Vehicle Integrated Propulsion Research (VIPR)

Ground-test Maturation of Engine Health Management (EHM) Technology

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Vehicle Integrated Propulsion Research (VIPR) Overview

EHM technology testing is challenging:

- Expensive
- Dedicated testing is necessary to demonstrate technology against known system "ground truth" state.

Partnerships make it possible:

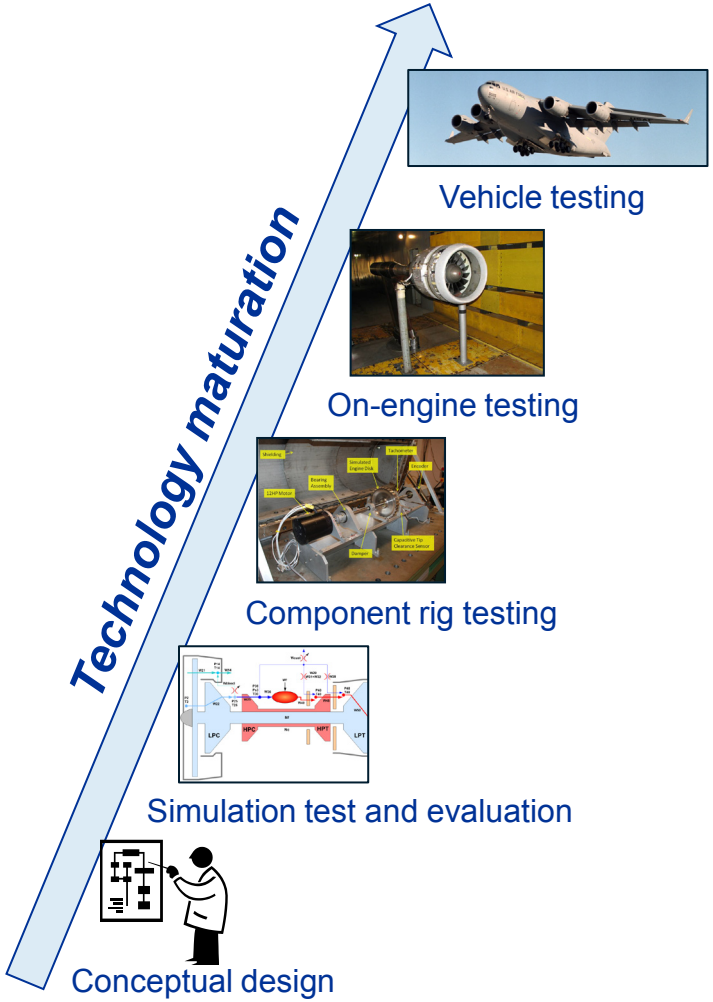
- Sharing of costs, results and benefits
- VIPR partners include NASA, Air Force, Pratt & Whitney and a growing list of other government agencies and industry partners.

Pratt & Whitney
A United Technologies Company

VIPR test approach:

- A series of on-wing engine ground tests
- Includes "nominal" and "faulted" engine operating scenarios
- Technologies under evaluation include advanced EHM sensors and algorithms

VIPR Test Schedule

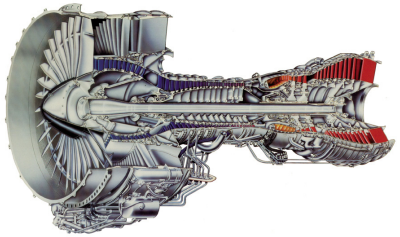


Testing is a necessary and challenging component of Engine Health Management (EHM) technology development.

VIPR I Test Overview

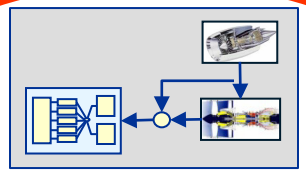
- VIPR I test was conducted in December 2011 at NASA Dryden / Edwards Air Force Base
- Test vehicle:
  - Boeing C-17 Globemaster III
  - Equipped with Pratt & Whitney F117 turbofan engines
- VIPR 1 EHM ground tests included:
  - A series of nominal and faulted engine test cases
  - Data collected over a range of power settings including quasi-steady-state and transient operating conditions

