NPL

Presented by

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Applications and challenges of SHM in the aerospace industry

Advanced SHM Seminar

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AIRBUS

Outline

- Motivations for SHM
- Aerospace SHM
- Applications
- Challenges
- Conclusions

Motivations

- Why do we want to use SHM?
  - It allows fast evaluation of damage locations
  - It prevents monitoring areas without damage, providing a more directed maintenance, and time savings ➔ cost savings
  - Human error also means that damage can be missed. SHM being a machine will not miss the damage ➔ greater safety, beyond high standard already available

Motivations

- Why do we want to use SHM?
  - It allows further improvements of aircraft structures
  - It allows huge design simplifications
  - It allows reduction of aircraft weight ➔ more passengers and more luggage, more freight, less kerosene consumption
  - Do not required highly skilled maintenance staff to operate these SHM techniques ➔ Less operating cost and less potential of mistakes again

Motivations

So many accidents could have been prevented
by the use of structural health monitoring

C130 Fire-Fighter 2002

Motivations

- By reducing inspection time, the availability of aircraft increases

- Having such SHM systems would also allow postponing major checks until required. Major change of philosophy.

Large areas to monitor

Quite lots of parts to be monitored

SHM Expectations

- SHM shall not produce positive or negative false alarms
- SHM technology shall be versatile, adaptable to the damage to be monitored
- SHM equipment should be able to monitor a wide range of damage, structural integrity: Need to have a combined set of SHM technique

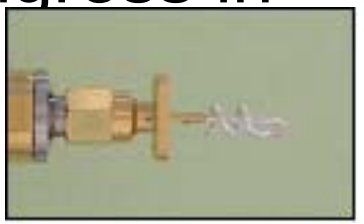
AEROSPACE SHM

Aerospace SHM Technologies

- The SHM technologies are:
  - Acoustics emission
  - Lamb wave propagation
  - Eddy current foil
  - Environmental degradation monitoring
  - Comparative vacuum measurement
  - Crack wire
  - Water ingress detector
  - Fibre optics
  - Functional coating (UV witness paints, damage amplifier…)
  - …

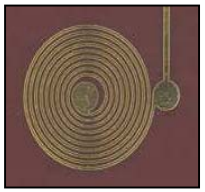
Aerospace SHM Technologies

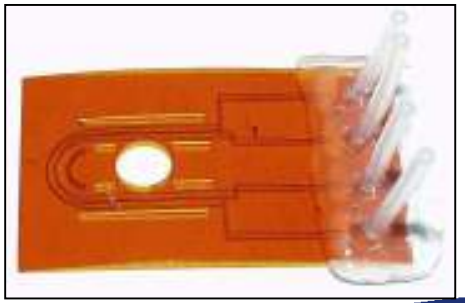
- Microwave antenna: Detection of water ingress in sandwich structures



- Crack wire: Detect the rupture of an element thanks to the breaking of wire

- ETFS: Eddy current foil bonded on metallic surface or embedded in assembly to detect cracks and monitor their propagation. Technology able also to monitor corrosion





- CVM: Measures accurately the crack initiation and growth in metallic structures

Aerospace SHM Technologies

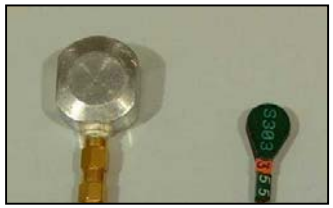
- FBG for strain measurement: Fibre Bragg grating sensor able to measure both surface and intra-lamina milli-displacements used for strain measurement in metallic and CFRP structures

- FBG for damage detection: Fibre Bragg grating sensor able to detect disbonding in composites structures

- FBG for AE measurement: Fibre Bragg grating sensor able to measure both surface and intra-lamina pico-displacements used for AE measurement in metallic and CFRP structures

Aerospace SHM Technologies

- AE: Acoustic emission sensor recording stress waves generated by cracks, fretting in metals and delamination for damage location of large structural areas

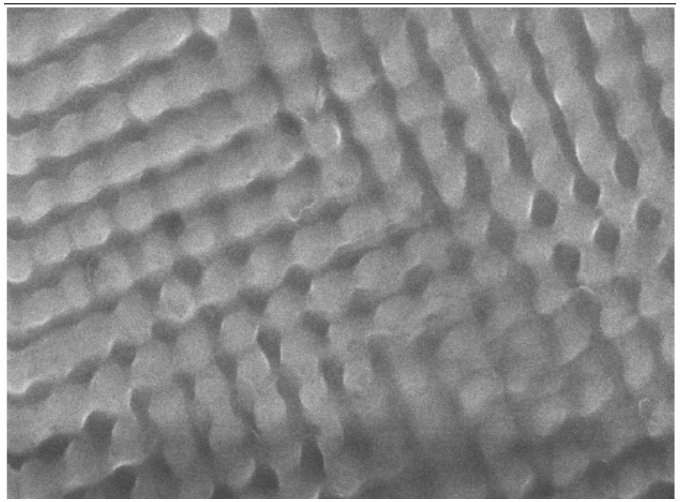


- AU: Locate and monitor metallic crack and delamination

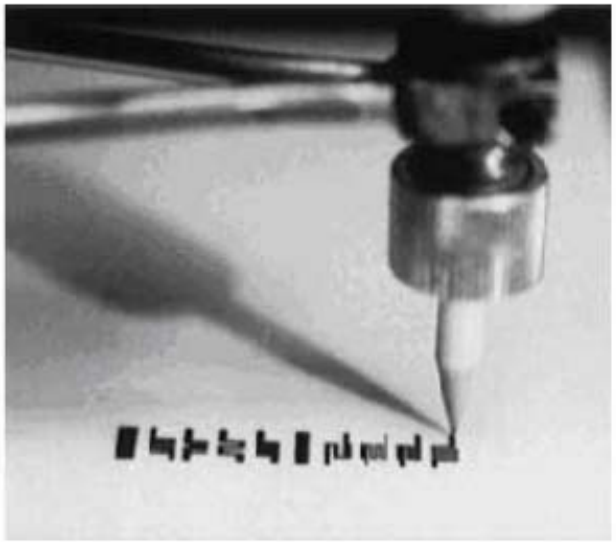
- EDMS: Environmental degradation monitoring sensor is a sensor based on measuring chemical changes of its constituents, for corrosion detection

Aerospace SHM Technologies

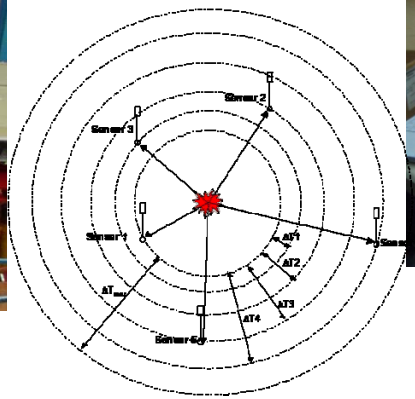
- Functional coating: This is a generic name for mainly paint that changes when damage, such as UV displayed paint

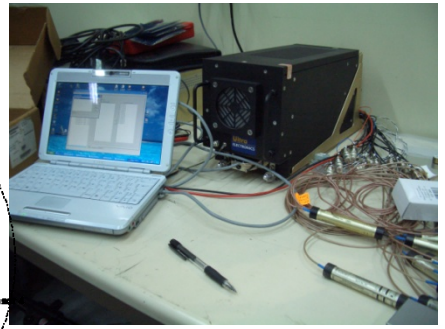


- Functional printing: This is the generic name for sensors directly written onto the structure surface



