COE CST Sixth Annual Technical Meeting

Task 323 Structural Health Monitoring Framework

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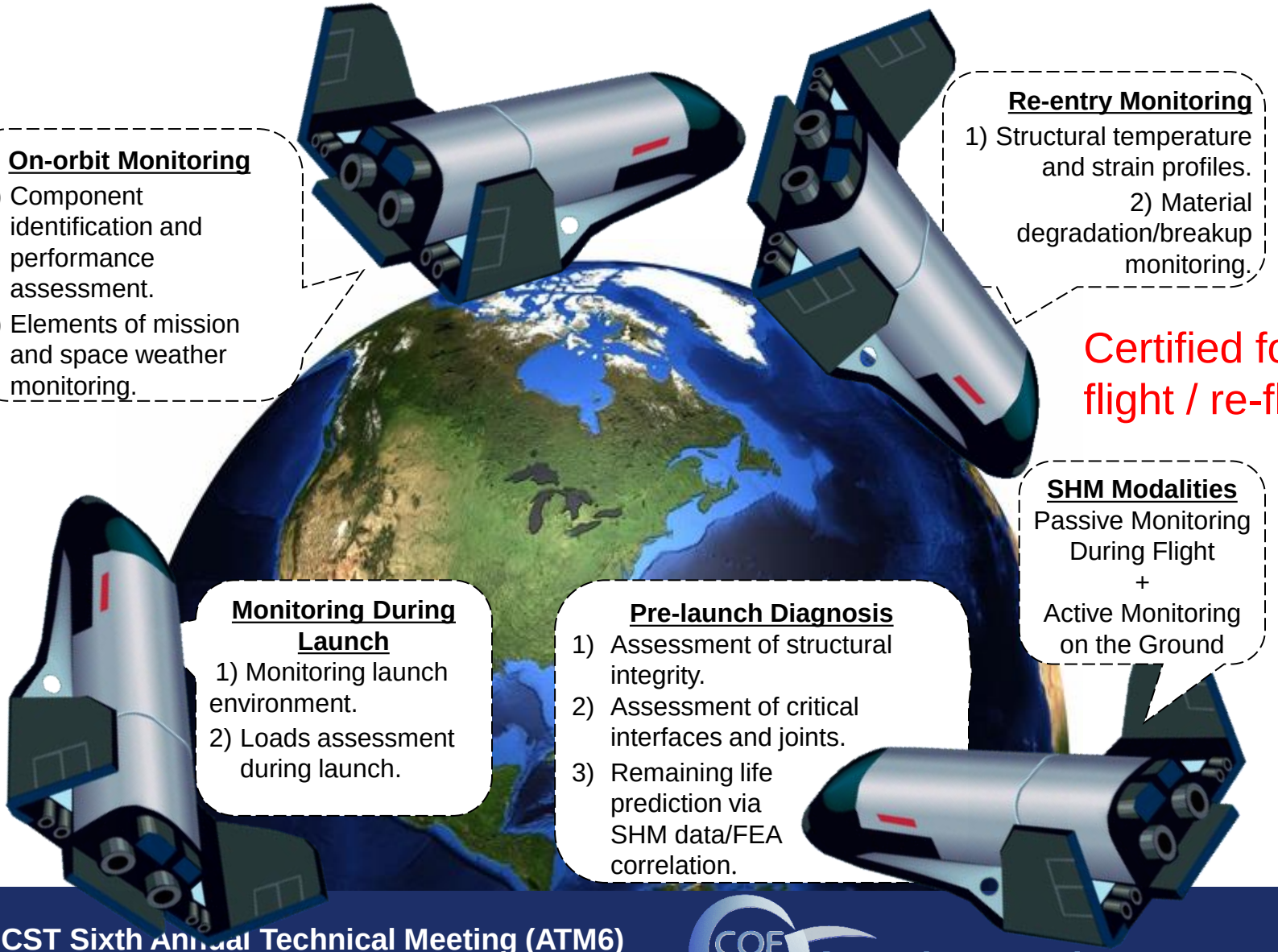
Center of Excellence for Commercial Space Transportation

Task 323 SHM Framework

- Task 323 focuses on SHM architecture and guidelines for integrating SHM with spaceflight recorder (aka “black box”).
- Investigation of thermal and radiation fatigue of smart structures for assessment of RVL’s condition during flight.
- Prepare hardware for evaluation of space effects on structural condition and sensor system.

Motivation



On-orbit Monitoring

1) Component identification and performance assessment.
2) Elements of mission and space weather monitoring.

Re-entry Monitoring

1) Structural temperature and strain profiles.
2) Material degradation/breakup monitoring.

Certified for flight / re-flight?

SHM Modalities

Passive Monitoring During Flight
+
Active Monitoring on the Ground

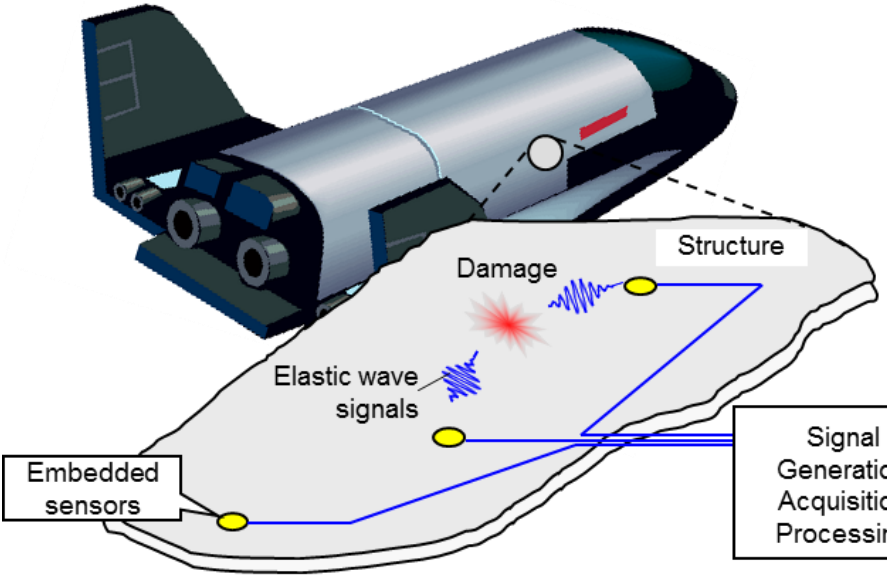
Monitoring During Launch

1) Monitoring launch environment.
2) Loads assessment during launch.

Pre-launch Diagnosis

1) Assessment of structural integrity.
2) Assessment of critical interfaces and joints.
3) Remaining life prediction via SHM data/FEA correlation.

