IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

CFD Analysis of Gas Turbine Blade to Improve Cooling Achieved Through Multiple Air Cavity Obtained By Drilled Passage inside the Structure

Payal N. Patel

Master of engineering student, Department of Mechanical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, India – 390002;

Dr. Amit R. Patel

Associate Professor, Department of Mechanical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, India – 390002

ABSTRACT

The temperature of turbine blades in advanced gas turbines is above the melting point of the blade material. To ensure continuous safe operation of high- performance gas turbines, a cooling scheme must be developed. A radial hole to pass high velocity cooling air along the blade span is one of the suggested methods.

In this project NACA 6409 airfoil is taking for turbine blade. Turbine blade is designed in CATIA V5R19 and for analysis we are using ANSYS 18.1 software. The turbine blades are cooled using convection cooling and radial holes to pass cooling air along the blade span. The heat transfer analysis of gas turbine with 6 different models consisting of No hole, 3, 5 and 7 inline one row of holes and compared with 7 and 9 models in staggered holes with different types of materials. Here we are using chromium steel, inconel-718 and inconel-625 as turbine blade material. CFD, Thermal and structural analysis is performing to determine the heat transfer rates, temperature distribution and stress of the blade.

Keywords: Turbine Blade, NACA6409, CFD Analysis, Inline holes, staggered holes, ANSYS 18.1, Temperature, Stress and Heat transfer rate.

1. NOMENCLATURE

N	Rotational speed (rev/sec)
U	Mean blade speed (m/sec)
A	Area of annular (m^2)
c	Chord length (mm)
h	Height of blade (mm)
r_{root}	Radius of blade at root (mm)
r_{tip}	Radius of blade at tip (mm)
r_m	Radius of mean rotor (mm)
ω	Angular velocity (rad/sec)
K	Thermal conductivity (W/m-k)
ρ	Density of material (kg/m^3)
Cp	Specific heat (J/kg-k)

2. INTRODUCTION

A Gas turbine engine is also known as a combustion turbine. It has an upstream compressor and downstream turbine with the combustor in between. High-pressure air enters the compressor, which compresses it and delivers it to the combustion chamber. The fuel injector continuously feeds fuel, which mixes with the compressed air in the combustion chamber and ignites, creating a continuous combustion at constant pressure. The high- pressure, high-temperature gases then enter the turbine, where they expand to drive the turbine, which is directly connected to the compressor. The gases expand further in the exhaust after the turbine. The schematic view of Gas Turbine Engine is shown in the Figure 1.

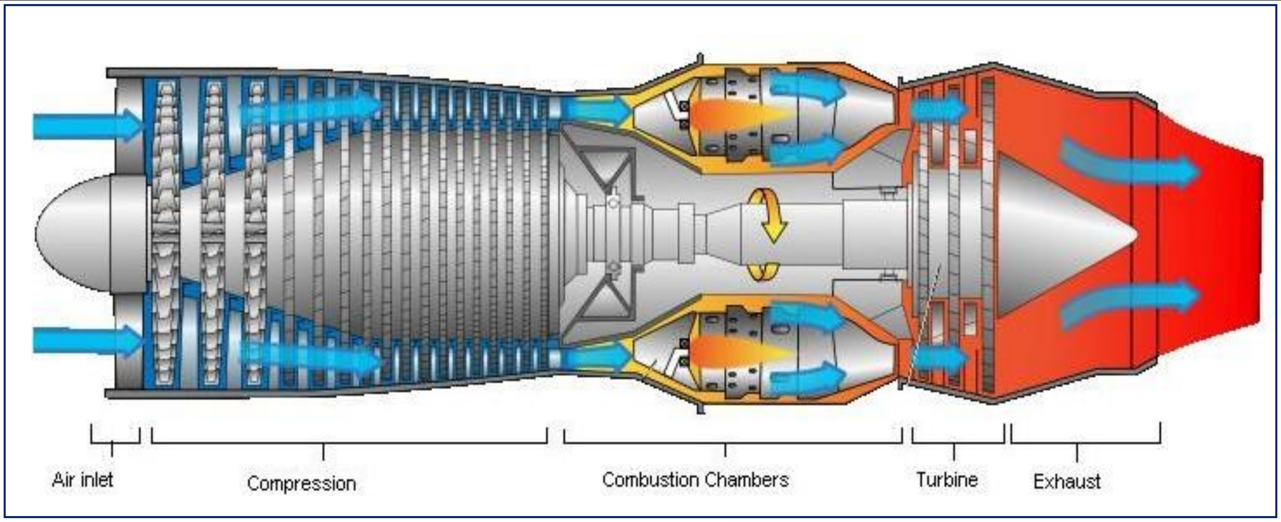


Figure 1: Schematic View of Gas Turbine Engine.(1)

3. METHODOLOGY

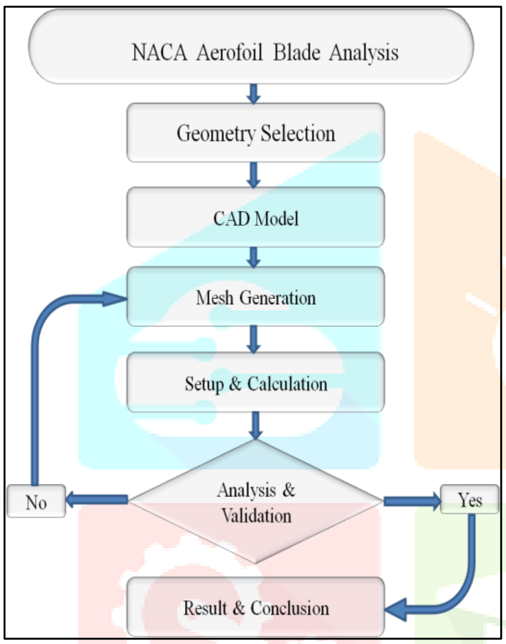


Figure 2: Flow chart of analysis

a. GEOMETRY SELECTION (9)

As per discussion of research gap here we generating NACA 6409 aerofoil in CATIA software. First we taken from the aerofoil coordinate and then using spline curve we generate aerofoil.

