Toward IVHM Prognostics

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Table of Contents

• Aircraft Operations – Today’s way of doing business
  – Examples
  – Data collection, analysis, and effects on operations

• Prognostics
  – Vision
  – Translation – Different goals between NASA and Industry
  – Dryden’s role

• NASA’s instrumentation data-system rack

• Data mining for IVHM

• NASA GRC’s C-MAPSS generic engine model
  – Conversion to install on Omega System
  – Test engine model using past flight data
  – Demonstrate model operation using real-time input data

• Concluding Thoughts
Aircraft Operations – Real Time
One Airport’s Worth of Inbound Traffic

September 10, 2007
0800 PDT Inbound Traffic to ATL
Aircraft Operations
Today’s Way of Doing Business

• **Aircraft operations** – The daily application of aircraft flights to meet a customers needs whether it be commercial or military
  - Regional – Short flights usually less than 3 hours, many takeoffs and landings per aircraft
  - Transcontinental – Flights 3-5 hours across the United States
  - Oceanic – Flights traveling across either ocean lasting 7+ hours

In a nutshell how many times a day do airframe/engines see cycles?
Aircraft Operations
Today’s Way of Doing Business – Regional

Daily flight from ATL to MIA
Takeoff, climb, cruise, descent and landing
Fairly stable environment
9X Daily, approx. 600 miles direct
Aircraft Operations
Today’s Way of Doing Business – Transcontinental

Daily flight from ATL to LAX
Takeoff, climb, cruise, descent and landing
Fairly stable environment
2X Daily, approx. 1900 miles
Aircraft Operations

Today’s Way of Doing Business – Oceanic
Aircraft Operations
Airframe/Engine Daily Usage

Number of Flights (Takeoff and Landings)

Atlanta

Miami

Regional

Transcontinental

Oceanic

Frankfurt

Los Angeles

Airframe/Engine Cycles
Aircraft Operations

All This Data!!!

• Data collection – typically done in a variety of ways
  – Snapshot data down linked in real-time
  – Onboard low resolution recorders
  – Event capturing with small amounts of transient support data, roughly 30 - 60 seconds duration
  – Use of current sensor suite on engine

• Analysis and decision making
  – Performed by engineers and maintenance personnel either centrally or on aircraft as troubleshooting task

• Effects on operations
  – In today’s world, slow and cumbersome
  – Time for analysis to reach aircraft can be minutes to days
  – Downtime costs airlines $$$$ 
  – Prognostics is minimal, fault detection and accommodation decisions are reactionary
Prognostics
Vision

• **Now:**
  – Develop algorithms capable of performing Feature Extraction (FE) of real-time and post-flight event data and embed these within the avionics suite
  – Ensure flight crew, maintenance personnel and scheduling has access to critical FE data prior to flights not during
  – Data mining techniques that create virtual sensing capabilities

• **Future:**
  – Consideration for greater aircraft/propulsion integration
  – Look at what the airframe imposes on the engine
  – New sensor technologies
Prognostics
The Decoder Ring

- **Performance Enhancement (1)**
  - Better fuel economy, lower emissions

- **Life Extension (2)**
  - Increase Time On Wing (TOW)

- **Damage Adaptability (3)**
  - Ways to utilize engine when damage has occurred, continued use while flying, ability for limited use.

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NASA Interest

- **Industry’s Interest – Safety/Economic Benefit**
  - NASA’s Interest - Safety
  - Industry’s Interest – Economic Benefit
  - NASA’s Interest - Environment
Benefits of Implementing IVHM Technologies
Aircraft Categories

**In Production Aircraft**
Primarily, develop algorithms that can be embedded into existing systems. Secondary, develop hardware that can “Buy Its' Way On” via retrofit into existing aircraft and incorporated into aircraft under production:
- On wing trending and diagnostics (1/2)
- Performance/maintenance feature extraction for storage and transmission (1/2)
- Performance enhancing control algorithms (1/2)
- Damage adaptive AFCS/ATS coupled control and indication (3)
- Intelligent pilot advisories (1/2/3)
- Neural network control and maintenance learning techniques (1/2)

**Legacy Aircraft**
Most practical, develop algorithms that can be embedded into existing systems to support:
- On wing & ground based trending and diagnostics (1)
- Performance enhancing control algorithms (2)
- Damage adaptive pilot fly-to indications (3)

**Aircraft Under Development**
- New sensors. (1/2/3)
- New hardware (1/2/3)
- Self learning, teaching and adaptive techniques for:
  - Control, normal, abnormal (i.e. wind shear, damage, turbulence)
  - Prognostics for maintenance (pre-trend to removal)
  - Normal maintenance
- Neural network control and maintenance learning techniques (1/2)
- Transition to space techniques. (1/2/3)
Prognostics and Mitigation
The Big Picture - Future

- Damage
- Survivability
- Adaptable

PHM concept used for ground based trending and diagnostics. Limited prognostic capability. Some airborne capabilities

Current control algorithms – Engine operates within pre-determined limits and stall margins

