



Embedded Life-Cycle Management  
for Smart Multimaterials Structures:  
Application to Engine Components

# The Importance and Benefits of SHM for the Aerospace Industry

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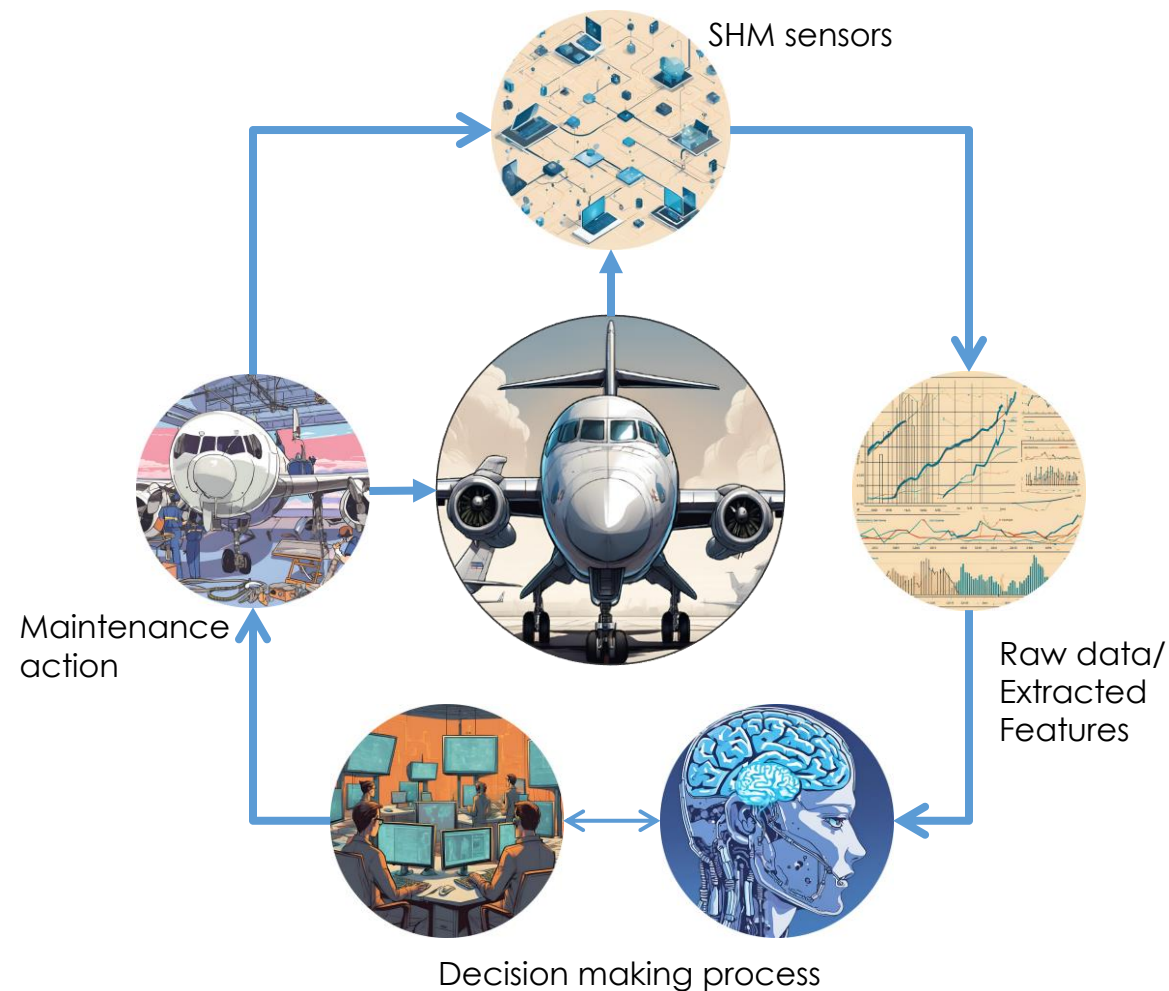
# SHM in Aerospace

Why?

- **Composite materials** are an essential part of modern-day aerospace structures
- **Complex failure** behaviors/ **BVID** make composites difficult to monitor
- Novel **SHM systems** are required to monitor the structure's **degradation**

