Vehicle Integrated Propulsion Research (VIPR) Gas Path Diagnostics and Volcanic Ash Ingestion Test Results

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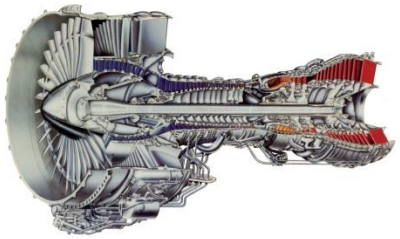
Outline

- Vehicle Integrated Propulsion Research (VIPR) Overview
- VIPR3 Gas Path Diagnostic (GPD) testing
  - Model-Based Gas Path Diagnostic Architecture
  - Bleed fault diagnostic results
- VIPR3 Volcanic Ash Environment (VAE) testing
  - VAE test overview
- Summary

Vehicle Integrated Propulsion (VIPR) Engine Test Program

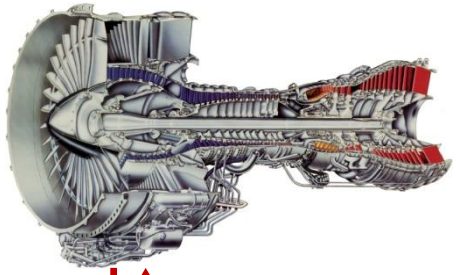
- VIPR is a series of ground-based on-wing engine demonstrations to mature aircraft engine health management technologies
- Test vehicle is a U.S. Air Force C-17 aircraft equipped with Pratt & Whitney F117 engines
- VIPR partners include NASA, U.S. Air Force and other external organizations
- VIPR test schedule
  - VIPR1 (2011)
  - VIPR2 (2013)
  - VIPR3 (2015)
- VIPR3 testing covered in this presentation:
  - Gas Path Diagnostics (GPD): A series of nominal and faulted engine test cases
  - Volcanic Ash Environment (VAE): Low concentration engine ash ingestion testing

Boeing C-17 Globemaster III



Pratt & Whitney F117 Turbofan Engine

VIPR3 Gas Path Diagnostics Test Architecture



Data acquired from aircraft bill-of-material sensors and advanced EHM sensors

On engine

In aircraft cargo bay

Bleed faults manually inserted

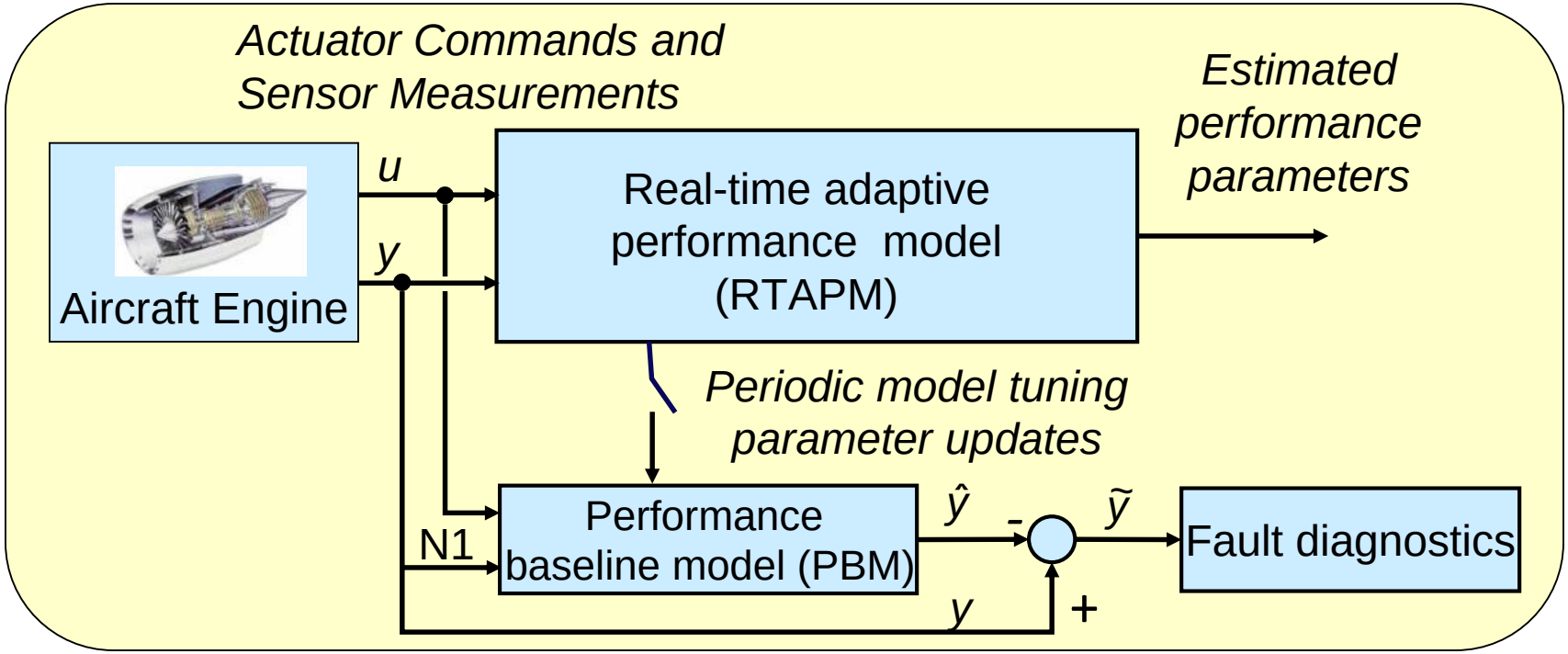
Bleed valve control boxes used to manually insert station 2.5 and 14th stage bleed valve faults

