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IN FLIGHT OPTICAL FIBER MEASUREMENT ON FLIGHT TEST AIRCRAFT

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Abstract

For many years, the Airbus Test Center has explored new ways of measuring with the optical fiber, mainly Fiber Bragg Grating sensors for temperature, stress, bending... This low intrusive instrumentation procures the advantage to be almost transparent, making aerodynamic effects negligible. Moreover, the insensitivity to the electrical environment due to its high level of galvanic insulation, enables measurement in a high Voltage environment which was nearly impossible with classical sensors.

This presentation will describe the main difficulties, benefits and results obtained in the frame of several Flight Tests campaigns.

Key words: Optical fiber sensors; Fiber Bragg Grating

Introduction

For more than a decade, Airbus Commercial Aircraft Test Center has been interested in optical fiber. Known to the general public for its qualities in the communication industry, the optical fiber presents many advantages such as: small size, low weight, insensitivity to EMI (Electromagnetic Interference), ability to be used in ATEX (ATmosphere EXplosive) environment, … but it also has sensing properties. The sensitivity to temperature and strain had particularly caught our attention. Several implementations were done in order to decouple these two phenomena. Metrological tests were realized in Lab with successful results and allowed us to continue to evaluate in flight tests conditions.

The objective of this paper is to provide an overview of several flight tests realized on Airbus aircraft with an OFDR (Optical Time Domain Reflectometry) based on distributed Fiber Bragg Grating (FBG) with different implementations. In the first part, the integration of optical fiber sensors in aerodynamic environment will be described. In the second part, we will focus on the integration in an electrical environment.

Part 1 : Installation in an aerodynamic environment

1. Detection of laminarity along the A340-300 MSN001 wing

In September 2017, Airbus launched the Breakthrough Laminar Aircraft Demonstrator in Europe (BLADE) project to evaluate the reduction of the friction drag over the wing.

Fig. 1: A340-300 MSN1 laminar wing demonstrator

The aircraft was the A340-300 MSN 1, fitted with two 8m-long laminar profile wings. A specific instrumentation had been developed to assess the performance of the laminar flow wings.

This BLADE project offered the opportunity to install and expose the optical fiber sensors to assess their ability to detect the transition line between the laminar flow and the turbulent flow all over the wing. The transition line is characterized by a temperature variation between 2°Celsius and 10°Celsius along a laminar wing profile. This temperature variation is usually measured either by Pt100 or InfraRed (IR) cameras. The optical fiber was a good candidate for such measurements as well. Despite the low intrusiveness of the optical fiber and its capillary, their total thickness was too high (~1mm) to directly measure the temperature without disturbing the laminar flow. The optical fiber sensors were integrated using a sandwich of very thin and smooth stickers as described here after.

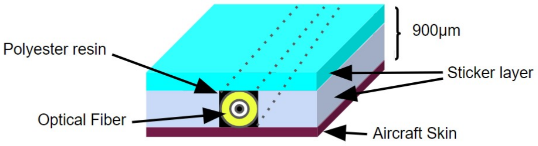

Fig. 2 : Schematic diagram of the optical fiber integrated within layers of stickers

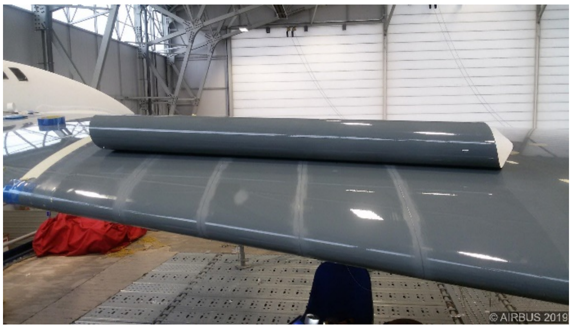

Fig. 3: Picture of the installation before upper sticker application

Fig. 4 : Installation finalized

Two optical fibers measured the temperature distribution along four wing chords during several flight tests and their results were compared to IR cameras (figure 5).

