Self Diagnostic Accelerometer testing on the C-17 aircraft.

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Overview

- **Introduction** to Self Diagnostic Accelerometer (SDA) and Vehicle Integrated Propulsion Research (VIPR) on the C-17 aircraft. (2 mins)
- SDA **Theory** (2 mins)
- SDA **Setup** (3 mins)
- SDA **Testing Method** (3 mins)
- SDA **Results & Analysis** (5 mins)
- SDA **Conclusion** (5 mins)
- **Questions** (5-10 mins)

Introduction

VIPR I

- Three weeks of aircraft testing in December 2011
- Collection of experimental NASA and Commercial technologies tested on the C-17 engine.

SDA

- Addresses the issue of Propulsion System Malfunction plus Inappropriate Crew Response which is a significant contributor to aviation accidents worldwide*
- Diagnostic system determines the health and attachment of a sensor (accelerometer).
- Consists of:
  - Accelerometer
  - Wiring
  - Signal Analyzer
  - Mounting base (attaches to aircraft engine)

*"AIA/AECMA Project Report" Volume I, Nov, 1998

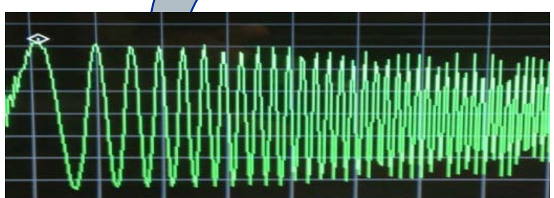
Theory

The SDA signal analyzer generates an electrical chirp that polls the sensor's crystal via the piezoelectric effect.

SDA Signal Analyzer

Output

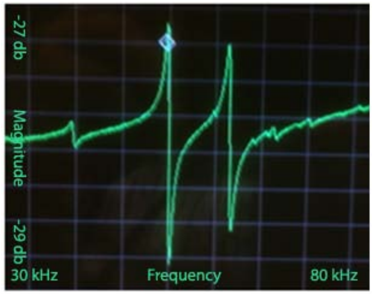
The corresponding response from the chirp returns to the SDA signal analyzer.



