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Heat Transfer in Trailing-Edge Channels with Slot Ejection Under High Rotation Numbers

Yao-Hsien Liu* and Michael Huh†
Texas A&M University, College Station, Texas 77843-3123
Lesley M. Wright‡
Baylor University, Waco, Texas 76798-7356
and
Je-Chin Han§
Texas A&M University, College Station, Texas 77843-3123

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The regionally averaged heat transfer coefficients were measured in a wedge-shaped channel ($D_h = 2.22$ cm, $A_c = 7.62\ \mathrm{cm}^2$) to model an internal cooling passage near the trailing edge of a gas turbine blade. This test section was configured so that the inlet coolant exhausts through the slots to simulate the trailing-edge ejection. Therefore, the local mass flow rate decreases along the streamwise direction due to the coolant discharging through the slots. The effects of slot ejection enhance heat transfer near the narrow side while decreasing heat transfer on the wide side of the channel at the stationary condition. The inlet Reynolds number of the coolant varies from 10,000 to 40,000, and the rotational speeds vary from 0 to 500 rpm. The inlet rotation number varies from 0 to 1.0. The local rotation number and buoyancy parameter vary by the different rotational speeds and local Reynolds number in each region. Detailed spanwise and streamwise heat transfer distributions are strongly affected by the slot ejection at both the stationary and rotating conditions. This study shows that the rotation number and buoyancy parameter are useful parameters to correlate the effect of rotation on heat transfer in the current study.

Nomenclature

A = projected surface area of a copper plate segment
A_j = cross-sectional area of the slot
AR = channel aspect ratio, $W{:}H$
Bo_x = local buoyancy parameter, $(\Delta\rho/\rho)_x Ro^2 (R_x/D_h)$
C_D = discharge coefficient
D_h = channel hydraulic diameter
H = channel height
h = regionally averaged heat transfer coefficient
k = thermal conductivity of the coolant
L = length of the heated portion of the test section
$\dot{m}_j$ = mass flow rate through the jth slot
$\dot{m}_n$ = mass flow rate radially at the exit of the nth region
$\dot{m}_{xn}$ = local mass flow rate at the nth region
Nu = regionally averaged Nusselt number
Nu_o = Nusselt number for fully developed turbulent flow in a nonrotating smooth pipe
Nu_s = regionally averaged Nusselt number under stationary condition
P_{exit} = pressure at the exit of the slot
P_{in} = pressure at the inlet of the slot
Pr = Prandtl number of the coolant
Q_{loss} = external heat loss
Q_{net} = net heat transfer
R = mean radius of rotation (from the center of rotation to center of heated channel)
R_x = local radius of rotation (from the center of rotation to local region within heated channel)
Re_x = local Reynolds number
Re_i = Reynolds number at the inlet of the test section
Ro = rotation number, $\Omega D_h/V$
Ro_i = inlet rotation number, $\Omega D_h/V_i$
Ro_x = local rotation number, $\Omega D_h/V_x$
$T_{b,x}$ = local coolant bulk temperature
$T_{f,x}$ = local film temperature
$T_{w,x}$ = regionally averaged wall temperature
V = bulk velocity of the coolant in the streamwise direction
V_i = bulk velocity of the coolant at the inlet of the test section
W = channel width
$(\Delta\rho/\rho)_{\mathrm{in}}$ = inlet coolant-to-wall density ratio, $(T_w - T_{bi})/T_w$
$(\Delta\rho/\rho)_x$ = local coolant-to-wall density ratio
β = angle of channel orientation with respect to the axis of rotation
μ = viscosity of the coolant
ρ = density of the coolant
Ω = rotational speed

Introduction

ADVANCED gas turbines operate at high temperatures to improve thermal efficiency. To protect the turbine blade from damage due to high temperatures, external (film) and internal cooling are applied to the turbine blades. Internal cooling is achieved by circulating compressed air in the multipass flow channels inside the blade structure. As shown in Fig. 1, the cross section of the internal cooling channels varies depending on their location in the blade. Cooling channels near the leading edge could be tall and narrow, whereas channels closer to the trailing edge are typically wide and short. The cooling channels are either single pass (with radial outward flow) or multipass (both radial outward and radial inward

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*Research Assistant, Department of Mechanical Engineering.

†Research Assistant, Department of Mechanical Engineering.

‡Assistant Professor, Department of Mechanical Engineering. Member AIAA.

§Distinguished Professor and M.C. Easterling Chair Professor, Turbine Heat Transfer Laboratory, Department of Mechanical Engineering; jc-han@tamu.edu. Associate Fellow AIAA.