From Anomaly Detection to Intelligent Digital Twins: The Recent Evolution of PHM for Aircraft Engines

Jérôme Lacaille - SAFRAN AIRCRAFT ENGINES

Abstract:
Over the past decade, Prognostics and Health Management (PHM) for aircraft engines has undergone a profound transformation driven by the increasing availability of high-resolution operational data, advances in machine learning, and the industrial need for more robust fleet monitoring. Traditionally centred on threshold-based diagnostics and statistical trend analysis, PHM is now evolving toward integrated, data-centric frameworks capable of capturing the full complexity of engine behaviour across production, acceptance testing, and early operation.

This presentation highlights this evolution from a manufacturer's perspective. We first show how mastering industrial variability—through bias correction, causal analysis, and unified modelling of acceptance-test and early-flight data—has become a prerequisite for reliable PHM. This shift has enabled the construction of more accurate initial health states and has paved the way for a new generation of predictive tools that combine physics, data, and mission context.

Building on these foundations, we introduce the emergence of **digital twins** for aero-engines: high-fidelity, data-driven simulators capable of reproducing engine behaviour at flight frequency and adapting to each engine's wear state. Such twins not only support condition monitoring and anomaly detection but also enable virtual missions, comparative robustness analyses, and early identification of "sensitive" engines.

The talk concludes by presenting recent advances from Abdellah Madane's doctoral research, which developed a deep-learning-based digital twin architecture for aircraft engines. His work demonstrates how generative models and latent-state estimation can simulate realistic engine trajectories, capture progressive degradation, and ultimately enhance predictive maintenance capabilities. Together, these developments mark a decisive step toward intelligent, adaptive, and simulation-driven PHM for modern propulsion systems.