Figure 3: NACA 6409 airfoil with distance 49.2mm (9)

Table 1: NACA 6409 with speed of 300rev/sec (9)

Parameters	300 rev/sec
Height	49.2mm
Radius of blade at root	197.4mm
Radius of blade at tip	246mm
Chord	38.4mm

b. Material Selection

Table 2: Material properties (3, 9)

Properties	Units	Chromium Steel	Inconel-625	Inconel-718
Yield Strength	MPa	275	448	1100
ρ	kg/m^3	7754	8440	8192
K	W/m-k	11.2	9.8	25.8
Cp	J/kg-k	435.801	550	586.253
Melting point	°C	1415	1350	1346
Young's Modulus	GPa	200	207.5	205
Poisson's Ratio	-	0.3	0.3	0.293

c. CAD DESIGN

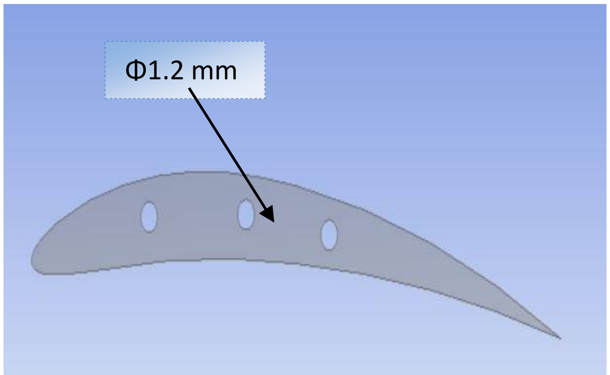


Figure 4: CAD design of 3 holes blade in CATIA software

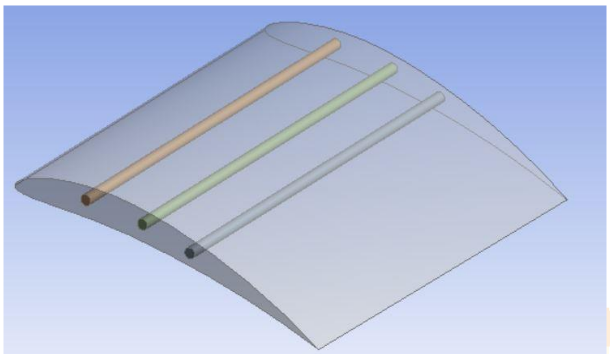


Figure 5: CAD design of regenerated 3 holes blade in ANSYS software

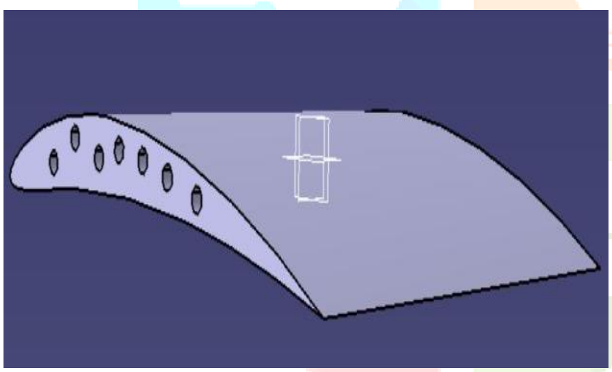
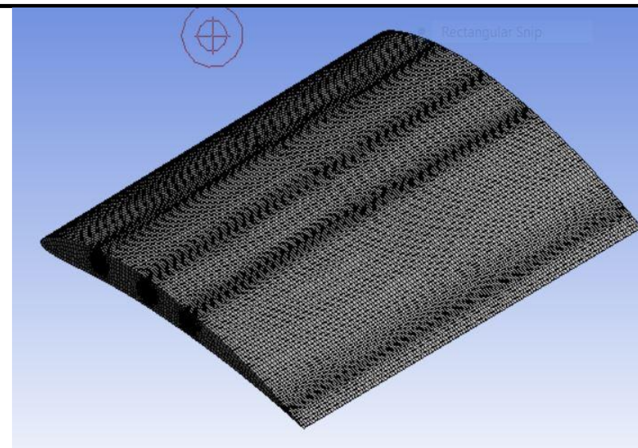


Figure 6: Cad model of 7 staggered hole

d. MESHING



(a)

Sizing	
Size Function	Proximity and Curvature
Relevance Center	Coarse
Transition	Slow
Span Angle Center	Coarse
Curvature Nor...	Default (70.3950 °)
Num Cells Acr...	Default (3)
Proximity Size Fu...	Faces and Edges
Min Size	Default (3.128e-002 mm)
Proximity Min ...	Default (3.128e-002 mm)
Max Face Size	Default (3.1280 mm)
Max Tet Size	Default (6.2560 mm)
Growth Rate	Default (1.20)
Automatic Mesh ...	On
Defeature Size	Default (1.564e-002 mm)
Minimum Edge L...	1.8850 mm
Quality	
Inflation	
Assembly Meshing	
Advanced	
Statistics	
Nodes	1752696
Elements	1736405

(b)

Figure 7: (a) Isometric view of 3 inline holes (b) Meshing details

e. SETUP

CFD analysis (10)

- Convective Heat Transfer Coefficient of outer surface of blade: 2500 W/m^2K
- Temperature of outer surface of blade: 1250 K
- Temperature of cold air: 300 K
- Velocity of cold air: 75 m/sec

f. Solution Method (2)

Energy equation was turned on and the (k-ε) realizable model, with standard wall functions was used to model the turbulent behavior. The SIMPLEC skewness correction allows ANSYS FLUENT to be obtaining a solution on a highly skewed mesh in approximately the same number of iterations as required for a more orthogonal mesh.

