COST TU1402: Quantifying the Value of Structural Health Monitoring

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Reliability Based Optimization of Inspection Planning for Composite Smart Components in Aircraft

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Framework

A reliability-oriented optimization of the maintenance scheme for aircraft composite panels is proposed. A structural health monitoring (SHM) system is built-in and its performances are given in terms of Probability of Detection (POD) and Probability of False Alarm (PFA). Hail impacts, which cause barely invisible damage on the composites panels, are modeled.
The discrimination between damaged and not damaged structural components based on SHM indicators is part of a decision process, in which the optimal discriminating threshold must be selected. The optimum is influenced by the cost and the risk associated to the decision whether the structure is damaged or not.
From a mathematical point of view, a constrained optimization problem, in which the constraints are reliability requirements, is formulated.
A damage tolerant approach with probability of failure of 10E-9 per flight hours (FH) is used.

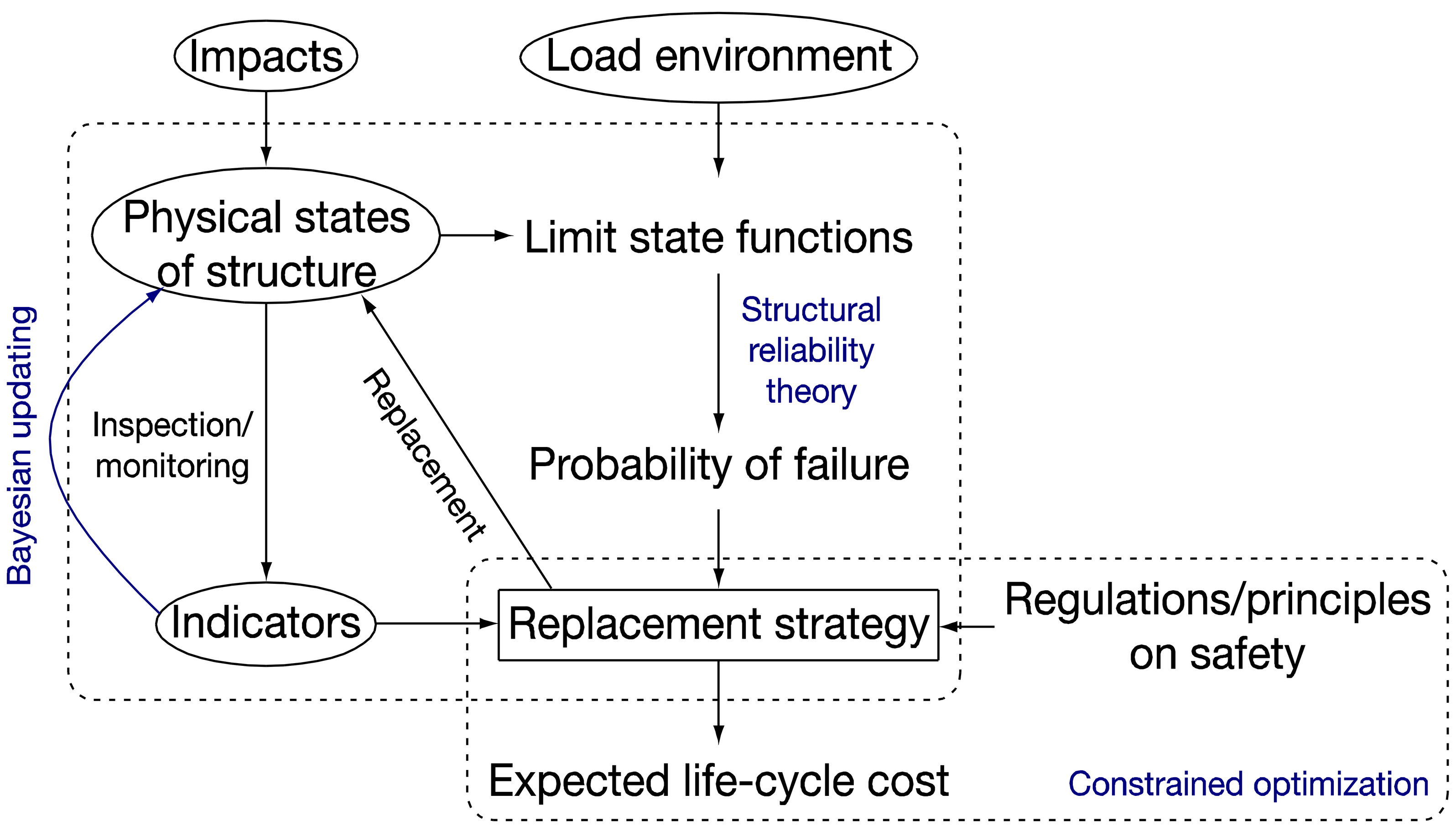

Fig 1. Framework for the optimization of the replacement strategy subjected to reliability constraints.

Statistical Performance of SHM

Uncertainty in SHM:

- random noise that affects the SHM signal;
- statistical uncertainty due to the limited set of trials in the experiments;
- model uncertainty coming from the empirical nature of the parametric model;
- model uncertainty coming from omitting all possible influencing factors other than defect dimension.

The statistical performances of the SHM can be evaluated by experiments and expressed in terms of POD and PFA.