Structural Health Monitoring



Damage Detection and Classification Results

Statistical Analysis

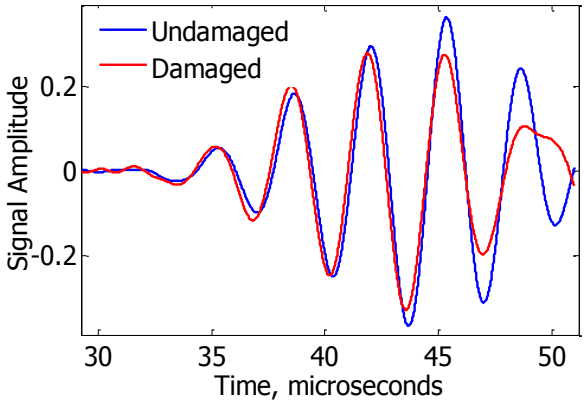
Neural Network

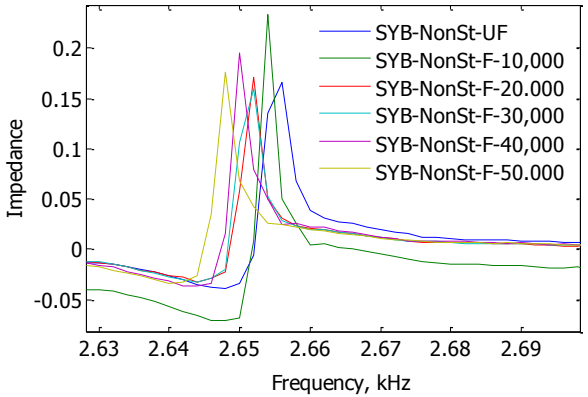
Signal feature extraction

Signal Generation Acquisition Processing

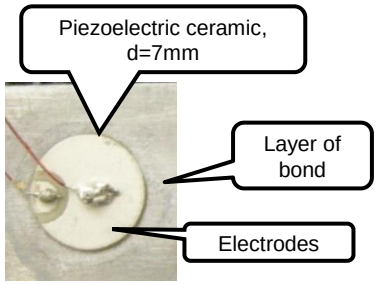
Ultrasonic data

Impedance response

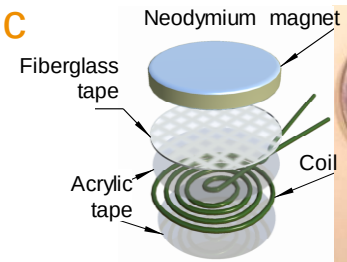


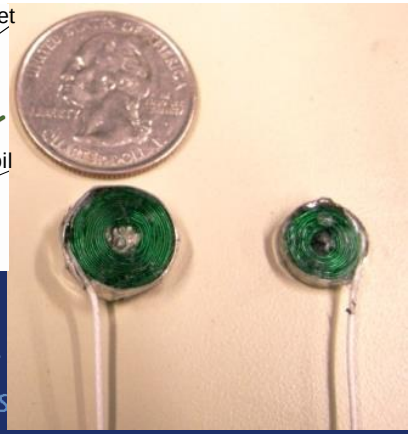


Thin Piezoelectric Sensors 7mm ×0.2mm

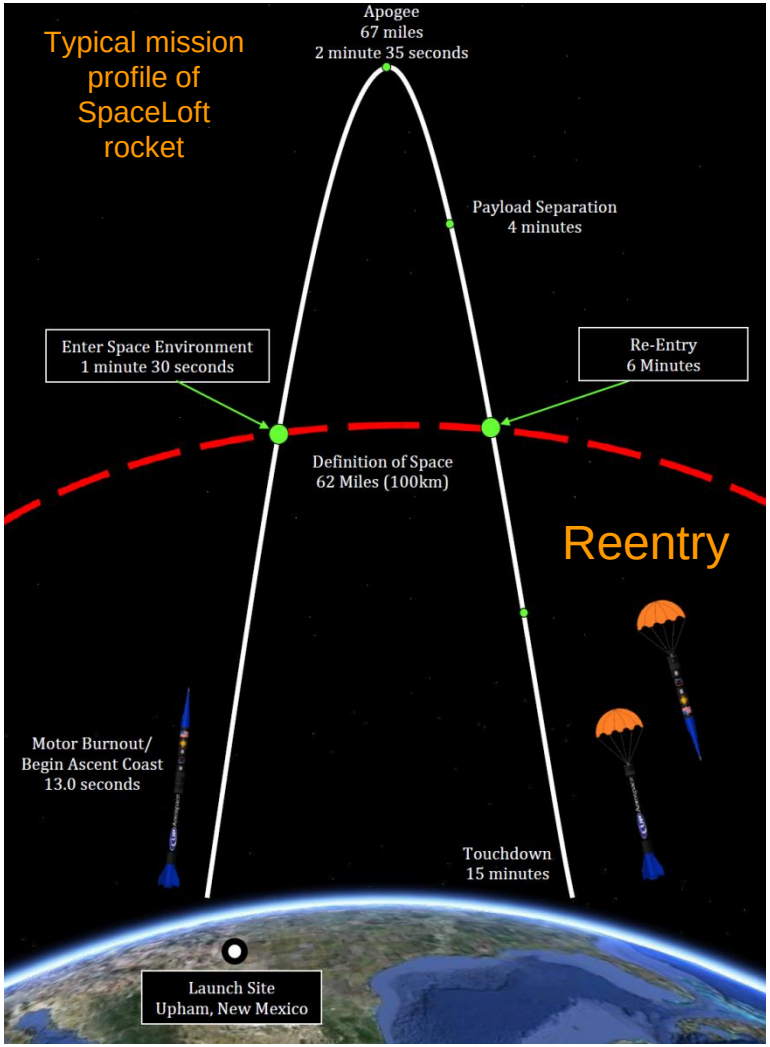


Magneto-elastic Active Sensor (MEAS)

