

# Engine Health Management in Safran Aircraft Engines

Guillaume Bastard<sup>1</sup>, Jérôme Lacaille<sup>2</sup>, Josselin Coupard<sup>3</sup> and Yacine Stouky<sup>4</sup>

<sup>1,2,3,4</sup> Safran Aircraft Engines, Réau, 77550 Moissy-Cramayel, France,

[guillaume.bastard@safrangroup.com](mailto:guillaume.bastard@safrangroup.com)

[jerome.lacaille@safrangroup.com](mailto:jerome.lacaille@safrangroup.com)

[josselin.coupard@safrangroup.com](mailto:josselin.coupard@safrangroup.com)

[yacine.stouky@safrangroup.com](mailto:yacine.stouky@safrangroup.com)

## ABSTRACT

Engine Health Management (EHM) is the up to date solution that is used by Aircraft Engine Manufacturers in order to maintain an engine operative through a reduction of operational events that impact its availability for end customers. The aim of EHM systems is to monitor and forecast the health status of an engine based on operational data in order to reduce the interruption of the clients operations and contribute to provide the best affordable maintenance of an engine. This paper describes the architecture of an EHM system designed to monitor Safran Aircraft Engines products.

## 1. INTRODUCTION

The most advanced engine health monitoring functions from Safran Aircraft Engines are integrated into this EHM system. It is designed to provide for the client services, maintenance cost reduction, avoidance of operations interruption and premature engine damage, and assist the aircrafts operator in continued airworthiness. Safran Aircraft Engines also benefits, by better services contracts drive and optimization, engine data and usage collect, and better proximity and individualized service providing to the clients.

The monitoring functions cover the monitoring of engine operational performances, the essential engine sub-systems (for example fuel system, or control system), the engine trim follow-up, and engine transmission system malfunctions.

The Safran Aircraft Engines EHM functions are split into an airborne component and a ground component hosted in the Support & Services management system. They comply with the OSA-CBM architecture: Data Acquisition (DA), Data Management (DM), State Detection (SD), Health Assessment (HA), Prognostics Assessment (PA), and Advisory Generation (AG). The communication between the

Guillaume Bastard et al. This is an open-access article distributed under the terms of the Creative Commons Attribution 3.0 United States License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

airborne and the ground components are done through the use of the aircraft's system. All the data are sent as soon as they are processed in the airborne system and generally before the end of the aircraft mission by wireless communication means (SATCOM, ACARS, 3G, Wi-Fi...). The ground system decodes and stores all these data in a dedicated database and then the EHM functions compute the trend indicators. These indicators are analyzed by the Customer Support Center team, translated into Customers Notification Reports (CNR) and made visible to the client through a web portal service.

At Safran Aircraft Engines, the EHM is designed to be adaptive and scalable in order to have a premium service on jet engine maintenance to ensure a long lasting lifetime of their engines.

## 2. EHM VISION OF SAFRAN AIRCRAFT ENGINES

For over 30 years, Safran Aircraft Engines is performing engine trend monitoring to provide clients with the best engines quality service.

This is not the first time that Safran Aircraft Engine built an EHM System.

For Safran Aircraft Engines, EHM is a remote monitoring service to forecast the engine condition. EHM contributes to customer loyalty in a competitive and changing environment.

Safran Aircraft Engines ambition is to provide value to engine data to ensure our customers the highest levels of services continuity. EHM can optimize the maintenance to obtain a profitable increase of availability and lowering of cost.

It's also a tool to better manage flying hour contracts, and obtain maintenance plans tailored to each customer.

EHM can be considered as the starting block to make an Integrated Engine Health Monitoring and Management (IEHM) system. By putting it in relationship with other systems, new services will appear for the different stakeholders:

- By linking with Computerized Maintenance Management System, “Just in Time” schedule can be provided, as well as supplying “Just as Necessary” spare parts.
- By linking with design office tools, automated RetEx is provided in terms of Mean Time Between Repairs (MTBR), and experience-based FMEA (Failure Mode and Effects Analysis) to improve future design.
- By linking with Enterprise Resource Planning (ERP), better management of assets is offered and next spending may be anticipated.
- By linking with Integrated Vehicle Health Management (IVHM) System, global health status of the vehicle (airplane) is available.
- Other integration can be done, with operations, insurance etc. to provide other valuable services.

### 3. CHARACTERISTICS OF AN EHM SYSTEM

In order to develop these services Safran Aircraft Engines needs to enhance its Engine Health Management ecosystem. Today this ecosystem consists of airborne and ground systems that collect data and process them for other systems. The complete workflow is described in Figure 1.

