EFFECTS OF ENTRANCE CROSSFLOW DIRECTIONS TO FILM COOLING HOLES

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INTRODUCTION

Besides simple cylindrical holes, film cooling holes with expanded exits have received an increased attention during recent years since they offer certain advantages which definitely improve film cooling efficiency. The enlarged cross-sectional area at the hole exit leads to a decreased mean velocity and thus a decreased momentum flux of the exiting coolant jet resulting in a reduced penetration of the coolant into the hot gas flow. For that reason the interaction and the mixing between coolant and hot gas is less intense and the cooling efficiency increases. Furthermore, expanding the holes in lateral direction provides an improved lateral spreading of the jet leading to a better coverage of the surface with coolant and accordingly higher laterally averaged film cooling efficiencies[1-3].

Most film cooling studies in the past have been performed using a stagnant plenum feeding the film cooling holes. A plenum however is not necessarily a correct means of representing the internal coolant supply passages of an airfoil. Particularely in film cooling applications of turbine blades, crossflow velocities with Mach numbers up to Ma_c=0.7 may occur. Besides the coolant crossflow's magnitude its orientation has to be taken into account as well. For film cooling applications on turbine blades the coolant supply crossflow is typically oriented in radial direction of the blades and thereby perpendicular to the main flow, whereas for turbine vanes coolant in the supply passages and main flow might be oriented parallel to each other. Even for extremely low coolant crossflow velocities, the coolant supply direction affects the surface adiabatic effectiveness values[4]. However the effect of internal coolant supply crossflow on film cooling performance has not yet been studied with sufficient detail, particularely at elevated coolant crossflow Mach numbers.

The objective of the present study therefore is to investigate to what extent coolant crossflow affects the performance of simple cylindrical and fanshaped holes. Experimental results of discharge coefficients and two-dimensional distributions of adiabatic film cooling effectiveness downstream a row of three film cooling holes are presented. An infrared camera system is used to perform highly resolved local measurements of the surface temperatures. In order to account for the non-ideal adiabatic conditions, the measured surface temperatures are interpolated onto a finite element (FE) model of the test plate. A steady state thermal analysis is performed to calculate the heat loss over the back surface and the remnant heat flux within the test plate. Based on the results of the FE analysis the measured surface temperatures are corrected accordingly. Additionally, radiative heat flux from the surroundings is taken into account during the postprocessing.

EXPERIMENTAL APPARATUS AND MEASUREMENT TECHNIQUE

Two different hole geometries have been considered. They comprise a cylindrical hole as reference case, and a fanshaped hole which is expanded in lateral direction, see Fig.1.

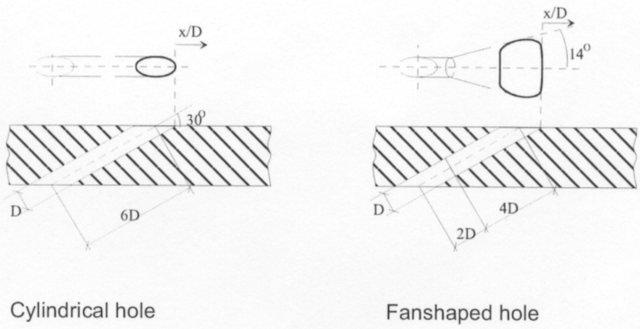

Fig.1. Hole geometries tested

For both hole geometries the hole axis was inclined 30° with respect to the hot gas flow. Operating conditions have been varied in terms of hot gas Mach number (0.3, 0.6), coolant crossflow Mach number (0.0, 0.3, 0.6), coolant crossflow orientation (perpendicular or parallel with respect to the main flow), and blowing ratio (0.5–1.5). The hole pitch to diameter ratio was kept constant at 4, the temperature ratio was fixed at 0.56 leading to an enginelike density ratio of 1.8.

Surface temperatures were measured using an infrared camera system (AGEMA 900), that consists of a scanner which is cooled by a Stirling motor and a PC with the associated software to controll the camera and to store the acquired thermographic data. The infrared camera provided a two-dimensional mapping of the temperatures that was digitized into an array of 272 times 136 pixels. Accounting for the optical setup used in the experiments this resulted in a spatial resolution of 0.8mm times 0.8mm per pixel. The surface of the test plate exposed to the hot gas was covered by a black paint with a well-known emissivity of 0.95. 17 0.5mm NiCr-Ni-thermocouples have been embeded flush with the surface in order to recalibrate the infrared camera readings. Another 15 0.5mm NiCr-Ni thermocouples were mounted flush to the back of the test plate in order to controll the remnant heat flux through the material. A simplified sketch of the setup is given in Fig. 2.