Example 1: Acoustic Emission

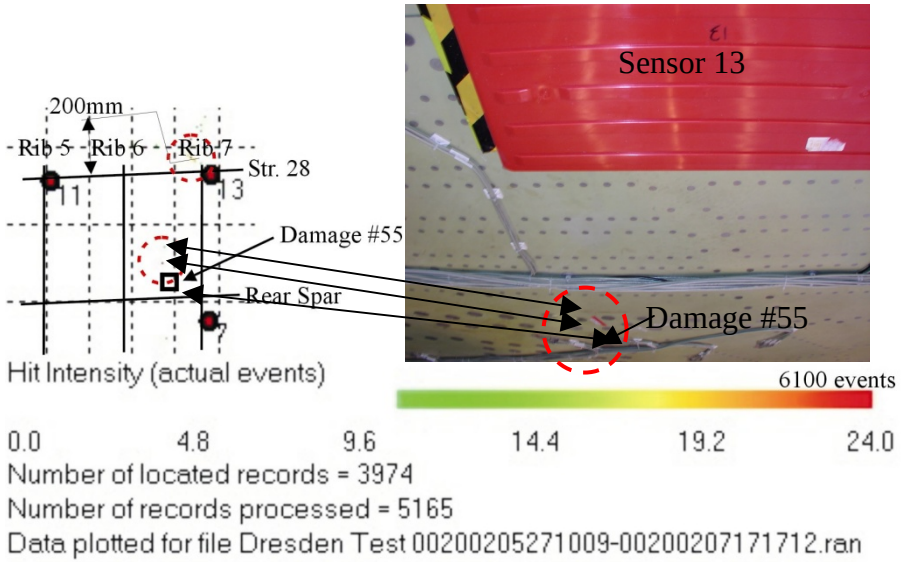


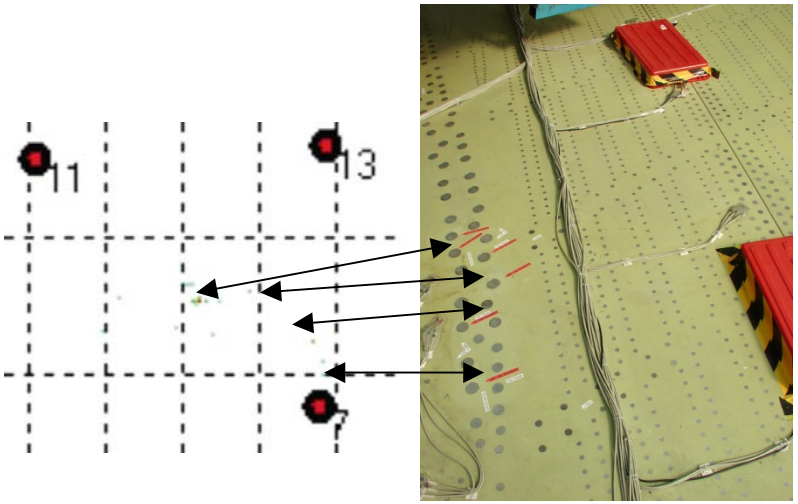


Early detected damage

Monitoring between May 2002 & June 2003

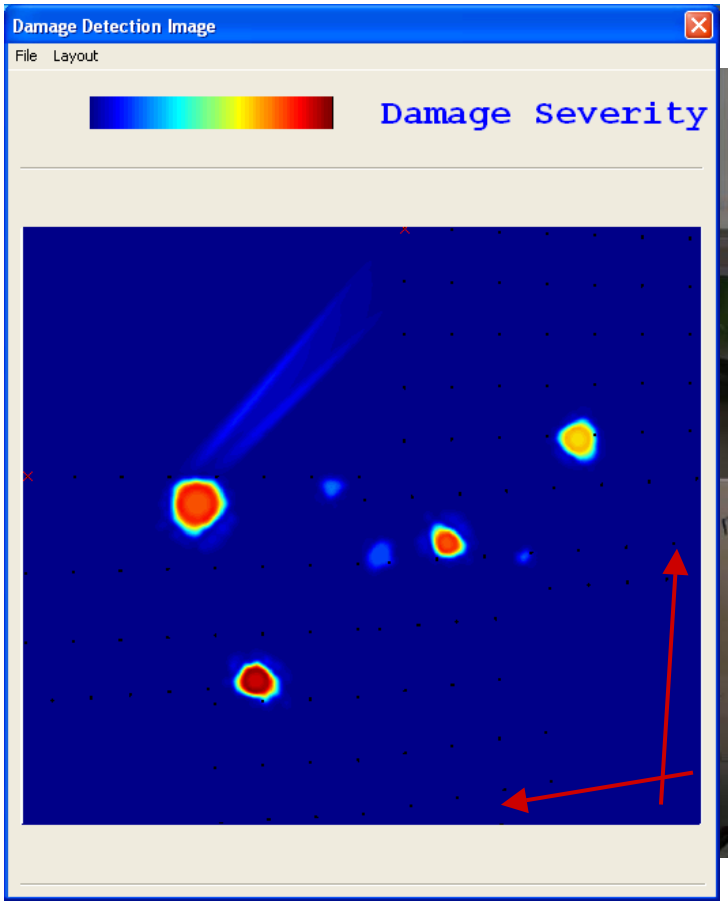
Monitoring between May & July 2002

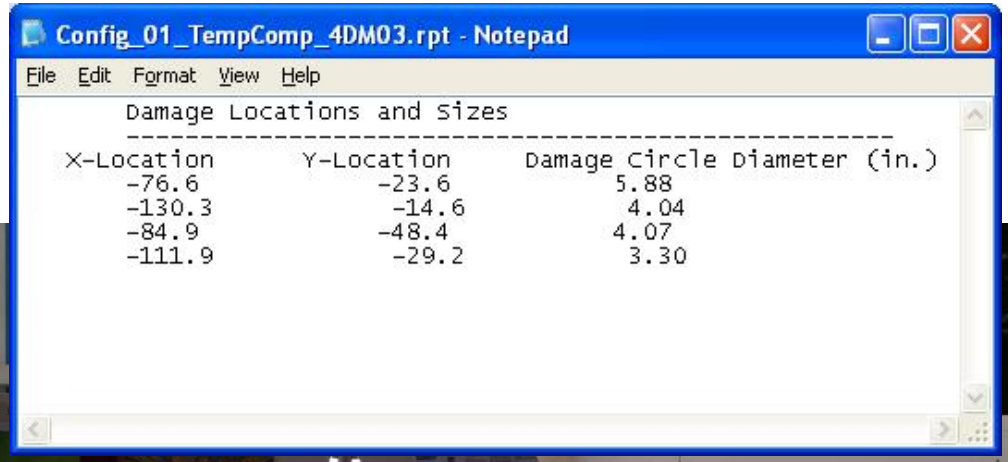




Example 2: Delamination by Guided Lamb Wave

- Measurement of artificial damage size (red patches)



