Diagnostics, Prognostics, and Health Management

**Health Management:** The capability to make intelligent, informed, & appropriate decisions about maintenance and logistics actions based on diagnostics/prognostics information, available resources and operational demand.

**Prognostics:** Material condition assessment which includes predicting and determining the useful life and performance life remaining of components.

**Diagnostics:** The process of determining the state of a system to perform its functions.

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With definitions borrowed from a Lockheed Martin presentation
Optimizing Removals And Workscope

BUSINESS PROPOSITION: LIFE CYCLE COST MANAGEMENT

- Monitor Health and Safety -- Prevent Unscheduled Engine Removals (UERs), Optimize performance
- Proactively Manage Configuration – Extend Average Time On Wing (ATOW)
- Plan Removals -- Minimize Disruptions
- Optimize Workscopes – Reduce Shop Visit Cost (SVC) and Minimize Turn Around Time (TAT)
Engine Health Monitoring Roadmap

Transitioning Capability Programs

Execute

Validate model accuracy and false detect rate

Gather engine data reduce data variation

Mature Set of Diagnostics Solutions Off-Board


System Capability

On-board Anomaly Detection

Life models

Oil Debris

Vibrations

Oil Condition

Off-board Diagnostics

APHM Board

Filter Health

Mature

Develop

Oil Debris

Life models

Vibrations

Fuel/Oil Filter Health

Off-board Diagnostics

Life models

Oil Condition

Oil Debris

Vibrations

Gather engine data reduce data variation

Validation model accuracy and false detect rate

Execute
Technology Transition Process

Measure of Technical Readiness

Technology Readiness Level

In Service

Qualification/Certification

Flight Test

System-level Validation

Rig/Core (Expanded Design Space)

Rig Test (Minimal Design Space)

Proof-of-Concept

Technology Application

Basic Principles

Technology Maturation & Transition

Fielded Systems

TRL Levels

9

8

7

6

5

4

3

2

1

F100-PW-229

F119

New
Off Board Diagnostics Facilitates On-Board PHM Systems

Off-board diagnostics algorithms hosted within secure database

Data collected few times per flight

Model parameters

KF estimation of deterioration

Detect trends

Report on the web

Infrastructure facilitates engine/fleet management solutions as well

Kalman Filter based isolation

Filter, remove outliers, validate data
P&W Tools to Support DPHM

On Board

On-board Anomaly Detection

Diagnostics and Prognostics

Trending

Early Warning Detection

Isolation

On Ground

On-Condition Management

Configuration and Utilization Tracking

Fleet Alert Summary and Watchlists

Modification Standardization

Removal and Shop Visit Planning

Removal Planning / Event Tracking

Modification Incorporation

Shop Maintenance Instructions

Sensors

Models

Algorithms

UTC Proprietary

October 2005
ADEM Portal for Trending and Alerting Engine Data

ADEM: Advanced Diagnostics and Engine Management
Measure factors affecting actual life remaining

- Engine used differently than worst-case assumption
- Aircraft flown differently than expected
- Engine-to-engine variations

Crack growth models
Thermal/stress analysis

Gas path parameters
Mission analysis

Finite element models
Thermal / stress algorithms

Reduction Methods

Life models (probabilistic)

On-board host (DEEC)

Advanced sensor data if any
Engine control parameters

On-Board Life Management Algorithms
On-Board Anomaly Detection

Anomalies: Deviations from “Normal” Operation

**Anomaly Detection:**
- Provides **trigger** to capture real-time data for subsequent off-board analysis
- Additional data to support fault isolation
- Can facilitate long-term performance deterioration tracking

**Causes for anomalies**
- Deterioration
- Physical faults
- Operational abnormalities
- Flight domain excursions

**Transient data and real-time models used to detect anomalies**

**Normal continuous data & physics used to build real-time engine models**
Advanced PHM Sensors

Early Detection of Various Problems

- Oil condition monitor
- Oil debris sensor
- Oil and fuel filter health
- Inductive / microwave probes
- Vibration pickups
Oil Health Monitoring

Technology Matured

- Sensors installed on production military engines
- Condition monitoring added to OLS
  - Tubes form capacitors for level and conductivity
  - A single probe provides lube oil capacity, condition, and calibration signal to the box
- ODM located on supply side of main oil pump

Transition process

- Analyze & develop algorithms
- Increase inputs in APHM board
- Prototype, test, and qualify APHM board
- Develop software
- Test and qualify system
Data Normalization Leads to Enhanced Fault Diagnostics

Flight data is gathered from engine

Normalized inputs

Empirical model

Ground Station

X (predicted)

Monitored Parameters

X_{nom}

Current model

Predicted Deterioration

Empirical prediction models
Empirical models allowed reduction in variance by as much as 17 times while maintaining fault sensitivity.

Reduction in variance for $\Delta WF = 4.7$

Reductions for other variables: $\Delta T_6 = 17.5$, $\Delta T_{41} = 6.7$, $\Delta N_2 = 15.5$
Hybrid Modeling: eSTORM

eSTORM Implementation Phase

Trained ANN will estimate Model/Engine difference and adjust the estimated parameters accordingly.

Hybrid Model

- Inputs (u)
- Estimated residuals \( \hat{r} \)
- Estimated Parameters \( \{ \hat{P} \} \)
- Adjusted Estimated Parameters \( \{ \hat{P}^* \} \)
- Residuals (r)

Standard STORM configuration with feedback

Measured Parameters \( \{ P \} \)

Residuals will now track performance changes

Tuners (\( \hat{x} \))
Diagnostics Using Hybrid Models: eSTORM

STORM vs eSTORM: Performance Fault Visibility

Module Performance Deltas (Tuners) absorb mismatch

Performance deviation becomes visible

eSTORM disabled

eSTORM enabled
Diagnostics / PHM Needs

Diagnostics & Prognostics Analysis Tools
- Signal processing (primarily vibrations)
- Empirical modeling techniques (Neural Networks, Support Vector Machines, Partial Least Square, Nonlinear regression, etc.)
- Anomaly detection and fault isolation
- Directed troubleshooting
- Data mining

Diagnostics Sensors and Computing Hardware
- Oil condition, debris, level – preferably low cost
- Robust clearance monitoring
- Acoustic sensors
- Aerospace qualified wireless and self powered sensors
- Distributed computing for health management and controls
- Data compression, storage, and secure transmission

Solutions available
Solutions Partially available
Solutions Needed