Input

Accelerometer

Frequency Response

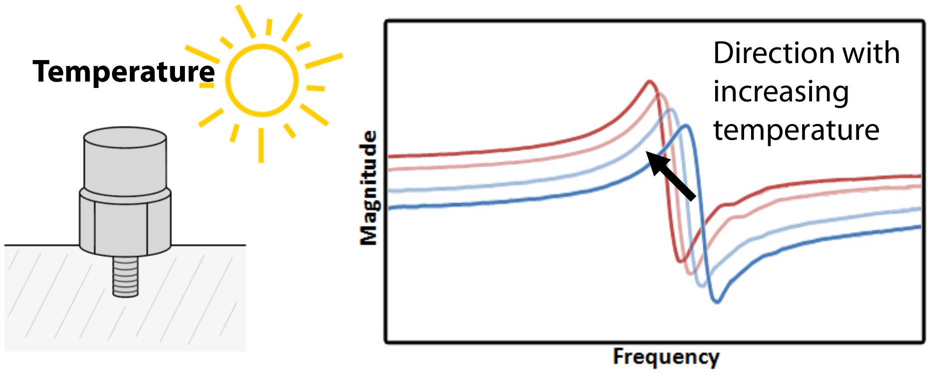


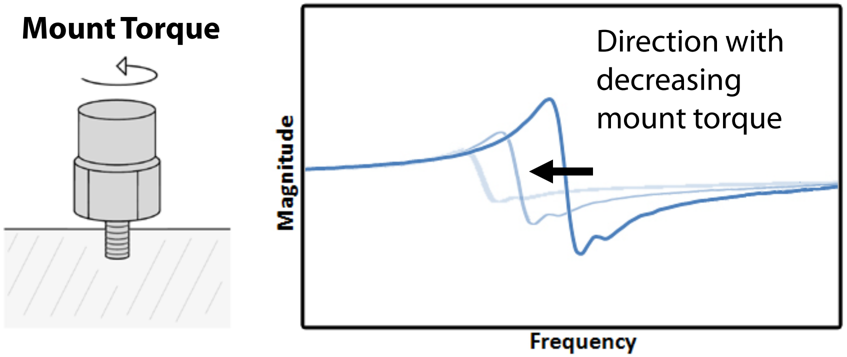
Result

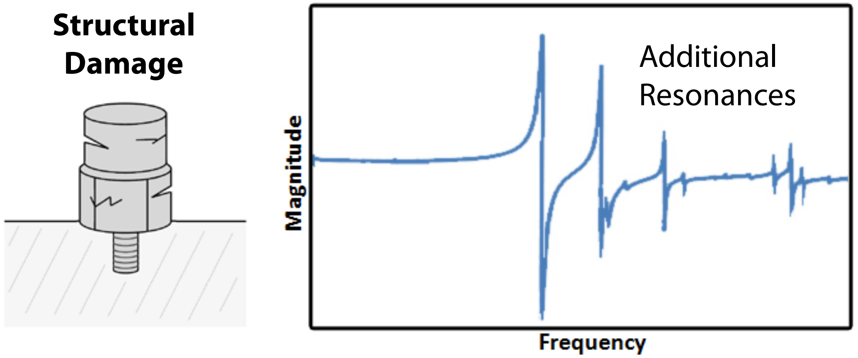
A frequency response with a resonant frequency pattern that correlates to sensor health and attachment condition.

Theory (continued)

Changes in the system influence the resonant frequencies.

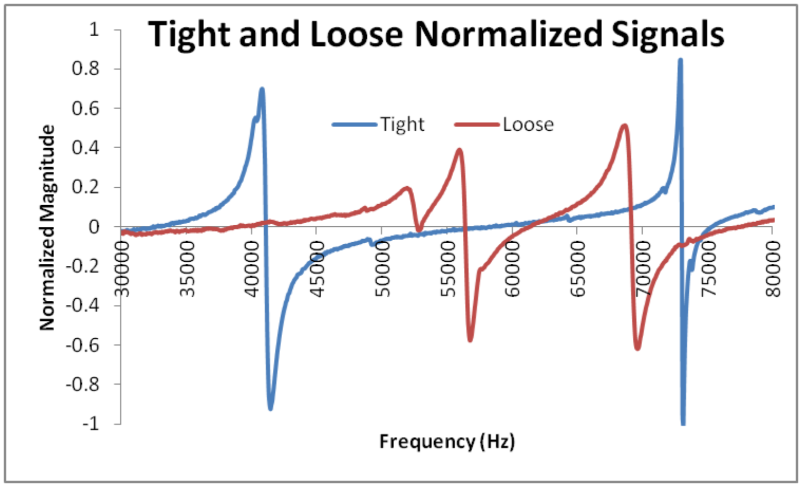






Theory (continued)

Comparing the tight and loose signals is an important baseline fault.



The tight or loose can be used as a reference to determine how well the experimental signal correlates.

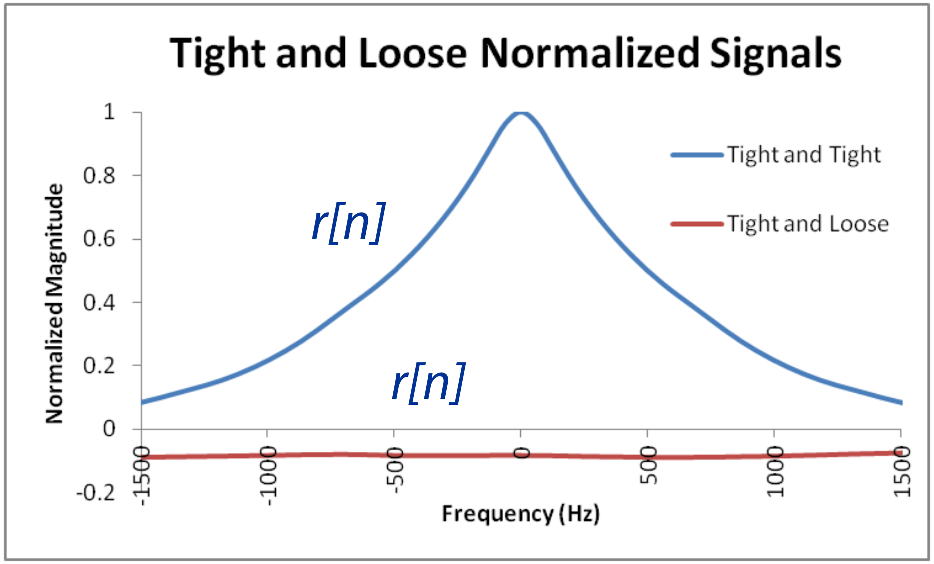
The cross correlation gives us a result where

r[n] close to 1 indicates high correlation.

r[n] close to 0 indicates low correlation.