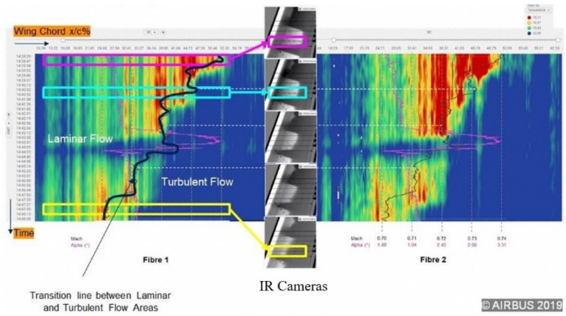

Fig. 5 : Visualization of the transition between laminar and turbulent flow area on 2 optical fibers

For each optical fiber, it was possible to detect the transition between the laminar and turbulent flow areas and there was a good coherence between them. Besides, the results showed an excellent correlation between optical fibers sensors and the IR cameras, spatially and over the time, as shown on figure 5. As the sensors are spaced 6.35mm apart, a very accurate resolution is achieved. This system can be valuable solution for areas where no direct view is possible for an IR camera.

2. Air inlet skin temperature measurement

Another application of the Optical Fiber temperature measurements in flight has been done on the engine inlet of an A350 aircraft.

Fig. 6 : A350-900 MSN1 aircraft

The request of the Design Office was to find a solution to measure the skin temperature of the air inlet without disturbing the air flow and without drilling any holes or cavities. The usual measurements are done with thermocouples bonded on the surface and covered with resin. Nevertheless, this installation is spatially limited (a few points only), complex (several wires to be routed) and considered aerodynamically too intrusive (a few millimeters thick and an uneven surface finish) as shown on the following pictures.

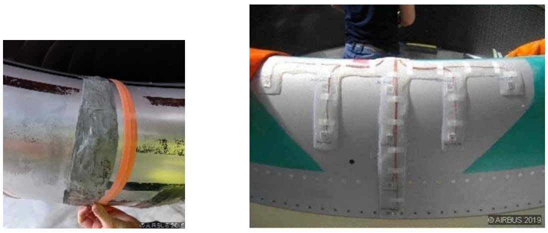

Fig. 7 : Pictures of thermocouples installation

To ease the routing of the optical fiber and to ensure the bonding, a dedicated fairing has been designed to encapsulate and maintain the optical fiber sensors.[1]

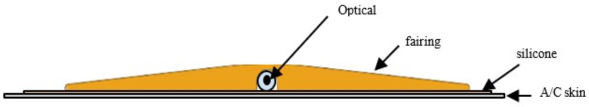

Fig. 8 : Schematic of the airbus patented fairing [1]

The integration of this concept was done on the A350-900 MSN1 at the end of 2019 and flew for a year. Four sections were instrumented with optical fiber sensors.

Fig. 9 : Pictures of the optical fibers' integration on an aircraft engine inlet

As shown on figures 8 and 9, the intrusiveness of this solution is negligible with a smooth and homogeneous profile. Besides the very small thickness of the installation, FBG optical sensors provide a huge number of measurements. Analysis has permitted the visualization of the effect of the Inlet de-icing activation. All along the four sections, the temperature distribution profile has been characterized as described in the figure 10.

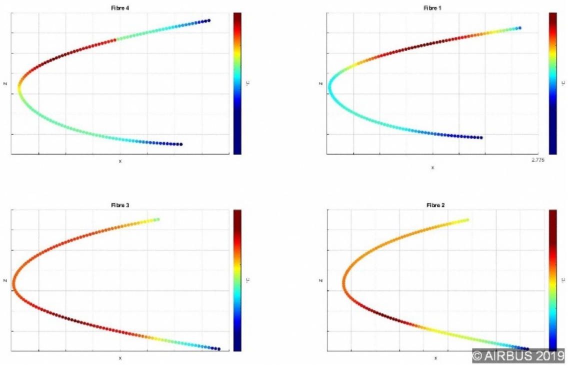

Fig. 10 : Temperature distribution measured by the four optical fiber sensors installed on A350-900 MSN1

The lesson learnt of this integration has shown several advantages:

- The sensors installation is flush and the aerodynamic impact is negligible,
- The lead time installation is reduced regarding the number of measurements,
- The post-treatment of the measurements is reduced with the absence of correction thanks to the low intrusiveness of the installation compared to the thermocouples and their resin cover.
- The optical fibers offer a fine spatial analysis compared to a few thermocouples.

