FILM COOLING FROM ROWS OF HOLES - EFFECT OF COOLING HOLE SHAPE AND ROW ARRANGEMENT ON ADIABATIC EFFECTIVENESS

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In the present study the film cooling performance in terms of the adiabatic film cooling effectiveness on the scaled suction side model of an actual turbine guide vane was investigated. The experiments were conducted in an open loop subsonic wind tunnel. An infrared thermography measurement system was used to determine highly resolved temperature distribution on the model surface. Two different film cooling hole configurations were investigated: a single row of fanshaped holes and a double row of cylindrical holes in staggered arrangement. The influence of blowing rate and mainstream turbulence level on effectiveness was investigated in a wide blowing rate range for both of the injection configurations.

INTRODUCTION

The demand of improved thermal efficiency and high power output of modern gas turbine engines leads to extremely high turbine inlet temperature and pressure ratios. Sophisticated cooling schemes including film cooling are widely used to protect the vanes and blades of the first stage from failure and to achieve high life-times. In film cooling applications, injection from discrete holes is commonly used to generate a coolant film on the blade's surface. To fully realize the advantages of increased turbine performance it is necessary to further develop advanced cooling technology with increased effectiveness while minimizing the required cooling air flow and the aerodynamic penalties. In an attempt to improve the cooling process, recent attention has been given to contouring the injection hole geometry. Modern manufacturing technology like precise electric-discharge machining or laser drilling enables to form the injection hole in more complex shapes.
In recent studies attention of the Institute for Thermal Turbomachinery and other researchers was focused on film cooling holes with a diffuser shaped expansion at the exit portion of the hole[1-6]. This paper reports on an experimental investigation of two different cooling hole geometries injecting cooling air into a realistic turbine like flowfield.

EXPERIMENTAL SET-UP

Wind Tunnel and Model

The film cooling experiments were conducted in an open loop atmospheric wind tunnel. A radial compressor delivers air at about 1.3 bar and 1 kg/s to the inlet section of the tunnel where the flow is split into main and coolant flow. The main flow enters an electrical heater enabling to heat the flow up to 550 K. A mixer behind the heating cartridges provides a thorough mixing of the heated air. After passing a settling chamber including flow straighteners, honeycombs and a contraction nozzle, the main flow is entering the test section. In front of the test section, different turbulence grids can be inserted to obtain various mainstream turbulence levels. The test section consists of a rectangular channel in which scaled models of an actual turbine guide vane can be inserted. The model used in this investigation was designed in order to simulate an almost realistic distribution of Reynolds-number and acceleration parameter k typical for a suction side of an actual guide vane. To maintain a realistic airfoil like flow, a boundary layer bleed is installed in front of the inserted model to establish a stagnation point at the leading edge. The model basically consists of three different parts: A base block, an injection module and a contoured test plate for measurements of surface temperature. The injection module can be changed easily in order to test various injection configurations on the same suction side model.

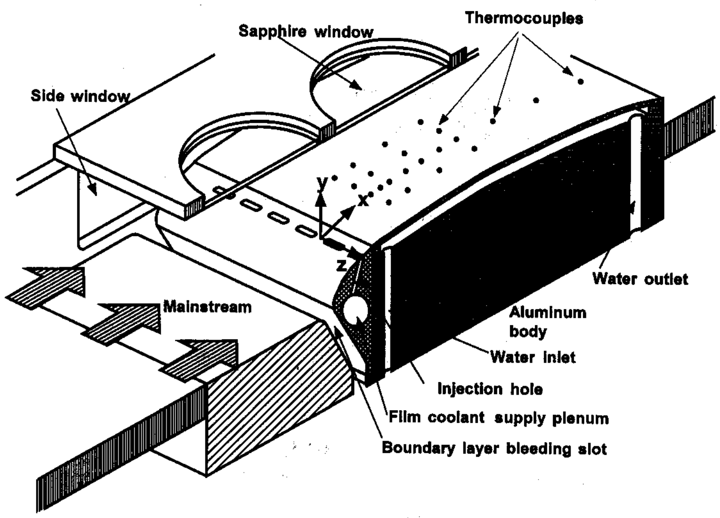

Figure 1: Suction side model used for the film cooling experiments

The investigated film cooling hole configurations are shown in figure 2. The cooling performance of a single row of 8 fanshaped holes was compared to the performance of a double row of standard cylindrical holes in staggered arrangement including 16 holes in total. The rows are placed at 10% of the chord length based on the stagnation point of the vane model. Both hole types have a diameter of 4 mm at the inlet part of the hole and are inclined 45° relatively to the models surface in streamwise direction. No lateral or compound injection angle has been applied. The fanshaped hole consists of a cylindrical part at the inlet with a length of 2 hole diameters and a lateral expanded section towards the exit part of the hole having an expansion angle was 14°. The distance between the holes in a row was 4 hole diameters and the distance between the rows in the double row arrangement was 2 hole diameters.