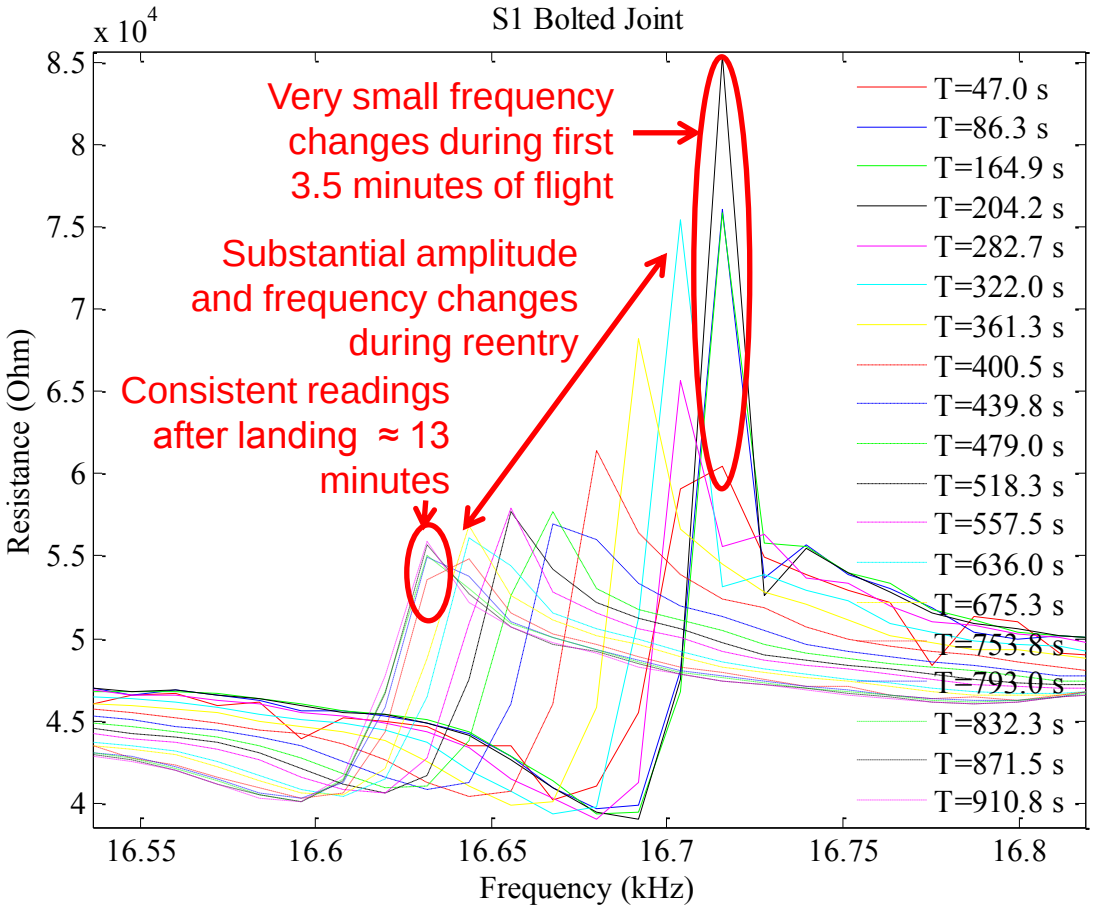




Suborbital flight data



Electro-mechanical impedance spectra



Extreme Space Environment

In space, structure will be exposed to

- Extreme temperatures
- Vacuum
- Radiation
- Atomic oxygen
- Micro-gravity
- Micro-meteroids and debris

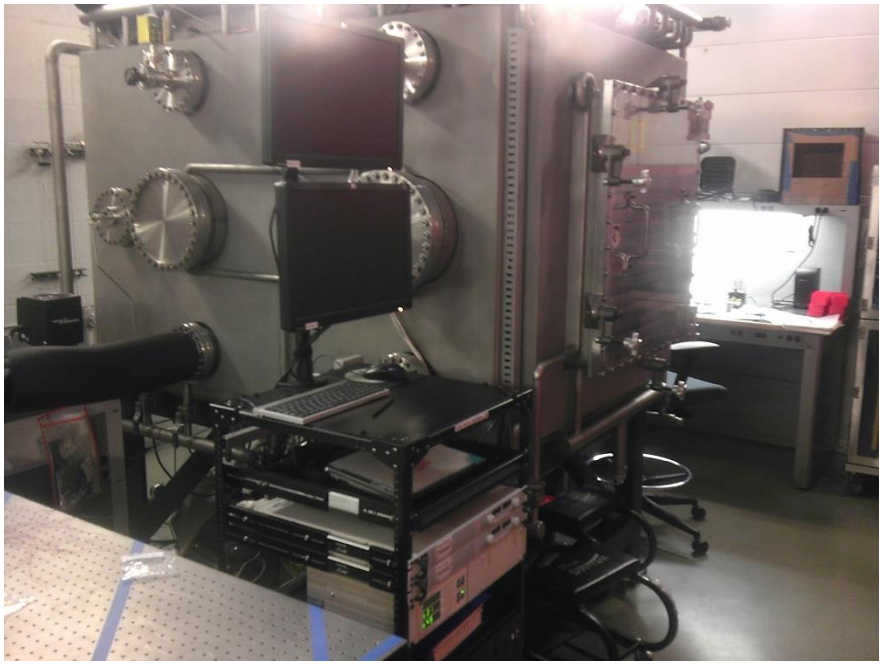
On Earth, aspects of space can be emulated

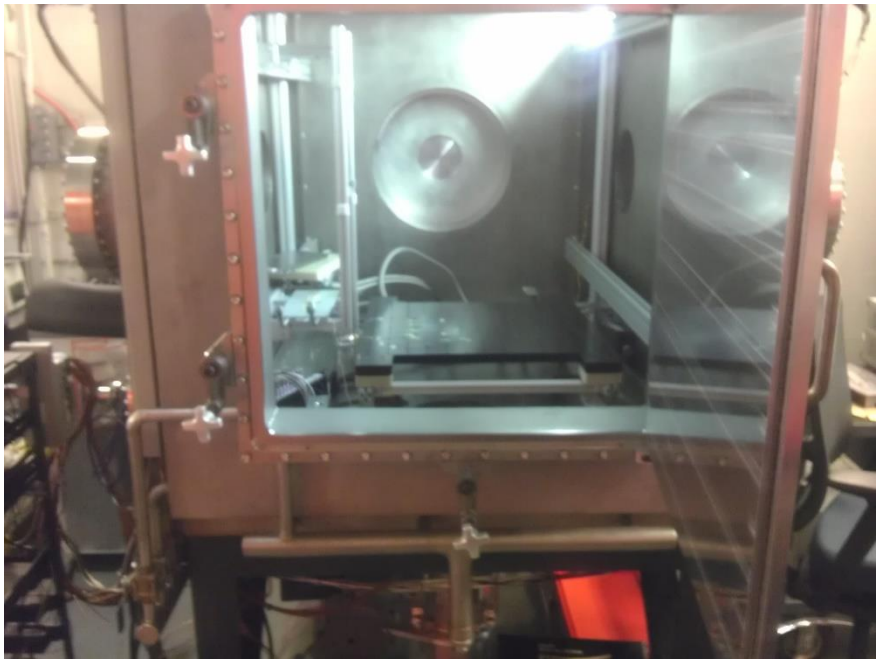
- Extreme temperatures and vacuum at AFRL
- Gamma radiation at WSMR

