Analysis of Compound Angled Gas Turbine Blade Leading Edge Model on Adiabatic Film Cooling Effectiveness by Numerical Investigation using CFD

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Abstract— This study aims at investigating the film cooling effectiveness using numerical analysis for the scaled up gas turbine blade leading edge model. A typical gas turbine blade leading edge model is selected for the study with five rows of holes, one at stagnation line, two rows of holes at 30° on either side of stagnation line and two rows of holes at 60° on either side of stagnation line respectively and each row consisting of five holes. This scaled up geometry has the film cooling hole diameter of 5.6mm, considered based on the literature survey and calculations. The film cooling hole rows are arranged in staggered manner to cover the more flow area on the blade surface. Each row has the five holes at a pitch of 22.4 mm with the varied hole angles of 25°, 35°, 40°, 50°, and 60° oriented with the stream line direction. Film cooling effectiveness analysis are found using CFD (Fluent) simulation by varying the blowing ratios (B.R) in the range of 1.0, 1.50, 2.0 and 2.50 at the density ratio (D.R) of 1.30 with nominal mainstream flow Reynolds number of 1,00,000 based on the leading edge diameter. The generated CFD results are compared with the previously published results in journal for the validation. The CFD results indicate similar trends of the cooling effectiveness results as that of experimental results. The CFD results has shown the increase in cooling effectiveness with the increase in blowing ratio up to 2.0 and found there is no increase in effectiveness above the blowing ratio 2.0 for this model. Hence, the optimized blowing ratio for this LECA model can be considered as 2.0 with the higher cooling effectiveness.

Key words: Gas Turbine Blade, Film Cooling Effectiveness, Blowing Ratio, Density Ratio, Computational Fluid Dynamics

I. INTRODUCTION

Over the past fifty years, aircraft and power generation gas turbine designers have endeavored to increase the combustor exit and high-pressure turbine stage inlet temperatures. With higher combustor exit temperatures, improved efficiency and reduced fuel consumption can be achieved. Similarly, in aircraft application, the higher temperatures lead to increased thrust. Unfortunately, these higher temperatures have jeopardized the integrity of the high-pressure turbine components and specifically the turbine blades. Modern turbine stage inlet temperatures exceed the melting point temperatures of turbine blade materials. To combat and avert failure of turbine blades in gas turbine engines resulting from these excessive operating temperatures, film cooling has been incorporated into blade designs.