Boeing C-17 Globemaster III



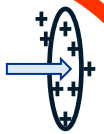
Pratt & Whitney F117 Turbofan Engine

VIPR I – EHM Technologies Under Test



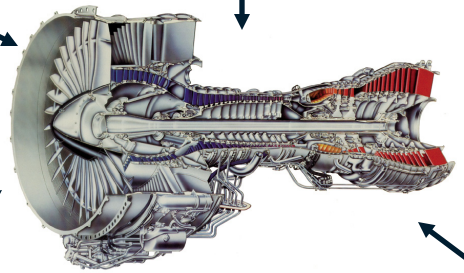
Model-based performance estimation and diagnostics

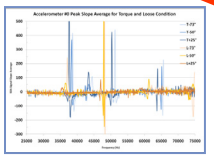
Legacy instrumentation
- Inlet debris monitoring system
- Station 2.5 pressure and temp
- High fidelity fuel flow measurement



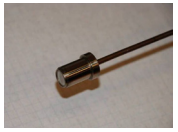
MAKEL ENGINEERING

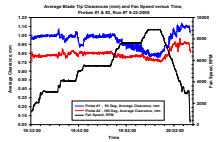
Emissions Sensor System (CO, Hydrocarbons, CO2, O2, NOx)





Self-Diagnostic Accelerometer and High Frequency Vibration Sensors



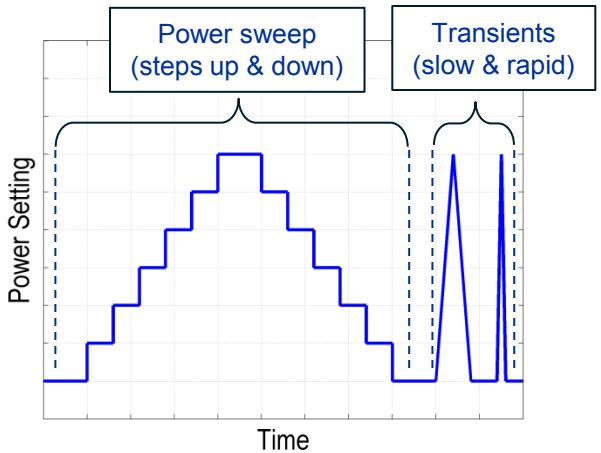


Microwave Blade Tip Clearance / Blade Tip Timing Sensors (EMI/EMC checkout only)

Multiple EHM sensors/algorithms tested during VIPR I
Valuable for identifying real-world implementation issues/concerns
Testing of multiple technologies also allows assessment of information fusion benefits

