National Aeronautics and Space Administration

Vehicle Integrated Propulsion Research Tests

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Propulsion Controls and Diagnostics Workshop
December 11, 2013
Cleveland, OH

VIPR Overview

Vehicle Integrated Propulsion Research (VIPR) engine tests to support the research and development of Engine Health Management Technologies for Aviation Safety

Engine testing is a necessary and challenging component of Aviation Safety technology development.

Partnerships make it possible.

Test Objectives:

Demonstrate capability of advanced health management technologies for detecting and diagnosing incipient engine faults before they become a safety impact and to minimize loss of capability

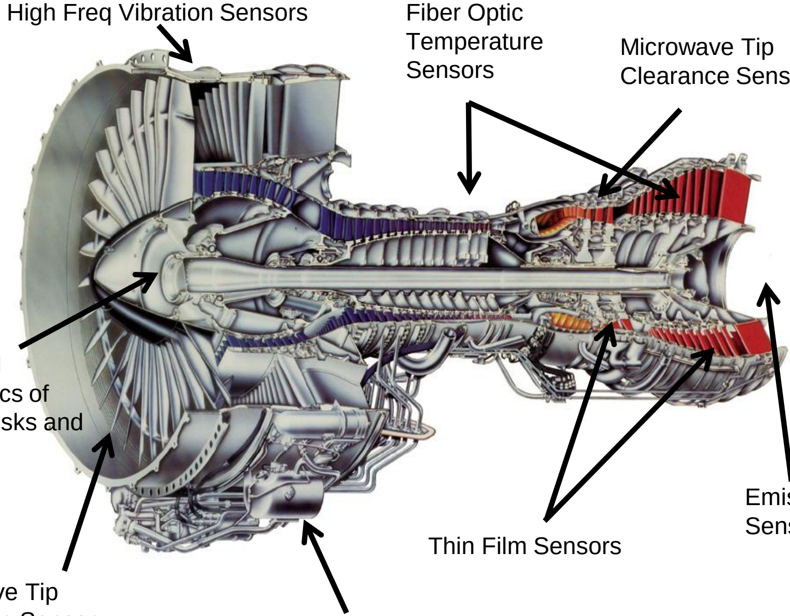
Approach:

Perform engine ground tests using large bypass transport engine

- **Normal engine operations**
- **Seeded mechanical faults**
- **Seeded gas path faults**
- **Accelerated engine life degradation through volcanic ash ingestion testing**

Partnerships:

- **NASA**
- **Air Force**
- **Federal Aviation Administration**
- **Pratt & Whitney**
- **GE**
- **Rolls-Royce**
- **United States Geological Survey**
- **Boeing**
- **Makel Engineering**
- **Others in discussion**



Model-based gas path diagnostic architecture

Ground Testing Overview

VIPR 1 (December 2011):

Modify a heavily instrumented F117 engine with an advanced suite of sensors, confirm sensor operation, characterize nominal engine operation parameters and validate gas path models.

VIPR 2 (July 2013):

Employ selected sensors to detect and characterize impacts of certain seeded faults and validate off-nominal gas path models. Faults are expected to include intentional operation with contaminated and/or inadequate lubrication, operation with intentional rotor or turbine imbalances, and other intentionally inserted and known faults.

