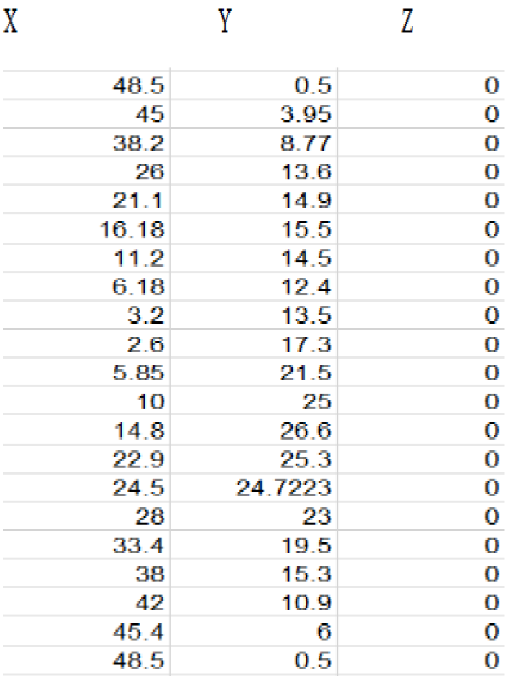
[4] Hadeel Raheem Jasim (June 2018), conducted analysis to improve thermal efficiency and power output required to increase turbine inlet temperatures. Several methods have been suggested for cooling of the blades. It mainly focuses on gas turbine blade heat transfer analysis and effect of increase of external film cooling holes with internal film cooling holes. Three different models consisting of without holes, 2 and 3 external row of film cooling with specific number of internal cooling holes were considered. The analysis was carried out using the commercial CFD software FLUENT. A turbulence realizable k-€ model with enhanced wall treatment was used. The analysis stated that increase in number of external film cooling holes always does not lower the blade leading edge temperature. Inconel 718 alloy was used as the optimum material for the blade. Nitrogen proved to be the preferred coolant for its cooling performance.

3 PROBLEM STATEMENT

Turbine blades are components that extract energy from the hot gases. They face prolonged interaction with hot gases for the duration of the flight. Due to prolonged interaction with hot gases, they undergo physical changes like expansion or contraction. Due to these changes that take place the efficiency of the turbine blade is reduced. This leads to lower thrust production, increase in fuel consumption and decrease in the life of the turbine, which leads to failure. In order to avoid these the turbine has to be cooled to a certain extent for proper functioning and to reduce the probability of failure. The problem which is commonly faced in the recent times is that the cooling that is supplied is not sufficient for the maximum extraction of power from the hot gases. So, the main focus is to improvise the cooling of the turbine blade to its maximum without compromising its structural integrity.

4. METHODOLOGY

Computational fluid dynamics was used which is a computer-based simulation. These analyses are based on fluid flow and heat transfer properties of the test model. The blade was designed using SOLIDWORKS software, using the coordinate file which was taken from [1]. The import function in SOLIDWORKS helped to import the blade into the software. The blade was first designed without any coolant channels and then modifications were done to the blade by adding channels that goes through the lateral axis of the blade. Then coolant channels were added above and below the camber line depending on the structural integrity of the blade.



X	Y	Z
48.5	0.5	0
45	3.95	0
38.2	8.77	0
26	13.6	0
21.1	14.9	0
16.18	15.5	0
11.2	14.5	0
6.18	12.4	0
3.2	13.5	0
2.6	17.3	0
5.85	21.5	0
10	25	0
14.8	26.6	0
22.9	25.3	0
24.5	24.7223	0
28	23	0
33.4	19.5	0
38	15.3	0
42	10.9	0
45.4	6	0
48.5	0.5	0

Fig -1: Turbine Blade Coordinates

The turbine blade was imported in an .IGES format file into ANSYS FLUENT for analysis. Boolean operation was performed on the geometry where the coolant tubes were subtracted from the turbine part and the result was preserved. An unstructured meshing was done to the geometry using Sweep method with manual source and target option and the resulting meshed model was a combination of both Tri and Quad elements. User defined edge sizing was given to the blade edges and to the coolant tube edges. This provides a fine mesh around the coolant tubes for more accurate results.