VIPR 1 – Test Scenarios

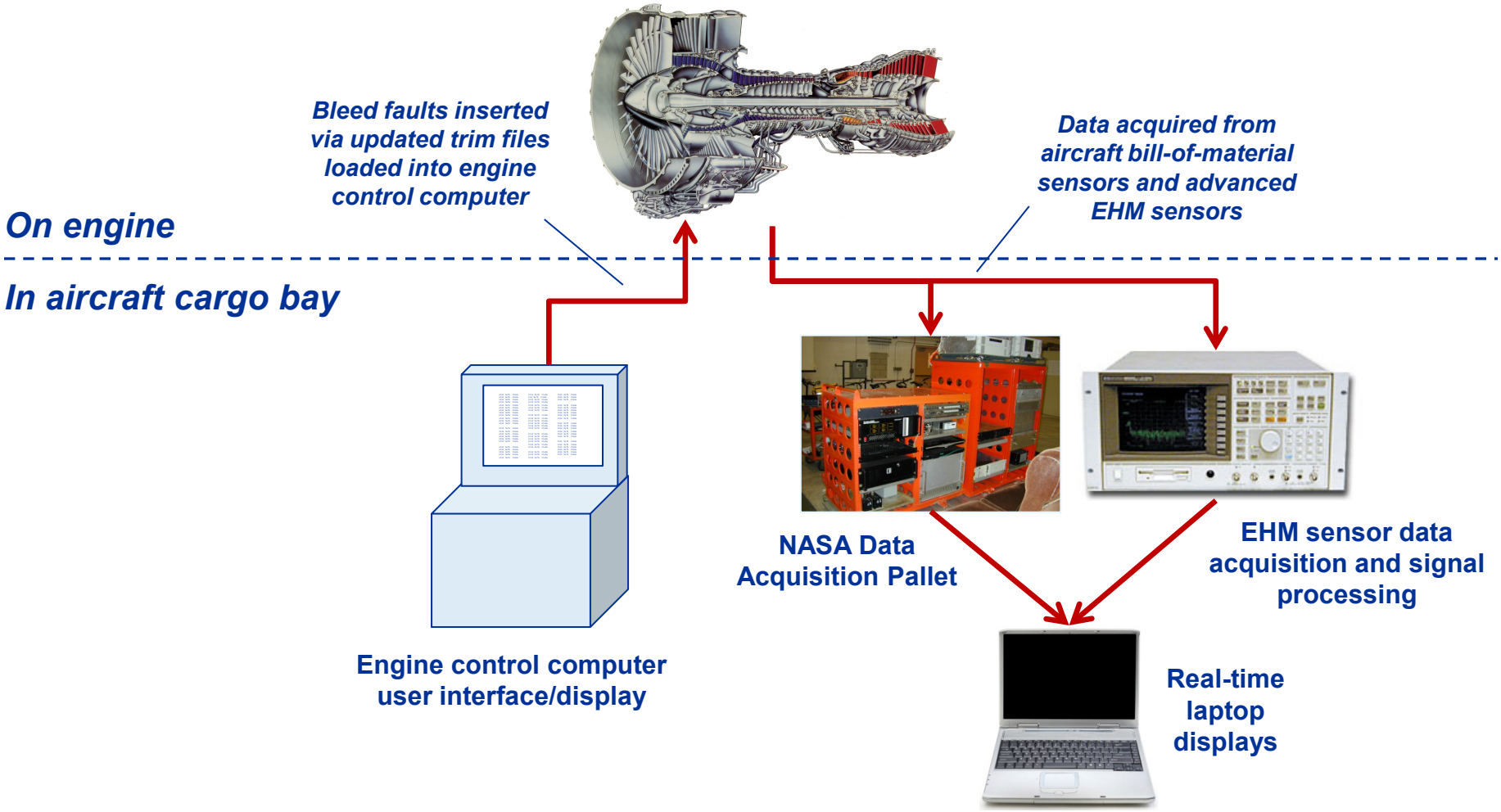
- Preservation oil burn-off during initial “green engine” run
- Nominal engine baseline runs
- Bleed fault engine runs
  - Station 2.5 bleed fault
  - Stage 14 bleed fault



VIPR Event Test Sequence (notional)

Test sequences conducted during VIPR I enabled data acquisition over a range of power settings, including quasi-steady-state and transient engine operating scenarios.

VIPR 1 – Test and Data Acquisition Process



VIPR Test Architecture

VIPR I Post-Test Data Analysis
(*Preliminary Results*)

- Model-based performance estimation and diagnostics
  - Steady-state measurement residuals (faulty vs. nominal baseline) found to be in good agreement with model predictions for each fault type.
  - Model-based diagnostic architecture trained on a single baseline run and then used to analyze remaining runs. With training:
    - Model-engine residuals reduced on subsequent baseline runs.
    - Model-engine residuals exhibit increases on fault runs.
  - Future steps will be taken to:
    - Improve model accuracy at specific power settings and during engine transients.
    - Evaluate the effectiveness of different machine learning techniques applied to capture engine-model mismatch.

VIPR I Post-Test Data Analysis
(*Preliminary Results - continued*)

- Emission Sensor System (ESS)
  - Baseline emission levels established.
  - Discernable change in emissions observed during preservation oil burn-off.
  - Demonstrated system under nominal and seeded fault conditions. The ESS system in general tracked a wide range of varying engine conditions.

- Microwave blade timing / tip clearance sensor
  - Successfully passed electro-magnetic interference (EMI) / electro-magnetic compatibility (EMC) checkout.
  - Cleared for actual on-engine use for future VIPR tests at DFRC.

- Self-diagnostic accelerometer (SDA)
  - Four SDAs, attached at engine B-flange and gearbox, successfully completed first-ever demonstration in engine environment.
  - SDA able to successfully detect un-torquing (loosening) of accelerometer connection.

VIPR Testing – Future Plans

- Continue VIPR I post-test data analysis
  - Develop and evaluate engine fault diagnostics
  - Develop and evaluate the benefits of information fusion combining advanced EHM sensors and algorithms

- VIPR II and VIPR III
  - Follow-on engine testing is planned to evaluate additional EHM sensors and algorithms under nominal and faulted engine operating scenarios