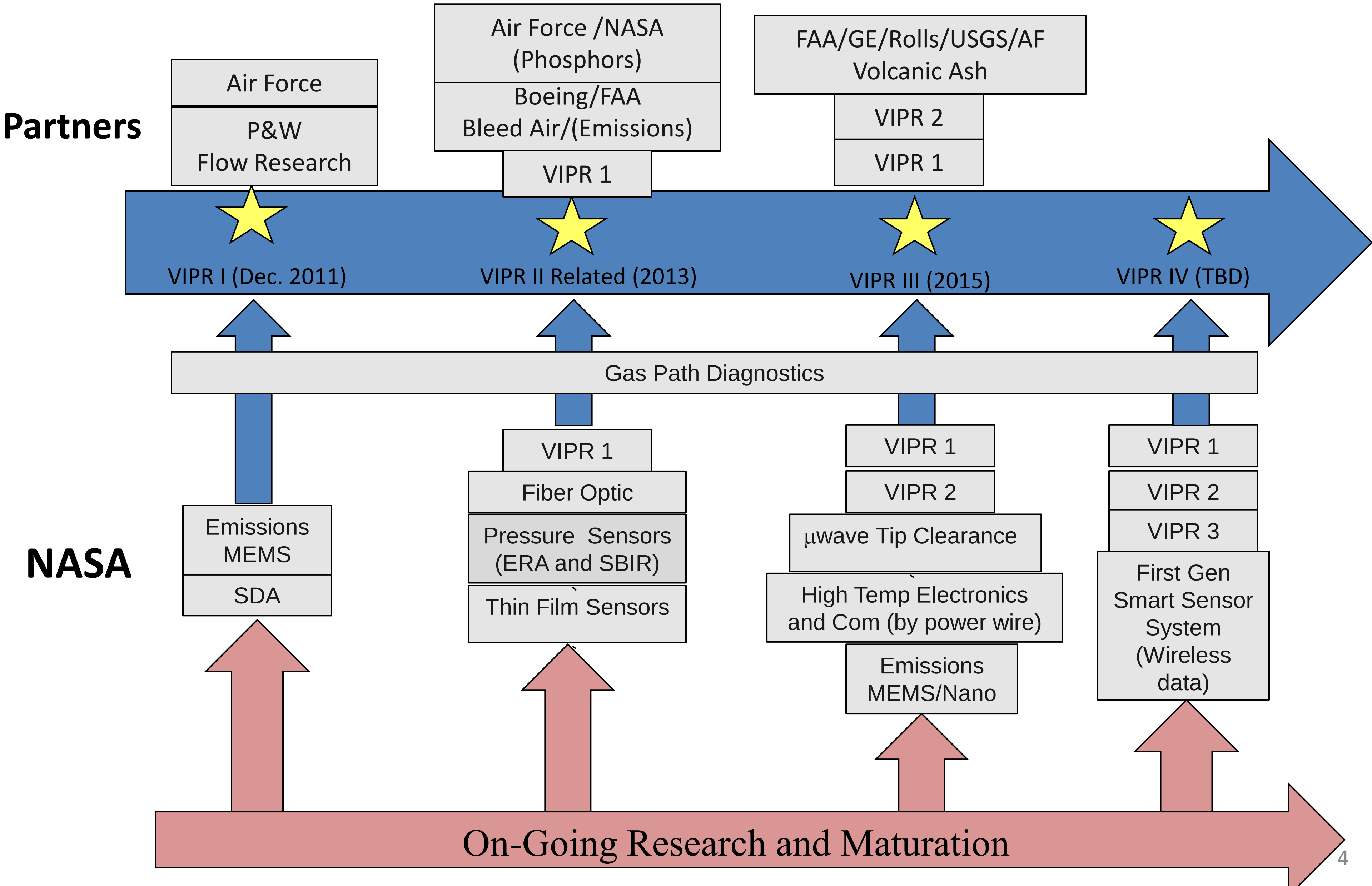
VIPR 3 (2015):

Determine capability of advanced detection and diagnostic systems to characterize engine performance, and identify fault modalities, in the presence of higher-risk conditions such as actual or synthetic volcanic ash, with operation potentially all the way to contained engine failures.

All VIPR ground testing is planned to be conducted on an Air Force C-17 aircraft at Edwards AFB, California.

VIPR Overview

Engine Testing as Part of Technology Development



VSST National Impact

VIPR Research maturing key turbine engine technologies
Relevant to a range of aerospace manufacturers

NASA's work on these technologies in VIPR

- Microwave Tip Clearance (design concept demonstrated)
- Fan research (CFD validation data set generated)
- Vibration Sensors (Concurrent sensor health and measurement validated)
- Gas Path Analysis (Transient fault behavior captured)

→ Incorporated for use here

Example: Relevant technology plan

- High performance turbine
- Ultra high bypass
- Engine Health Monitoring
- Model based control

→ Benefit

- Weight reduction
- Improved fuel burn
- Reduced maintenance cost
- Maintain safety

