Controls and Diagnostics
Development Work at Rolls-Royce

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Topics

- Overview
- Controls efforts
- Stages of engine health management
- Sense technologies
- Acquire technologies
- Transfer technologies
- Analyze technologies
Rolls-Royce Overview

- Working to advance controls & health management capabilities
  - Global organization, diverse capabilities
    - United Kingdom
    - United States
    - Canada
    - Germany
  - Major business sectors
    - Aerospace
    - Marine
    - Energy
    - Nuclear
Controls efforts

- Aircraft engine control integration
  - Integrate engine control with aircraft systems to optimize functionality
  - Provide seamless operation of all systems

- Modular controls
  - Decentralized data processing, recording and communication
  - Open Systems Architecture
Controls efforts

- Adaptive control
  - Adjust engine operation based on health monitoring assessment of components

- Electric systems for engines
  - Working to integrate electrically actuated accessories and systems
  - Replace mechanical system losses with electric power that can be modulated
Equipment health management stages

- **Sense** - Measurements made on-board to allow detection of degraded systems
- **Acquire** - Data capture system, some data processing, analysis or compression
- **Transfer** - Remote accessibility to review the data and information acquired
- **Analyze** - Data fusion, pattern recognition & fault isolation
- **Act** - Trouble-shooting and maintenance actions
Sense technologies

● High-frequency sensors
  • Higher data acquisition rates to capture high resolution events
    - Dynamic issues such as compressor surge & combustion instability

● Emissions sensors
  • Ability to analyze combustion process to enable better control, reduced emissions
    - Evaluate gas composition and adjust
Sense technologies

- **Wireless sensors**
  - Apply communication and energy harvesting techniques to sensors
  - Eliminate wire harness reliability issues and weight

- **Smart sensors**
  - Integrated computer processors
  - Analyze data and determine what to share with other system components
Sense technologies

- MEMS sensors
  - Small, low power electronics using wireless & energy harvesting
  - Embed in components closer to the failure source
  - Transmit data to central location for assessment

- Fiber optic sensors
  - Allow sensor electronics location in a less hostile environment
Sense technologies

● Oil quality sensor
  • To analyze multiple oil characteristics
    - Level, quality (TAN, Viscosity, moisture, etc)

● Debris monitoring
  • Detect unexpected particles in lubrication, fuel & gas path
    - Detect bearing, gear or other metallic debris in oil
Acquire technologies

- Related to and dependent upon control system developments
  - Use hardware and software developments from control systems
- Philosophy evolving with new systems
  - Analyze moving on-board
- Storage driven by Act philosophy
  - Transfer data in-flight, near term action
  - Transfer post flight, delayed action
Transfer technologies

- Dependent on system architecture
  - Process real-time and transfer summary
    - Reduce storage volume & download time
    - Data acquisition algorithm management
  - Capture all data and process on-ground
    - Allows post processing and quick adjustment to new issues
    - Minimal software requirements
Analyze technologies

- Acquisition capability and associated software must support
  - Continuous data allows analysis on entire operation
  - Condensed summary information is greatly limited on what can be analyzed and used for detection

- Data mining/fusion
  - Correlations that indicate anomalies
Analyze technologies

- **Performance**
  - Overall engine performance
  - Modular performance allows assessment of deteriorated module on-wing

- **Lifing**
  - Assess usage based on flight operating conditions
    - More accurate assessment of life usage than typical one cycle per flight
Analyze technologies

- **Vibrations**
  - identify imbalance conditions
  - identify bearing and structural anomalies

- **Blade health monitoring**
  - Tip clearance
    - For performance assessment
    - Useful as control parameter
  - Tip timing
    - detect blade cracks and other anomalies
Analyze technologies

- **Combustion**
  - Analyze composition of by-products
    - Optimize combustion process
  - Analyze temperature profile
    - Diagnose location of faulty fuel nozzle
    - Diagnose combustion liner faults

- **Electronics**
  - Isolate faults to optimize detection and repair
Analyze technologies

- **Exceedances**
  - Detect conditions requiring maintenance action

- **LRU monitoring**
  - Use dedicated sensors and data fusion to assess LRU condition
    - Direct maintenance action based on data
Analyze technologies

- Prognostics
  - Detect incipient failure
  - Develop physics-of-failure models
  - Use operational history to predict the future
  - Use probabilistics to predict remaining useful life and likelihood of failure
Act technologies

- Use EHM information and techniques to manage equipment assets
  - Part procurement and logistics
  - Optimize workscope
  - Maintenance planning
  - Individual engine assessment
  - Fleet data analysis