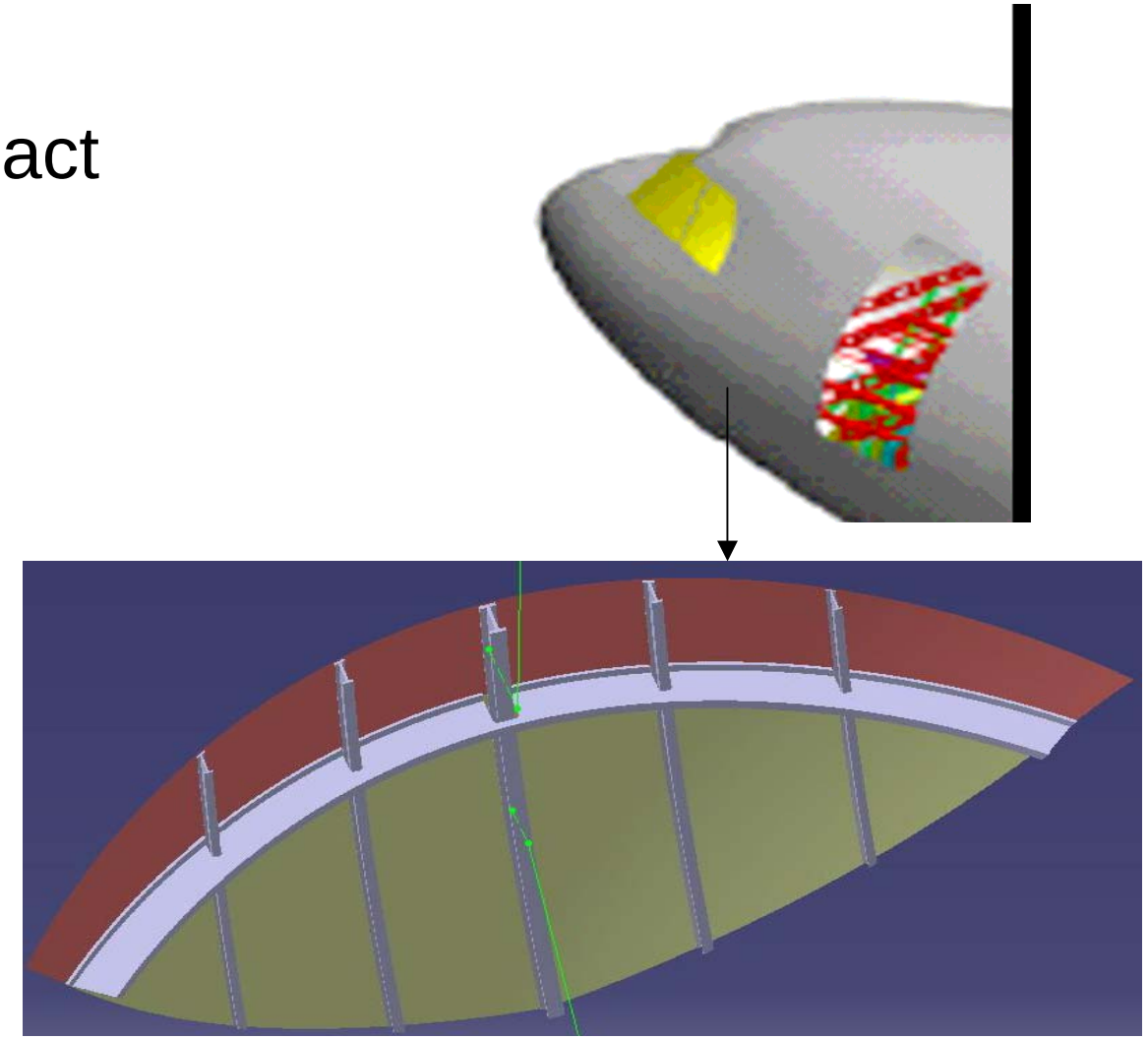


SHM APPLICATIONS

SHM Application Scenarios

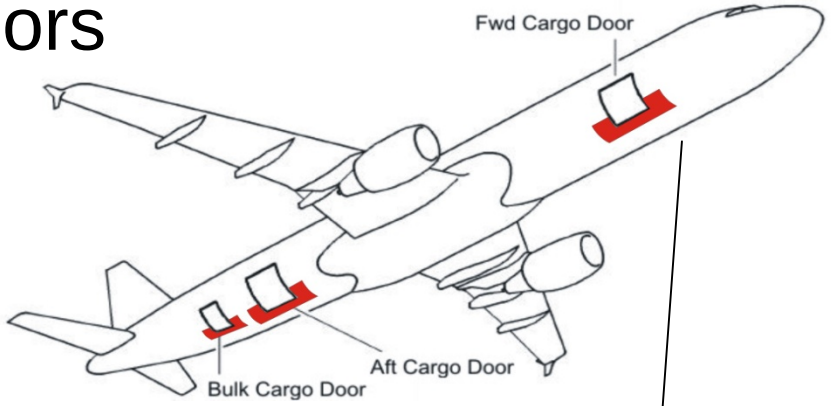
Example of applications for information only

