COE CST Fifth Annual Technical Meeting

Task 228: Magneto-Elastic Sensing for Structural Health Monitoring (SHM)
Task 323: SHM Framework

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Team Members

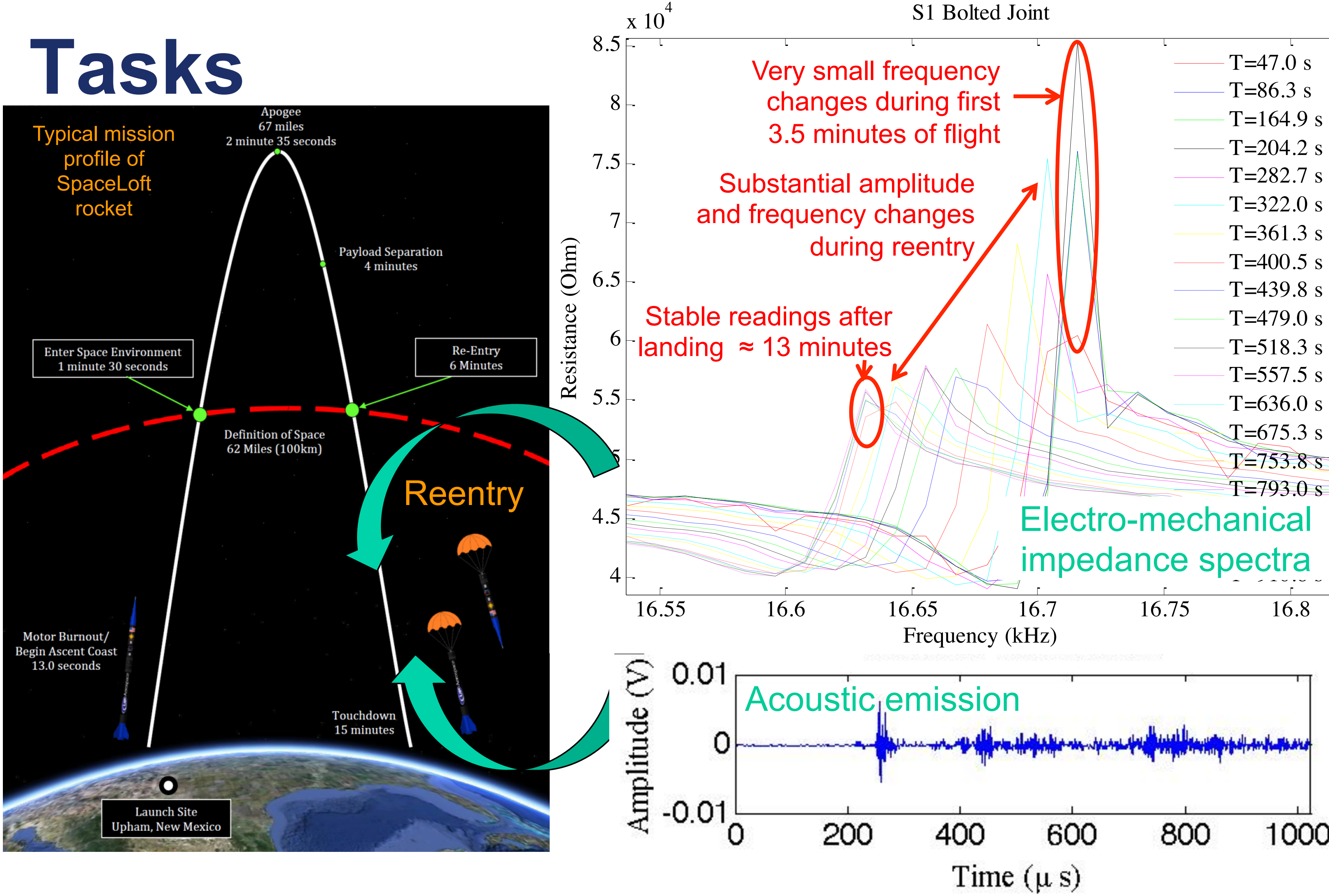
- Andrei Zagrai & Warren Ostergren (PIs)
- Blaine Trujillo (GR ME)
- Mary Anderson (GR ME) - also supported by NMSGC
- 2 Undergraduate student design teams working on space payload

- Valerie Jenkins (lead), Daniel Archuleta, Daniel Wimberly, Dylan Purcell, Carl Peart, Tyler Marquis, Aaron Zucherman

Task Description

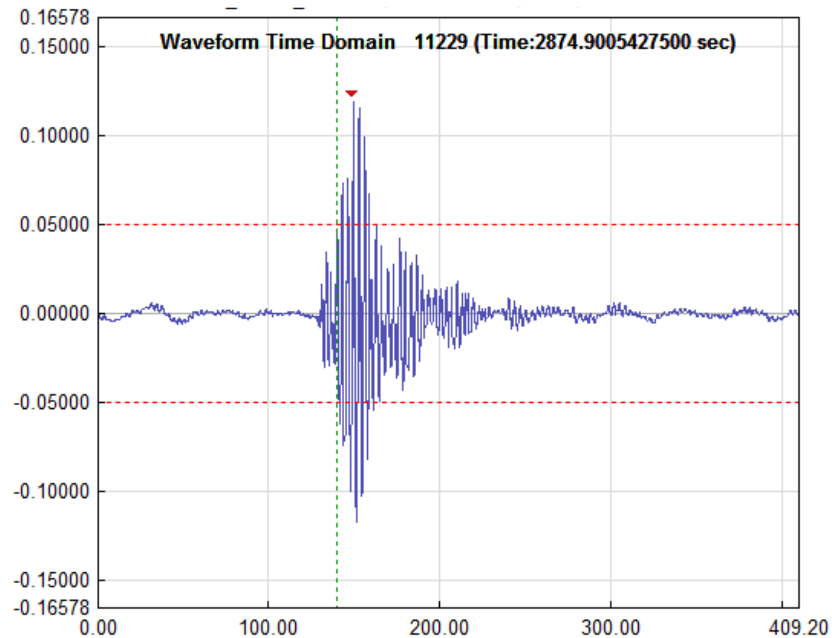
- The GOAL of the task is to make commercial spaceflight safer and less expensive
- OBJECTIVES of the task include:
  - Explore various Structural Health Monitoring (SHM) as safety enhancers and cost reducers for commercial space vehicles and demonstrate their utility during space flights.
  - Investigate acoustic emission due to thermal fatigue and thermal dependence of electro-mechanical impedance method.

