On Structural Health Monitoring Sensors in Aeronautics: Recent Research and Applications

Dr.-Ing. Felix Heinrich

ZAL

ZAL Center of Applied Aeronautical Research

ZAL Center of Applied Aeronautical Research

Shareholders

Background

- founded in 2009 on the initiative of the Free and Hanseatic City of Hamburg (FHH) based on the leading-edge cluster Hamburg Aviation
- successful Public-Private-Partnership
- status as an independent small and medium sized enterprise

Business Areas

• Research & Technology	Expertise in 8 Technology Fields
• Research Infrastructures	Project Planning, Operational Management & Support
• FoLuHH	Aviation Research Network
• ZAL TechCenter	Rental & Building Operation

ZAL TechCenter in Numbers

• area	~ 26,000 m² (280,000 sq ft)
• workplaces	~ 600 / 35 partners
• construction/financing costs	~ 82 M€
• R&T infrastructures	~ 13.7 M€

ZAL Research Infrastructures

ZAL Center of Applied Aeronautical Research

Cabin & Cargo Test Rig

AVANT Test Rig

Laser Shock Peening

Acoustics Lab

AI Lab

Fuel Cell Lab

ZAL Research & Technology

ZAL Center of Applied Aeronautical Research

ZAL R&T

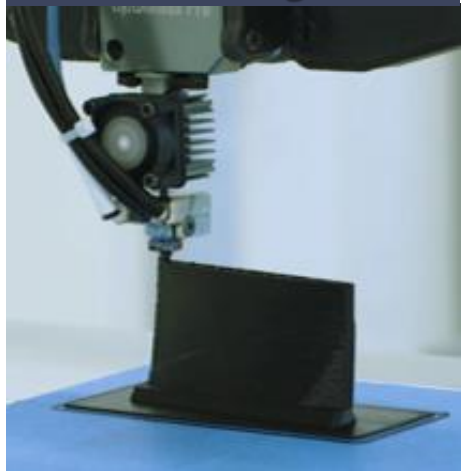
approx. 35 Technical Experts

8 Technology Fields

Industrial Projects: 1,8 Mio. € *2018

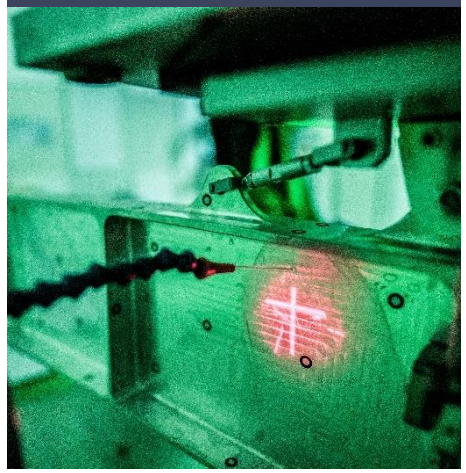
Research Funding: 0,8 Mio. € *2018

Additive Manufacturing



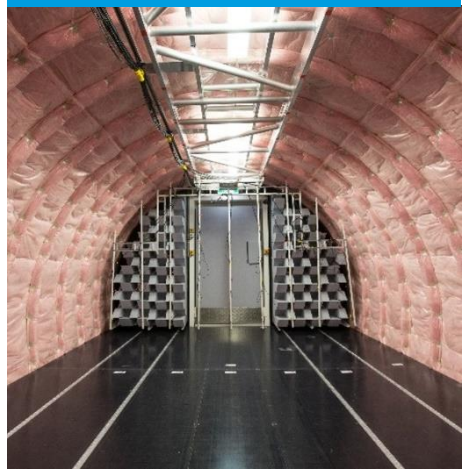
Automation & Robotics

Laser Shock Peening



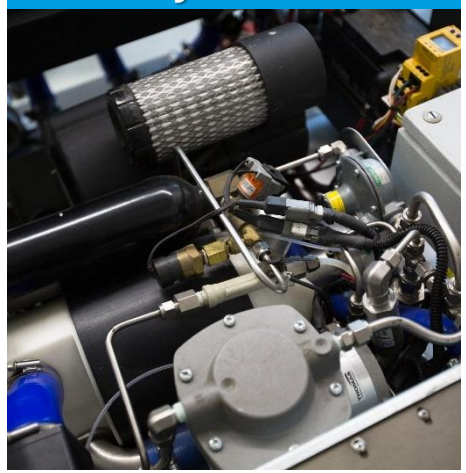
Industrial AI

Acoustics & Vibration

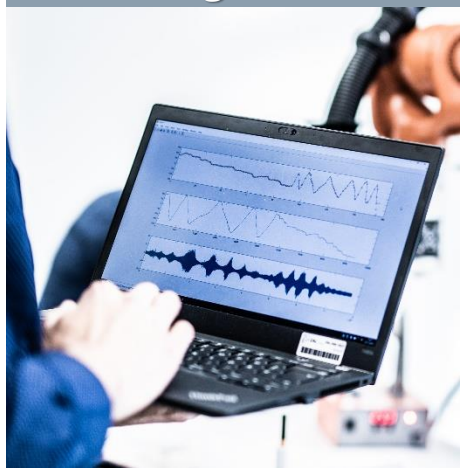


Intelligent Digital Cabin

Fuel Cell & Electrical Power Systems



Data Acquisition & Processing



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SHM Sensors in Aviation

Present Situation

Present situation

- SHM is an important topic in the aviation industry
- 2009: Aerospace Industry Steering Committee *SHM-AISC* was formed
- 2013: *Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft* was issued

Structure Health Monitoring

A real-time on-board 'stethoscope' for Condition-Based Maintenance

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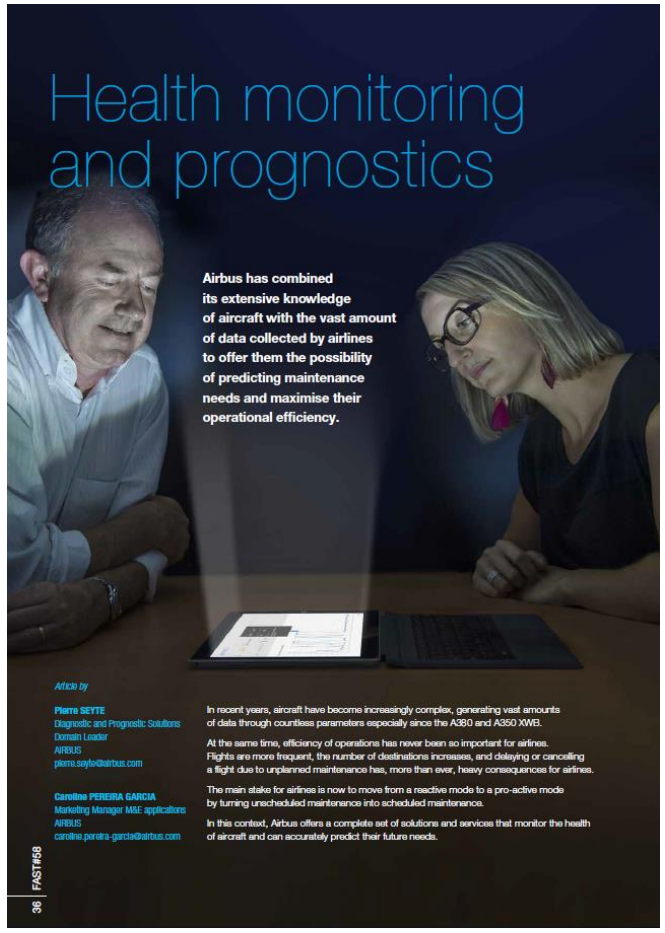
Structural Health Monitoring (SHM) is an innovative way of on-board Non-Destructive Testing (NDT) to directly assess the integrity of aircraft structures. The principle of SHM is comparable to the human nervous system. Discrete sensors which form a network remain permanently mounted onto, or embedded into the aircraft structure, detect and diagnose inevitable structural damage, mechanical loads or abnormal conditions. The sensors are interrogated via an 'on-board' or 'off-board' diagnostic system and information on the structural state is reported to maintenance.