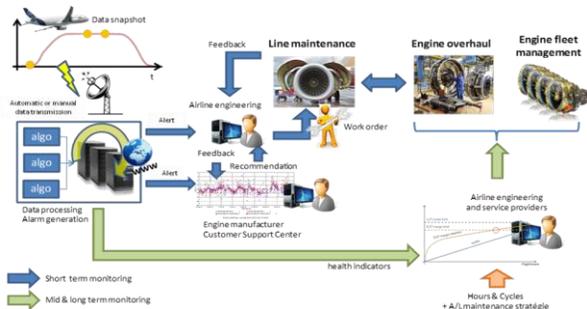


Figure 1. EHM System for Safran Aircraft Engines.

#### 3.1. On Board: Integration from the Start of the Development Cycle

Reducing the development time is critical for a new technology business, and the question “Why is it necessary for the Embedded PHM system to be integrated at the start of the engine development cycle?” needs to be considered.

The embedded EHM system is not only designed for the operational phase of the engine; it also provides quantifiable value during the engine development phase, both for engine designers, but also for EHM designers.

For engine designers, EHM can provide a set of methods for automatic detection of anomalies in all the test data as well as helping to improve conception by avoiding malfunction or premature degradation of the engine.

EHM designers may capitalize on the early stages of engine design, to ensure its efficiency for detection of engine conditions. They can also use test data for mitigation in the future, when real data from customer will be available.

EHM also helps to meet the specifications of airplane designer, related to the testability (detection, localization etc.) and more generally related to maintainability.

#### 3.2. The Challenge of the Automatic and Adaptable Data Transmission and connection.

Over the last few years, big data initiatives have shown that the sources of data are multiple. As such they have to be integrated from different heterogeneous sources. To do so, one needs is to decode data from most common interfaces (ACARS, ADS-B/C ...) but also be adaptable to other formats that are used for data transmission or compression through wireless means.

If data needs to be transmitted manually, for example, high volume of data in case of troubleshooting, an interface for customer should be provided to facilitate the transfer via a web portal. If customers need to integrate their own input and models, a data link should be provided. Open environment is a key to successful collaboration.

Safran and CFM engines are also integrated with various aircraft manufacturers, for different programs, thus EHM system need to be adapted and be suitable both for onboard communications systems, but also for ground transmission from airplane/airline facilities.

#### 3.3. On Ground Function: A new EHM Standard for an Optimal Workflow

Once data has been transferred on ground, it must be processed to extract information about engine status, health estimation, prognosis of next maintenance operation, etc. This dataflow should meet standards like OSA-CBM and ISO 13374. See for example the SAE presentation (Bense, 2013).

Using these standards, generic algorithm’s blocks have to be built to ensure easier and optimized cost for designing monitoring functions. The cost for maintaining such system in operation is greatly reduced. Among such generic blocs are algorithms for data normalization (Lacaille, 2009b), fault identification (Lacaille, 2010a), time signal analysis for control (Lacaille & Nya Djiki, 2010) and monitoring (Lacaille, 2012).

After automatic execution of monitoring functions, generated alerts need to be confirmed by engine manufacturer Customer Support Center. This step is necessary to ensure that only true positive alerts were transmitted to the airline, and correct maintenance recommendation can be done, after investigation if needed. EHM system needs to provide interface for making recommendation, accessible by the airline engineering, in order to track engine states over time

and ensure that the effective maintenance operations are known. Every piece of information, recommendation and operation is further capitalized in a knowledge base for future investigations.

#### 4. THE CHALLENGE OF A NEW EHM SYSTEM

To meet these requirements, Safran Aircraft Engines has developed the Silvercrest EHM System. Thereafter, the components of this system will be introduced.

##### 4.1. Embedded System

The embedded part of EHM system acquires data all along the mission. As each function is unique in terms of observed signature, they are triggered independently. However they respect the same architecture flow: first, acquisition of the relevant data snapshot from the raw data of the engine or the aircraft; then, processing of the data in order to consolidate and compress them.

Those embedded computation results are sent into flight reports to the ground part with the aircraft's systems data. All the high frequency unprocessed data are also stored and are accessible for troubleshooting.

##### 4.2. Ground System

The ground system decodes the flight reports, parses and stores all data.

Aircraft and engines transferred data constitutes the basis input for ground-based EHM functions, but it also can be merged with data coming from other Support & Services departments. EHM ground part computes the health parameters of the engine, it allows the user to visualize the results, raise alerts in case of drift or unusual trends, and helps in generating a Customer Notification Report (CNR). It allows our customers to access their engine data through a secured web portal with high availability rate (expected around 99%).