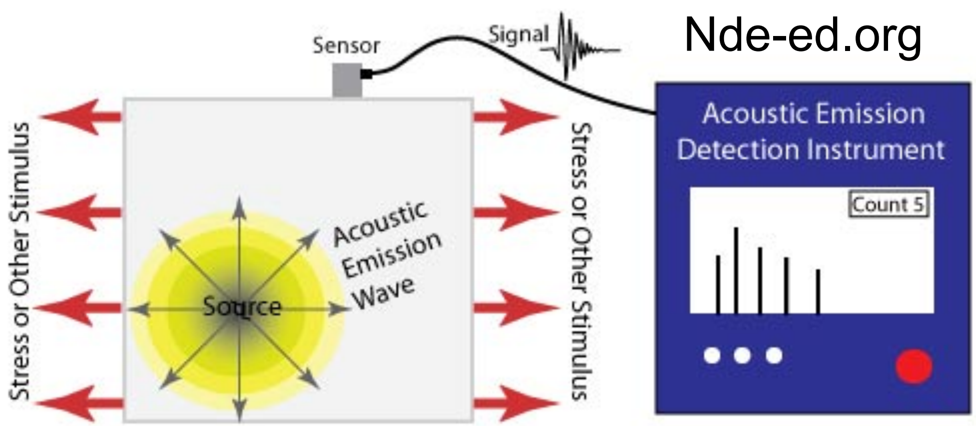
Tasks


Typical mission profile of SpaceLoft rocket
Apogee
67 miles
2 minute 35 seconds
Payload Separation
4 minutes
Enter Space Environment
1 minute 30 seconds
Re-Entry
6 Minutes
Definition of Space
62 Miles (100km)
Reentry
Motor Burnout/
Begin Ascent Coast
13.0 seconds
Touchdown
15 minutes
Launch Site
Upham, New Mexico
S1 Bolted Joint
x 10^4
Resistance (Ohm)
Frequency (kHz)
Very small frequency changes during first 3.5 minutes of flight
Substantial amplitude and frequency changes during reentry
Stable readings after landing ≈ 13 minutes
T=47.0 s
T=86.3 s
T=164.9 s
T=204.2 s
T=282.7 s
T=322.0 s
T=361.3 s
T=400.5 s
T=439.8 s
T=479.0 s
T=518.3 s
T=557.5 s
T=636.0 s
T=675.3 s
T=753.8 s
T=793.0 s
Electro-mechanical impedance spectra
Acoustic emission
Amplitude (V)
Time (μ s)

Acoustic Emission Principles

- Acoustic emission (AE) is passive sensing technology that allows for monitoring acoustic activity in structural material
- AE acquisition hardware includes state-of-the-art Mistras Micro-II Digital AE System and a variety of conventional (Micro-80) or new (PWAS) acoustic





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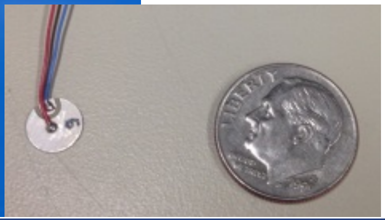
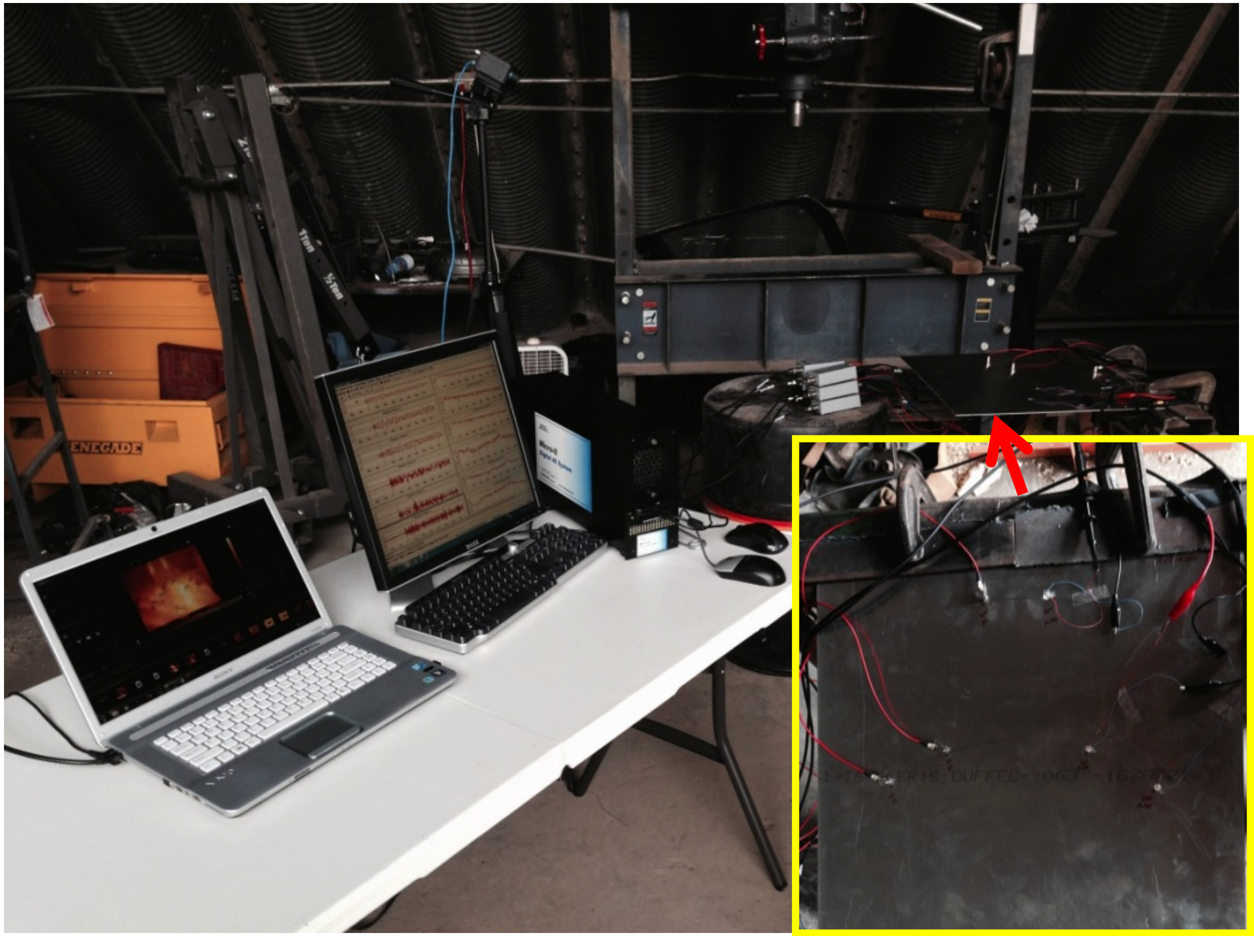
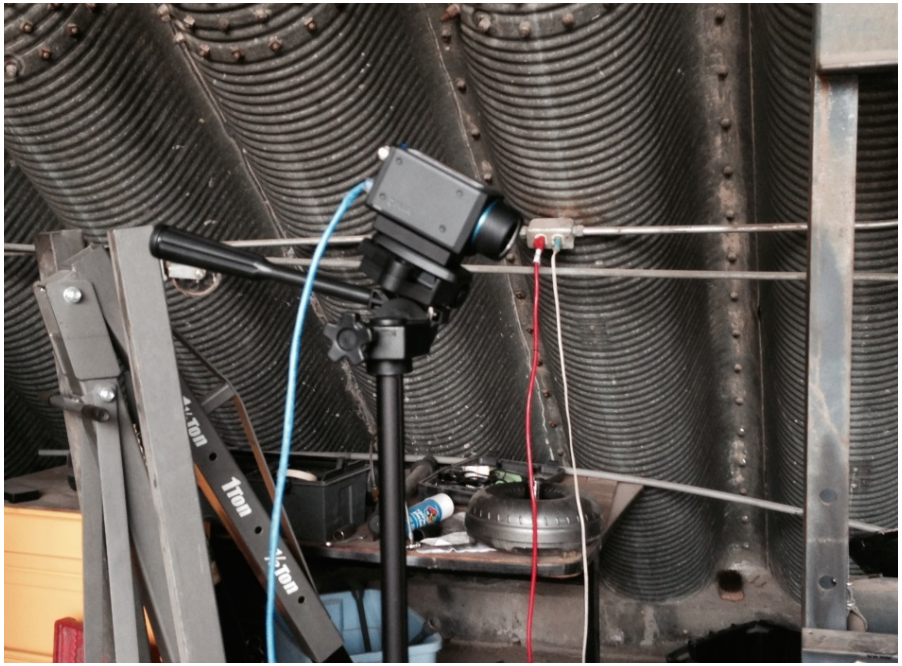