$$r[n] = \frac{\sum_{m=30\ kHz}^{80\ kHz} \left\{ \begin{matrix} \left(refr[m] - refr_{Avg}\right) \cdot \\ \left(expr[n+m] - expr_{Avg}\right) \end{matrix} \right\}}{\sqrt{\sum_{m=30\ kHz}^{80\ kHz} \left\{\left(refr[m] - refr_{Avg}\right)^2\right\} \cdot \sum_{m=30\ kHz}^{80\ kHz} \left\{\left(expr[m] - expr_{Avg}\right)^2\right\}}}$$

Theory (continued)

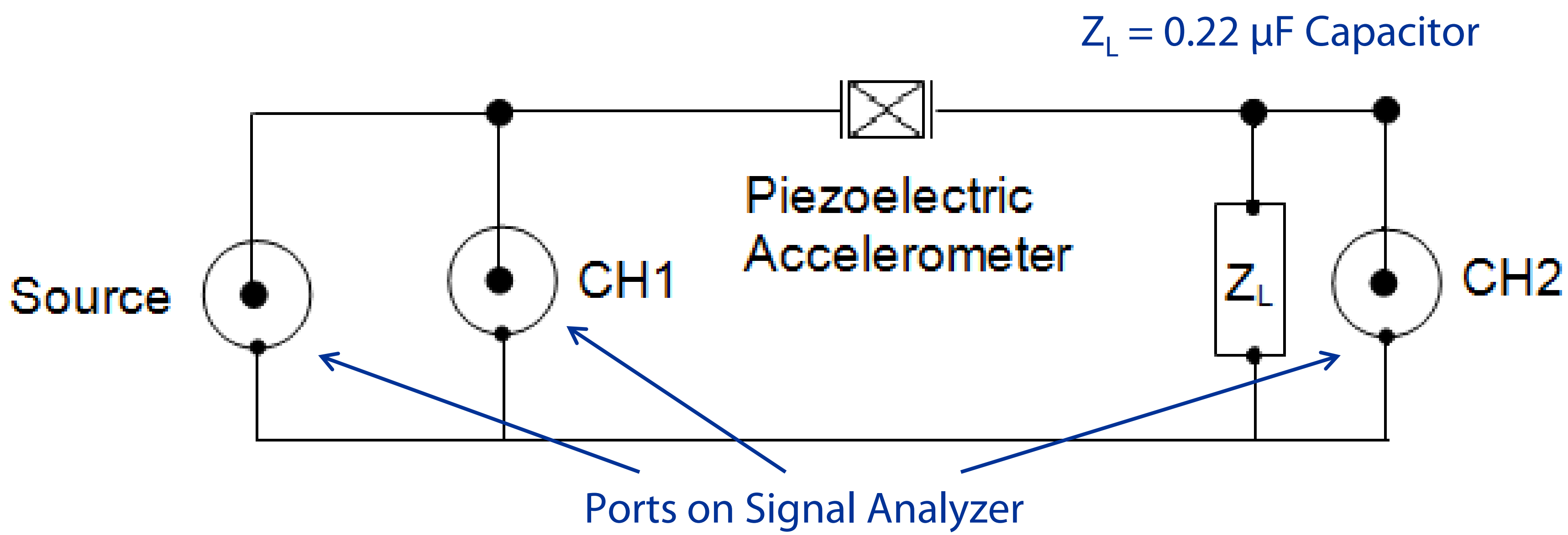


$$Health\ Index = maximum\ (r[n])$$

over 3 kHz range

Compensates for shift in pattern due to temperature and minor torque changes.