Newly developed control algorithms allow engine to be operated outside the normal envelope for use as flight control effectors

Smart/Intelligent Performance Control Algorithms Integrated With Airframe Seek Out Optimal Environment In Which To Operate

Current PHM Capability

Newly Developed PHM Capability

Dynamic PHM Oriented Algorithms Run In Realtime

- Performance
- Environment
- Safety

Intelligent Control Algorithms Operating Over Engine Envelope Utilizing Existing PHM Technology Coupled With Advanced Sensor Hardware and Control Software
IVHM - Dryden’s Role

• **Research/Test Vehicle**
  – Four engine transport with commercial type engines currently in use today
  – Long duration flights
  – Flights local or transcontinental
  – Diverse and austere airframe/engine operating environment
IVHM - Dryden’s Role

- **Research engineering pallet (flying control room)**
  - Capable of aircraft and simulator interface
  - Real-time monitoring and in-flight playback
  - Embedded engine models running real-time
  - Can host and evaluate engine and prognostic control laws and algorithms
  - Integrated aircraft and engine data
  - Acts as virtual avionics sub-suite
  - Provides for data fusion, virtual sensors and metadata
  - Telemetry downlink upgrades planned
  - Can be relocated to other research team locations

- **Specialized engine instrumentation on research engine**
  - Hi/Lo speed data transmission from engine to airframe
  - Gas path
    - Inlet/Exhaust Debris Monitoring Sensors
    - Flight test certification suite installed
  - Mechanical
    - Hi/Lo Freq vibration sensors in several locations
    - Acoustic sensors
  - Growth for several other types of sensing for both mechanical and gas path research
NASA Onboard Instrumentation System Rack

- Omega PHM Decom and Thin Client
- SWAN system
- Operator Displays
- Metrum Model 64 Recorder and MUX
- Omega PHM Thick Client
Wyle Real-Time Processing System and Omega Data Environment (ODE)
First Step Toward Feature Extraction
Installing Generic Engine Models Into Wyle System

- **Commercial Modular Aero-Propulsion System Simulation (C-MAPSS)**
  - Developed at NASA GRC
  - Code is a combination of Matlab and Simulink with GUI screens
  - Can simulate the response to engine faults and deterioration
    - Can add sensor and actuator dynamics, other inputs, and functions
  - Includes a comprehensive engine control system
    - Open loop or closed loop evaluations
    - Limit regulators to prevent exceeding engine design limits
    - Accel and decel limiters for the core speed
    - The fan-speed controller and 4 limit regulators are scheduled to perform over the entire flight envelope and power levels
      - These can be modified using the controller-design GUI which uses a Linear Engine Model (LEM) to represent the engine
First Step Toward Feature Extraction
Installing Generic Engine Models Into Wyle System

• **Convert the Matlab/Simulink model to C++ code using the Mathworks Real Time Workshop**
  – Code will be optimized using the Mathworks xPC Target
• **Install C-MAPSS in the NASA onboard rack (Wyle Telemetry Data System)**
  – Install as a “user-application”
• **Verify model operation using past flight data**
  – Wyle ODE greatly simplifies this task
• **Demonstrate a working C-MAPSS model using real-time flight data as inputs**
  – Create capability for users to modify inputs
  – Insert different fault types for analysis
Concluding Thoughts

• In today’s aircraft operations environment, the amount of data generated is immense
  – Time-based maintenance not condition-based maintenance
  – It is slow and cumbersome process to analyze data and provide feedback back to the fleet or airplanes
  – Prognostics is minimal, fault detection and accommodation is reactionary

• Implementation of an IVHM research environment that allows
  – Creation of adaptive, reconfigurable systems
  – Creation of feature extraction techniques
  – Hosting, development, and modification real time of models and algorithms
  – Fault detection research using real-time or post flight data

• Successful operation of the C-MAPSS engine model with real-time flight input data will be a good first step toward real-time analysis of feature extraction methods
Back Up Charts
Prognostics and Mitigation
Real-Time Example

• **Noise Mitigation Smart Terminal Approach Technique (NMSTAT)**
  – Supporting ARC research activity
  – Airborne control room
  – Airplane crew (diverse)
    • DFRC Pilot/USAF Pilot
    • DFRC Flight Test Engineer
    • American Airlines pilot (observer)
    • 2 DFRC propulsion engineers
    • 1 ARC PI
  – Ground personnel
    • ARC PI
    • Up to 17 student researchers
    • Northrop Grumman acoustics engineer
    • Ground/Range Safety
Real-Time Example

NMSTAT

Student Researchers
On Lakebed

Normal Approach
Real-time Position
Of Aircraft With
Historical Tracking
Real-Time Example
NMSTAT

Research Approach
Real-time Position of Aircraft With Historical Tracking

Student Researchers On Lakebed

Target Runway

National Aeronautics and Space Administration
Aviation Safety Technical Conference
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Real-Time Example
NMSTAT Display
Prognostics and Mitigation
Real Time – Throttles Only Control