3AF
Association Aéronautique et Astronautique de France

Testing of composite materials

Fibre optic sensing opportunities

7th December 2023

HELICOPTERS

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AIRBUS

Overview

- **Introduction**
- **Fibre optic sensor technology**
  - Overview
  - Strain or temperature measurements
  - Shape or angle measurements
  - Benefit over electrical strain gauges
- **Previous & recent activities**
- **Technology impact**
- **Summary & outlook**

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[Airbus Amber]

Introduction

- Real-time track and balance monitoring
- Damage detection / change of structural behaviour

Maintenance perspective

- Increased fleet availability through condition-based and usage-based maintenance
- Reduced costs through optimized and tailored maintenance

Operator perspective

FIBRE OPTIC SENSING TECHNOLOGY

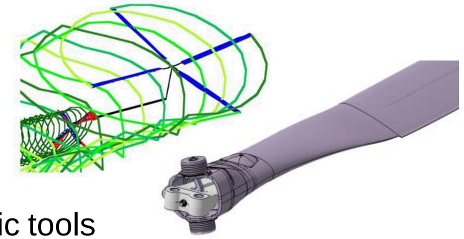
- Replace traditional strain gauge
- Support certification processes, e.g. temperature sensing for the detection of icing condition

Ground / flight testing

Manufacturing / Product monitoring

- Polymerization monitoring (springback)
- Increase traceability of product's life cycle (digital twin)

Designer perspective



- Validation of aeroelastic tools
- Optimized and disruptive design solutions
- Real-time usage of data to support flight control system (noise reduction) or load alleviation

[Airbus Amber]

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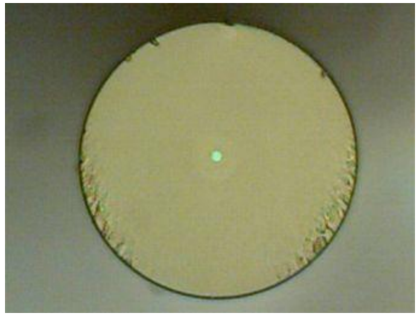
Fibre optic sensor technology

Overview

- Small dimensions (diameter of 125 µm)
- Light weight
- Dielectric material - insulator
- Immune to electromagnetic interference
- Flexible, strong
- Safe for use in hazardous environments
- No electrical power to the sensor
- Compatible with composite materials



Fibre optic sensor technology

Overview – 1 optical fiber, 3 main technologies for data processing

Optical fiber, Optical Frequency Domain Reflectometry (natural backscattering)

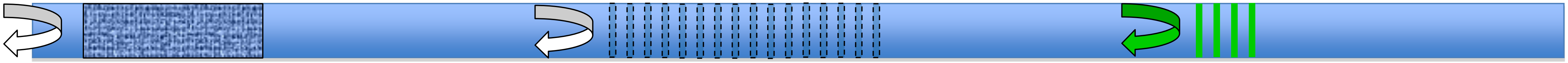
- Strain, temperature static measurement
- Distributed up **to 1500 sensors/meter**
- TRL3
- 11,4kg 366x345x165mm.

Bragg sensor Optical Frequency Domain Reflectometry

- Strain, temperature static measurement
- Quasidistributed up to **153 sensors/meter**
- TRL6
- 3.0 kg 206 x 274x 79 mm

Bragg sensor Wavelength Division Multiplexing

- Strain, temperature high frequency (up to 20 kHz)
- **≈10 sensors per fiber**
- TRL6 ongoing
- 0,8kg, 99x70x63mm



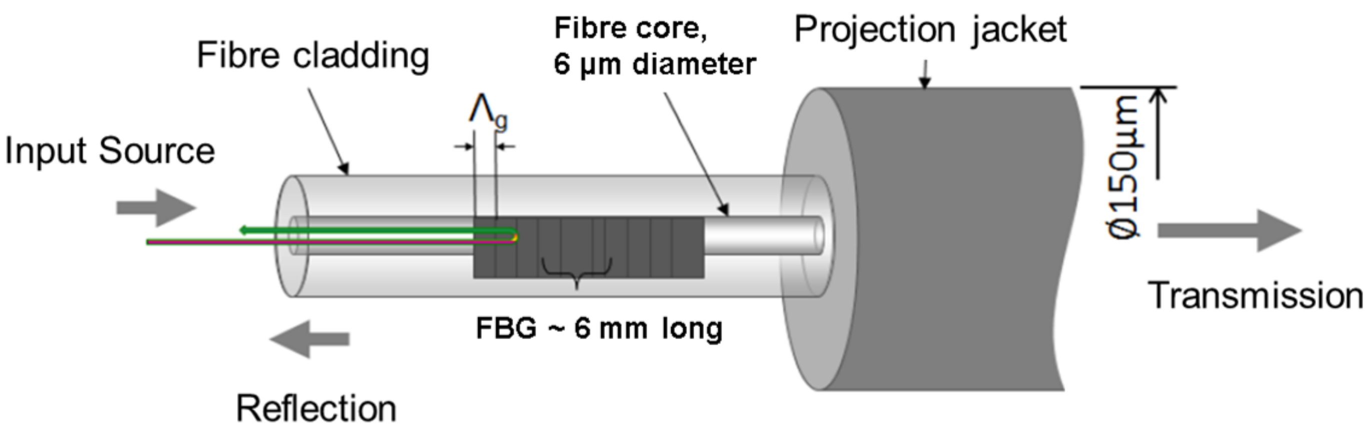
- **Ground test system :** Comparison between classic technology and optical fiber sensor
- **System under development:** Overheat Detection Systems (Saab)
- **Flight test demonstration** : Deformation measurement on the blade (Cranfield)
- Detection de hard landing Meggitt (ALgesmo