Temperature and Vacuum Effects

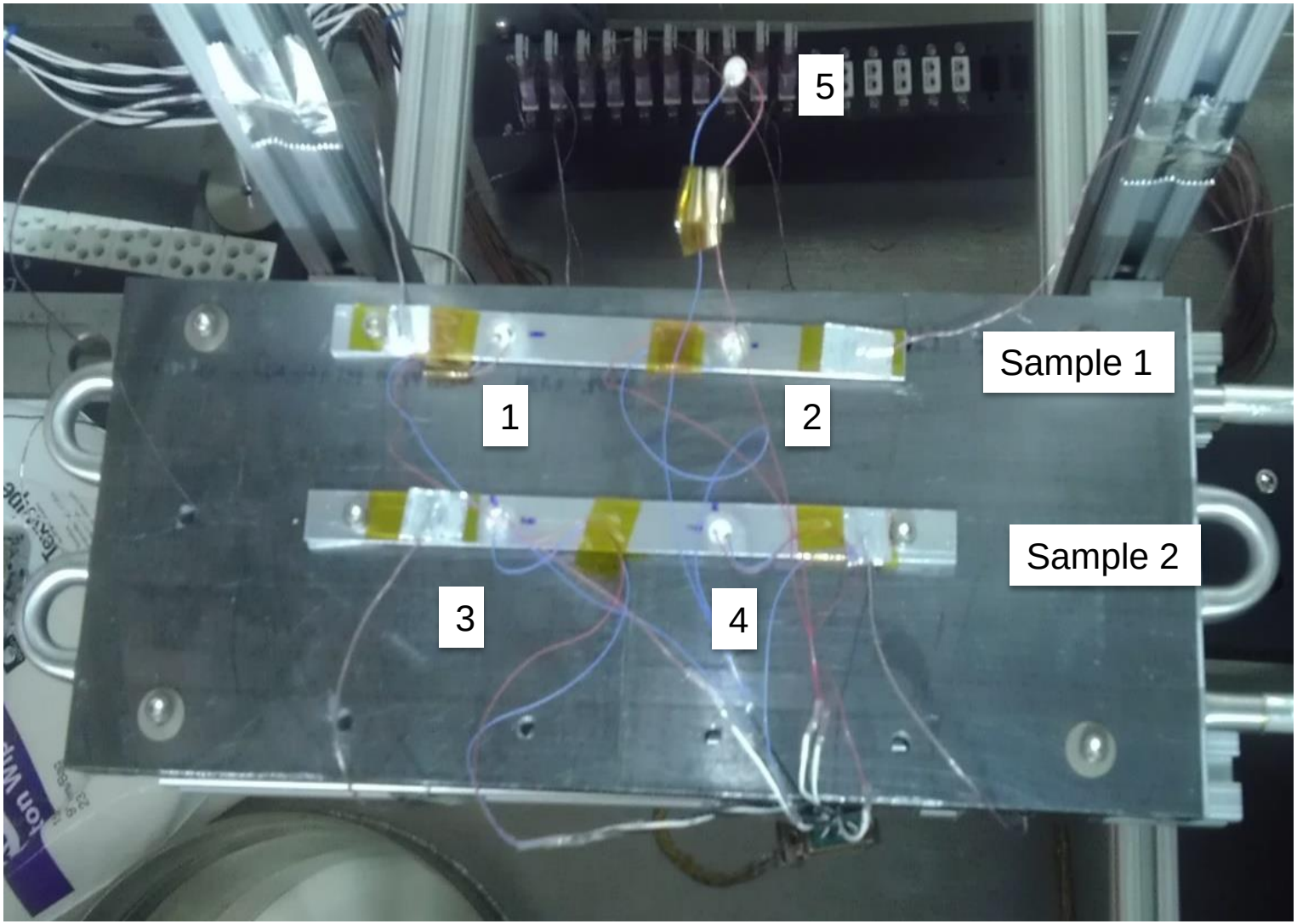
AFRL Vacuum Thermal Chamber

- Chamber Pressure 2 x 10^{-6} Torr
- FTS RC2111 Recirculating Chiller

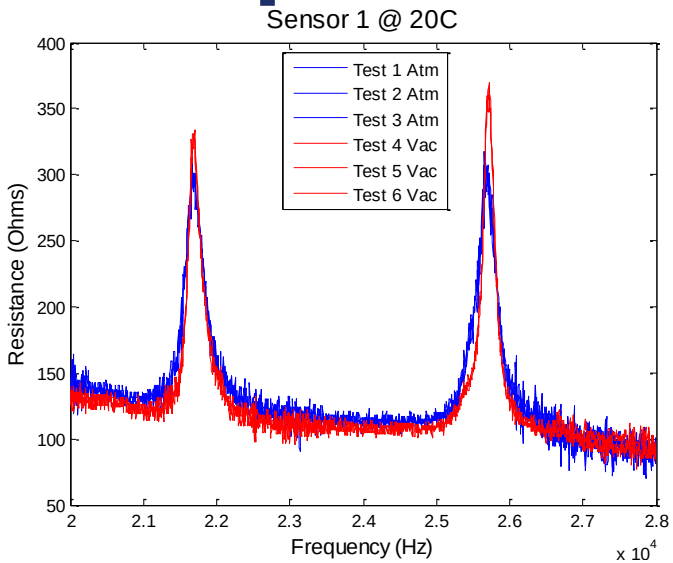


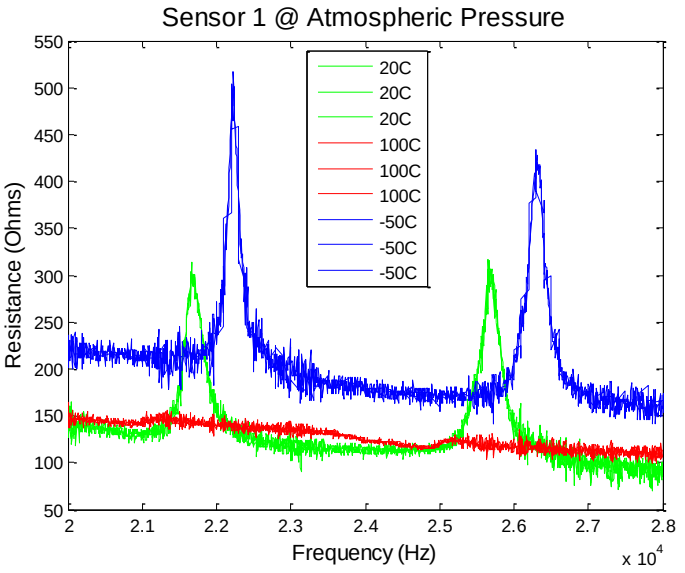


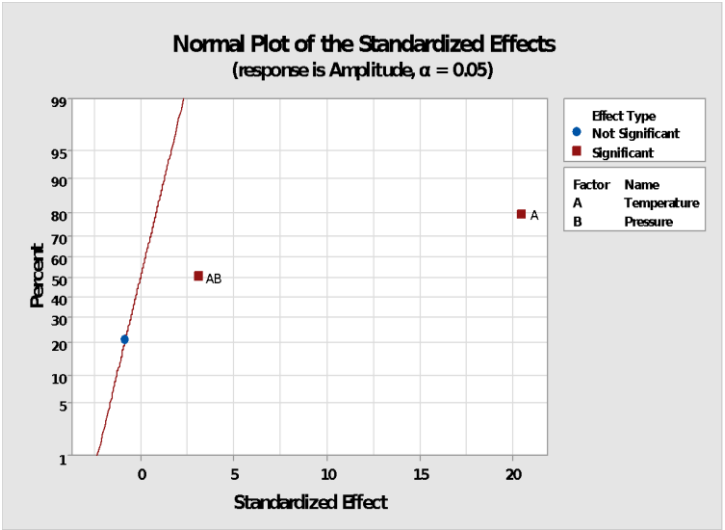
Temperature and Vacuum Effects

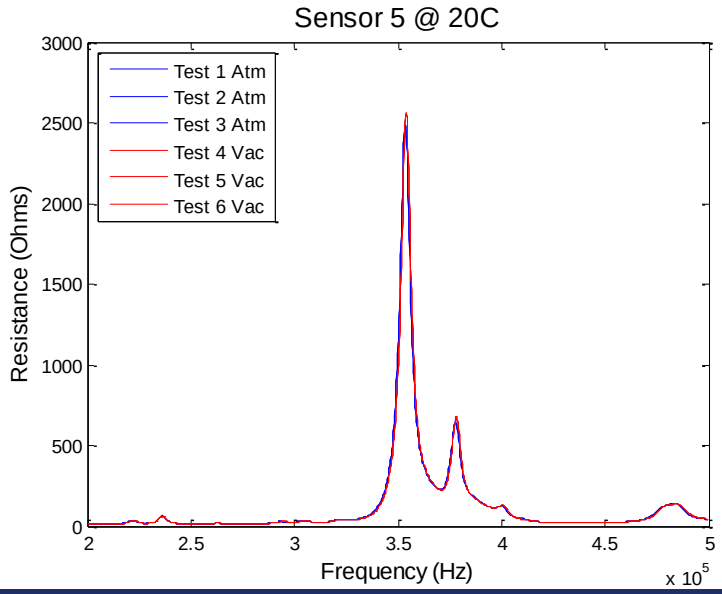


Temperature and Vacuum Effects









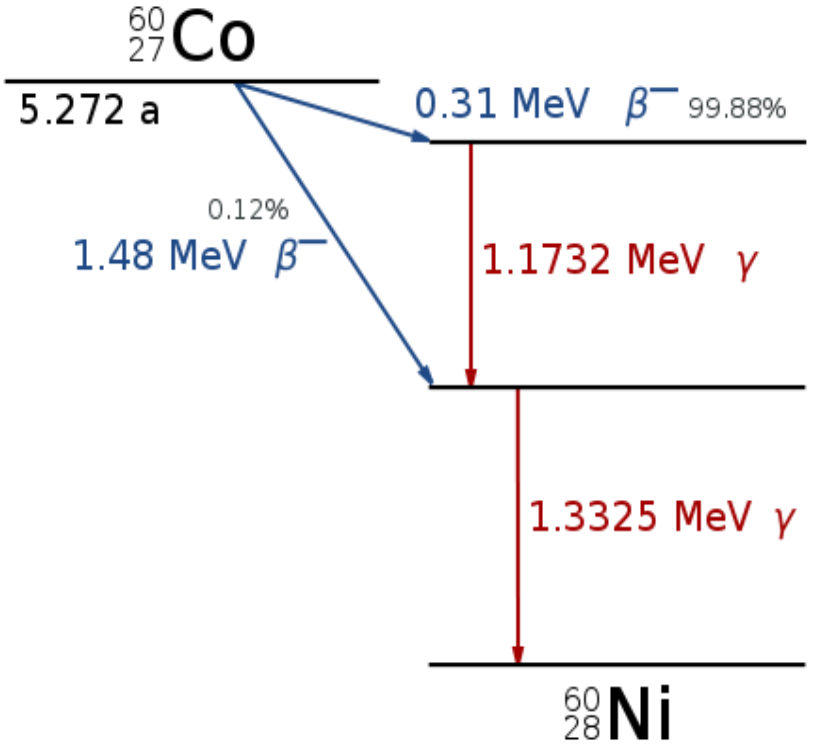
Investigation of Radiation Effects