VIPR 2 Summary
Testing complete: highly successful overall

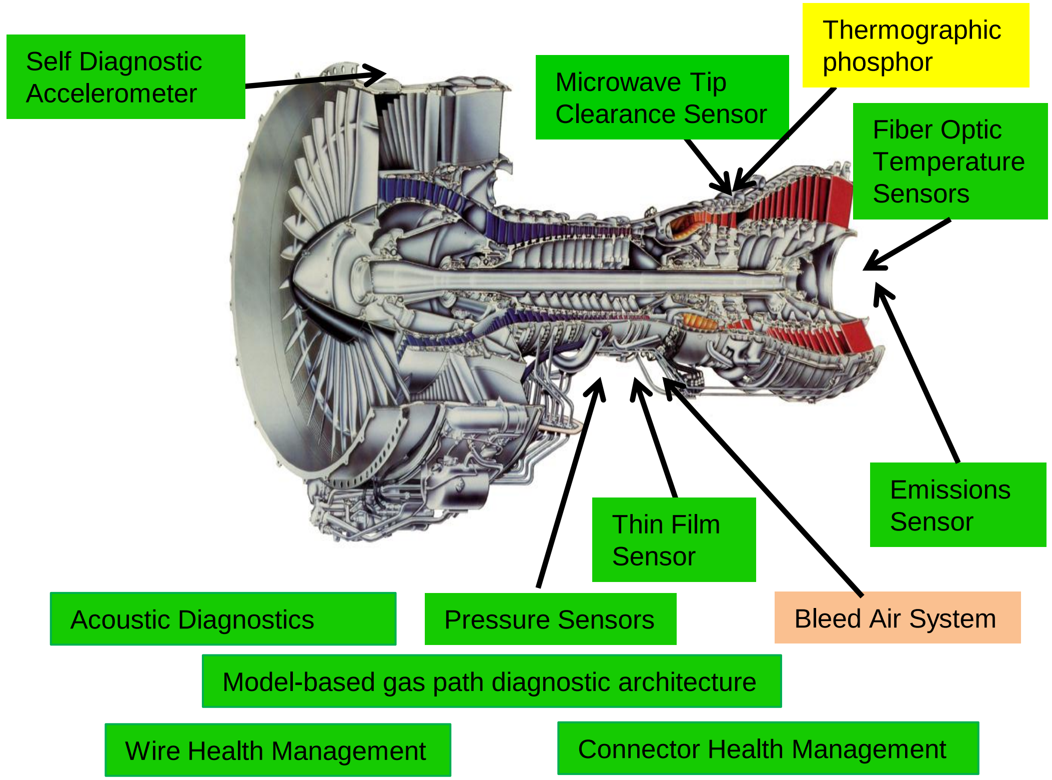
<u>Highlights:</u>

- Normal engine operations
- Seeded mechanical and gas path faults
- 9 Health Management Technologies fully successful
- Bleed Air Integrated and prepared for test but not tested

