Preliminary Study on Acoustic Detection of Faults Experienced by a High-Bypass Turbofan Engine

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Outline

- Background on VIPR research
- Introduction to VIPR acoustics research objectives
- Motivation
- Test setup
- Research engine
- Preliminary detection of simulated failures
- Future work
- Conclusion

VIPR Background

- Vehicle Integrated Propulsion Research (VIPR) project currently in Phase III of ground-based engine testing
- The project is using F117-PW-100 engines (military derivative of PW 2000 used on the Boeing 757) in the 40k-lb thrust class
- Engines are representative of typical high-bypass commercial turbofans
- VIPR is a way to introduce 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

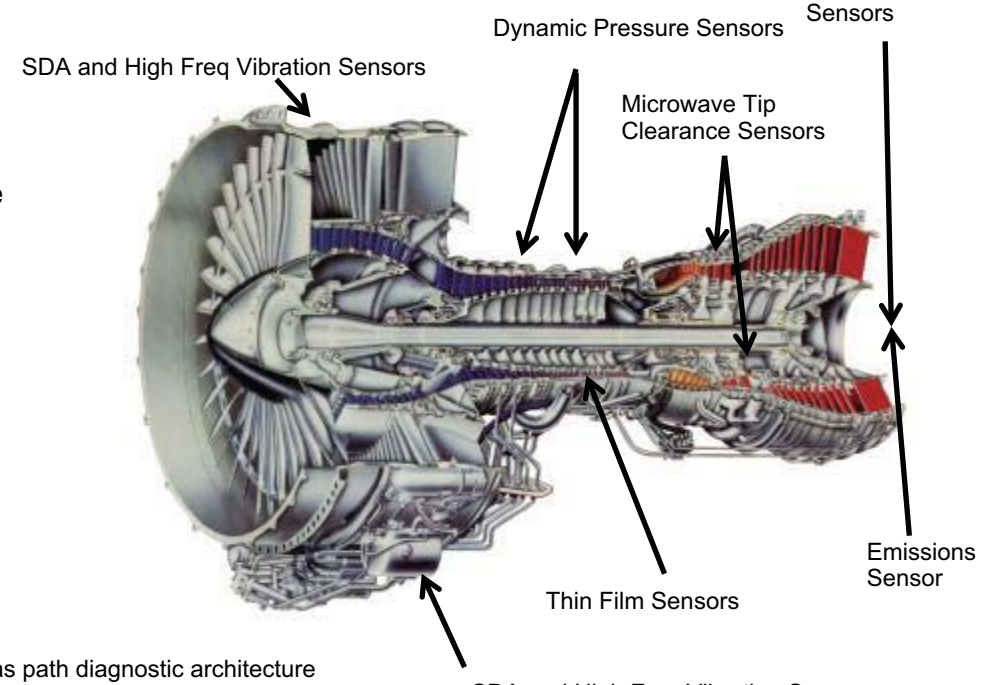
Approach:

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



Model-based gas path diagnostic architecture
Acoustic Engine Health Monitoring

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
  - Bleed Air Environment Testing (Boeing and Partners)
    - To evaluate and characterize bleed air sensors, sampling and purification technologies in a relevant operating environment
  - Volcanic Ash Ingestion Testing (AFRL and Partners)
    - Run engine to end of life
    - 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
- VIPR III is possible with the combined efforts/resources of the consortium

VIPR Acoustics Research

- Goal: Characterize the engine core, fan, and exhaust acoustics under nominal and off-nominal/ seeded fault conditions
  - Objective: Obtain engine core, fan, and exhaust acoustic health monitoring (AHM) data under nominal and off-nominal / seeded fault conditions
- Faults introduced during VIPR II included the simulated failures of the engine station 2.5 and 14th stage bleed valves to their failsafe positions