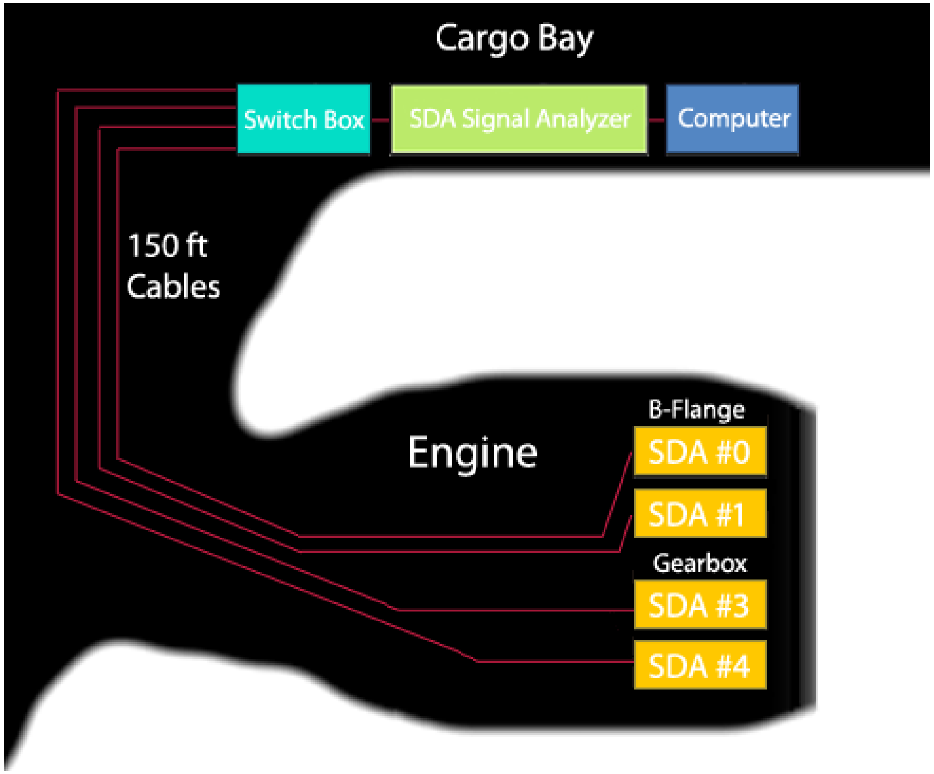
Setup: SDA Electrical Connections



The SDA electrical setup resembles a voltage divider, where changes in the SDA are measured indirectly through the constant impedance element Z_L.

Setup: SDA VIPR1

- The researcher is located in the Cargo Bay and operates the Switch Box, Signal Analyzer, and Computer.
- 150 ft Cables run along the aircraft wing to make the connection between the Switch Box and SDAs.
- The Switch Box switches between each of the four SDAs which are mounted to the engine.