The objective is to process and deliver engine data to the customer within five minutes after reception of the flight reports.

This system will also be interfaced with Safran Research & Technology departments. Its design is adaptable and may evolve, in order to continuously improve the implemented EHM functions and integrate future needs.

##### 4.3. Structure of Health Functions

PHM functions are structured according to OSA-CBM standard. An example of application of algorithm based on OSA-CBM architecture is given hereafter:

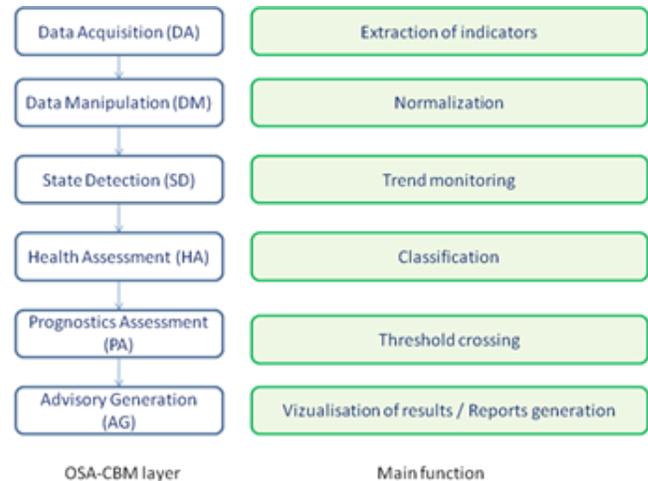


Figure 2. OSA-CBM architecture and example of application.

In DA layer, data are selected, depending on specific context criteria. One can distinguish endogenous data: used to analyze the studied system, and exogenous data: describing the acquisition context.

In DM layer, data are manipulated in order to represent the operation of the studied system. For example, a first process to suppress irrelevant data (missing, or out of range for example) can be done before any manipulation. A usual step is the normalization, where the context is removed from the endogenous data (Lacaille, 2009b). The aim is to make observations comparable regardless of their acquisition context (altitude, temperature, pressure, etc.).

In SD layer, the system is modeled in order to detect normal or abnormal behavior. For example, results from DM layer observed within a defined time window allows trend computation (using slope computation with least square approximation for example). A state can be defined by comparison with a normal baseline (with the z-score or Mahalanobis method for instance), then raising alerts if a defined threshold has been crossed (Bellas et al. 2014). The output of SD layer are such alert messages. Each SD layer can generate several messages. EHM functions target is to generate less than 5% of messages not related to a real event.

In HA layer, the aim is to establish a diagnostic of anomalies. This diagnostic may be achieved for example, by recognition of a failure signature (using supervised classification algorithms). This assumes that the defects are known and characterized (Lacaille, 2009b; Lacaille & Côme, 2011). The expected output is the identification and isolation of the failure. EHM functions are designed to detect at least 80% of the events to be detected.

In PA layer, a Remaining Useful Life (RUL) prognostic is established, it uses trends to anticipate anomalies (Lacaille et al. 2013). Several methods exist, such as extrapolations and case base similarities. In the end, the result allows answering

to the question “How long can my customer still operate his engine before a maintenance action is required?”

In AG layer, Custom dashboard / Visualization / Report generation, Decision models and algorithms should be done to help the CSC operator in his decision making process (Rabenoro et al. 2014b).

#### 4.4. Health Functions on Silvercrest Engine

In this section, existing health functions of engine health management system for the Silvercrest engine are described.

The Silvercrest is a new engine developed by Safran for small bizjet aircrafts.

A more detailed description of functions can be found in the following reference papers, respectively (Flandrois et al. 2009) for Start Sequence Monitoring, (Lacaille & Djiki, 2009) for Actuation Control Loop Monitoring, (Lacaille, 2009a) for Sensors Drift Monitoring, (Griffaton et al. 2014) for Bearing Vibration Monitoring, (Lacaille, 2010b) and (Lacaille et al. 2014) for Generic Health Monitoring Concepts. This paper highlights a novel monitoring function, Thrust Reverser Monitoring.

##### 4.4.1. Start Sequence Monitoring

This function monitors the start sequence and particularly the systems used during this sequence to guarantee the capacity to start, and identify the premises of potential anomaly. Its principle is to detect relevant points during the sequence (initiation, injection, ignition, idle... see Figure 3) then building indicators (mainly time delays) related to each subsystem failure mode identified in the FMECA. More details is given in (Flandrois et al. 2009).