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 the aircraft

Test Setup

- Image courtesy Google earth

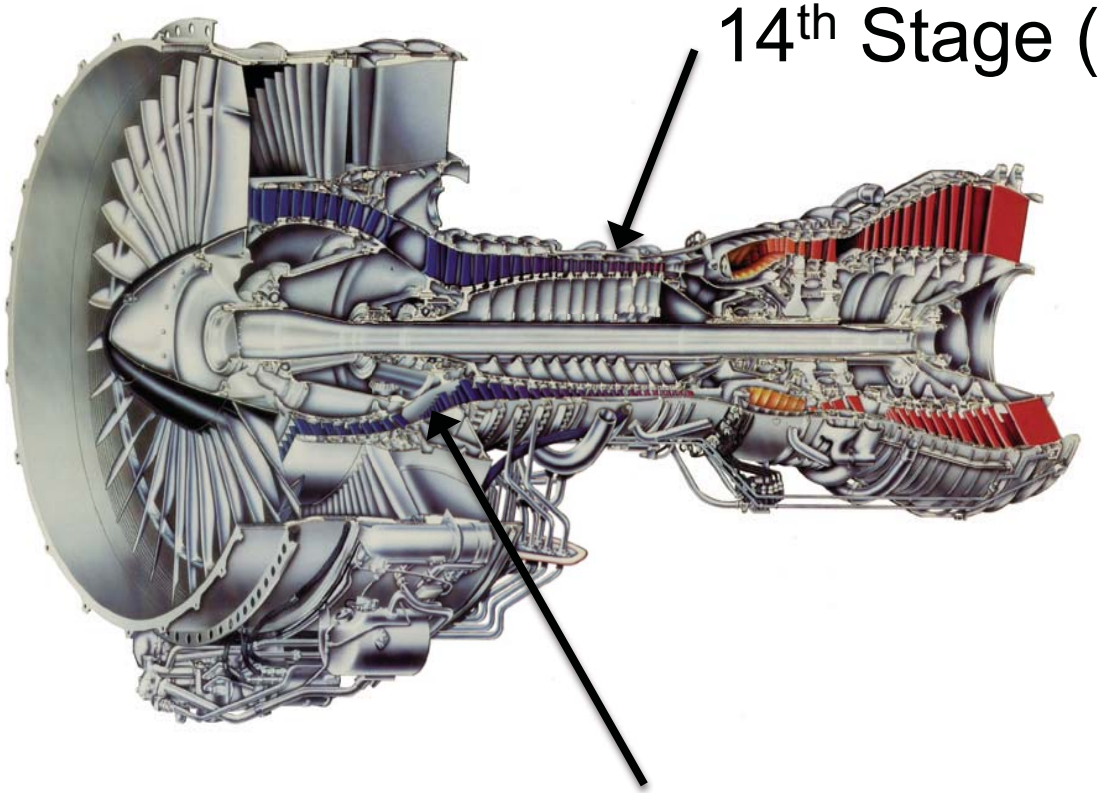
Test Setup (Continued)