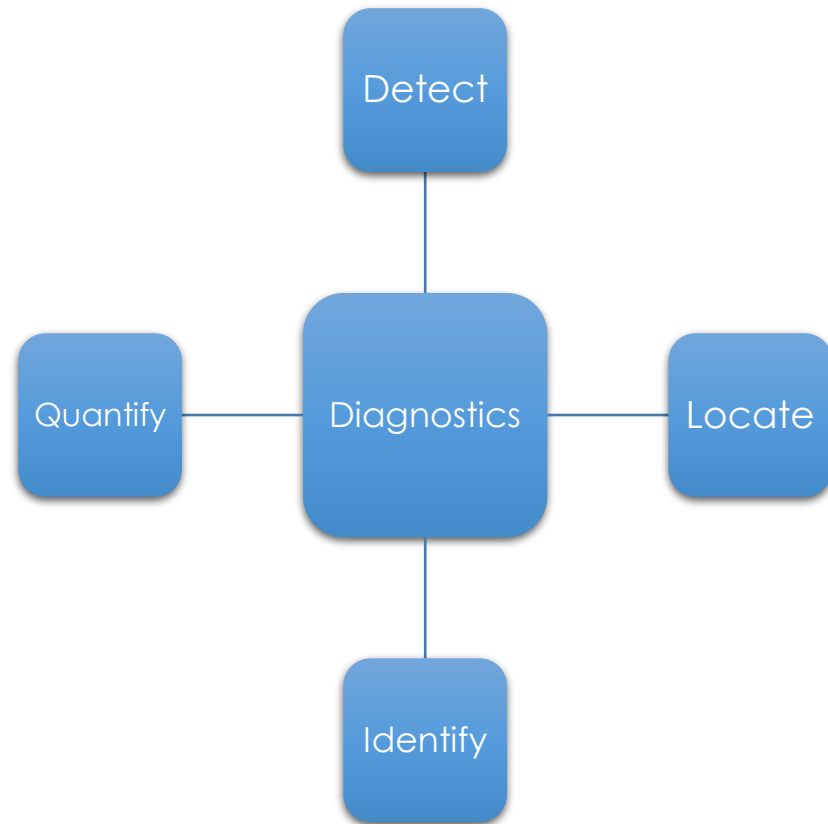
Benefits

- SHM measurements used for **diagnostics** and **prognostics**
- **Diagnostics & Prognostics** assist in **maintenance decision making**
- **Shift from preventive/ corrective to condition based maintenance**

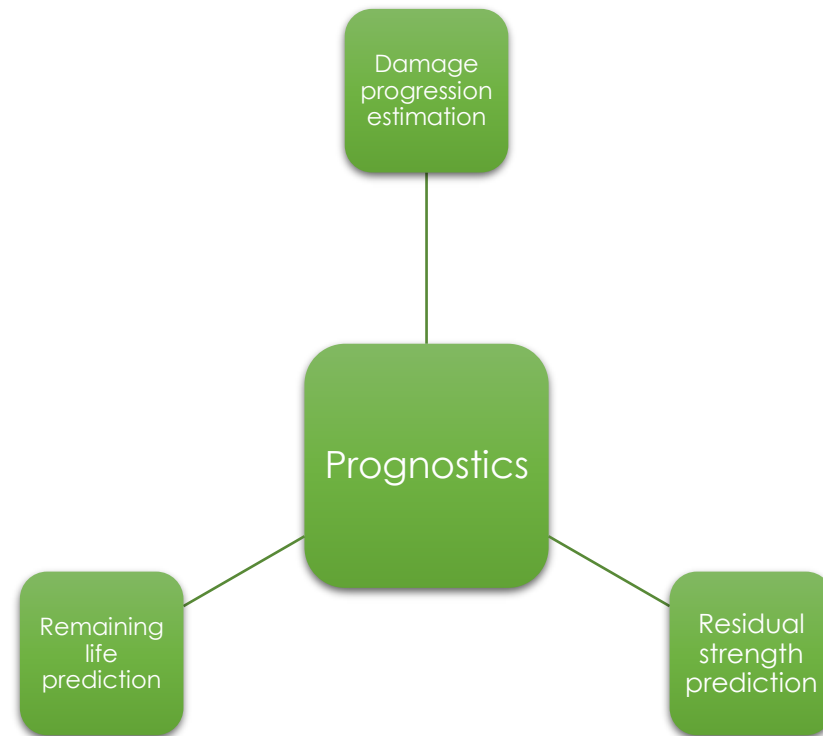


# Purpose of SHM

## Level 1



## Level 2



# Popular SHM technologies

## Fiber optical sensors

Strain – temperature - vibrations

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- Distributed
- FBG

## Piezoelectric transducers

Wave propagation – vibrations

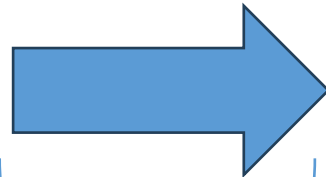
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- Accelerometers
- Acoustic emission
- Active lamb wave (guided waves)