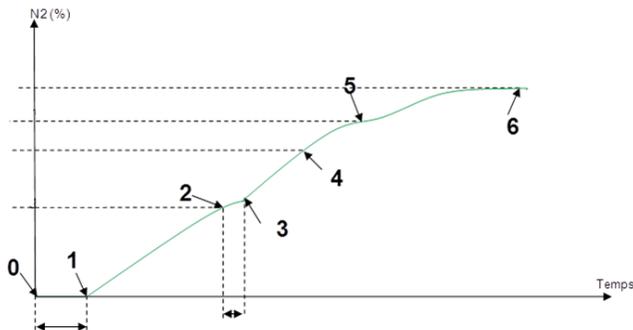


Figure 3. Schema of starting sequence. The numbers identify some relevant points used to the computation of state indicators.

##### 4.4.2. Oil Consumption Monitoring

This function monitors the engine oil consumption to assess the oil system health after each flight (Massé et al. 2013). Its principle is to measure a corrected engine oil level (independent of effects such as the engine cores speed,

pressure, temperature, altitude, yaw, pitch, roll, aircraft speed), compute an average consumption over successive flight while detecting if any refilling occurred, and prognostic the remaining time before a required maintenance. In figure 4, Oil level are described on the upper part of the figure, and average oil consumption on the lower part of the figure.

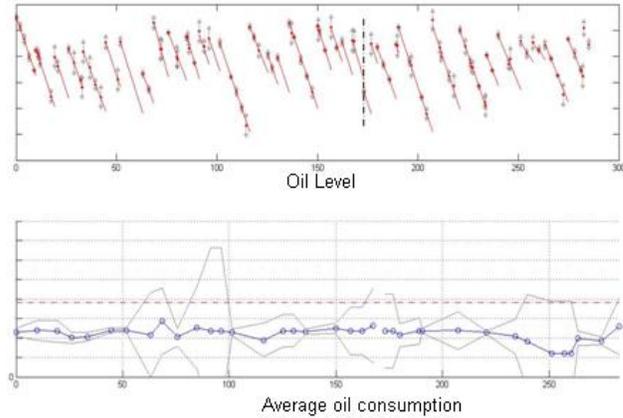


Figure 4. Normalized measured oil level (top) and computed average consumption (bottom).

##### 4.4.3. Oil & Fuel Filters Monitoring

This function monitors the fuel, and the oil filter clogging at a larger horizon than the impending by-pass cockpit warning. Its principle is to characterize the clogging through the filter differential pressure (DP), in order to assess the filter health, and remaining time on wing. This method gives a better reliability than the mechanical switch which deliver an electrical information once the pressure drop threshold has been reached. However, it has to take into account the context given by the parameters such as the fluid flow, the fluid temperature, the filter age, or the flight conditions. Figure 5 shows evolution of Differential Pressure (DP), Engine Oil Pressure (EOP) and Engine Oil Temperature (EOT).

##### 4.4.4. Actuation Control Loop Monitoring

This function monitors the VSV, VBV and FMV (valves) actuation loops. Its principle is to characterize the acquisition and command chain in stabilized phases, and the dynamic of the servo valve during transient phases. These indicators are used to detect degradation in the actuation loop or the electric chain of command, and to perform a prognosis about the evolution of the monitored characteristics (Lacaille & Djiki 2009).

##### 4.4.5. Actuators' Use Monitoring

This function monitors the on-off pneumatic valves (HBV, OSDS, HPTACC and HPV). Its principle is to follow the actuations of these valves in order to anticipate the remaining number of flights before crossing a limit threshold.

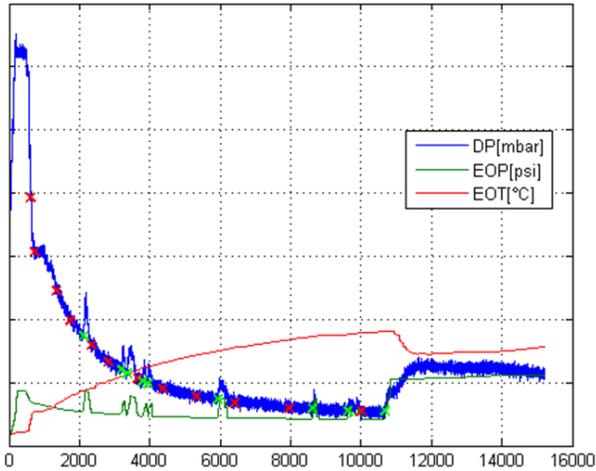


Figure 5. Evolution of differential pressure, engine oil pressure and temperature.