Table -1: Blade Design Specifications

Chord length	4.59cm
Max Thickness	1.13cm
Leading Edge Thickness	0.86cm
Mid-Section Thickness	1.11cm
Trailing Edge Thickness	0.14cm
Blade Height	8cm
Hole Diameter	0.075cm
Camber Length	5.48cm

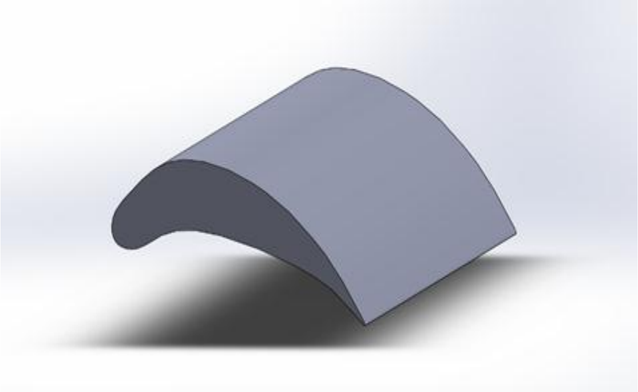


Fig -2: Imported Model of the Turbine Blade

Table -2: Technical Data for Analysis

Type of Flow	Turbulent
Coolant	Air
Isothermal Turbine Temperature	1100K
Coolant Temperature	220K
Coolant Velocity	140 m/s

In the problem setup, the energy equation was enabled as the analysis involved temperature. A realizable k-€ turbulence model was used with enhanced wall treatment which enables conjugate (or) convective heat transfer. A pressure-velocity coupling method was used with a SIMPLE solution scheme to solve the equations and second order upwind conditions were given to pressure, momentum, turbulent kinetic energy, turbulent dissipation rate and energy. The convergence criteria were given accordingly to continuity, x, y and z velocities, energy, kinetic energy (k) and dissipation rate (€).

5. RESULTS AND DISCUSSIONS

The temperature distribution of the blade depends on the thermal conductivity of the material. The analysis was carried out for steady state heat transfer conditions. This was performed for all three materials with a single hole turbine. Titanium Alloy proved to be the best suited for the turbine blade material due to the difference in temperatures.

Table -3: Material Temperatures

Material Temperature	**Titanium Alloy**	**Nickel**	**Inconel 718**
Before cooling	1100K	1100K	1100K
After cooling	1060.921K	1096.628K	1087.79K

Coolant was injected at a temperature of 220K and at a velocity of 140m/s for all the cases.