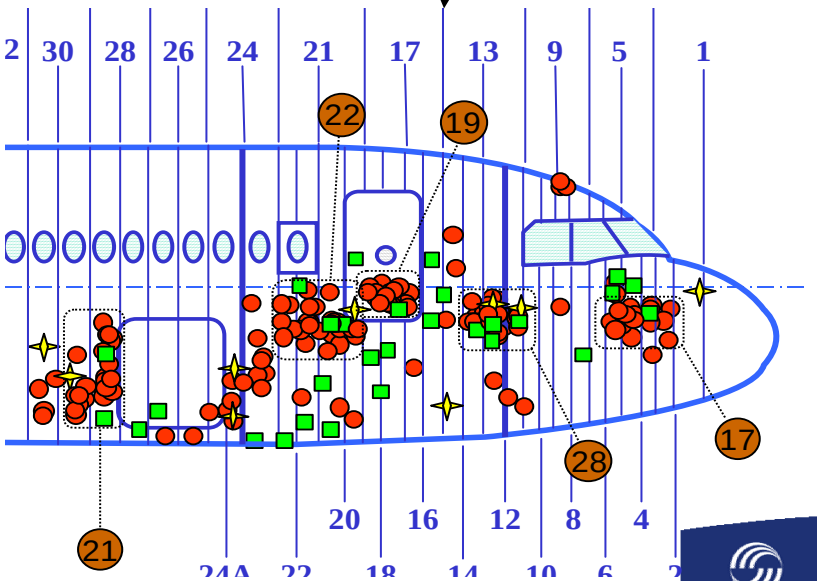
- Hail impact



SHM Application Scenarios

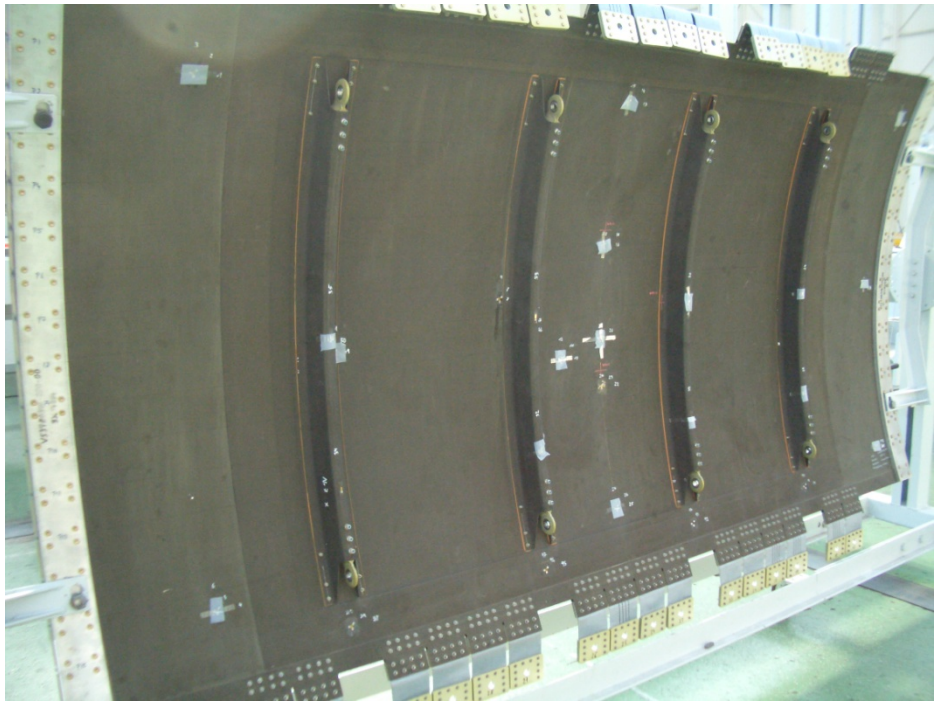
- Impact surrounding doors



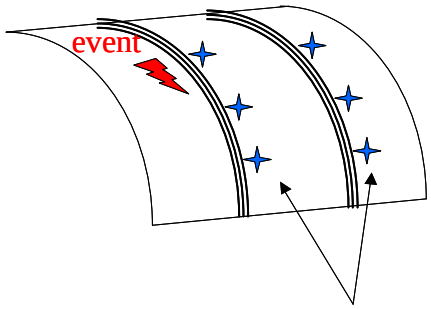


SHM Application Scenarios

- Damaged frame



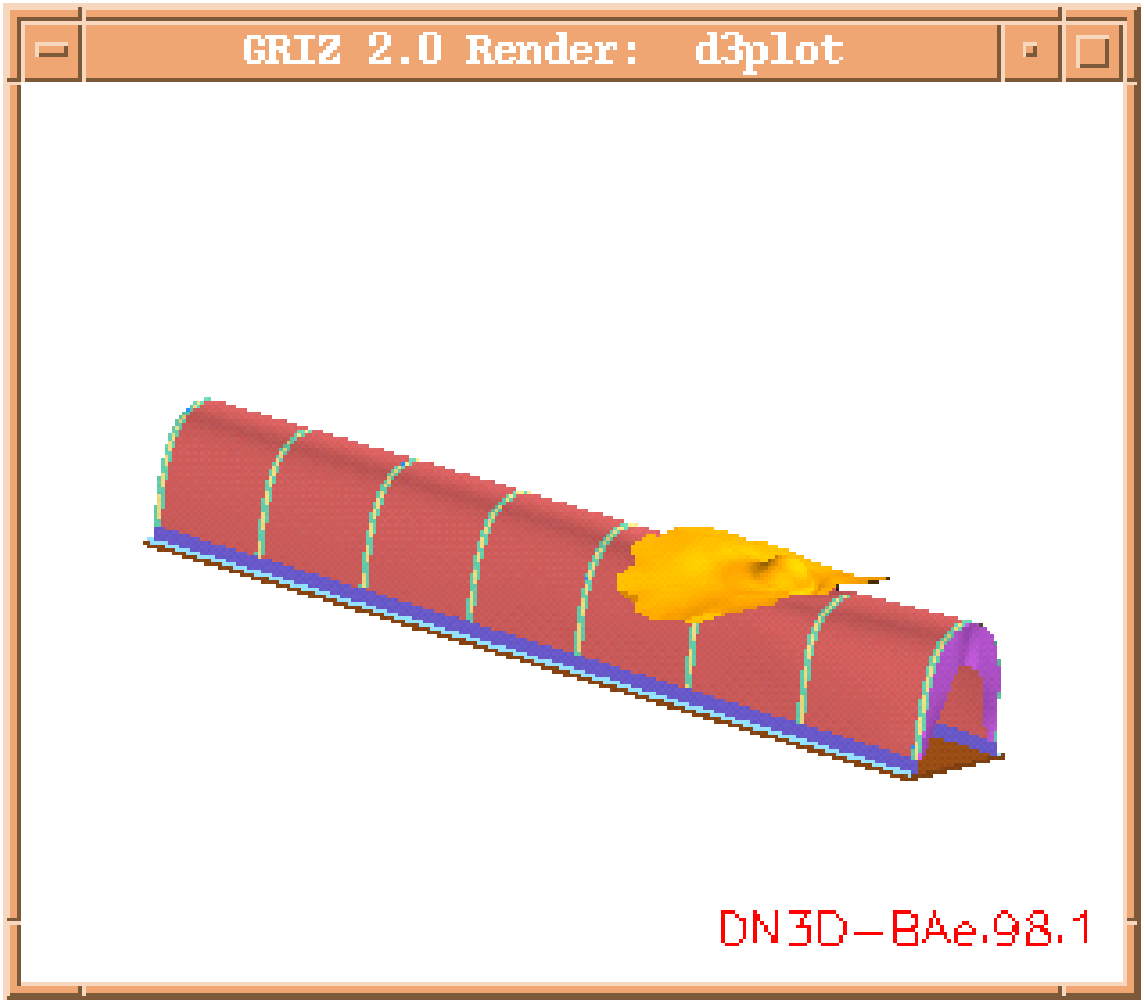
If Frame damaged stress 30% higher



Sensors to measure strains

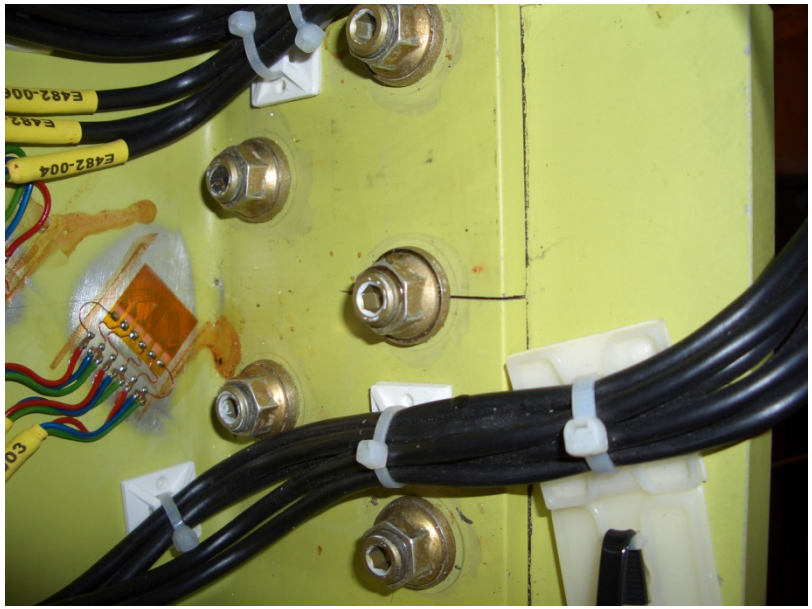
SHM Application Scenarios

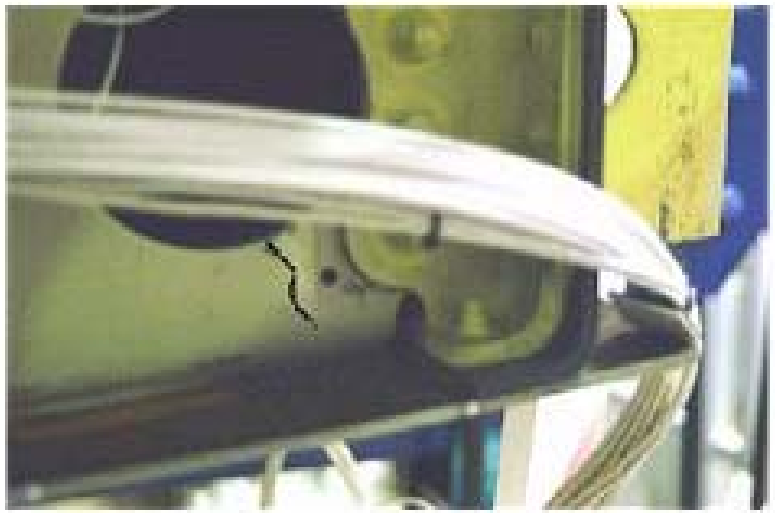
- Bird Strike



SHM Application Scenarios

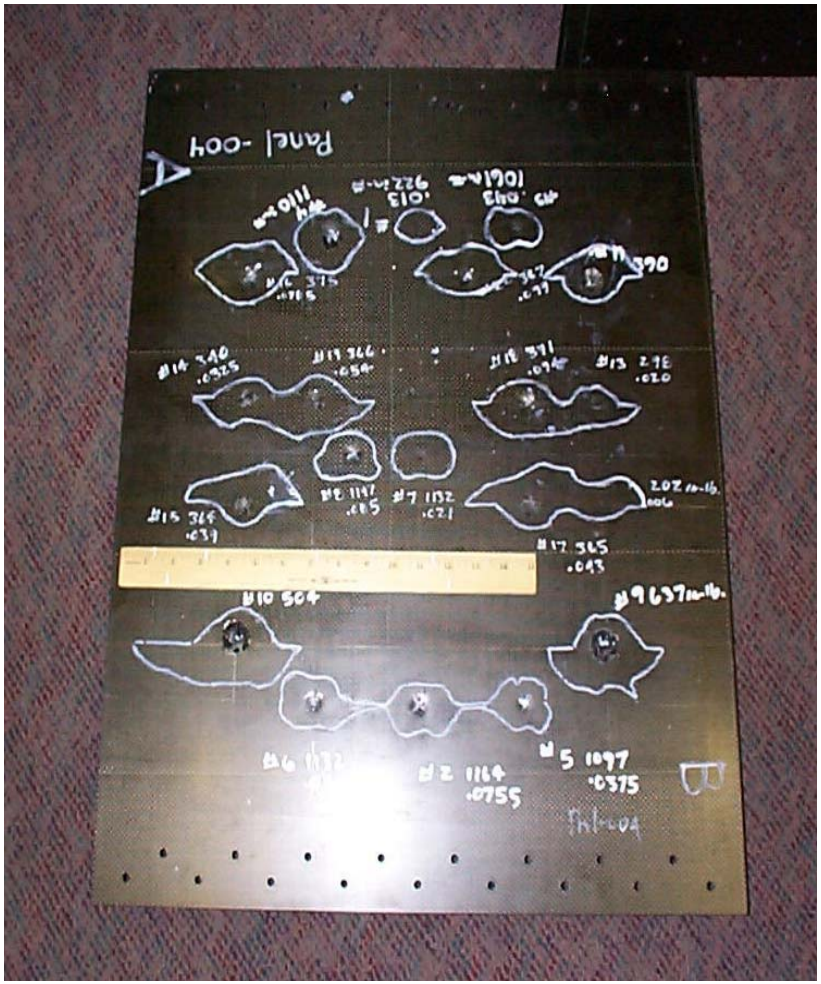
- Fatigue Crack

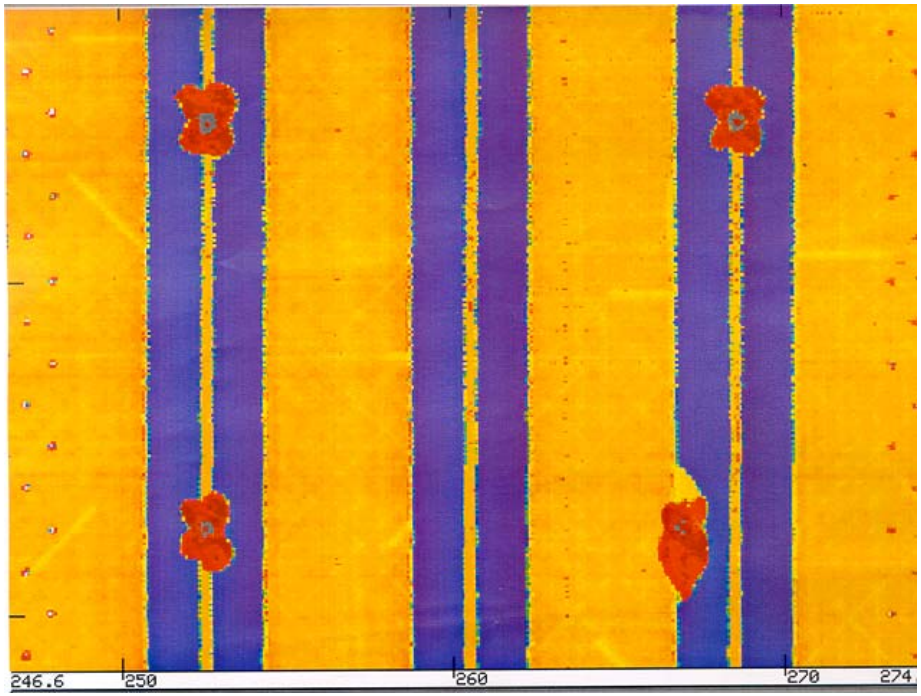


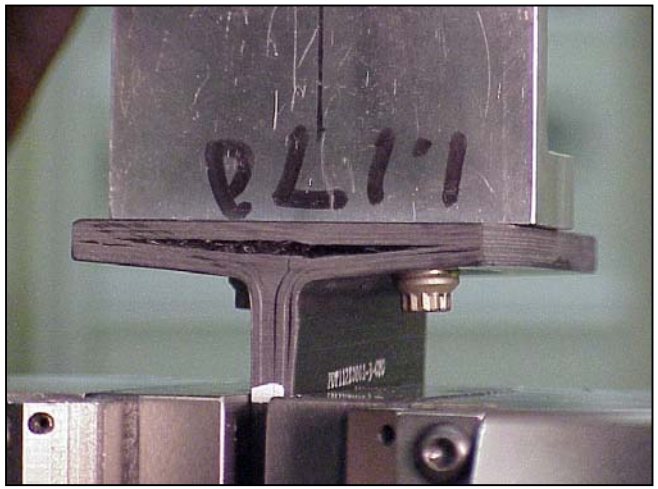


SHM Application Scenarios

- Delamination / Disbonding

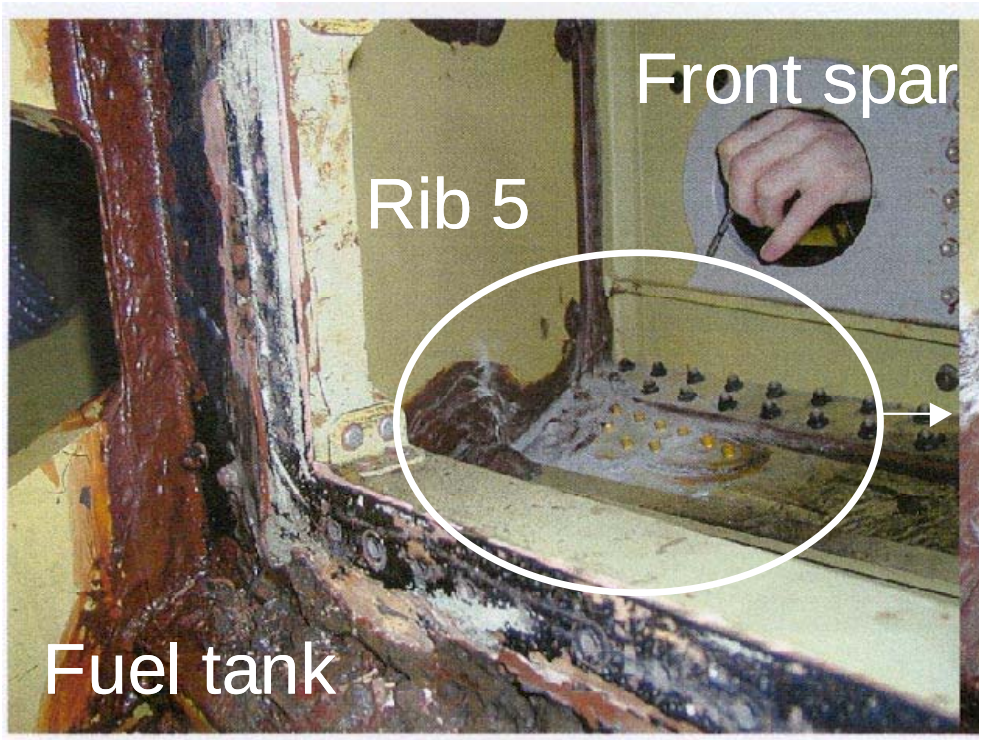






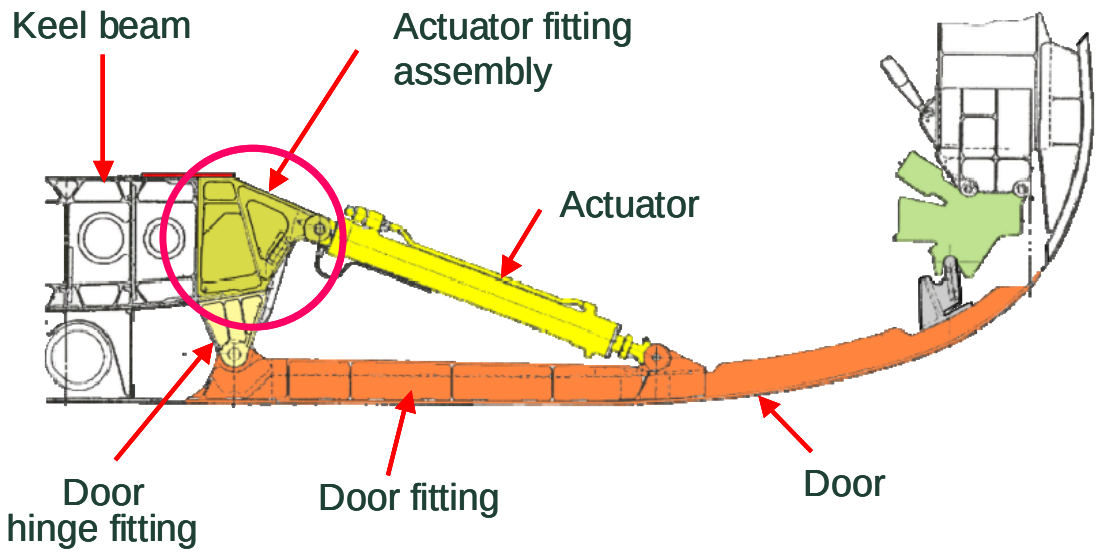
SHM Application Scenarios

- Corrosion



SHM Application Scenarios