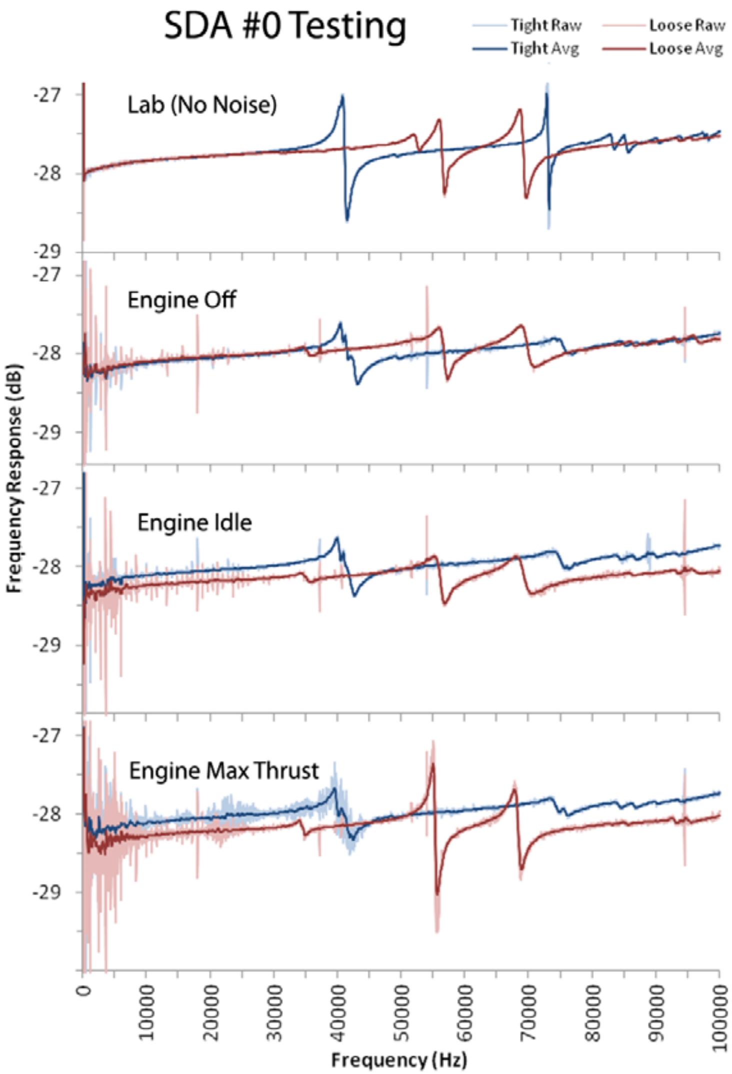
Setup: Accelerometer Locations

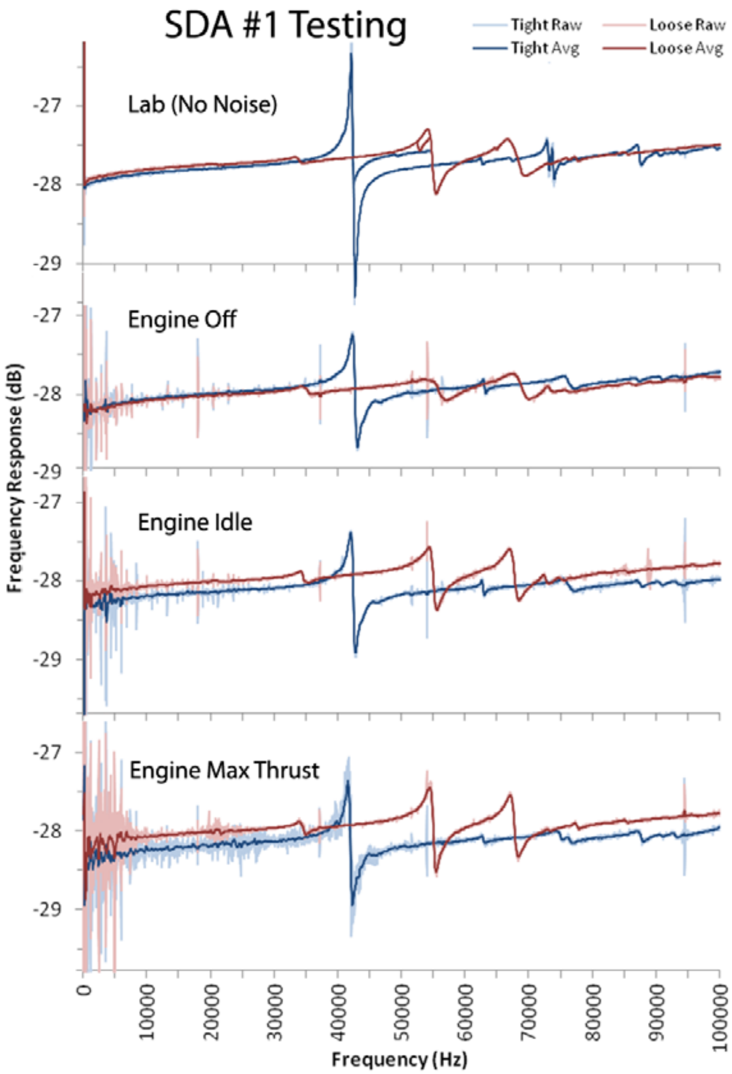
- Two Installations
- Each having one tight and one loose accelerometer

Testing Method

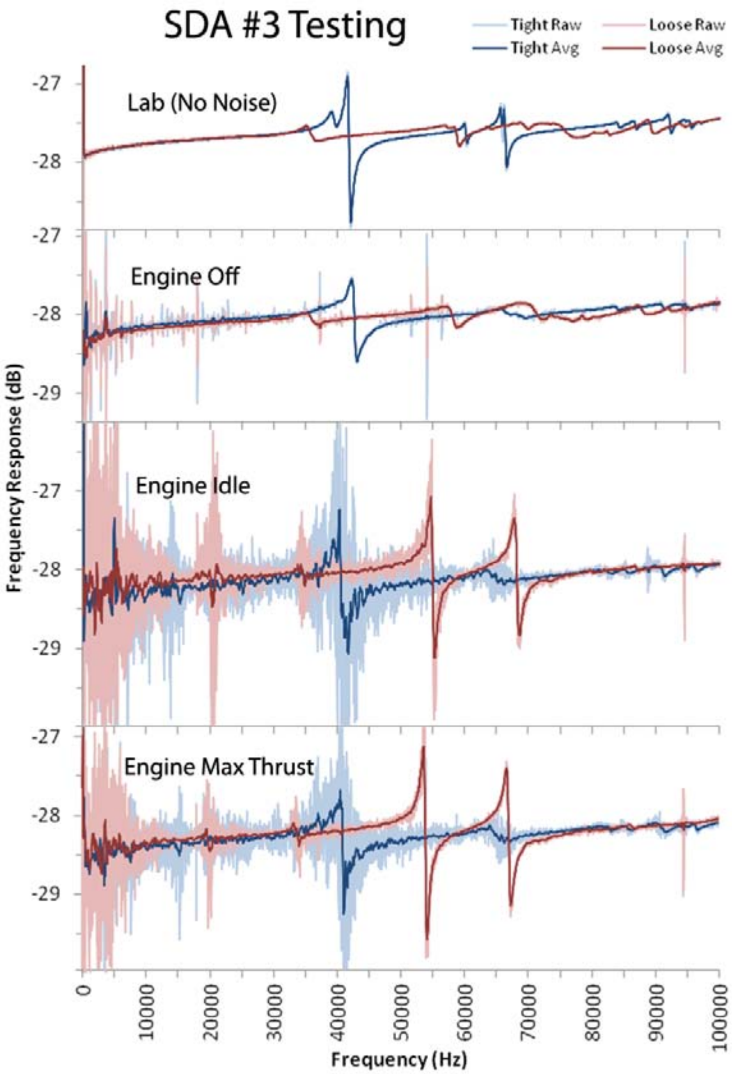
- Collect SDA data from 30 kHz to 100 kHz (switchbox used to switch between accelerometers).
- Test conditions of interest:
  - Engine off
  - Engine on with a thrust from 0% (idle) to 100% (max).
    - Held constant (2 to 5 mins)
    - Ramp/Jam (acceleration/deceleration 30 secs to 2 mins)
- SDA data compared to Legacy Accelerometers (engine vibration data).
- SDA tight/loose conditions swapped halfway through testing.

