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Effect of pin fin arrangement on the heat transfer characteristics in a convergent channel with impingement

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ABSTRACT

The protection of the inlet components of an aircraft engine from the adverse effects of ice accretion has been a crucial design problem since the very early years of flight. Therefore, the configuration with efficient heat transfer is the focus on the design of a hot-air anti-icing system in an aero-engine. This paper studies experimentally on the heat transfer in a convergent channel with pin fins within the strut. Experiments are carried out by using a transient liquid crystal technique. The pitch ratio (*D/d*, where *D* is the diameter of the pin fins) of the pin fins and impingement hole, the dimensionles lateral distance (*S/d*, where *S* is the distance between the leading edge and pin fins, *d* is the diameter of the impingement hole) as well as the dimensionless vertical distance (*S1/d*, where *S1* is the distance between pin fins) are respectively investigated to study the heat transfer on the surface of convergent channel. The Reynolds number based on the hydraulic diameter of the impingement hole ranges from 6300 to 12700. Within the experimental range, the result shows that the increasing pitch ratio *D/d* leads to a lower Average Nusselt Number, the Average Nusselt Number has the highest value when *D/d* = *1/3*. The Average Nusselt Number increases at first and then decreases as the dimensionless lateral distance *S/d* increases, the Average Nusselt Number has the highest value when *S/d* = 2.5. When the dimensionless vertical distance *S1/d* increases, the Average Nusselt Number goes up at first and then reduces, the Average Nusselt Number has the highest value when *S1/d* = *3*. The Average Nusselt Number increases as the Reynolds number increases.

1. Introduction

The protection of the inlet components of an aircraft engine from the adverse effects of ice accretion has been a crucial design problem since the very early years of flight. Ice formation on the inlet of an aircraft engine has a great influence on the aircraft engine's working condition. Therefore the configuration with efficient heat transfer is the focus on the design of a hot-air anti-icing system in an aero-engine.

In early years, people investigated the damage of ice on gas turbines on the ground. Lacey et al. [1] described the effects and damage of ice on gas turbines. He also briefly presented some methods of protecting the engine against icing and proposed a method of automatic anti-icing operation. Kissling et al. [2] described the test and evaluation of anti-icing systems in four different conditions. He told us how to simulate and evaluate anti-icing system in early years. The adequacy of facilities for various types of icing tests was discussed by Olsen et al. [3] provided basis for the improvement of anti-icing system. Some people focused on the external heat transfer to prevent ice formation. Downs et al. [4] investigated how exhaust slot effected the boundary layer downstream of a aero-engine intake to prevent ice formation, which is different from the typical arrangement for an engine intake anti-icing system. Riley et al. [5] investigated various exhaust slot geometry designs in an experimental study to make sure the engine intake air upstream of the compressor could be used efficiently downstream of the exhaust slot to effect heating of the downstream surface (acoustic liner) to facilitate the prevention of ice build-up in the inlet of an aircraft engine. He found the most significant variables were assembly length, exit plane width, exhaust angle and slot depth. A 2D Navier-Stokes CFD code was used by Saeed et al. [6] to simulate jet impingement on (a) a flat plate and (b) the inner surface a slat of a multi-element airfoil. He coupled the CFD code to an ice accretion and anti-icing simulation code to simulate and analyze the hot-air anti-icing system. Some people focused on the internal heat transfer to prevent ice formation. Planquart et al. [7] presented experimental study on a full scale mock-up of the leading edge section of a jet aircraft slat and dealt with the mapping of the convective heat transfer in a multijet anti-icing

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Nomenclature

c	discharge coefficient
d	diameter of the impingement hole
D	diameter of the pin fins
h	heat transfer coefficient
LCD	liquid crystal display
$\dot{m}$	mass flow rate
p	pressure
P	error
Q_v	volume flow rate
Nu	Nusselt number
R	molar gas constant
Re	Reynolds number
S	lateral distance
S1	vertical distance
S2	distance of leading edge area
t	the heating time
T	temperature
T_i	initial temperature of the airfoil
Y	vertical direction

Greek symbols

λ	thermal conductivity
ρ	density
μ	dynamic viscosity coefficient
θ	excess temperature
Θ	ratio of excess temperature