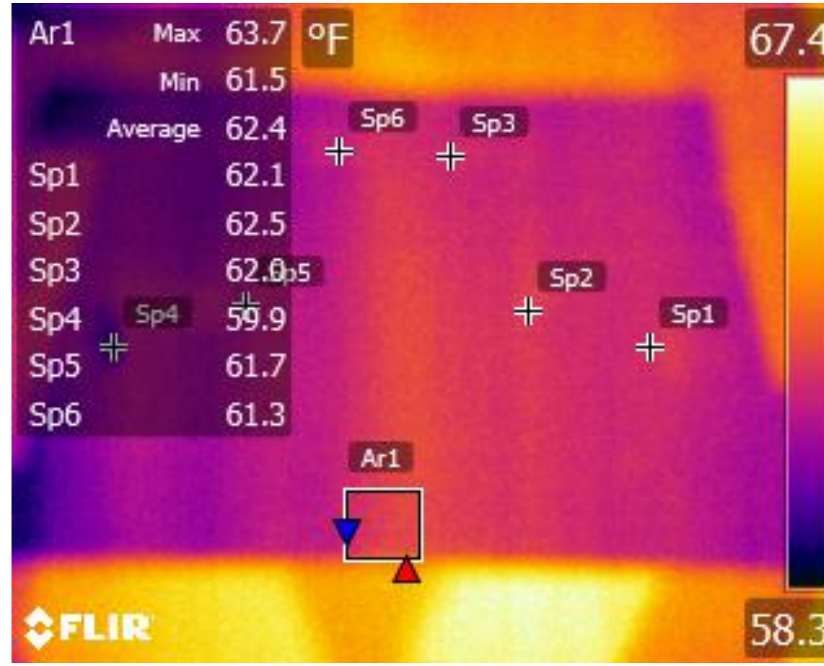
Thermal Fatigue Experimental Setup

- Observe AE during thermal fatigue of 6061-T6 aluminum
- PWAS and Micro-80 sensors
- Infrared (IR) data
  - FLIR Ax5 series camera
- Heat Application
  - Butane torch