# SHM towards CBM in aerospace

## SHM

- On-line monitoring
- Degradation information
- Diagnostics & prognostics



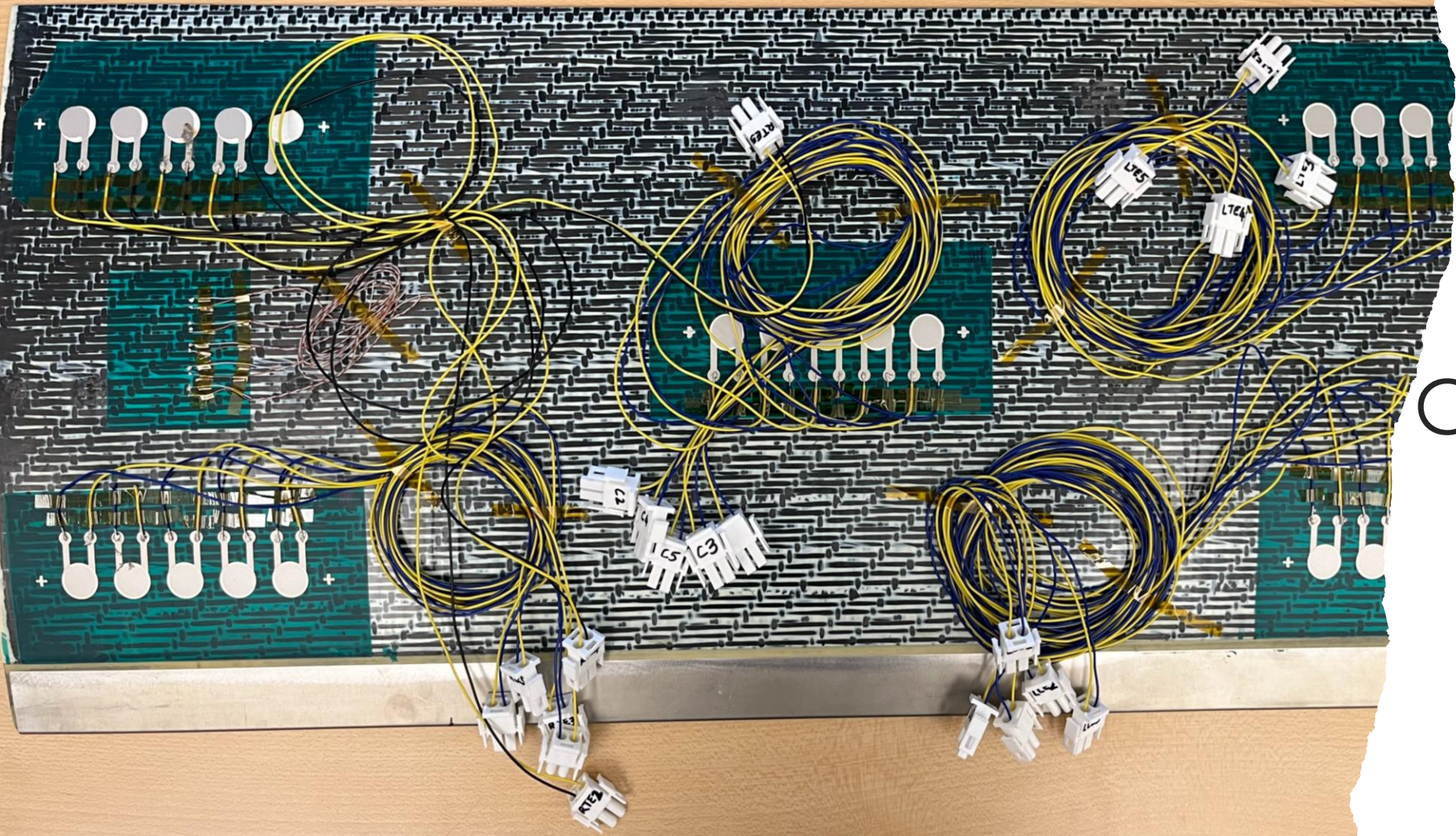
## CBM

- Increased safety & availability
- Cost reduction
- Increased sustainability

Expert knowledge  
Decision making  
Predictive Maintenance

## Challenges

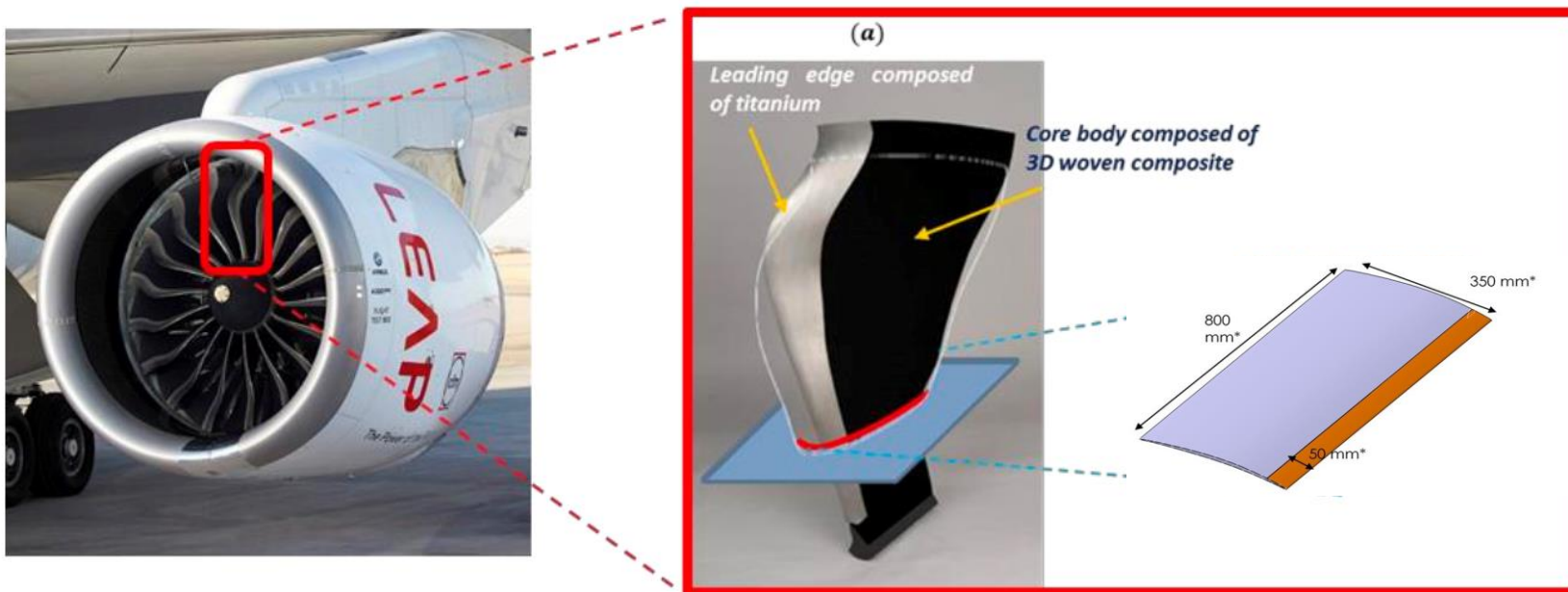
- Ground truth
- Data processing
- Implementation
- Integration



