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Numerical investigation of film cooling effectiveness on the curved surface

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Abstract

This paper deals with a numerical investigation of the film cooling effectiveness on five different curved surfaces and a flat surface. The models consist of 11 rectangular cross-sectioned injection holes aligned in a single row. The blowing ratios are from 0.5 to 2.0, and the injection angle with respect to the horizontal plane is 30°. The hole geometry, the slope of the curved surface and the blowing ratio have important effects on the film cooling effectiveness. The results show that the film cooling effectiveness of a given curved surface, both along the mainstream and the spanwise direction, depends on the optimum selection of the parameters mentioned above.

Keywords: Film cooling; Film cooling effectiveness; Numerical investigation; Curved surface

1. Introduction

High turbine inlet temperatures are required to obtain high cycle efficiency in modern gas turbines. However, high temperatures also damage the blade and vane materials. Therefore, it

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Nomenclature

M	blowing ratio, –
V_j	injection fluid velocity, m/s
V_∞	main flow velocity, m/s
$T_{adiabatic}$	adiabatic wall temperature, K
T_j	injection fluid temperature, K
T_∞	main flow temperature, K
ρ_∞	main flow density, kg/m^3
ρ_j	injection fluid density, kg/m^3
η	film cooling effectiveness, –
$x^* = x/L$	characteristic length in mainstream direction, –
$z^* = z/L$	characteristic length in lateral direction, –
L	length, mm
c	curvature maximum height, mm
x	length in mainstream direction, mm
z	length in lateral direction, mm
I	momentum flux ratio, –

is necessary to either use blade materials that can work at the high temperatures or to apply efficient cooling schemes to the turbine vanes and blades. The latter solution is usually a cheaper alternative.

Blades and vanes can be used at temperatures above their critical limit if they are cooled. One of the methods of turbine cooling is to form a film layer on the external surfaces of the blades and vanes, so that they can work at the high temperatures. The surface curvature and the blowing ratio are parameters that affect the film cooling effectiveness.

The first investigations focusing on the influence of curvature have been published by Nicolas and Le Meur [1], Folayan and Whitelaw [2] and Mayle et al. [3]. They conducted measurements on generic curved walls with slot injection. Compared to the results on flat surfaces, injection at low blowing ratios ($M = 0.5$) increases the adiabatic film cooling effectiveness on convex and decreases it on concave curved surfaces. The film cooling effectiveness is higher on convex than on flat and concave surfaces at moderate blowing ratios ($M = 1.0$).

The effects of large density differences and momentum flux ratio on film cooling effectiveness were investigated through the heat-mass transfer analogy [4]. Airfoil pressure and suction side effectiveness with flat plate data were compared by Ito et al. [5]. Kruse [6], Schwarz and Goldstein [7] and Schwarz et al. [8] presented results for generic curved surfaces (convex, concave and flat plate) with variations of the surface curvature to cooling hole diameter ratio. The laterally averaged film cooling effectiveness was observed to increase with increasing curvature ($-1/R$ to $+1/R$), especially for small blowing ratios, until the coolant film separates on strongly curved walls. Schwarz et al. [8] pointed out that the lateral profiles of local effectiveness are much flatter on the concave surface than on the convex one. Goldstein and Stone [9] investigated film cooling on convex and concave curved surfaces for double row injection. The results were compared to