NASA Data Acquisition Pallet

EHM sensor data acquisition and signal processing

Real-time laptop displays

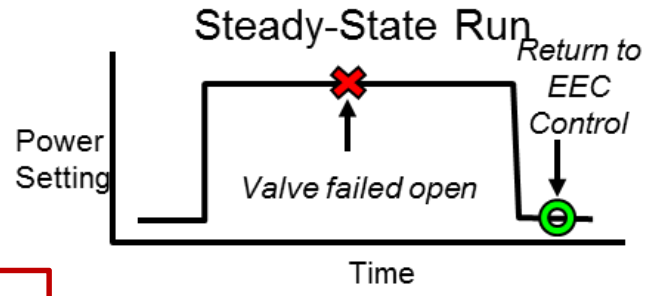
Model-Based Gas Path Diagnostic Architecture

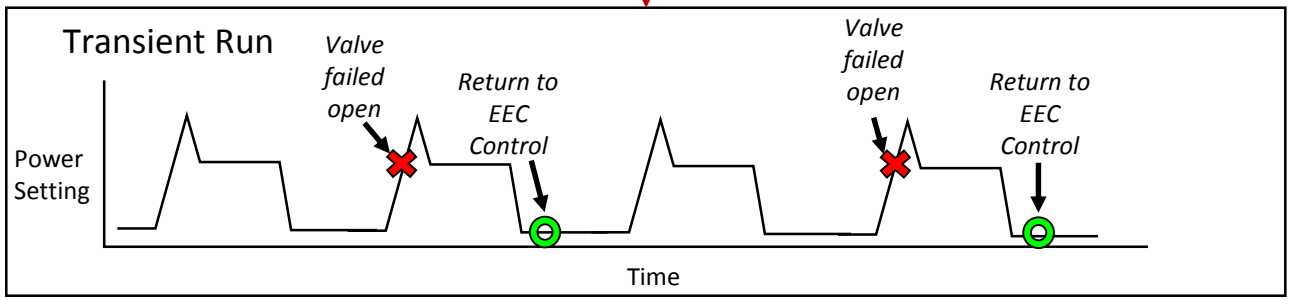


- Real-time adaptive performance model (RTAPM): Self-tuning Kalman filter design which applies NASA-developed optimal tuner selection methodology. Provides estimates of unmeasured engine performance parameters.
- Performance baseline model (PBM): Serves as a baseline of engine performance.
- Fault diagnostics: Analyzes residuals between sensed engine outputs and PBM estimated outputs for fault detection and isolation purposes.