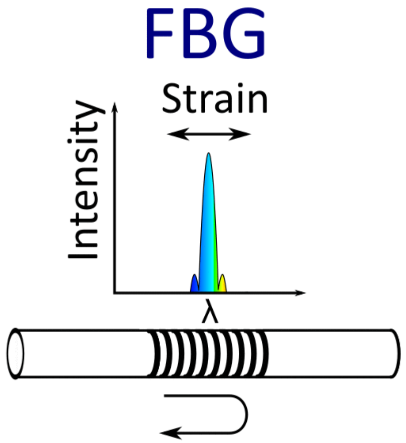
Fibre optic sensor technology

Multiplexed arrays of fibre Bragg gratings (FBG): Strain or temperature measurements

Fibre Bragg Gratings (FBG):

Detecting strain-induced wavelength changes in the optical return spectrum of the sensor

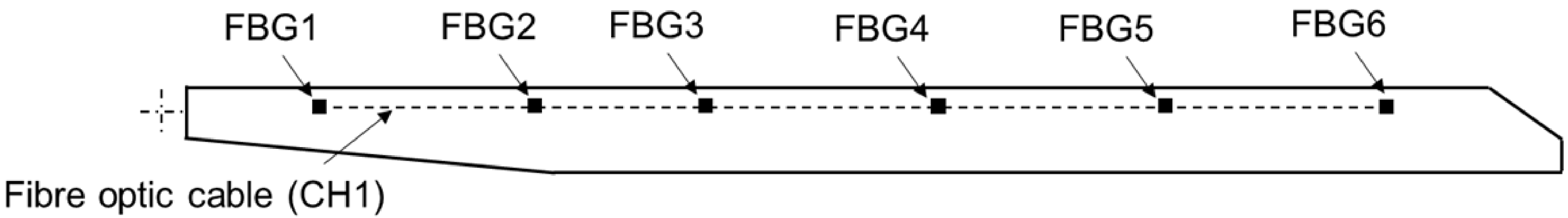


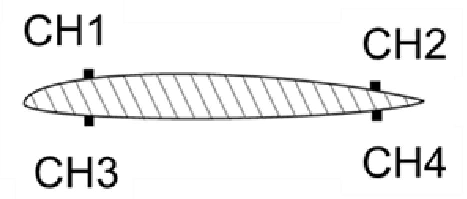


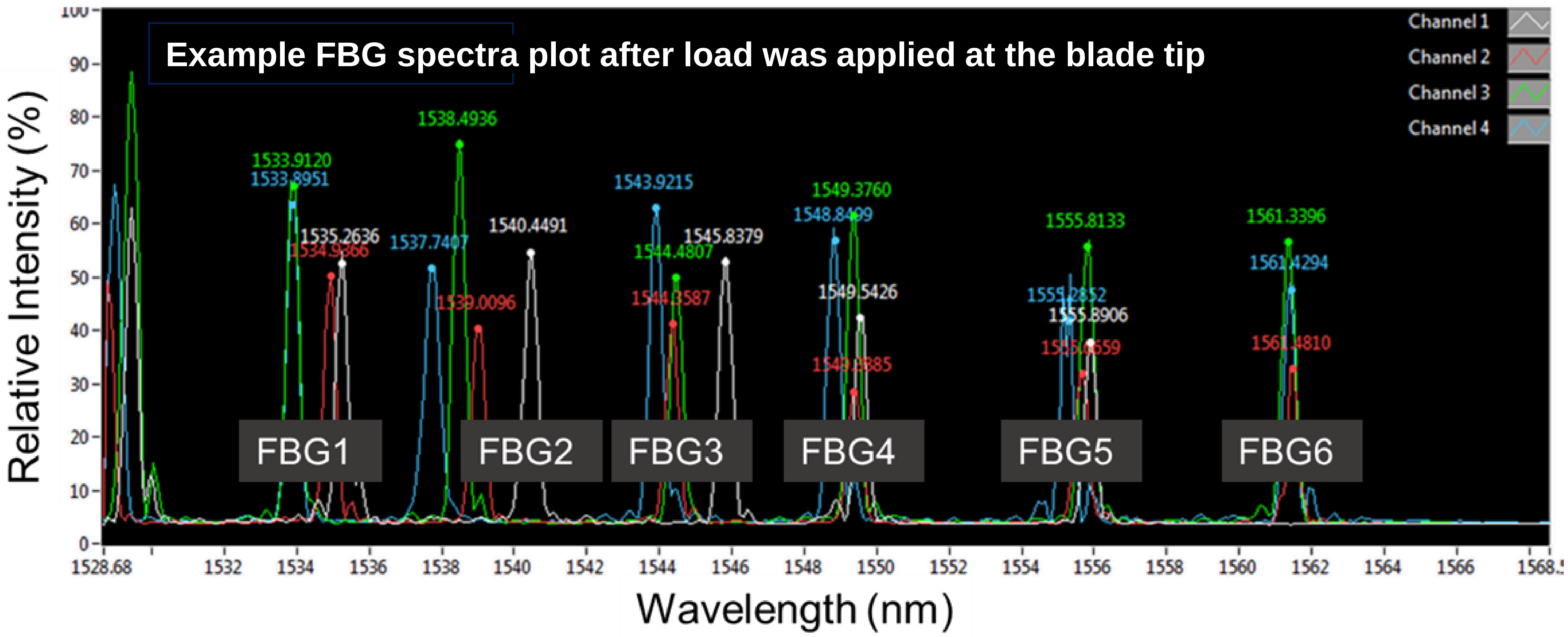
Gauge length ~5 mm

Fibre optic sensor technology

Multiplexed arrays of fibre Bragg gratings (FBG): Strain or temperature measurements