$$\mathrm{PFA}(y_T) = \int_{y_T}^{\infty} f_{Y|\bar{D}}(y)dy$$

$$\mathrm{PoD}(y_T, a) = \int_{y_T}^{\infty} f_{Y|D}(y|a)dy$$

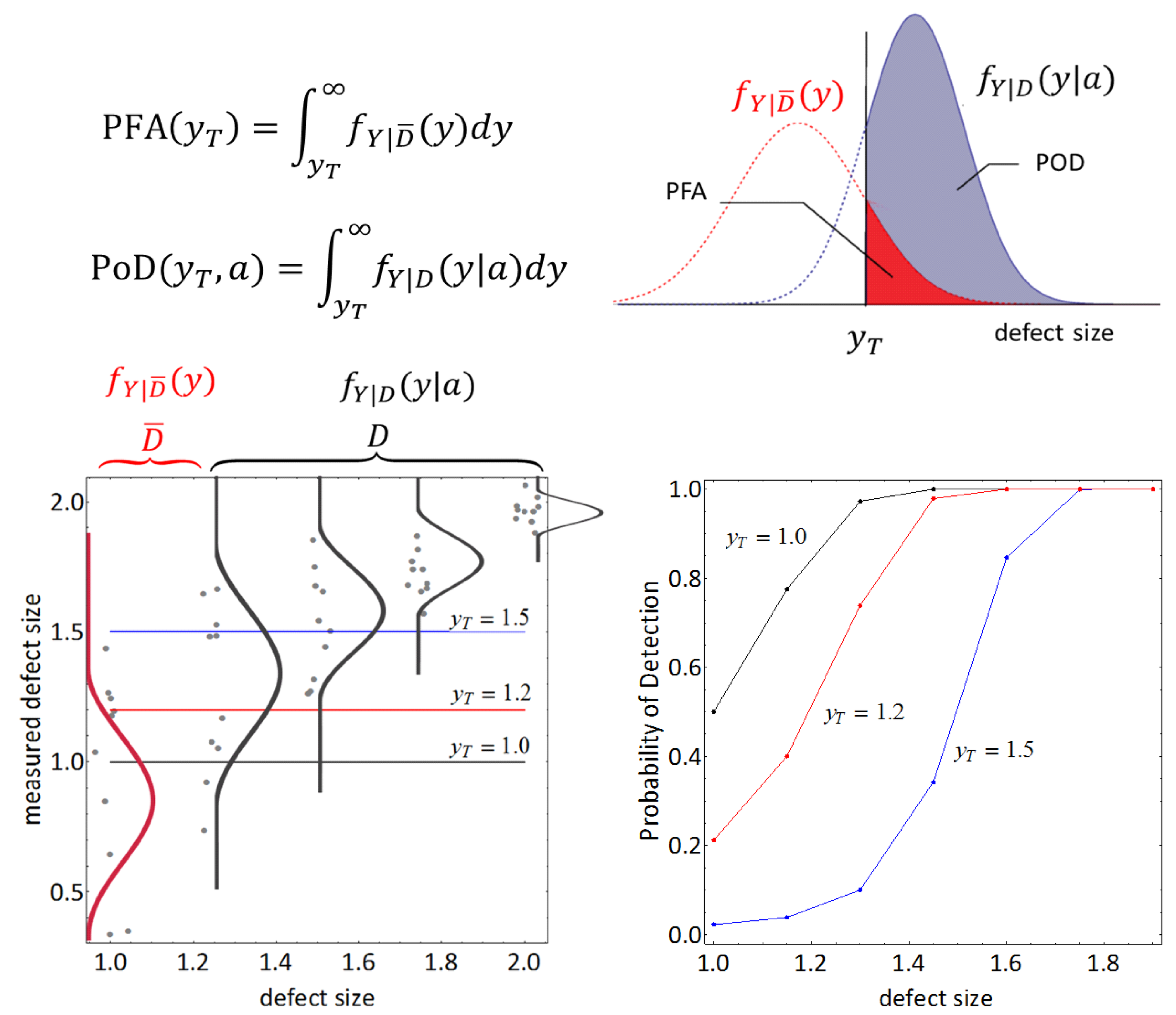

Fig 2. The detection discriminator (between the binary choices damage/no damage) is the parameter y_T.

Application

The method is applied to a composite stiffened panel of the inner wing upper skin of the airplane F/A-18A.[1]. The model includes:

- A Poisson model for the impact energy derived from statistical data.
- A meta-mechanical model for the evaluation of the post-impact strength (Stiffness reduction method).
- Inspection and SHM strategy.
- Different POD and PFA scenarios.
- Bayesian Updating via POD.

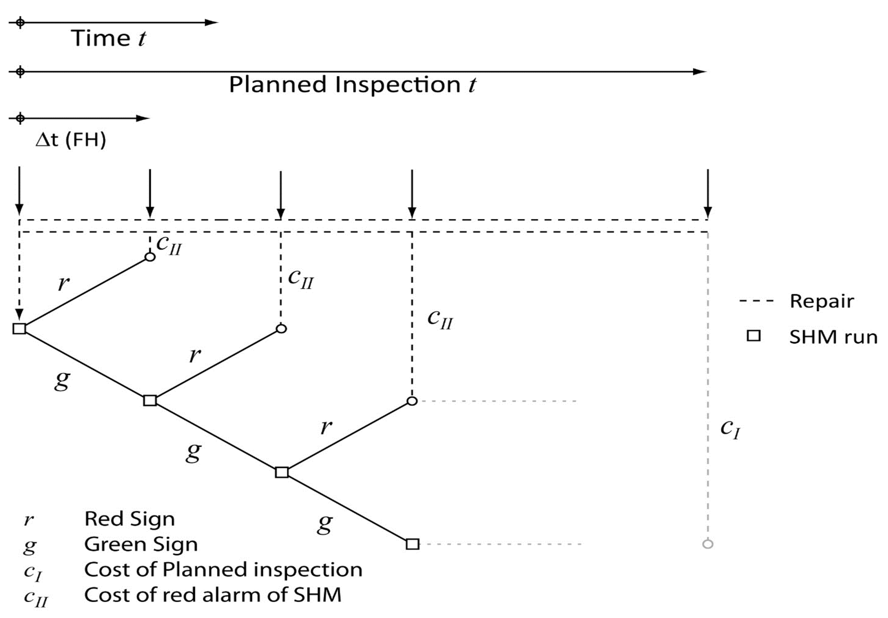

Fig. 4: Inspection and SHM strategy.