Scheme: SIMPLEC (Semi Implicit Method for Pressure Linked Equations Consistent)

Gradients: Least Square Cell Based

Solver: Pressure based

Fluid material: Air

4. RESULT

Material - Chromium steel

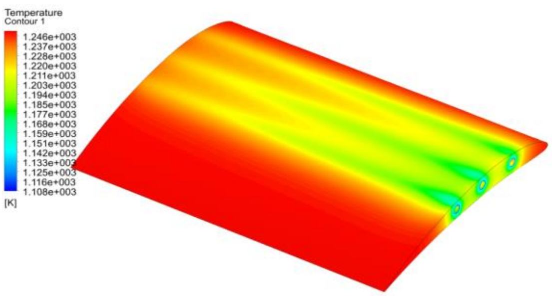


Figure 8: Temperature of blade with 3 inline holes

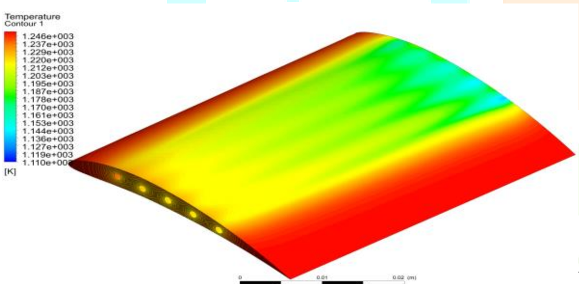


Figure 9: Temperature of blade with 5 inline holes

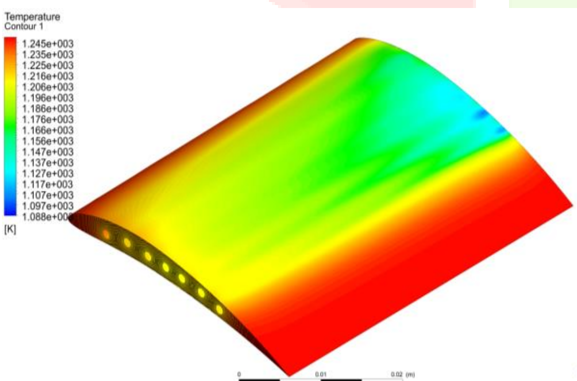


Figure 10: Temperature of blade with 7 inline holes

Material - Inconel-718

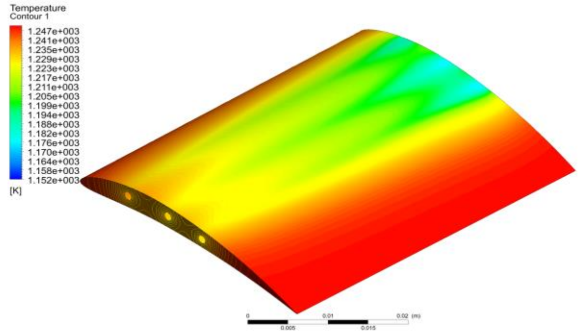


Figure 10: Temperature of blade with 3 inline holes

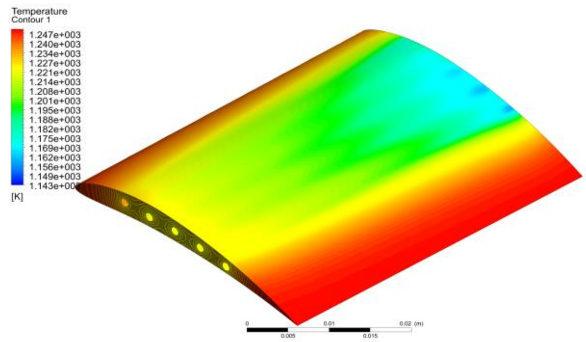


Figure 11: Temperature of blade with 5 inline holes

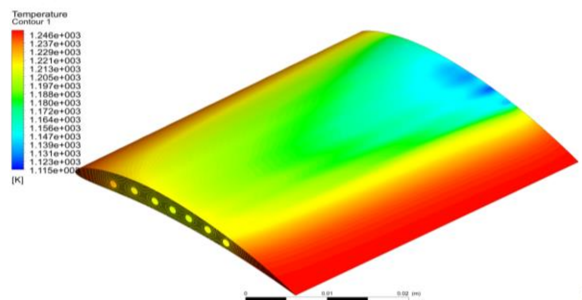


Figure 12: Temperature of blade with 7 inline holes

Material - Inconel-625

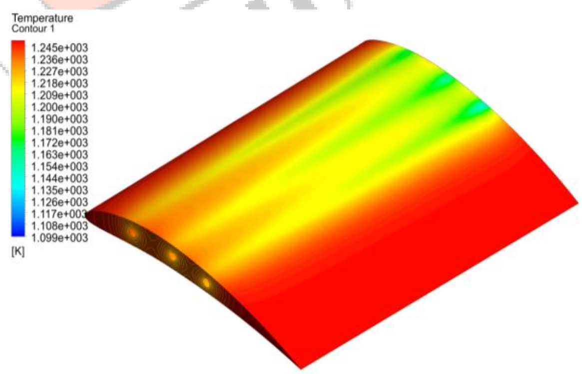


Figure 13: Temperature of blade with 3 inline holes

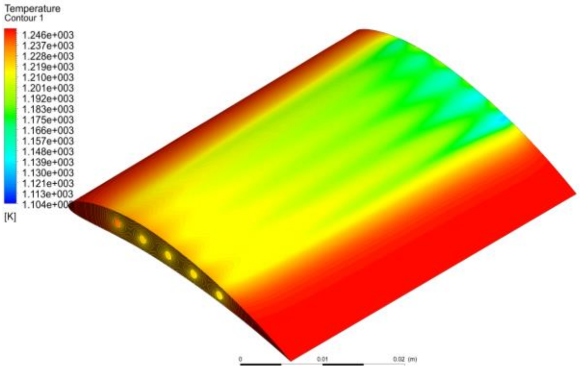


Figure 14: Temperature of blade with 5 inline holes

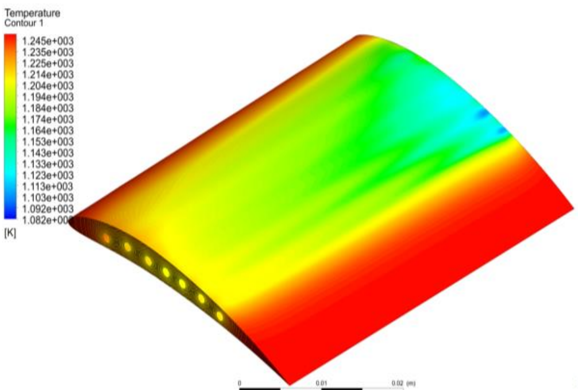


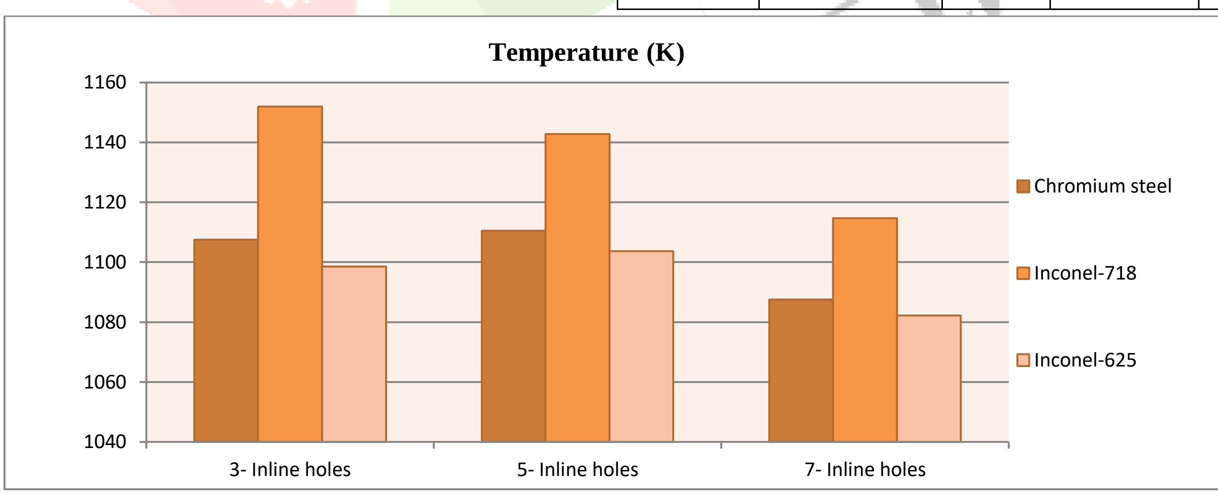
Figure 15: Temperature of blade with 7 inline holes

