Rolls-Royce

Health Management at Rolls-Royce

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01 October 2009

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

Sense

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

Acquire

Manual
- Flight engineer recorded data during cruise operation

Transfer

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

Analyze

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

Action

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

1990s

Sense

Dedicated EHM sensors added
- Interstage gas path measurements

Acquire

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

Transfer

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

Analyze

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

Action

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

Transfer

Real-time
- ACARS enables data to be sent by VHF or SatCom
- Options to manage larger quantities of data through GATELINK

Analyze

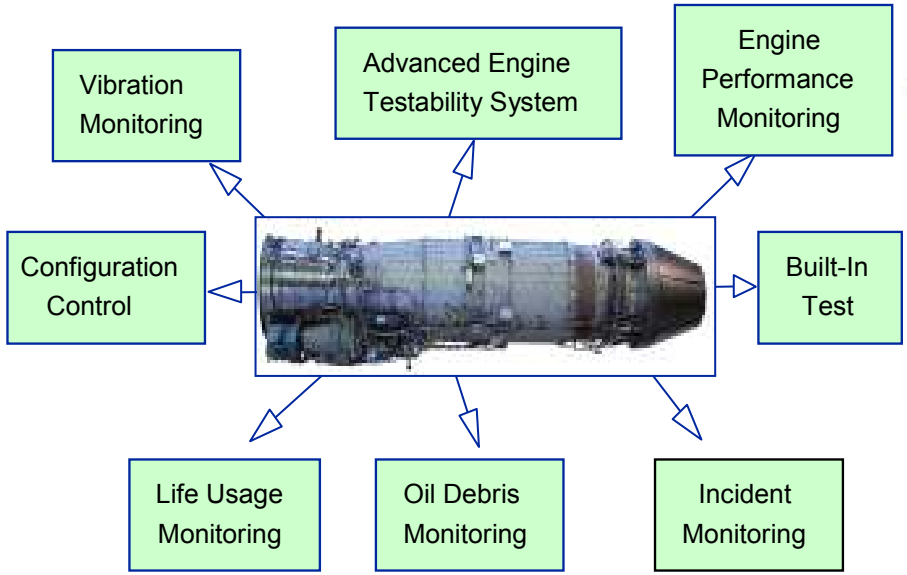
Data analyzed by specialist companies
- Investment in data analysis and diagnosis systems (CI tools)
- Application of fleet-wide knowledge - improved detection