**4.4.6. Sensors Redundant Measures Monitoring**

This function monitors the acquisition chain of redundant measures. Its principle is to compare the A and B redundant channels of each measure in order to find premises of a future FADEC fault and localize the fault in the global measuring chain. In figure 6, example of differences is observed on two redundant measurements of a sensor signals.

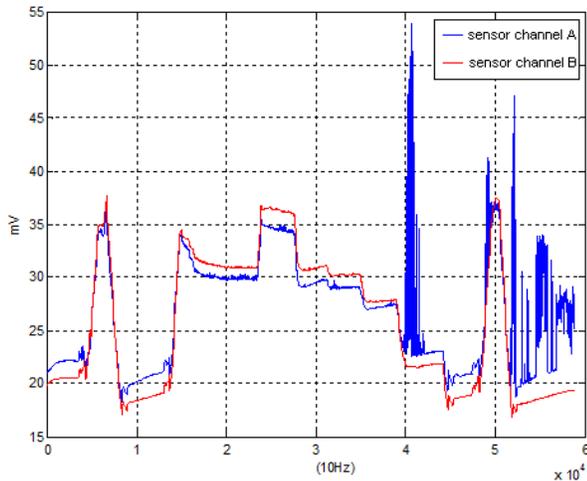


Figure 6. Observation of differences between two redundant sensors signals.

**4.4.7. Sensors Drift Monitoring**

This function monitors the slow drift of the engine temperature sensors. Its principle is to compare the local channels when core speed and thermal stability is reached, to find or confirm intermittent faults and prognostic remaining time before a FADEC alert due to these sensors (Lacaille, 2009a). Figure 7 shows channel A and B of a sensor signals and fault detected from sensors drift.

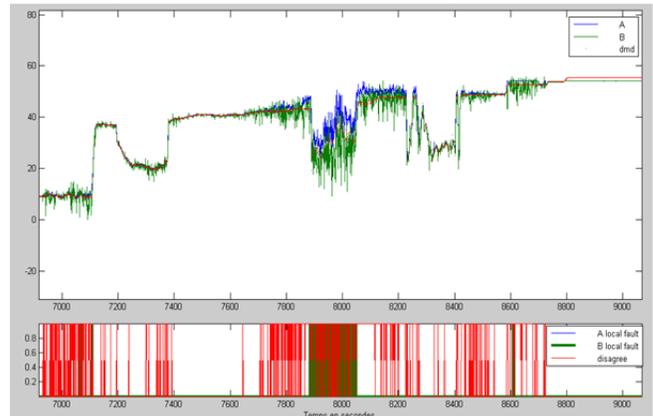


Figure 7. Example of sensors drifts, the two channels on top and the FADEC channel disagree message in red (bottom).

**4.4.8. Bearings Vibration Monitoring**

This function monitors bearings health. Its principle is to follow the trends of characteristic indicators, coming from the spectra of accelerometers located at the front and rear of the engine. The function suppresses the signal noise by applying a specific filter and identify the engine bearing signature made of peaks and local modulations. The signatures are classified according to each flight context and the results are compared to a baseline model (Griffaton et al. 2014; Klein et al. 2011b). Figure 8 shows an example of vibration spectrum, for a snapshot of 10 seconds.

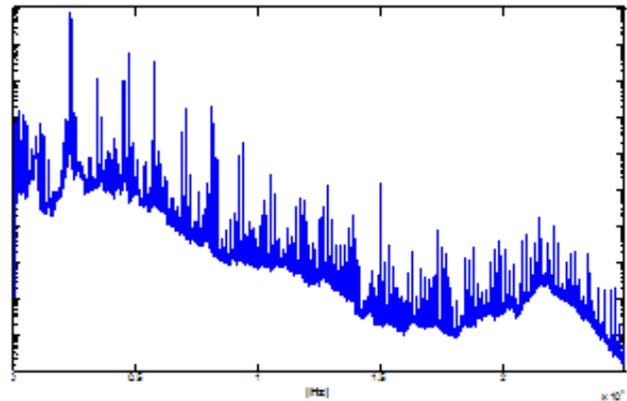


Figure 8. Example of raw vibration spectrum.

**4.4.9. Automatic Low Pressure Rotor Balancing**

This function computes the optimal correction of balancing configuration of the Low Pressure (LP) rotor. It is used during maintenance operations, the user specifies the available configuration and the algorithm provides the optimized solution based on the vibration levels monitored during the flights.

**4.4.10. Modular Unbalance Analysis**

This function monitors the modular engine unbalance. Its principle is to follow the engine vibration levels measured on the LP and HP rotor (Klein et al. 2011a).

