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Rotating heat transfer measurements on realistic multi-pass geometry

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Abstract

In this contribution, a novel rig was used to assess the heat transfer coefficients on a full internal multi pass cooling scheme. Transient liquid crystal technique was used for the measurement of the heat transfer coefficient (HTC) on channel's internal surfaces.

A first set of experiments were performed at engine similar conditions of Re=21000 and Ro=0.074. In order to assess the reliability of the measurement methodology and to explore the thermal behavior at higher rotation numbers, tests were also carried out at Re=17000 and Ro=0.074-0.11. From the spatially resolved HTC maps made available, it is possible to characterize the thermal performances of the whole passage and to highlight the effect of rotation.

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Keywords: blade cooling; internal cooling; transient liquid crystal; rotation; multi-pass

1. Introduction

Safe and efficient operation of gas turbine engines strongly relies on effective blade cooling. Consequently, the performance required to the cooling systems is ever increasing, which leads to the definition of passage geometries that are increasingly complex. A commonly adopted solution is a multi-pass geometry with different types of turbulent promoters used to enhance heat transfer. The choice of which kind of turbulator to install is constrained by the channel

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cross section dimensions and aspect ratio, which in turns depends upon the blade region where the passage is located. Several studies have been carried out in order to define the behavior and the efficiency of different turbulent promoters [1].

Another important aspect that has to be taken into account in the design process of a cooling passage is the combined effect of turbulators, rotation, and channel orientation. Fundamental contributions are given by Hart [2], Lezius and Johnston [3], Speziale [4], and Speziale and Thangam [5]. These contributions describes the Coriolis effects on the flow field inside basic channel geometries (square or rectangular channels with outward flow in orthogonal rotation, i.e. the rotation axis is parallel to the channel height).

In addition, in real turbines blades, channels are not always in orthogonal rotation, and since gas turbine blades are manufactured by casting, it is difficult to ensure that the internal passages have sharp edges or perfectly squared ribs. Experimental studies have been performed in order to study the heat transfer behaviour in channels rotating with different orientations with respect to the rotation axis [6]. Only few contributions can be found in literature regarding the behaviour in terms of enhancement and pressure losses of realistic turbulators geometries and all demonstrated a deterioration in heat transfer due fillets at the base of the rib [7-9] or pin-fin [10].

It should be therefore clear that the complexity of the modern internal cooling designs makes difficult to predict the expected thermal performances starting from the available knowledge. Indeed, the majority of the data refers to stereotyped geometrical configurations or the results cannot be projected straightforward to the engine because of lack of full similarity between experiments (real or virtual) and real engine conditions. The present work investigates the rotational effects inside a three-pass channel for cooling of land based gas turbine engine. The geometry still brings some simplifications with respect to the real application, but the main features are considered, such as realistic cross section with rounded walls, angled ribs and filleted pin fins. Channel orientation is consistent with the real application as well as the imposed flow split among the different coolant discharges.

Nomenclature

Bo	buoyancy parameter	Ro	Rotation parameter
d	pin fin diameter	T_b	bulk flow temperature
d_h	hydraulic diameter	T_{he}	temperature at the outlet of heat exchangers
HTC	heat transfer coefficient	T_i	initial flow temperature
k	air thermal conductivity	T_w	wall temperature
Nu	Nusselt number	U_b	bulk velocity
Nu_0	reference Nusselt number	μ	air dynamic viscosity
Pr	Prandtl number	ρ	air density
R	rotation radius	Ω	rotational speed
Re	Reynolds parameter		

2. Experimental setup

2.1. Channel geometry

The test section is a model of a full internal cooling scheme of an idealized blade. Figure 1 reports a drawing of the test section and a view of its installation on the rig. The cooling scheme has a multi-pass design. First two passages are two-sided ribbed channel with ribs arranged in a line-on-line configuration. At the blade tip, part of the coolant is discharged through a dust hole (10% of inlet mass flow rate), while the greater part of it goes through a 180° bend and flows radially inwards inside the 2nd passage characterized by a higher aspect ratio cross section with respect to the first one. At the end of the second passage, another 180° bend diverts the flow inside the 3rd leg, where low aspect-ratio cylindrical pin fins ($d/d_h = 0.34$) are arranged in a staggered configuration to promote flow turbulence. Inside the 3rd passage, the coolant is progressively discharged through holes at the blade trailing edge (55% of inlet mass flow rate) and finally at the blade tip (35% of inlet mass flow rate). The geometrical features of the ribs used in the 1st and 2nd legs are: square section with rounded edges and base fillet, rib pitch/height of 8 and inclined at 60° with respect to