# Case study

FOD panel

# FOD panel definition



- LEAP engine blade
- Hybrid material build
  - 3D woven composite
  - Metallic leading edge
- Curved panel
- 350x800 mm<sup>2</sup>
- Varying thickness: 2.8-10.8 mm
- 50 mm steel leading edge

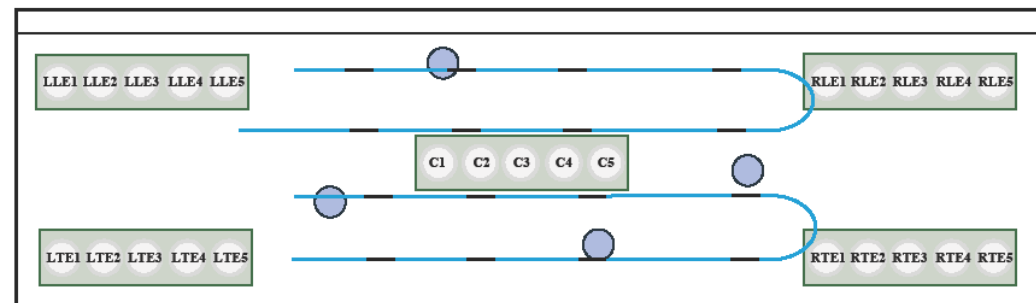
# SHM sensors available

- Sensor placement

- Novel printed & ceramic PZT sensors
- Arrays of 5 sensors at 5 locations

- FBG sensor

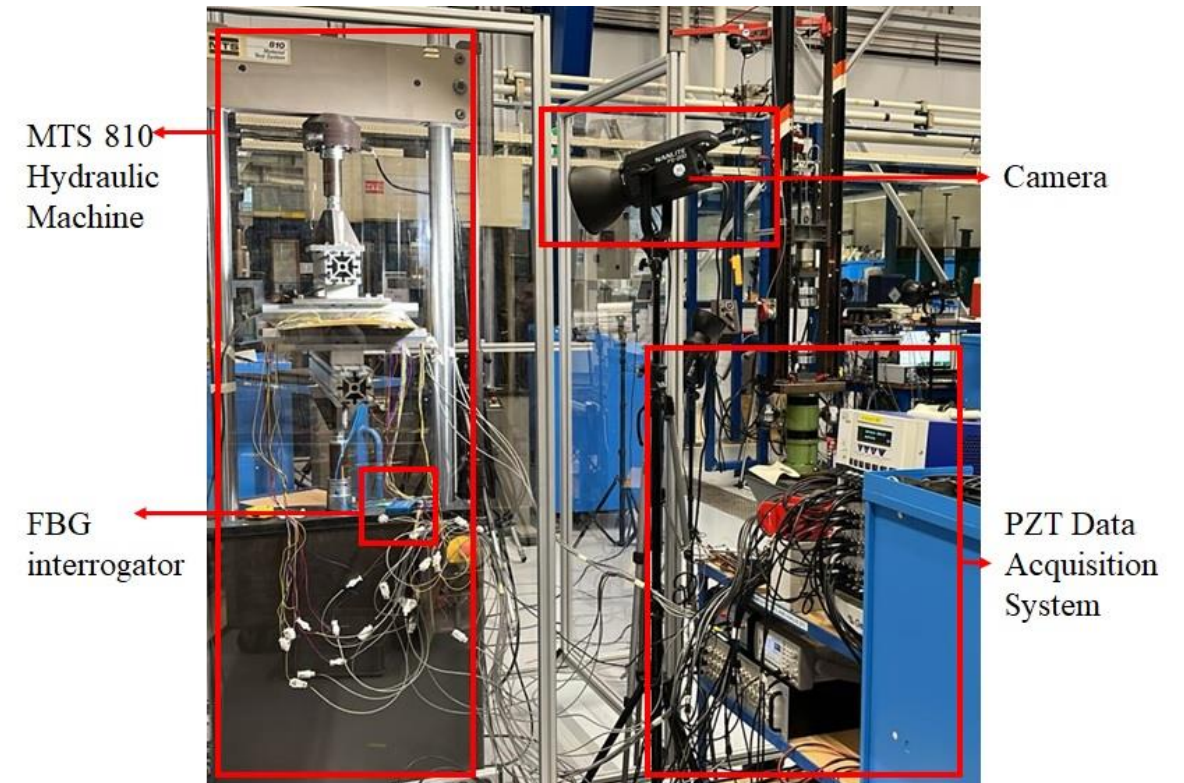
- Surface bonded
- Embedded → majority did not survive after the injection process/  
shipping





# Experiment definition

- 4 point bending test (ASTM D7264/D7264M – 07)
  - Evaluate flexural properties
  - Close correlation to operational loads
  - QS collapse load: 28 kN
- Repeated load—unload test (low frequency fatigue 0.3 Hz)
  - Increased severity loading
  - Run until collapse