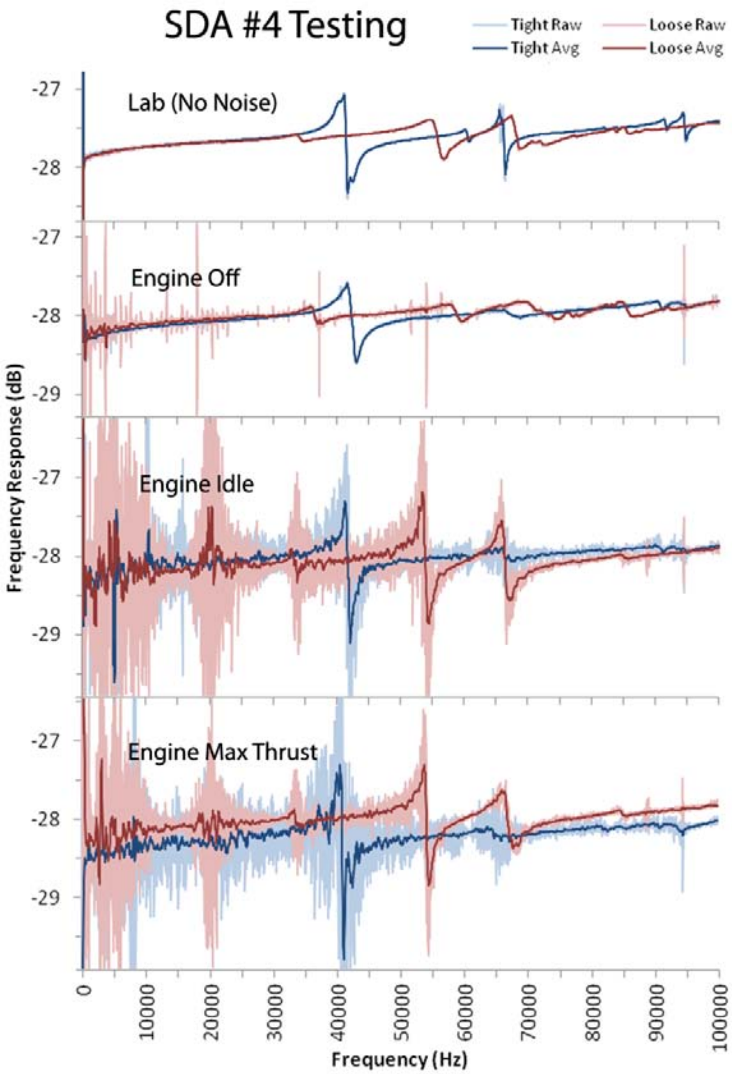
Results & Analysis: SDA B-Flange





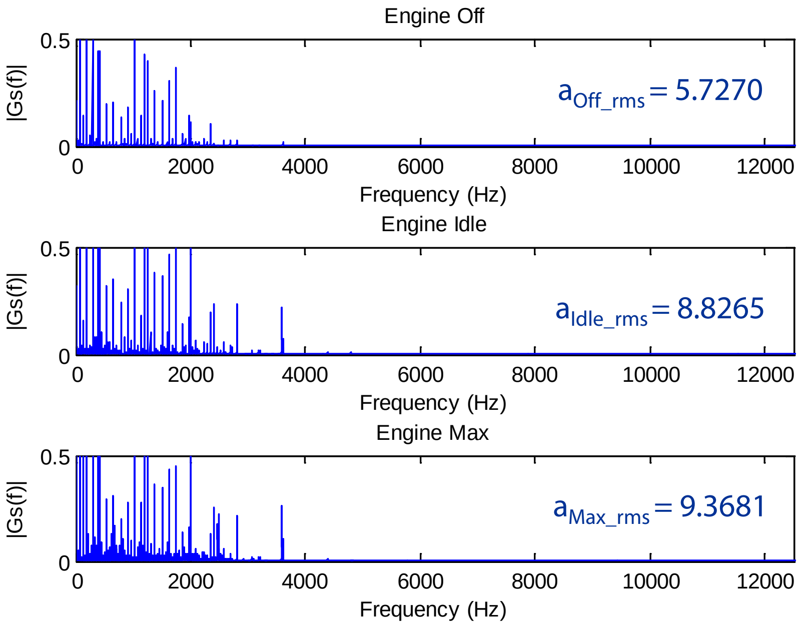
Results & Analysis: SDA Gearbox



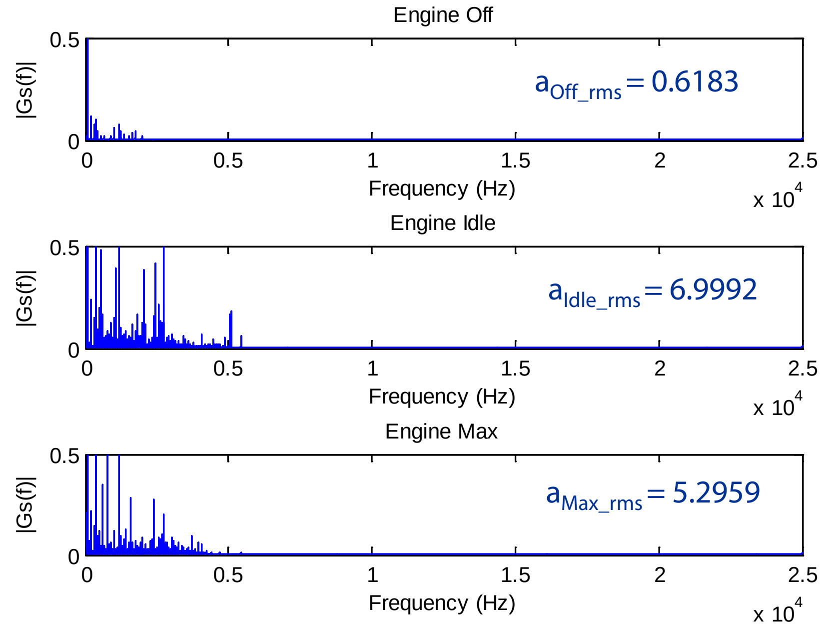


Results & Analysis - B-Flange and Gearbox for Off, Idle, Max

B-Flange Vibration



Gearbox Vibration



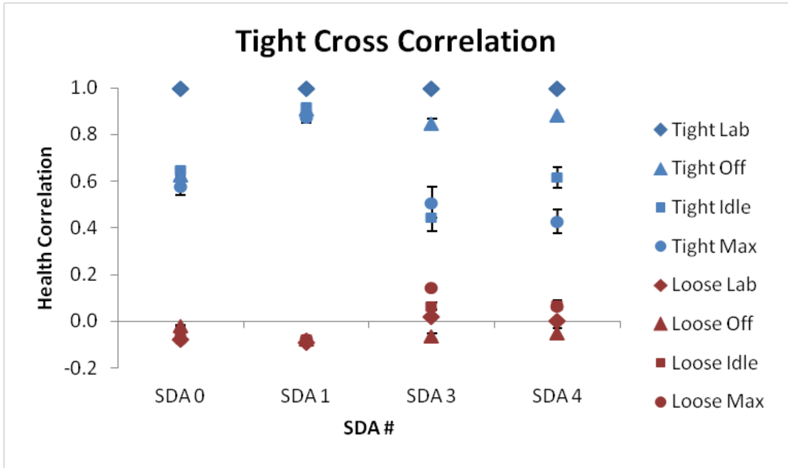
25 kHz sampling rate → 12.5 kHz FFT

50 kHz sampling rate → 25 kHz FFT

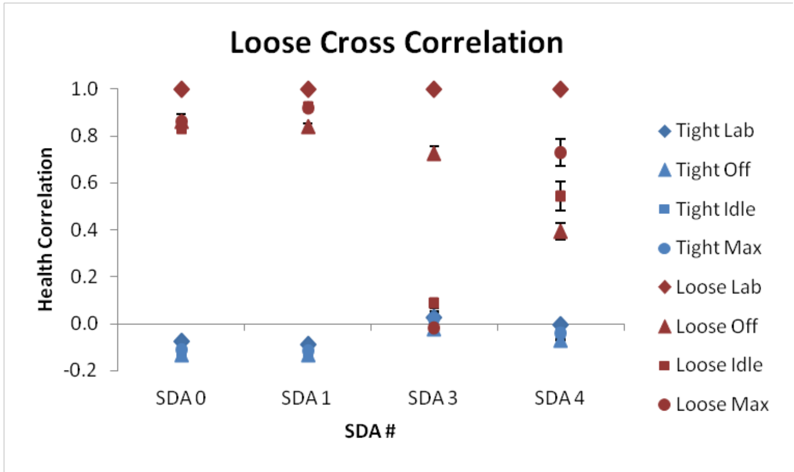
Test Day 349
FFT over 1 minute

Analysis

Tight Reference								
	SDA 0		SDA 1		SDA 3		SDA 4	
	mean	±	mean	±	mean	±	mean	±
Tight Lab	0.9999	0.0000	0.9999	0.0000	0.9999	0.0000	0.9998	0.0001
Tight Off	0.6266	0.0024	0.9090	0.0052	0.8481	0.0209	0.8817	0.0007
Tight Idle	0.6504	0.0044	0.9180	0.0047	0.4433	0.0555	0.6175	0.0442
Tight Max	0.5765	0.0338	0.8732	0.0228	0.5093	0.0672	0.4274	0.0507
Loose Lab	-0.0775	0.0011	-0.0901	0.0008	0.0219	0.0012	0.0034	0.0001
Loose Off	-0.0176	0.0027	-0.0781	0.0019	-0.0647	0.0144	-0.0481	0.0191
Loose Idle	-0.0644	0.0098	-0.0766	0.0025	0.0658	0.0152	0.0704	0.0193
Loose Max	-0.0773	0.0074	-0.0749	0.0032	0.1428	0.0061	0.0631	0.0150



Loose Reference								
	SDA 0		SDA 1		SDA 3		SDA 4	
	mean	±	mean	±	mean	±	mean	±
Tight Lab	-0.0763	0.0008	-0.0906	0.0015	0.0235	0.0002	-0.0038	0.0016
Tight Off	-0.1350	0.0032	-0.1326	0.0049	-0.0249	0.0044	-0.0706	0.0021
Tight Idle	-0.1279	0.0028	-0.1229	0.0098	0.0186	0.0308	-0.0399	0.0176
Tight Max	-0.1098	0.0050	-0.1174	0.0043	0.0190	0.0320	-0.0399	0.0120
Loose Lab	0.9998	0.0001	0.9998	0.0001	0.9990	0.0004	0.9997	0.0000