CASE Ⅰ: 10 Hole Turbine

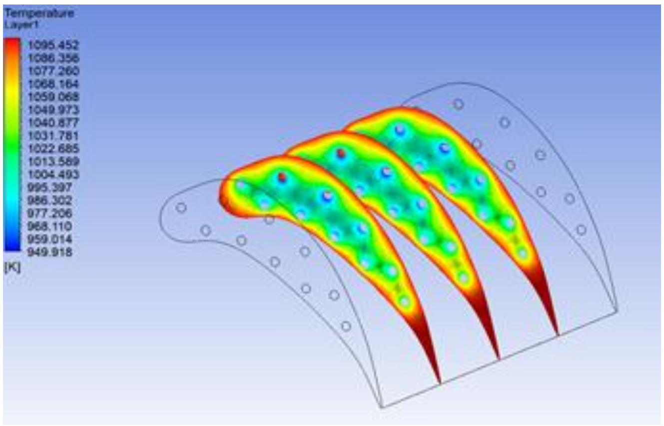


Fig -3: Temperature Distribution using section planes

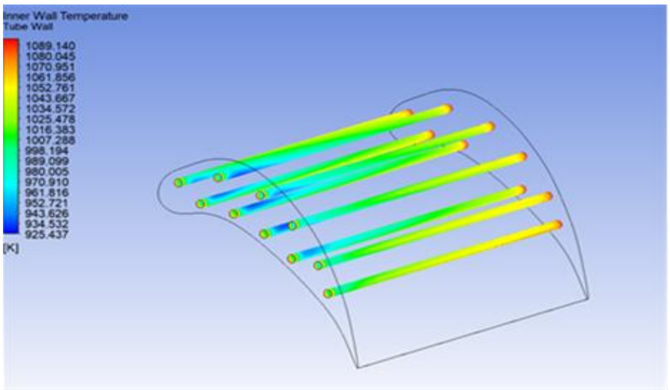


Fig -4: Inner Wall Temperature Distribution

CASE Ⅱ: 12 Hole Turbine

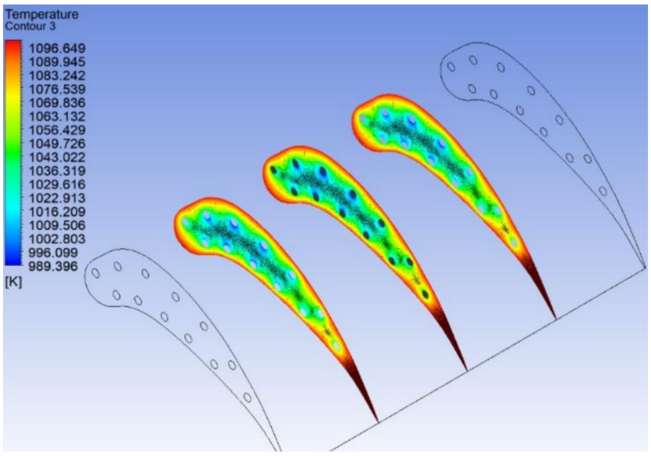


Fig -5: Temperature Distribution using section planes

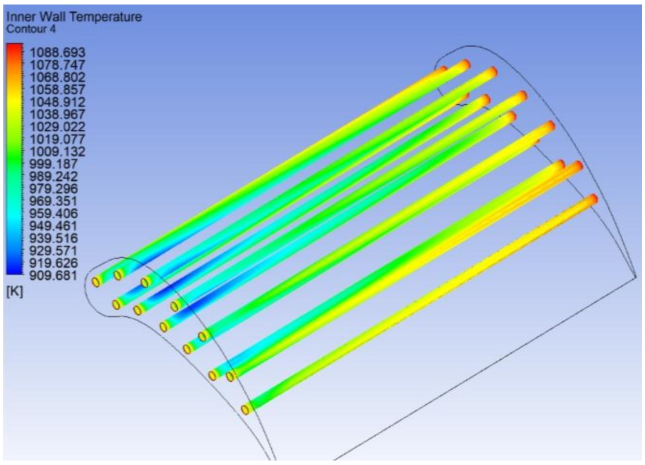


Fig -6: Inner Wall Temperature Distribution

CASE Ⅲ: 14 Hole Turbine

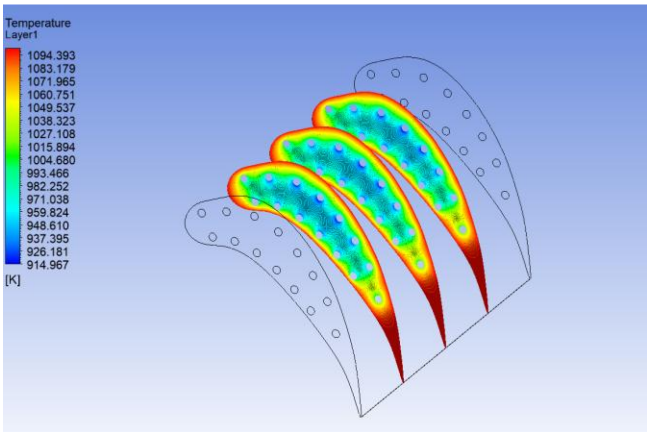


Fig -7: Temperature Distribution using section planes

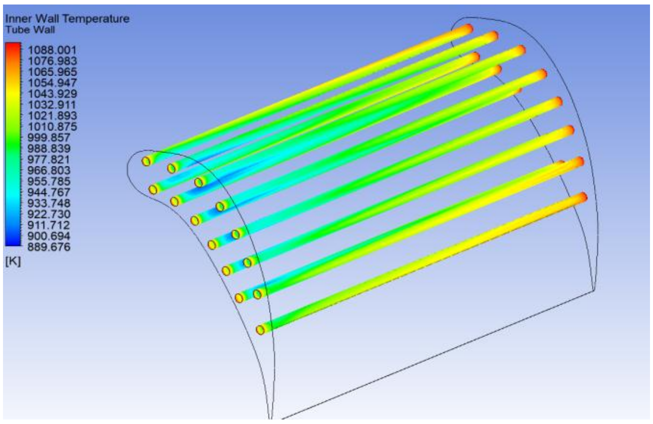


Fig -8: Inner Wall Temperature Distribution

CASE Ⅳ: 18 Hole Turbine

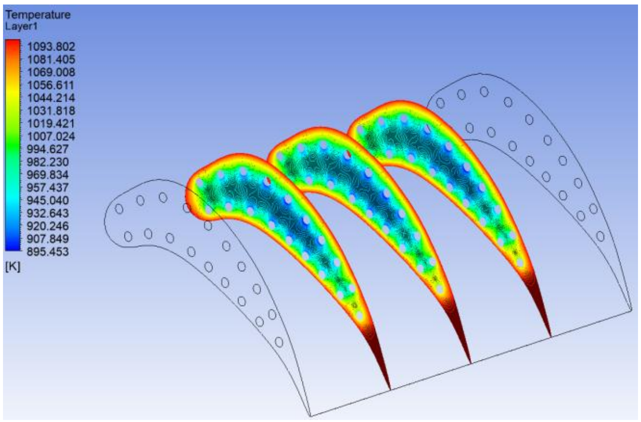


Fig -9: Temperature Distribution using section planes

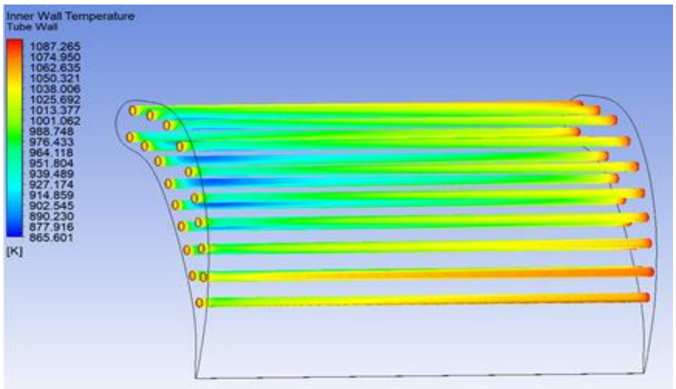


Fig -10: Inner Wall Temperature Distribution

Fig. 3, 5, 7 and 9 displays the temperature distribution on 3 section planes created at a distance of 0.02m, 0.04m and 0.06m from the root of the blade. Fig. 4, 6, 8 and 10 displays the Inner wall temperature distribution of the coolant channels after heat transfer takes place.

6. CONCLUSIONS

Gas turbine blade cooling is studied for 4 different models of the turbine blade. Among the various modifications done (10,12,14 and 18) holes, the 18 hole turbine proved to be the most efficient in cooling of the turbine blade. This in turn shows that with increase in number of holes, the cooling effectiveness also increases progressively.

The temperature of the 18 hole turbine dropped by 7.85% from 1100K original temperature to about 1013.627K. This is the least temperature value when compared to the other turbine cases and they are shown below.

Table -4: Overall Reduction in Blade Temperature

Turbine Configuration	Original Temp (K)	Reduced Temp (K)	% Reduction
10 Hole	1100	1040.033	5.45
12 Hole		1033.589	6.03
14 Hole		1022.351	7.05
18 Hole		1013.627	7.85