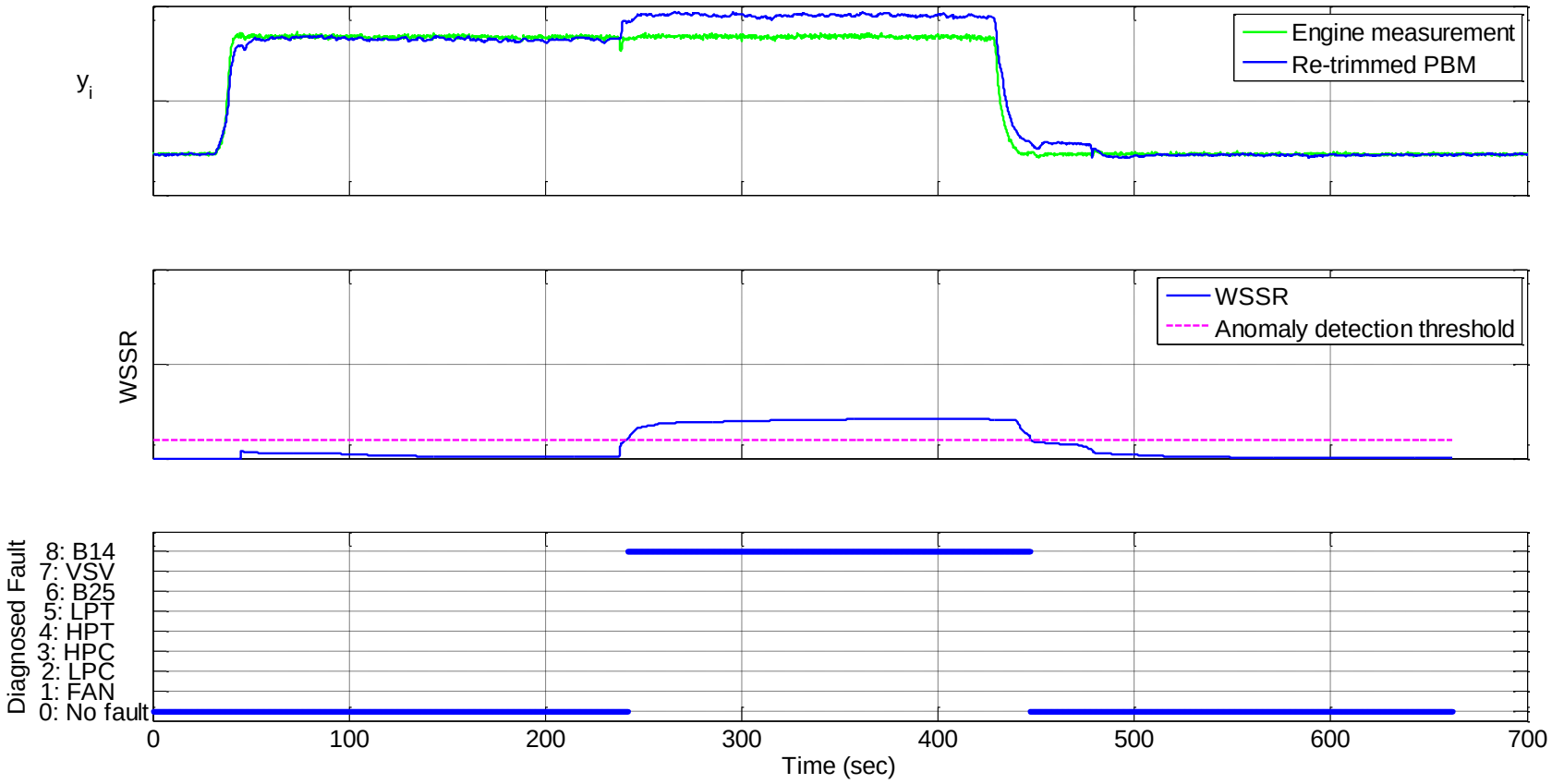
VIPR3 GPD Bleed Fault Testing

- VIPR3 GPD Bleed Fault Scenarios
  - EHM Baseline Engine Run
  - 2.5 Failed full-open baseline
  - 2.5 Failed full-open at steady-state
  - 2.5 Failed full-open during ramp accel
  - 2.5 Failed full-open during snap accel
  - 14th Failed full-open baseline
  - 14th Failed full-open at steady-state
  - 14th Failed full-open during ramp accel
  - 14th Failed full-open during snap accel

