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Numerical Analysis and Comparison of Film Cooling and Convective Cooling for Turbojet Engine Application

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Abstract: This paper discusses various cooling methods for turbojet blades. It focuses on film cooling and its effect on performance of turbine. A turbine blade is designed and heat transfer analysis is performed considering various parameters likes gas temperature, coolant temperature etc. Final blade temperature is derived using numerical investigation for both convective cooling and film cooling. Based on result and analysis output, implementation of film cooling for turbo jet engine application is suggested.

Keywords: Turbojet Blades, Film Cooling, Convective Cooling

I. INTRODUCTION

In high temperature gas turbine the vane and blade will be exposed to the harshest thermal conditions. The latest sophisticated cooling scheme has been adopted to keep the metal temperature under the metallurgical limit temperature. In such cooling methods, film cooling is used to decrease the heat load from a high temperature mainstream by blowing a coolant through discreet holes. Such a cooling scheme was adopted in the high heat flux region of the vane and blade where large thermal stress will be generated if only internal convection cooling is used.

Film cooling might be applied to the first rotating blades whose turbine inlet temperature is over 1500°C. Film cooling on the rotating turbine blade is influenced not only by the cascade geometry but also the rotating effect and unsteady flow generated by nozzle wakes. To design a film cooled turbine blade, it is very important to understand the rotation effect on film cooling effectiveness in addition to the data taken by the stationary cascade test. They investigated that the result fitted to the stationary cascade data on suction surface and the low level of efficiency on pressure surface. The present experimental work has been done to study the film cooling effectiveness on a rotating blade. In this paper, typical film cooling test data are presented and film cooling on a rotating blade is discussed.

II. NOMENCLATURE

T_b	–	Blade Temperature
T_g	–	Gas Temperature
T_{c1}	–	Coolant Inlet Temperature
T_{c2}	–	Coolant Outlet Temperature
m^*	–	Mass flow function
m_{cb}	–	Blade mass flow
C_{pc}	–	Specific heat capacity
H_g	–	Heat Transfer Coefficient of gas
S_g	–	External perimeter of whole blade
L_b	–	Blade span
N_{pass}	–	Number of passes
N_c	–	Number of coolant channel
S_c	–	Channel Perimeter
ε	–	Convective Cooling Effectiveness
ε_f	–	Film Cooling Effectiveness
T_f	–	Film Temperature

III. LITERATURE SURVEY

Cohen & Roger has reviewed and listed out various types of cooling as Convective cooling, Film cooling for High temperature turbojet blades applications.[1] . Dr.P.Rubini (2009) has explained the concept of Film Cooling and Convective cooling and has derived various governing equations based on which comparison of cooling methods is done. [2]

James D Heidmann (2008) in his study has explained The Concept of Film Cooling. Film cooling is highly used on high pressure turbine vanes and blades, combustor to increase turbine inlet temperature for improved cycle's performance. Relatively cool air is taken from the compressor to supply the film cooling to the turbine. The film cooling is mainly done to reduce the temperature of blades, vanes or combustor as the technology of aerodynamics devolved the amount of heat coming out of the combustion chamber is also increased to very high level as the materials of the blade cannot hold such high temperature.[3]

Richard J Goldstein (1971) in his study has explained effects of film cooling. Though film cooling has primarily been used to reduce the convective heat transfer rate from a hot gas stream to an exposed wall, it could also be used to shield a surface from thermal radiation. This can be effectively accomplished with gas particle suspensions or a liquid coolant. [4]

David G.Bogard in his study has explained concept of film cooling effectiveness here the primary measure of film cooling performance is the film effectiveness, η, since this has a dominating effect on the net heat flux reduction. Furthermore, industrial designers typically will focus on the laterally averaged film effectiveness, η , which is the average η over a line normal to the flow and extending a distance equal to the pitch between holes. Besides the simplification in processing film effectiveness results by using only laterally averaged data, there is a physical rationale for using only the laterally averaged film effectiveness. However the large conductivity of the metal turbine aerofoil causes a much more uniform distribution of the "metal temperature". Consequently the laterally averaged film effectiveness is a reasonable representation of the effect of the coolant jet, and most of the correlations for film effectiveness presented in this section are in terms of laterally averaged cooling effectiveness.[5]