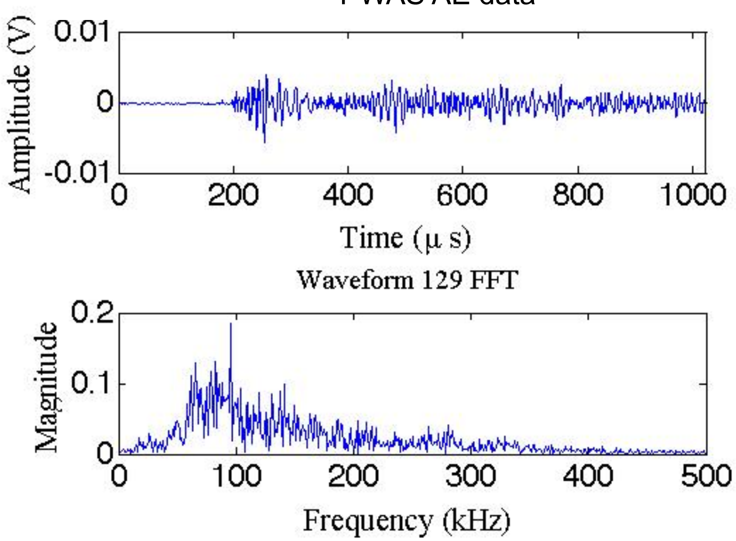


AE and Thermal Results

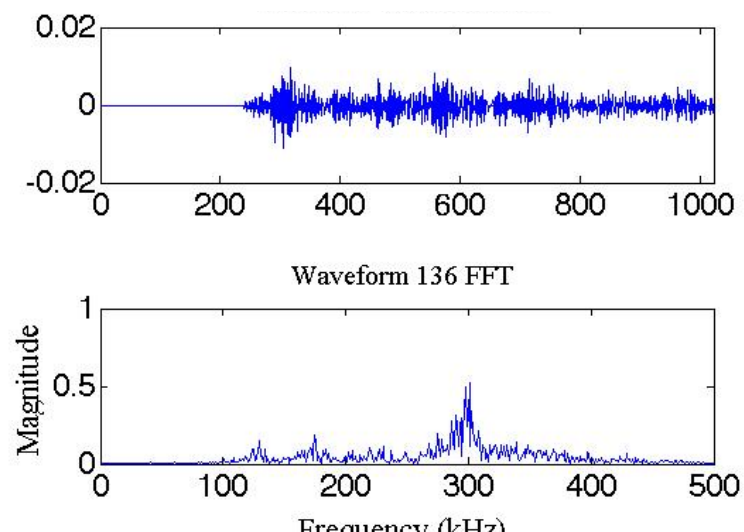




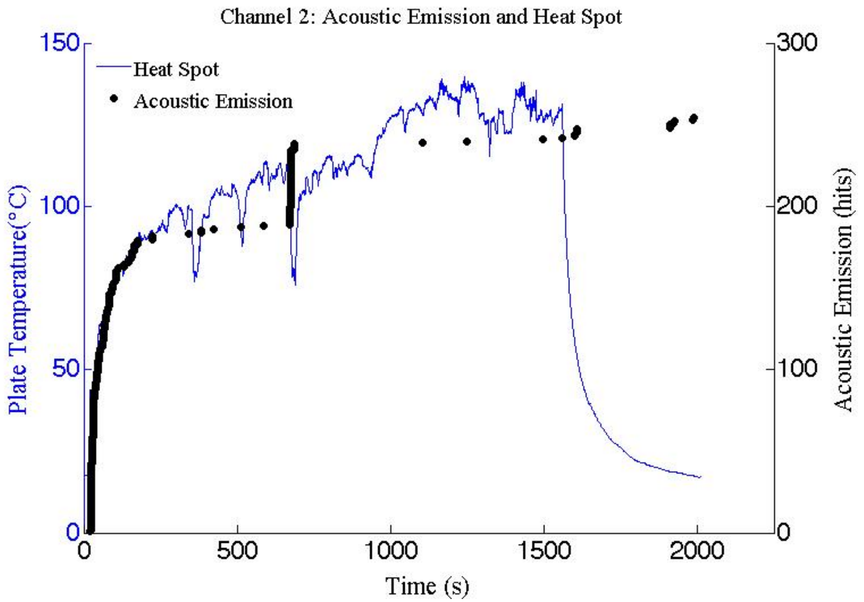
PWAS AE data



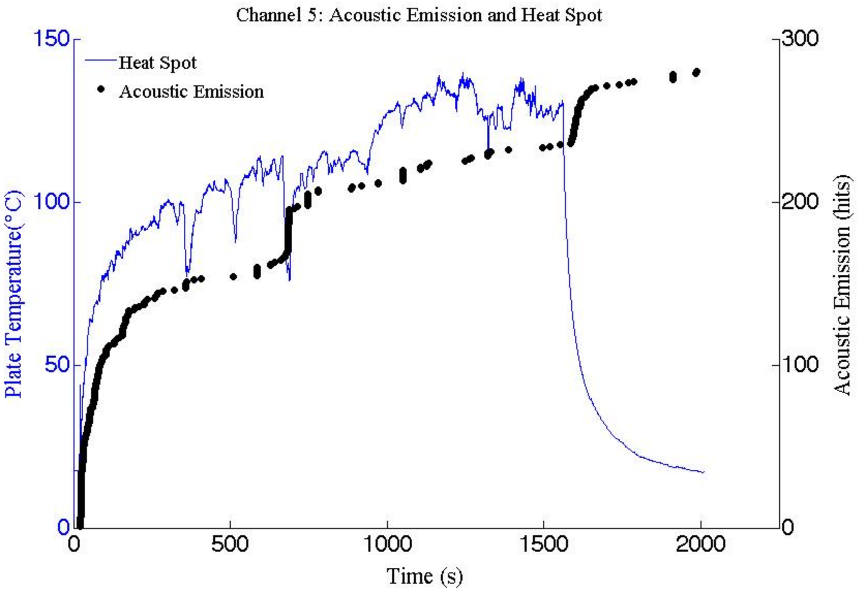
Micro-80 AE data



Test 1 Clamped-Clamped Plate

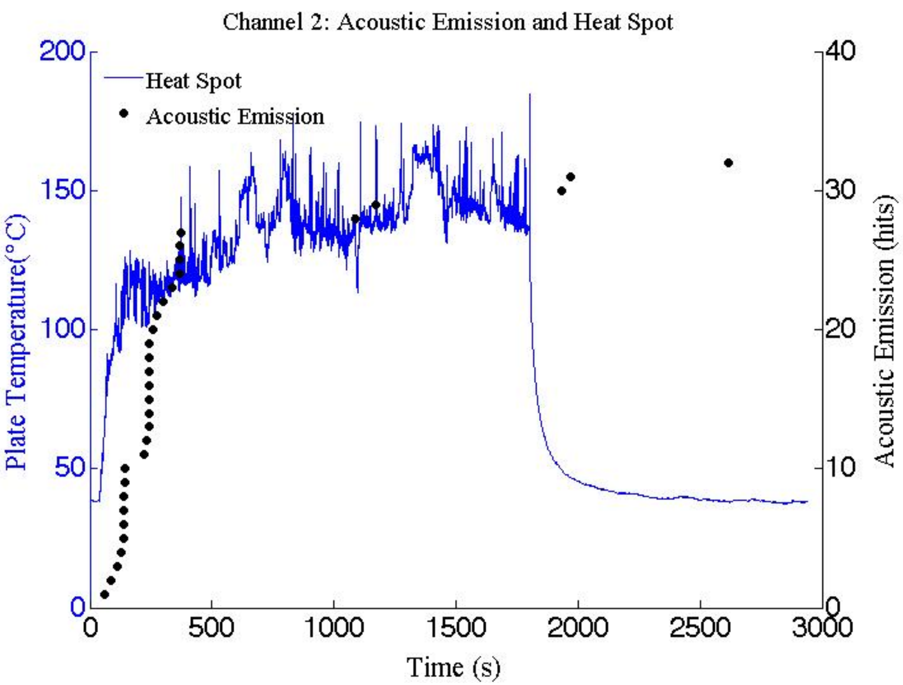


PWAS AE data

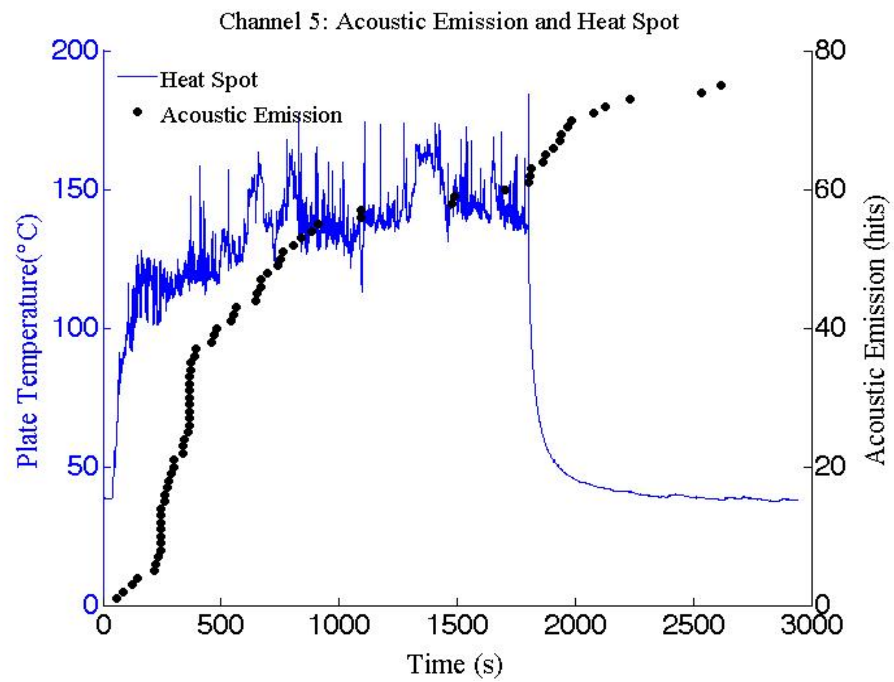


Micro-80 AE data

Test 2 Clamped-Free Plate

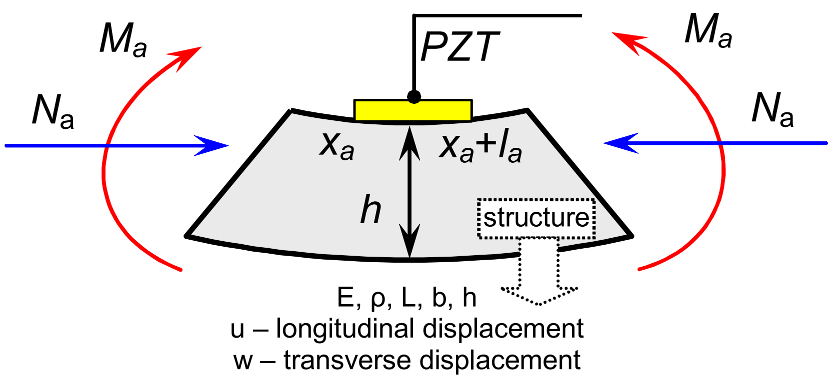


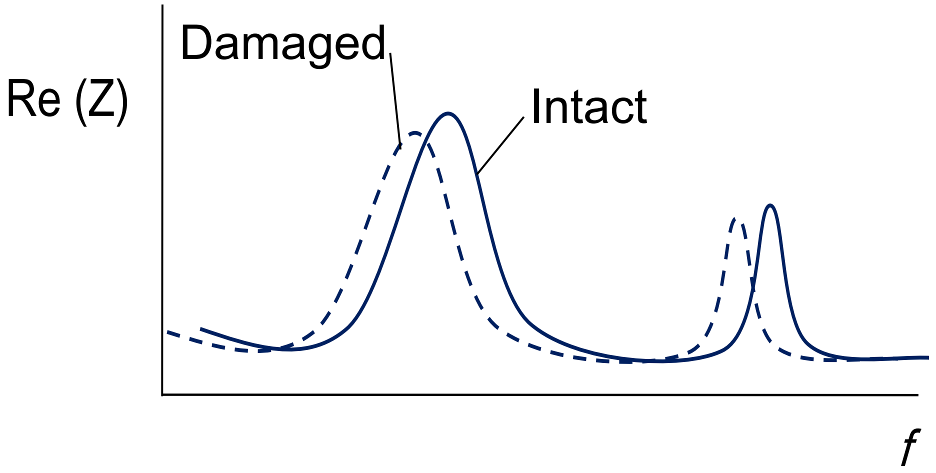
PWAS AE data