In contrast to conventional NDT, there is no need for a qualified NDT inspector to access the area of inspection and to perform the measurement by hand-held NDT probes which is in most cases costly and time consuming.

As a result, SHM shows for selected use cases a great potential to reduce time and cost for maintenance, to increase the aircraft availability and to realise innovative aircraft design for the reduction of weight.

Airbus is developing SHM onto its new generation aircraft to ease structural maintenance, beyond the wider Condition-Based Maintenance (CBM), meaning doing maintenance when the need arises (i.e. after one or more indicators show that equipment or structure is going to fail or is deteriorating).

The evolving integration of on-board systems into the avionics' network and broadband data communication capabilities are setting the scene for a step change that aims at bringing significant benefits to the operators.



Health monitoring and prognostics

Airbus has combined its extensive knowledge of aircraft with the vast amount of data collected by airlines to offer them the possibility of predicting maintenance needs and maximise their operational efficiency.

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In recent years, aircraft have become increasingly complex, generating vast amounts of data through countless parameters especially since the A380 and A350 XWB.

At the same time, efficiency of operations has never been so important for airlines. Flights are more frequent, the number of destinations increases, and delaying or cancelling a flight due to unplanned maintenance has, more than ever, heavy consequences for airlines.

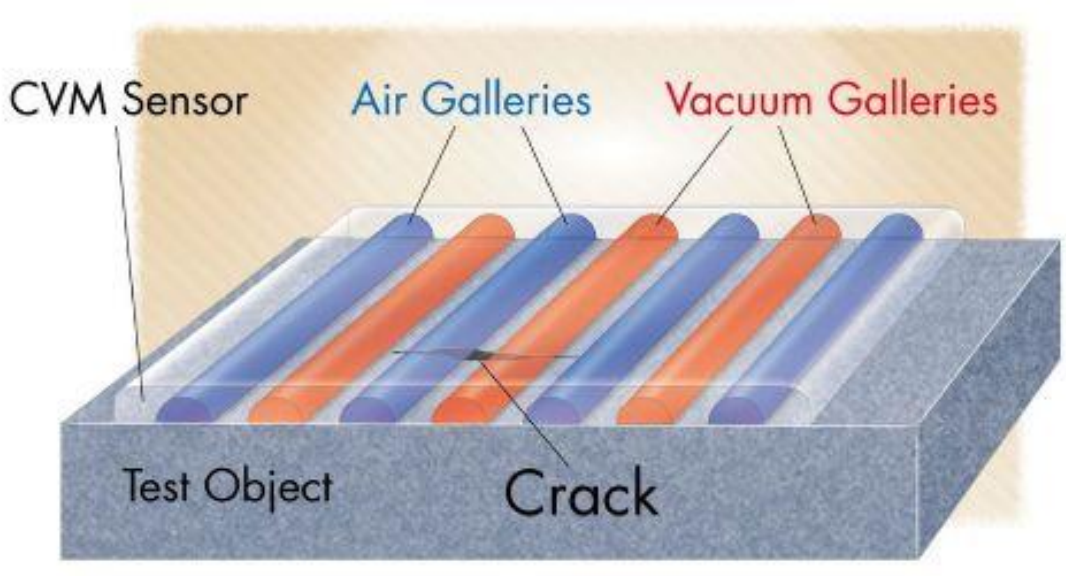
The main stake for airlines is now to move from a reactive mode to a pro-active mode by turning unscheduled maintenance into scheduled maintenance.

In this context, Airbus offers a complete set of solutions and services that monitor the health of aircraft and can accurately predict their future needs.

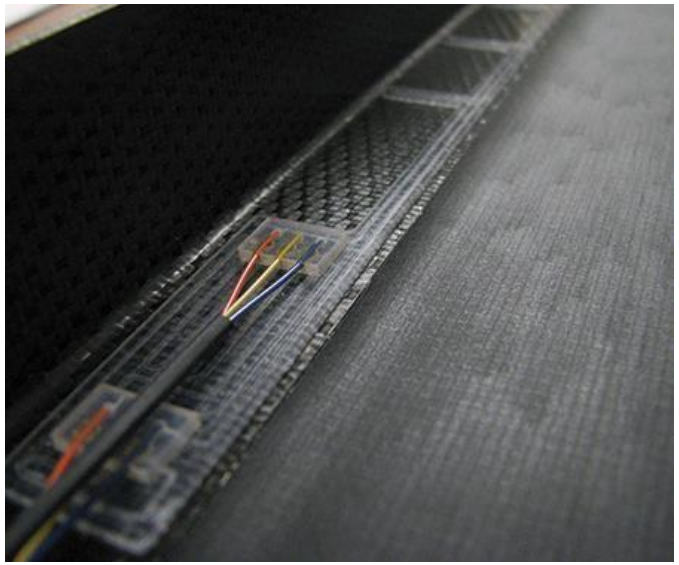
Source: Airbus FAST Magazine, 08/2014 and 08/2016

Deployed SHM sensors
Comparative Vacuum Monitoring (CVM)

- Sensor consists of air- and vacuum galleries
- Structure is part of the sensor
- Surface cracks lead to a change in vacuum that can be measured

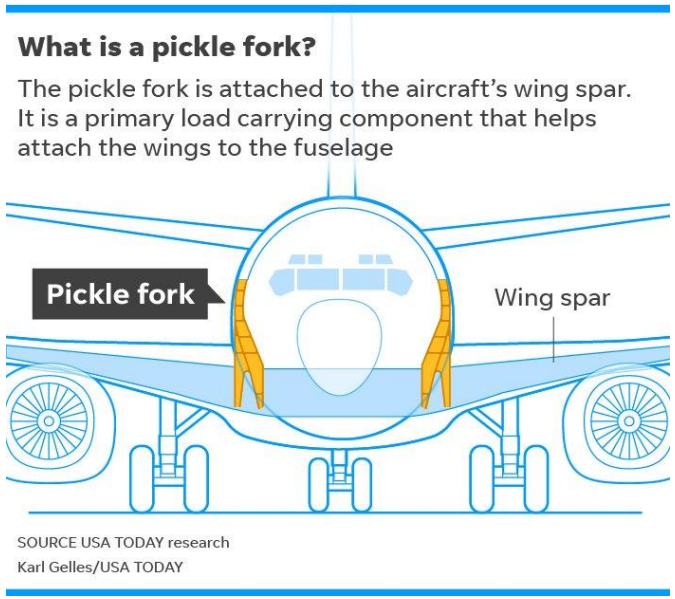


Source: Structural Monitoring Systems plc

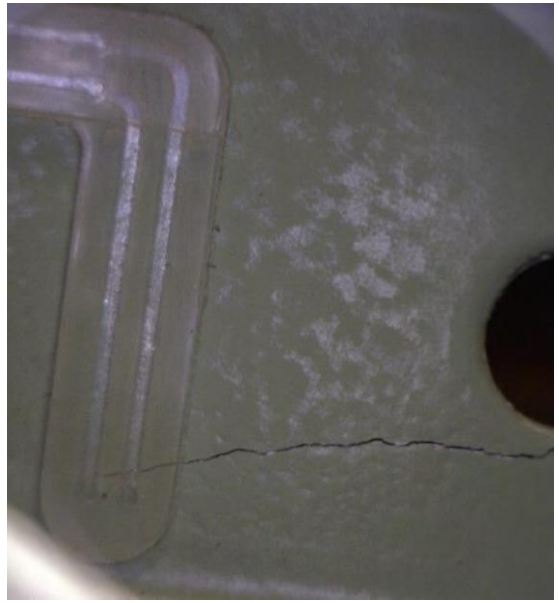


Source: Structural Monitoring Systems plc

Deployed SHM sensors
Comparative Vacuum Monitoring (CVM)