Radiation in Space

- Background galactic cosmic radiation
- Solar event radiation
- Radiation from particles trapped in the Van Allen Belts

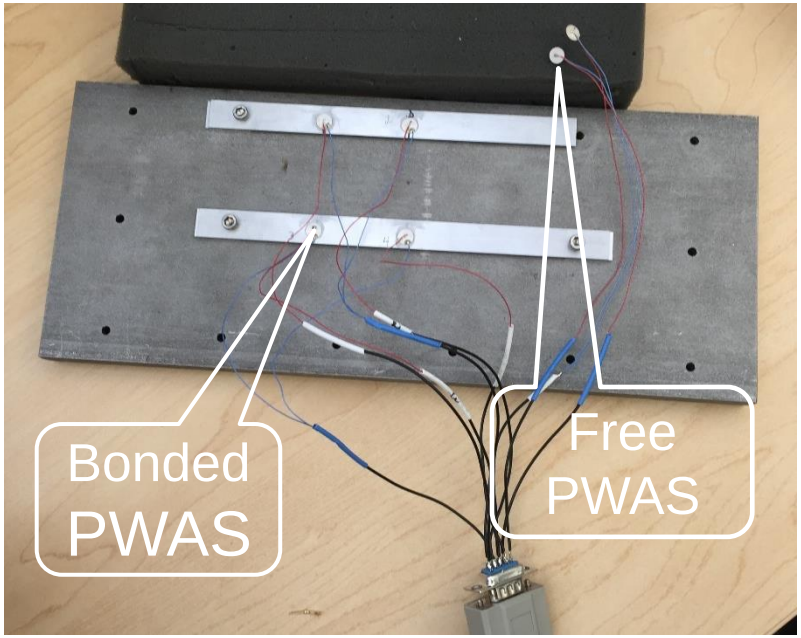
Gamma Radiation

- Suitable for emulating space environment (ESA)

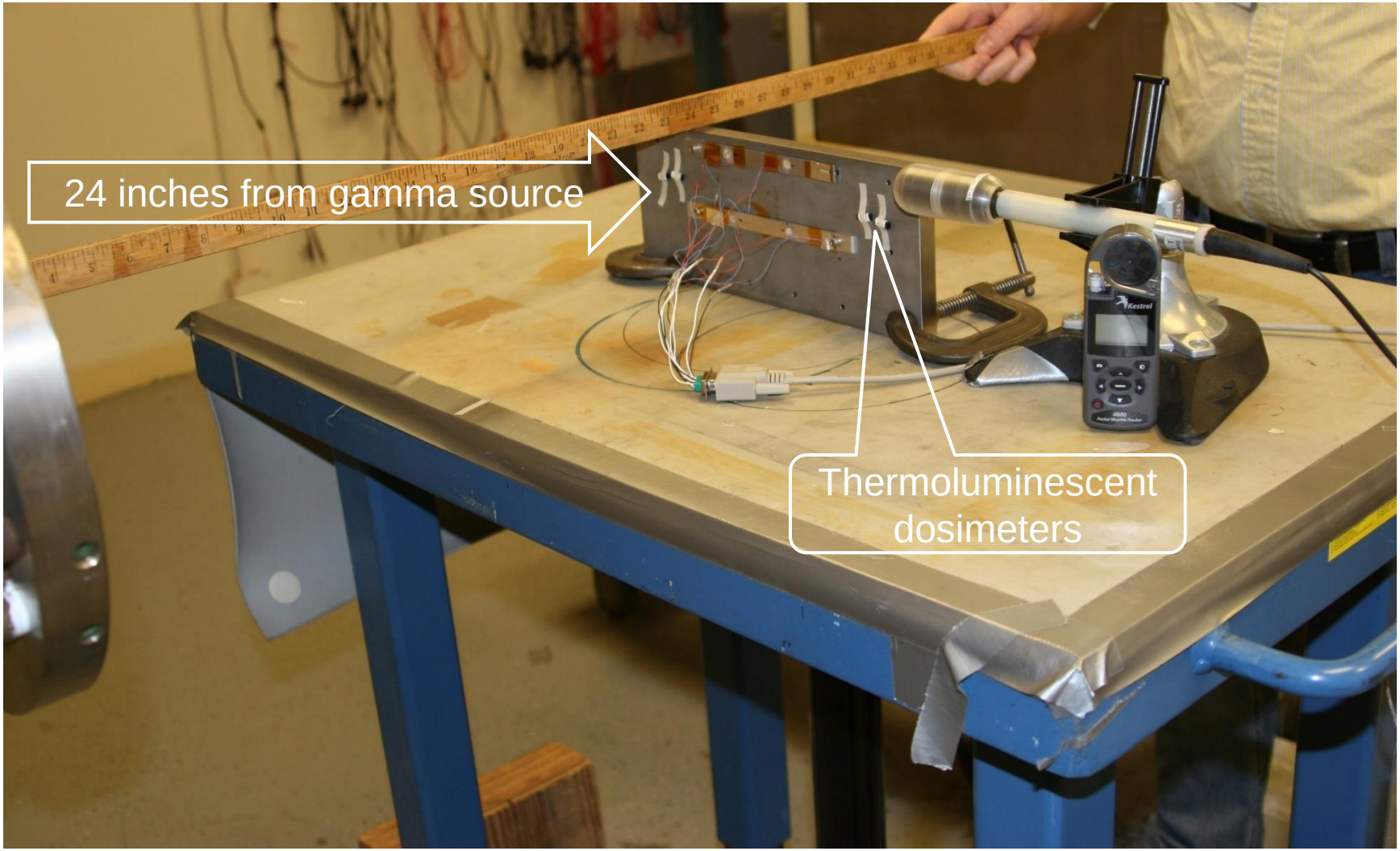


White Sands Gamma Facility Test

- Cobalt 60 gamma radiation
- PZT sensors bonded to 6061-T6 aluminum beams
- Frequency sweeps with impedance analyzer
- Data collection and analysis