<u>Status in 2013:</u>

- VIPR 2 Test completed in July at DFRC
- Green Run test completed in October

VIPR 3 planned for Spring 2015



DFRC GRC

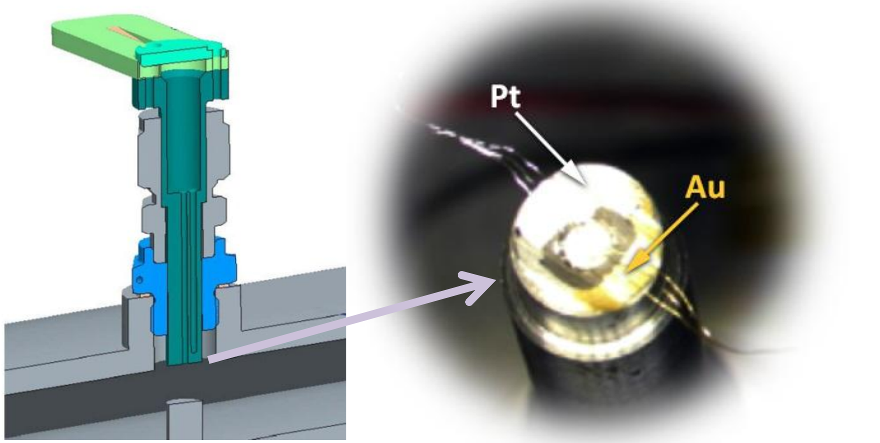
VIPR 2 Summary Results

VIPR 2 Research Area	Summary Results
Self Diagnostic Accelerometers (GRC)	All test objectives met
High Temperature Fiber Optic Sensors (GRC)	All test objectives met
Emission Sensor Suites (Makel, GRC, DFRC)	Successfully obtained data during all of EHM test points.
Thin Film Temperature Sensor (GRC)	Tested in borescope location during engine green run
Pressure Sensors (GRC)	All test objectives met
Bleed Air and Extraction System (Boeing, Makel, GRC)	Successful integration and implementation but not tested
Acoustic Diagnostic (DFRC)	All test objectives met
Connector Health Monitoring (UTRC)	All test objectives met
Wire Health Monitoring (ARC)	All test objectives met
Microwave Blade Tip Clearance Sensor (GRC)	Successfully tested in High Turbine during engine green run
Thermographic Phosphors for blade temperature (GRC)	System tested for a short time during engine green run but removed after optical probe failure
Gas Path Health Management (GRC)	All test objectives met

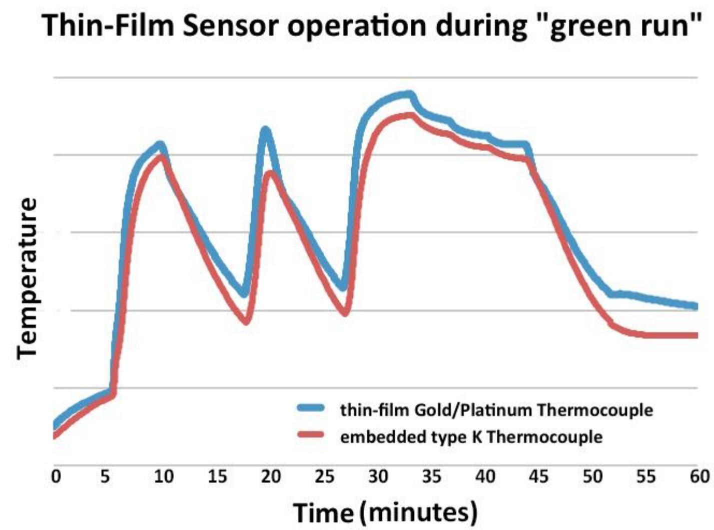
VIPR II+ Thin Film Thermocouple Successfully Demonstrated

- Thin-Film thermocouple sensor prototype operation validated during F117 engine "green run" check-out
  - Sensor tracked dynamic temperature changes as engine cycled through multiple power settings
  - Embedded ANSI-standard Type K thermocouple monitored for comparison
  - Provides information related to dynamic conditions within the engine; part of information fusion to better understand the overall health state of the engine
- Sensor prototype fabricated in-house
  - Thin films of Au, Pt deposited on tip of steel body
  - 0.003" wires bonded to films and cemented into body
  - Custom adapter for mounting in borescope port
  - Qualified in-house for vibration, temperature and pressure (20g shock, max. 633°C at 777 psig)
- Next Challenges:
  - Shift to ceramic sensor body for harsher environments
  - Incorporate sensors in active control systems