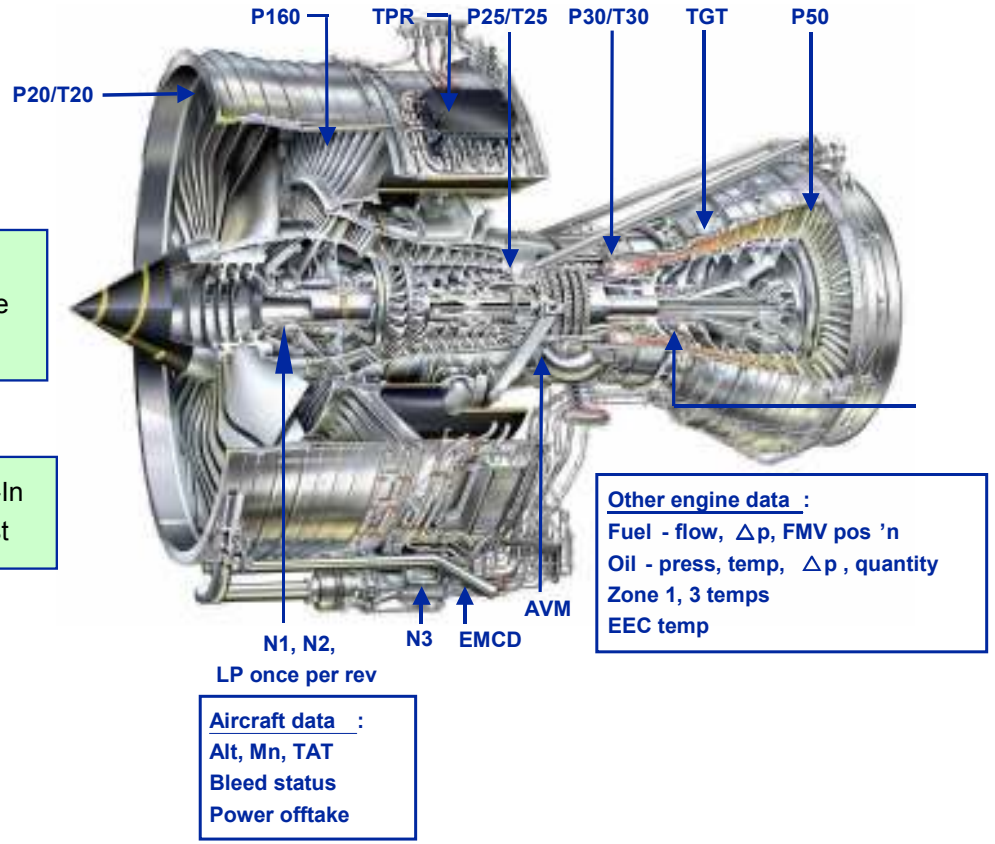
Action

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

EHM Stage - Sense

- **Sense -** Measurements made on board



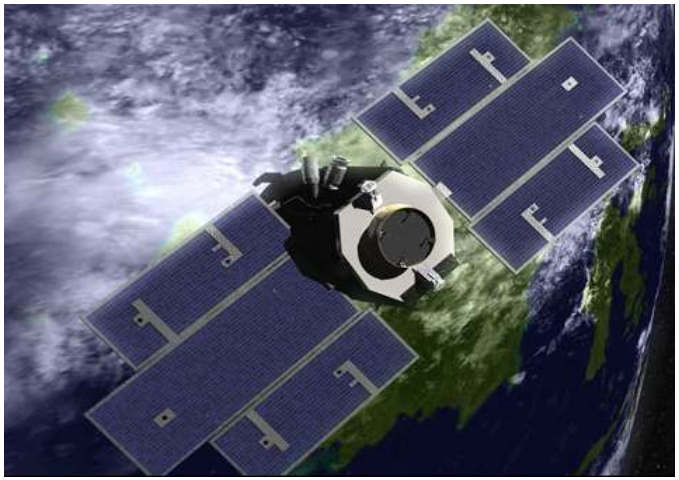


EHM Stage - Acquire

- **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

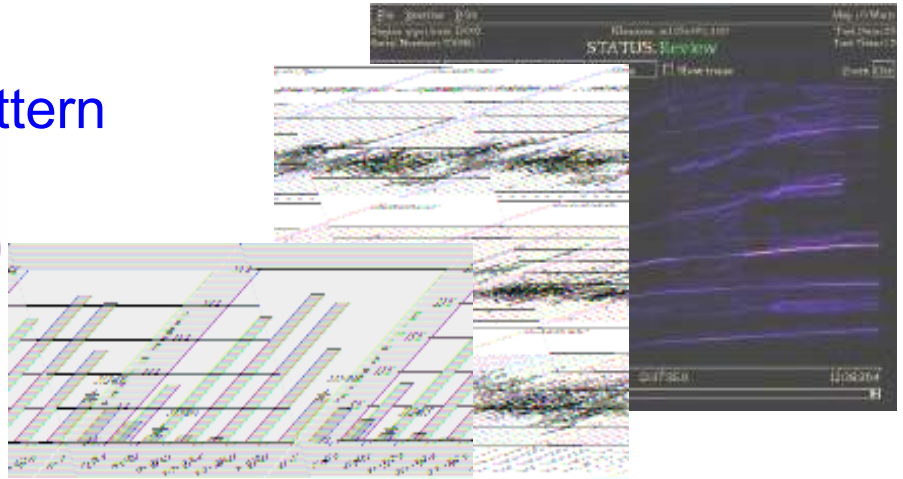


EHM Stage - Analyze

- **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?