In this analysis we are using Inconel-625 and observe that temperature decrease more as compare other two materials. Alloy 625 is primarily nickel-based, while Alloy 718 is nickel + cobalt (Ni + Co) based. The use of nickel + cobalt in Alloy 718 means that it has greater hardness and strength. Alloy 625, on the other hand, has higher levels of chromium and molybdenum, so it is more corrosion-resistant. Therefore this material is better and also other properties are better than other two materials.

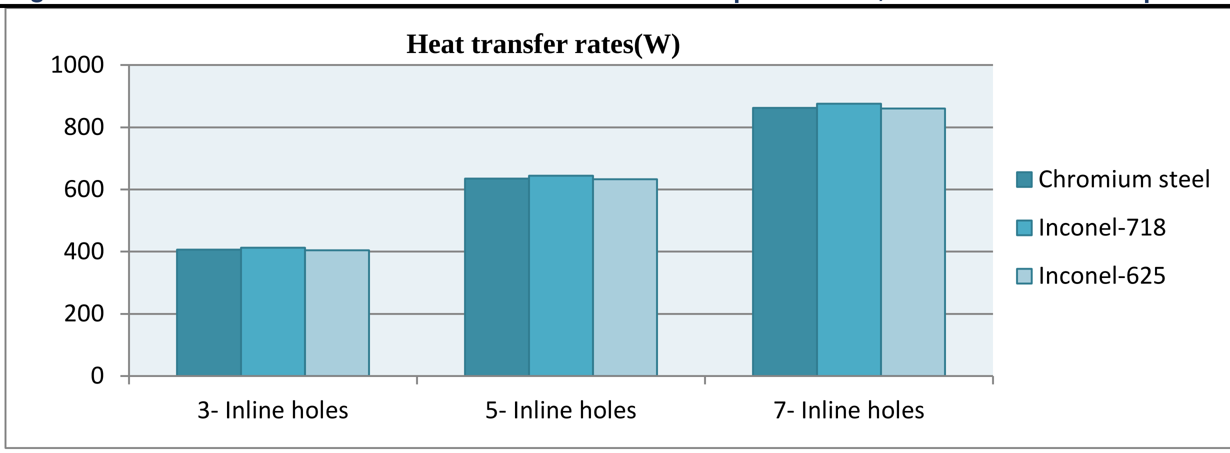
Here we can see in figure 32 temperature is higher on blade surface except hole area. When we increase number of hole we can see in figure 34 the leading and trailing edge temperature is decrease and on upper surface observed root to tip blade was cooled. So we observe that 7 numbers of holes are better with Inconel-625 than the other two materials and holes also. Due to the blade shape we cannot make more number of holes at trailing edge with 1.2 diameters. But we can do more holes not in inline but staggered hole. Because inline holes takes more space on tip and root area. In staggered hole we can do more hole than the inline holes.