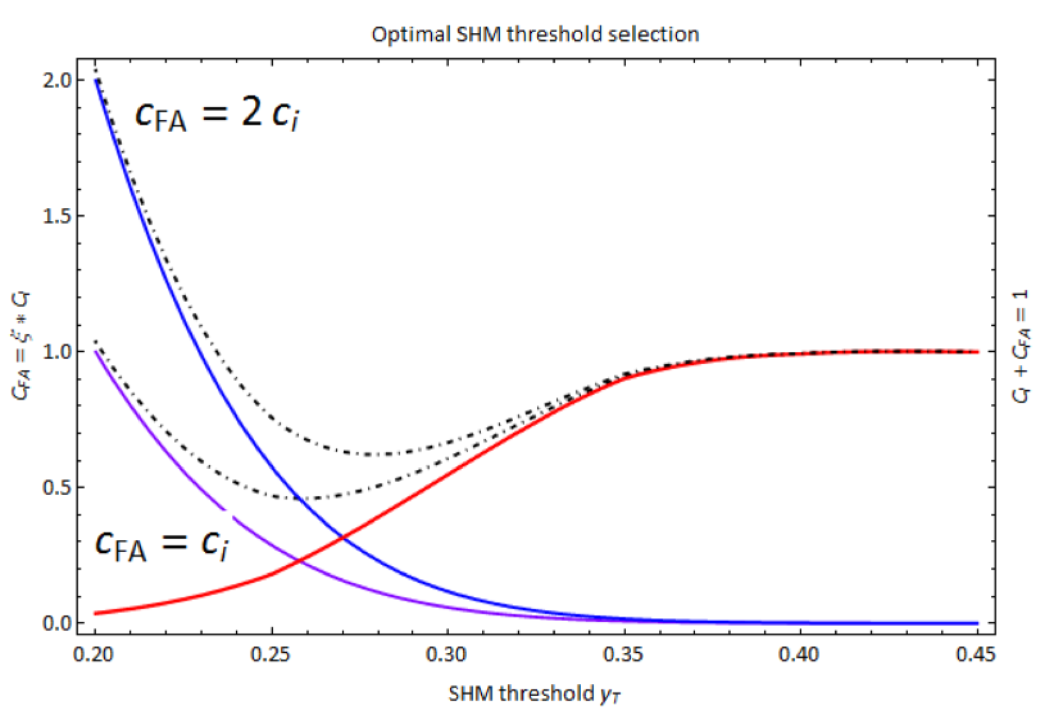

Fig. 6: Optimization of the SHM threshold, inspection costs (red line) and false alarm costs (blue lines).