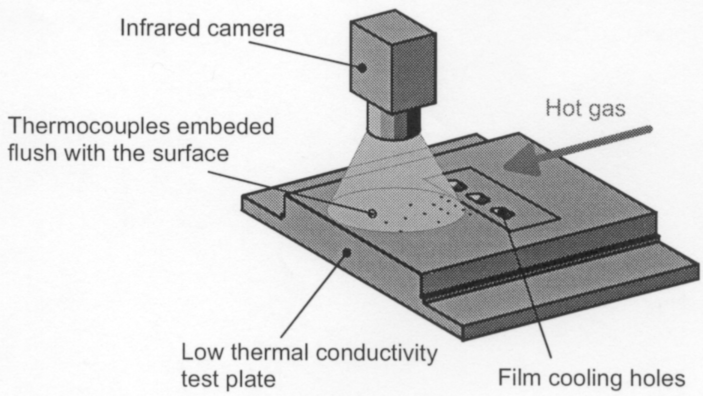

Fig. 2. Experimental setup for thermographic measurements

RESULTS

As expected in most cases the fanshaped holes exhibit a superior behaviour in comparison to the cylindrical holes in terms of lateral spreading and coverage of the surface with coolant. Additionally, the fanshaped holes in general lead to larger values of film cooling effectiveness. This is attributed to the well known effect of decreased penetration into the main flow leading to less intense mixing of coolant and hot gas.

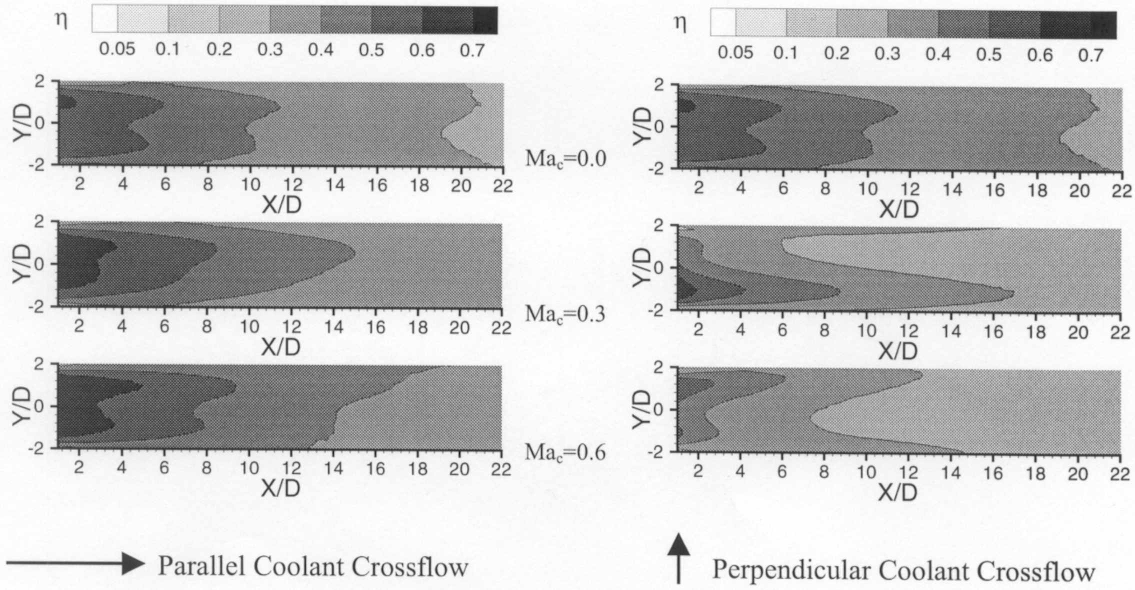

Fig. 3. Adiabatic film cooling effectiveness contours downstream a row of fanshaped holes (blowing ratio M=1.0, hot gas Mach number Ma_m=0.6)

The impact of hot gas crossflow velocity on film cooling effectiveness is small within the range of Mach numbers investigated. The effect of internal coolant crossflow velocity however is very pronounced and strongly depends on coolant crossflow orientation with respect to the hot gas flow direction, hole geometry, and blowing ratio. In case of the cylindrical holes, the lateral spreading of the coolant is improved by the presence of a coolant crossflow. With parallel coolant crossflow applied, the surface area of intense cooling is stretched in streamwise direction and the effectiveness maximum is shifted downstream. Perpendicular coolant crossflow causes a delay of jet detachment and keeps the coolant closer to the wall. In case of the fanshaped holes, Fig. 3, film cooling effectiveness is increased when parallel coolant crossflow is present. In contrast to the cylindrical holes however, perpendicular coolant cossflow does always have a detrimental effect on film cooling effectiveness for the fanshaped holes. The coolant entering the expanded section is highly distorted causing a poor performance of the diffuser. The effectivess contours downstream the holes are skewed, leading to steep temperature gradients in lateral direction and reduced overall effectiveness.

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