Demonstrating Detection Capability in the context of Airframe SHM – Damage Monitoring: the Airbus approach

A4A Forum

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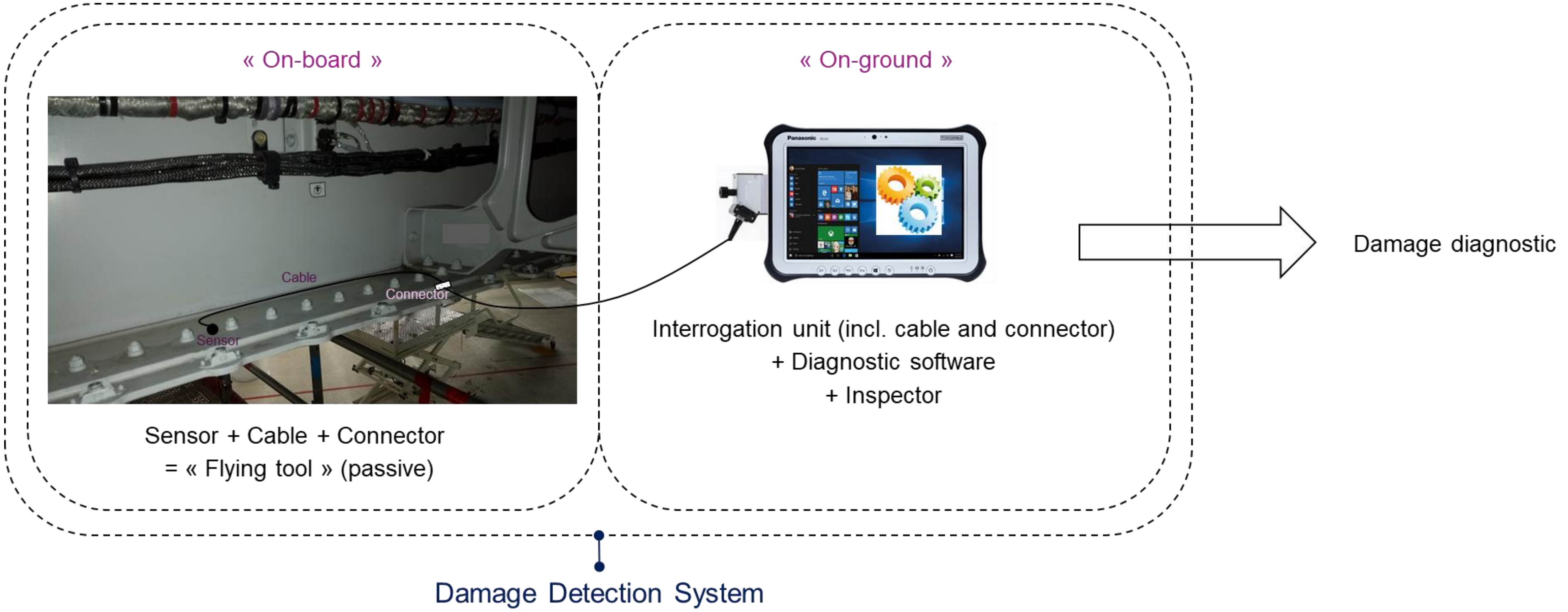
Context and Generalities

SHM Damage Detection System: a case study

This presentation describes an approach for detection capability demonstrations of « SHM Damage Detection Systems »

- which are interrogated from time to time (by opposition to system acquiring data at high frequency or continuously),
- Interrogation being done in principle on-ground.