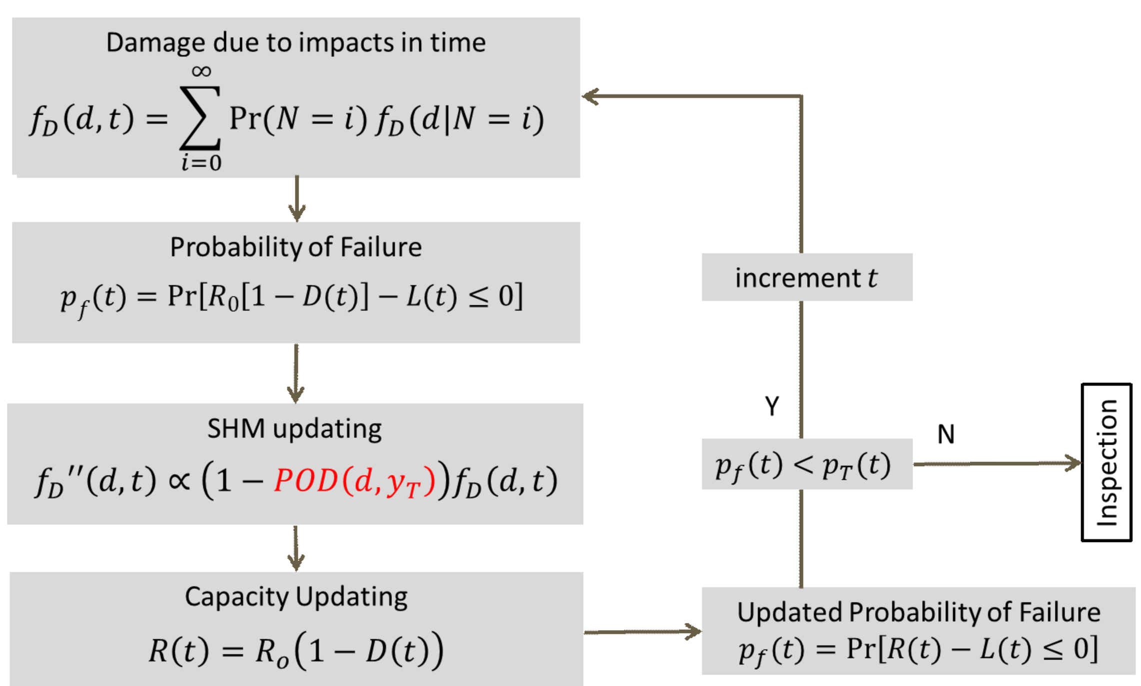

Fig 3. Flow chart for the evaluation of the inspection time for assigned y_T.

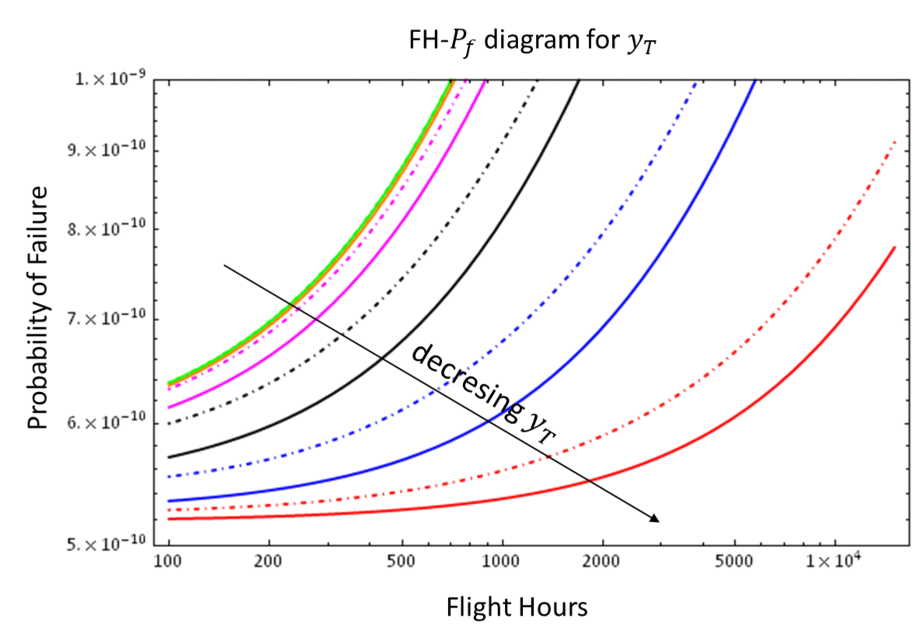

Fig. 5: Comparison btw inspection time for two different PODs (dashed line worse performances).

Acknowledgements

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References

[1] Kan H.P., Cordero R., Whitehead R.S. (1997) *Advanced Certification Methodology for Composite Structures.* Final Report Office of Aviation Research.

[2] Cottone G., Straub D., Gollwitzer S., Fisher J. (2013).*Reliability-Oriented Optimization of Replacement Strategies for Monitored Composite Panels for Aircraft Structures.* [ed.] Fu-Kuo Chang. Structural Health Monitoring 2013: A Roadmap to Intelligent Structures.