Acoustic Detection of Faults and Degradation in a High-Bypass Turbofan Engine During Vehicle Integrated Propulsion Research (VIPR) Phase III Testing

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Outline

- Background on VIPR research
- Introduction to VIPR acoustics research objectives
- Motivation
- Test setup
- Volcanic Ash Ingestion Test Results
- 14^{th} Stage Bleed Valve Simulated Failure Results
- Station 2.5 Bleed Valve Simulated Failure Results
- Conclusion

VIPR Background

- Vehicle Integrated Propulsion Research (VIPR) project concluded Phase III of ground-based engine testing in Summer 2015
- Modified pre-production F117-PW-100 engine (military variant of PW 2000 used on the Boeing 757) in the 40k-lb thrust class
- Engines are representative of typical high-bypass commercial turbofans
- VIPR offered a way to introduce damaging faults that would otherwise be prohibitive

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

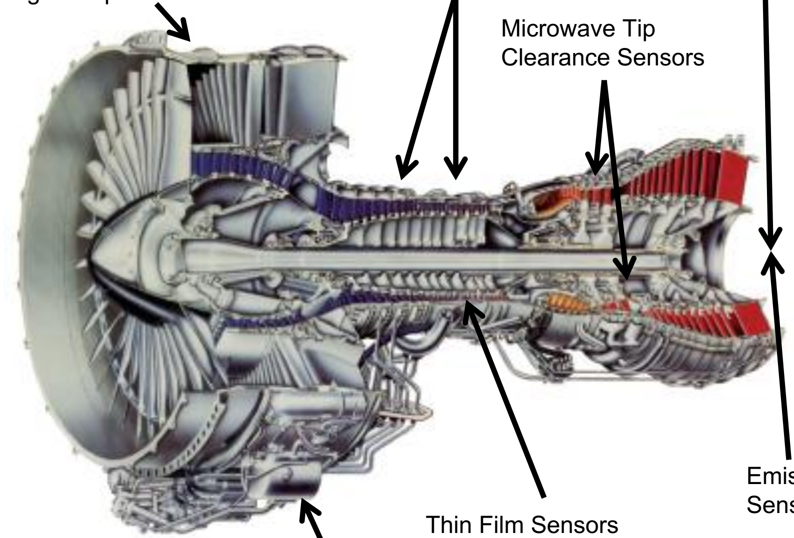
Approach:

Perform engine ground tests using high-bypass transport engine

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

Partnerships:

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



VIPR III Overview

- VIPR III Test Objectives (Summer 2015)
  - Engine Health Management (NASA):
    - Initial steps toward EHM sensor fusion with advanced sensors
    - 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
  - Volcanic Ash Ingestion Testing (AFRL and Partners)
    - Run engine to end of life (negative EGT margin)
      - Engine came out of overhaul with a fairly large positive margin
      - Goal was to run engine through accelerated performance degradation with research instrumentation collecting data throughout
    - To improve understanding of the effect on the engine of several hours of exposure to low to moderate concentrations of volcanic ash
    - Determine how well engine degradation from volcanic ash is detected with an expanded engine health management system
  - Pratt & Whitney Testing
  - Bleed Air Environment Testing (Boeing and Partners)