→ SHM configurations with Ultrasonic or Eddy-currents sensors (« NDT-like »)



The damage detection system is composed of the full chain of inspection (sensor, acquisition and diagnostic)

Relationship between « Reliability » and « Probability of Detection »

The probability that the « Damage Detection System » (DDS) detects a damage (true detection) is

$$\Pr[\text{"System is operational"}\ AND\ \ \text{"System detects"}]$$

Following Bayes theorem (conditional probability) it writes

$$\Pr[\text{"System is operational"}\ AND\ \ \text{"System detects"}] = \Pr[\text{"System is operational"}] * \underbrace{\Pr[\text{"System detects"} \mid \ \text{"System is operational"}]}_{\text{Probability that the system detects , knowing it is operational}}$$

$$POD_{DDS} = \boxed{\cancel{\Pr[\text{"System is operational"}]}} * \boxed{\Pr[\text{"System detects"} \mid \ \text{"System is operational"}]}$$

« Pure reliability » term

« Detection capability » term = POD

In this presentation we focus on the **detection capability demonstration** term.

This term is usually called **« Probability Of Detection »**.

Detection Capability Assessment Plan

Detection Capability Assessment Plan

Designing Experiments: the assessment of detection capability shall cover for, or integrate, the <u>variability sources</u> through a proper Design of Experiments.

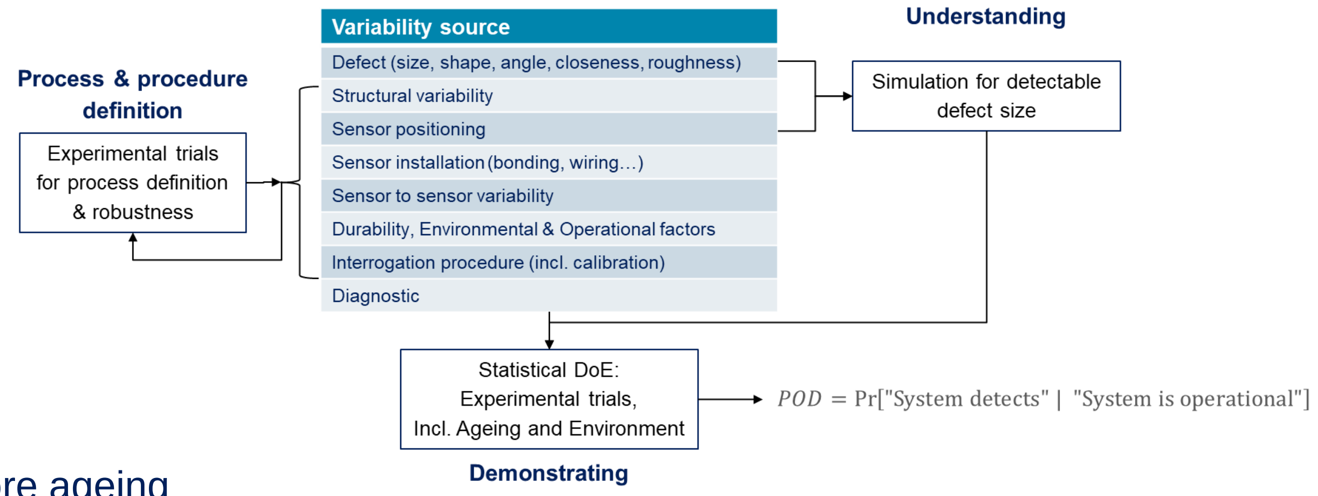
- Typical SHM variability sources

	Variability source	Linked to
On-board	Defect (size, shape, angle, closeness, roughness)	Aircraft design and manufacturing
	Structural variability (e.g. local thickness or delta to DMU)	Aircraft design and manufacturing
	Sensor positioning	Installation process
	Sensor installation (bonding, wiring…)	End to end installation process
	Sensor to sensor variability	Sensor manufacturing quality process
	Durability, Environmental & Operational factors	Environmental conditions
On-ground	Interrogation procedure (incl. calibration)	Interrogation procedure and procedure application
	Diagnostic	Interrogation procedure and procedure application

Notice:
« On-ground » parts and variability sources could move « on-board » for next SHM scenarios without affecting the genericity of the proposed approach

Detection Capability Assessment: as sequential approach

- **Phase 1: Preparation**
  Preliminary trials & simulations for
  - Process & procedure definition
  - Understanding the potential capability of detection and define target detectable size



