An On-Board Model-Based Diagnostic Architecture

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Introduction

- Implementation of on-board model-based gas-path diagnostics
- Provides advantages
  - Real-time unmeasured parameter estimation
  - Decreased latency for gas-path fault diagnosis
  - Model-based control
Architecture Overview

- **Current Ground-Based Methodology**
  - Examines snapshot residuals
    - Differences between sensed and a reference
  - Significant research in applicable fault detection/isolation algorithms

- **Leverage Ground-Based Algorithms in On-Board Design**
Architecture Overview

- Enhances existing on-board controls and diagnostics
- Co-exists with ground-based performance trending and diagnostics
Architecture Details

Real-Time Adaptive Performance Model (RTAPM)

Sensors

Commands

Unmeasured Outputs

Periodic Tuner Update

Health Transformation

Power Reference

Performance Baseline Model (PBM)

Sensor Residuals
RT Adaptive Performance Model

- Incorporates Piecewise Linear Kalman Filter
  - 3D Interpolation (Altitude, Mach, Power)
  - Kalman gains are pre-computed
- Produces unmeasured parameter estimates
- Generates real-time tuning parameters
Tuning Parameters

- Underdetermined system
  - Model assumes 2 health parameters per rotating module
  - Typically exceeds available sensors

- Employs optimal tuner selection
  - Uses linear combination of health parameters
    \[ q = V^* h \]
  - Optimized for unmeasured parameter estimation across flight envelope
Performance Baseline Model

- Piecewise linear model
  - Incorporates power reference parameter
  - Periodic tuner updates

- Captures gradual engine degradation
Periodic Tuner Update

- Cellular approach
  - Three-Dimensional (Altitude, Mach, Power)

- Tuners from RTAPM averaged for storage
  - “Committed” at flight conclusion

- Estimates delivered to PBM
  - Based on prior flights only
  - Age-weighting
RTAPM Evaluation

- Compared against C-MAPSS
  - Nonlinear turbofan model with controller
  - Includes sensor noise
RTAPM Evaluation – Data

- Takeoff-climb-cruise profiles measuring ~2000s
- Random engine performance based on fleet distribution
- **500** Engines x **10** Nominal Profiles
RTAPM Evaluation – Results

- Mean Unmeasured Parameter Estimation Error
  - Instantaneous errors averaged across each flight profile

![Bar Chart](chart.png)
RTAPM Evaluation – Results

- Mean Health Parameter Estimation Error
  - Tuners optimized for unmeasured parameter estimation
PBM Evaluation

- Compared against:
  - C-MAPSS results
  - Actual Engine Data
PBM Evaluation

• Diagnostics
  - Maximum Residual (MR) Threshold Fault Detection
    - Compares the largest magnitude residual to fixed threshold value
  - Neural Network Fault Isolation
  - Operates on signed percent of sum-squared residuals
  - Employs pre-trained probabilistic neural network
PBM Evaluation – Data

• Takeoff-climb-cruise profiles measuring ~2000s
• Random engine performance based on fleet distribution

• **500** Engines x **20** Profiles
  - May contain faults
## Confusion Matrix

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- Tuned for 1% False Positive Rate
  - 78% Correct Detection Rate
PBM Evaluation

• Based on Actual Engine Data
  ▪ Architecture “learns” engine-model mismatch correctly
  ▪ Select fault signatures can be observed in transient data
  ▪ Problematic during transients
  ▪ Large tuner values
Future Work

• Additional Actual Engine Data Testing
  ▪ To better understand the effectiveness

• Neural Net / Machine Learning
  ▪ To capture and absorb engine-model mismatch

• Model Simplification
  ▪ Removes PBM
  ▪ Performs diagnostics based on tuners directly
Conclusion

- Real-time Unmeasured Parameter Estimates
  - Available for control system integration
- Improved Fault Detection/Isolation
  - Latency effectively one flight
- Promising Performance with Actual Engine Data

Research conducted under the Vehicle Systems Safety Technologies project of NASA’s Aviation Safety Program
More Information