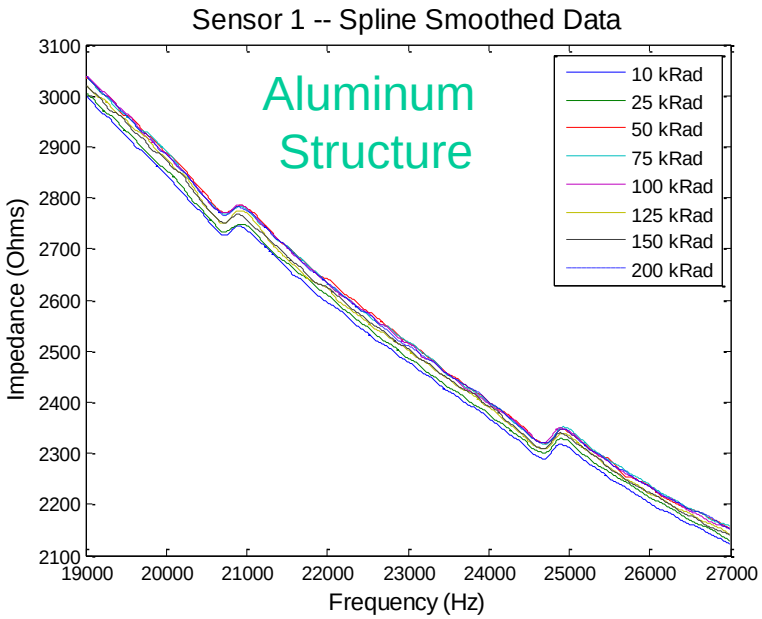
White Sands Gamma Facility Test

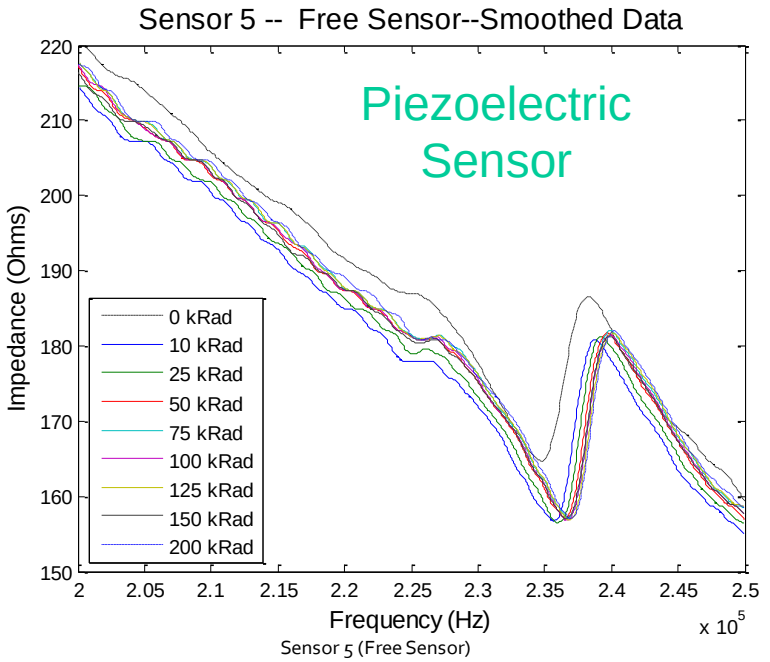


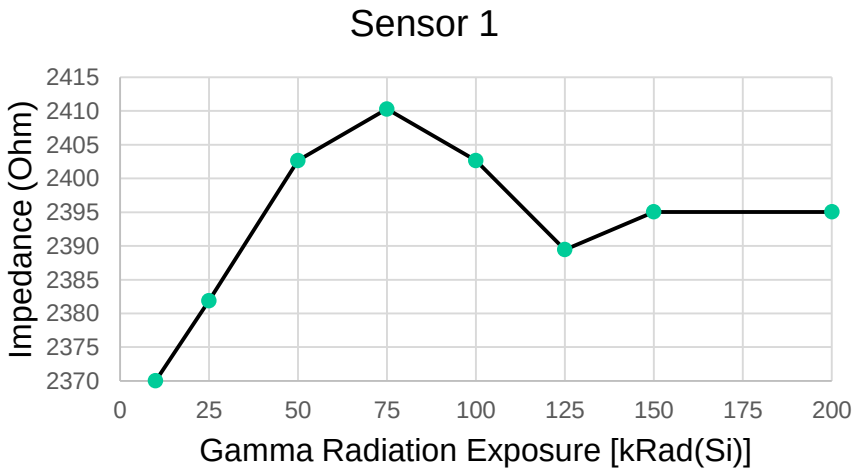
Irradiation Plan for LEO Simulations

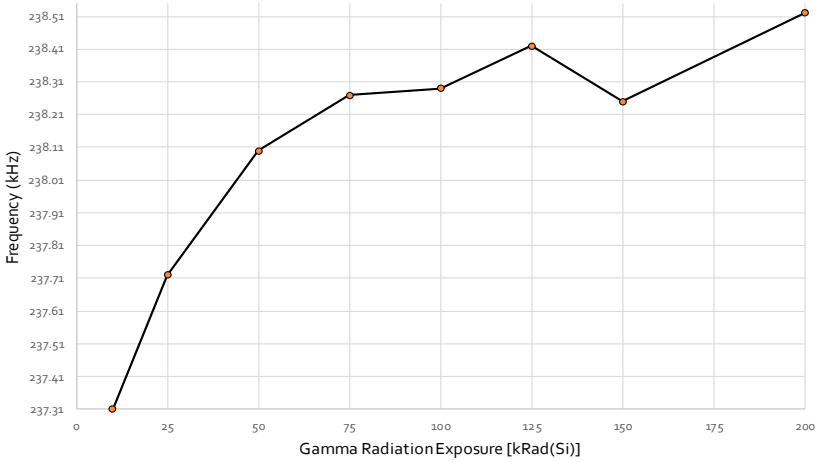
	Target Dose [Rad(Si)]	Target Exposure [R]	Actual Exposure	Estimated Dose [Rad(Si)]
	10,000	11,547	11,494	9,954
	25,000	28,868	16,119	13,959
	50,000	57,737	31,110	26,941
3 month	75,000	86,605	24,560	21,269
	100,000	115,473	33,100	28,665
6 month	125,000	144,342	28,710	24,863
	150,000	173,210	27,320	23,659
1 year	200,000	230,947	62,510	54,134