Micro-80 AE data

Electro-Mechanical Impedance



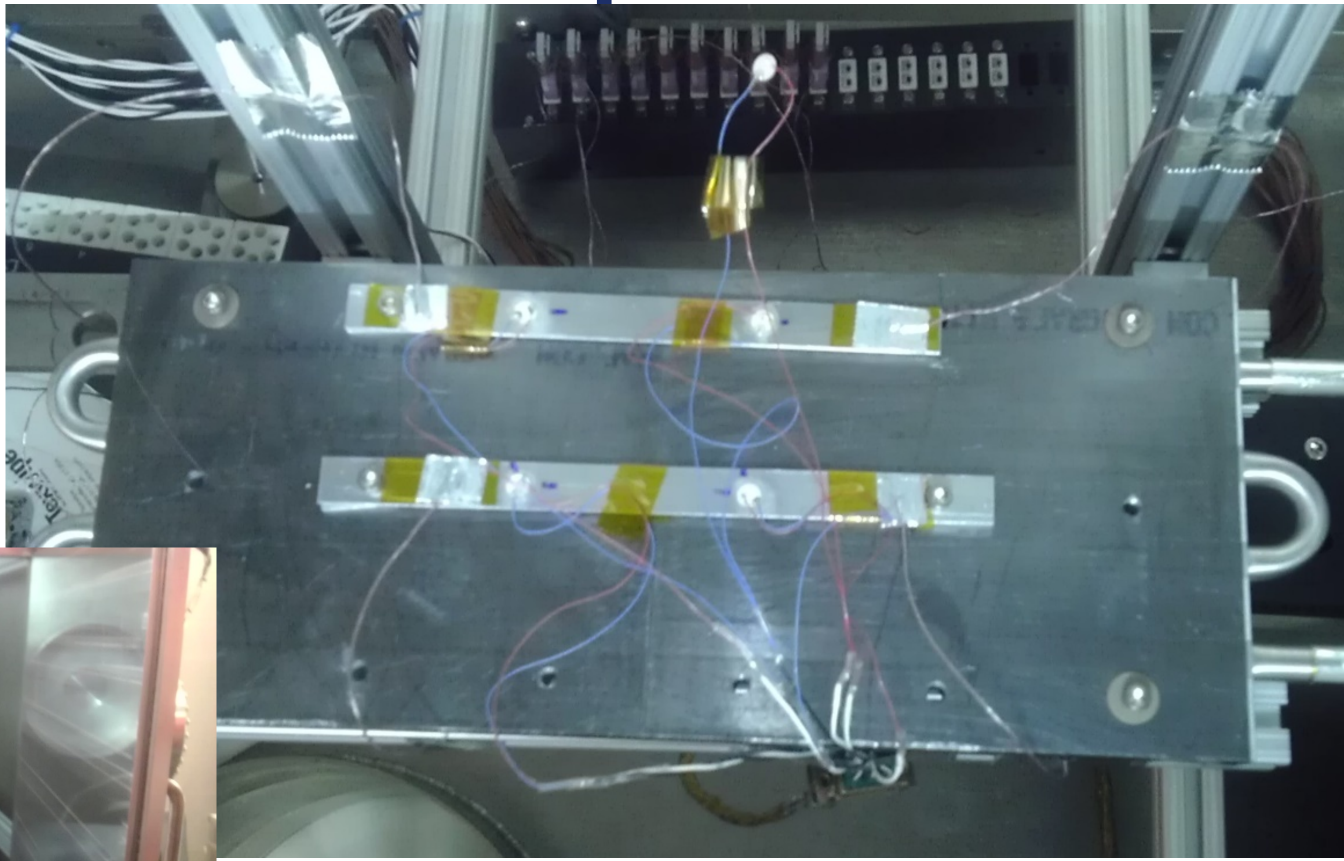


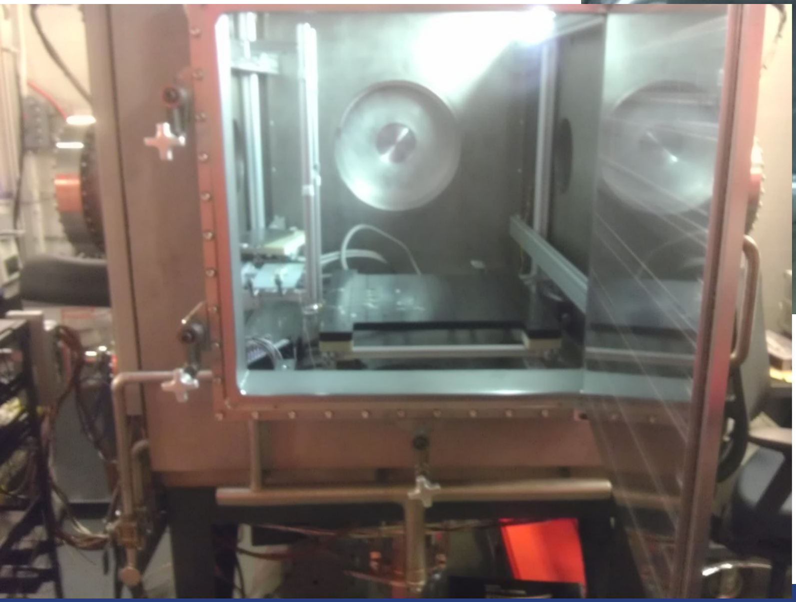
- Mechanical coupling between sensor and host structure (**Rigid Adhesive**)
- Internal coupling between piezoelectric electrical and mechanical properties (**Piezoelectric Effect**)
- Mechanical properties of host structure reflected in piezoelectric electrical properties (**Electromechanical Impedance**)
- Allows measurement of structure dynamics as an electrical quantity