Thin Film TC Sensor Design

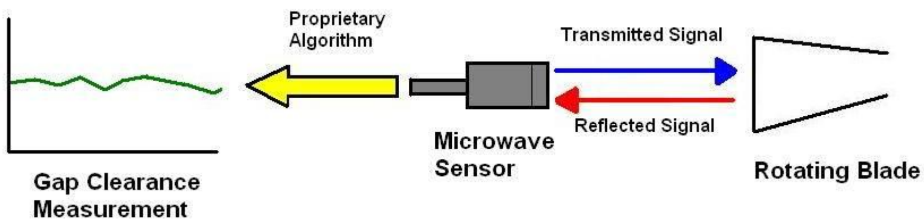


Sensor tip with 0.003" wires attached to deposited thin films



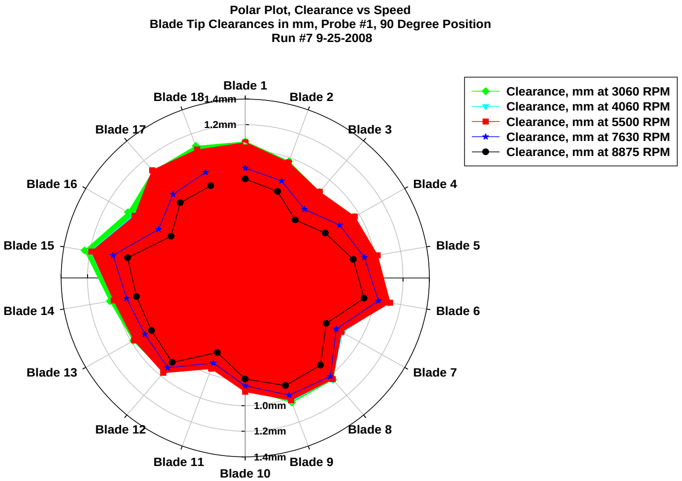
Microwave Tip Clearance Sensor

- Microwave blade tip clearance sensor technology for use in turbine engines
  - Structural health monitoring – tip clearance and tip timing
  - Active closed loop clearance control - tip clearance



Microwave sensors installed on the NASA Turbofan Test Rig at the GRC's 9x15 LSWT

- Targeted for use in hot sections of turbine engines (High Pressure Turbine section)
  - Rated for use in high temperature environment, ~1200 ºC
  - Highly accurate, current goal of ~25um for this technology
  - Able to see through contaminants that exist in the engine flow
- MWBTCS successfully tested in engine test in October 2013. First known test of integrally cooled tip clearance sensor in the high turbine.



Clearance data acquired on the NASA Turbofan Test Rig

VIPR I testing of the Self Diagnostic Accelerometer

Roger Tokars (GRC) John Lekki (GRC) December 2011

The Self Diagnostic Accelerometer (SDA) was mounted and tested on the C-17 engine in order to demonstrate the SDA's flight worthiness and robustness.