NASA Photograph ED13-0228-157

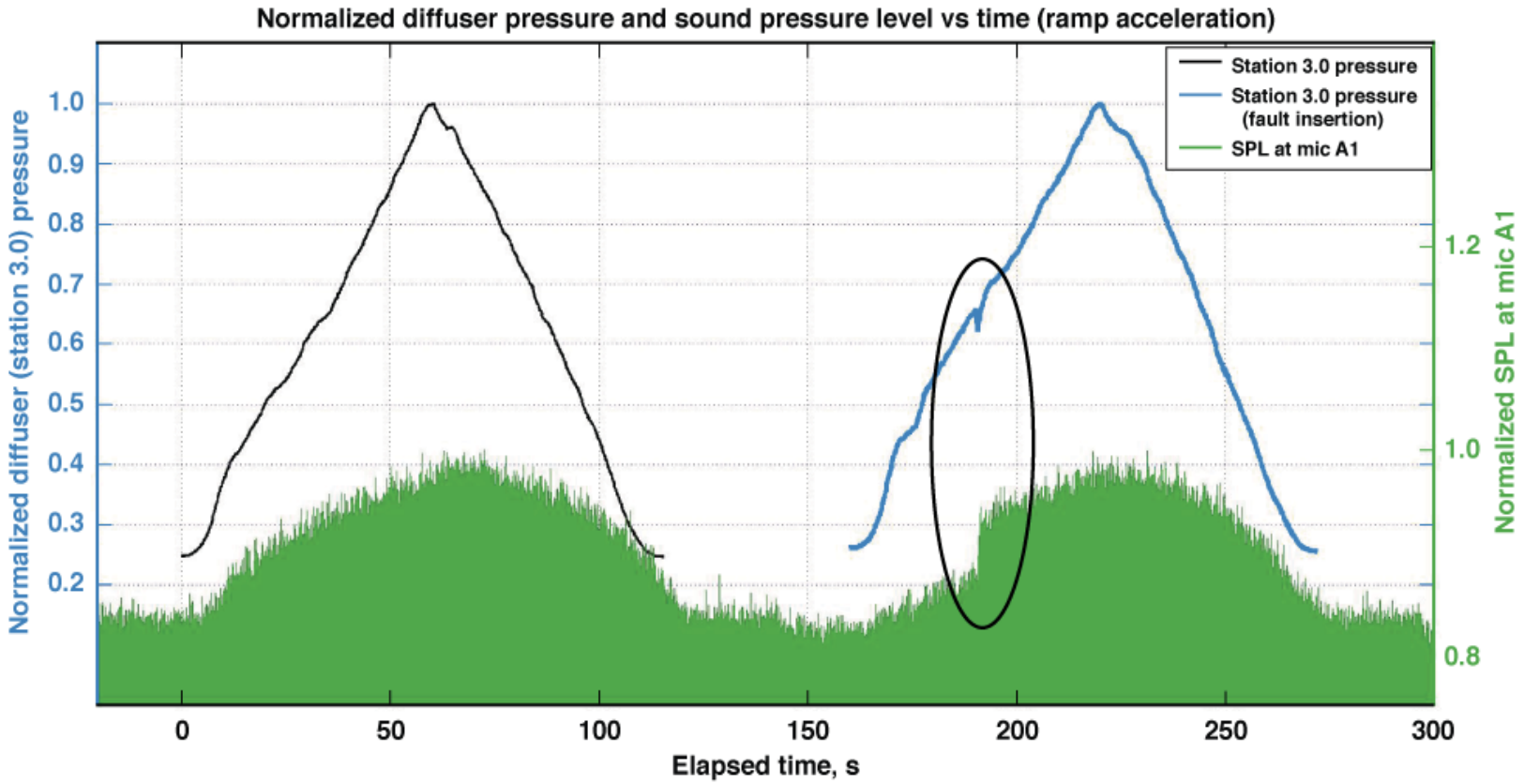
NASA Photograph ED13-0228-156

NASA Photograph ED13-0228-160

Research Engine

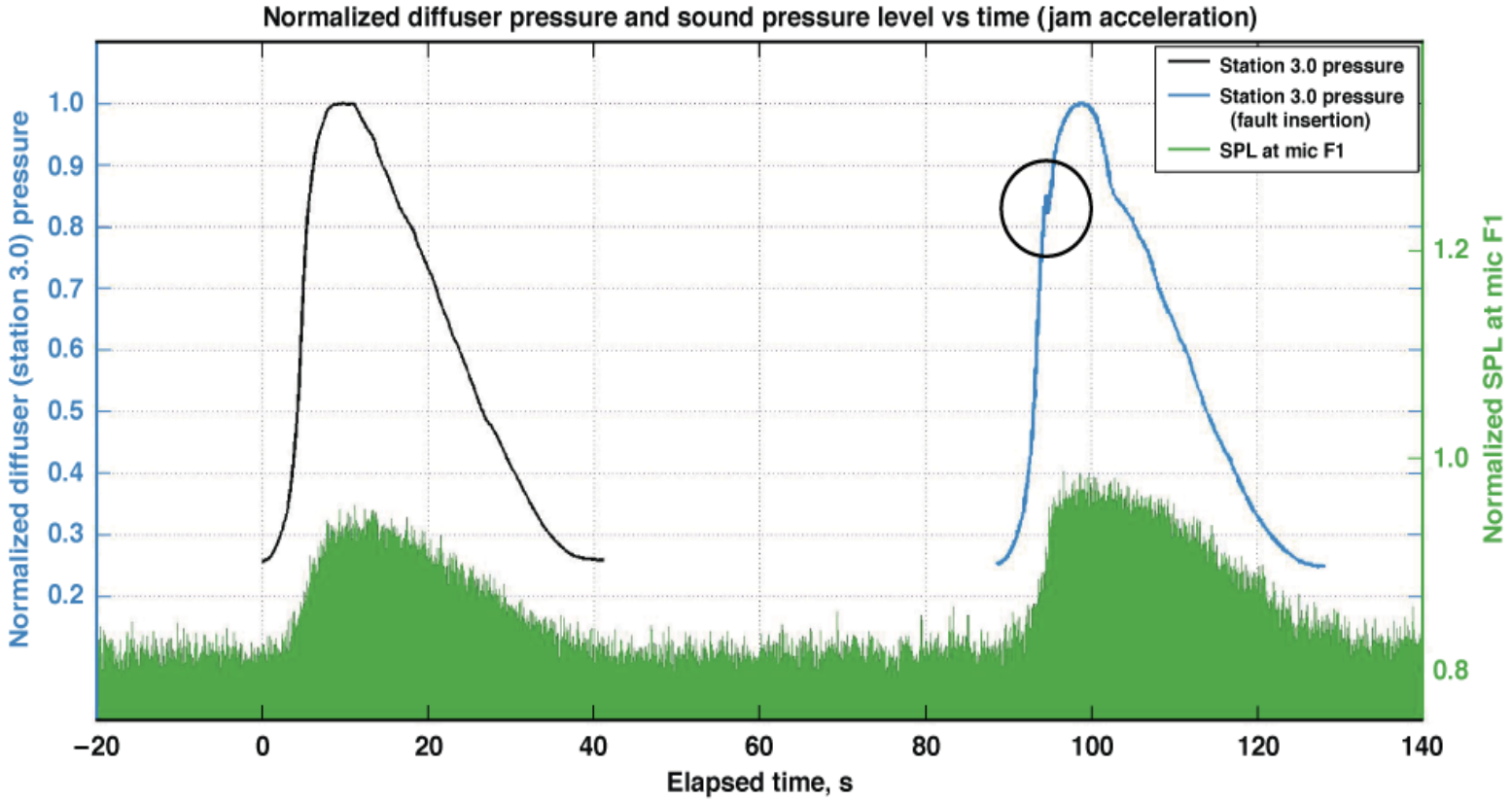


Detection of 14th Stage Bleed Valve Fault



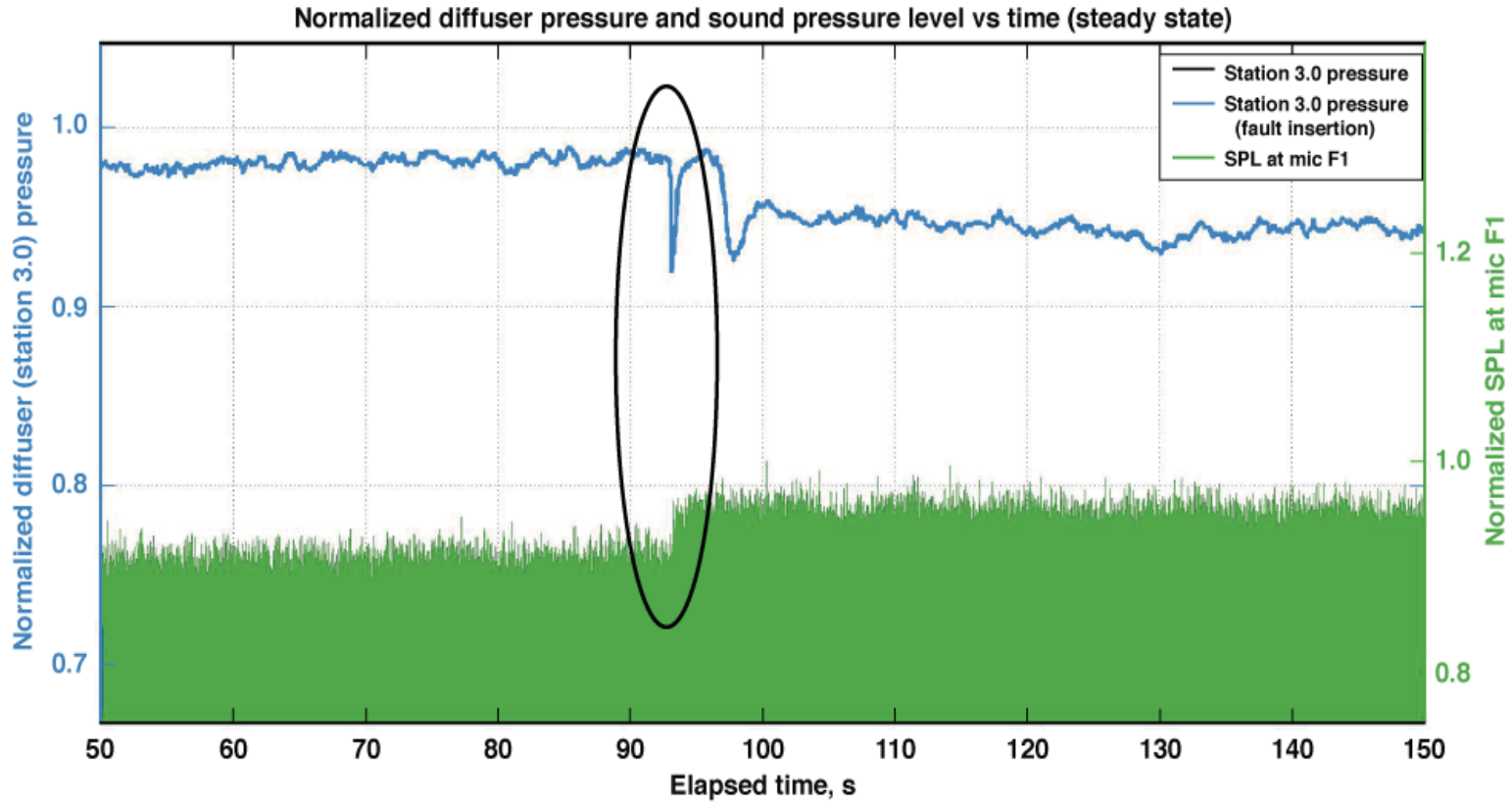
- Ramp Acceleration (approx. 1 min. from idle to target power) for normal and fault insertion

Detection of 14th Stage Bleed Valve Fault



- Jam Acceleration (rapidly from idle to target power) for normal and fault insertion

Detection of 14th Stage Bleed Valve Fault



- Engine steady operation for normal and fault insertion

Station 2.5

- Detection of the seeded faults of the station 2.5 proved troublesome
- 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)
- All of these factors suggest that the magnitude of the noise resulting from the failure of the station 2.5 valve was much lower than from the 14th stage

Anticipated Future Work

- A greater variety of failures is expected for VIPR III testing (Summer 2015)
- Volcanic ash ingestion offers a tremendous opportunity to detect subtle changes (degradation) to engine performance
- More bleed valve simulated failures
- Injection of oil simulating failure of forward bearing seal
- Further analysis of current data set

Conclusion

- Preliminary analysis of simulated failure of 14th stage bleed valve to its failsafe position suggests feasibility of far field acoustic microphone array to detect the fault
- Fault of station 2.5 bleed valve proved more difficult to detect due to the circumstances
- The results offer justification for continuation of work in this area

Acknowledgements

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- Bruel & Kjaer representative from Southern California offered advice on test setup

Questions?