Infrared thermography analysis of the transient aerothermal evolution in a turbofan core compartment model

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Abstract

Aeronautical actors are widely involved in research for transient conjugate heat transfer problem. The jet engine manufacturers are especially interested in the development of methods to simulate the aerothermal phenomena occurring during the engine speed changes in several critical areas as the engine core compartment. This last one, localized between the IFS and the primary flow carter, is in the vicinity of high pressure compressor stages and combustion chamber. The important heat transfer occurred induces complex aerothermal behaviour. Despite a global air cooling which is taken directly from the cold fan flow, the thermal conditions could be severe in transient engine phases for the different items (valves, ducts and controls) installed in this part of the nacelle.

The ONERA, in association with major French aeronautical industries, has decided to develop an efficient method to characterize accurately the transient aerothermal coupling. In this way, a set of experiments are defined to analysis the transient aerothermal evolution in a turbofan engine core compartment configuration. His important experimental study is cut in two complementary parts. On one hand, the global ventilation is modelling with a simplified and modular half scale mock-up based on the CFM56-5C core compartment configuration (see figure 1). It is made up with a cylindrical cowl with optical facilities built around a heated internal case. The entire cavity is ventilated with air at ambient temperature (flow rates between 60 and 240 g/s at 293K) and several items could be installed to generate realistic aerothermal behaviour. On the second hand, the global transient aerothermal problem is then divided in several simple models which simulated each specific case which can be observed in real configuration, as an air cooling of the internal heated case by cold jet impingements or the influence of a leakage (see figure 2). The two simple cases presented here involve vertical and cold jets blowing in a crossflow at ambient temperature. They are in strong thermal interaction with a thick, opaque and homogenous flat plate heated on its back face at a constant temperature of 325 K. The plate is made In vitroceramic (Macor). The dimensions of jets and their positions in front of or above the target plate are defined to be representative of the engine real conditions, with an effective velocity ratio from 6 to 7.5 in jet impingement configuration and 1.0 to 1.8 in the case leakage modelling. The mock-ups are integrated in a wind tunnel chich produce a cross flow with a velocity of 4.6 m/s at ambient temperature (295 K).

In each experiment, the transient aerothermal study is carried out by varying the flow rate of the main ventilation or of the local air cooling linearly in several seconds between two beforehand definite extreme values. This flow rate evolution is well controlled and reproducible which allows accurate phase average measurements. In all cases, infrared thermography was used to follow the transient response of surface temperature during the flow rate evolution and until the thermal equilibrium. To complete the study an evaluation of the experimental uncertainties is conducted.

In the case of the simple models, a phase averaged approach was carried out on 100 cycles of 660 s with an acquisition frequency equals to 1 Hz. In parallel, several thermocouples are used to follow the air temperature In jet and main flow. They are also used to quantify the wall temperature of all test section sides in order to checz the adiabatic assumption and evaluate the radiant interchange error induced by using the Gebhart coefficient method in a simple model ($\Delta T_{radiant}$ = 0.2K). From these first results, all the experimental methodology could be then adapted to the core compartment mock-up, which looks more complex. The cowl is equipped with ZnSe windows which allowed the wall temperature measurement of a part of the heated case. By turning the cowl around the axis, all the case can be observed. Moreover, all sides are equipped with thermocouples. As the transient conditions are longer than in the simple cases, the thermal response during transient evolution is quantified in only one 1800 seconds cycle. As the infrared camera is worked at a frequency of 50 Hz, a 1Hz measurement is obtained by meaning 50 frames each second. An analysis of the accuracy of this method is proposed compared to a real phase averaged technique.

Due to thermal conditions, complex geometry and gre body approximation, the radiant interchange terror could not be neglected in this last configuration. Thus an algebraic method is proposed to correct thermography data by taking account an evaluation of the radiation exchange in the cavity during all the transient evolution. It is an adaptation of the classical Gebhart method to an unsteady case. In this way, both infrared thermography and thermocouple data acquired during the cycle have to be synchronised and interpolated on a case mesh used toevaluate view factor matrix. Finally, the radiant exchange error is deduced on the case grid for each time step.

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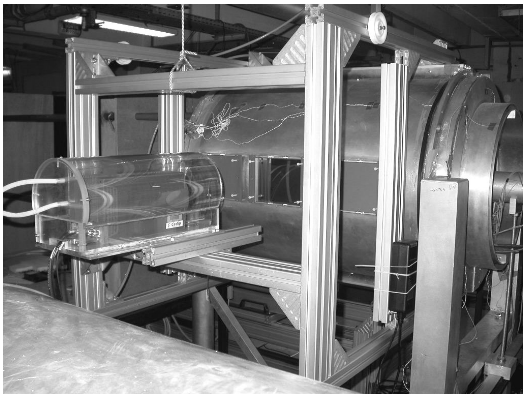

Fig. 1. Nacelle core mock-up – Infrared thermography measurements

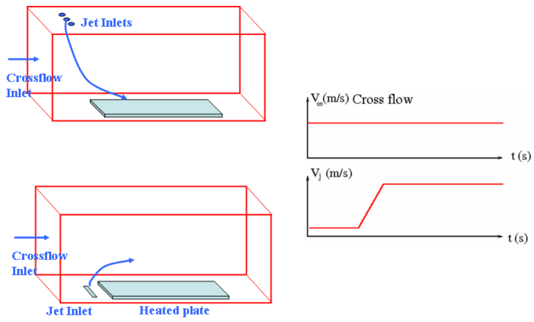

Fig. 2. Basic experiments for transient aerothermal studiem ((a)air cooling – (b) case leakage)

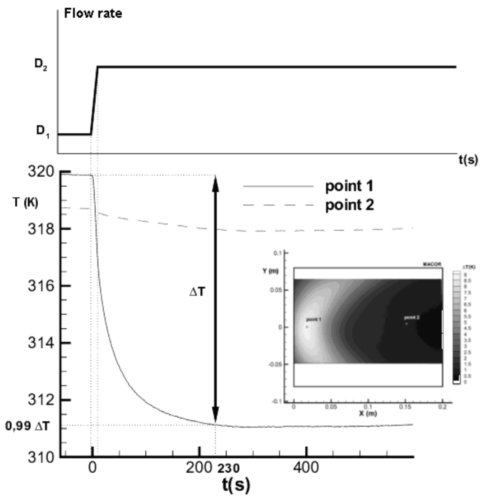

Fig. 3. Air cooling – Thermal measurement during transient evolution

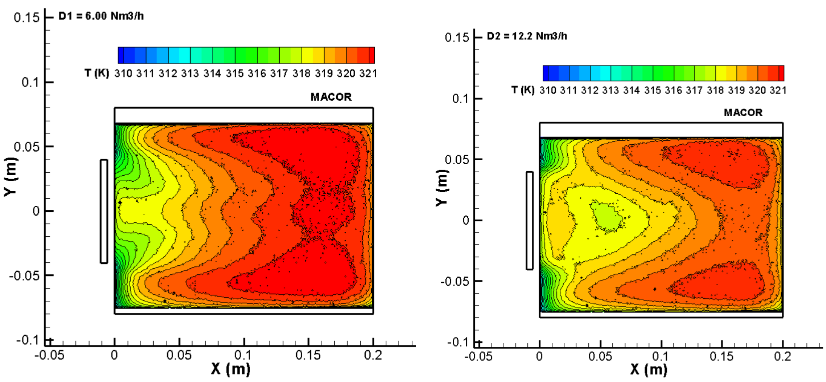

Fig. 4. Case leakage – Thermal measurements for steady configurations

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