Health Management at Rolls-Royce

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Stages of Engine Health Management

- **Sense** - Measurements made on-board
- **Acquire** - Data capture system with some data processing, analysis or compression
- **Transfer** - Remote accessibility to review data and information acquired. This may entail a combination of online real-time access to remote information or transferring the captured data to a support center
- **Analyze** - Provide information to maintenance support experts to consider and provide recommendations.
- **Action** - Accurate trouble-shooting and maintenance support advice given to the equipment operator in time to manage or avoid a potential adverse event
1970s

- Basic cockpit indicators only
  - Shaft speeds, EPR, fuel flow, vibration

- Manual
  - Flight engineer recorded data during cruise operation

- Manual
  - Paper reports physically mailed to powerplant engineering
  - Entered into system by hand

- Data analyzed by airline using simple engine model to correct data
  - Determined changes in TGT and shaft speed margins

- Longer term planning
  - Airline planned for engine removals at zero margin
1990s

Dedicated EHM sensors added
- Interstage gas path measurements

Automatic
- ACMS recorded snapshots during take-off, climb and cruise
- Exceedences and abnormal events captured

Real-time option available
- ACARS enabled data to be sent by VHF or SatCom

Data analyzed by airline using comprehensive models
- Better margin assessments from take-off and climb data
- Assessed gas path performance trends

Longer term planning and some event avoidance
- Airline plans for engine removals at zero margin
- Significant changes in performance detected
Today and tomorrow

Sense
- More dedicated EHM sensors and systems
  - EMCD
  - EMU

Acquire
- Automatic
  - ACMS records snapshots during take-off, climb and cruise
  - Continuous data capture and on-board analysis
  - Real-time
    - ACARS enables data to be sent by VHF or SatCom
    - Options to manage larger quantities of data through GATELINK

Transfer
- Data analyzed by specialist companies
  - Investment in data analysis and diagnosis systems (CI tools)
  - Application of fleet-wide knowledge - improved detection

Analyze
- Focus on ability to react to information
  - Links through field service offices into airlines
  - Rolls-Royce Operations Room provides OEM expert knowledge

Action
EHM Stage - Sense

- Sense - Measurements made on board

- Vibration Monitoring
- Advanced Engine Testability System
- Engine Performance Monitoring
- Built-In Test
- Configuration Control
- Life Usage Monitoring
- Oil Debris Monitoring
- Incident Monitoring

Other engine data:
- Fuel - flow, Δp, FMV pos 'n
- Oil - press, temp, Δp, quantity
- Zone 1, 3 temps
- EEC temp

Aircraft data:
- Alt, Mn, TAT
- Bleed status
- Power offtake

Rolls-Royce
EHM Stage - Acquire

- **Acquire** - Data capture system with some data processing, analysis or compression
EHM Stage - Transfer

- **Transfer** - Remote accessibility to review the data and information that is acquired. This may entail a combination of online real-time access to remote information or transferring the captured data to a support center.
**EHM Stage - Analyze**

- **Analyze** - Provide information to maintenance support experts to consider and provide recommendations.

  **Advanced data analysis & pattern recognition tools**
  - Data smoothing
  - Data fusion
  - Neural net pattern recognition

  **EHM service support (operations room)**
  - Diagnostics/prognostics
  - Manage/track alerts
  - Fleet management
  - Life usage monitoring
EHM Stage - Action

**Action** - Accurate trouble-shooting and maintenance support advice given to the equipment operator in time to manage or avoid a potential adverse event.
Lessons learned

- Develop EHM system with engine from project start
  - Service philosophy drives requirements
    - Manage issues on wing or in shop
    - Who needs data to make decisions
  - End-to-end system definition
    - Late integration leads to rework or compromise
    - Planning can yield optimized design
Lessons learned

- Need data available quickly and consistently to make timely decisions
  - Events can happen any time during operation
    - Missed event detection can lead to secondary damage
  - Automated data transfer facilitates action
    - Manual data transfer inconsistent
    - Procedures are not always followed
Lessons learned

- Use multiple data sources to provide enhanced analysis capability
  - Looking at only one data source (sensor) may not lead to correct conclusion
  - Interaction between components can provide additional data source
    - Response of different components can differentiate conditions
Lessons learned

- Realize false alarms undermine credibility
  - Need to understand operation to set effective alert limits
    - Initial limits may not be correct
    - Need to be able to modify as needed
  - Tighten limits as experience is gained
    - Use human intervention to check computer results prior to notification
    - Incorporate experience into computer capability as confidence is gained
Lessons learned

- Relate maintenance tasks to performance analysis
  - Maintenance actions can cause shifts in performance trends
    - Typically positive shift
  - Change in performance trends cause search for cause
    - Record maintenance action to eliminate need to determine if trend shift is related
Lessons learned

- Retain control of data acquisition system to improve analysis
  - Knowledge is gained about system analysis as applications mature
    - Need to adjust data acquisition criteria to detect new scenarios of issue identification
  - Data acquisition part of aircraft system
    - Difficult to separate engine data from other data
    - Implementation of software controlled by others
Lessons learned

- Anticipate unexpected failures as fleet ages
  - Detection of known conditions accounted for in design and development (FMECA)
  - Interactions between components can result in unexpected failure modes
  - Flexible system allows quick updates to detect new failures
Lessons learned

- Understand that system cost justification is difficult to quantify
  - Depends on business model
    - Cost of situations EHM can reduce?
  - Costs to consider:
    - Sensor and software development
    - Support organization
- Knowledge of cost/benefit is competitive advantage
Lessons learned

- Assess technology developments since design of last system
  - Determine if new capabilities are available to satisfy requirements
    - Start with old system and add new capabilities
  - System requirements not satisfied by current capabilities drive new ones
Lessons learned

- Be conservative in identifying benefits of new technology
  - The actual capability of new technology often ends up being less than planned
    - Ideas are “sold” to generate investment
  - It takes time to fully develop the capability of new technologies
  - Users may lose interest/confidence if lofty claims are not met
Lessons learned

- Recognize safety critical failures are not mitigated by EHM
  - Product is safe without EHM
  - Analysis capability provides information allows better economic decisions
  - Actions based on analysis are result of human decisions
  - Automated decision making requires higher level certification
Next Steps

- Integrate EHM analysis into...
  - Engine control real-time
  - Aircraft systems
- Data acquisition and analysis
  - Continuous
  - Snapshot
Next Steps

- System architecture
  - Open
  - Distributed
- Validation & verification
  - Prognostics
  - Configurable software
- Special needs for UAV applications?