C-17 Aircraft

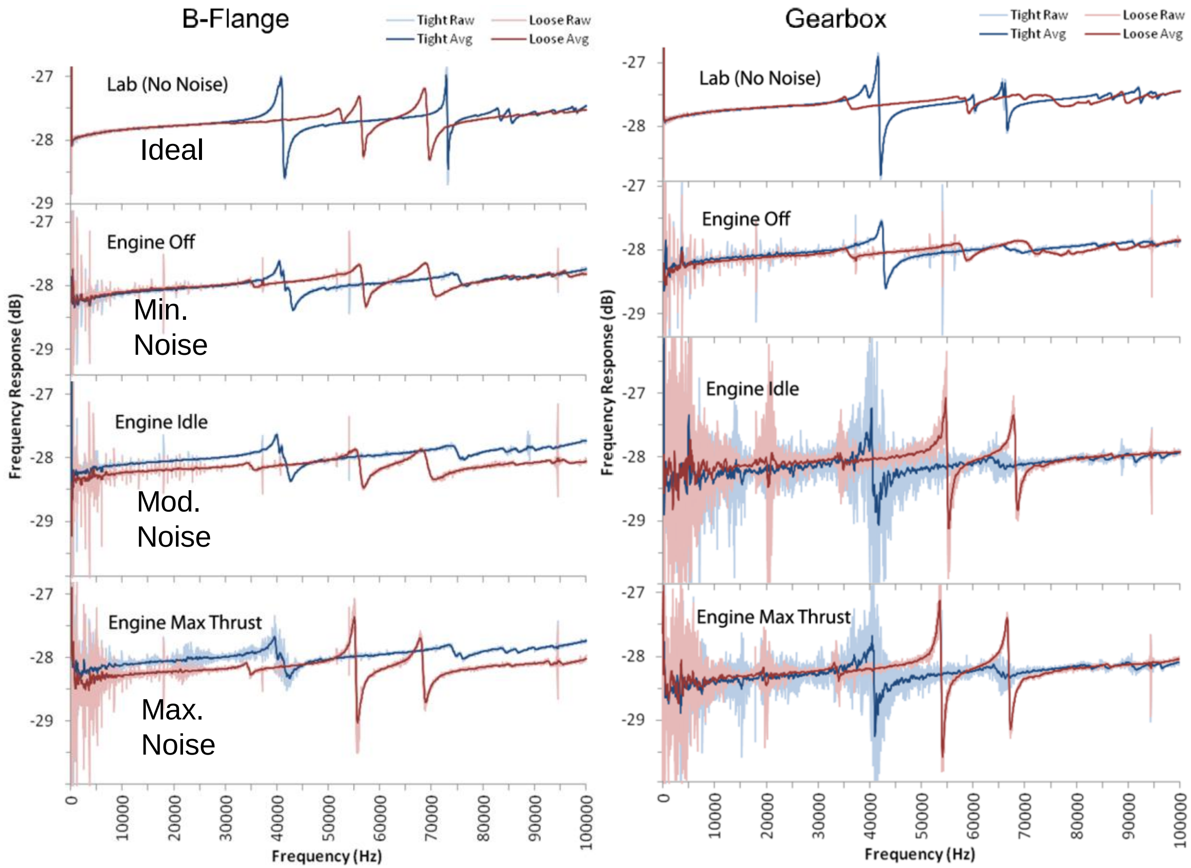
Test Locations

Accelerometer mount

Secured with safety wire

Results

Pattern recognition software successfully discriminates **all** tight and loose conditions.

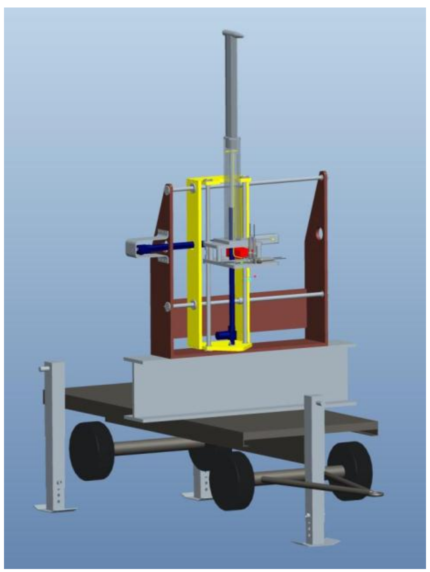


Conclusion

The Self Diagnostic Accelerometer System was successfully demonstrated in providing electro-mechanical data including the health of the sensor attachment under the extremes of an aircraft engine environment.

Preservation Oil Burn-off

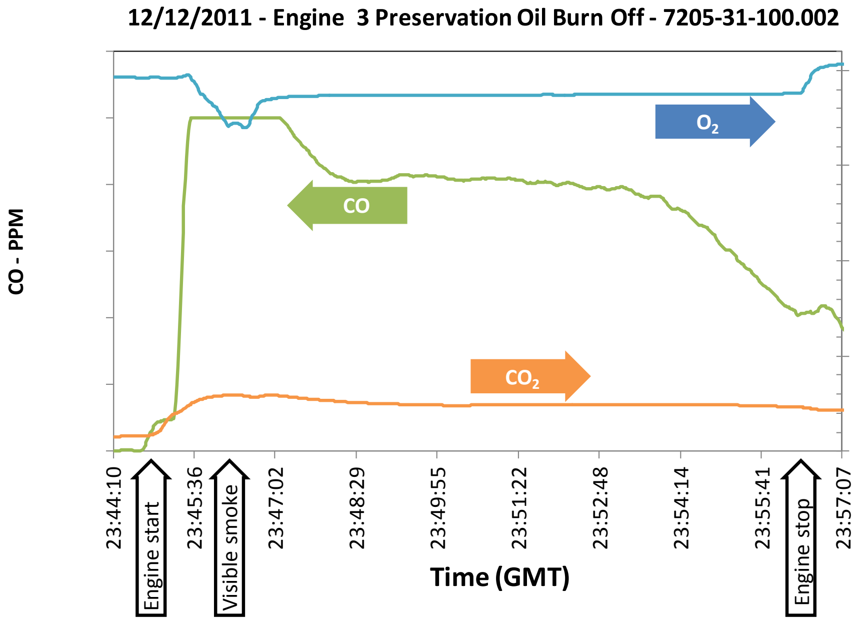
- Day 1 of VIPR testing was a “green engine run” (first time the test engine was run post-overhaul)
- Provided an opportunity to evaluate the Emission Sensor System (ESS) during preservation oil burn-off