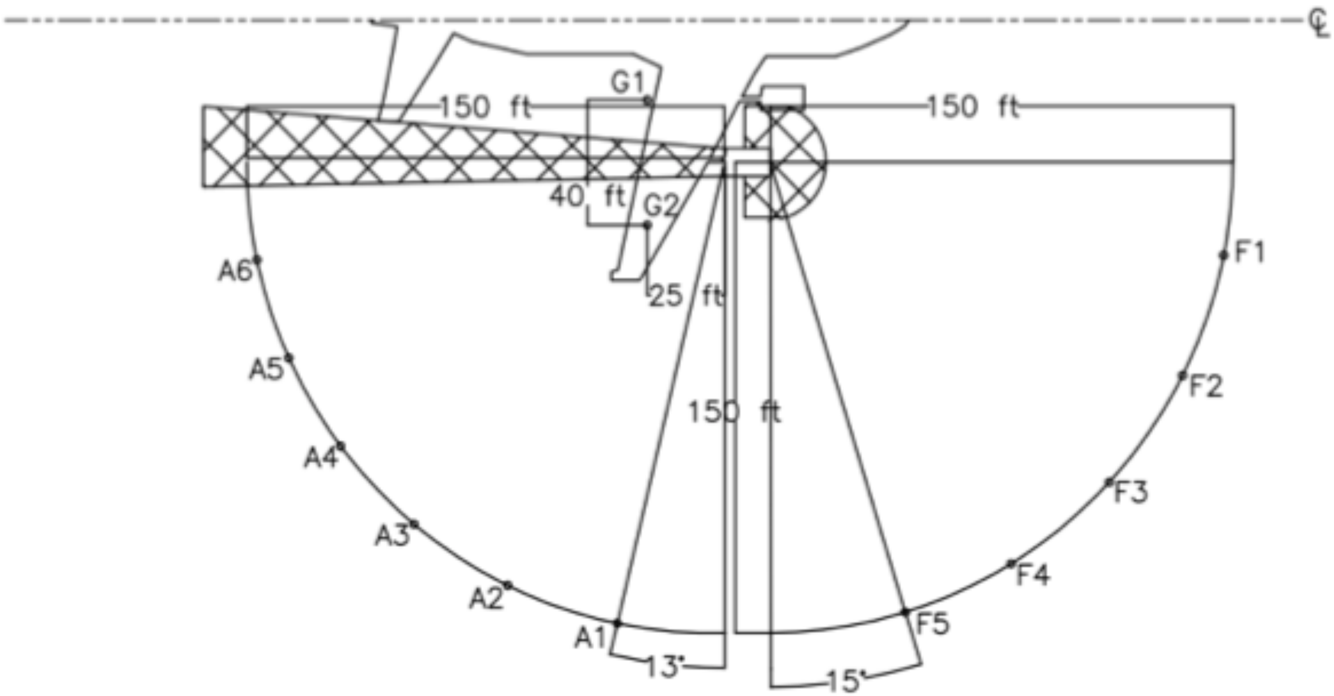
VIPR Acoustics Research

- Goal: Characterize the engine core, fan, and exhaust acoustics under nominal and off-nominal/seeded fault conditions
- Faults introduced during VIPR III included the simulated failures of the engine station 2.5 and 14th stage bleed valves to their failsafe positions as well as the accelerated performance degradation of the engine due to volcanic ash ingestion

Motivation

- The use of acoustics, if proven successful in detecting and potentially identifying faults, can progress toward condition-based maintenance
  - Ultimate goal is detection and eventual identification of common faults
- External acoustic measurements of engines is a simple and non-intrusive inspection process
- Additionally, microphones may characterize the progression of engine operational degradation
- System doesn’t have to survive the harsh environment of an engine installation in its current form

Test Setup



- 11x ½" microphones in far-field radial array relative to inlet and core exhaust planes
- 2x ¼" microphones in near-field of exhaust plane
- All mics mounted inverted one microphone diameter above steel plate

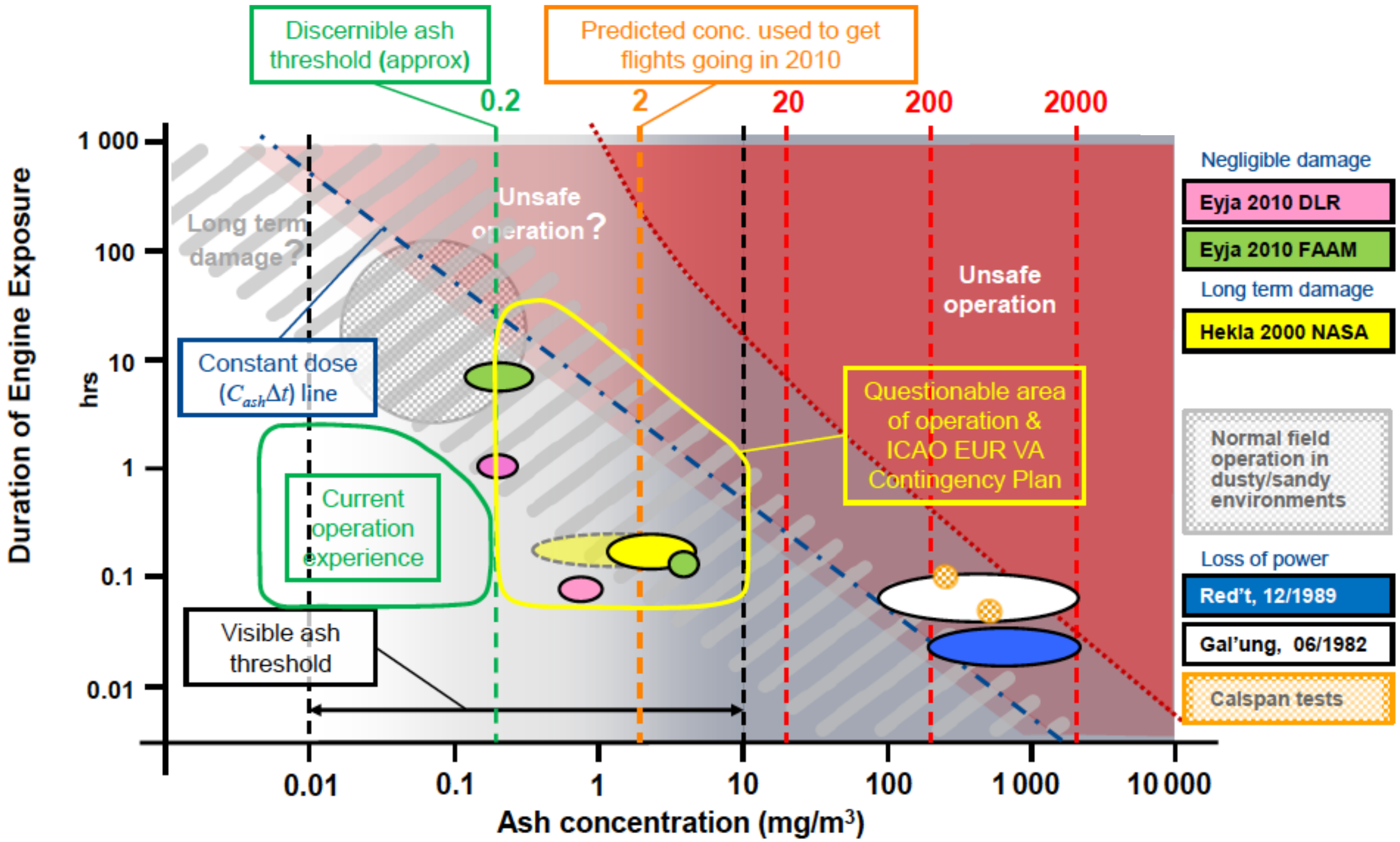
Test Setup (Continued)