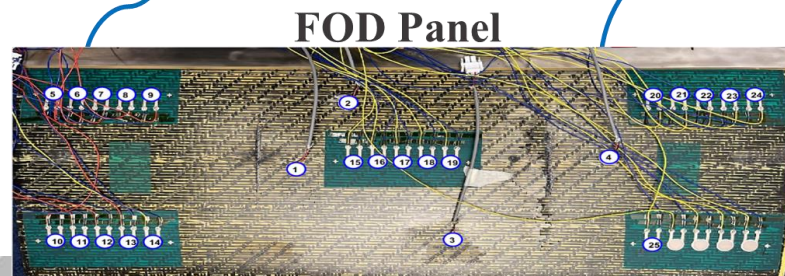
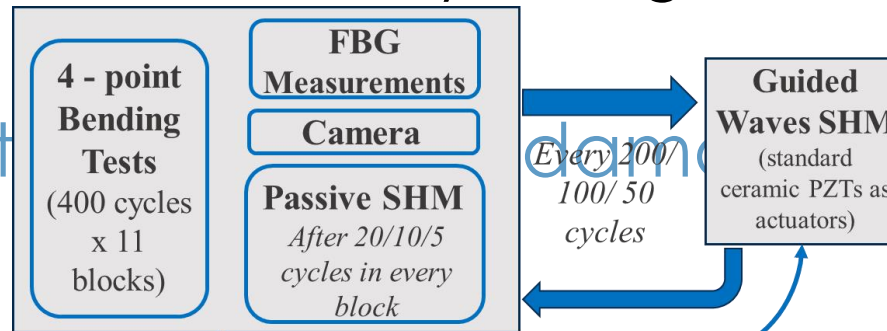


# Experiment definition

- Test is run in “blocks”
  - Load change every 400 cycles
  - Paused every 200, 100, 50 for LW measurement
  - FBG record constantly during each “block”

## • Introduction

- Before
- In-situ
- 50-60 J



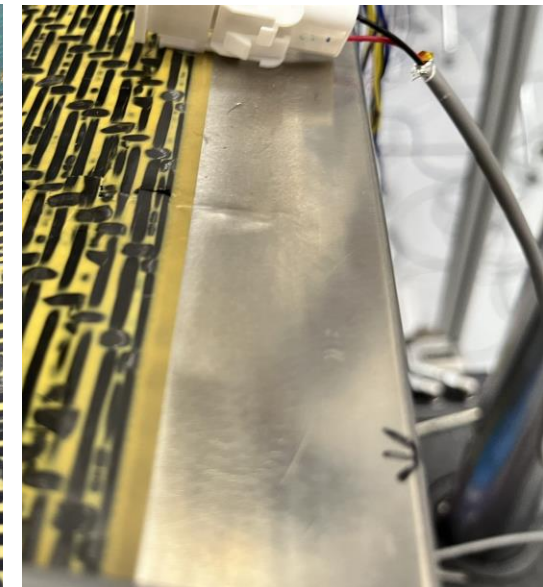
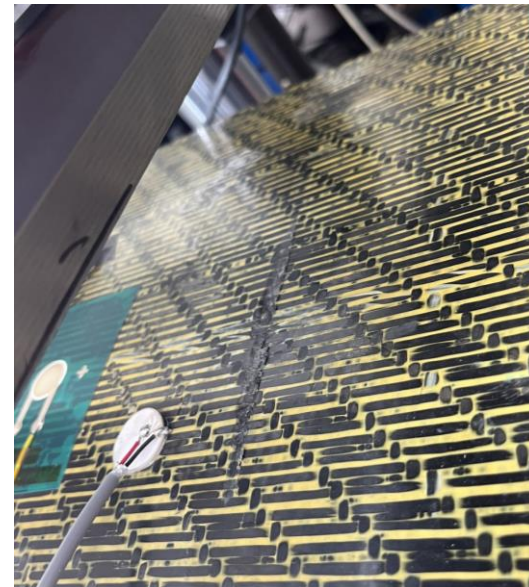
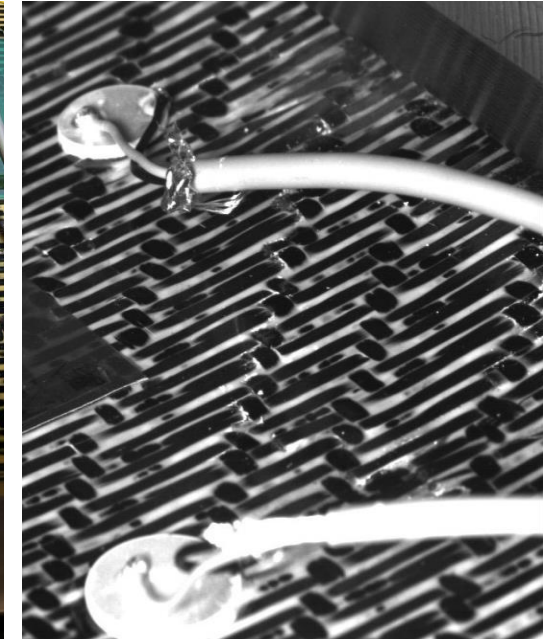
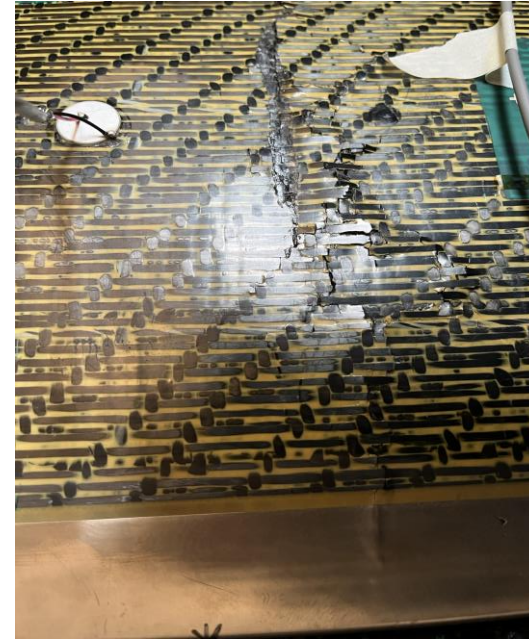
#	Load [kN]
1	4