**4.4.11. Global Performances Monitoring**

One measures EGT (Exhaust Gas Temperature) and N2 (High Pressure core speed) to compute a normalized residual temperature margin before maintenance. The algorithm follows the trends of this margin in order to prognostic the remaining number of cycles before crossing a limit threshold. Figure 9 explains how the EGT margin are calculated.

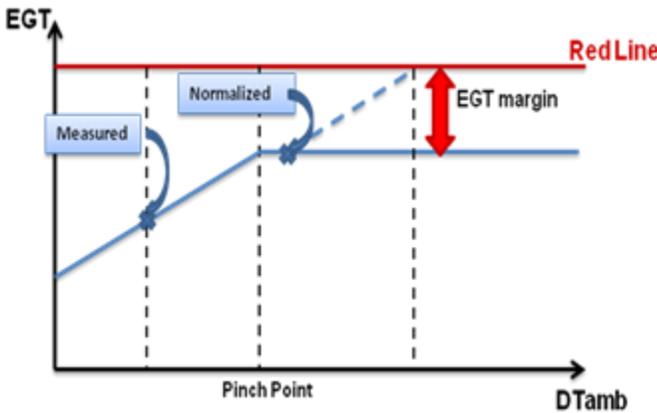


Figure 9. EGT margin is the residual temperature margin when the engine is operated on ISO conditions at sea level and 15°C. A thermodynamic model compute the ISO normalized temperature according to each flight real context. The EGT Margin Red Line is defined at conception.

**4.4.12. Modular Performances Monitoring**

The thermodynamic compartment of each main module of the engine (fan, booster, HP compressor, HP turbine and LP turbine) is followed to detect and localize anomalies. This algorithm uses an embedded physical model of the engine and compares the current behavior to the baseline defined by the model to estimate the efficiency of each of the five main modules.

**4.4.13. Nacelle Anti Ice Valve Monitoring**

Nacelle Anti Ice (NAI) valve is monitored by comparing NAI pressure to air pressure supply (Figure 10). Depending on the context of use and the duration of opening and closing phases it becomes possible to detect anomalies. Its principle is quite similar to the THR monitoring function, it learns a normal model, and detects anomalies by comparison with this model (Lacaille, 2010b; Lacaille et al. 2014).

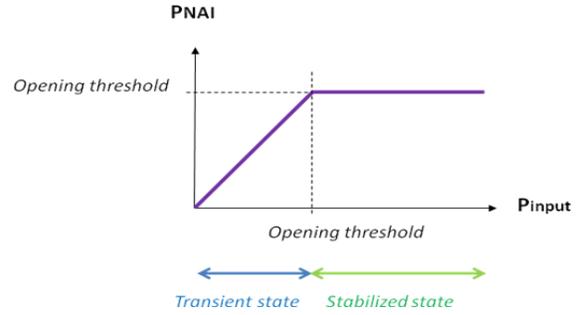


Figure 10. Pressure supply in NAI valve.

**4.4.14. Thrust Reverser Monitoring**

The Thrust Reverser (THR) is an engine-nacelle-integrated system which purpose is to slow down the aircraft during landing. It is manually commanded by the pilot during landing. It has several actuators to provide multiple lines of security in order to avoid any untimely opening.

The THR monitoring function allows for monitoring of anomalies from the Thrust Reverser actuators by evaluating commutation time for each of these actuators and normalize with contextual data.

This function comprises an embedded part and a ground part detailed hereafter.

During each opening and closing of THR, a snapshot of relevant data is taken. The recorded data (mainly hysteresis of switch and actuator, and contextual data for THR) is stored in embedded memory for troubleshooting.

Then, the embedded part of the THR monitoring function computes embedded indicators like commutation time for each actuator, switch, and contextual data average (like Ambient temperature average) In Figure 11, an example for two switches (LowIn and LowOut) and one contextual data (Tamb) during THR opening is introduced. Commands for each switch are shown in green, and real state in red. The same is done for other switches, actuators, or security lines from the THR system.

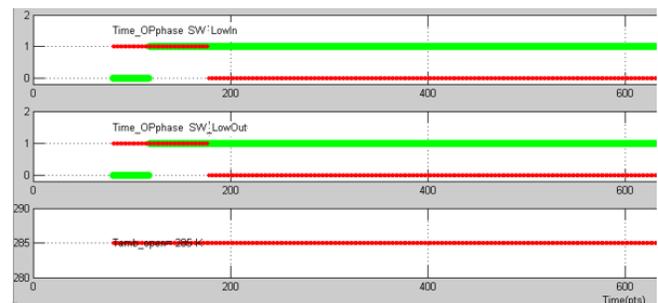


Figure 11. Commutation calculation for THR switch.