Effect of Radiation on Impedance Signatures



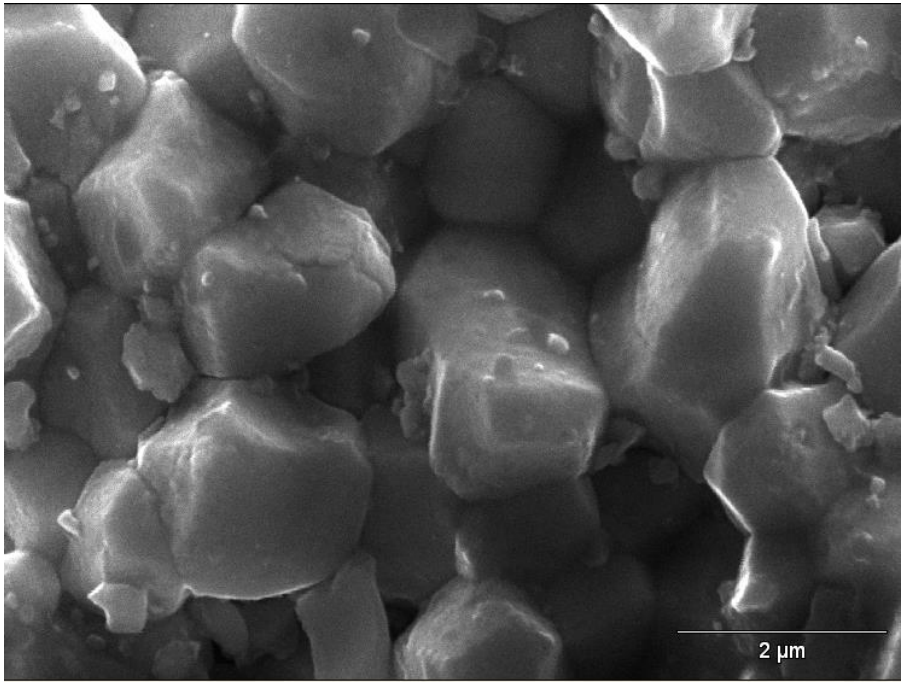




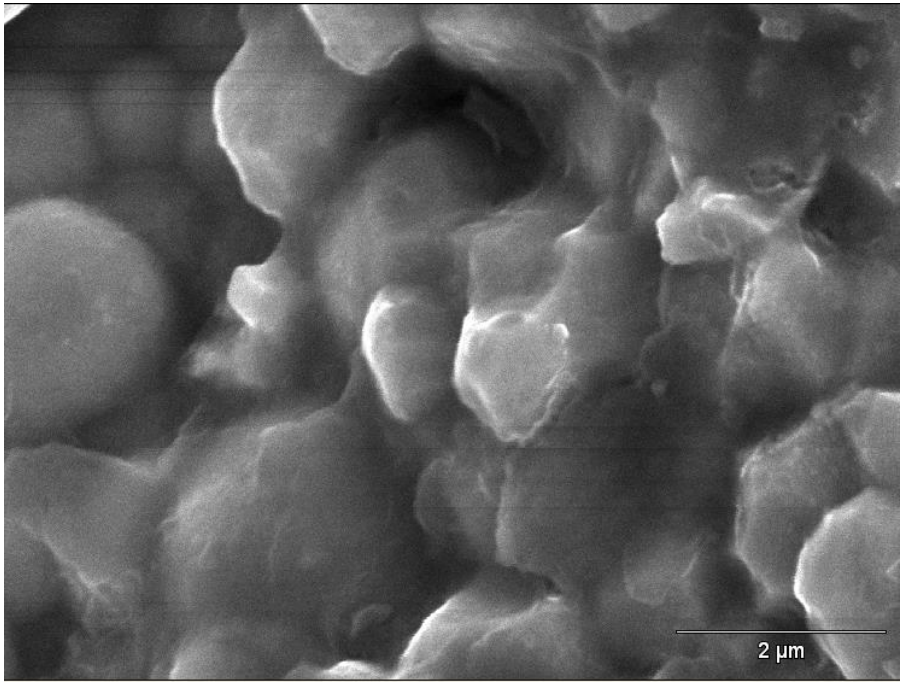


Effect of Radiation on Piezoelectric Ceramic

Before Irradiation



After Irradiation



Analytical Model

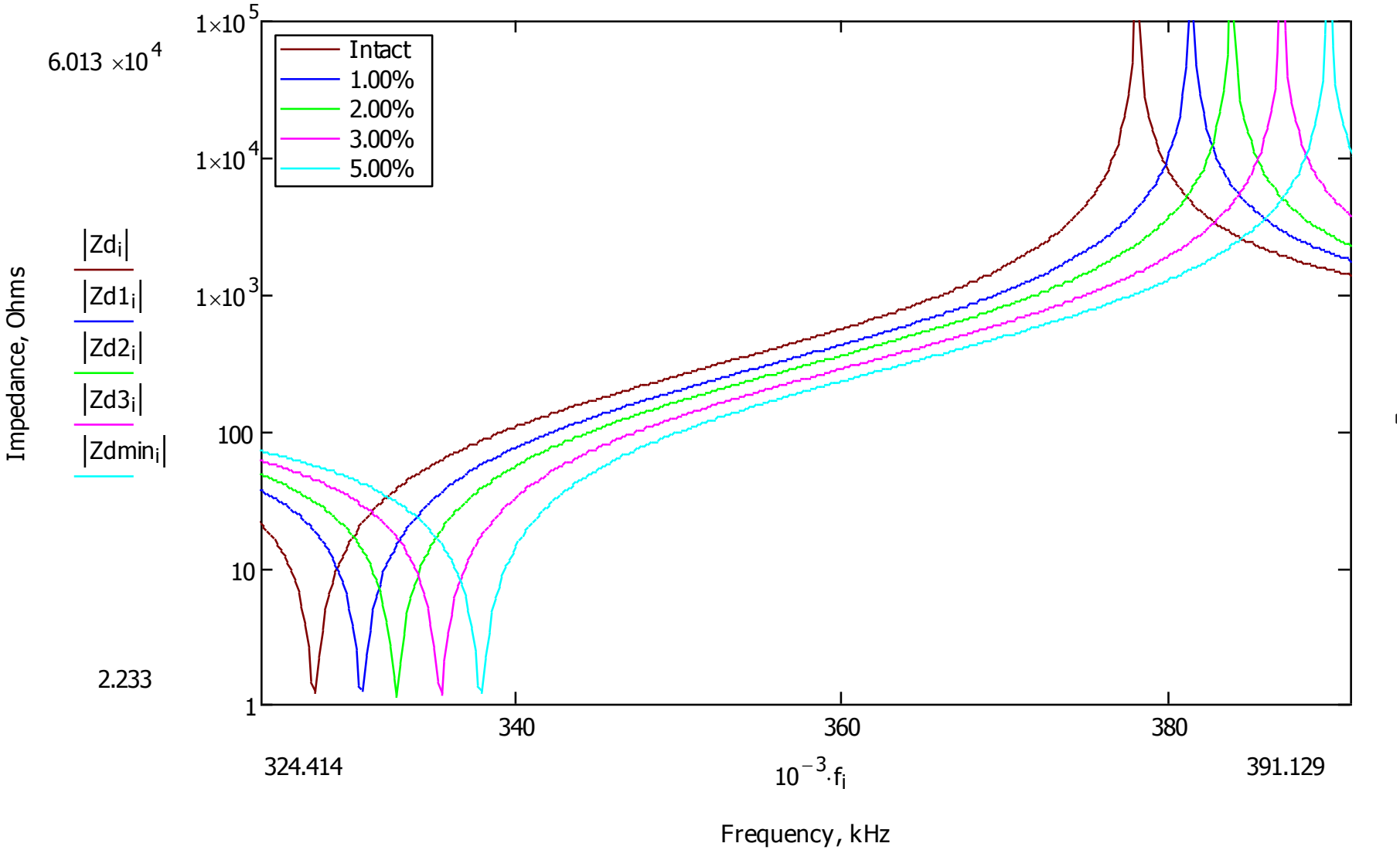
In our modeling efforts,

we propose that exposure to gamma radiation causes:

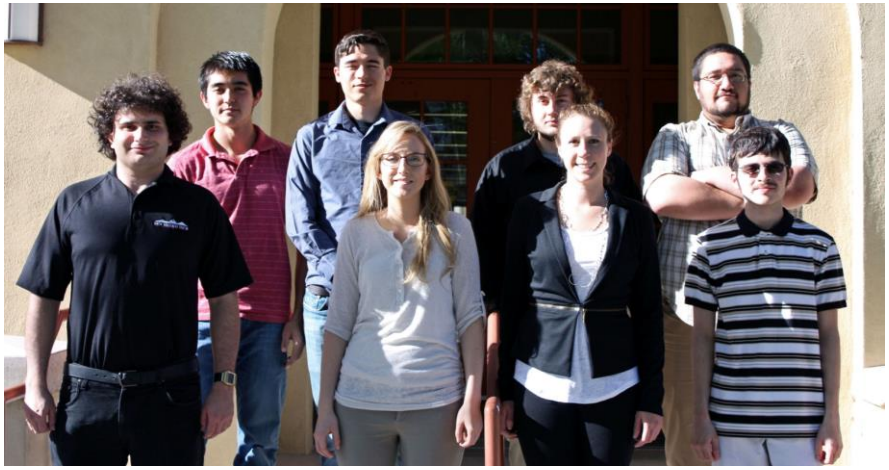
- Density loss in piezoelectric ceramics
- Decreased capacitance in PZT sensors

$$Ydmin_i := i \cdot \omega_i \cdot C_a \cdot \left[1 - \left(k'_p\right)^2\right] \cdot \left[1 + \frac{\left(k'_p\right)^2}{1 - \left(k'_p\right)^2} \cdot \frac{\left(1 + \sigma_{PZT}\right) \cdot J1\left(\phi min_i\right)}{\phi min_i \cdot J0\left(\phi min_i\right) - \left(1 - \sigma_{PZT}\right) \cdot J1\left(\phi min_i\right)}\right]$$

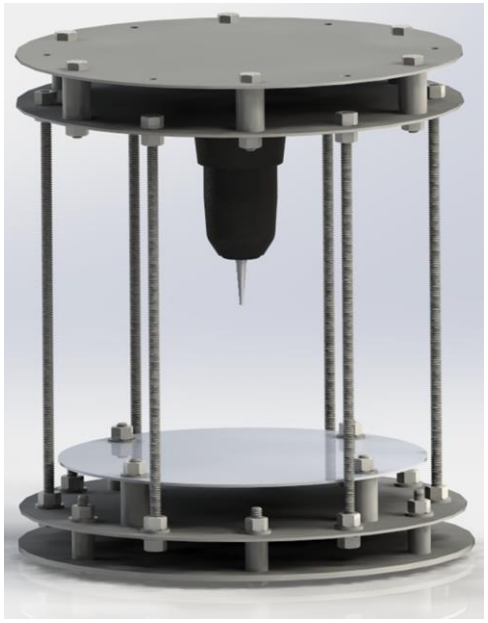
Analytical Model

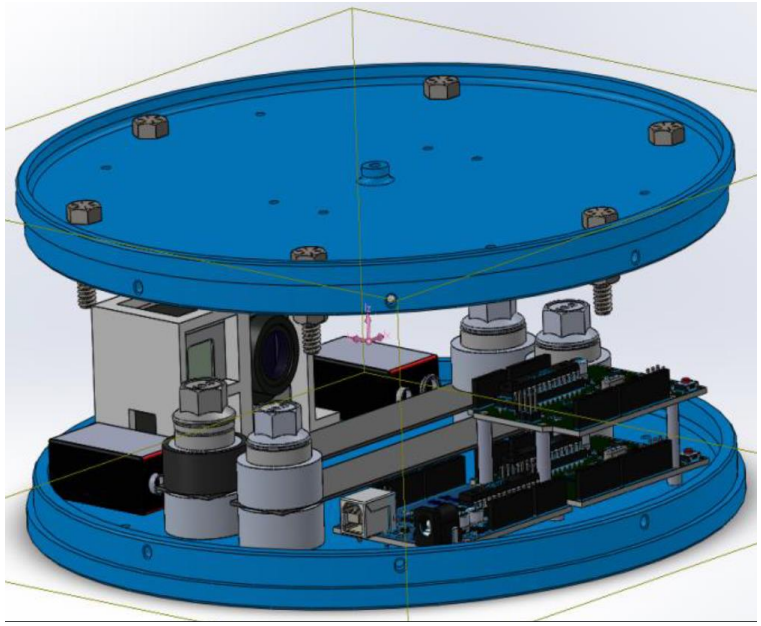


Undergraduate SHM Team



- Develop SHM capability for space structures
- Evaluate via NASA suborbital flight opportunity (NASA USIP proposal)
- Participation in future FOP





Acknowledgements

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  - Dr. Nickolas Demidovich
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- New Mexico Space Grant Consortium
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  - Graduate Student Association,
  - Ian Lopez-Pulliam, William Valiant and Ryan Borden, NMT Machine Shop
  - Gary Chandler, NMT Materials Department.

Publications/Presentations

- Zagrai, A., and Demidovich, N. (2016) “Structural Health Monitoring Potential of Commercial Space Vehicles,” **invited talk** at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 20-23, 2016, Westminster, Colorado.
- Zagrai, A., Trujillo, B. and Demidovich, N. (2016) “Acoustic Emission during Thermal Fatigue of Aluminum Alloy,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 20-23, 2016, Westminster, Colorado.
- Anderson, M., Zagrai, A., Daniel, J.D. (2016) “Potential Use of Piezoelectric Sensors For Structural Health Monitoring In Radioactive Environments”, presentation for the workshop organized by Institute of Nuclear Materials Management Technical Exchange, Taos, New Mexico, May 19, 2016.
- Trujillo, B. and Zagrai, A., (2016) “Embedded and Conventional Ultrasonic Sensors for Monitoring Acoustic Emission During Thermal Fatigue,” SPIE's 23rd Annual International Symposium on Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, 20-24 March 2016, San Diego, CA, v 9805, paper 98051K.