10	26	} 50
11	28	

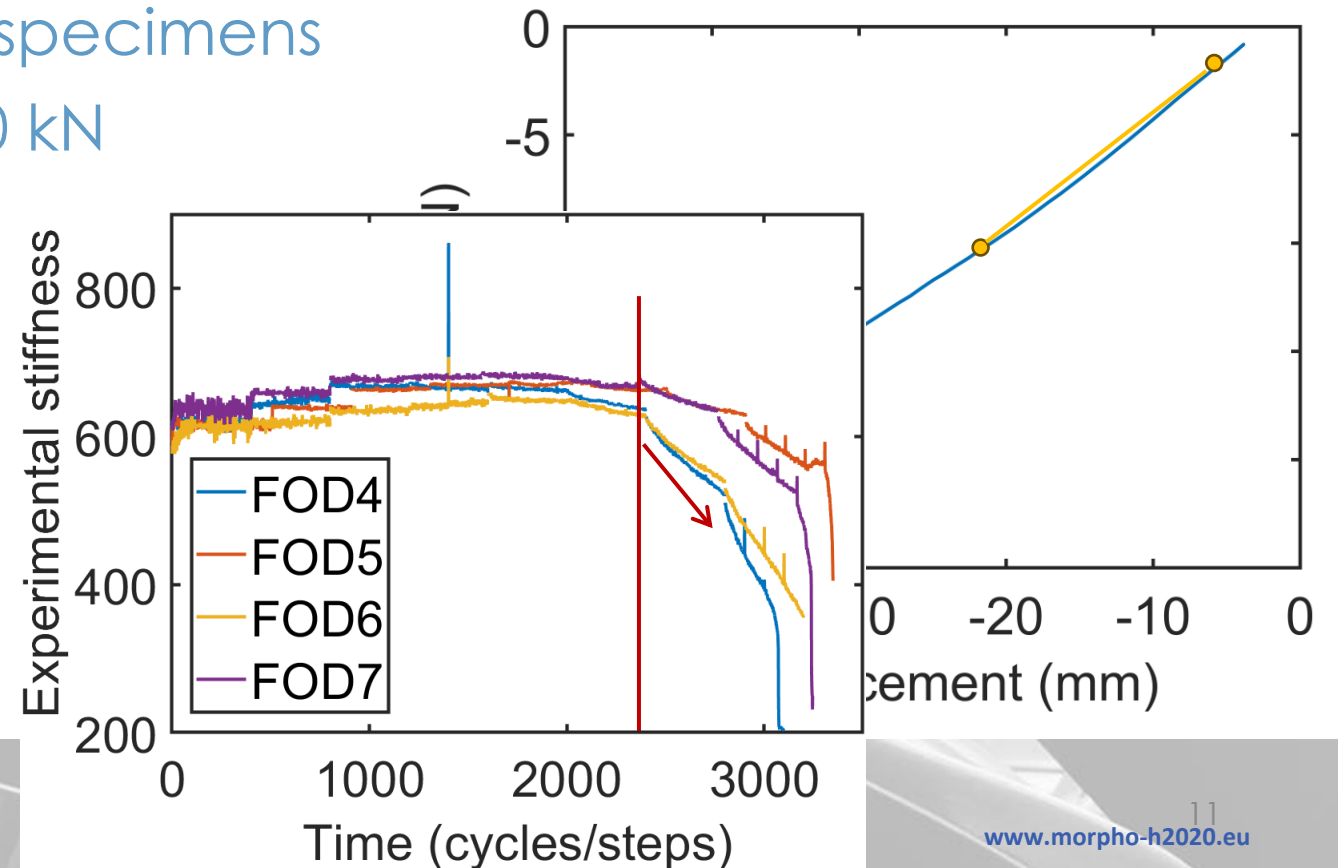
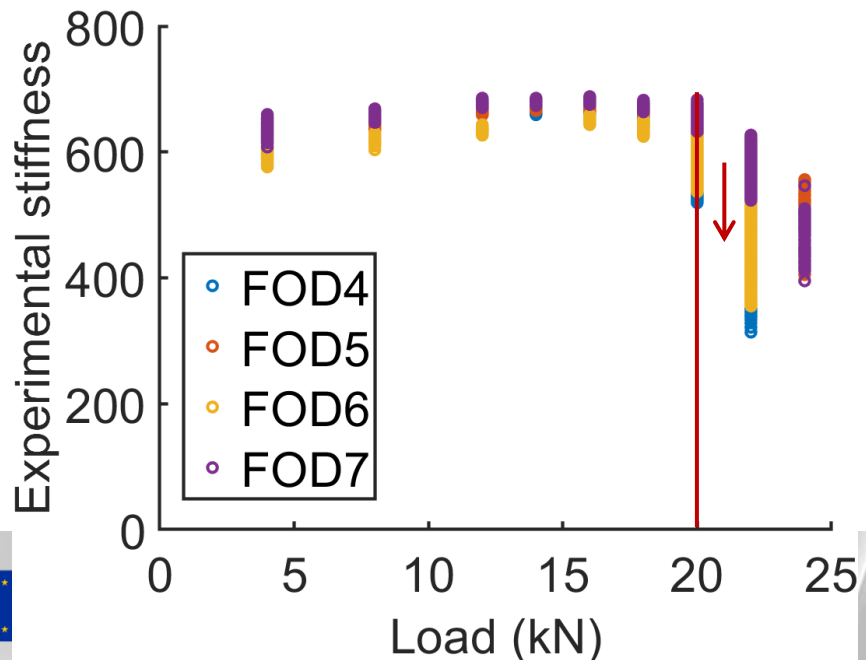
# Lifetime & failure