Fibre optic sensor technology

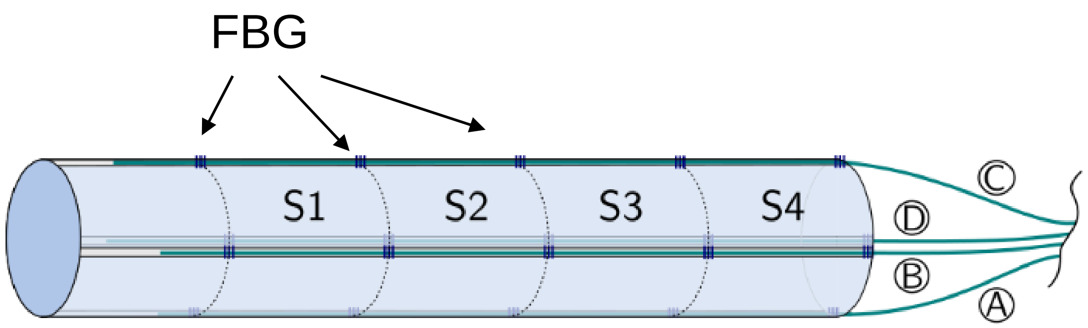
Direct fibre-optic shape sensing: Direct angle or shape measurements

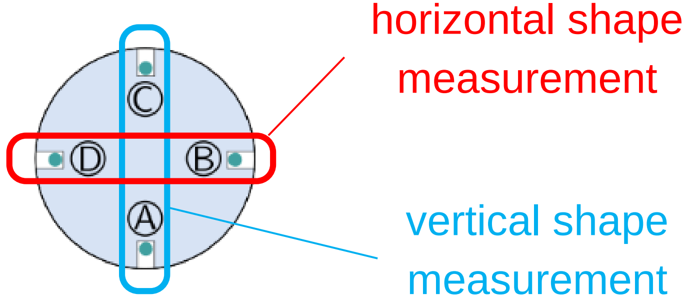
Principle:

Measurement of curvature-induced differential strain between separate cores within sensing fibre
 insensitive to temperature

Direct fibre-optic shape sensing:

- Optical measurement of the geometrical path of the sensing fibre in two dimensions
- Shape sensing rod Ø 2mm or multicore fibre Ø 0.2mm

