Studies in “Health Monitoring”
Health monitoring

- Event future occurrence detection
- Involved LRU localisation
- System approach
- Use of in-system existing parameters
  Protected by the MMEL (Master minimum equipment list)

Prognostic Assessment

Health Assessment

State Detection

Data Manipulation

Data Acquisition

Measures ➔ Parameters ➔ Symptoms ➔ Syndromes or Signatures
• Modular performance

Engine

Health parameters

Calculation

measurements

- Temperatures, Pressures, Shaft speeds, Variable geometry positions
- Number of Load Cycles
- High Pressure Turbine Efficiency

Observed EGT

Red line

Engine cycles

Performance parameters

SW12
SE12

SW2
SE2

SW26
SE26

SW41
SE41

SW49
SE49
Engine systems

- Hydromechanics' actuation loop
  - Actuators
  - Servo-valve
  - Position indicators

Diagnosis

<table>
<thead>
<tr>
<th></th>
<th>TFG</th>
<th>TFA</th>
<th>Flight phase</th>
<th>Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servo</td>
<td>X</td>
<td></td>
<td>Stationary</td>
<td>Slow</td>
</tr>
<tr>
<td>Sensor</td>
<td></td>
<td>X</td>
<td>Any</td>
<td>Fast</td>
</tr>
<tr>
<td>Actuator</td>
<td>X</td>
<td></td>
<td>Cruise</td>
<td>Slow</td>
</tr>
</tbody>
</table>

Trending
Engine systems

- Actuator seal “wear count” degradation predictor

1-Explain
2-Predict

Crack
Wear

TOTAL VOLUME LOSS

Pressure
Displacement
Start capability

- Experts knowledge
- Field event reports
- Test
- Simulation

Measures $\rightarrow$ Parameters $\rightarrow$ Symptoms $\rightarrow$ Syndromes or Signatures

(5) $\rightarrow$ (7) $\rightarrow$ (15)
Examples

Main Fuel Pump

Known or measured

\[ Q = A_0 \cdot N_2 + A_1 \cdot \Delta P_{HP} + A_2 \cdot \sqrt{\Delta P_{HP}} \]

Evolve with ageing

Volumetric gear pump principle

Housing  Input

Bearings wear

Gear cavitations
Symptom extraction

Test inputs
\[ x = \text{Oil temperature, pressure,} \]

Endurance bench tests
\[ G(x, d) \]

Variable of interest: Follow up parameter
\[ Z = G(x, d) \]

Regression coefficient,
\[ \hat{Z} = \hat{G}(X, d) \]

Measure of uncertainty
CDF of
\[ Z - \hat{Z} \]

Quantity of Interest
Decision threshold on
\[ Z - \hat{Z} \]

Decision criteria
Based on
\[ Z - \hat{Z} \]
Symptom extraction → Start capability

\[ T1 = 7.85 - 2.65 \text{ PASTAR} + 0.00806 \text{ PressAtm} - 0.00557 \text{ Toil} - T1 - 0.0304 \text{ TAMB} \]
Syndrome extraction

Detection

Localisation

12 LRU

Start capability
Training data generation

Model inputs

*Endurance bench test data*
- Failure injection data
- With various levels of intensities

System model

\[ G(x, d) \]

Variables of interest

Follow up parameters with various levels of failure intensities

\[ Z = G(x, d) \]
Training data generation

- Actuators

- Position indicators

Local control loop
Sensitivity analysis

Input Uncertainty
- Measure of uncertainty
  - Joint cdf on $X$
- Parameters of the uncertainty model
  - Fixed

Model inputs
- Uncertain input ($X$)
  - Fuel temperature, fuel type, pump age, pump initial efficiency, ...

System model
- $G(x, d)$

Variables of interest
- $Z = G(x, d)$
  - $N2$ at specific cycle moment

Output Uncertainty
- Quantity of Interest
  - Variance and $P(Mr < 0)$
  - Sensitivity indices on variance and $P$

Uncertainty Propagation

Sensitivity analysis / Importance ranking
Sensitivity analysis

Main Fuel Pump

- Temperature
- Atmospheric pressure
- Fuel Type
- Production
- Ageing

Cavitation

Wear

Degradation follow up
Other studies

- Lubrication oil quantity track

- Electrical motor follow up
Join us!

A set of stochastic and algorithmic topics candidate for training & thesis

From the left to the right, D. Kettler, F. Delamour, A. Ausloos, A. Dupuis (trainee), X. Flandrois, J-R. Massé, R. Meuret, J. Benitah, M. Vernochet