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

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

Following Bayes theorem (conditional probability) it writes

\[ \text{Pr["System is operational" AND "System detects"]} = \text{Pr["System is operational"]} \times \text{Pr["System detects" | "System is operational"]} \]

\[ POD_{DDS} = \text{Pr["System is operational"]} \times \text{Pr["System detects" | "System is operational"]} \]

« 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 variability sources through a proper Design of Experiments.

• Typical SHM variability sources

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

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

**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 for process definition & robustness

**Demonstrating**
- Statistical DoE: Experimental trials, Incl. Ageing and Environment

\[ POD = \Pr["System detects" \mid "System is operational"] \]
Detection Capability Assessment
Phase 1 - Preparation

**Process & procedure definition**
Experimental trials for process definition & robustness

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**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 $L_{det}$
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 influential 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 $L_{det}$
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 call rate.

⇒ If 29/29 is successfully reached, then the SHM Damage Detection System demonstrates the capability to detect defects of $L_{det}$ mm with at least a probability of 90% and 95% confidence.
⇒ If not the sample size has to be increased or the $L_{det}$ 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

\[
\begin{align*}
\text{Effect of durability: signal degradation (ref. echo)} \\
\text{Signal to Noise Ratio} \\
\text{Cycles (or Time)}
\end{align*}
\]

With a replacement plan on the « flying tool » « Inoperationality » threshold

• 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

$L_{\text{det}}$ 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

 Trials on smaller sizes  

$L_{\text{det}}$  

Defect size (mm)
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