Table 3: Temperature and heat transfer rate for three different materials of inline holes blade

Inline Models	**Materials**	**Results**		
		Temperature (K)		**Heat transfer rates(W)**
		Max.	**Min.**	
3-holes	Chromium steel	1250	1107.53	406.4865
	Inconel-718	1250	1151.92	412.537
	Inconel-625	1250	1098.52	404.7995
5-holes	Chromium steel	1250	1110.5	635.0833
	Inconel-718	1250	1142.8	644.441
	Inconel-625	1250	1103.67	633.2109
7-holes	Chromium steel	1250	1087.51	862.7646
	Inconel-718	1250	1114.67	875.4104
	Inconel-625	1250	1082.18	859.9073



Graph- 1: Temperature vs. no. of inline holes with material



Graph- 2: Heat transfer rate vs. no. of inline holes with material

- **Temperature contours with staggered hole**

<u>Material - Chromium steel</u>

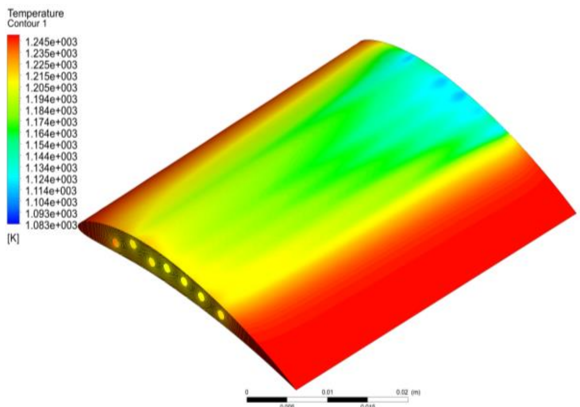


Figure 16: Temperature of blade with 7 staggered holes

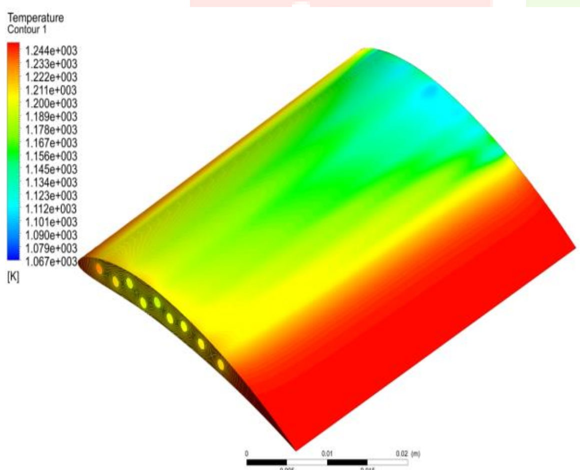


Figure 17: Temperature of blade with 9 staggered holes

<u>Material - Inconel-718</u>

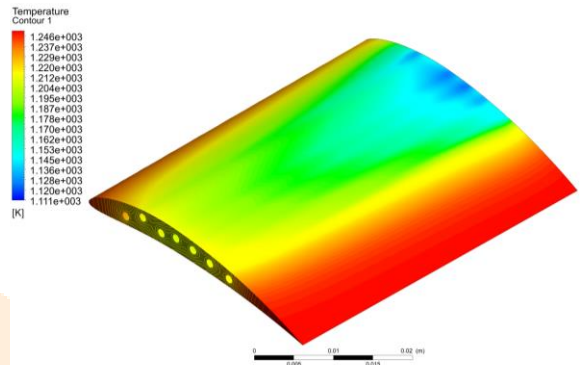


Figure 18: Temperature of blade with 7 staggered holes

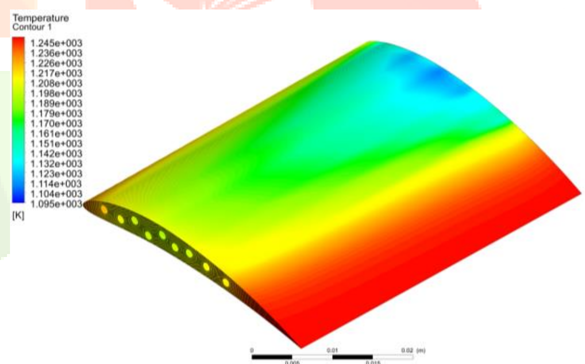


Figure 19: Temperature of blade with 9 staggered holes

<u>Material - Inconel-625</u>

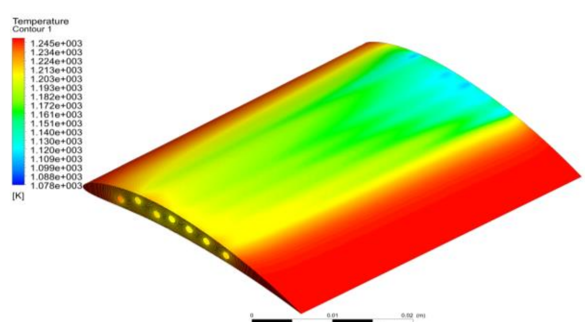