- Similar lifetime for the different panels
  - "Fatigue" failure load **~15% lower** than QS
  - Average lifetime: **3186**
- Failure modes/mechanisms
  - Skin tearing
  - Skin/ fiber breackage across width
  - Damage @ pin locations
  - Plastic deformation on LE



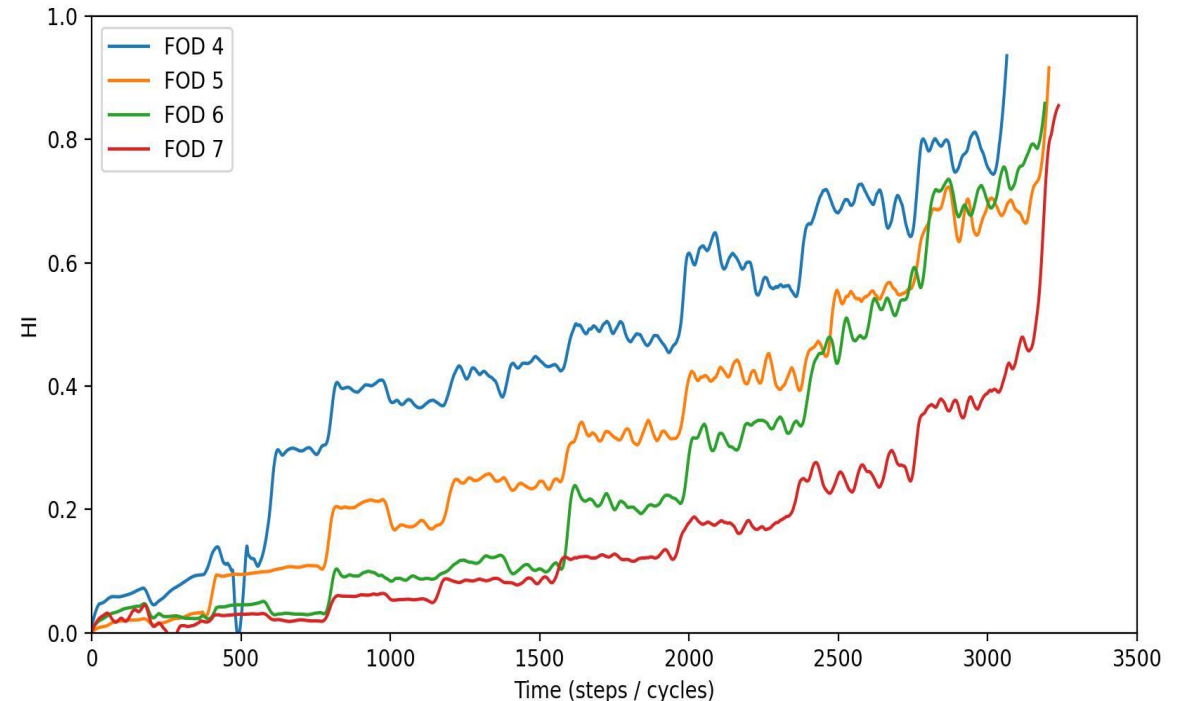
# Stiffness degradation

- **Experimental stiffness** is used as a measure of degradation
  - **Slope** of linear part of **load-displacement** curves
- Similar trend for the different specimens
- Significant reduction after 20 kN