Source: Structural Monitoring Systems plc



Source: Federal Aviation Administration

Deployed SHM sensors
Acousto-Ultrasonics (AU)

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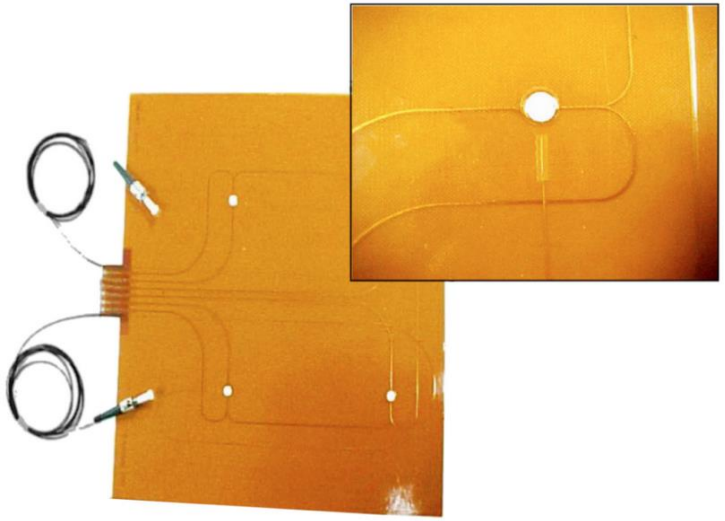
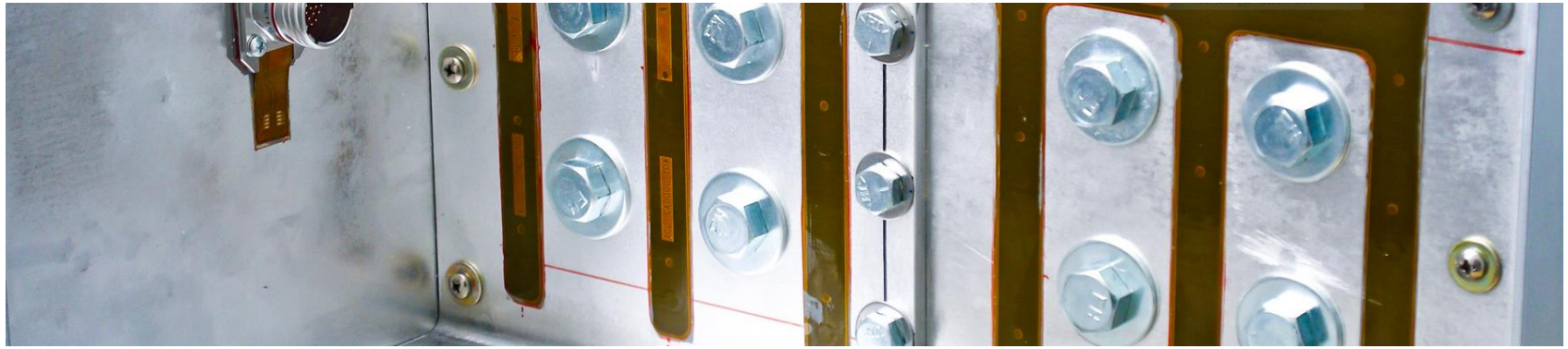
- Piezo actuators induce ultrasonic elastic waves in solid media
- Piezo sensors detect secondary waves in case a defect is present



Source: Acellent



Source: Acellent

Deployed SHM sensors
Eddy-Current Inspection

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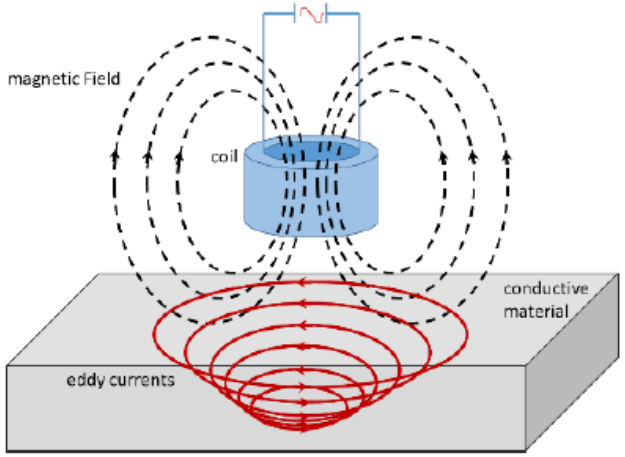
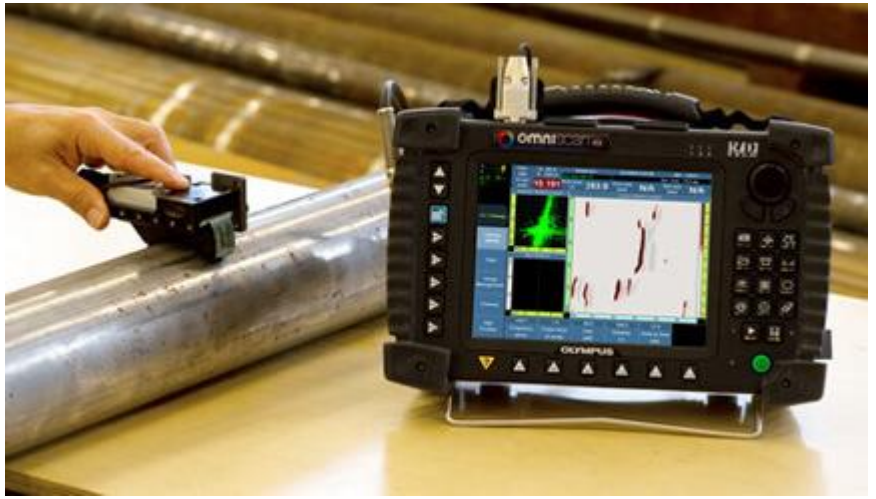
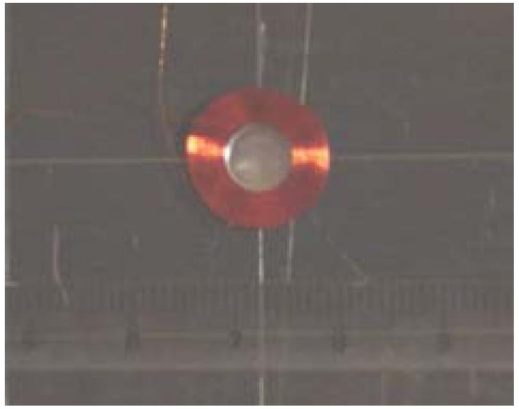
- Eddy-curent field is generated by a sensor and distorted by present defects in metallic materials
- Usually NDT sensors, but can be deployed as thin foil sensors for SHM