Figure 20: Temperature of blade with 7 staggered holes

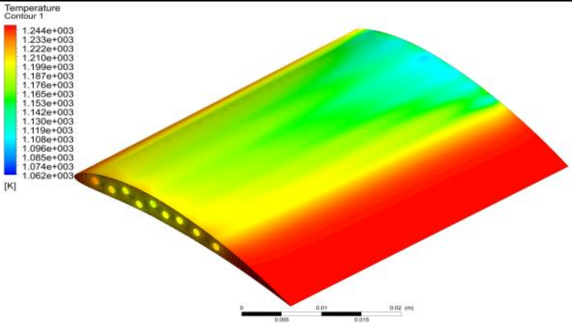
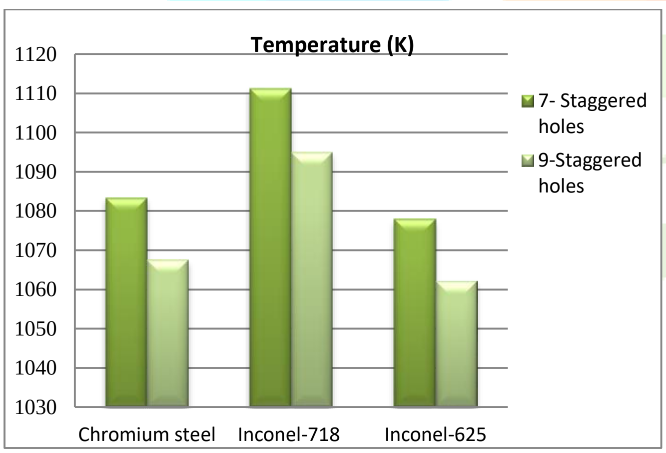


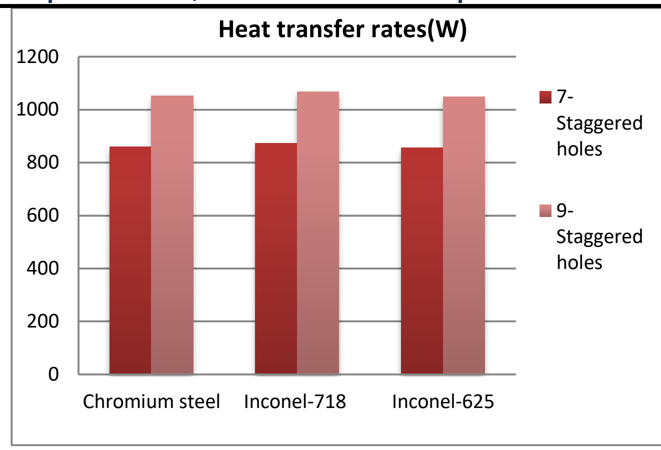
Figure 21: Temperature of blade with 9 staggered holes

Table 4: Temperature and heat transfer rate for three different materials of staggered holes blade

Staggered Models	Materials	Results		
		Temperature (K)		Heat transfer rates(W)
		Max.	Min.	
7-holes	Chromium steel	1250	1083.34	860.1815
	Inconel-718	1250	1111.21	873.0596
	Inconel-625	1250	1077.93	857.0347
9-holes	Chromium steel	1250	1067.48	1053.495
	Inconel-718	1250	1094.92	1069.148
	Inconel-625	1250	1062.14	1049.904



Graph 3: Temperature vs. no. of Staggered holes with material



Graph- 4: Heat transfer rate vs. no. of Staggered holes with material

- **Stress contours with inline holes**

Here we taking blade root as fixed support because we taken inlet at root. The blade rotational speed is 300rev/sec (1885.7 rad/sec).

Material - Chromium steel

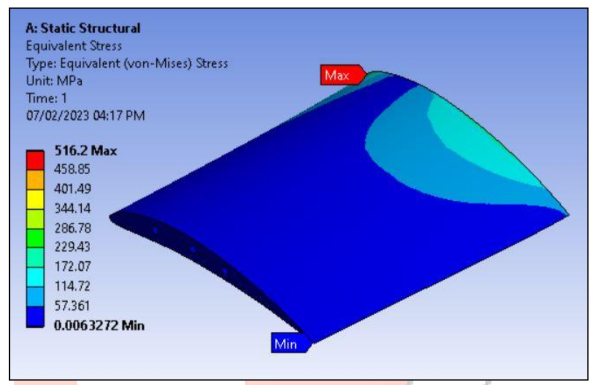


Figure 22: Stress of blade with 3 inline holes

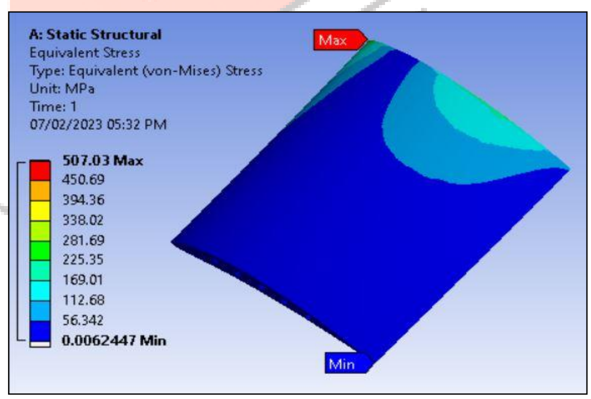


Figure 23: Stress of blade with 5 inline holes

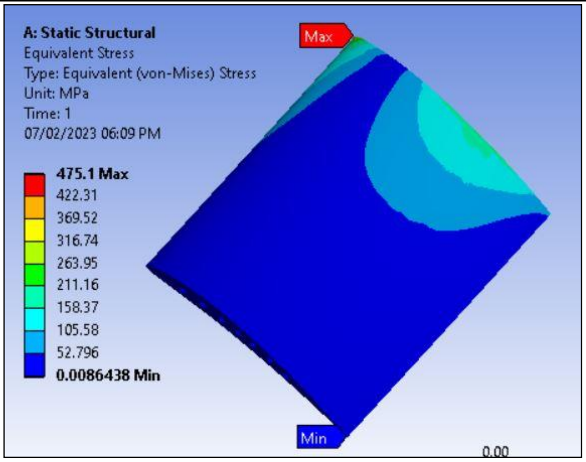
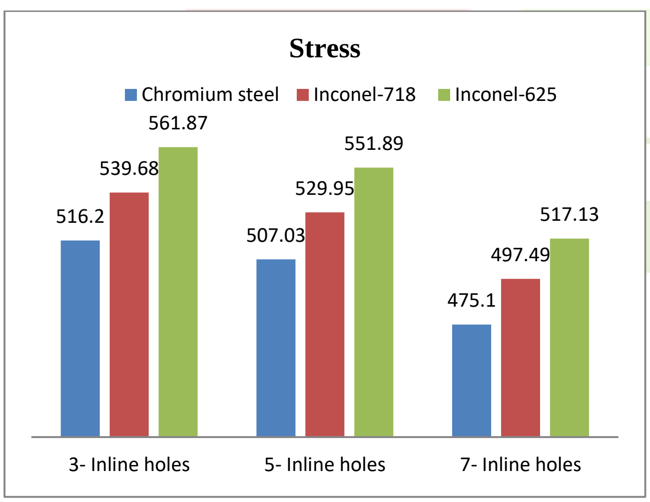