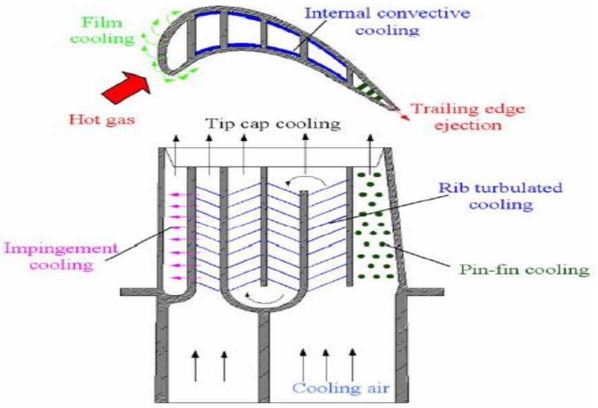

Fig. 1: Typical Cooling Techniques of Turbine Blade

In film cooling, cool air is bled from the compressor stage, ducted to the internal chambers of the turbine blades, and discharged through small holes in the blade walls. This air provides a thin, cool, insulating blanket along the external surface of the turbine blade. The approaches that have been taken to investigate film cooling phenomenon can be separated into general two areas: experimental and computational. This literature review will concentrate on both the computational and experimental side as this is the area where the current research program focuses. Recently Giridhara Babu Y et al. [1], studied both experimentally and numerically the scaled up gas turbine blade leading edge compound angle model by investigating the film cooling effectiveness. In order to cover the more flow area on the blade surface, the film cooling hole rows are arranged in a staggered manner. The results indicate the increase in cooling effectiveness increases with increase in blowing ratio up to 2..0 and found the decrease over the 2.0 for the model. Hence, the optimized blowing ratio can be found as 2.0. Also Srinath Ekkad and Je Chin Han [2], studied on recent development in turbine blade film cooling for continuous safe operation of gas turbines with high performance. Gas turbine blades are cooled internally and externally but this paper focuses on external blade cooling or film cooling. The accurate and detailed film cooling and local heat transfer for turbine edge region would be useful for the prevention of blade failure due to local heat spots. The results of flow visualization or measurements and CFD predictions would give the valuable information for effective designing of cooled blades for advanced gas turbines. And Je Chin Han [3], studied on recent studies in turbine blade cooling. This includes unsteady high free stream turbulence effects on film cooling performance with a discussion of detailed heat transfer coefficient and film cooling effectiveness distributions for standard and shape of film hole geometry using the newly developed transient liquid crystal image method. Film cooling holes with diffuser shaped expansion at the exit portion of the holes are used to improve the film cooling performance on a gas turbine blade. The increased cross sectional area at the film hole exit compared to standard cylindrical hole leads to the reduction in velocity of the coolant jet for given blowing ratio. It results in an increased film cooling effectiveness and lateral expansion of the hole provides an improved lateral spreading of the jet, which intern provides better lateral film cooling of the blade.

From the above detailed literature survey, we found the optimization of turbine blade leading edge film cooling requires the investigation of various flow and geometrical conditions like hole shape, hole location, diameter of the hole, hole angle with respect to the leading edge surface, coolant to main stream blowing ratio and density ratio. Among them blowing ratio has significant effect on the film cooling effectiveness, heat transfer coefficient and controlling the bleed air from the compressor.

II. GEOMETRY AND SETUP OF SIMULATIONS

The model considered for this study is as shown in the Fig 2. It consists of film cooling hole diameter of 5.6mm, considered based on the literature survey and calculations. The film cooling hole rows are arranged in staggered manner to cover the more flow area on the blade surface. Each row has the five holes at a pitch of 22.4 mm with the varied hole angles of 25°, 35°, 40°, 50°, and 60° oriented with the stream line direction. Rests of the features of the geometry are similar to those of Giridhara Babu Y et al. [1] for a scaled up geometry.

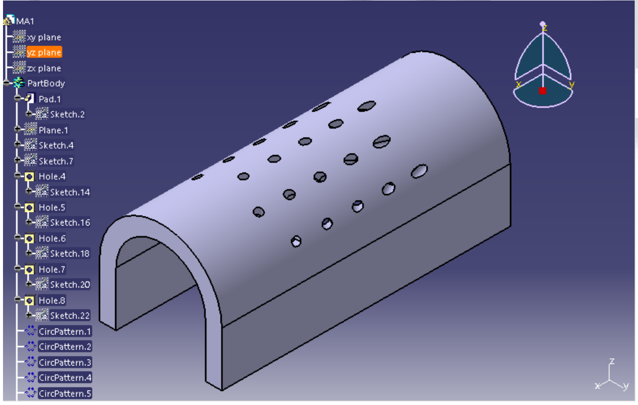

Fig. 2: LECA Model With 5.6mmhd_22.4mmpitch And 25°,35°,40°,50° And 60° Hole Orientations

Above the model is modeled using CATIA V5 R18 based on the below parameters as in Table I.

SI. No.	**Model Description**	**Dimensions**
1	Leading Edge OD	89 mm
2	Leading Edge IN	65 mm
3	Film Cooling Hole Diameter and Pitch	D=5.6 mm and Pitch= 22.4mm
4	Leading Edge Model Height	210 mm
5	No. of Rows	5
6	Compound Hole angles	25°, 35°, 40°, 50° and 60° with Stream line direction
7	Hole Orientation Angle	0°, 30° and 60° Angles from stagnation line

Table 1:

The completed model is imported to the ICEM Meshing tool to mesh using ANSYS WORK BENCH 15.

