

Experimental and Numerical Investigation of Film Cooling Effectiveness on Squealer Tip of a Turbine Blade

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ABSTRACT

In this article, the effects of Squealer on aerodynamic performance and thermal load distribution on the blade tip region are investigated. Experimental results are presented at Blowing Ratios of 0.5, 0.75, 1.0, and 1.5. The Film-Cooling Effectiveness is measured via the steady-state Heat Transfer Measurement Technique. A numerical approach has been applied to compare the Film Cooling performance and Aerodynamic Losses in the plane and recessed blade tips. The experimental results indicate that, as the blowing ratio increases, the coolant jets provide better cooling coverage on the cavity surface. The numerical results show that the Plane Tip Film-Cooling Effectiveness is lower than that for the Squealer Tip. It can be observed that, for the Plane and Squealer Tip configurations, as the blowing ratio increased, the Heat Transfer Coefficient decreased by about 43% and 44%, respectively. Moreover, the Film-Cooling Effectiveness on Squealer tip surface and Rim walls increased by 15% and 23%, respectively. Furthermore, the lower Heat Transfer Coefficient was observed at a higher Blowing Ratio on the surfaces mentioned above. The Squealer Tip geometry showed better aerodynamic performance, which results in weaker tip leakage vortex and lower tip leakage flow rate with respect to the plane tip geometry.

KEYWORDS

Axial Turbine, External Cooling, Squealer, Film-Cooling Effectiveness, Aerodynamic Performance

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1. Introduction

Film-Cooling is one of the most effective methods to protect gas turbine components against high thermal loads and reduce blade tip temperature. Squealer tip can help to resist the tip leakage flow by the back-pressure created by cavity vortices between the rims. Moreover, Squealer reduces aerodynamic loss and heat transfer to the blade tip [1, 2]. Nho et al.[3] studied the impact of tip gap on the heat transfer coefficient in the Squealer tip. Cheng et al.[4] carried out a numerical study to predict the cooling performance on the blade tip surface with various film-cooling hole configurations.

In comparison with Plane Tip configuration, due to the presence of highly complex flow structures inside the squealer cavity, the cooling performance near the blade tip region requires further investigations. In this study, the effects of various blowing ratios on the blade tip Film-Cooling Effectiveness and Heat Transfer Coefficient were investigated both experimentally and numerically.

2. Test Set-up and Experimental Method

Experiments are performed in a low-speed linear cascade consist of five blades. Table 1 and Table 2 show the detailed specifications for the blade dimensions and test conditions respectively.

Table 1. Geometrical Parameters of Cooled Blade

Parameter	Value	Unit
Design Inlet Angle	30	deg.
Design Outlet Angle	69.5	deg.
Stagger Angle	38.5	deg.
Axial Chord	139.8	mm
Blade Height	136	mm
Gap size	4	mm
Rim Height	4	mm
Tip Holes Number	10	-
Cooling Hole Diameter	1.6	mm

The steady-state heat transfer technique was applied to measure adiabatic wall temperature. An Infrared Thermometer was used to measure the adiabatic wall temperature distribution of Squealer tip. Experiments were carried out at four different blowing ratios and the density ratio was considered 1.0 for all cases. The Film-Cooling Effectiveness and Heat Transfer Coefficient are defined, as follows:

$$\eta = \frac{T_{\infty} - T_{aw}}{T_{\infty} - T_{c,exit}} \quad (1)$$

$$h = \frac{q}{T_{aw} - T_w} \quad (2)$$

Table 2. Test Conditions

	BR=0.5	BR=0.75	BR=1.0	BR=1.5
Re_{∞}	1.6×10^5	1.6×10^5	1.2×10^5	0.8×10^5
V_c	10	15	15	15

3. Uncertainty Analysis

As illustrated in Equation (1), the experimental uncertainty for Film-Cooling Effectiveness mainly results from the measured precision of mainstream, coolant and adiabatic wall temperatures. Consequently, the total uncertainty of Film-Cooling effectiveness is determined to be 5.931%.

4. Numerical Simulation

A numerical study has been conducted in this study to determine the Heat Transfer Coefficient on the Blade tip surface. A two-equation turbulence model ($k-\epsilon$) was performed in the calculations [5].

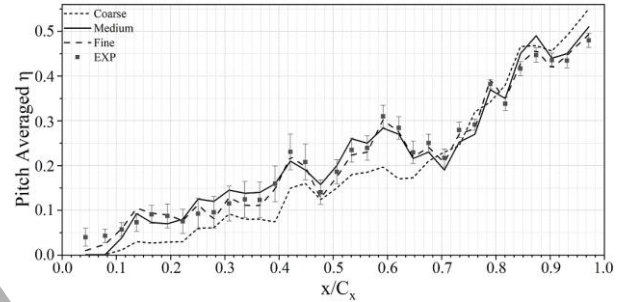


Figure 1. Comparison between pitch-averaged Film-Cooling Effectiveness obtained by the $k-\epsilon$ model using different grid resolutions and experimental data at BR = 1.0

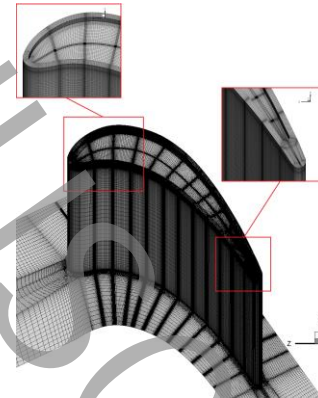


Figure 2. Schematic view of computational Mesh for Squealer Tip

Three different computational grids, namely coarse, medium, and fine, have been employed to determine an optimum grid resolution. "Figure 1" illustrates that the medium grid is in good agreement with the experiment. The medium computational grid for the squealer tip geometry is depicted in "Figure 2".