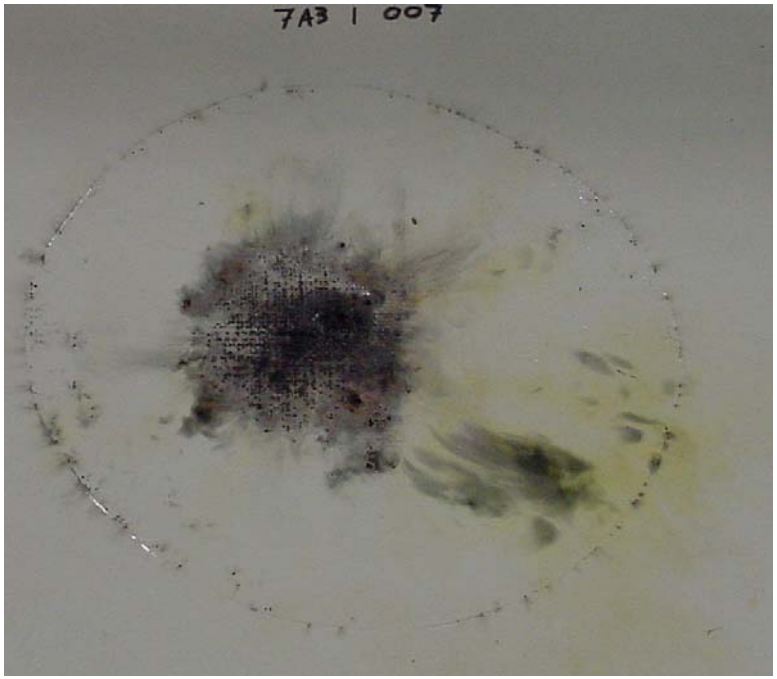
- Load measurement



View looking aft

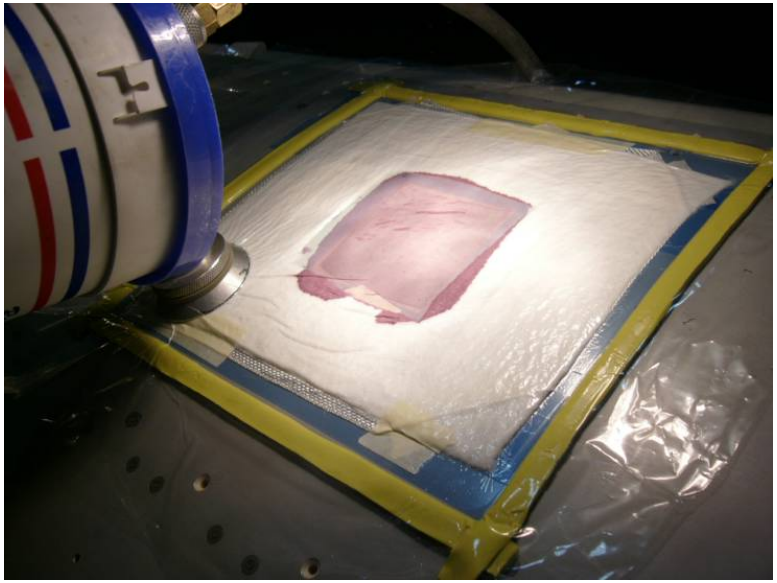
SHM Application Scenarios

- Lightning Strike



SHM Application Scenarios

- Monitoring of CFRP repairs

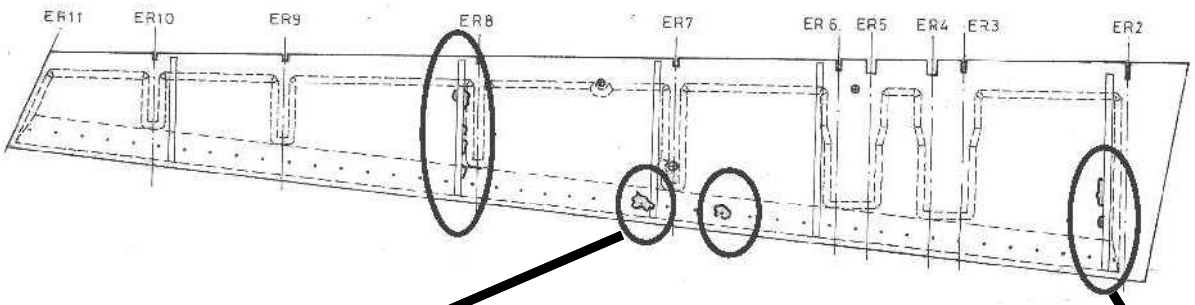


SHM Application Scenarios

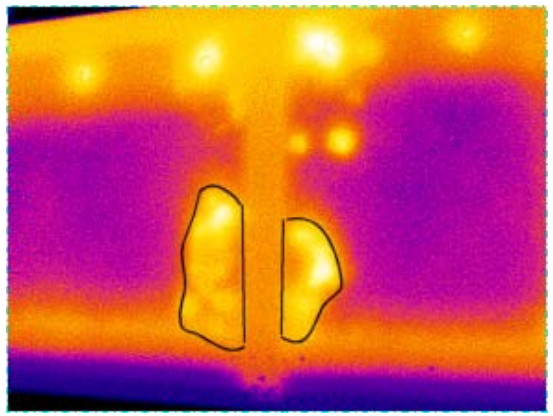
- Sandwich debonding

SHM Application Scenarios

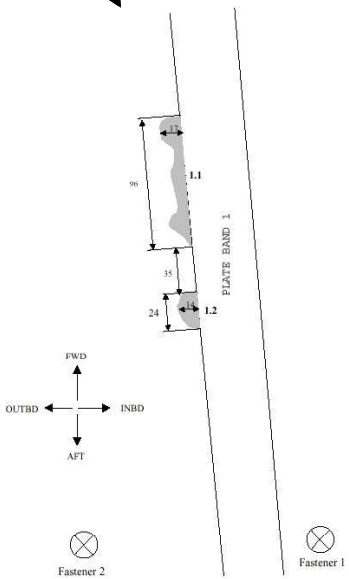
- Water Ingress



Water ingress around trailing edge bolts



Water ingress along lightning straps



CHALLENGES

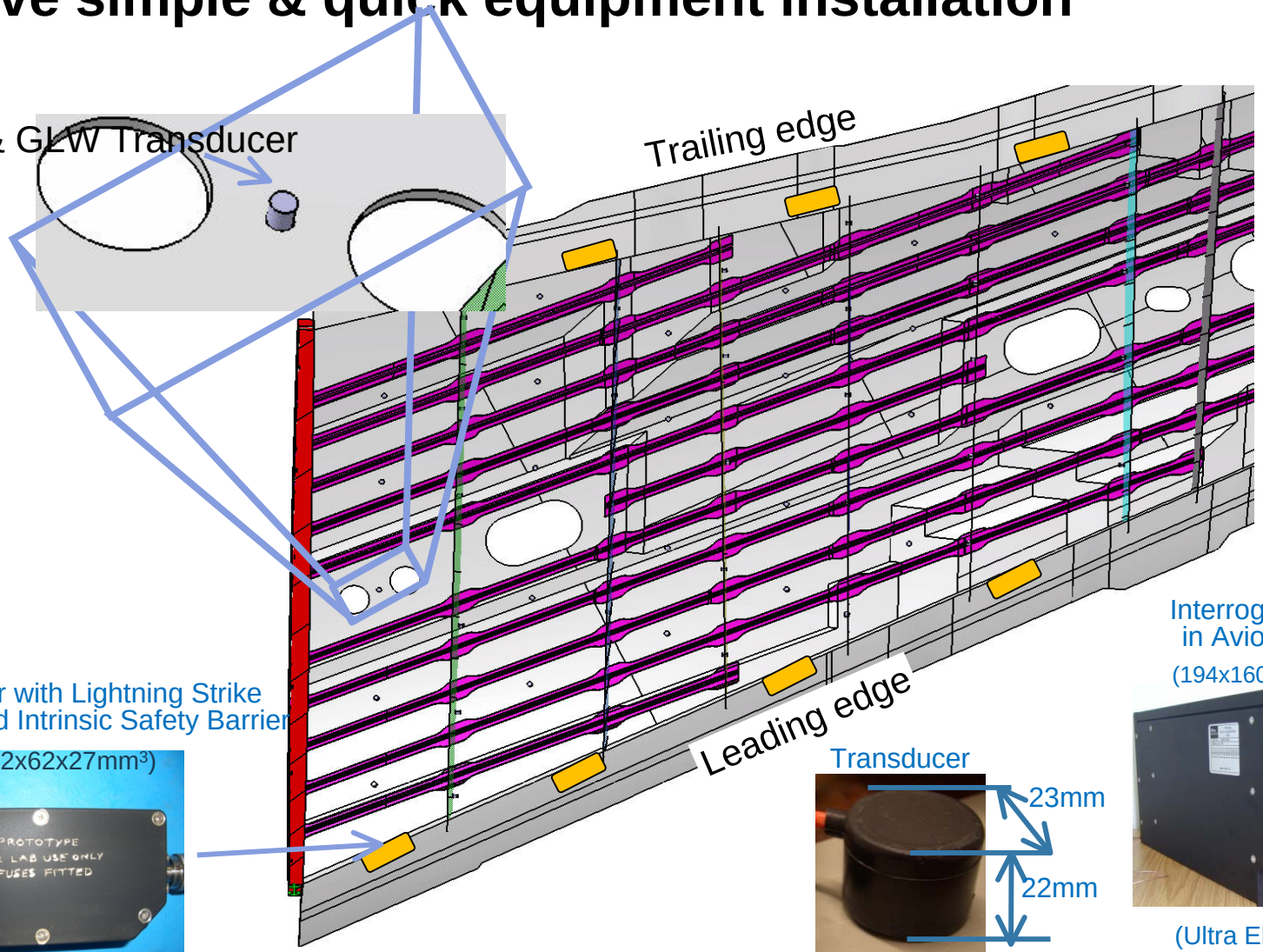
Challenges

To get SHM on aeronautical vehicles it is important to:

- Stop scepticisms by working hand to hand with the end-user
- Have simple & quick equipment installation
- Provide return from investments within 2-3 years