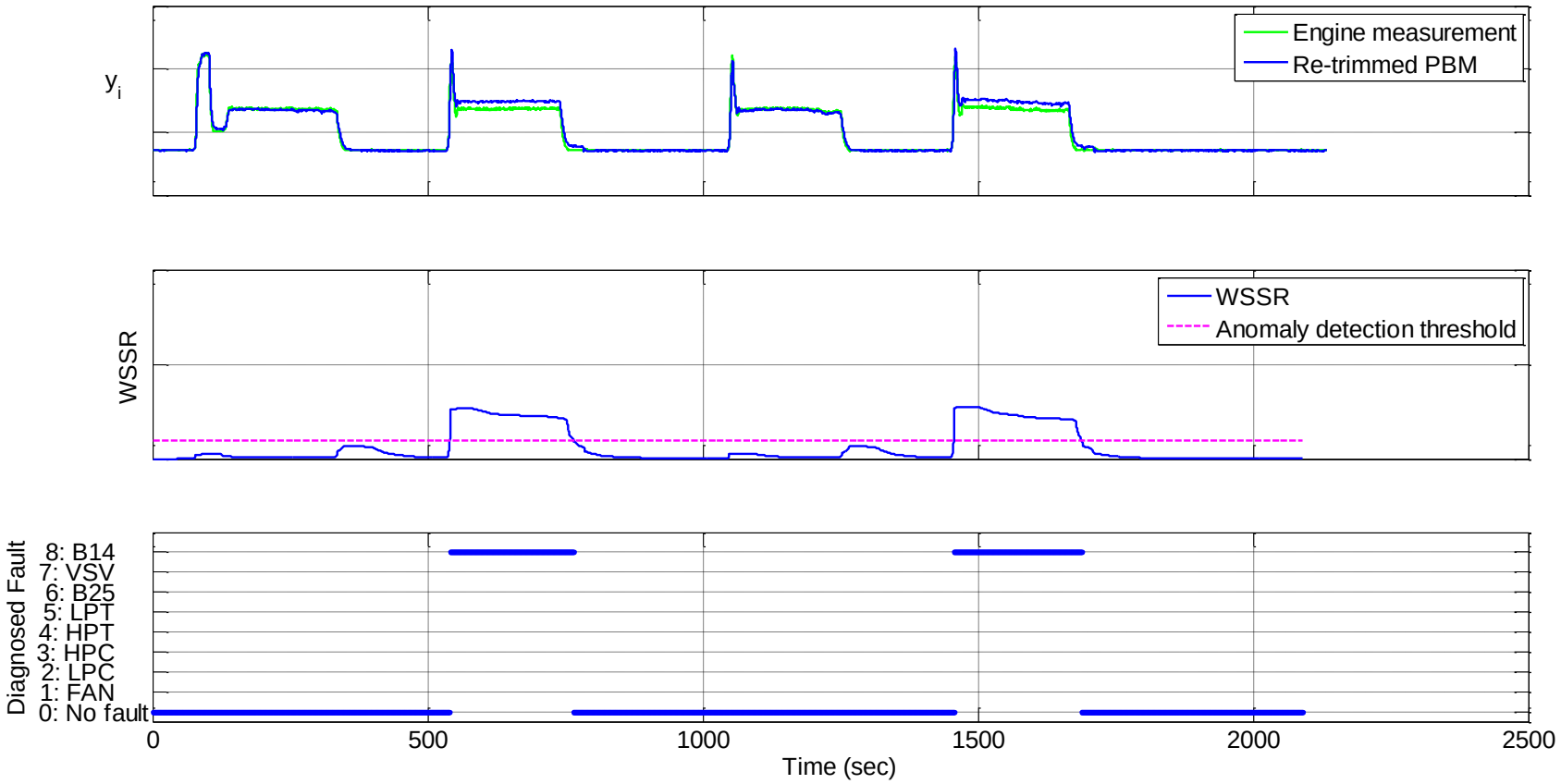




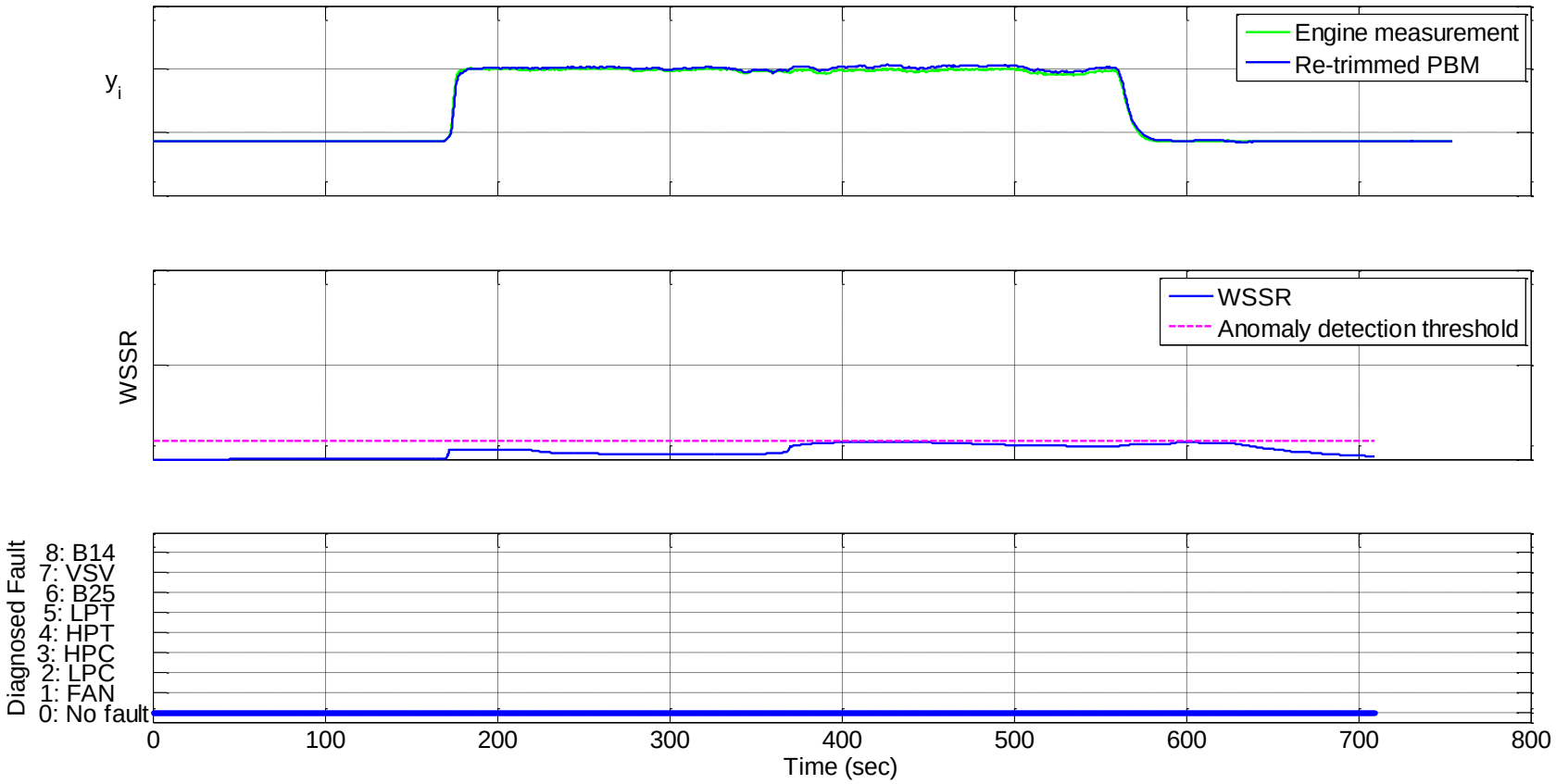
BLD14 Failed at Steady-State



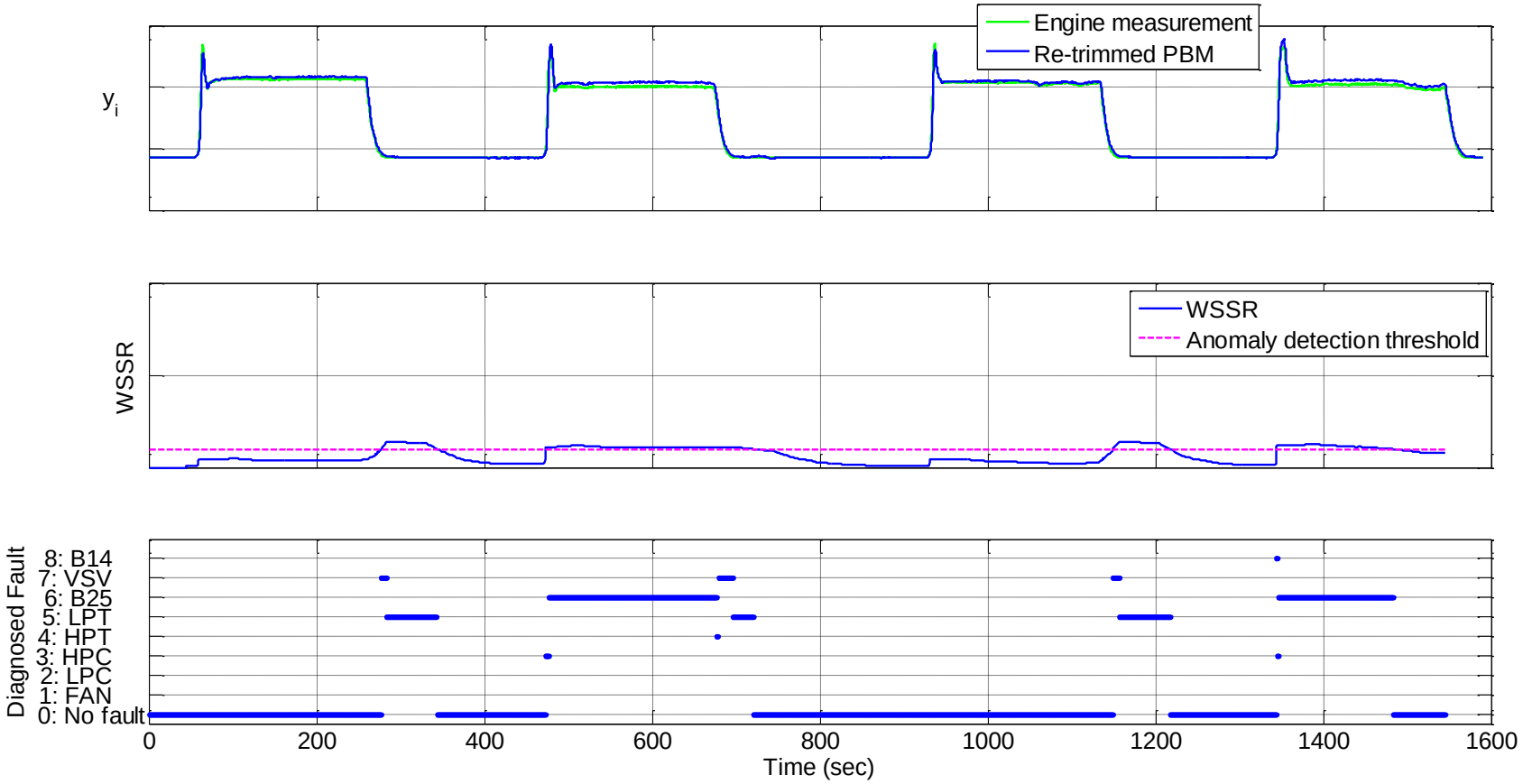
BLD14 Failed During Snap Accel



BLD25 Failed at Steady-State



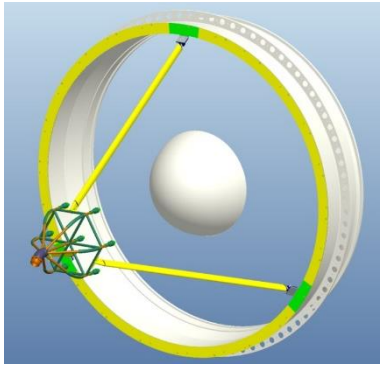
BLD25 Failed During Snap Accel



VIPR3 Volcanic Ash Environment (VAE) Testing

- Background:
  - Airborne volcanic ash poses a significant risk to aircraft gas turbine engines and can interrupt air travel resulting in revenue loss
  - Limited understanding of the effect of low ash concentration level encounters (previous volcanic ash engine testing conducted by Mike Dunn (Calspan) evaluated much higher ash concentrations levels)