Source: Zetec



Source: Geartest, IXT



Source: Airbus – Speckmann, Henrich

Deployed SHM sensors
Strain Gauges

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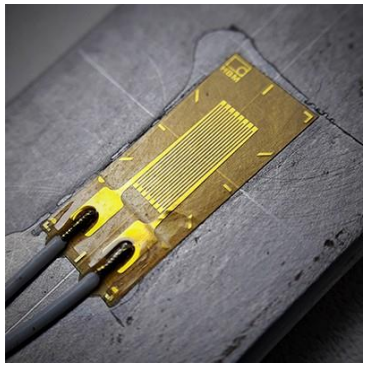
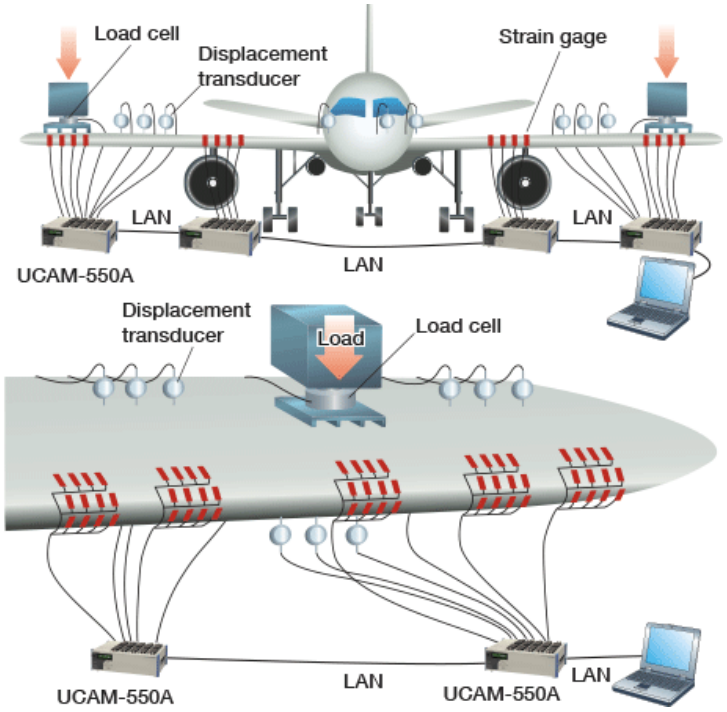
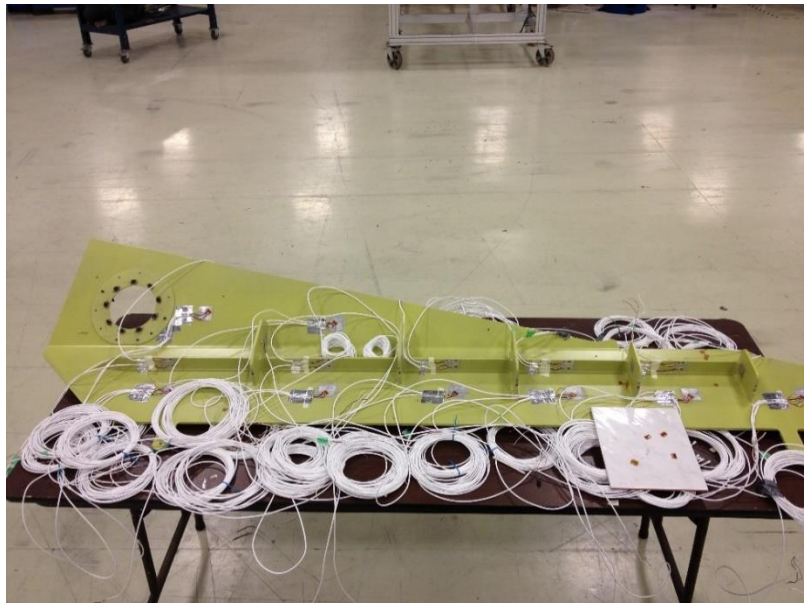
- Common sensor that measures strain
- Useful to monitor overload and load cycles



Source: EncardioRite

Source: Kyowa

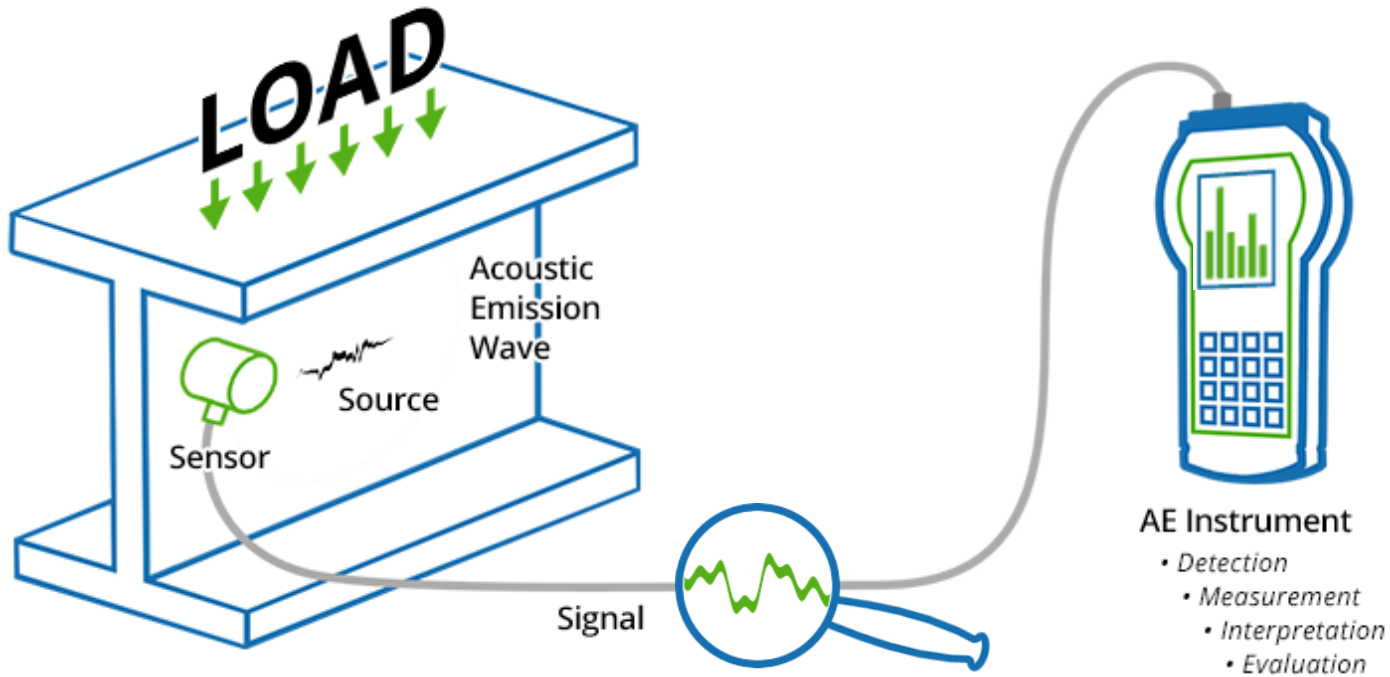




Source: Marsh Group

Deployed SHM sensors
Acoustic Emission

- Sounds of failing materials are detected by a microphone
- Depending on the post-processing algorithms, occurring sounds can be classified