Zhihong Gao (2007) in his study of cooling, has suggested that Advanced cooling technologies must be applied to cool the blades, so they can withstand the extreme conditions. Film cooling is widely used in modern high temperature and high pressure blades as an active cooling scheme. In this study, the film cooling effectiveness in different regions of gas turbine blades was investigated with various film hole/slot configurations and mainstream flow conditions. effect of upstream wake on blade surface film cooling, effect of upstream vortex on platform purge flow cooling, influence of hole shape and angle on leading edge film cooling and slot film cooling on trailing edge. [6]

Vijay K. Garg (1997) in his study has explained Film cooling is one of the most efficient ways of protecting a turbine blade from the hot gas around it. However, the cooler air injected through the film-cooling holes in the blade is bled directly from the compressor before it passes through the combustion chamber. Thus, in order to minimize the use of coolant flow, turbine designers need to have an accurate prediction of the component heat load and film cooling effectiveness. While a considerable effort has been devoted to understanding the coolant film behavior and its interaction with the mainstream flow, many studies on film cooling have been confined to simple geometries. [7]

X. C. Li, G. Subbuswamy, J. Zhou (2013) in their study of film cooling, they coolant air is drawn from compressor and directed into the cooling channel of turbine blades after bypassing the combustion chamber. It is then injected through small holes onto the blade surface in a proper angle to form a thin layer and blanket the surface. The thin film with relatively low temperature is later deteriorated in the downstream because of the mixing of hot gas and coolant. The quality of film cooling is generally measured by an adiabatic film cooling effectiveness. The performance of film cooling is largely affected by many parameters such as the flow Reynolds number, blowing angle, blowing ratio, and the shape of the hole. [8]

Christopher N. LeBlanc (2012) in his study has explained the most basic implementation of film cooling uses cylindrical holes aligned with the flow direction to inject a layer of cooler fluid that protects the surface from exposure to the hot mainstream flow. A typical cylindrical hole will have an injection angle between 20° and 45°, with a common angle being 30°.[9]

IV. TYPES OF COOLING METHODS

4.1 CONVECTIVE COOLING:

Convective Cooling of blades is achieved by passing of air or liquid through internal cooling passages from the hub towards the blade tip. The internal passage may be circular or elliptical and are distributed over the entire surface of the blade. The cooling of the blade is achieved by conduction and convection. Relatively hotter air escapes to the main flow from the blade tip after traversing entire blade length in the cooling passage. [10]

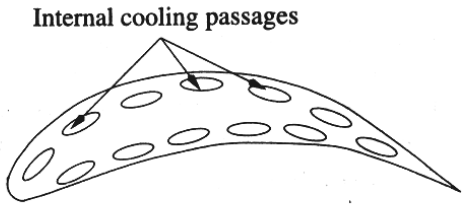

Fig 1: Convective Cooling

4.2 FILM COOLING:

The most critical areas of a turbine blade may be film cooled through a row of film cooling holes. The coolant is ejected through a hole at an angle with respect to the flow which in turn bends and covers a portion of the surface with a “blanket” of coolant. Film cooling can be applied by drilling holes on precision cast blades by the process of EDM. The cooling air flowing out of these small holes forms a thin film over the blade surface. Besides cooling the blade surface, it decreases the heat transfer from the hot gas to the metal blade. [10]

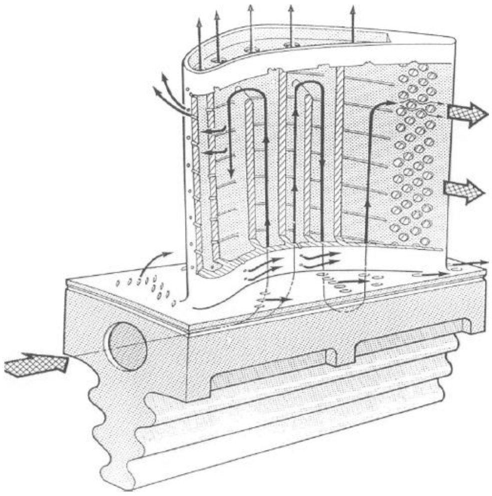

Fig 2: Film Cooling

V. GOVERNING EQUATIONS

Our main aim is to arrive at a equation that states a relation between Blade temperature and gas temperature. Convective cooling equations are as follows,

Convective Cooling Effectiveness,

$$\varepsilon = \frac{m^* \times \eta}{1 + m^*\eta} \qquad -\ (1)$$

Where,

$$m^* = \frac{m_{cb} \,.\, c_{pc}}{H_g \,.\, S_{g.} L_b} \qquad -\ (2)$$

And

$$\eta \ = \ 1 - \exp\left[\frac{-x}{m^*}\right] \qquad -\ (3)$$

where X = Technological Factor calculated from,

$$\mathrm{x} \ = \frac{H_c \,.\, N_{pass} \ .N_{c.} S_c}{H_g \,.\, S_{g.}} \qquad -\ (4)$$

Finally Blade Temperature for Convective Cooling is given by,

$$T_b \ = \ T_g - \ \varepsilon\big(T_g - T_{c1}\big) \qquad -\ (5)$$

Film Cooling comprises of heat transfer of both convective cooling and heat transfer initiated by formation of thin layer of coolant film.