- **Phase 2: Demonstration of detection capability**
  - Demonstrate POD for the target detectable size, before ageing
  - Demonstrate POD for the target detectable size, including ageing

- **Phase 3: Complementary understanding**
  Complementary trials to increase understanding and touching the lower detection limits

Detection Capability Assessment: Design of Experiments

Process & procedure definition

Experimental trials for process definition & robustness

Variability source
Defect (size, shape, angle, closeness, roughness)
Structural variability
Sensor positioning
Sensor installation (bonding, wiring…)
Sensor to sensor variability
Durability, Environmental & Operational factors
Interrogation procedure (incl. calibration)
Diagnostic

Understanding

Simulation for detectable defect size

Statistical DoE: Experimental trials, Incl. Ageing and Environment

$$POD = \Pr[\text{"System detects"} \mid \text{"System is operational"}]$$

Demonstrating

AIRBUS

Detection Capability Assessment
Phase 1 - Preparation

Process & procedure definition

Experimental trials for process definition & robustness

Variability source
Defect (size, shape, angle, closeness, roughness)
Structural variability
Sensor positioning
Sensor installation (bonding, wiring…)
Sensor to sensor variability
Durability, Environmental & Operational factors
Interrogation procedure (incl. calibration)
Diagnostic

Understanding

Simulation for detectable defect size

Process & procedure definition: experimental trials to define the inspection procedure, including calibration and detection criteria

Understanding: use simulation to define the « range of defect sizes »

Variables taken into account: defect size, shape, angles / Structural variability / Sensor positioning

⇨ Procedure and target Ldet

Detection Capability Assessment
Phase 2.1 – Demonstration before ageing

We want to estimate the quantity $POD = \Pr[\text{"System detects"} \mid \text{"System is operational"}]$, including the influent variability sources through a Design of Experiments (DoE).

POD can be demonstrated by a 29/29 POD approach

1. 29 sites with defects of the target size Ldet
2. 29 sensors
3. Sensor implementation with 3 different operators
4. Sensor interrogation with 3 NDT inspectors

Additional sensors and samples without defects shall be introduced in the experiments to control false calls rate.

	Variability source	Linked to
✓	Defect (size, shape, angle, closeness, roughness)	Aircraft design and manufacturing
✓	Structural variability (e.g. local thickness or delta to DMU)	Aircraft design and manufacturing
✓	Sensor positioning	Installation process
✓	Sensor installation (bonding, wiring…)	End to end installation process
✓	Sensor to sensor variability	Sensor manufacturing quality process
	Durability, Environmental & Operational factors	Environmental conditions
✓	Interrogation procedure (incl. calibration)	Interrogation procedure and procedure application
✓	Diagnostic	Interrogation procedure and procedure application