- Enables high-frequency structural response characterization and SHM

Space Environment Emulation

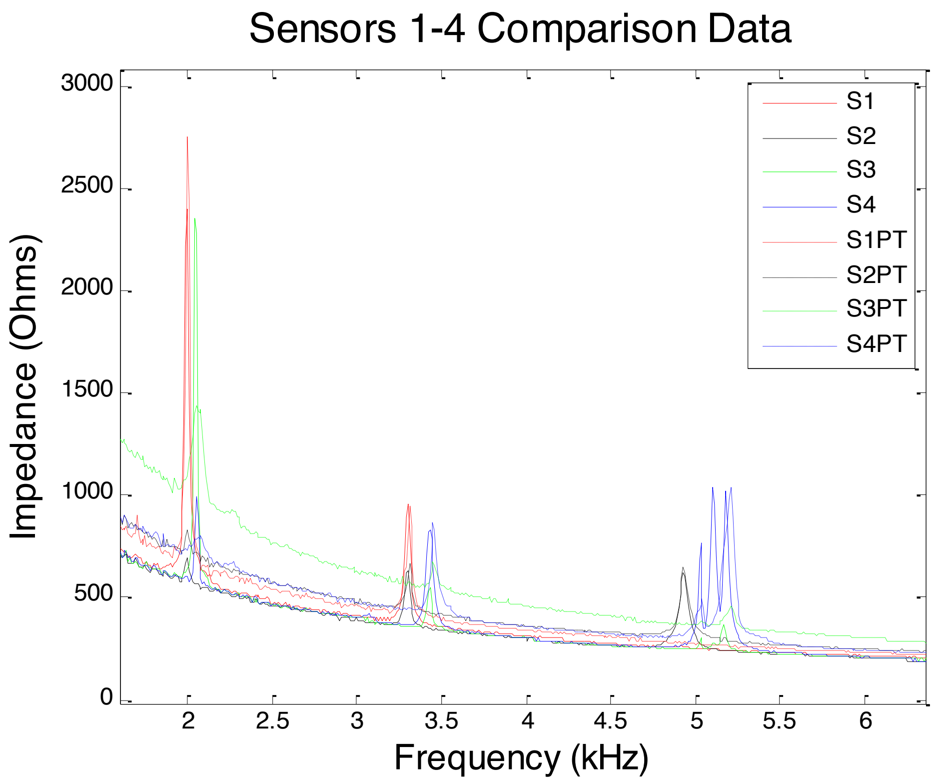
- How does the harsh environment of space affect a known method of structural health monitoring?
- Emulate space environment
  - Vacuum
  - Extreme temperatures
- Vacuum Thermal Chamber at AFRL
  - Chamber Pressure 2 x 10-6 Torr
  - FTS RC2111 Recirculating Chiller
  - Range -80ºC to +75ºC
- HP 4192A Impedance Analyzer (5 kHz to 13 MHz)