Film Cooling Equations are as follows,
Overall Effectiveness is given by,

$$\varepsilon = \frac{m_f{}^{*}\eta_c + \varepsilon_f(1-\eta_c)}{1 + m_f{}^{*}\eta_c - \varepsilon_f\eta_c} \quad - (6)$$

where,

$$\varepsilon_f = \frac{T_g - T_f}{T_g - T_{c2}} \qquad and\ m_f{}^{*} = \frac{m_{cb}\, c_p}{h_f s_g L}$$

Finally Blade Temperature for Film Cooling is given by,

$$T_b = T_g - \varepsilon(T_g - T_{c1}) \quad - (7)$$

Input parameters for calculations,

T_g	–	1600 K
T_{c1}	–	750 K
m_{cb}	−	0.0313 kg/s
H_g	−	2000 W/m^2K
S_g	−	0.0990 m
L_b	−	0.0500 m

VI. RESULTS AND CONCLUSION

The purpose of this research is to design & analyze a quick model that can be used to cool the blade of gas turbine. Initially, this research required identification and selection of a rotor blade profile and the method for designing it. Later, based on that reference profile, study is carried out & an analytical model was designed that can handle any kind of turbine blade parameters. This model is capable of estimating metal temperature distribution of a blade profile to justify the performance of the cooling system design.

With the designed blade, we have numerically investigated the heat transfer for both convective cooling and & film cooling. Performance of gas turbine cooling depends on Gas Temperature, coolant Temperature, the shape and blade area. Some parameters are assumed based on the standards used in Aerodynamic Industries Such as HAL – BANGLORE such as size of the cooling holes, film cooling pattern design, heat transfer distribution, turbulence intensity, mass flow rate, in the upstream flow surface roughness.

Input parameters and standard assumptions are substituted in the governing equations and results are arrived as

Blade Temperature on Convective Cooling – 1253 K
Blade Temperature on Film cooling – 946 K

Based on the comparisons of numerical investigation & other Analytical Result we conclude that film cooling is more efficient in preventing the blades from getting damaged compare to other cooling techniques

VII. REFERENCES

[1]. HIH Saravanamuttoo, GFC Rogers, H Cohen, Gas Turbine Theory,Pearson Education, Ltd, (1951).
[2]. P.Rubini,, Turbine Blade Cooling, Cranfield University, 2010)
[3]. James D. Heidmann , A Numerical Study of Anti-Vortex Film Cooling Designs at High Blowing Ratio, Turbo Expo 2008, NASA/TM—2008-215209
[4]. R. J. Goldstein, Film Cooling Effectiveness Data for Simple Injection Geometries: A Collection of Three-Axis Plots, International Journal of Rotating Machinery 1994, Vol. 1, No. 1, pp. 73-81
[5]. David G. Bogard, Aerofoil Film Cooling, University of Texas, 2007
[6]. Zhihong Gao, Experimental Investigation of Film Cooling Effectiveness On Gas Turbine Blades, Thesis for PhD, Texas A&M University, (2007)
[7]. Vijay K. Garg, Heat Transfer on a Film-Cooled Rotating Blade Using a Two-Equation Turbulence Mode, (International Journal of Rotating Machinery 1998, Vol. 4, No. 3, pp. 201-216)
[8]. X. C. Li, G. Subbuswamy, J. Zhou, Performance of Gas Turbine Film Cooling with Backward Injection, Energy and Power Engineering, 2013, 5, 132-137
[9]. Christopher N.LeBlanc, Design, Analysis and Development of a Tripod Film Cooling Hole Design for reduced coolant Usage, Thesis for PhD, Virginia Polytechnic Institute and State University, 2012.
[10]. V.Ganeshan, Gas Turbines, Blade cooling Chapter 13 (Tata McGraw-Hill 1999).