Measurement Technique

Surface temperatures were measured in high resolution using an infrared (IR) scanning system and thermocouples placed on the surface of the contoured test plate. The IR-system provided a two dimensional distribution of the temperature on the plate surface in high spatial resolution. The IR image of the test plate surface was digitized into an array of pixels. Accounting for the optical setup used with the IR camera, a spatial resolution 0.6 mm x 0.6 mm per pixel could be achieved. The accuracy of the IR measurement was improved by employing a special In-Situ calibration procedure taking the physical radiative exchange inside the test section into account. For this calibration about 12 thermocouples were distributed on the model surface in order to cover the entire range of surface. By using the In-Situ calibration procedure highly resolved surface temperature data with an uncertainty within 1% have been obtained.
The acquired surface temperature data were further processed in order to correct to the adiabatic wall temperature. Three dimensional heat flux values inside the test plate have been calculated by an finite element analysis with the measured data given as boundary conditions. The analysis shows that there is quite an important influence of lateral heat flux on the local distribution of adiabatic wall temperature and therefore the adiabatic film cooling effectiveness.

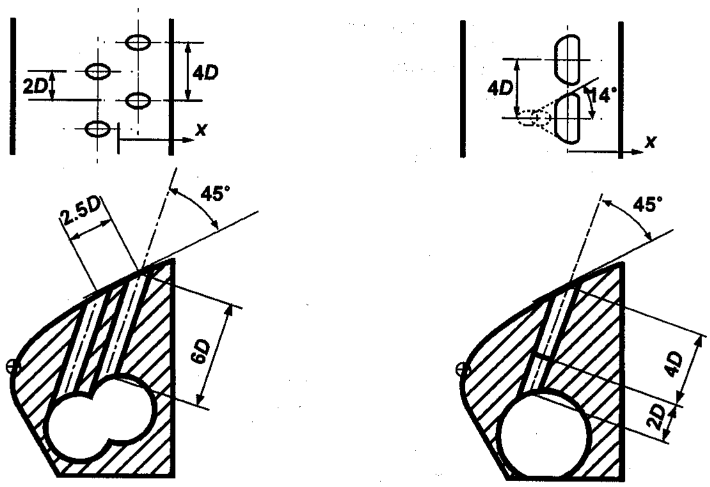

Figure 2: Geometry and arrangement of investigated film cooling hole configurations: double row of cylindrical holes (left) and single row of fanshaped holes (right)

RESULTS

It was found that the double row of cylindrical holes provides similar adiabatic film cooling effectiveness values compared to the fanshaped holes at small blowing rates below 1.0. Due to the staggered arrangement of the two rows, the coolant is well spread in lateral direction and a quite uniform distribution of effectiveness is achieved. Comparing the results for equal total coolant mass flow, double rows of cylindrical holes give as good effectiveness values as the single row of fanshaped holes in this low blowing rate range. At higher blowing rates the injection from the single row of fanshaped holes show better adiabatic effectiveness in the near hole region than the injection from the double row due to coolant jet separation of the cylindrical holes injection. The fanshaped holes have shown to provide a good surface protection in a wide range of blowing rates whereas the cylindrical holes have to be used at their optimum working point to provide similar quality of protection.

The improvement in film cooling performance when using shaped holes is caused mainly by the reduction of the jet exit momentum due to the increased cross sectional area at the hole exit compared to the standard cylindrical hole. Therefore, the penetration of the jet into the mainstream is reduced resulting in increased cooling efficiency. Furthermore, lateral expansion of the hole provides an improved lateral spreading of the jet leading to a better coverage of the surface and a higher laterally averaged effectiveness.

REFERENCES

1. Gritsch, M. ; Schulz, A. ; Wittig, S. (1997): *"Adiabatic Wall Effectiveness Measurements of Film Cooling Holes with Expanded Exits"* ASME Paper 97-GT-164
2. Gritsch, M. ; Schulz, A. ; Wittig, S. (1998): *"Heat Transfer Coefficient Measurements of Film Cooling Holes with Expanded Exits"* ASME Paper 98-GT-28
3. Goldstein, R.J. ; Eckert, E.R.G. ; Burggraf, F. (1974): *"Effects of Hole Geometry and Density on Three-Dimensional Film Cooling"* International Journal of Heat and Mass Transfer, Vol. 17, pp. 595-607
4. Makki, Y. ; Jakubowski, G. (1986): *"An Experimental Study of Film Cooling from Diffused Trapezoidal Shaped Holes"* AIAA Paper 86-1326
5. Reiss, H. ; Bölcs, A. (1999): *"Experimental Study of Showerhead Cooling on a Cylinder Comparing Several Configurations using Cylindrical and Shaped Holes"* ASME Paper 99-GT-123
6. Thole, K. ; Gritsch, M. ; Schulz, A. ; Wittig, S. (1996): *"Flowfield Measurements for Film Cooling Holes with Expanded Exits"* ASME Paper 96-GT-174