DEVELOPMENT OF A FAST-RESPONSE TOTAL TEMPERATURE PROBE FOR SHORT-DURATION TURBINE RIGS

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Abstract
This paper presents the design, realization and experimental testing of a fast response thin film probe conceived for high-frequency gas total temperature measurements. The main goal of the probe is the thermal characterization of the unsteady flow field at the outlet of a high pressure turbine (HPT) stage operated at engine-scaled flow conditions in the short-duration turbine test rig of the von Karman Institute. The proposed design reconciles the high frequency response (up to 100 kHz) and high spatial resolution of the thin film array (0.9 mm sensor height) with a low measurement intrusiveness. The thermal status of the probe is adjustable prior to each test by means of an integrated heater, dimensioned with the aid of high-fidelity numerical computations. A high-accuracy data reduction methodology is proposed to infer the gas total temperature from the wall temperature and heat flux, based on a detailed comparison between 1-D and 2-D heat flux predictions. The dynamic testing of the probe is performed in a controlled environment. A dedicated hot air jet facility is employed to generate a series of test-relevant heat transfer steps at different initial wall temperature values, demonstrating a global error on the evaluation of the gas total temperature below 0.5 K.

Introduction
The development of modern aeroengines is committed to the pursuit of ever-increasing cycle efficiency and components lifespan. A comprehensive understanding of the unsteady flow field of the high pressure turbine (HPT) stage is fundamental for the achievement of these multiple, conflicting design objectives. Despite the significant body of published work, a critical shortage of time-resolved temperature data collected at engine-scaled conditions still constitutes a limit for the validation of numerically-predicted unsteady loss mechanisms.

The present research work addresses the conception, design and experimental validation of a high-bandwidth gas temperature probe for the evaluation of the time-varying flow field at the outlet of a HPT stage. The test article is operated at high degree of engine flow similarity in the short-duration turbine test rig of the von Karman Institute. The probe head, shown on the left-hand-side of Figure 1, is constituted by a Macor cylinder of 6 mm diameter. The sensing elements consist of an array of nine miniaturized Platinum thin films deposited horizontally onto the ceramic substrate. Each sensor presents a thickness of 0.9 mm and the sensor resistance (50 ± 1 Ω) is set in order to achieve an optimal temperature sensitivity while limiting the power dissipated by Joule effect. The semi-infinite assumption for heat conduction inside the probe body is verified for a time period of 0.5 s, consistently with the duration of the blow-down tests performed in the turbine test rig.

Results
Figure 1b shows a preliminary experimental assessment of the probe conducted by infrared thermography. In the present case, the internal heater provides a power of 1.05 W and a current of 20 mA is supplied to the nine thin film sensors. This analysis is instrumental in quantifying the uniformity of the thermal field established along the sensor array and determining the impact of the power dissipated by the thin films.

Figure 1c presents the computation of the adiabatic wall temperature from a selection of five tests operated in the hot air jet facility. Each of the tests is characterized by a different heater power and, hence, initial thin films temperature. The gas total temperature is found by extrapolation as the wall temperature value that provides null heat flux. The estimated discrepancy between the gas total temperature, measured in the hot jet nozzle by means of a calibrated thermocouple, and the extrapolated value results below 0.5 K.

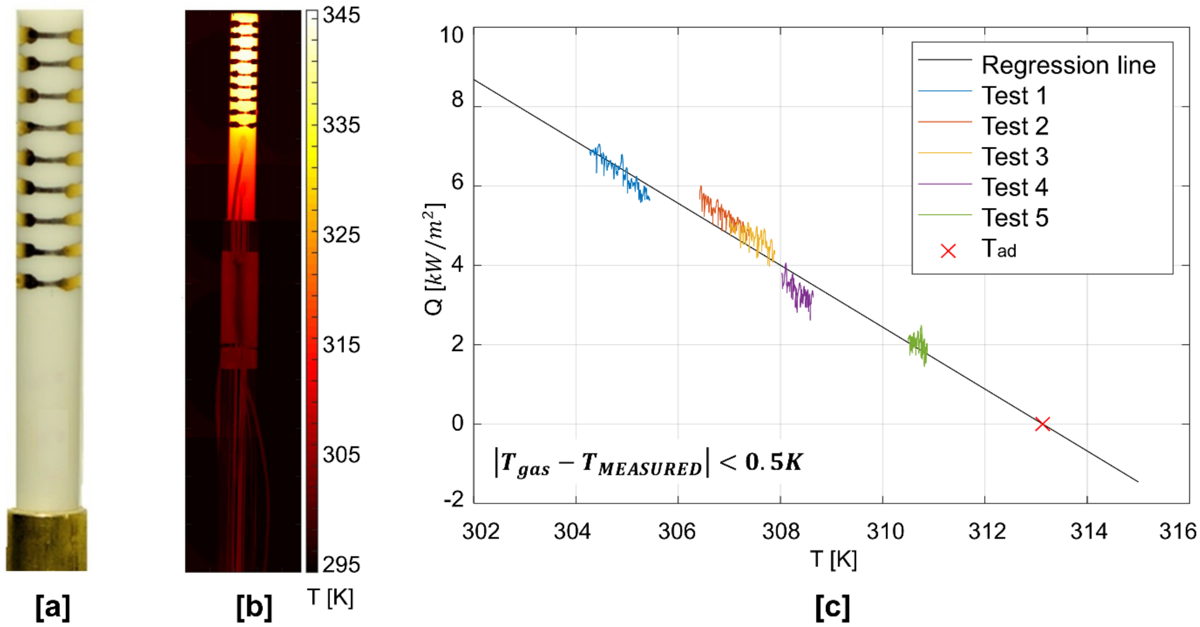

Figure 1 Gas temperature probe front view (a), infrared image of probe with operating heater [b] and gas temperature computation from dynamic tests in hot air jet facility [c]