Subscripts

aw	adiabatic wall
g	mainstream
c	coolant
w	wall

system by application of the quantitative infrared thermography technique. He also performed three dimensional numerical simulations with the commercial CFD code FLUENT. Results showed that the heating performance of such a multijet system depended on the jet Reynolds number, the distance of the supply duct and the skin and the spanwise and chordwise jet arrangement. Recently the numerical method was used by Bianco et al. [8] to analyze an anti-icing system based on hot air impinging jets on internal wing surface in order to find the optimal geometrical configuration to avoid the ice formation on the external wing surface. An anti-icing system was analyzed by Andreozzi et al. [9] based on hot air impinging jets on internal wing surface in order to check the efficiency of the system. The two-dimensional model showed that when jet impacted on wing for an impact angle equal to zero, the better configuration for anti-icing system is that with a distance 1.8 cm from wing profile. Pellissier et al. [10] presents a methodology for the optimization of hot-bleed-air anti-icing systems, known as Piccolo tubes. He constructed an optimization method based on three-dimensional computational fluid dynamics, reduced-order models, and genetic algorithms to determine the optimal geometric configuration of the Piccolo tube (jet angles, spacing of jets, and distance from leading edge). A hot-air anti-icing system of a gas turbine engine inlet was analyzed by Kamel et al. [11] who developed a computational method to analyze the anti-icing system used to protect a jet engine inlet. The method incorporates a potential flow panel code for flowfield computation, a water droplet trajectory code for impingement-rate estimation, and energy balances on the runback water and the metal skin of the nacelle for prediction of the corresponding temperature distributions. People can also use hot lubricating oil from the engine rather than using hot air to prevent ice formation. Dong et al. [12,13] used the computational method to study the temperature distribution and heat transfer distribution of an aero-engine strut under icing conditions and he gave some recommendations for an optimized design of hot oil anti-icing system. He also performed an experimental study on the performance of hot oil anti-icing system of aero-engine strut in icing wind tunnel to compare with the computational results. The results showed that the heat transfer coefficient is an important parameter in accurately predicting the surface temperature of the components under icing conditions.

In this study, we selected the strut of the inlet components of an aircraft engine as the research object to investigate the internal heat transfer. Due to the strut is similar to a convergent channel, a further study on the heat transfer characteristics of the convergent channel with pin fins was performed to obtain the optimal pin fin array within the scope of this study. This would enrich the theoretical research results of the heat transfer in the convergent channel with pin fins.

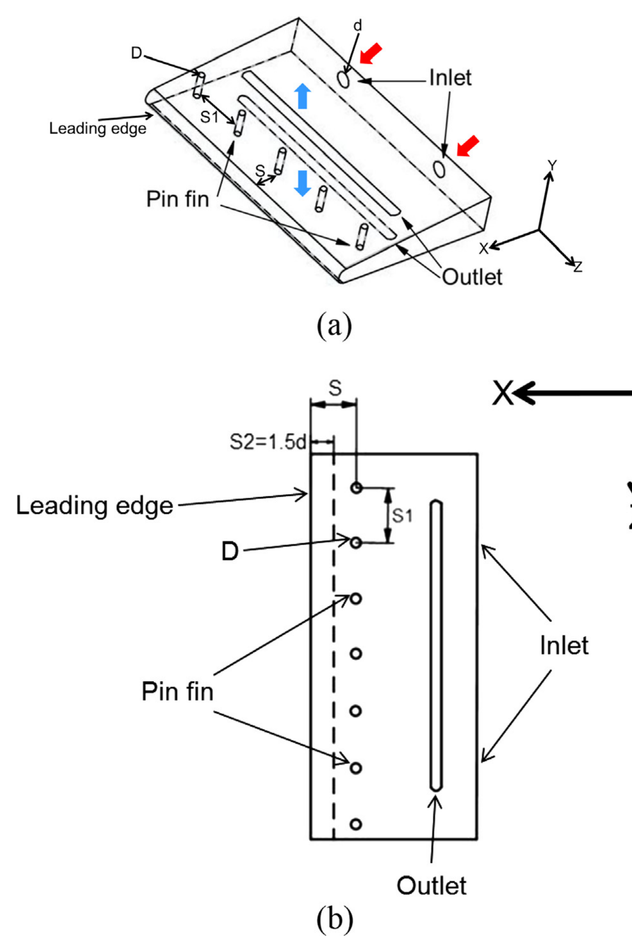

Fig. 1. Sketch of convergent channel.