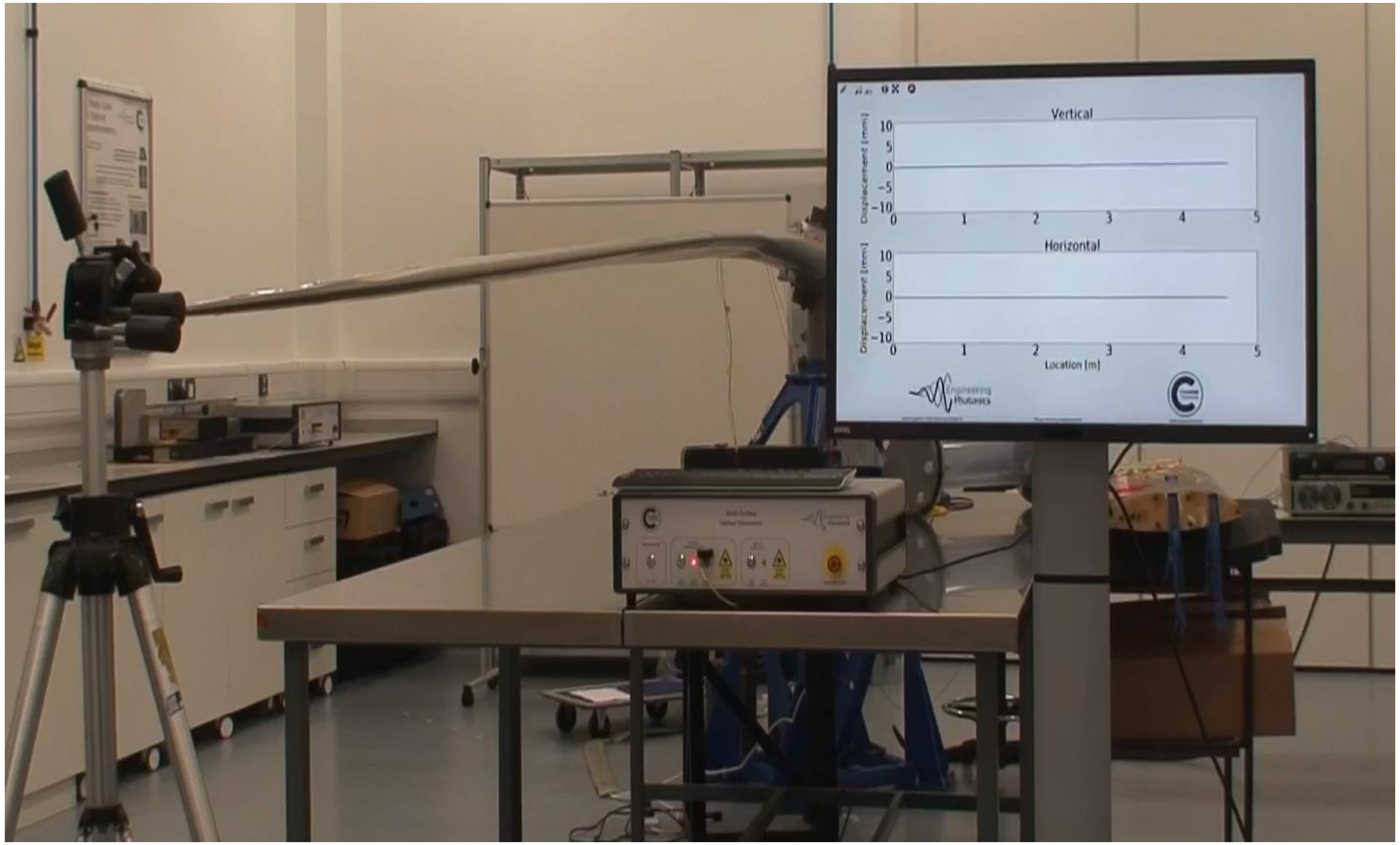




Multicore fibre

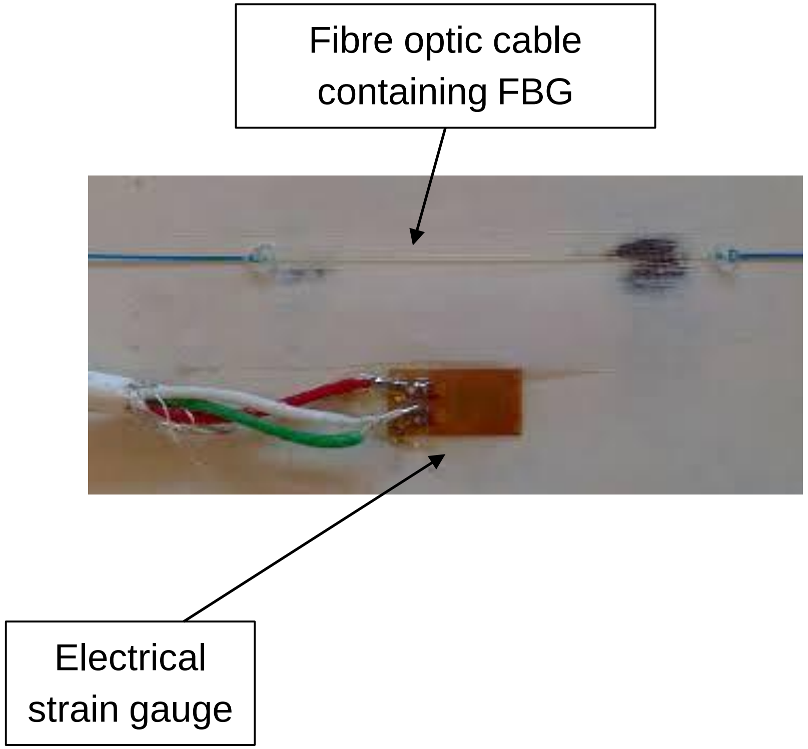
Fibre optic sensor technology

Direct fibre-optic shape sensing: Direct shape measurements



Fibre optic sensor technology

Benefit over electrical strain gauges



Technical side	Operating Temperature	Lifecycle	Distributed sensor	Wire number/section
Fiber optic sensing	-269°C to >700°C	$>>1^{E}6$ cycle	Yes	1
Strain Gauges	-75°C-200°C	$<1^{E}6$ cycle	No	>10

Market side	System cost	Implementation cost	Maintenance Cost
Fiber optic sensing	High but decreases	Low	Low
Strain Gauges	Low but increases	Medium	High

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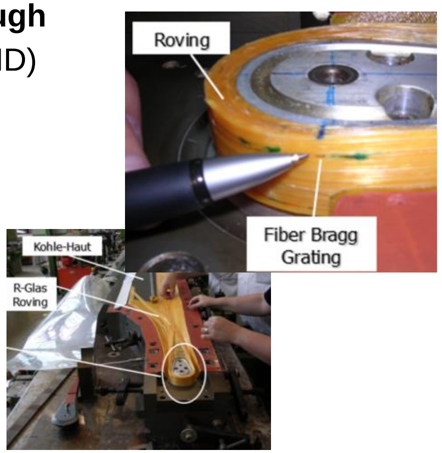
Previous & recent activity