3. Wing bending on A350-1000 MSN059 aircraft

In 2008, the National Aeronautics and Space Administration (NASA) presented its results to measure strain and wing bending on their Ikhana test vehicle [2, 3, 4, 5]. After several studies, the Airbus Flight Test Center has launched a study to evaluate the applicability of this method on a wider wing. The installation was done in 2021 on the A350-1000 MSN059. Eight optical fibers sensors were installed along the wing on the front spar area: four fibers were glued on the lower and the upper wing surfaces, dedicated to strain measurements and four other fibers were inserted inside a capillary to measure the temperature distribution. As the strain measurements are sensitive to temperature variations, a temperature compensation is necessary to improve the accuracy of the strain data. The optical fiber sensors were installed just after the engine pylon up to the winglet area, as described on figure 11 over a length of 23 meters.

Fig. 11: Schematic diagram of the optical fiber sensors installation on the A350 wing

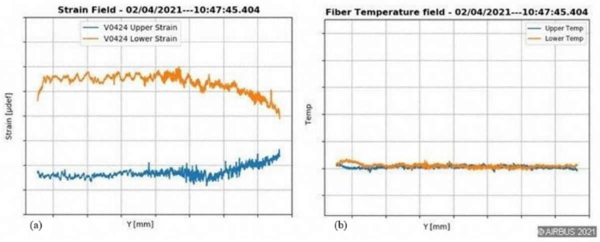

Fig. 12 : a) Strain field along the wing, b) Temperature distribution along the wing

In cruise conditions, the optical fiber sensors showed that the typical temperature distribution along the wing is quite homogeneous over the span but also between the upper and lower surfaces, the variations being a few degrees only. Using this result, confirming the numerical simulation, the model has been simplified from the temperature compensation. Applying the theory of Kho, Eq.1, from the strain measurements [5], the bending of the wing in cruise condition can be deduced:

$$\frac{d^2y}{dx^2} = \frac{\varepsilon\,(x)}{c\,(x)} \qquad (1)$$

in which y is the vertical displacement, x is the span-wise coordinate, c is the uniform beam half depth and ε(x) is the bending strain at the beam bottom (or top) surface.

The measurements done in flight with the optical fibers had been compared to a set of inclinometers, the current reference measurements. These inclinometers are installed into the wing, on the spars and are used to measure the wing twist and bending for this aircraft.

After post-processing, inclinometers and optical fiber measurements are consistent with a maximum deviation of 10 mm at the wing tip, when comparing the wing vertical displacements. This result offers the possibility to simplify the installation as the fiber is glued on the surface whereas the inclinometers should be wired inside the wing.

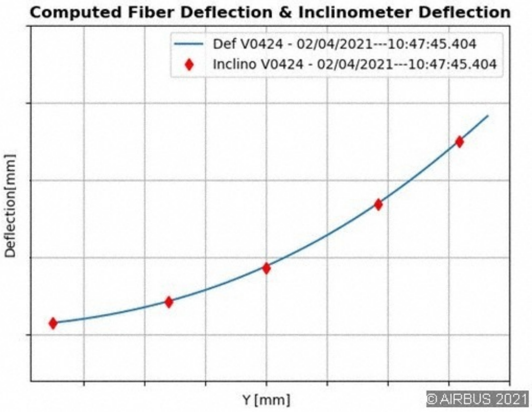

Fig. 13: Comparison between the inclinometers and the optical fiber measurements along the wing span

The next step is the investigation of the wing twist measurements as the fiber can provide a fine spatial resolution enabling to notice every twist variation over the span.

PART 2 : INSTALLATION IN ELECTRICAL ENVIRONMENT

1. Instrumentation of Beluga XL battery

Fig. 14: Beluga XL

In the frame of the Beluga XL development, we had a request to monitor the temperature inside a battery installed in the avionic bay. For safety reasons, the conventional electrical measurement with PT100 or thermocouple, has been refused, due to the risk of short circuit. Thanks to the high level of galvanic insulation of the fiber, Test Center Instrumentation teams have proposed to insert 8 optical FBG sensors between the different cells without affecting the integrity of the battery. Here after, you can see the integration of the optical fiber sensors and the 3D visualization of the thermal mapping.