Loose Off	0.8629	0.0086	0.8402	0.0138	0.7258	0.0288	0.3945	0.0364
Loose Idle	0.8285	0.0039	0.9225	0.0030	0.0871	0.0187	0.5436	0.0623
Loose Max	0.8614	0.0337	0.9179	0.0089	-0.0203	0.0041	0.7289	0.0582



Conclusions

- SDA tight/loose conditions successfully determined regardless of noise.
- SDA tight/loose resonant peaks are consistent for the same mounting hardware whether in the lab or engine.
- Significant amount of noise present in the Gearbox Triax location when the engine is turned on.
- EMI noise persistent in aircraft install regardless of engine state.

Questions?

VIPR I test team

Biographies

Roger Tokars *received a B.S. in Electrical Engineering from Purdue University, West Lafayette in 2007. He has been with NASA GRC for more than 8 years. He has been the study lead for the SDA in the Optical Instrumentation and NDE Branch. He has also been involved in hyperspectral imaging and flow visualizations. Currently he is pursuing his M.S. in Physics from Cleveland State University.*

John Lekki *received a B.S. in Electrical Engineering from Michigan State University in 1993, M.S. in Physics from Cleveland State University in 2002, and Ph.D in Electrical Engineering from Michigan State University in 2008. He has been with NASA for more than 20 years. He has been the Principal Investigator for the following research activities: Engine Health Management Sensor Technologies, VIPR, Hyperspectral Remote Sensing of freshwater resources, and Quantum Sensing and Communications. He currently works in the Optical Instrumentation and NDE Branch.*