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Thermographic inspection system for micro-perforated metal sheets in hybrid laminar flow control wings

by P. Venegas*, J. Velasco*, R. Sánchez**, R. Martín**, I. Sáez de Ocáriz*

* *Aeronautical Technologies Centre, Advanced Manufacturing, Alava Technology Park, Miñano Mayor, Spain*
** *Aerometallic Components S.A., Alava Technology Park, Miñano Mayor, Spain*

Abstract

The reduction of emissions in air transport is a matter of high importance nowadays. Great efforts are being devoted to various lines of research to achieve the goal of a zero-emission aircraft by 2050. Among the main lines of work to reduce emissions in the aviation sector is the development of Hybrid Laminar Flow Control technology. Motivated by this goal, a monitoring system capable of detecting anomalies in the micro-perforations used in this flow control technology has been developed in this study. This system was based on the combination of infrared thermography and deep learning, and provided highly satisfactory results.

1. Introduction

The reduction of emissions in air transport is a matter of high importance nowadays. Great efforts are being devoted to various lines of research in order to achieve the goal of a zero-emission aircraft by the year 2050 [1]. Among the main lines of work to reduce emissions in the aviation sector is the development of new engine technologies, the optimization of fuselage aerodynamics, and the development of Hybrid Laminar Flow Control (HLFC) technology [2].

HLFC technology enables to control the transition from laminar air flow to turbulent flow over wings, tail planes or nacelles, combining a moderate suction of the air flow through micro-holes made in the aerodynamic surface (Laminar Flow Control) with a gradient of adequate pressure generated naturally (Natural Laminar Flow) [3]. This approximation reduces the complexity and weight of the suction system and does not interfere with the main part of the aircraft component, while providing a drag reduction and the corresponding decrease in fuel consumption.

The current state of the HLFC technology is advanced but an integrated approach considering aerodynamic, structural, manufacturing and systems design is still required to achieve a series production. Among the problems that must be solved is the need to guarantee that the micro-perforations made in the material, through which the air flows during the operation of the HLFC system, have the correct size, are in the correct position, and remain unobstructed by some foreign object that prevents the correct functioning of the system.

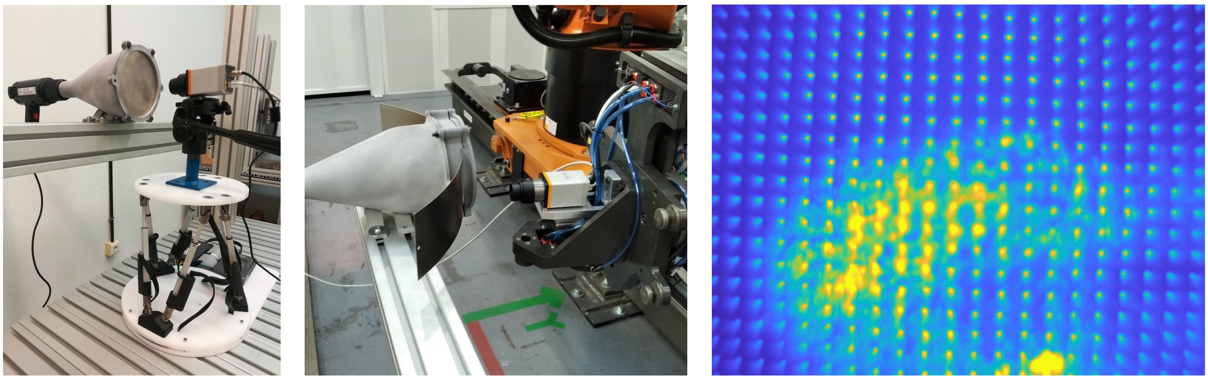
There are some technologies that could solve this problem but find limitations. For example, a visible spectrum machine vision system equipped with a suitable macro optics could monitor the dimensional characteristics of the micro-perforations. However, the high reflectivity of the base material makes the required lighting adjustment highly complex, and the closed and watertight configuration of the aeronautical components makes transmission lighting unfeasible. Another option could be the use of a pressure system that measures the air flow that crosses the micro-perforated surface and calculates the percentage of perforations based on the measurement obtained. However, despite detecting the existence of obstructions, this approach does not allow a precise positioning of the affected areas, and therefore the repair works are poorly localized.

Motivated by the mentioned problem in the micro-perforations of the HLFC systems, a monitoring system capable of detecting anomalies both in the size of the micro-drills and in their distribution, and which also allows the precise positioning of the faults detected to apply specific corrective actions, has been developed in this study. This system is based on infrared thermography technology [4, 5] complemented with deep leaning systems to automate the detection and classification of defects [6, 7].

2. Results

The objective of this study was to develop an inspection system for micro-perforations of HLFC systems, based on infrared thermography and capable of automatically detecting and positioning defects of dimensioning, distribution and obstruction. In addition, this system had to carry out dynamic inspections during the movement of a robotic arm in charge of guiding the infrared sensor over the surface to be inspected.

To meet this objective, progress has been made in successive stages. First, an analysis of thermal stimulation techniques and types of optics was carried out. Once the hardware of the inspection system was defined, the thermal characterization of the micro-perforations and the types of failure were studied. In this stage, several thermographic data processing techniques were analyzed using flat specimens that were statically inspected in the laboratory. Once the processing that best classifies the defects was identified, its application was adapted to inspections in motion (figure 1a). The final stage of the project focused on transferring the methodology developed at the laboratory level to inspections in industrial plant, with 3D



(a) (b) (c)

Fig. 1. *Representative images of different stages of the project: (**a**) 2D laboratory inspection; (**b**) 3D workshop inspection; (**c**) detection of a cluster of obstruction defects.*

movement on curved surfaces of real components (figure 1b). The data obtained in every stage of the project were used to train image classification deep learning models to automatically detect and classify defects. The project concluded with a final stage of plant inspections to validate the system, using a robotic arm and a technological demonstrator of HLFC micro-perforated component, which produced highly satisfactory results (figure 1c).

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