Figure 24: Stress of blade with 7 inline holes

Table 5: Stress for three different materials of inline holes blade

Inline Models	Materials	Stress(MPa)
3-holes	Chromium steel	516.2
	Inconel-718	539.68
	Inconel-625	561.87
5-holes	Chromium steel	507.03
	Inconel-718	529.95
	Inconel-625	551.89
7-holes	Chromium steel	475.1
	Inconel-718	497.49
	Inconel-625	517.13



Graph- 5: Stress vs. no. of Inline holes with material

- **Stress contours with staggered holes**

Material - Chromium steel

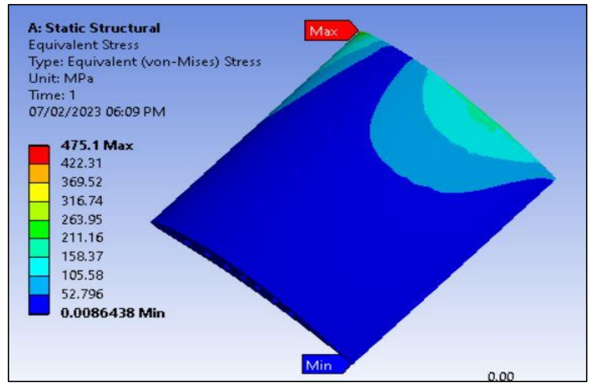


Figure 25: Stress of blade with 7 staggered holes

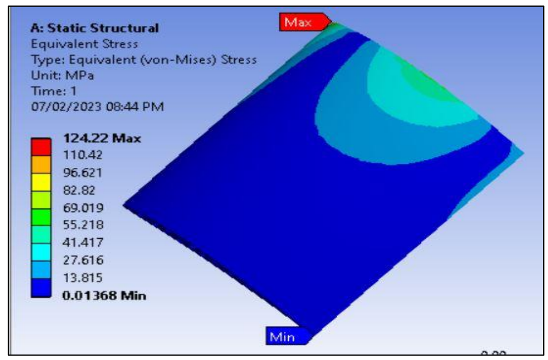
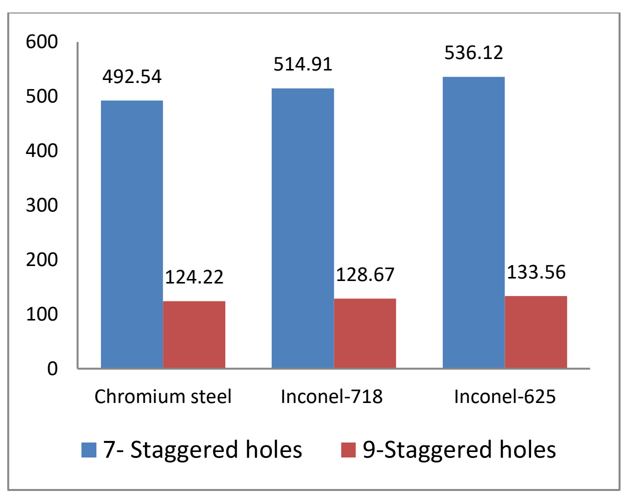


Figure 26: Stress of blade with 9 staggered holes

Table 8: Stress for three different materials of staggered holes blade

Staggered Models	Materials	Stress(MPa)
7-holes	Chromium steel	492.54
	Inconel-718	514.91
	Inconel-625	536.12
9-holes	Chromium steel	124.22
	Inconel-718	128.67
	Inconel-625	133.56



Graph- 6: Stress vs. no. of staggered holes with material

5. Discussion on stress, temperature and heat transfer rate

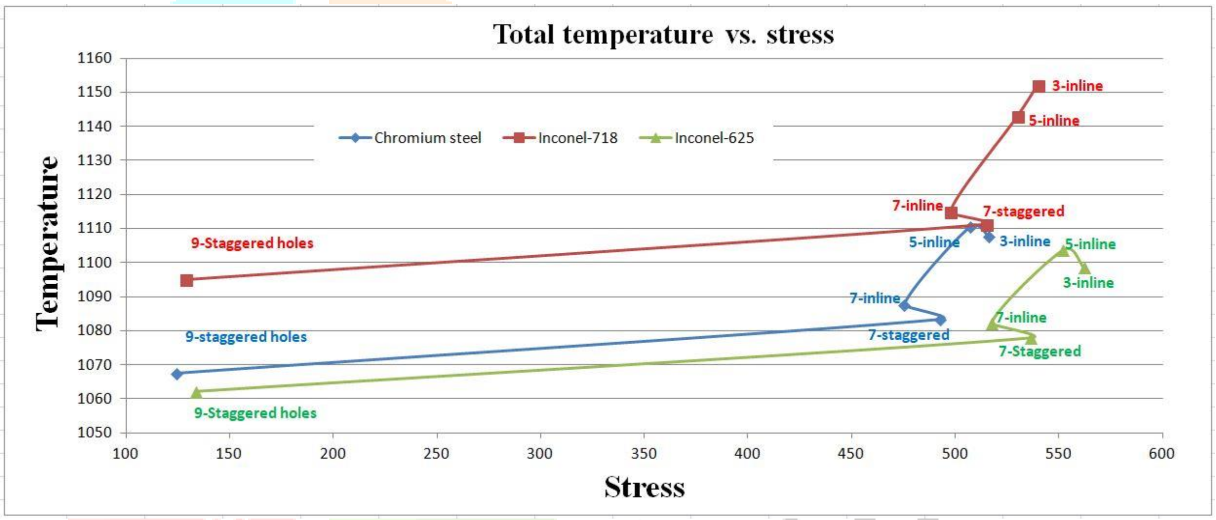
The providing of cooling passages reduces the body temperature of the blade and the temperature reduces with the increase in number of holes. It is also observed that the stresses induced in the blade root. There is an appraisable decreasing in the induced stresses when holes are provided. When we increase number of holes we observed that the decreases in induced stress. It may be due to the reduced in thermal expansion in blade is reduce temperature when we provided holes.