Source: PhysicalAcoustics

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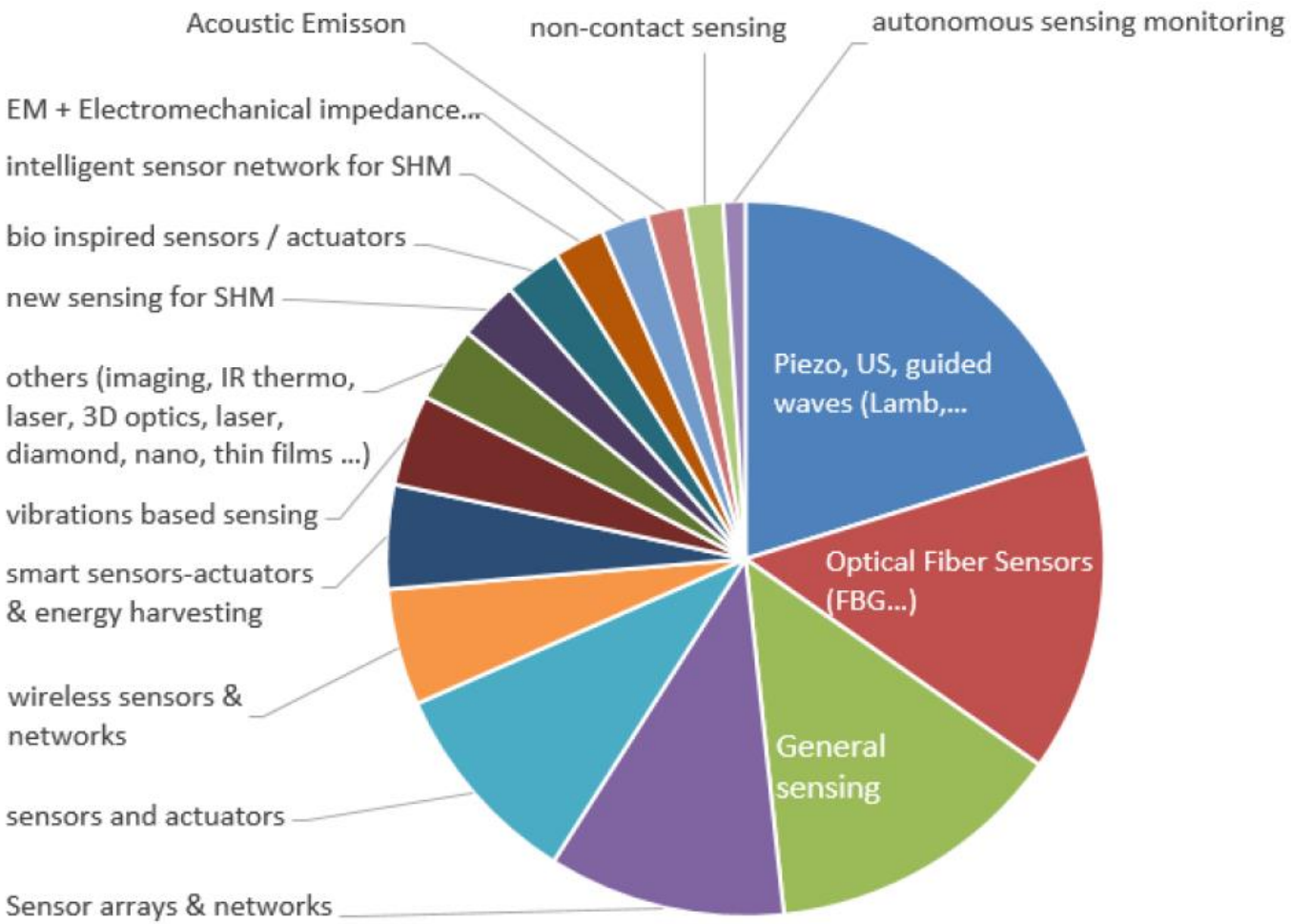
SHM Sensors in Aviation

Ongoing Research

Ongoing research on SHM sensors



Source: Ferdinand, 2014

- Overview of SHM sensing techniques by QUELLE.
- Diagram describes amount of contributions in the conferences EWSHM and IWSHM between 1999 and 2014

Ongoing research on SHM sensors
Piezo elements & Guided ultrasonic waves

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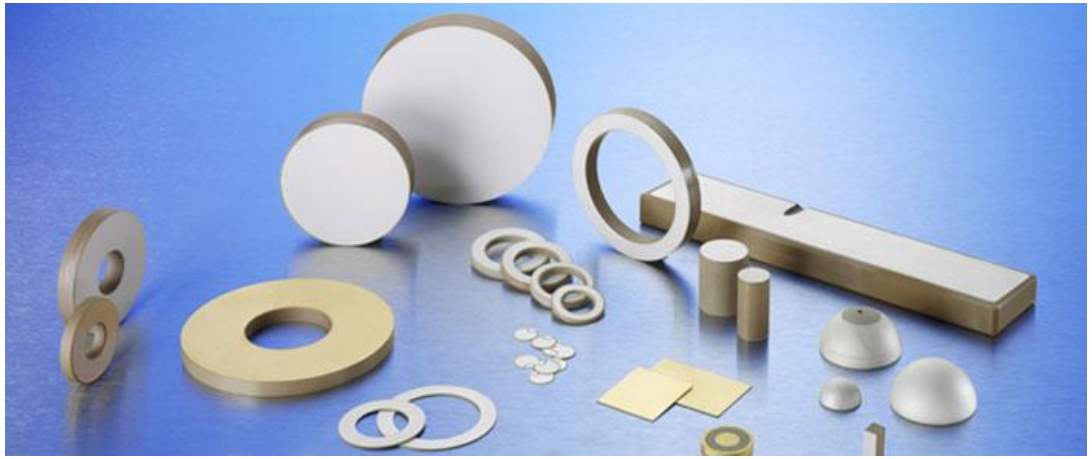
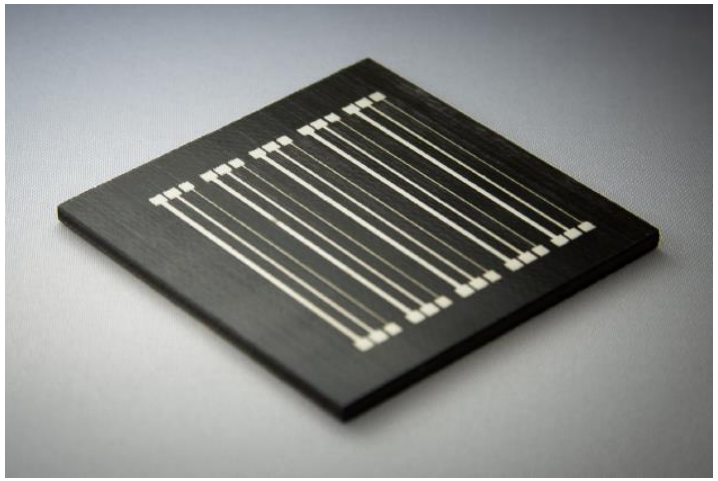
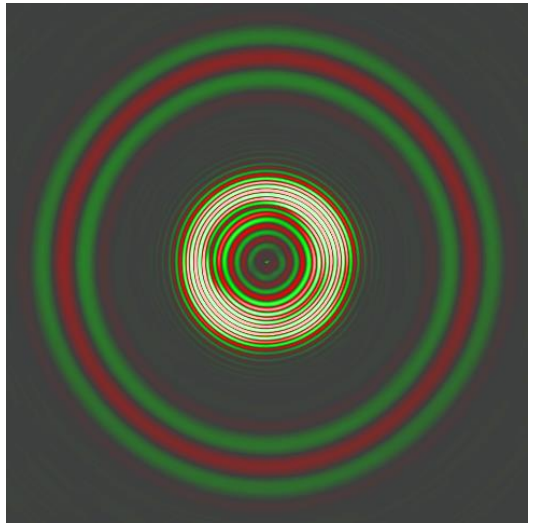
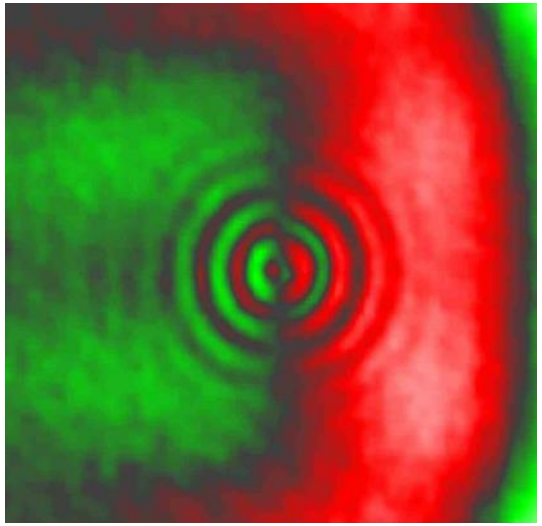