In order to obtain better design in CFD, The mixing of a 3D-cooling hole in a turbulent flow is more complicated to analyze than in the 2D-slot.

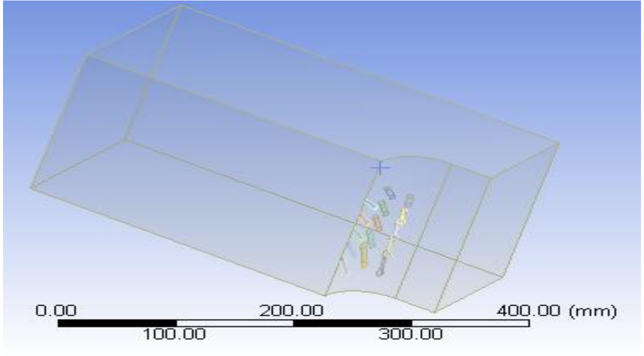

Fig. 3: LECA Model in ICEM

The geometry for the meshing is done in ICEM Meshing; the output mesh file obtained is in .msh format which is used to run in fluent. Hexa type mesh is used for main stream till leading edge of the fluid region in order to obtain highest accuracy And O grid mesh is used for the coolant flow as shown in Fig 4. The mesh nearby to walls is fine meshed to cope-up the thermal and velocity boundary layer formation and at the centre it is coursed meshed.

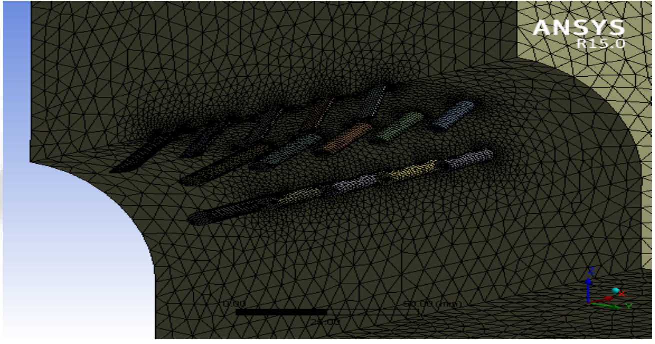

Fig. 4: Meshing of LECA Model in ICEM Meshing

The k-epsilon realizable turbulence model is used for all the blowing ratios for the CFD simulation. The type of boundary conditions applied in the computational model is shown in the Table II. The boundary condition values are used same as per Giridhara Babu Y et al. [1] for a scaled up geometry.

The detailed boundary conditions are shown and tabulated in the below Fig.5 and Table II respectively as per geometry.

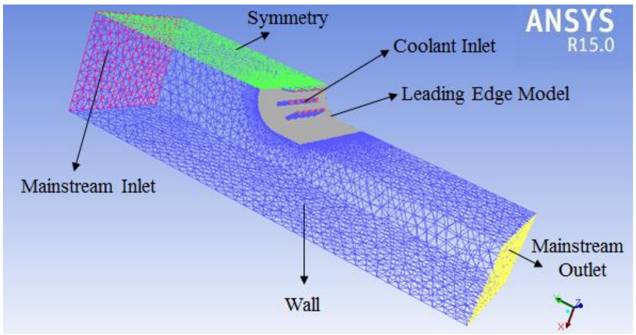

Fig. 5: Mesh Details and Parts Of LECA Model

SL No.	PART	BOUNDARY TYPE
1	MAIN STREAM INLET	PRESSURE INLET
2	MAINSTREAM OUTLET	PRESSURE OUTLET
3	COOLANT INLET	PRESSURE INLET
4	COOLANT OUTLET	INTERIOR
5	WALL	WALL
6	LEADING EDGE	WALL
7	SYMMETRY	SYMMETRY

TABLE 2:

From the above boundary conditions run the Fluent using the .msh file by importing it using Ansys Work Bench 15. Then extract the temperature (K) on leading edge of the turbine blade model using ICEM CFD-Post.