5. Results and Discussion

“Figure 3” presents the distribution of Film-Cooling Effectiveness for the Squealer tip. Further increase in coolant momentum results in more uniform film cooling effectiveness over the cavity surface.

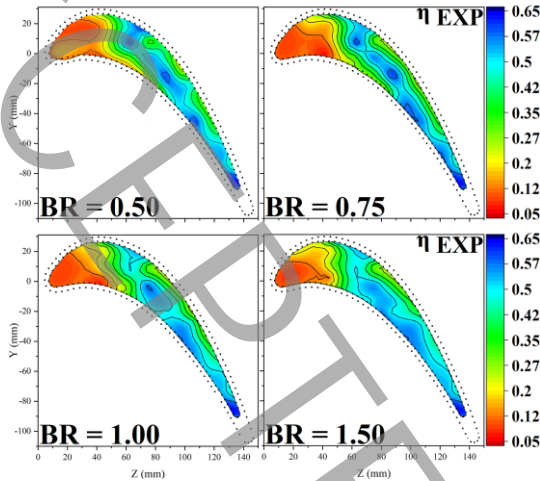


Figure 3. Film-Cooling Effectiveness contours on Squealer Tip at four different Blowing Ratios.

The leakage flow rate at the tip gap is shown in “Figure 4”. Compared to the Plane Tip, the squealer tip has better performance in reducing the flow rate within the tip gap.

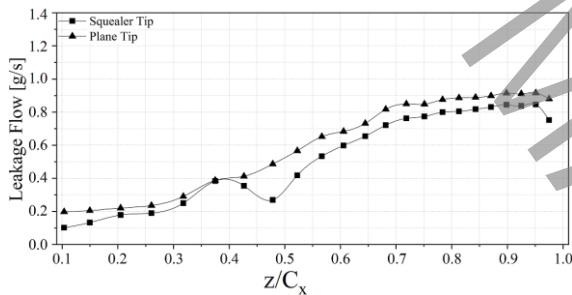


Figure 4. Tip leakage flow rate of the Plane Tip and Squealer through the tip gap

The comparison of the overall averaged Heat Transfer Coefficient for both geometries are presented in “Figure 5”. The Plane tip showed a higher averaged Heat transfer coefficient. Generally, the Heat Transfer Coefficient decreased as the Blowing ratio increased.

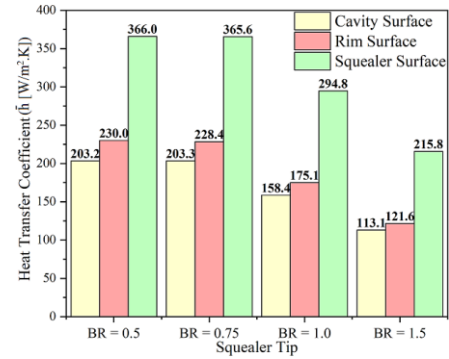
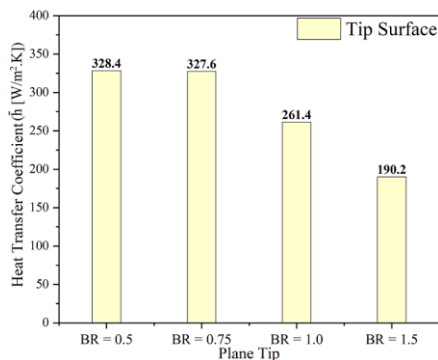


Figure 5. Area-averaged Heat Transfer Coefficient for the Plane Tip and Squealer Tip Geometries

6. Conclusions

The experimental test results showed that at lower blowing ratios, film-cooling effectiveness was high at downstream of the cooling holes due to attachment of coolant jet to the cavity surface. The numerical results showed that compared to Plane tip, Squealer tip demonstrates a better Aerodynamic performance. Furthermore, when the blowing ratio increases to 1.5, the coolant jet lift-off results in a higher Heat Transfer Coefficient.

7. References

- [1] F. Cheng, J. Zhang, H. Chang, J. Zhang, Investigations of film-cooling effectiveness on the squealer tip with various film-hole configurations in a linear cascade, *International Journal of Heat and Mass Transfer*, 117 (2018) 344-357.
- [2] L. Kavurmacioglu, H. Maral, C.B. Senel, C. Camci, Performance of partial and cavity type squealer tip of a HP turbine blade in a linear cascade, *International Journal of Aerospace Engineering*, (2018).
- [3] Y. Nho, Y. Lee, J. Kwak, Effects of tip shape on the gas turbine blade tip heat transfer, *Journal of Thermophysics and Heat Transfer*, 26(2) (2012) 305-312.
- [4] F. Cheng, H. Chang, J. Zhang, X. Tian, Effect of film-hole configuration on film-cooling effectiveness of squealer tips, *Journal of Thermal Science and Technology*, 12(1) (2017).
- [5] I. Sadrehaghghi, *Essentials of Turbomachinery in CFD*, 2019.