Source: Ceramtec

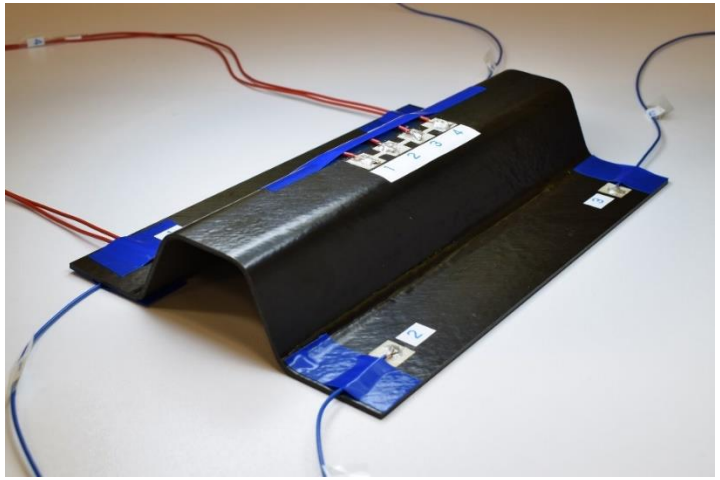


Source: Heinrich, 2018



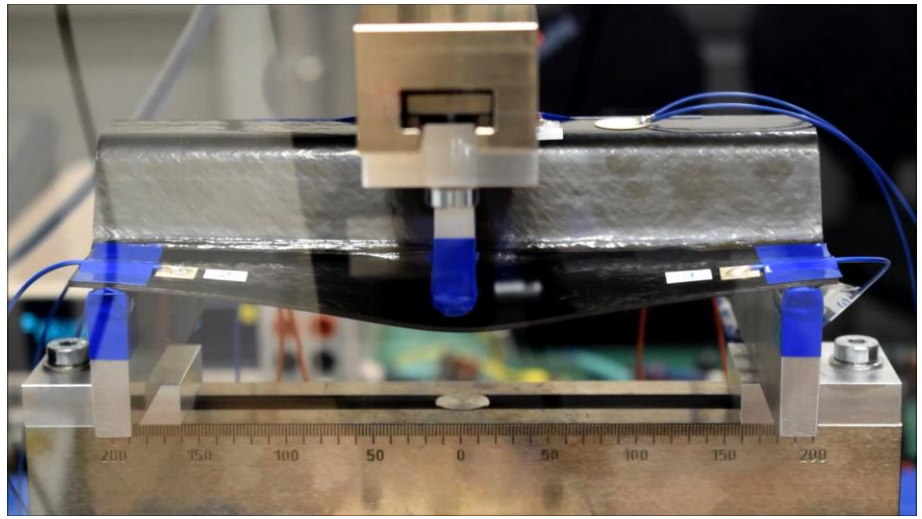


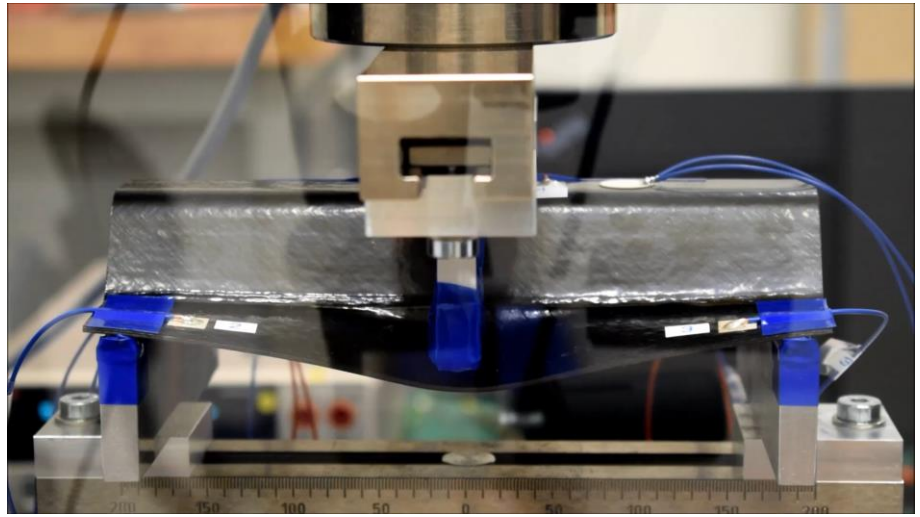
Source: Neumann, Hennings, Lammering, 2014