- Be compliant to airworthiness authority rules (RTCA DO-160, DO-254 , DO-178, SFAR 88 AC25.981-1c, ARP-4754, AC 25.1309)
- Be compliant to application – DAL (RTCA DO-180), PoD, Self-diagnostic tool, survive manufacturing and assembly
- Optimise the maintenance schedule to enable structure maintenance only tasks to be replaced by SHM
- Modify the existing EASA & FAA rules when using SHM

Challenges - Installation

- **Have simple & quick equipment installation**



Preamplifier with Lightning Strike Protection and Intrinsic Safety Barrier

(122x62x27mm³)

(Ultra Electronics)

Transducer

(Ultra Electronics)

Interrogation Unit in Avionics Bay

(194x160x400 mm³)

(Ultra Electronics)

Challenges – RfI

- **Provide return from investments within 2-3 years**
  - Reduce SHM equipment weight to lower fuel consumption
  - Reduce SHM equipment non-recurring cost
  - Reduce risk/cost of maintenance
    - High MTBF for all components MIL STD 781 (up to 50,000 flights)
    - Transducer, cabling, connectors lasting the life of craft
    - Easily maintainable
    - Not adding maintenance burden
    - Able to repair within turnaround time (30min – 1hr)

Challenges – Fuel tank

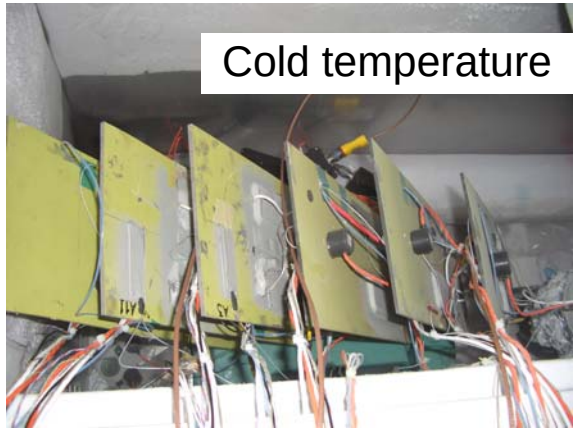
- **Be compliant to airworthiness authority rules**
  - SFAR 88 AC25.981-1c
    - Reduce current consumption to 15mA
    - Reduce energy storage to 20μJ
    - Intrinsic safety barrier
    - Lightning strike protection
  - TDD92 (Airbus directive only)
    - Single mode failure
    - 25mm tracking distance
    - Grounding cable shielding every metre
    - 25mm safety separation

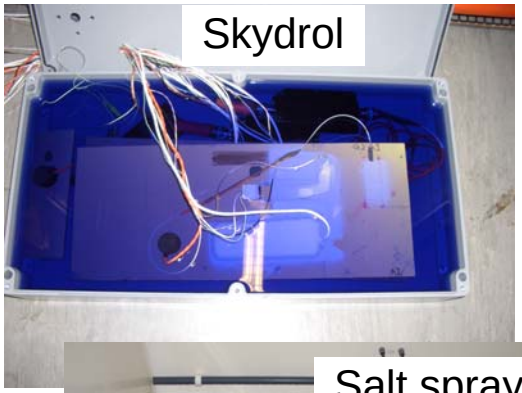
Chosen for being a worse case scenario

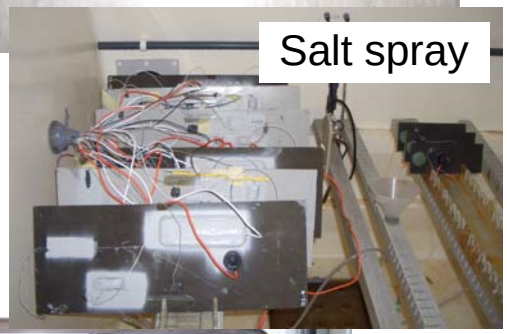
Challenges – DO160 sect. 11 for 30-year use