Overview of projects (list is not exhaustive)

2008

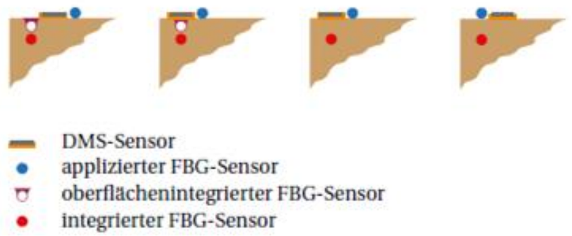
ARTIMA – Aircraft Reliability Through Intelligent Material Application (AHD)
TRL3

Type: FBG strain sensor
Installation: Surface mounted and embedded within loop of blade attachment
Achievements: Static and dynamic tension tests (non-rotating)



2015

Validation of a hybrid sensor network (AHD & TUM)
TRL3



Type: FBG strain & temperature sensor
Installation: a) embedded, b) surface-integrated, c) surface-mounted
Achievements: Comparison of electrical strain gauges with FBG sensors (non-rotating)

2020

BladeSense (AHUK & Cranfield University)
TRL5

BLADESENSE

Type: Strain & shape sensing
Installation: Surface mounted
Achievements: Ground run with H135 (rotating)

2022

Optical fiber strain transducer (AHF)
TRL4

Type: FBG strain sensors
Installation: Embedded within blade
Achievements: Sensor calibration within host material, residual strain measurement during manufacturing. Proof of concept on drone.

Since 2023

Mean time between failure evaluation (AHD, AHF & PLB)
TRL5

Type: Strain sensing
Installation: a) embedded, b) surface-integrated, c) surface-mounted
Achievements: Manufacturing of flexbeam with integrated fibre optic sensors

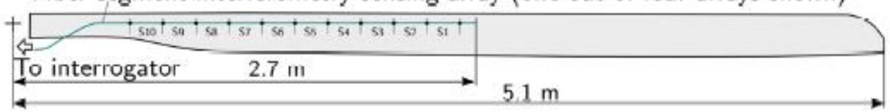
Previous & recent activity

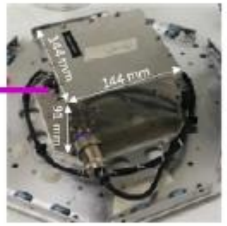
Completed: BladeSense at AHUK (2015 – 2020)

Proof of concept of two fibre optic instrumentation technologies during ground runs:

(1) Fibre Bragg gratings measuring strain and(2) direct fibre optic shape sensing approach.

Differential fibre-optic strain measurements yield dynamic blade shape changes:

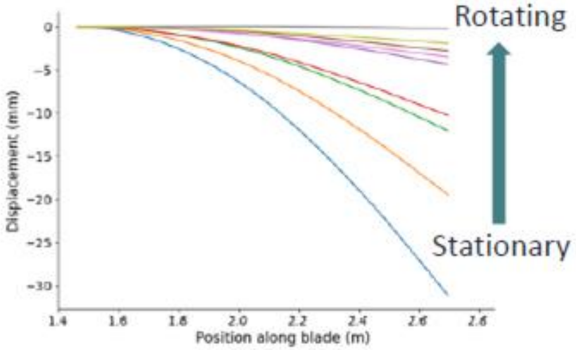




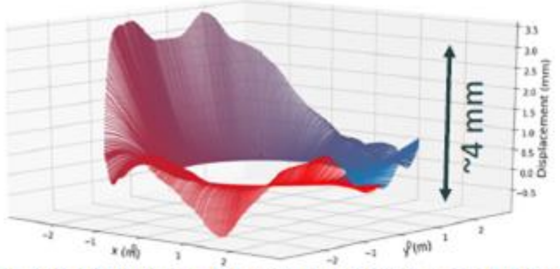
Robust interferometric interrogator

Shape change data was acquired and streamed while blade rotated at 380 rpm during several ½ hour trials

Some initial results:

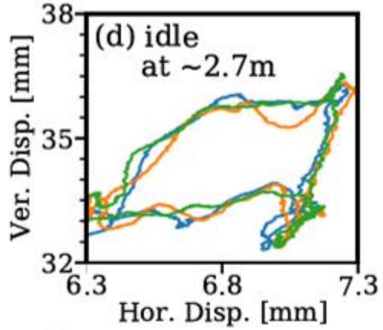


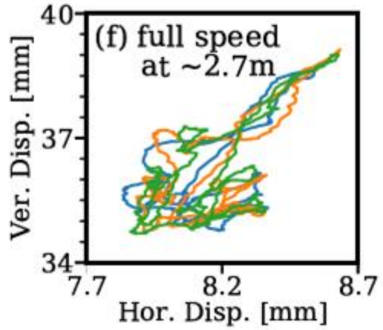
Helicopter blade rising on start-up



Vertical shape change over one revolution

Typical blade vertical and lateral movement over three revolutions





Previous & recent activity

Completed: Optical fiber sensor activities at AHF

Responsible of the metrology and integration process sensor (**Thesis**)