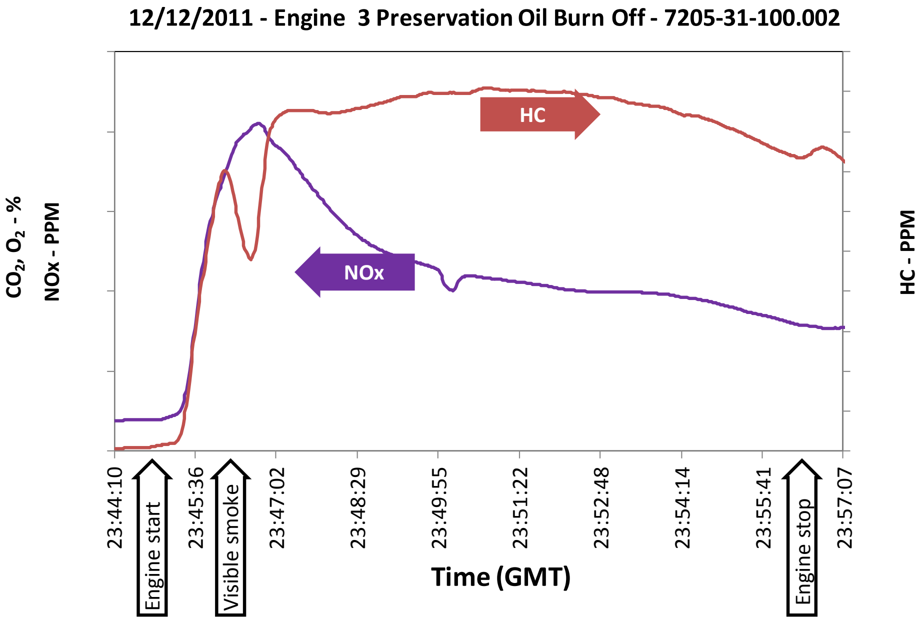


ESS Rig

Preservation oil burn-off!

Engine 3 Preservation Oil Burn Off





- Start up - ESS observed fast rise in concentrations
  - Exception – oxygen concentration dropped, as expected
- ~2 min from start up - noticeable change and recovery
- The high levels eventually tapered down to somewhat lower concentrations with the engine stable at idle

VIPR 3 Volcanic Ash Background

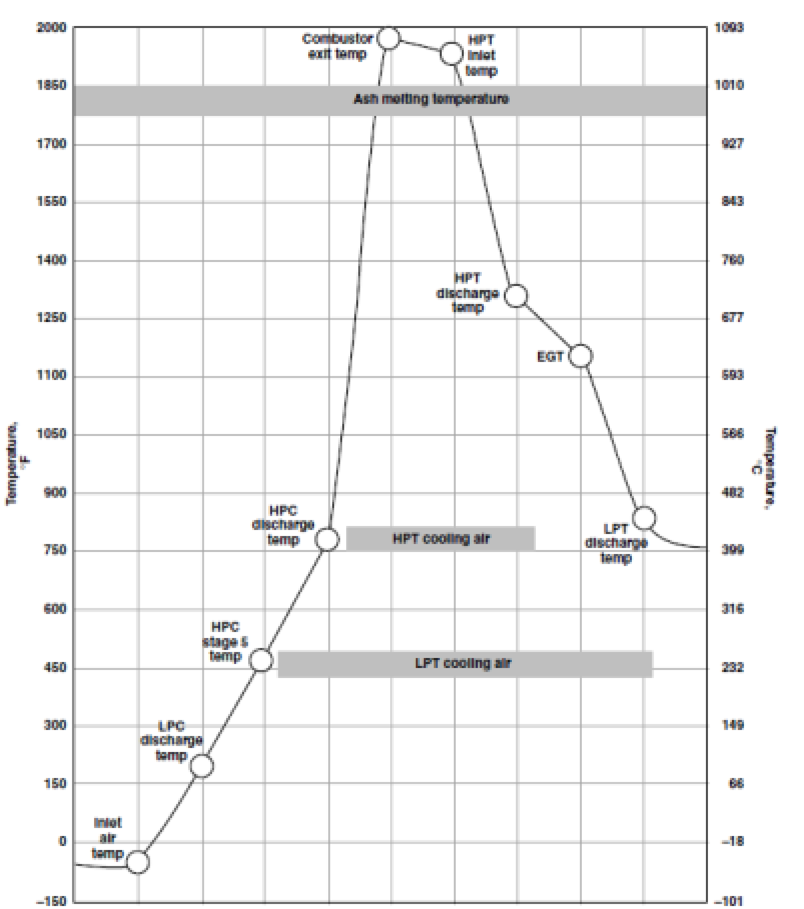
- Ash ingestion tests were conducted in the 1980's as outgrowth of nuclear bomb scenarios.
  - Tests documented severely damaging effects of high concentrations (100's of mg/m^3) of "dust" (blends of materials, one of several components being volcanic ash).
- Prompted by the situation that developed during the 2010 eruption of Eyjafjallajökull Volcano, we now want to know more about the effect of flying through much lower concentrations—i.e., a few mg/m^3.
- Current test is being conducted under the auspices of an ongoing NASA program, Vehicle Integrated Propulsion Research (**VIPR**), which supports development of sensors and models to measure jet-engine performance and diagnose problems during operation. So, VIPR is well-suited to address ash-ingestion testing.