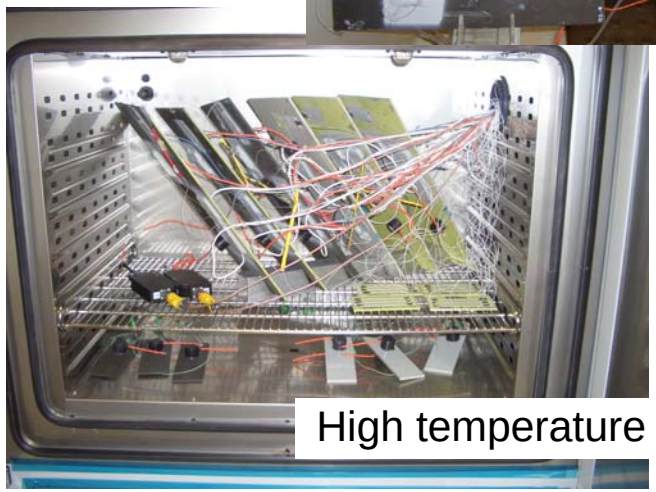
•Be compliant to airworthiness authority rules

At high temperature
At low temperature
During temperature variation
In skydrol
In kerosene
In MEK
In distilled water
In high humidity
In toilet fluid
In insecticide
In salt spray
In anti-icing and de-icing fluid
In disinfectant
In near vacuum (cruising altitude pressure)
In overpressure
Under fire condition
Under flammability, smoke density and toxicity conditions
In lubricating oils
In coolant dielectric fluid
In fire extinguishants


Cold temperature


Skydrol


Salt spray


High temperature

Challenges – DO160 other sections

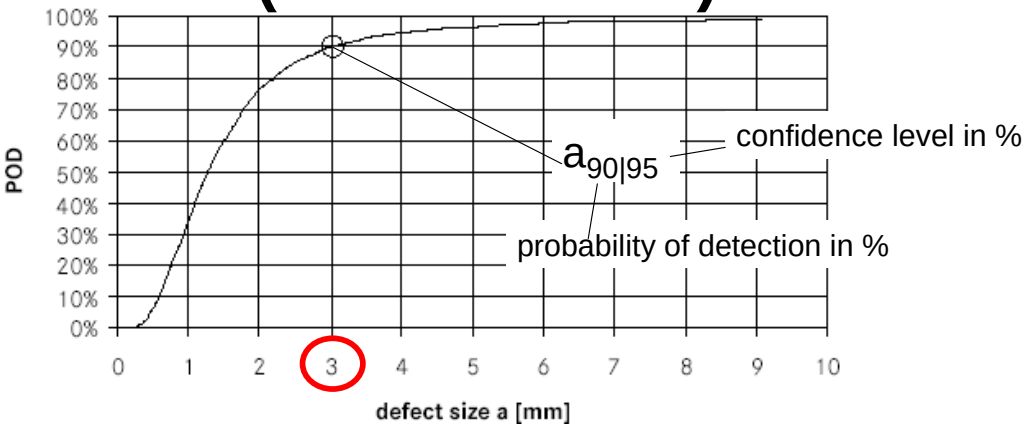
- **Be compliant to airworthiness authority rules**
  - Operational and crash safety shock
  - Structural vibration
  - Explosion susceptibility
  - Sand and dust
  - Fungus
  - Magnetic effect
  - Power Input
  - Voltage spike
  - Audio Frequency
  - Induced signal susceptibility
  - Radio frequency susceptibility
  - Emission of radio frequency energy
  - Lightning induced transient susceptibility
  - Lightning direct effects
  - Dielectric compliant
  - Insulation resistance

Challenges – DAL / PoD

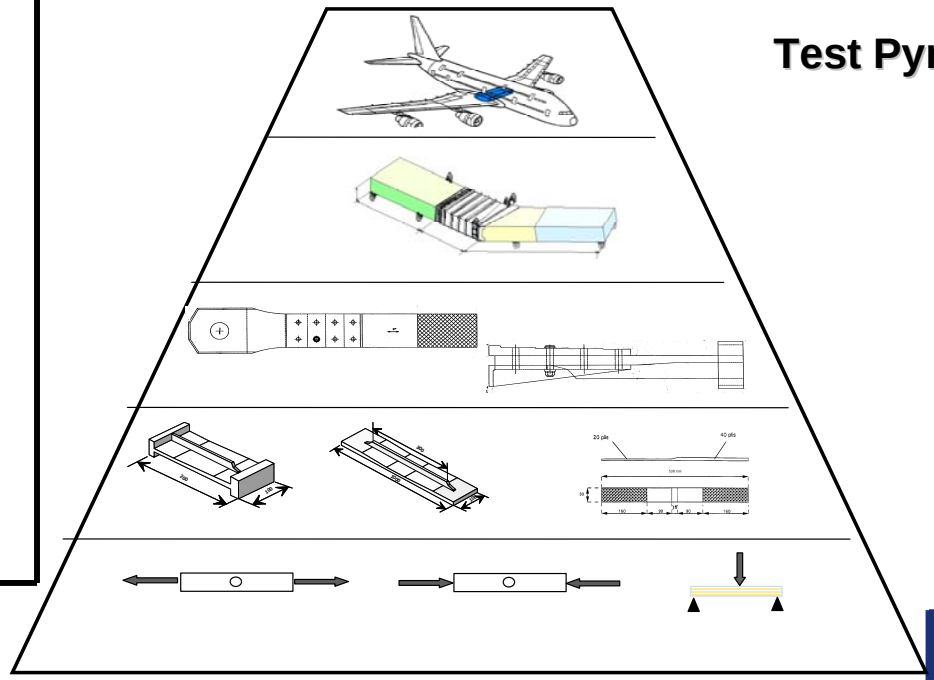
Be compliant to application – DAL (RTCA DO-180)

Requirement
Verify detection capability
Criteria
• Probability of detection: 90 / 95 • Influencing effects - Structural complexity - Dimensional boundaries - Sensor & structure repair - Relevant in-service loading - Crack closure - Sensor installation - Detection range • Relevant tests: 29 / 51

POD Curve



Test Pyramid



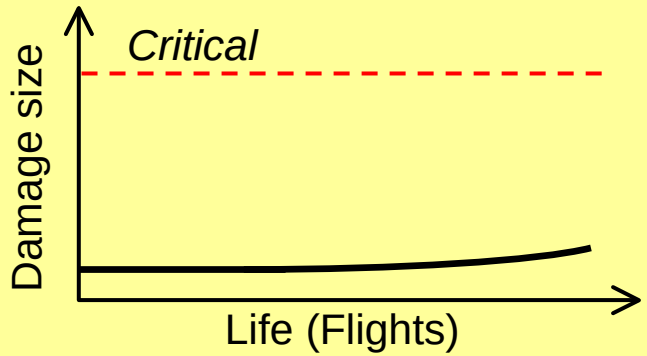
Challenges – Benefiting fully from SHM

- **Modify the existing EASA & FAA rules when using**

Current design principle of CFRP structures

(Aircraft without SHM system)

No damage growth design

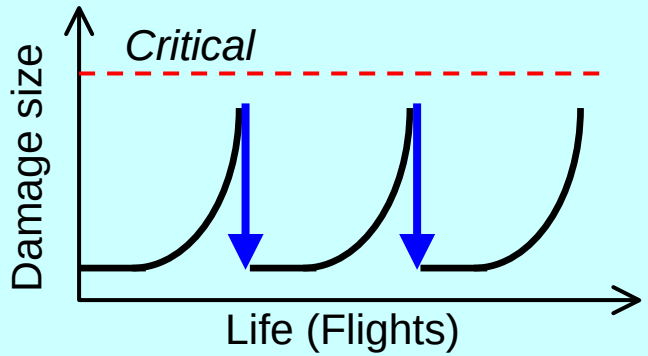


Even if barely visible damage exists in the structure, the damage never grows. Therefore, sufficient safety and reliable margin is secured.

Future design principle of CFRP structures

(Aircraft with SHM system)

Damage growth design



Growth of the existing damage can be monitored by SHM system prior to the critical size. Therefore, CFRPs can be applied with their optimum properties .

Conclusions

- Provided the motivations for SHM
- Described the most promising SHM technologies for aerospace
- Given examples of applications
- Given the ingredients for an attractive business case
- Provided the challenges from an industrial qualification point-of-view
- Emphasised the present and future challenges to benefit more from SHM