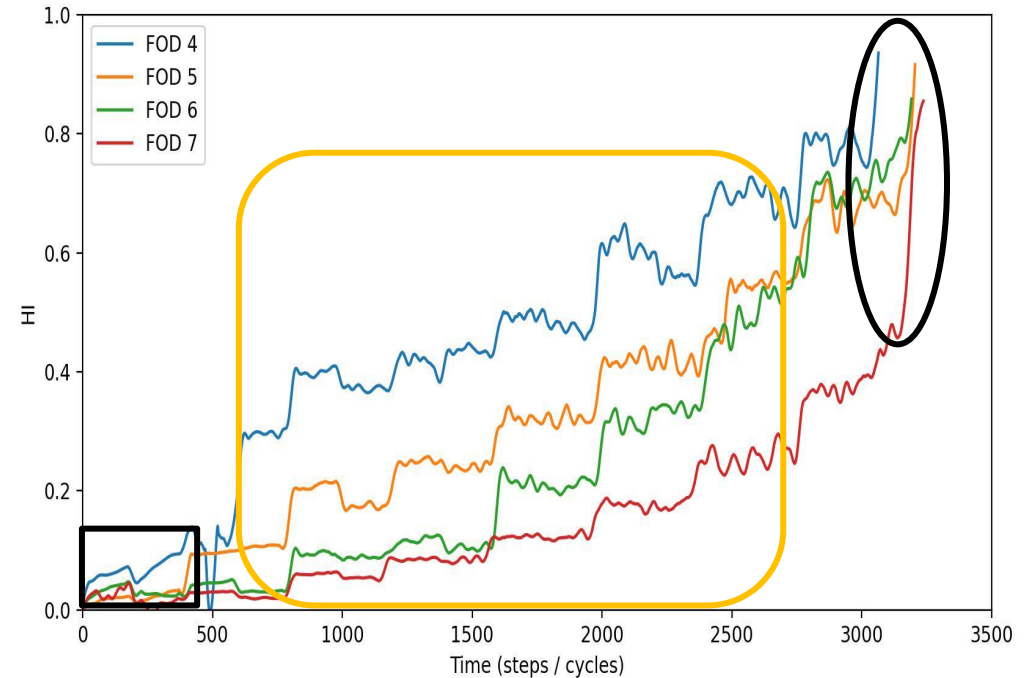
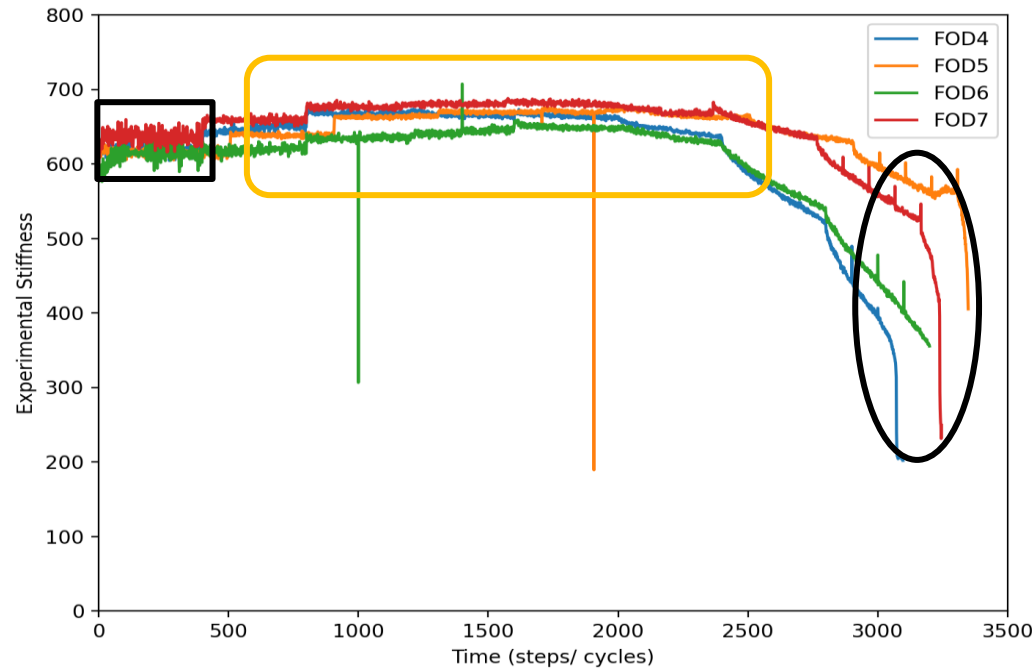


# FBG behavior

- Strains are load dependent – increase as load increases
  - Load steps are clearly distinguishable
  - Degradation signs are not clear
- Reduce load dependency
- Create HI representative of degradation



# Comparison HI with degradation



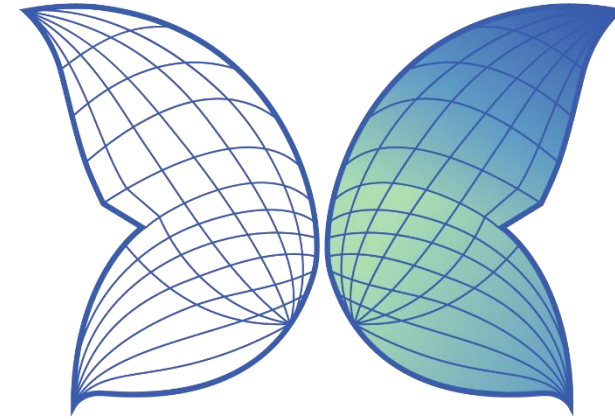
# Discussion: SHM & CBM in aerospace

## Benefits

- **Enhanced safety**
  - Early damage detection
  - Continuous monitoring
- **Enhanced component life – sustainability**
  - Targeted inspections
  - Maintenance when necessary
  - Less waste due to unneeded maintenance
- **Increased availability**
  - Reduced grounding time
  - Efficient resource allocation
- **Cost saving**
  - Reduced unexpected downtimes
  - Avoid catastrophic failures

## Challenges

- **High initial implementation cost**
  - Installation and integration
  - Specialized software/ hardware
  - Specialized personnel
- **Integration to structures in operation**
- **Sensor reliability/ durability**
  - Sensor failure
  - Noisy operational environments
- **Certification**
  - Strict safety regulations from aviation authorities
  - Lack of ground truth



morpho

Thank you!



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