These data are transmitted to a ground station via 6 embedded reports: THO1, THO2, THO3 for openings data (it is considered that the THR may be opened and closed no more than three times in a mission - considering preflight testing - in a usual mission, THR is used one time or none) and THC1, THC2, THC3 for closing data.

The THR ground function is housed in a Ground System, which triggers ground functions according to triggering conditions specific for each function. Input data for THR ground function come from both embedded reports and the Ground System itself (other contextual data, ESN, CSN, TSN...).

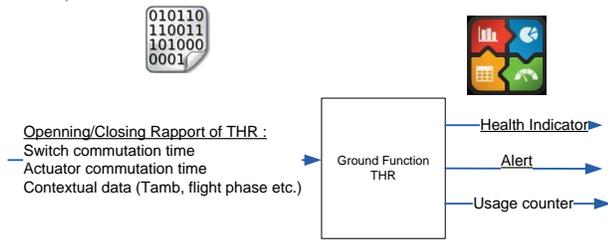


Figure 12. THR ground function.

Ground THR function uses a generic anomaly detection function. For each of THR operating mode (Opening and Closing), commutation time is normalized with contextual data and a slope detection process is done on this normalized commutation time. In Figure 12, a block diagram of THR Ground function is presented, and in figure 13, OSA-CBM-based structure of THR monitoring can be seen.

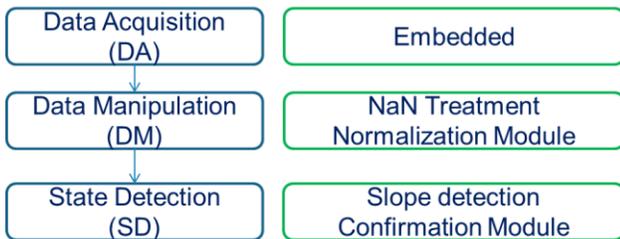


Figure 13. OSA-CBM-based structure of THR monitoring function.

Computed data are stored in a database and alerts generated by the THR ground function are analyzed by a PHM operator. In future, root cause analysis will be available with alert/symptom to determine which Thrust reverser subsystem needs to be replaced in case of degradation, and provide troubleshooting capacity for Thrust Reverser subsystem. This troubleshooting capacity will be improved by use of existing fusion method like fuzzy logic, bayesian network or random forest. Mainly, bayesian networks are used for their interpretability and the help they can give for troubleshooting operations. Better results are given using random forest which ensure robustness of the decision but are less

interpretable. Existing Safran Aircraft Engines work on fusion and decision can be found in (Rabenoro et al. 2014a).

**5. CONCLUSION & FUTURE PERSPECTIVES**

We present in this paper the EHM system developed at Safran Aircraft Engines for the Silvercrest Engine. New platforms at Safran also emerge for the LEAP engines (mounted on B737MAX and A320neo aircrafts) and for other Safran Aircraft Engines. Safran is currently implementing a common environment to ensure consistency between the various engine programs and allow for common algorithmic tools.

**NOMENCLATURE**

<b>ACARS</b>	Aircraft Communication Addressing and Reporting System
<b>AG</b>	Advisory Generation
<b>CNR</b>	Customer Notification Report
<b>CSN</b>	Cycles Since New
<b>D&amp;C</b>	Delays and Cancellations
<b>DA</b>	Data Acquisition
<b>DM</b>	Data Management
<b>EGT</b>	Exhaust Gas Temperature
<b>EHM</b>	Engine Health Management
<b>ESN</b>	Engine Serial Number
<b>FADEC</b>	Full Authority Digital Engine Control
<b>FMV</b>	Fuel Metering Valve
<b>FP</b>	Flight Phase
<b>HA</b>	Health Assessment
<b>HBV</b>	Handling Bleed Valve
<b>HP</b>	High Pressure
<b>HPTACC</b>	High Pressure Turbine Active Clearance Control
<b>HPV</b>	High Pressure Valve
<b>IFSD</b>	In Flight Shut Down
<b>LP</b>	Low Pressure
<b>N2</b>	High pressure core speed
<b>NAI</b>	Nacelle Anti Ice
<b>OSA-CBM</b>	Open Systems Architecture for Condition-Based Maintenance
<b>OSDS</b>	Oil Sump Depressurization System
<b>PA</b>	Prognostic Assessment
<b>SATCOM</b>	Satellite Communication
<b>SD</b>	State Detection
<b>THR</b>	THRust Reverser
<b>TSN</b>	Time Since New
<b>RUL</b>	Remaining Useful Life
<b>VBV</b>	Variable Bleed Valve
<b>VSV</b>	Variable Stator Valve

