IN-SITU CALIBRATION OF INFRARED FILM COOLING MEASUREMENTS WITH THE SEED GAS CONCENTRATION TECHNIQUE

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ABSTRACT

This paper presents a novel hybrid approach to film cooling measurement, combining infrared (IR) thermography with the seed gas concentration technique. The seed gas concentration technique is used as an in-situ calibration ground truth for the IR measurements to correct for imperfect insulation and test facility-induced thermal disturbances, such as heat up of the coolant through viscous dissipation in the cavities as well as ingress and egress in the uncooled baseline case. This new approach allows the final film cooling results to inherit the advantages of both measurement techniques. The robustness against thermal disturbances, as well as the high accuracy, are inherited from the point-wise seed gas concentration technique, while the high spatial resolution is inherited from the full surface coverage IR measurements.

This new approach is demonstrated for purge film cooling measurements in a turbine center frame (TCF) tested under Mach-similarity in the transonic test turbine facility (TTTF) at Graz University of Technology. The TCF, also known as intermediate turbine diffuser, is a stationary duct that connects the high-pressure turbine (HPT) to the low-pressure turbine (TCF) in modern high-bypass ungeared turbofan engines. The TCF was operated in an engine-representative 1.5-stage test vehicle, where a fully purged HPT was operating upstream of the TCF and a row of LPT vanes was situated downstream of the TCF. The sources of film cooling investigated here are the purge flows that emanate from the hub cavities of the HPT. These hub purge flows bear significant cooling potential for the downstream TCF hub surface. The TTTF is a good example to showcase the benefits of this new measurement approach as the complexity of the rig is high, and the challenging boundary conditions imposed on the technique are representative of many continuously operated and high technology readiness level (TRL) turbine test facilities.

INTRODUCTION

All thermal techniques for the measurement of the adiabatic film cooling effectiveness have one common drawback: none is truly adiabatic. Furthermore, engine-representative test facilities that can cater high TRLs in turbomachinery are an extremely challenging environment for thermal measurement techniques. For instance, viscous dissipation of the rotating discs heats the coolant in the wheelspace cavities, falsifying the thermal measurements, and not all flow-wetted components can be made out of insulating materials for safety reasons. In addition, most film-cooled surfaces are cooled by multiple injections of coolant and purged from multiple sources with different coolant temperatures. Consequently, a flat plate test facility's idealised conditions can barely be transferred without cutbacks to a high TRL test facility. Mass transfer techniques facilitate the heat and mass transfer analogy and, thus, are inherently truly adiabatic. However, mass transfer techniques have their own drawbacks, and their implementation into a high TRL facility can be challenging as well. For instance, the pressure-sensitive paint technique needs a large optical access and heavy calibration, the seed gas concentration technique needs a large amount of static wall pressure taps and the naphthalene sublimation, as well as the ammonia and diazo technique are heavily dependent on a constant main flow temperature.

RESULTS AND DISCUSSION

The herein investigated purge flow emanates from the aft hub cavity of the HPT and bears significant cooling potential for the downstream TCF hub surface. Neither the IR nor the seed gas techniques alone were able to capture the true behaviour of the cooling film alone. While the IR technique proved the existence of longitudinal film cooling streaks, as can be seen in Fig. 1 (a), the results were clearly influenced by thermal conduction and the viscous heating of the aft hub purge flow in the rotating wheelspace cavity. Furthermore, the mainstream temperature at the HPT outlet (=TCF inlet) is far from uniform, further complicating the postprocessing of the IR data.

The seed gas technique delivered accurate and robust results, as shown in Fig. 1 (b). However, the spatial resolution was too low to detect the existence of the longitudinal film cooling streaks fully. The static wall pressure taps, where the gas concentration was sampled, are shown as black dots. The in-situ calibration offset is shown in Fig. 1 (c) and is obtained by subtracting the IR results in (a) from the seed gas results in (b). By adding this in-situ calibration offset to the IR results in (a), the final η field in (d) is obtained. Only when the IR results were in-situ calibrated with the seed gas results clear, undistorted, spatially fully resolved and, most importantly, correct film cooling results were obtained, shown in Fig. 1 (d).