NASA Photograph ED15-0188-165

NASA Photograph ED15-0188-284

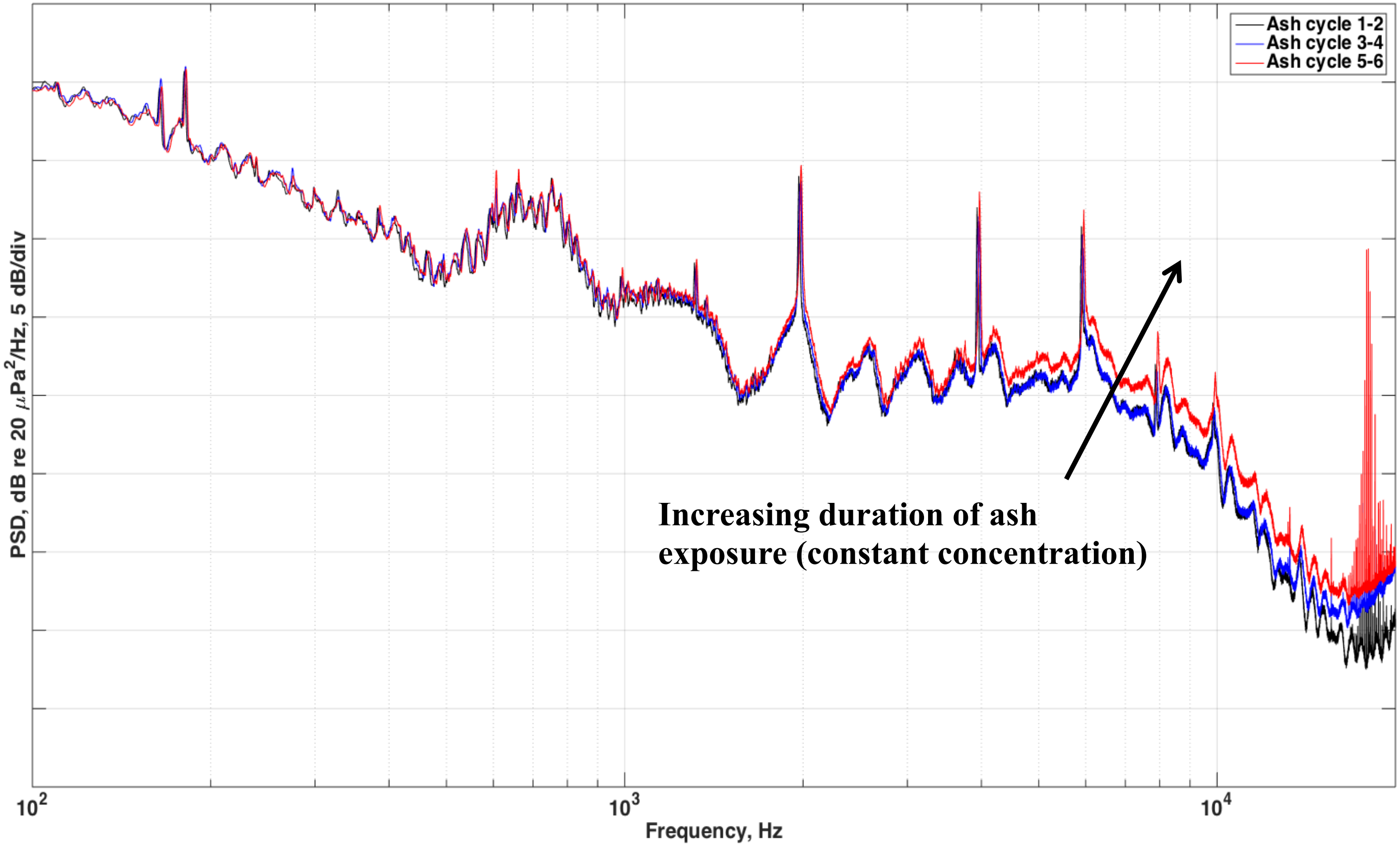
NASA Photograph ED15-0188-1005

Volcanic Ash Ingestion Testing Context



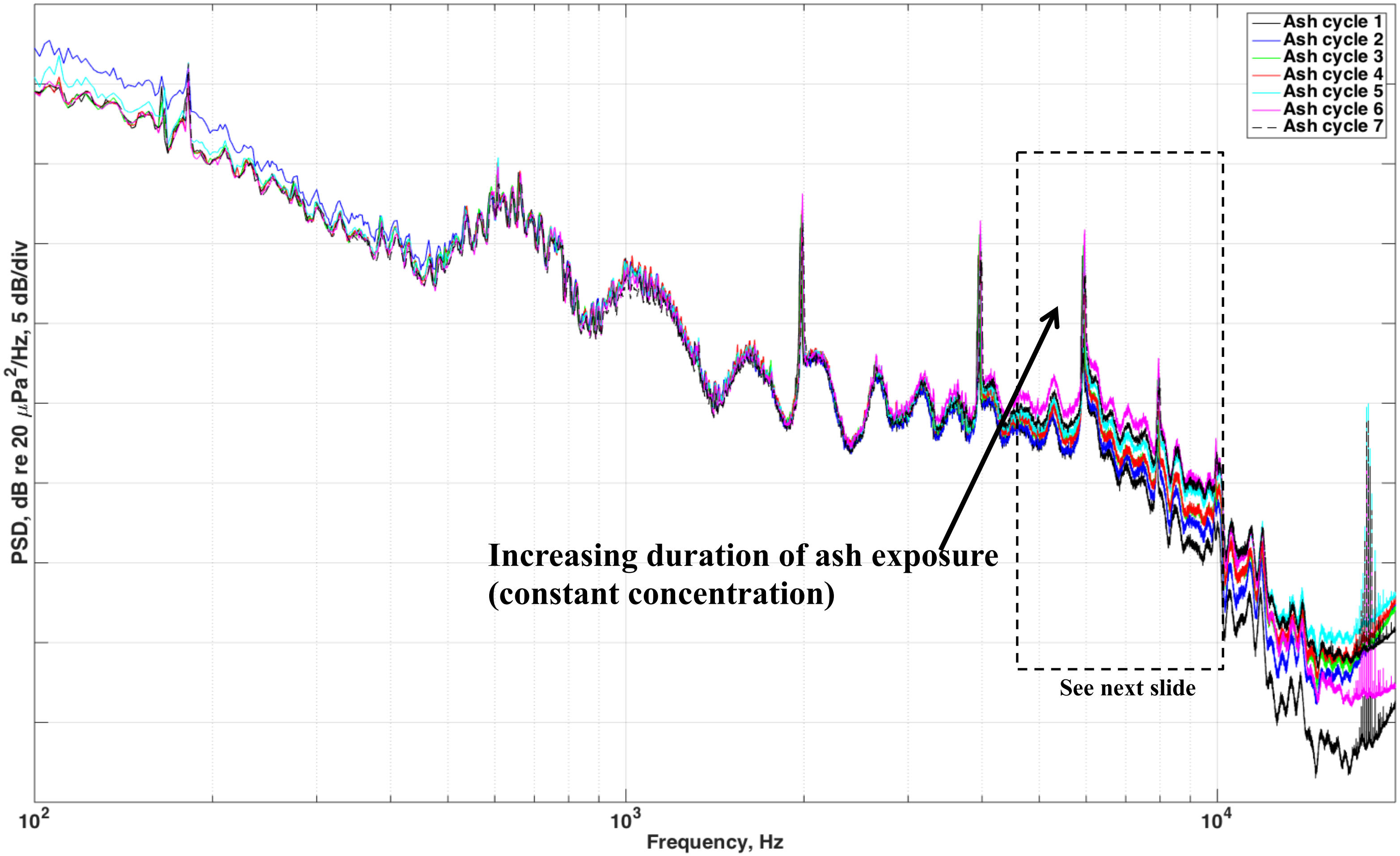
- Duration of Exposure v. Ash Concentration (DEvAC Chart), used with permission © 2015 Rolls Royce PLC

Volcanic Ash Ingestion Testing



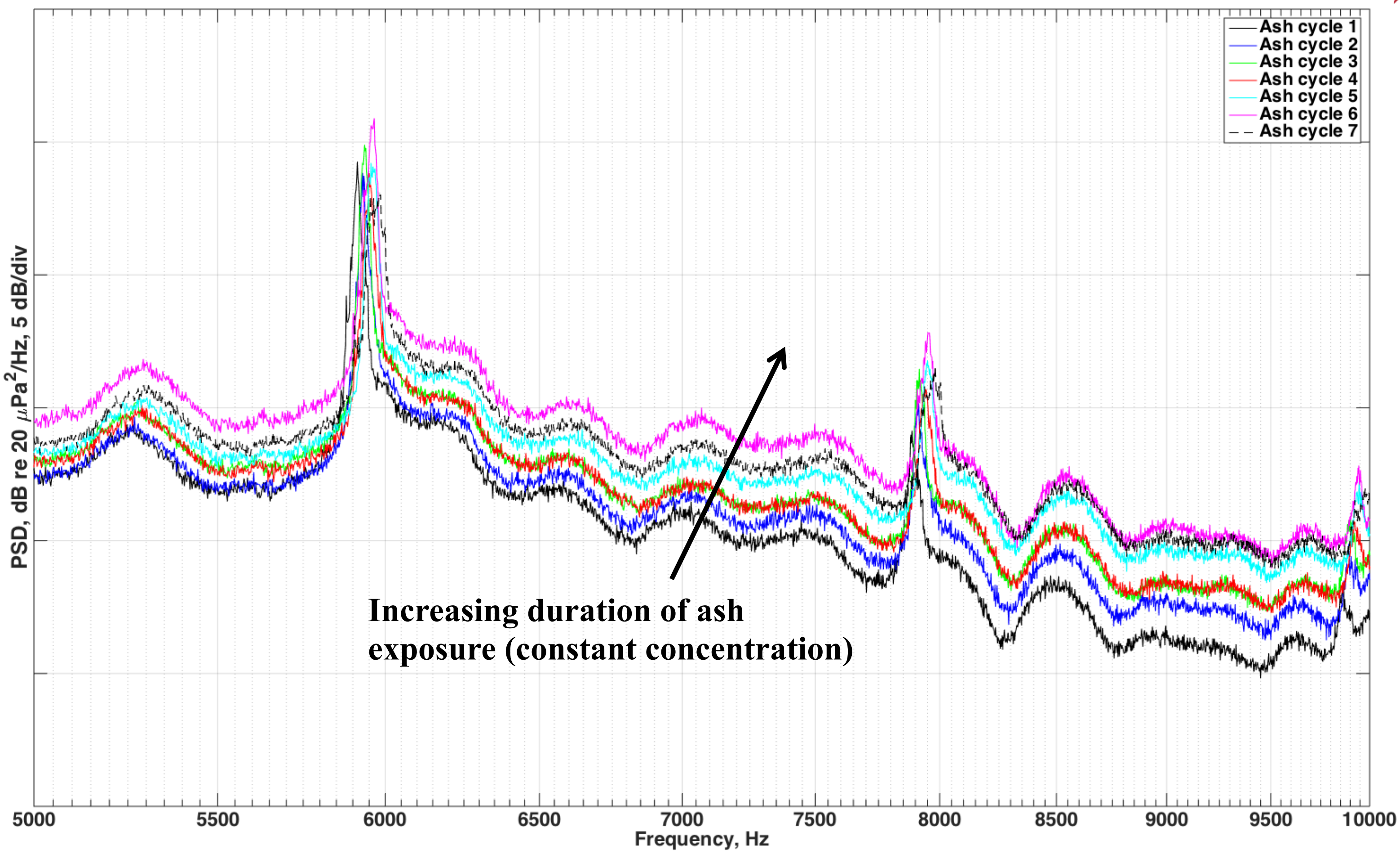
- Aft microphone A5 PSD for multiple cycles of volcanic ash ingestion at 10 mg/m^3 (Day 1 of higher-concentration)