Ground and flight test instrumentation

Blades applications

Other Projects/Applications

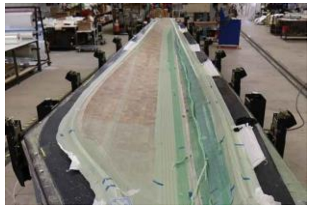
Research applications

Thermomechanical calibration by Dynamic Mechanical Analysis

Results:

- Rigidity of the sample test under thermomechanical load
- Thermal and strain sensitivity of the sensor with its host material under multi-load

Blade stress relaxation measurement by optical fiber



Results:

- Polymerisation monitoring
- Residual strain measurement at the mold opening
- Ground test of validation (comparison between the model and the sensor).

Blade deformations measurement in flight by FBG sensor

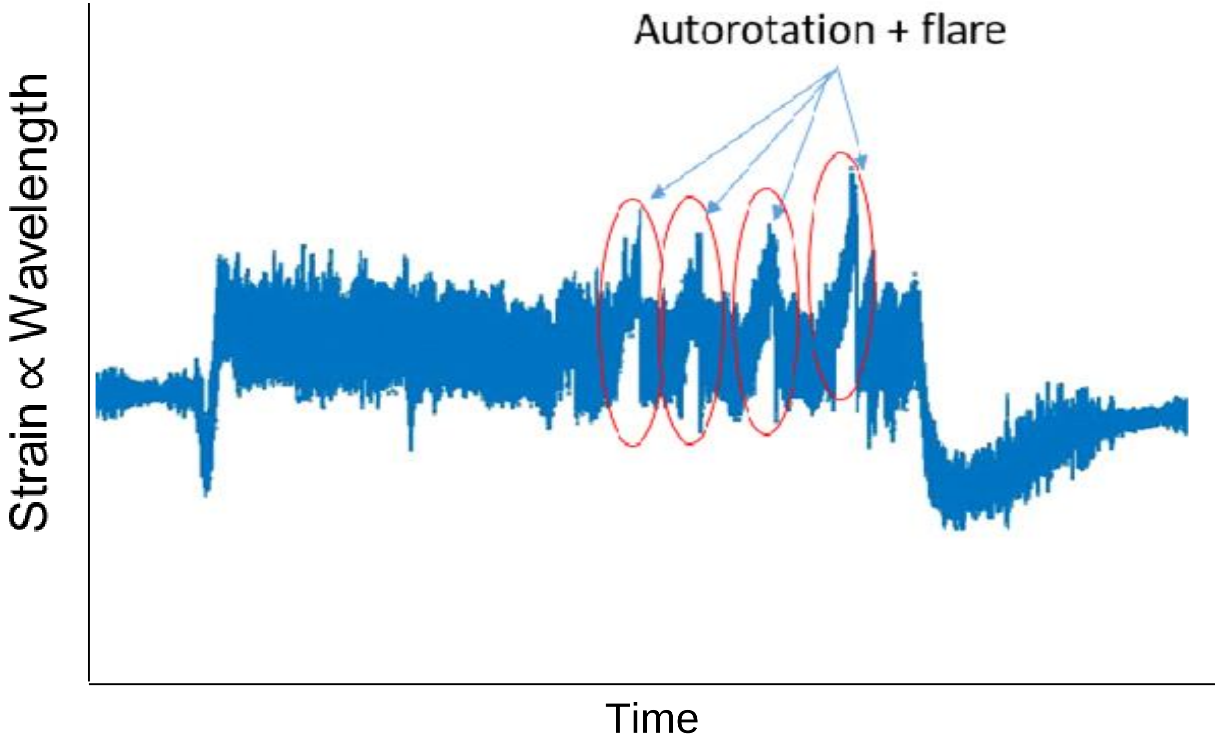
Results:

- Blade deformation measurement during flight mock-up test
- rotor frequency measurement

Previous & recent activity

Completed: Optical fiber sensor activities at AHF

Helicopters mockup flight lab.



Previous & recent activity

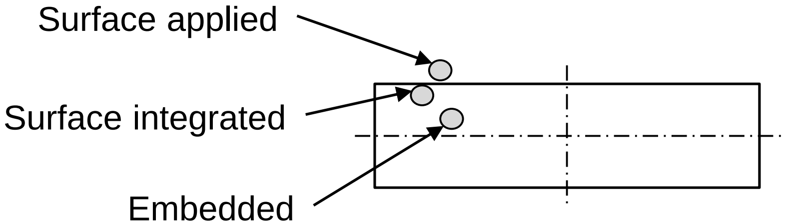
Ongoing: Mean time between failure evaluation

Aim:
Mean time between failure (MTBF) evaluation of the fibre optic cables.