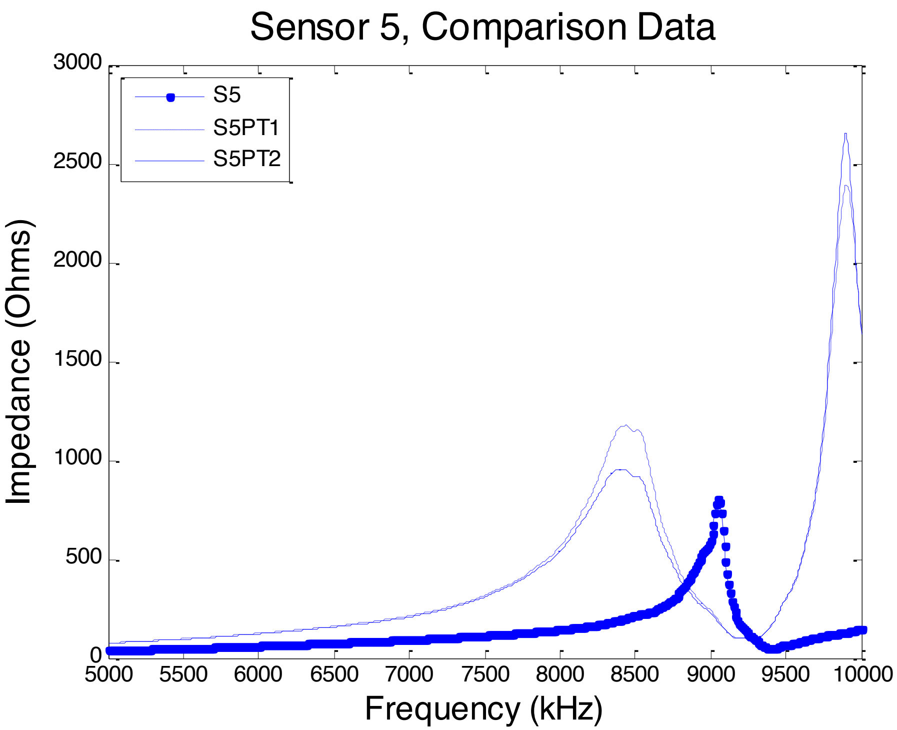
ThermalVac Test Setup





Baseline Data

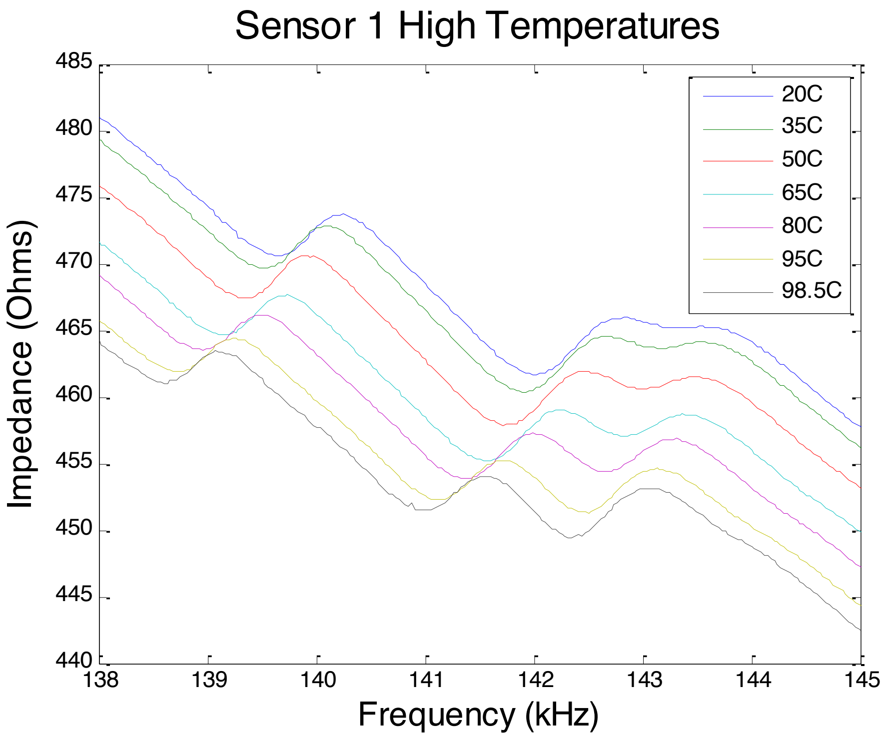


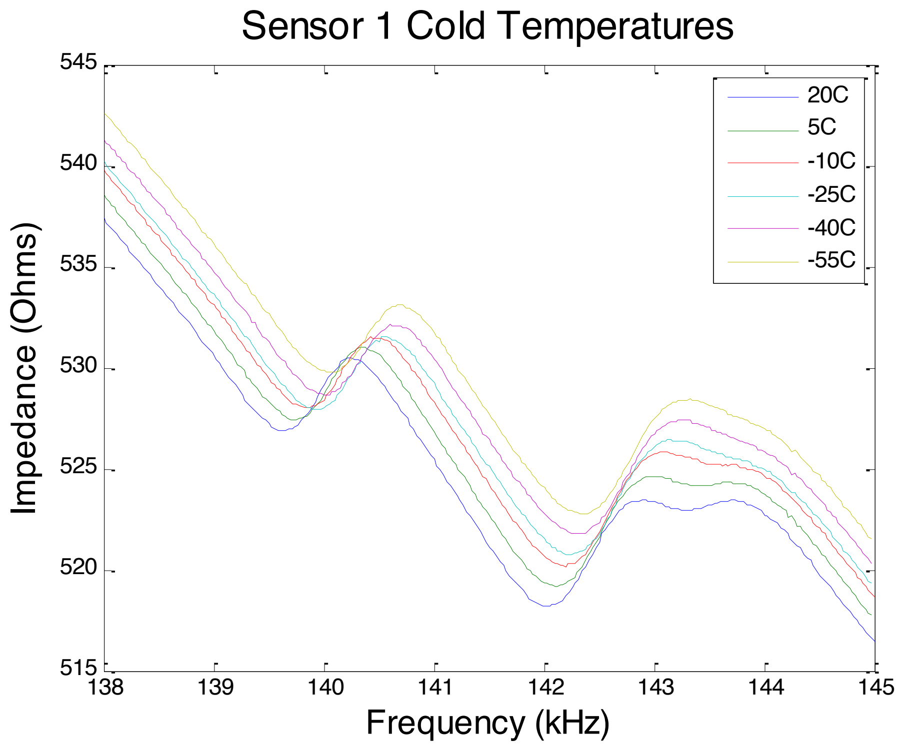


Thermal Vac Test

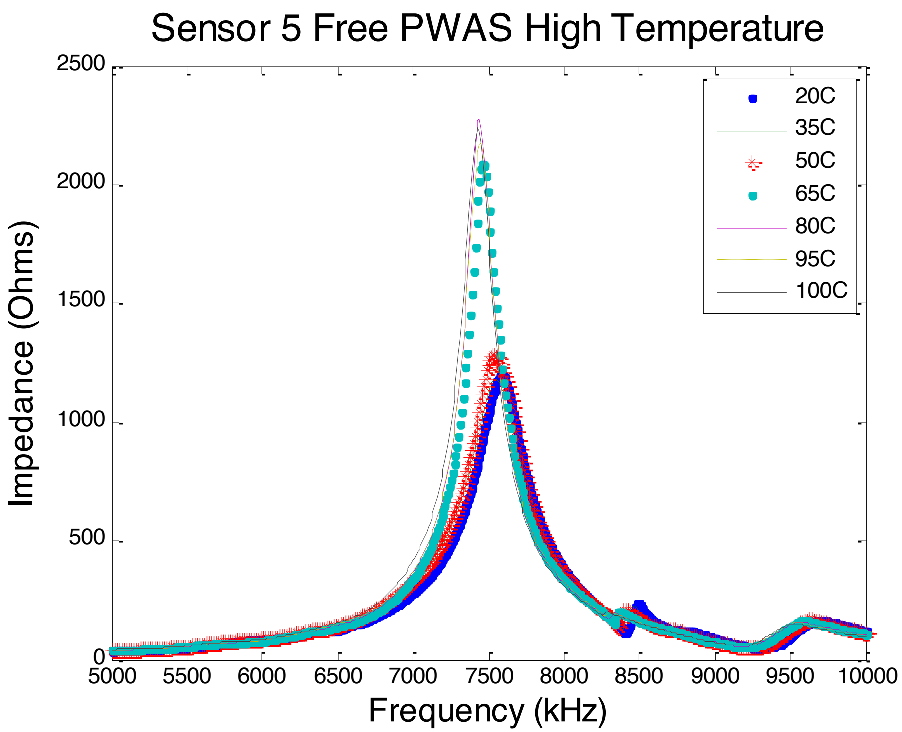