Volcanic Ash Ingestion Testing



- Aft microphone A5 PSD for multiple cycles of volcanic ash ingestion at 10 mg/m^3 (Day 2 of higher-concentration)

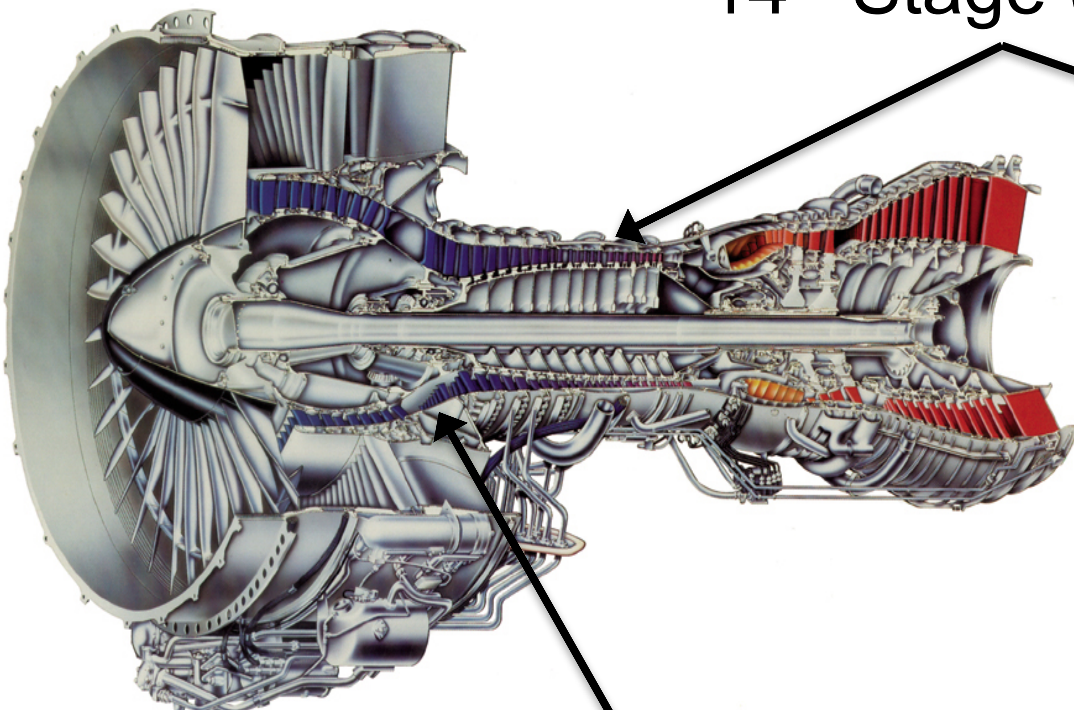
Volcanic Ash Ingestion Testing



- Aft microphone A5 PSD for multiple cycles of volcanic ash ingestion at 10 mg/m^3 (Day 2 of higher-concentration)

Research Engine (F117-PW-100)