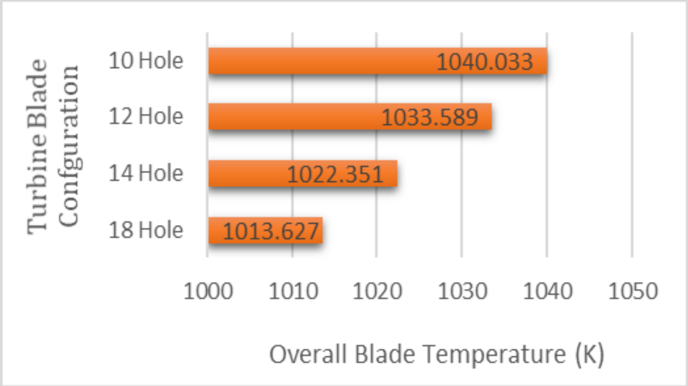


Chart 1: Reduction in Blade Temperature

Table -5: Temperature of Coolant at Inlet and Outlet

Turbine Configuration	Average Coolant Temperature at Inlet (K)	Average Coolant Temperature at Outlet (K)
10 Hole	220	718.42
12 Hole	220	715.137
14 Hole	220	710.007
18 Hole	220	705.317

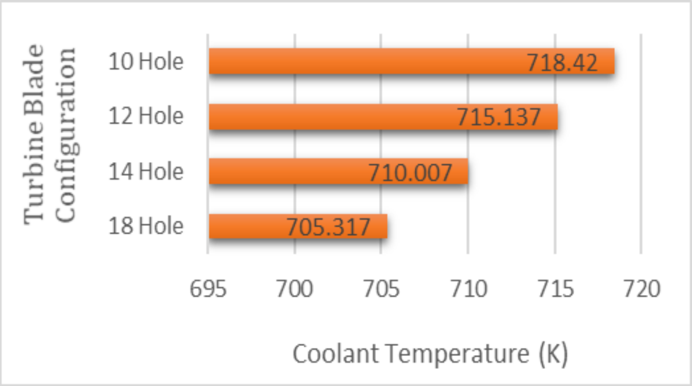


Chart 2: Average Coolant Temperature at Outlet

REFERENCES

[1] Aqeel Jomma Athab, "CFD Analysis of a Gas Turbine Blade Cooling in the presence of holes", International Journal of Magazine and Engineering, Vol 2, Pages 1637-1644, August 2015.

[2] N. Nandakumar, N. Selvamoorthi, "Performance Analysis of Gas Turbine Blade cooling using CFD", International Journal on Applications in Mechanical and Production Engineering, Vol 1, Pages 3-9, April 2015.

[3] Prakhar Jindal, AK Roy, "Numerical Study of Film Cooling for Various Coolant Inlet Geometries", International Journal of Engineering and Technology, Vol 7, Pages 1659-1670, October 2015.

[4] Hadeel Rahim, Narsimhulu Sanke, "Heat Transfer Simulation of Gas Turbine Blade with Film Cooling", International Journal of Modern Engineering and Research Technology, Vol 5 Pages 73-82, June 2018.

[5] Je-Chin Han, "Studies in Turbine Blade Cooling", International Journal of Rotating Machinery, Pages 443-457, 2004.

[6] Li Shaohua, Tao Peng, "Numerical Simulation of Turbine Blade Film-cooling with Different Blowing Ratio and Hole-to-hole Space", International Conference on Power Engineering, Pages 1372-1375, October 2007.

[7] Luca Andrei, Luca Innocenti, "Film Cooling Modelling for Gas Turbine Nozzles and Blades", Journal of Turbomachinery ASME, , Vol 139, Pages 011004 1-9, January 2017.

[8] Arkan.K.Al-Taie, "Turbine Blade Cooling by Air using different methods", The Iraqi Journal for Mechanical and Material Engineering, , Vol 11 Pages 220-241, 2011.

[9] R.J Goldstein, S.Ito, "Film Cooling of a Gas Turbine Blade", Journal of Engineering of Power ASME ,Vol 100, Pages 476-481, July 1978.

[10] R.Z Aminov, A.B Moskalenko, "Optimal Gas Turbine Inlet Temperature for Cyclic Operation", Journal of Physics, Series 1111, Pages 1-13, 2018.

[11] Robert P Schroeder, Karen A Thole, "Effect of In-hole Roughness of Film Cooling", Journal of Turbomachinery ASME, , Vol 139, Pages 031004 1-9, March 2017.

[12] T Povey, "Effect of Film Cooling on Turbine Capacity", Journal of Engineering for Gas Turbine and Power ASME, Vol 32, Pages 011901 1-10, January 2010.