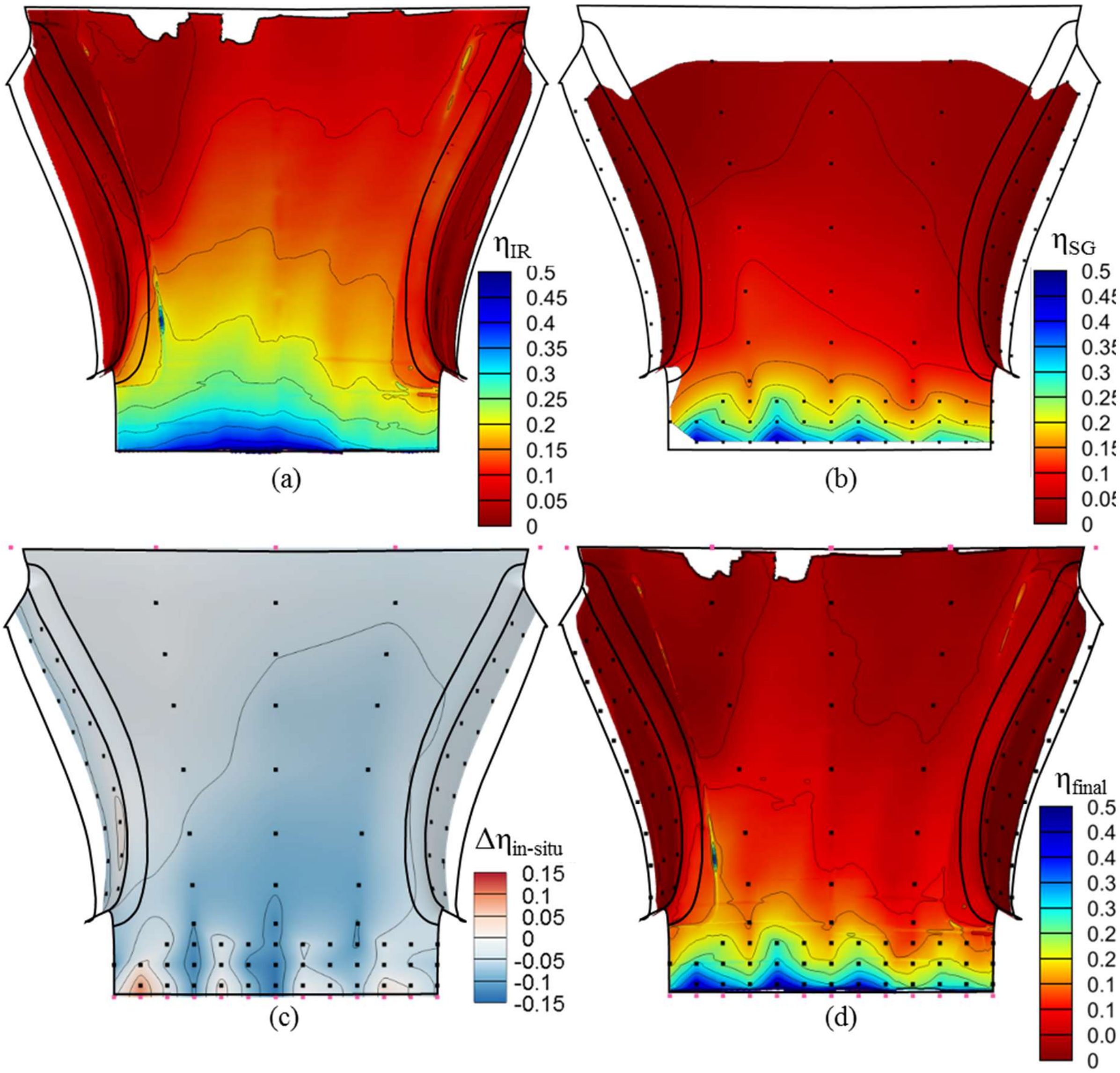

Figure 1 (a) Purge film cooling effectiveness from IR technique, (b) from seed gas concentration technique, (c) in-situ offset, (d) final purge film cooling effectiveness