Ash Concentrations

- Two ash concentrations around the "visible" threshold will be tested, **1 and 10 mg/m^3**. Want to have data to address the question "How stringent does the mitigation strategy of ash avoidance have to be?"
- Depending on conditions, 1 mg/m^3 ash cloud may or may not be visible to the human eye. It also represents the approximate lower limit of what reliably can be injected into the engine in a controlled experiment.
- 10 mg/m^3 ash cloud most likely will be visible and the order of magnitude difference in concentrations is expected to cause discernible differences in engine degradation effects.
- This test range also includes the "safety-case" threshold used on ash concentration charts introduced in Europe in 2010 (2-4 mg/m^3).

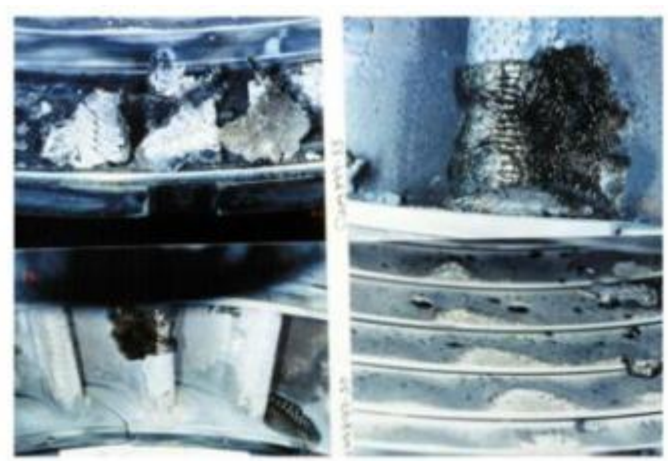
Ash in the Engine

- Compressors: Drying of ash occurs. Ash particles pulverized. Compressor erosion & abrasion possible.
- Combustion chamber at cruise in engine being tested not quite hot enough to melt all crystals (e.g., 1100-1500 ^{o}C for feldspars). But it is hot enough to soften glass (Δ viscosity at ~800^{o}C for rhyolite to ~1000 ^{o}C for basalt).
- Exiting gas stream hits *nozzle guide vanes.* Softened glass sticks (cooled slightly but still softened?). Temperature drops through turbines hundred of degrees. Any remaining softened glass moving through cools & re-hardens (to get blown out engine?).



MODERN ENGINES RUN HOTTER THAN TEST ENGINE.

Engine Temperature Data is from: NASA/TM-2003-212030



Damage from 1989 severe ash encounter in Alaska

Expected Test Results

Proprietary data rights and ITAR*/export control are issues being discussed.

***I**nternational **T**raffic in **A**rms **R**egulations– US Govt. regulations that control export & import of defense-related technical data.

However, various results are expected to be publicly available (published) including:

- Normalized performance changes in compressors and turbines.
- Hardware evaluation.
- Borescope inspections from the test.
- Teardown inspections after the test.

Summary

- VIPR 1 successfully completed in 2011
- VIPR 2 successfully completed in 2013
  - 2x research from VIPR 1
- VIPR 3 Planned for 2015
  - 3x research from VIPR 1
  - Inclusion of Volcanic ash testing
  - Rapid Engine Degradation with full suite of EHM technologies installed on Engine

Questions