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AGUMENTED HEAT TRANSFER OF AN INTERNAL BLADE TIP BY FULL OR PARTIAL ARRAYS OF PIN-FINS

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Cooling methods are much needed for the turbine blade tips to ensure a long durability and safe operation. A common way to cool the tip is to use serpentine passages with 180-deg turn under the blade tip-cap taking advantage of the three-dimensional turning effect and impingement like flow. Improving internal convective cooling is therefore required to increase the blade tip life. In the present study, augmented heat transfer of an internal blade tip by pin-fins has been investigated numerically. The computational models consist of a two-pass channel with 180-deg turn and an array of pin-fins mounted on the tip-cap, and a smooth-tip two-pass channel. The computational domain includes the fluid region and the solid pins as well as the tip regions. Turbulent convective heat transfer between the fluid and pins, and heat conduction within pins and tip are simultaneously computed. The main objective of the present study is to observe the effect of the full or partial pin-fins arrays on heat transfer enhancement of the pin-finned tips. Results show that due to the combination of turning impingement and pin-fin crossflow, the maximum heat transfer coefficient of the full and partial pin-finned tip is a factor of 3.0 and 1.8 higher than that of a smooth-tip, respectively. Disregarding the factor of the increased active heat transfer area, the tip with partial pin-fins array provides around 6% higher heat transfer enhancement than the tip with full pin-fins array. It is suggested that the use of partial pin-fins array might be suitable for improving blade tip cooling when considering the consequences of the added weight and there by the increased stress on a blade.

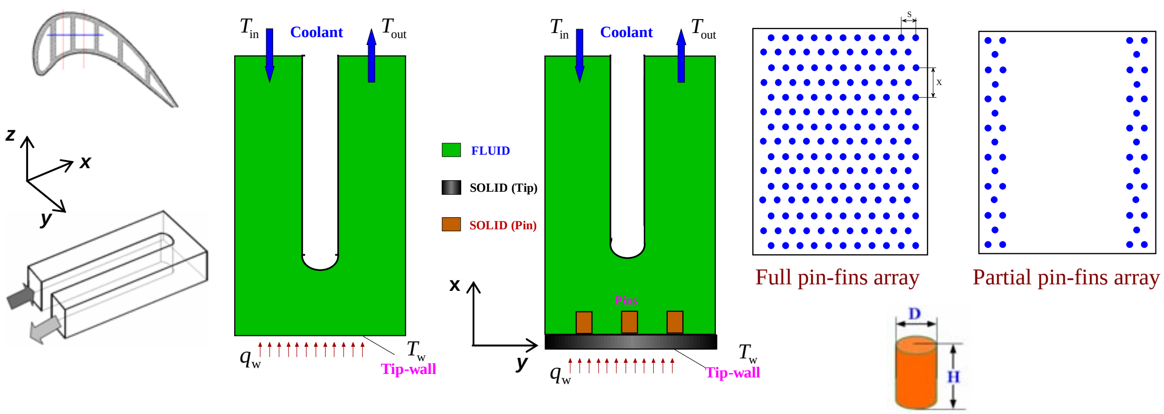
INTRODUCTION

For turbine blades in particular operation, the hot leakage flow results in high thermal loads on the blade tip. It is therefore very essential to cool the turbine blade tip and the region near the tip. A very common way to cool the blade tip is to adopt internal cooling by designing serpentine (two-pass, three-pass or multi-pass) channels with a 180-deg turn/bend inside the blade. Taking the advantage of impinging and turning effects, the tip can be cooled to some certain extent. Consequently, augmenting internal convective cooling is required to increase the blade tip life. Fortunately, it is well documented that many augmented devices, i.e., fins, ribs, pins, dimples, can be used to improve the heat transfer significantly. Many previous investigations have proven that pin-fins can improve the cooling in low aspect ratio channels for gas turbines, typically at the trailing edges. The application of pin-fins has received much attention for enhancing heat transfer in cooling channels, e.g., turbine blades, heat sinks, compact heat exchangers. Most recently, Bunker [1] presented a method to provide substantially increased convective heat flux on an internal cooled blade tip-cap by shaped pins arrays. It was found that the effective heat transfer coefficient could be increased up to a factor of 2.5 while the tip turn pressure drop was negligible compared to that of a smooth surface.