## REFERENCES

- Bellas, A. et al., (2014). Anomaly detection based on confidence intervals using SOM with an application to Health Monitoring. In *WSOM*. Saxony (Germany).
- Bense, W., (2013). Prognosis and Health Monitoring Systems for Aircraft Engines. In *SAE*. Montréal (Canada), pp. 1–9.
- Flandrois, X. et al., (2009). Expertise Transfer and Automatic Failure Classification for the Engine Start Capability System. In *AIAA InfoTech*. Seattle (USA, Washington).
- Griffaton, J., Picheral, J. & Tenenhaus, A., (2014). Enhanced Visual Analysis of Aircraft Engines Based on Spectrograms. In *ISMA*. Leuven (Belgium).
- Klein, R., Rudyk, E. & Masad, E., (2011a). Decision and Fusion for Diagnostics of Mechanical Components. In *PHM*. Montreal (Canada): PHMSociety, pp. 1–9.
- Klein, R., Rudyk, E. & Masad, E., (2011b). Methods for Diagnostics of Bearings in Non-Stationary Environment. In *CM & MFPT*. Cardiff (UK, Wales): BINDT, pp. 2–7.
- Lacaille, J., (2009a). An Automatic Sensor Fault Detection and Correction Algorithm. In American Institute of Aeronautics and Astronautics (AIAA), ed. *Aviation Technology, Integration, and Operations Conference (ATIO)*. Hilton Head (USA, South Carolina).
- Lacaille, J., (2010a). Identification of Defects in an Aircraft Engine.
- Lacaille, J., (2012). Monitoring of an Aircraft Engine for Anticipating Maintenance Operations. , p.45.
- Lacaille, J., (2010b). Standardization of Data used for Monitoring an Aircraft Engine.
- Lacaille, J., (2009b). Standardized Failure Signature for a Turbofan Engine. In *IEEE Aerospace conference*. Big Sky (USA, Montana): IEEE Aerospace society.
- Lacaille, J. et al., (2014). Turbofan Engine Monitoring with Health State Identification and Remaining Useful Life Anticipation. *International Journal on Condition Monitoring (IJCM)*, (1), pp.1–21.
- Lacaille, J. & Côme, E., (2011). Visual Mining and Statistics for a Turbofan Engine Fleet. In *IEEE Aerospace Conference*. Big Sky (MT): IEEE.
- Lacaille, J. & Djiki, R.N., (2009). Model Based Actuator Control Loop Fault Detection. In *8th European Conference on Turbomachinery: Fluid Dynamics and Thermodynamics, ETC 2009 - Conference Proceedings*. Gratz (Austria), pp. 889–899.
- Lacaille, J., Gouby, A. & Piol, O., (2013). Wear Prognostic on Turbofan Engines. In *PHM*. pp. 1–8.
- Lacaille, J. & Nya Djiki, R., (2010). Detection of Anomalies in an Aircraft Engine.
- Massé, J. et al., (2013). System PHM Algorithm Maturation. *Chemical Engineering Transactions*, 33, pp.283–288.
- Rabenoro, T. et al., (2014a). A Methodology for the Diagnostic of Aircraft Engine Based on Indicators Aggregation. In *ICDM*. Saint Petersburg (Russia).
- Rabenoro, T. et al., (2014b). Interpretable Aircraft Engine Diagnostic via Expert Indicator Aggregation. *Transactions on Machine Learning*, pp.1–21.

## BIOGRAPHIES

**Guillaume Bastard** is an EHM system architect at Safran Aircraft Engines. He received the degree of Engineer from the Conservatoire National des Arts et Métiers (CNAM) in 2013 and received a MSc. in system engineering, diagnostic and prognostic at the University of Lorraine.

**Jérôme Lacaille** is a Safran Emeritus Expert which mission is to help in the development of mathematic algorithms used for the engine health monitoring and statistical analysis of company data. Jérôme has a PhD in Mathematics on “Neural Computation” and habilitation thesis on “Algorithms Industrialization” from the Ecole Normale Supérieure (France).

**Josselin Coupard** is an EHM system architect at Safran Aircraft Engines. He has several engineering degrees from Ecole Nationale Supérieure de l’Electronique et de ses Applications (ENSEA) and Georgia Institute of Technology.

**Yacine Stouky** is at the head of the EHM system architect teams at Safran Aircraft Engines. He received an engineering degrees from Supélec (Ecole Supérieure d’électricité) and an MSc degrees from University College London.