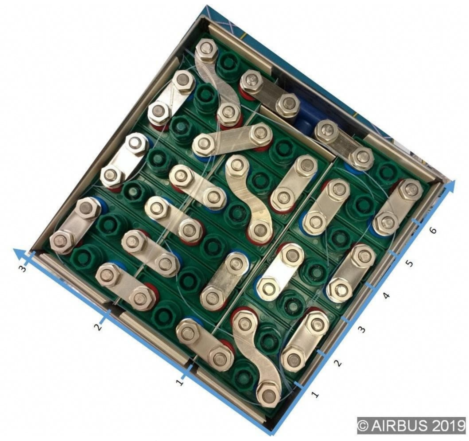

Fig. 15 :picture of the batterie with the optical fiber

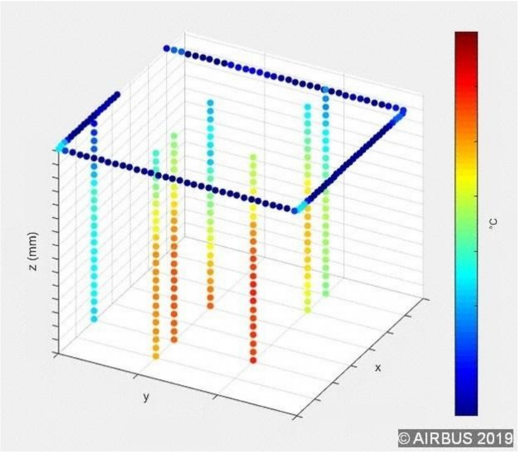

Fig. 16 : visualization of the thermal mapping

2. Temperature monitoring for High Voltage wiring

The future generation of Airbus aircraft will be more and more electric, involving new electrical power generators and convertors, using higher voltage levels. In this frame, Airbus works on the characterization of new electrical cables and connectors. The thermal dissipation of these new wires and connectors pins, is an important parameter that we want to analyze at different levels of current injection. For this purpose, conventional electrical Pt100 or thermocouple are not recommended in Lab and forbidden in flight.

That's why, we have decided to implement optical fiber technology, all along the wires and above electrical components, in order to have the temperature mapping and monitoring in the core of this harsh environment. Another advantage of the optical fiber is the immunity to the EMI (Electro-Magnetic Interference) constraints, which is a favorable asset to get accurate values in this kind of environment.

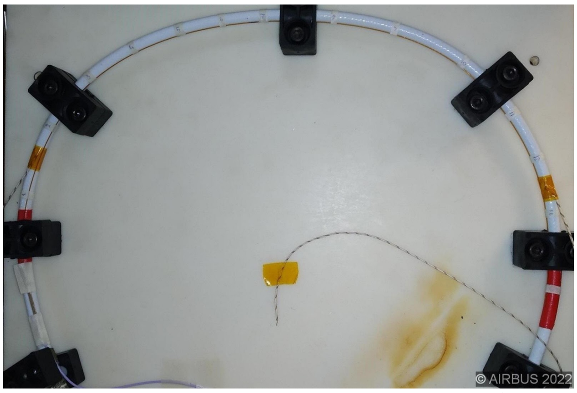

Fig. 17: temperature monitoring with optical fiber sensors of electrical cable

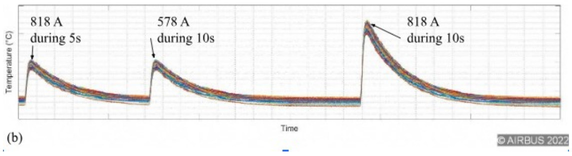

Fig. 18 :graph showing the temperature monitoring after several current impulsions

On the curves above, we can observe the temperature measurements mapping along the cable.

CONCLUSIONS

15 years ago, the Airbus Flight Test Center considered the optical fiber as a promising temperature and stress sensor. After many years of Lab testing and a long period of COTS devices evaluation, metrology verification and installation rules definition, we have been able to expose this technology in Flight, these last 5 years. The results have confirmed the promising hopes.

Thanks to the EMI immunity, galvanic insulation, low intrusiveness, …, the optical fiber sensors are well adapted to the future aircraft ambitions of Airbus. All these characteristics are in line with the challenges and needs of the new aircraft development roadmap. The number of measurements able to be collected along an optical fiber provides a measurement mapping very useful for the design office in order to improve their design models.

To continue further, our expectations are now:

- to have small and ruggedized systems able to be embedded and installed in any aircraft areas;
- to collect measurements in real time;
- to be connected with our FTI over IENA Ethernet protocol (Specific application layer developed by AIRBUS);
- to explore other kinds of physical measurements requiring a higher data rate: pressure, acoustics, …
- to continue the technical survey on different optical means (punctual, semi-distributed, fully distributed).

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