Even though similar heat transfer results in two-pass channels with pin-fins can be found in the experimental work by Bunker [1], limited details of the heat transfer and flow field on the pin-fins and tip-walls are available. Furthermore, most previous studies were concerned about the heat transfer on the leading or/and trailing walls of two-pass channels, and thus very limited information is available for tip walls, thus it is desirable to present more details on the heat transfer enhancement over tip walls, and to facilitate better understanding of three dimensional flow and heat transfer for pin-finned tips. Besides, the previous works by Bunker [1] and by the authors [2-4] focused on the heat transfer enhancement from the full array of pin-fins, few comprehensive studies focused the partial array of pin-fins on the heat transfer of augmented surfaces. The addition of pin-fins on a tip-cap produces an added surface area and hence an added weight, resulting in a possible additional stress on a blade. For these reasons the main objective of the present study is to investigate the effect of full or partial pin-fins arrays on the heat transfer enhancement over the pin-finned tips in a rectangular two-pass channel at high Reynolds number. Detailed flow field and heat transfer characteristics are presented, and the overall performances of pin-finned-tip two-pass channels are compared and evaluated.

DESCRIPTION OF PHYSICAL MODELS

A schematic diagram of the geometrical models considered in this study is provided in Fig. 1. The detailed geometrial parameters can be found in [2-4]. The numerical models of the rectangular two-pass channels are similar to those in the experiments by Bunker [1], but the pin-fin configurations and arrangements in the present study and the experiments are different. In all simulations, the pin-fins are assumed to be perfectly straight circular without base-fillet or tip-radius.



(a) smooth-tip channel (b) pin-finned-tip channel

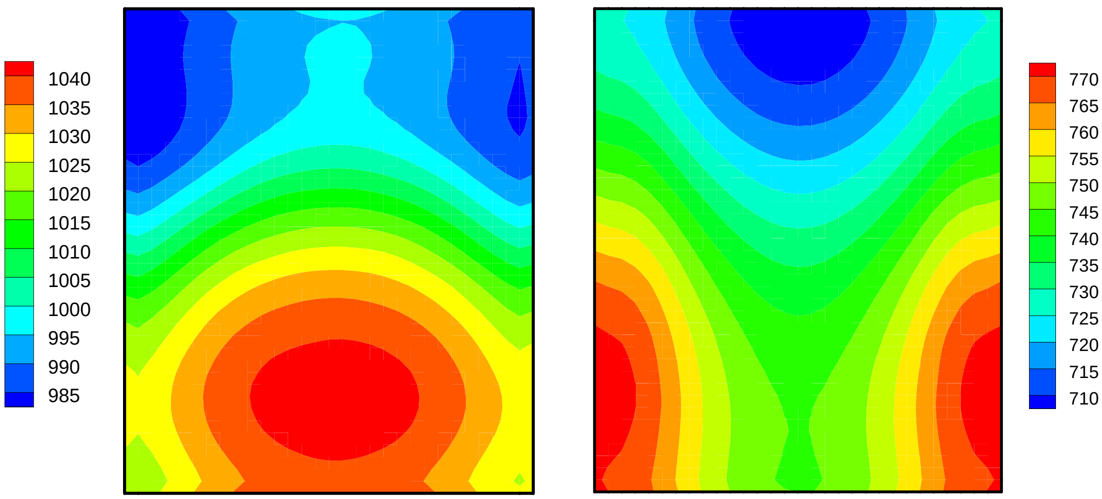
FIGURE 1. Schematics of computational models: smooth-tip channel and pin-finned-tip channels

COMPUTATIONAL METHOD

Overview: In the present study, the finite volume modeling was conducted by applying the simulation software FLUENT version 6.3.26. This code uses the finite volume method to solve the governing equations of fluid flow and heat transfer with appropriate boundary conditions. The pressure and velocity fields are linked by the Semi-Implicit Method for Pressure Linked Equations Consistent (SIMPLEC) algorithm. Another commercial software GAMBIT version 2.4.6 providing geometry generation, geometry import and mesh generation capabilities was used to set up the computational models. Details of the conjugated heat transfer approach, a grid dependence study, choice of turbulence model, the governing equations and boundary conditions will be presented in the full paper.

RESULTS AND DISCUSSION

Typical local Nusselt number distributions are shown in Fig. 2. It is found that, for the tip with full pin-fins array larger local heat transfer coefficients are produced at the center of the first-pass, while for the tip with partial pin-fins array large local heat transfer coefficients are produced at the sides of the first-pass.



(a) Full pin-fins array (b) Partial pin-fins array

Figure 2. Local Nusselt number distributions

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