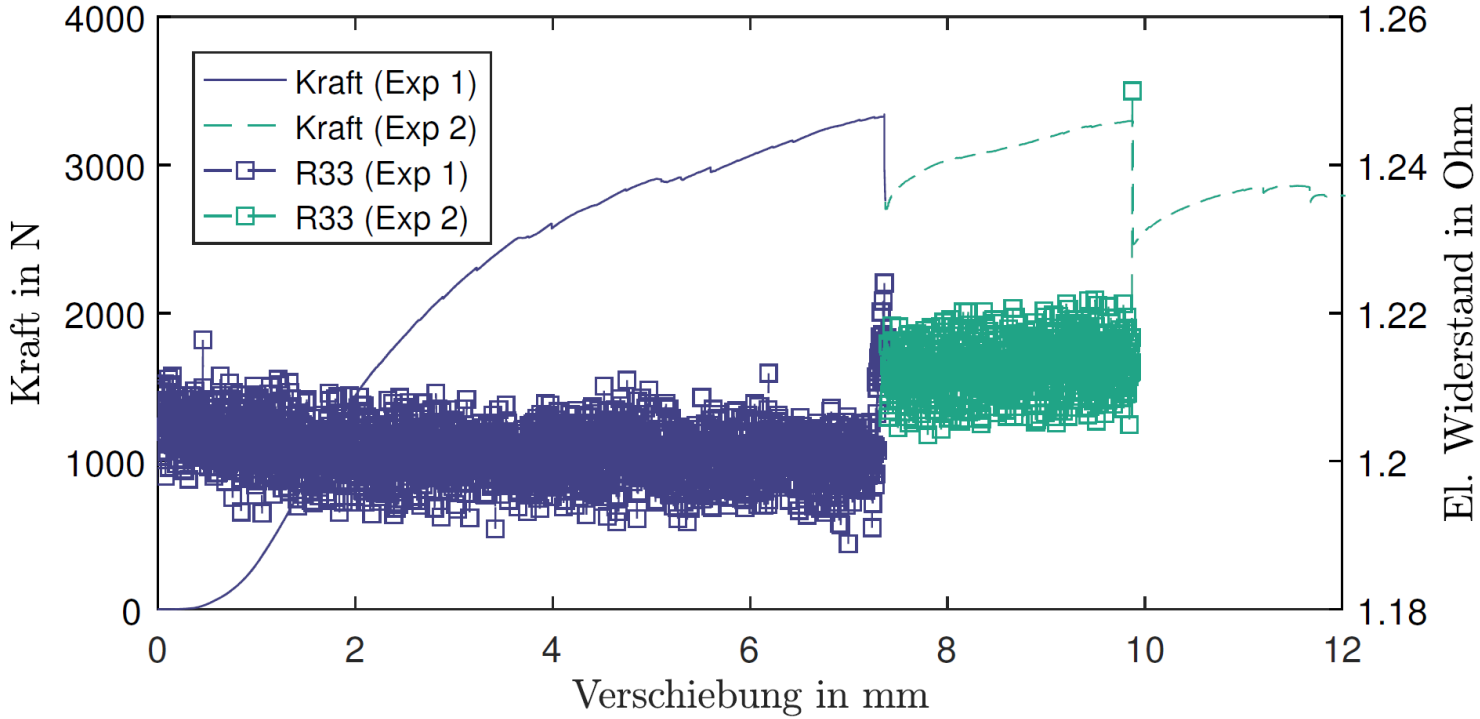


Source: Heinrich, Genco, Lammering, 2018

Ongoing research on SHM sensors
Piezo elements & Guided ultrasonic waves







Source: Heinrich, Genco, Lammering, 2018

Ongoing research on SHM sensors
Fiber Bragg Grating Sensors

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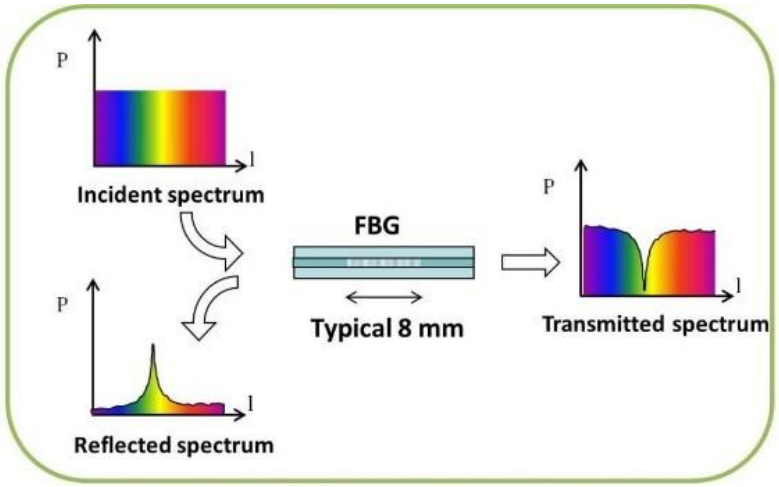
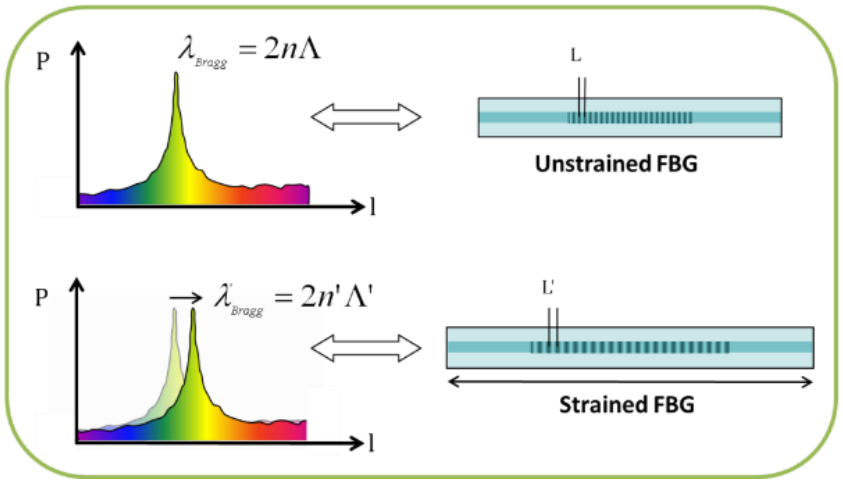
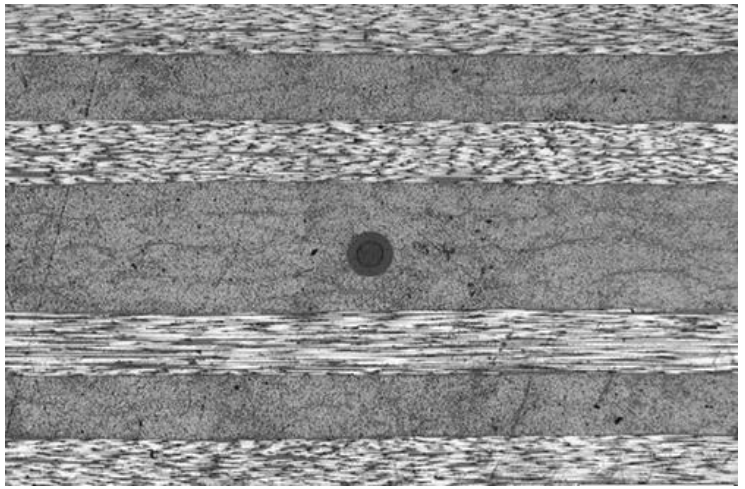
- Optical sensors that act as a band-pass wavelength filter
- Can be integrated into composite structures





