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An Experimental Investigation of Showerhead Film Cooling Performance on a Turbine Blade

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Abstract

Experimental tests were performed to investigate the film cooling performance at the leading edge region of a turbine blade using the Infrared Radiation (IR) thermography technique. The test blades were enlarged by five times the natural size with three showerhead rows of radial-angle hole and one row of streamwise angle hole on pressure and suction side, respectively. Six different leading edge cooling geometries were designed by varying the radial angle from 35°to 90°. The effects of mainstream Reynolds number and coolant-to-mainstream blowing ratio were discussed. Results show that the blowing ratio has a marked influence on the cooling effectiveness with the existence of an optimum blowing ratio. High mainstream Reynolds number produces larger coolant flow rate and hence better cooling effectiveness. For $x/C<0.15$ on suction side close to the stagnation region and the overall pressure side, small radial angle improves the leading edge film cooling performance ,whereas large radial angle facilitates the effectiveness downstream of $x/C>0.15$ on suction side. In current investigation, 45° showerhead radial angle relatively produces the least pressure loss and 75° or 90° gives the most aerodynamic loss that increases with the blowing ratio.

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Keywords: showerhead film cooling; IR thermography; blowing ratio; Reynolds number; adiabatic cooling effectiveness

1. Introduction

Nowadays, the desire for higher overall efficiency and higher specific power output in advanced gas turbines renders the need for increase in turbine inlet temperatures which have typically reached greater values than the

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Nomenclature

A	total cross-section area	*Subscripts*	
C	blade chord length	aw	adiabatic wall
d	cascade inlet hydraulic diameter	c	coolant or secondary flow
D	diameter of film hole or impinging hole	f	film hole
l	perimeter of cascade inlet cross section	i	impinging hole
$\dot{m}$	mass flow rate	o	cascade exit
M	coolant-to-mainstream blowing ratio	t	total
p	hole pitch	∞	cascade inlet or mainstream
P	pressure		
Re	mainstream Reynolds number		
T	temperature		
u	velocity		
x	x coordinate		
α	streamwise angle		
β	radial angle		
η	adiabatic film cooling effectiveness		
ξ	total pressure loss coefficient		
ρ	density		

turbine blades can withstand. Some innovative cooling techniques are necessary to protect the turbine components from overheating and maintain their working life. A comprehensive introduction about the available internal and external turbine blade cooling techniques can be seen in detail from Han's book [1].

As a kind of effective cooling technology, film cooling has been widely applied to maintain the blade temperature at acceptable levels. Numerous studies focused on film cooling have been performed for discussing the film cooling mechanism in the past decades, including the combined effects of mainstream turbulence intensity, coolant-to-mainstream blowing, density, and momentum ratio [2-5]. The classical kidney vortexes induced downstream of a cylindrical hole are proved to be the most important factor adversely influencing the film cooling effectiveness. As a result, it is meaningful to restrain the kidney vortexes and improving the film cooling effectiveness by optimizing the geometry of film cooling holes. Gritsch et al. [6, 7] presented adiabatic effectiveness and heat transfer measurements on fan shaped holes. Due to the expansion of the cross-section, the exit momentum of the coolant jet is reduced and hence the penetration into the hot gas. Additionally, the lateral expansion leads to film spread and better coverage of the coolant. Leylek et al. [8-10] made a detailed analysis of film cooling physics for cylindrical and shaped holes with streamwise injection and compound-angle injection. Shaped-hole and compound-angle-hole system changes the ejection exit flow structure and pressure distribution with a much improved lateral distribution of coolant. Moreover, the formation of an additional vortex pair, which is counter rotating to the kidney vortex pair, weakens the kidney vortexes. This effect leads to a reduced tendency towards jet lift-off and improves the film cooling effectiveness. Additionally, a new cooling scheme with the convergent slot hole (CONSOLE) was presented by Sargison et al. [11, 12]. The geometry convergence leads to an acceleration of the coolant flow, providing a chance to suppress the separation regions and reduce the mixing with the hot gas. Results from Yao et al. [13, 14] demonstrate that the CONSOLE produces better effectiveness and cuts down the aerodynamic loss compared with the cylindrical hole. Other investigators [15-17] also came up with some innovative cooling geometries which were verified to produce better cooling performance than fan-shaped holes.

The leading edge region on a turbine blade suffers from extreme thermal loads and hence becomes a concentration and difficulty for blade cooling due to the direct impact from the hot gas exiting the combustion. Ou and Rivir [18] employed a transient liquid crystal image method to experimentally investigate the combined effects of turbulence intensity, Reynolds number, and coolant-to-mainstream blowing ratio on the film effectiveness and heat transfer coefficient of a large scale symmetric circular leading edge with three rows of film hole. Lu et al. [19] presented that the additional compound angle in the transverse direction for the two rows adjacent to the stagnation