III. RESULTS AND DISCUSSION

The Film temperature obtained on the leading edge surface by numerically simulated by varying the blowing ratios from 1.0, 1.50, 2.0 and 2.50. By using this film temperature values on the leading edge surface, the film cooling effectiveness is calculated theoretically along stream-wise direction for all the blowing ratios. The temperature contours obtained by CFD are shown in the Fig.6 to Fig.9 for varying B.R.

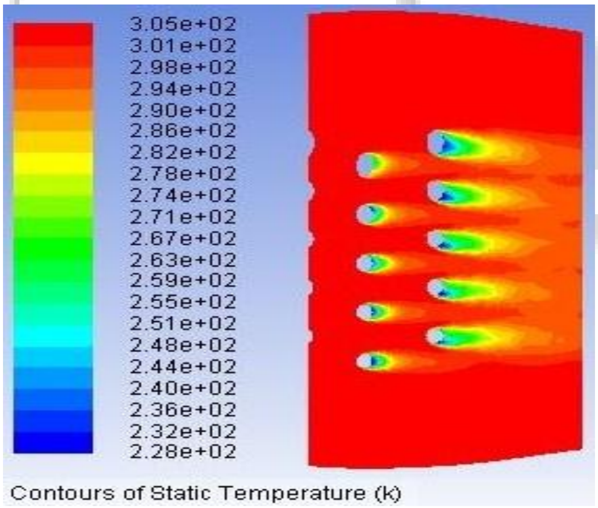

Fig. 6: Temperature Contour For BR=1.0

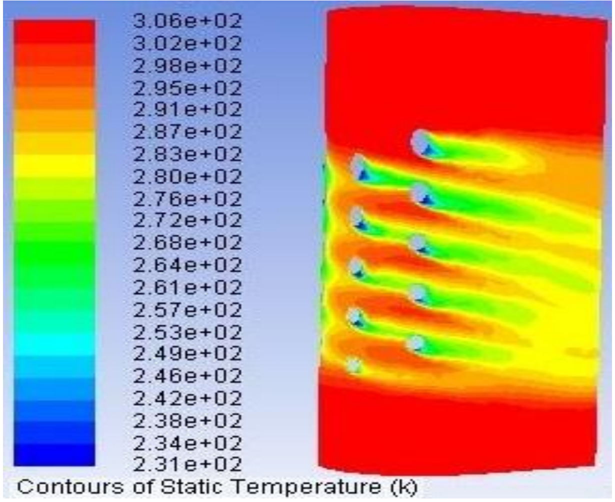

Fig. 7: Temperature Contour For BR=1.50

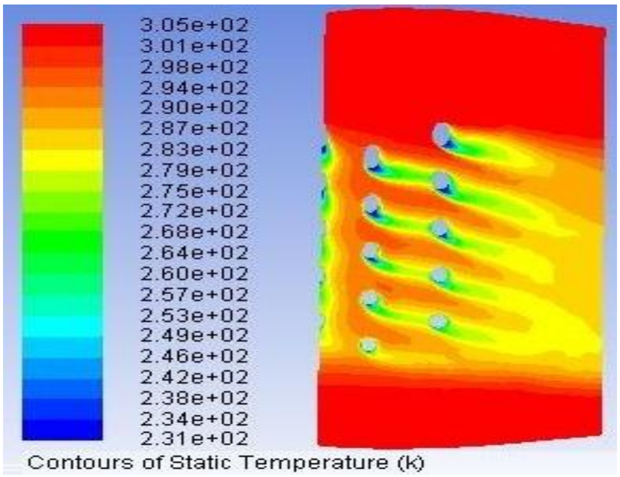

Fig. 8: Temperature Contour For BR=2.0

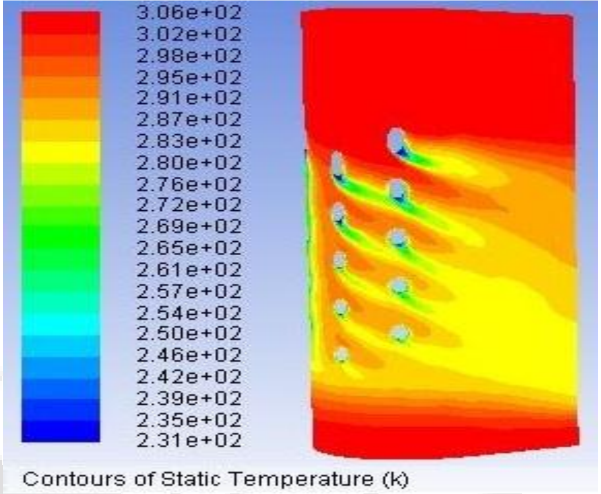

Fig. 9: Temperature Contour For BR=2.50

