Implementation of an In-situ Infrared Calibration Method for Precise Heat Transfer Measurements on a Linear Cascade

Svenja Aberle[1], Martin Bitter[1], Florian Hoefler[2], Jorge Carretero Benignos[2] and Reinhard Niehuis[1]

[1] Institute of Jet Propulsion, Universität der Bundeswehr München, Neubiberg, Germany

[2] GE Global Research, Garching, Germany

Long Abstract

Introduction

The aim of emissions reduction and fuel saving is widely spread in all parts of technology, especially in aerospace engineering. In that respect, there are various fields of research concerning the propulsion system of civil and military aircrafts targeting an improvement of the engine's efficiency. One of these fields is the heat management in specific engine components, which has been addressed as an experimental research topic by the Institute of Jet Propulsion (ISA) of the University of the German Federal Armed Forces in Munich for many years. To widen the range of temperature measurement methods in the Institute's test facilities, the infrared measurement technique was established in cooperation with GE Global Research in Garching, Germany.

This paper focusses the precise estimation of the heat transfer coefficient on a linear cascade by means of the infrared measurement technique. A measurement procedure is described, which accounts for three major impacts on the accuracy of the results: Firstly, the correlation between the measured infrared intensity and the surface temperature; Secondly, the angular dependency of the emissivity coefficient in particular; Thirdly, the precise determination of the conductive loss of the heat flux. Whereas the latter one is estimated by an FEM simulation, the former ones have to be considered using a powerful in-situ calibration method, which was established and demonstrated on a cascade in low-speed test conditions.

1. Imaging thermography for heat transfer measurements

In the field of flow characterization, the infrared thermography is commonly used for the visualization of boundary layer conditions as described by Grawunder et al. [1]. The estimation of the convective heat transfer is another application that is discussed in detail by Carlomagno et al. [2].

Independent from the way of measurement, a high accuracy of the measured surface temperature is required in order to determine the heat transfer precisely. At the ISA, previous investigations on the heat transfer of blades in a linear cascade were conducted in the high-speed cascade wind tunnel. With this test facility, transonic cascade tests at moderate flow temperatures between 298 and 333 K can be conducted. So far, thermochromatic liquid crystals were utilized for the determination of the surface temperature distribution as a base of the subsequent calculation of the heat transfer, see Gomes et al. [3]. Another imaging thermography used at the ISA is the application of temperature-sensitive paint, see Bitter [4]. A major disadvantage of both measurement techniques is the limitation to a certain temperature range for commercially available paints. To enable investigation on the heat transfer for higher surface temperatures in the near future, the infrared thermography was implemented based on the later described in-situ calibration method for cascade testing.

2. In-situ calibration method

The correlation between the measured infrared intensity and the local temperature depends on the emissivity coefficient, but also on environmental conditions [2]. A further challenge is the comparably high angular dependency of the emissivity coefficient, especially at shallow angles of view. Due to the curved blade surface, a consideration of the local emissivity is essential for high precision infrared temperature measurements on a cascade. To address the angular dependency, a pixel-by-pixel calibration is chosen to account for the local effects of the emissivity coefficient as well as of environmental conditions in the same step. Hence, the calibration is conducted directly at the test set-up, by heating the blade surface to several discrete temperatures. With the corresponding local infrared intensity detected by the camera, a calibration function is set up for each pixel. Thus, each angle of view towards the blade that occurs from one camera position is calibrated in the same step.

The procedure was applied on a linear cascade in the atmospheric low-speed wind tunnel at GE Global Research. To achieve a convective heat transfer, the center blade of the cascade was equipped with a heating foil. The temperature distribution to be reached for several flow conditions was evaluated by means of the local calibration. A detailed description of the calibration procedure will be given in the full paper.

3. Results

Targeting the determination of the heat-transfer coefficient on the suction side as well as on the pressure side for the surface length, two set-ups for both sides were realized. Only the respective side of interest was heated to detect the local temperature for specific flow conditions using the corresponding calibration. The resulting heat transfer is finally determined under additional consideration of conductive heat losses calculated by an iterative FEM simulation, compare Gomes et al. [3].

The heat-transfer coefficient for one operating point determined by the described method is shown in Figure 1 for the suction side as well as for the pressure side. A detailed discussion of the results will be presented in the full paper.

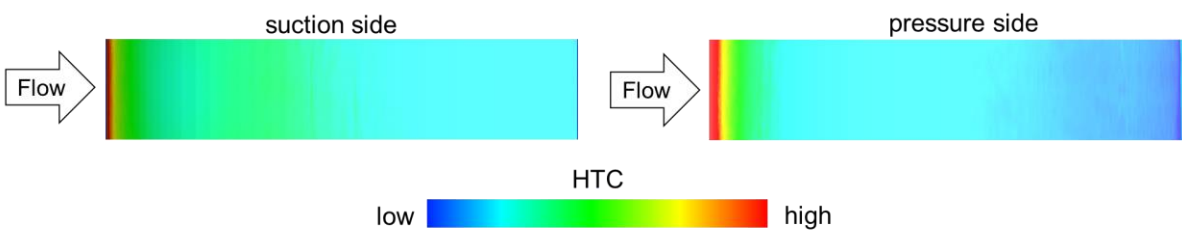

Figure 1. Measured heat-transfer coefficient (HTC): suction side (left) and the pressure side (right)

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