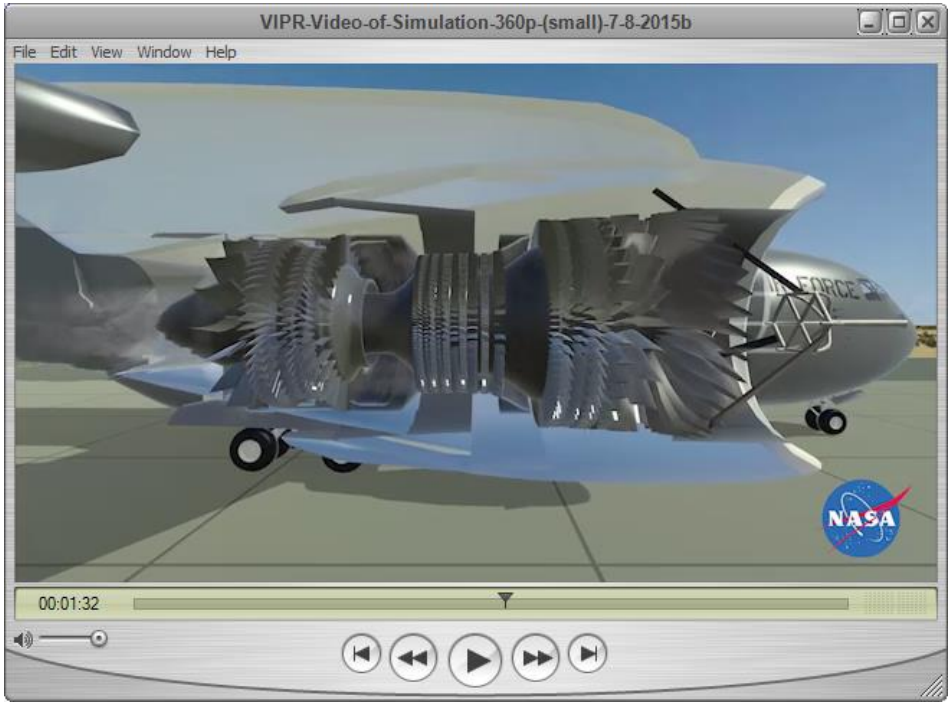
- VIPR3 VAE Goals:
  - Introduce volcanic ash into the engine inlet to emulate engine ash ingestion due to ash cloud encounters in flight
  - Focus on low concentration levels (near the visually discernable threshold)
  - Characterize engine performance degradation due to ash ingestion
  - Evaluate the capability of advanced engine health management technologies for diagnosing volcanic ash induced engine degradation



Spray nozzle configuration for introduction of volcanic ash into engine

- VIPR3 VAE Approach:
  - Utilized Mazama ash in the 5 to 60 micron particle size range
  - Exposed the engine to ash mass ingestion rates equivalent to ash cloud encounters in the 1 to 10 mg/m^3 concentration range

VIPR3 Volcanic Ash Environment (VAE) Testing Overview



Video overview of VIPR3 Volcanic Ash Environment (VAE) Test

Summary

- Gas Path Diagnostic (GPD) Testing
  - Model-Based Gas Path Diagnostic Architecture applied for processing streaming (continuous) aircraft engine measurement data and diagnosing bleed faults
- Volcanic Ash Environment (VAE) Testing
  - Successfully introduced volcanic ash into engine
- Additional data analysis ongoing

References

- Model-Based Diagnostic Architecture
  - Simon, D. L., (2010), “An Integrated Architecture for Onboard Aircraft Engine Performance Trend Monitoring and Gas Path Fault Diagnostics,” Proceedings of The 2010 JANNAF Joint Subcommittee Meeting, Colorado Springs, CO, May 3-7.
  - Armstrong, J.B., Simon, D.L., (2011), “Implementation of an Integrated On-Board Aircraft Engine Diagnostic Architecture,” AIAA-2011-5859, 47th AIAA Joint Propulsion Conference & Exhibit, San Diego, CA, July 31-August 3.
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  - Gary W. Hunter, John D. Lekki, Donald L Simon. “Development and Testing of Propulsion Health Management,” Proceedings of the Workshop on Integrated Vehicle Health Management and Aviation Safety; Bangalore, India; January 2012.
  - Lekki, John D., Simon, Donald L., Hunter, Gary W., Woike, Mark, Tokars, Roger P., “Vehicle Integrated Propulsion Research for the Study of Health Management Capabilities,” Turbine Engine Technology Symposium, September 2012, Dayton, OH.