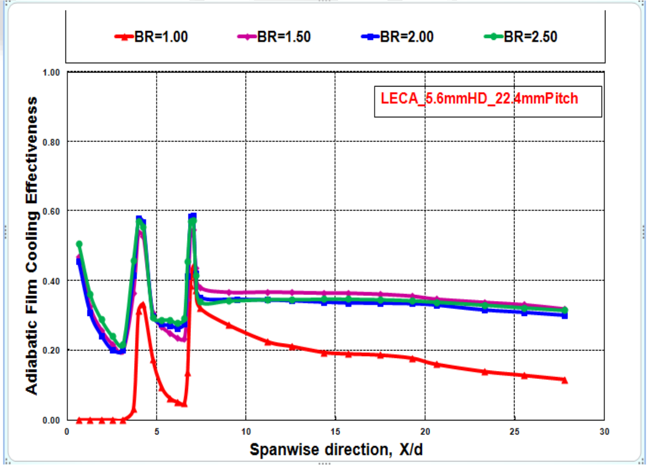

Fig. 10: Numerically Evaluated Averaged Adiabatic Film Cooling Effectiveness, BR=1.0 to 2.50 for 5.6mmHD

Numerically investigated results at the B.R from 1.0 to 2.50 are shown in the Fig.10. The numerical data shows the increase in cooling effectiveness with the increase in blowing ratio from 1.0 to 2.0, and from 2.0 to 2.50 the effectiveness decreases. The higher cooling effectiveness is observed at BR=2.0 due to the mass flow increase in coolant holes at higher B.R. Hence the optimized blowing ratio for this configuration can be considered as 2.0.

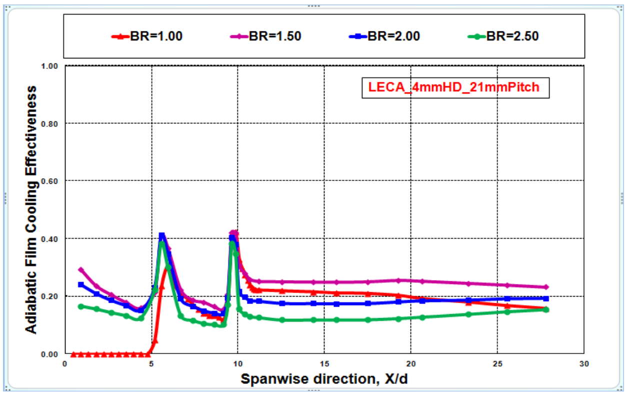

Fig. 11: Numerically Evaluated Averaged Adiabatic Film Cooling Effectiveness, BR=1.0 to 2.50 for 4mmHD