The maximum stresses induced for 9 staggered holes model are 133.56 MPa and 124.22 MPa for Inconel-625 and Chromium steel respectively. These values are within limits. The decreasing in stresses is due to increase in cooling passages which are closely spaced. The cooling is more uniform and the passages are provided will allow the blade material to expand freely. This phenomenon is responsible for reduction in the stresses.

When the temperature is reduced, the heat transfer rate increases. For cooling need higher heat transfer rate. From table 6 we can see that 9 numbers of staggered holes have more heat transfer rate and temperature is also less than the inline holes of blade. The maximum temperature and heat transfer rate of 9 staggered holes model are 1094.92**K** & 1069**W** and 1062.14**K** & 1049**W** for Inconel-718 and Inconel-625 respectively. However, when we look at stress, we can see that the materials are almost identical, with little difference between chromium steel, Inconel-718, and Inconel-625.

6. CONCLUSION

CFD analysis of gas turbine blade is done with three different materials i.e., chromium steel, inconel-718 & inconel-625 and different models like staggered and inline holes. It can be concluded from this work that the claims made by various researchers in the past years as far as the cooling effects on turbine blade by holes are concerned are true and verified. In the overall stresses the temperature showed significant effect in the turbine blade.As compare to inline holes result, staggered holes give better solution. When we focus on inline holes temperature there is not much different between temperature but there is little bit different in heat transfer rate with all three material because these all three material are very strong for gas turbine blade. It found that maximum heat transfer rate and minimum temperature is observed in 9 staggered



Graph- 7: Stress vs. Temperature for holes

holes. Due to the cooling holes get higher temperature at root and tip, but when we increase number of holes we reduced root temperature, and for this 9 staggered holes give better result. Stress is found lesser in 9 staggered holes for all three material then yield strength of material because of higher young modulus. So we conclude that for all three materials 9 staggered holes give better cooling. As per convenience of cost we can used any material from these three material But we can give first preference for material then **Inconel-625** is best material for turbine blade.

ACKNOWLEDGEMENTS

First and foremost, I offer my sincerest gratitude and respect to my guide**, Dr. Amit R. Patel**, Associate Professor Department of Mechanical Engineering, Faculty of Technology and Engineering, M. S. University of Baroda, for his valuable guidance and suggestions during my study. I consider myself extremely fortunate to have the opportunity of associating myself with him for course of this work.

I am grateful to **Dr.P.P.Gohil**, Head of Department, Department of Mechanical Engineering and **Dr.D.P.Patel**, Dean, Faculty of Technology & Engineering for providing us the necessary facilities in the department and college.

I am also thankful to **Mehul Bambhaniya** sir ,who is Assistant professor of the department of Mechanical Engineering and the other staff of the department of Mechanical Engineering and my friends for the provide all necessary guidance and support as and when required.

REFERENCES

1. Suryakar HA, Alchewar S, Bhalerao S. Effect of Heat Transfer Coefficient on Cooling of Gas Turbine Blades. Int J Sci Res Sci Eng Technol [Internet]. 2020; 7 (3):316–24. Available from: www.ijsrset.com

2. Behera A, Satapathy AK. CFD Analysis of Matrix Cooling Method In Gas Turbine Blades. 2014

3. Singh P, Shukla OP. Heat Transfer Analysis of Gas Turbine Rotor Blade through Staggered Holes Using CFD.

International Journal of Engineering Research And General Science [Internet]. 4(2). Available from: www.ijergs.org

4. Bathineedi Nagababu, V.S.Nagi Reddy, Abdul Arif.Design and CFD Analysis on Coated Steam Turbine Blade.2018

5. Brahmaiah H, Lava Kumar M. Heat Transfer Analysis of Gas Turbine Blade Through Cooling Holes [Internet]. Vol. 04, International Journal Of Computational Engineering Research. 2014. Available from: www.ijceronline.com

6. Jabbar AA, Rai AK, Reedy PR, Mahmood &, Dakhil H. Design And Analysis Of Gas Turbine Rotor Blade Using Finite Element Method.

7. Pulicherla A, Ganta Suresh M, Kilari N, Kothakota P. DESIGN, Cfd And Vibrational Analysis Of Gas Turbine Blade With Cooling. International Research Journal Of Engineering And Technology [Internet]. 2021; Available from: www.irjet.net

8. Ravi Ranjan Kumar and Prof.K.M.Pandey.Static Structural and Modal analysis of Gas Turbine Blade.2017

9. Konderu A, Purushothaman G. Determination of Thermal Stresses on Turbine Blades of Gas Turbine with NACA Airfoils By Finite Element Analysis [Internet]. Vol. 2, International Journal Of Innovative Science And Research Technology. 2017. Available from: www.ijisrt.com393

10. Hadeel Raheem Jasim,Narsimhulu Sanke. Heat Transfer Simulation of Gas Turbine Blade with Film Cooling.2018; Available from: http://www.ijmert.org