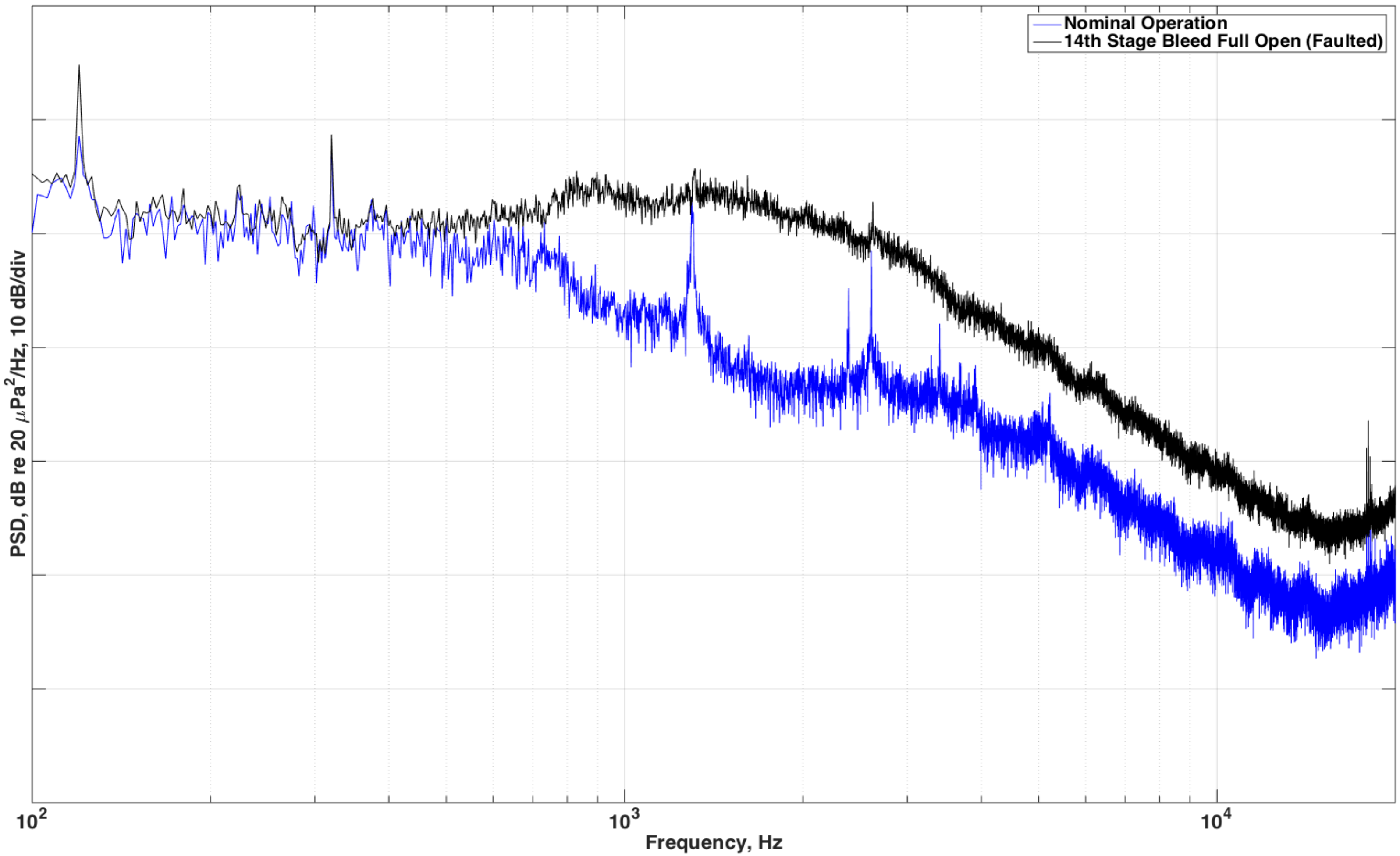
14th Stage (HPC)



Station 2.5 (LPC Exit)