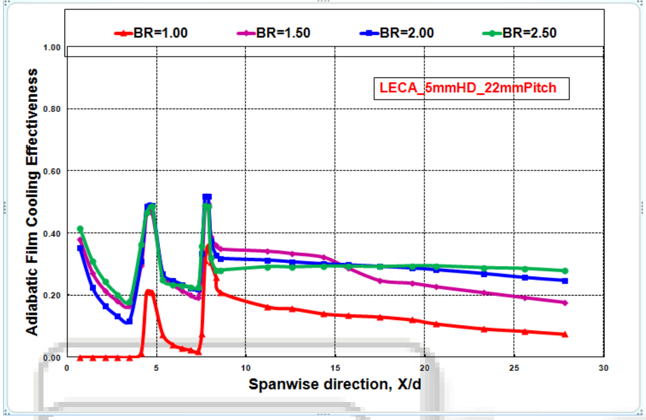

Fig. 12: Numerically Evaluated Averaged Adiabatic Film Cooling Effectiveness, BR=1.0 To 2.50 For 5mmhd

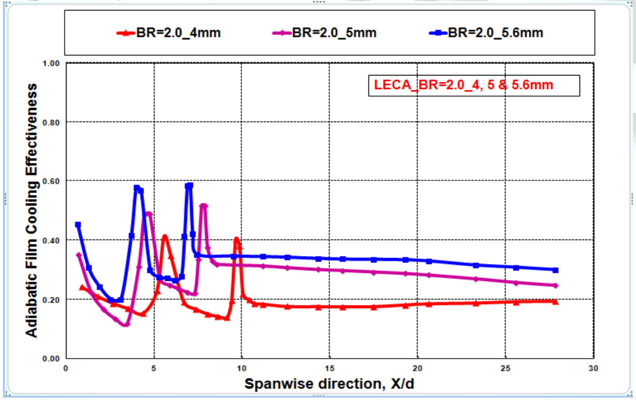

Fig. 13: Numerically Evaluated Averaged Adiabatic Film Cooling Effectiveness for BR=2.0 with varying HD

From Fig.10, the numerically evaluated film effectiveness shows the increase with the increasing B.R as that of Giridhara Babu Y et al. [1] values. The Fig.13, shows the comparative film cooling effectiveness at BR=2.0 by numerically for different types HD and orientation. That results the adiabatic film cooling effectiveness is increased by nearly 20% in 5.6mmHD model but further we cont go due to cavitations problem on the surface of the leading edge.

IV. CONCLUSIONS

The present study deals with numerical investigation of adiabatic film cooling for gas turbine blade leading edge compound angled model having the different cooling hole injection angles of 25°, 35°, 40°, 50° and 60° with main stream direction. From numerical investigation, film effectiveness increase with increasing blowing ratio. it is found that for the lower blowing ratios the film cooling effectiveness is very low and as the increase in blowing ratio the effectiveness increases up to B.R=2.0 and decreases above B.R=2.0 and hence the optimized blowing ratio can be considered as 2.0 for this type of configuration.

For compound angles 25°, 35°, 40°, 50° and 60°, as concluded from the results, performed very well for all L/D ratios and as compared to higher compound angle it has shown very significant increases in averaged film cooling effectiveness.

Adiabatic film cooling effectiveness is increased by nearly 20% as Giridhara Babu Y et al. [1]. So, the cooling effectiveness is better than that. And the life of the blade will get increased. Hence this is the optimized adiabatic film cooling effectiveness for this type of configuration.

V. ACKNOWLEDGEMENT

We would like to thank Mr. Anbalagan M and My friends for helpful discussions concerning numerical computations.

VI. NOMENCLATURE AND SYMBOLS

- LECA - Leading edge compound angle
- HD - Hole Diameter
- BR - Blowing Ratio
- DR - Density Ratio
- Vc - Coolant Velocity (m/s)
- Vm - Mainstream Velocity (m/s)
- η - Film cooling effectiveness
- Tm - Mainstream Temperature (K)
- Tc - Coolant Temperature before Injection (K)
- Tw - Wall Temperature (K)

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