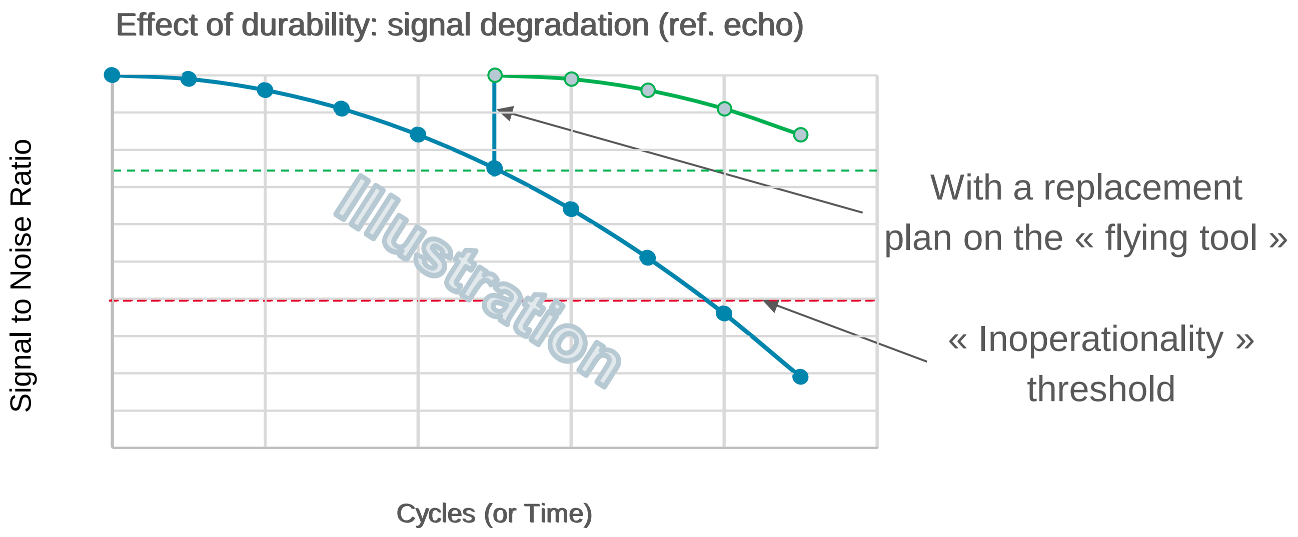
⇒ If 29/29 is successfully reached, then the SHM Damage Detection System demonstrates the capability to detect defects of $Ldet$ mm with at least a probability of 90% and 95% confidence.

⇒ If not the sample size has to be increased or the *Ldet* reconsidered

Detection Capability Assessment
Phase 2.2 – Demonstration including ageing

« Ageing and environmental impact » might affect the performance of the on-board part of the Damage Detection System
→ Signal degradation to be assessed from « durability » tests campaign

The 29 « successfull » samples shall go for additional tests **to assess detection capability evolution with respect to ageing and environmental impact**.
→ Interrogation of the 29 sensors to be done at several steps of the cycling to assess the effect on the sensors ability to detect



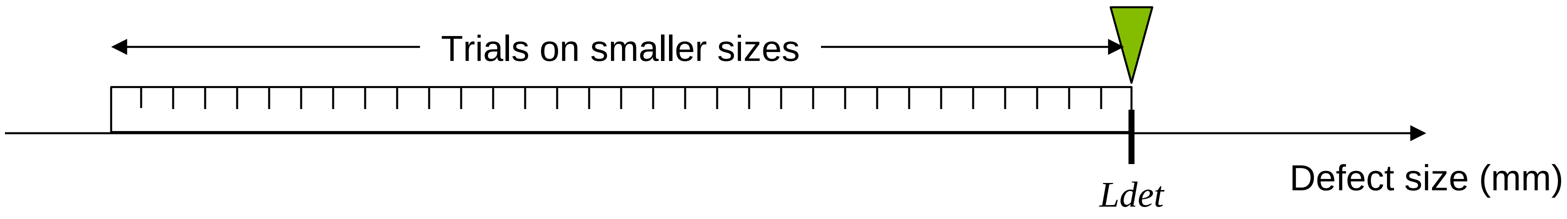
- A sensor replacement plan might be put in place to overcome the effect of ageing and environment, if necessary.

Detection Capability Assessment
Phase 3 – Complementary understanding

Ldet validation by 29/29 POD obviously introduces some conservatism in the evaluation of the detection capability.

In addition it is interesting to

Understand the lower detection limits of system



Conclusions

- Detection capability demonstration for SHM has to account for the specific fact that sensors are fixed and installed permanently on the aircraft

- An approach to demonstrate detection capability adapted to SHM Damage Detection Systems is proposed
  - Detection capability is determined by estimation of a Probability of Detection (POD) adapted to SHM, which is

$$POD = \Pr[\text{"System detects"} \mid \text{"System is operational"}]$$

  - The Design of Experiments enables to cover for specific SHM influent variability sources, including ageing and environment

- An alternative NDT procedure shall be proposed to cover for any Damage Detection System failure (triggered by self-diagnostic functional test)

- Concrete detection capability demonstration campaigns are being put in place for short terms scenarios, which will enable to improve the concepts and pave the way for the future