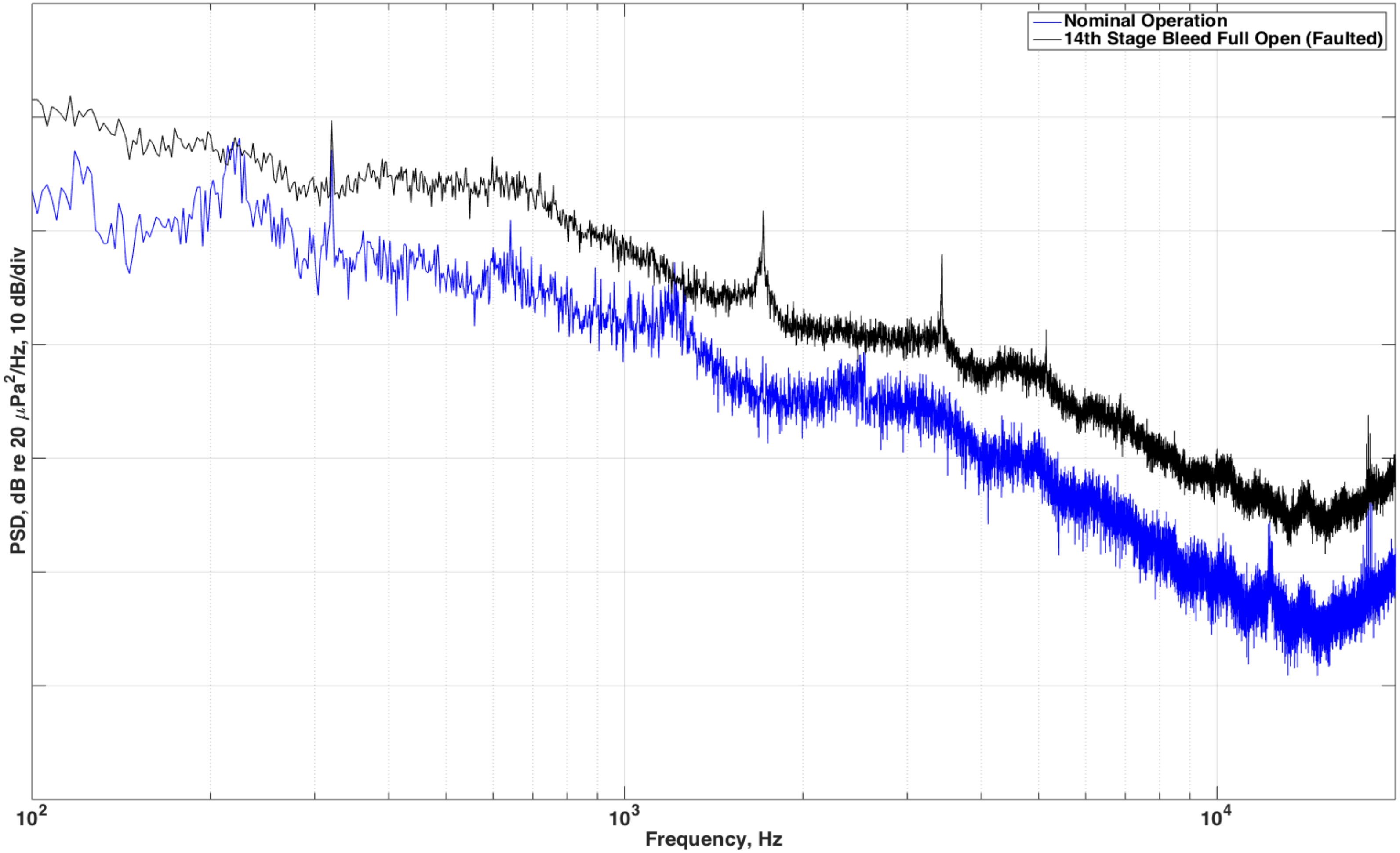
- Fn ~ 40,000 lbf
- BPR = 6

Simulated Failure of 14th Stage Bleed Valve



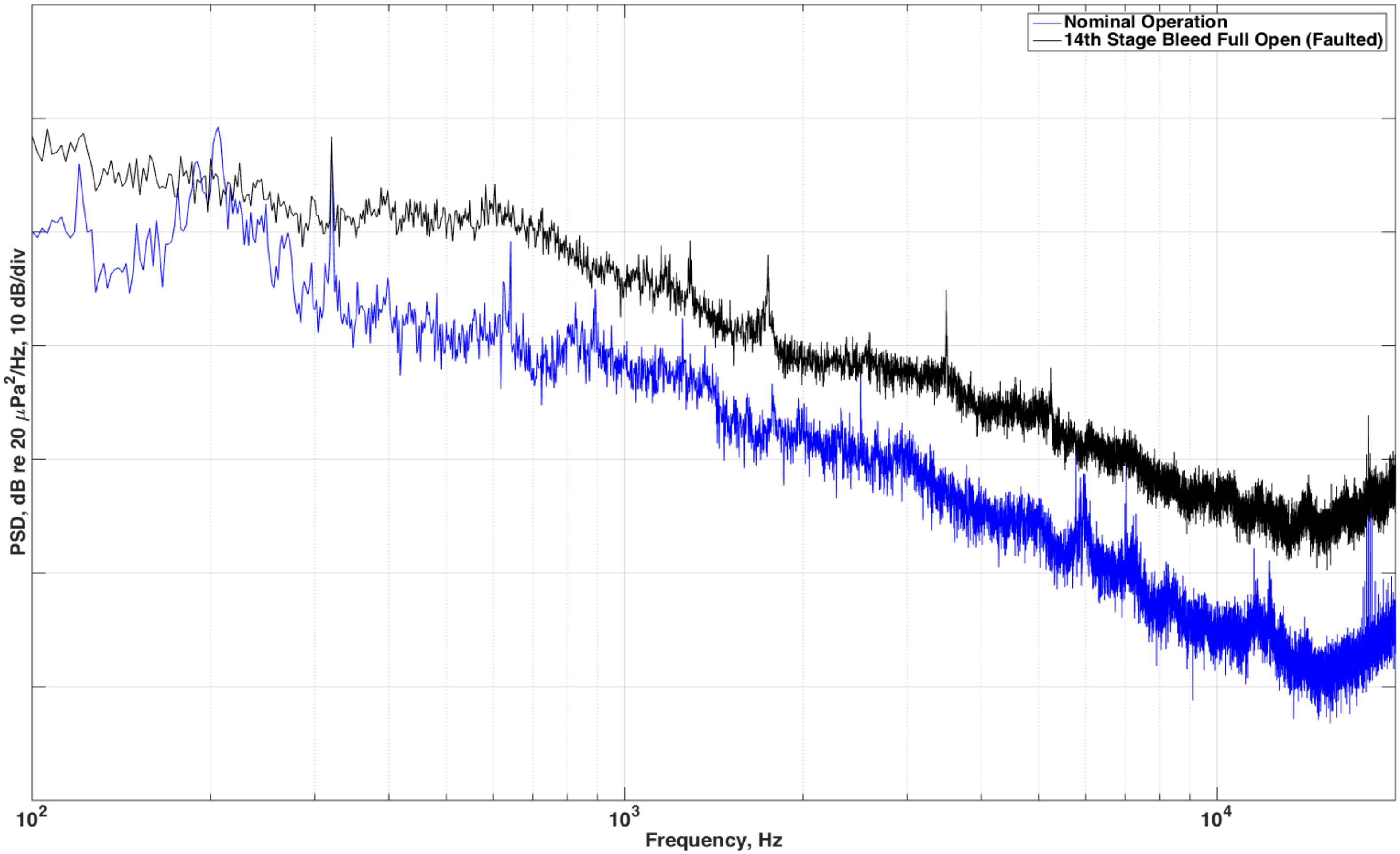
- Microphone A4 simulated failure of 14th stage bleed valve to full-open failsafe position during steady state operation of engine