Objective:
A **flexbeam bending test** at **fatigue loads** with embedded fibre optic cables will be performed in order to demonstrate that the fibre optic cables with FBG strain sensors (results to be expected by Q1 2024):

1) provide comparable measurements to electrical strain gauges,
2) have no negative influence on the fatigue behaviour of the flexbeam and
3) are still functional after the fatigue test (sensors MTBF covers the save life of the part)

3 installation methods to be investigated

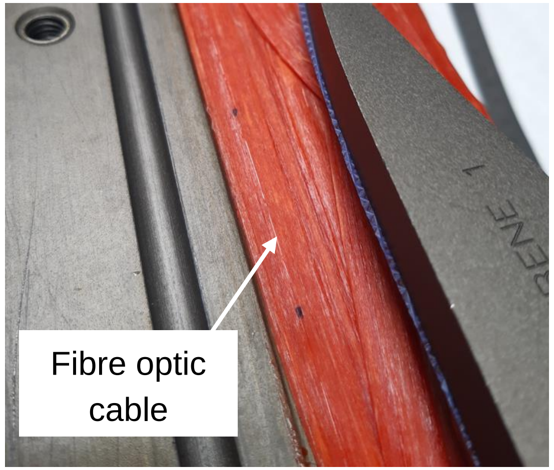


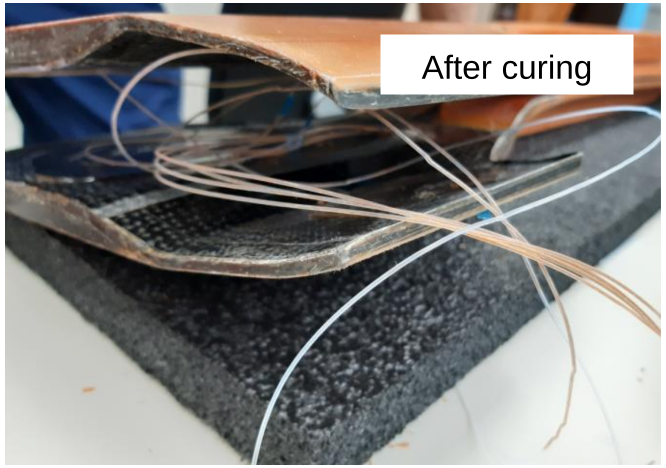
Cross section flexbeam

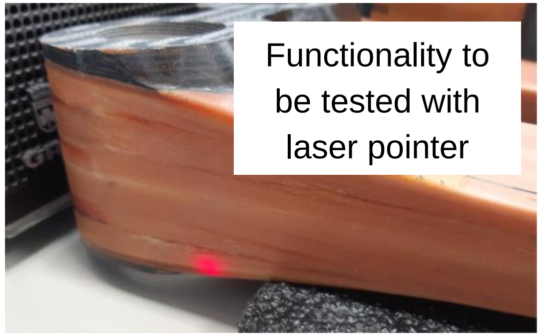
Previous & recent activity

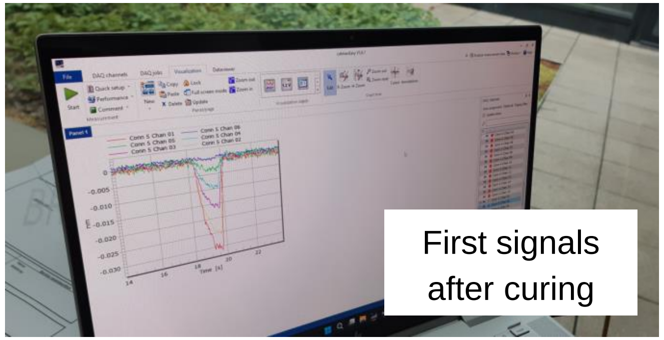
Ongoing: Mean time between failure evaluation

Integration of fibre optic sensors in the flexbeam:



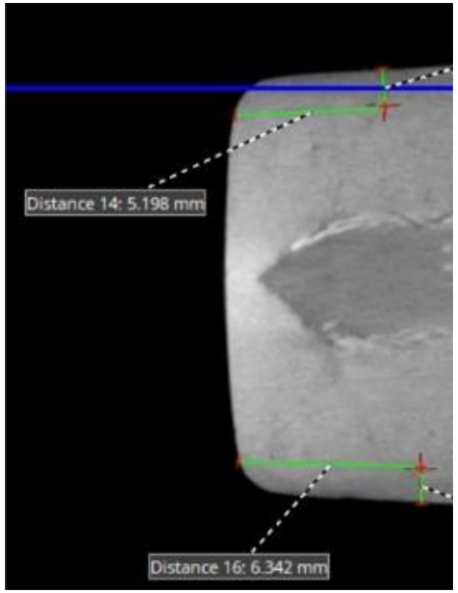


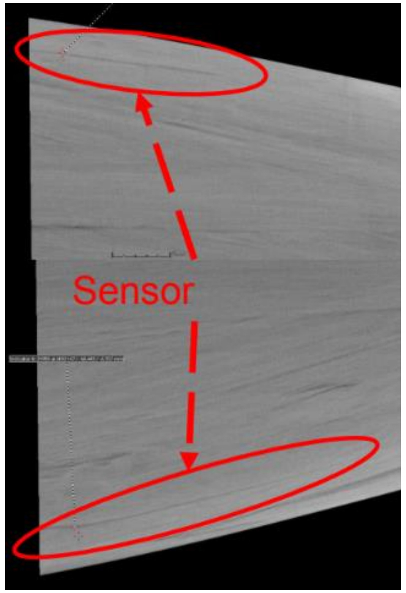




Micro computer tomography was performed to investigate the integration of fibre optic sensors:

- A deviation of the position of sensors after curing was +/- 2 mm
- No delamination due to sensors were found





Previous & recent activity

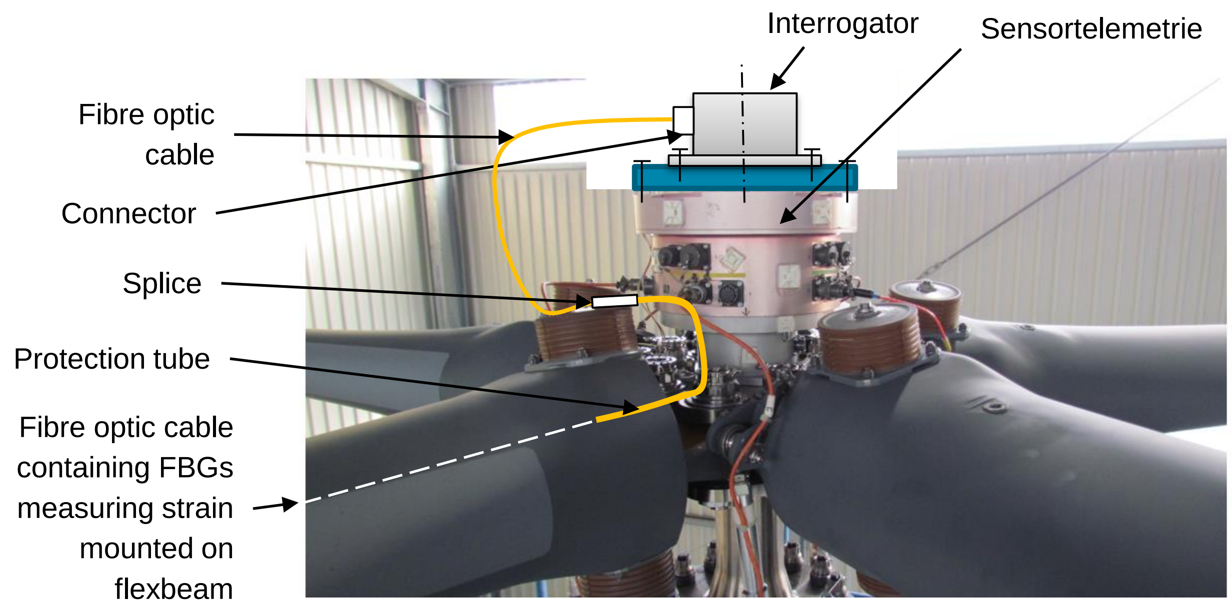
Ongoing: Examine measurement performance during whirl tower test

Aim:

Show that strain measurements using FBGs are in the same range of accuracy than of electrical strain gauges.

Objective:

A flexbeam was externally instrumented using FBG as strain sensors that will be tested in a fully dynamic whirl tower test environment. Results to be expected by Q1 2024.



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Technology impact

On the rise towards Industry 4.0 which will enable **sustainable aerospace design** by **improving** its **full product life-cycle** through:

- **Manufacturing / product monitoring:**
  - Polymerization monitoring and self-tests of the internal model know-how about manufactured state, improvement of production processes
  - Increasing the traceability of a product's life cycle
- **Operational in-flight data collection will open up new pathways within the maintenance sector:**
  - Online track and balance monitoring using the novel shape sensing system.
  - Condition-based maintenance and usage-based maintenance for reducing operating costs
- **Big data, artificial intelligence and advanced analytics for:**
  - Optimized and disruptive design solutions
  - Validation of aeroelastic tools through the use of operational in-flight data.
- **Innovative and intelligent structures and increase autonomy:**
  - Deploy cutting edge data acquisition systems, such as fibre optic-based instrumentation systems measuring strain or shape that could be linked to real-time usage to support flight control system or for load alleviation
  - Intelligent morphing materials, such as memory shape alloy composites for active shape control
  - Smart manufacturing through additive manufacturing for zero-waste
- **Ground and flight testing**
  - Replace the traditional strain gauge approach with fibre optic instrumentation system to avoid imbalance and vibration problems during whirl rig test for routine tasks of load determination

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Outlook

Opportunities at Airbus Helicopters

Structural health monitoring

Measure
Detection corrosions & cracks
Monitoring temperature and strain during all service life
2D or 3D shape monitoring.

High durability

Application
lifetime
locates and quantifies the damage & impact.
Condition based maintenance

Manufacturing / Product monitoring

Production
Optimization production
Polymerization monitoring
Self-test

Improved process or prospecting

Ground and flight testing

Blade monitoring
Deformation monitoring
Temperature monitoring
Internal measurement

Harsh Environnement

Blowing monitoring
Quantify the temperature of the output gas

Landing monitoring
Strain mapping of the landing gear

Serial application

Application
Deicing system and Icing detection
Hard landing detection

Minimum weight and energy

Thank you