Source: FBGS

Source: Strantech



Source: LaserFocusWorld

Ongoing research on SHM sensors
Fiber Bragg Grating Sensors

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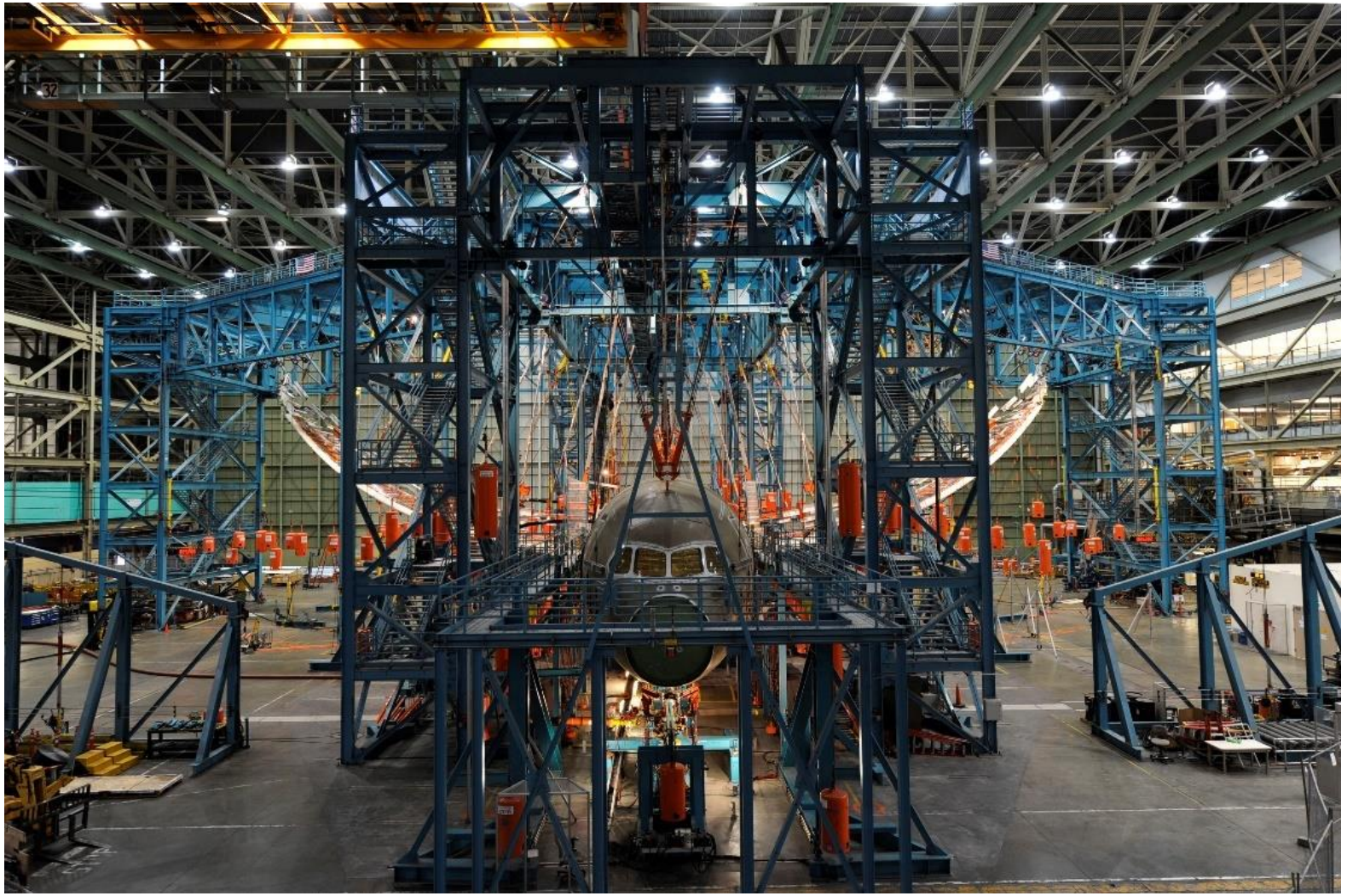

Potential application?

Source: Wired

Ongoing research on SHM sensors
Image based crack detection

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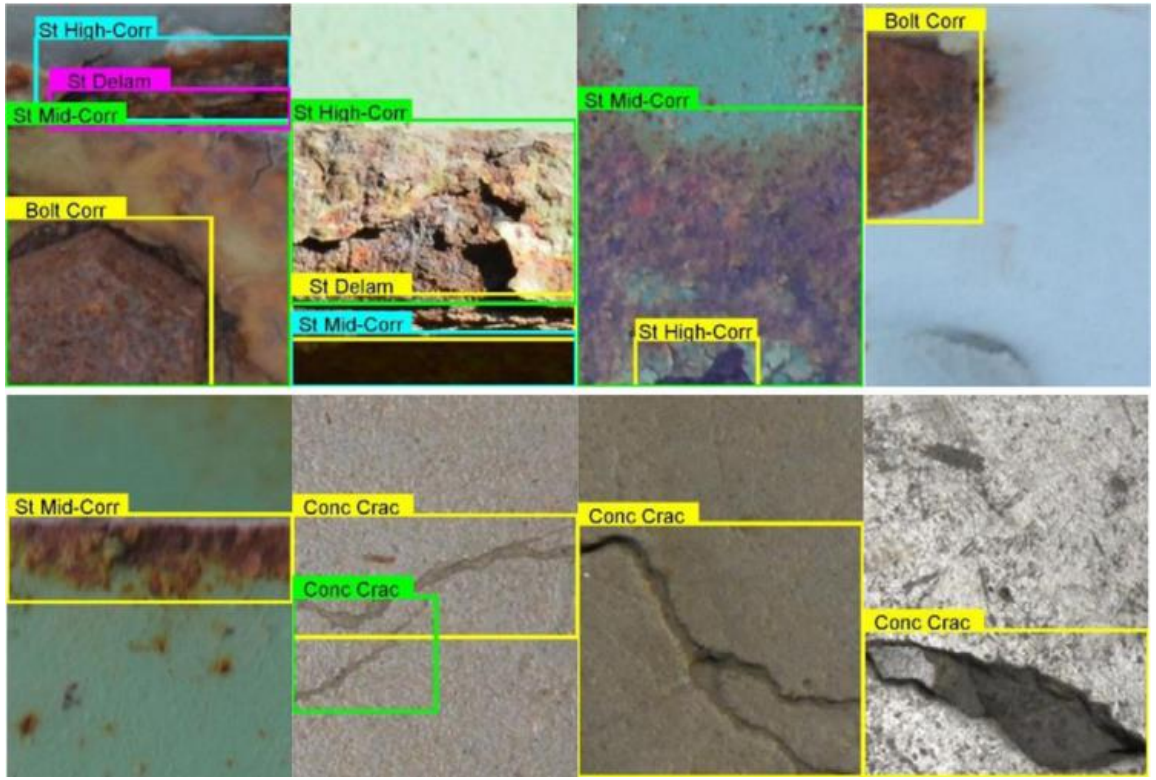
- Image based defect detection:
  - Conventional image recognition for simple defect geometries or
  - Deep Learning based algorithms for complex defect geometries



Source: Cha et al., 2018

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SHM Sensors in Aviation

What the ZAL offers

What the ZAL offers

ZAL Center of Applied Aeronautical Research

The ZAL offers SHM related support in the following areas:

Consulting

- ✓ Data
- ✓ Sensors
- ✓ Algorithms

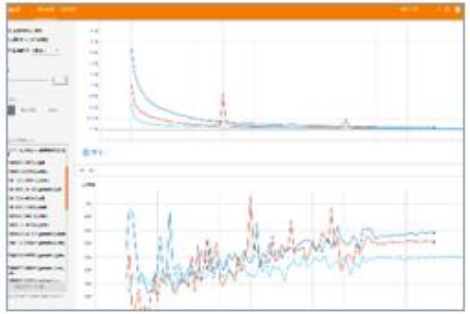
Data Acquisition

- ✓ Test bench set-up
- ✓ Data recording
- ✓ Data simulation

Implementation

- ✓ Data preprocessing
- ✓ Algorithm selection

Training



- ✓ Algorithm optimization
- ✓ Fine-tuning

Quality Control

- ✓ Accuracy
- ✓ Precision & recall
- ✓ Test in real environment

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