Simulated Failure of 14th Stage Bleed Valve



- Microphone A4 simulated failure of 14^{th} stage bleed valve to full-open failsafe position during ramp acceleration of engine

Simulated Failure of 14th Stage Bleed Valve

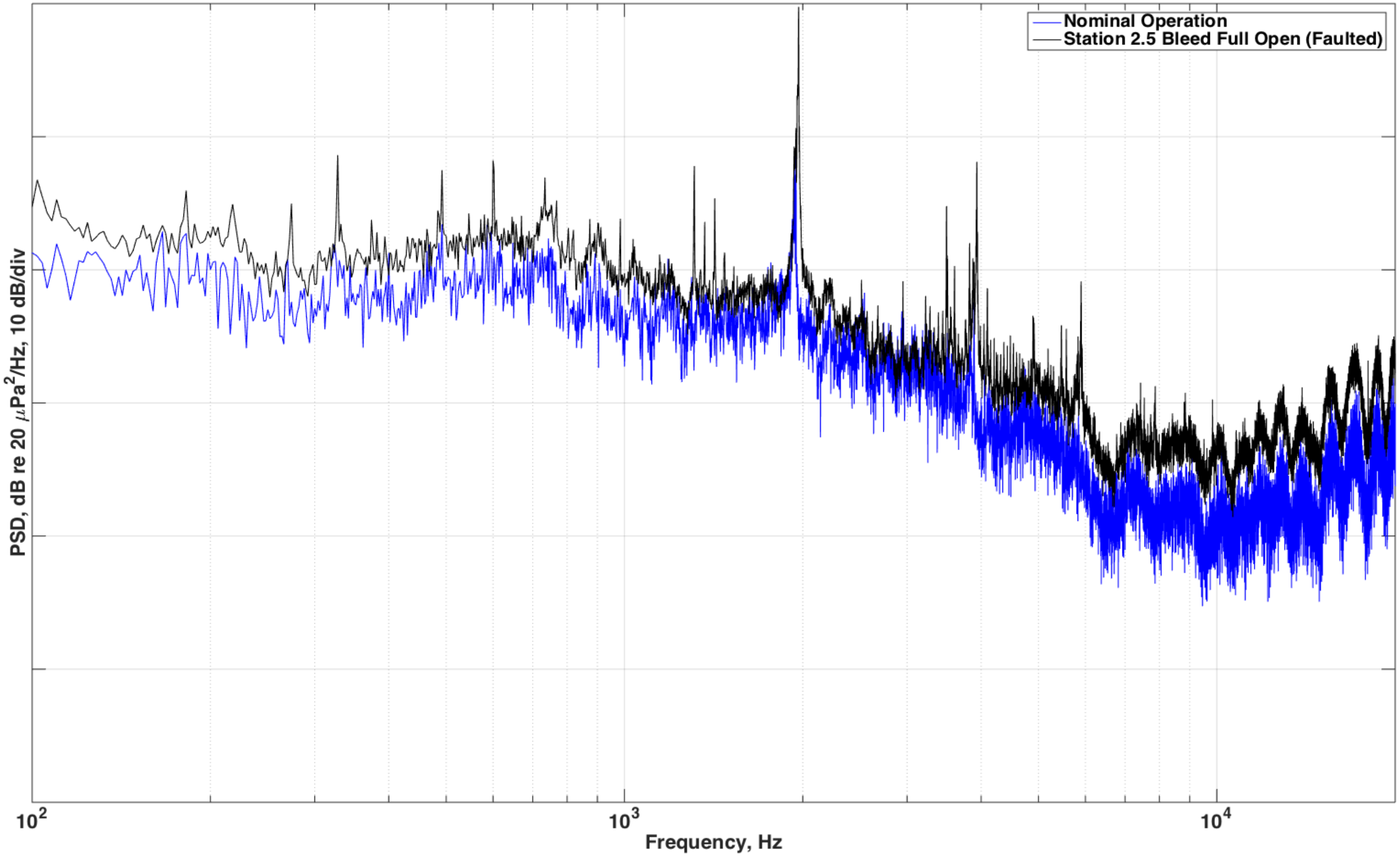


- Microphone A4 simulated failure of 14th stage bleed valve to full-open failsafe position during snap acceleration of engine

Station 2.5

- Acoustic changes due to simulated faulting of the station 2.5 bleed valve were more subtle
- Several factors contributed to this:
  - Pressure at the 14th stage bleed valve is an order of magnitude greater than at station 2.5
  - Station 2.5 modulates as the engine transitions between idle and max power, whereas 14th stage valve is discrete (fully closed to “failed” fully open)
  - Station 2.5 exhausts bleed air through distributed manifold rather than single location

Simulated Failure of Station 2.5 Bleed Valve



- Microphone F1 simulated failure of station 2.5 bleed valve to full-open failsafe position during snap acceleration of engine

Conclusion

- Correlation between changes to engine's acoustic power spectral density and cumulative ingestion of volcanic ash suggests causation from mechanisms in engine core
- Simulated failure of 14th stage bleed valve to its failsafe position detected by far-field acoustic microphone array
- Fault of station 2.5 bleed valve proved more difficult to detect
- The results offer justification for continuation of work in this area
- Next steps could include characterization of the acoustic changes for diagnostic applications

Acknowledgements

- NASA Armstrong Flight Research Center Center Innovation Fund provided funding for procurement and labor
- Several employees helped in the somewhat arduous daily task of setup and teardown during testing
- Input from GRC acoustics researchers on improving mounting methods and tips on post-processing data

Questions?