A New Test Rig for the Investigation of Film Cooling on Rough Surfaces

Long Abstract

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Introduction

Increasing demands for the efficiency of cooling systems in modern turbo engines require an even deeper understanding of proven cooling concepts such as film cooling. Surface roughness on turbine blades is induced by thermal barrier coatings or arises during operation of the engine. Particularly convective heat transfer on surfaces with real roughness is still not entirely understood. Roughness has a great effect on fluid flow and heat transfer and thus also on film cooling. Computational methods concerning the prediction of heat transfer are still struggling with such complex flow phenomena. Thus, an experimental approach is chosen to investigate the effect of surface roughness on film cooling effectiveness and heat transfer coefficients.

Similar investigations were conducted by Goldstein et al. [1], Barlow and Kim [2], Schmidt et al. [3], Schmidt and Bogard [4], Bogard et al. [5], or Rutledge et al. [6]. However, density ratio between hot gas and cooling air did not match realistic values in all studies leading to difficulties when transferring the results to the real engine. Additionally, some of the studies use roughness heights and shapes that differ from roughness present on real turbine components. Furthermore, to the knowledge of the authors shaped cooling hole geometries have not been investigated in combination with surface roughness. Since this is the state of the art in modern engines, there is a need for further investigations including systematical variation of roughness parameters in order to characterize their effect on film cooling effectiveness and heat transfer.

The aim of this paper is to introduce a new test rig for the investigation of film cooling on rough surfaces which meets the requirements of all relevant non-dimensional parameters. A description of the measurement principle and measurement uncertainties is included as well as the design of the test surfaces for the laboratory experiments. Test surfaces are based on previous investigations by Glasenapp et al. [7] assessing real turbine blade roughness parameters. The final paper will include measurement results that prove homogeneity of the hot gas flow approaching the film cooling holes. Furthermore, preliminary results of heat transfer coefficients on a smooth surface without film cooling are shown to demonstrate the quality of the measurement principle.

Methods

The new test rig which is introduced in this paper is designed for generic film cooling studies. Focus is set on influencing parameters regarding surface roughness. Based on a similarity analysis by Fraas et al. [8], the test rig is geometrically scaled up resulting in a cooling hole diameter of 10 mm. All relevant non-dimensional parameters are considered to ensure transferability of the results. The test rig is integrated into the test facilities at the Institute of Thermal Turbomachinery (ITS).

Hot gas is provided by a centrifugal compressor and heated in an electric heater. Cooling air is compressed by a different compressor and fed to a plenum from which it enters the cooling holes. Temperatures are chosen in a way that realistic density ratios between hot gas and cooling air can be achieved. In the test section, different turbulence grids can be applied in order to adjust the turbulence intensity. A boundary layer bleed ensures matching of the boundary layer thickness. Various cooling hole geometries at different lateral spacing can be investigated for realistic blowing ratios. Furthermore, acceleration of the hot gas flow can be simulated. Extensive optical access is provided in the test section for future PIV and LDV measurements. Focus of investigations carried out on this test rig, however, is set to a variation of the surface roughness. The roughness is induced by generic roughness elements shaped as truncated cones. Design and scaling of the test roughness is presented in the paper. The authors emphasize the necessity of respecting not only roughness height, but also density and shape of the roughness elements.

Knowledge of local heat transfer coefficients and adiabatic wall temperature is required in order to fully describe a film cooling configuration. For the calculation of these parameters, the principle of superposition according to Choe et al. [9] is used in this study. It is implemented to the test rig by changing the heat flux through the measurement plate which is cooled in one case and uncooled in the other case. Temperatures on the surface downstream of the film cooling holes are measured by high-resolution in-situ calibrated infrared thermography. Heat flux perpendicular to the surface is calculated using a 3D Finite Element Method. This measurement technique has been used and further developed at ITS by Gritsch et al. [10], Ochs et al. [11, 12], Kneer et al. [13, 14] and Fraas et al. [8]. Data is processed accordingly in this study and measurement uncertainties are given.

Temperature and velocity profiles of the flow approaching the film cooling holes are measured using a combined total pressure total temperature probe and static pressure measurements at the wall of the channel. Heat transfer coefficients without film cooling are obtained by FEM calculations and infrared measurements of the temperature on the test surface. These heat transfer coefficients are compared to a correlation as a validation of the test rig.

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