Temperature Increments for Thermal Experiment	
20 °C	20 °C
35 °C	5 °C
50 °C	-10 °C
65 °C	-25 °C
80 °C	-40 °C
95 °C	-55 °C
Maximum (TBD)	Minimum (TBD)
80 °C	-40 °C
50 °C	-10 °C
20 °C	20 °C

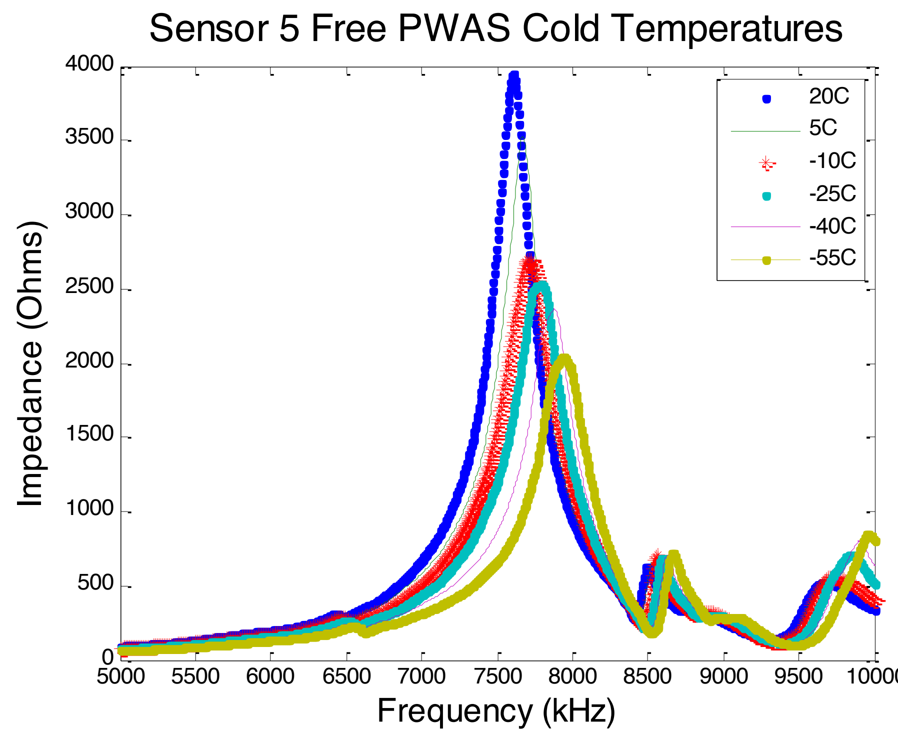
Thermal Vac Test





Thermal Vac Test

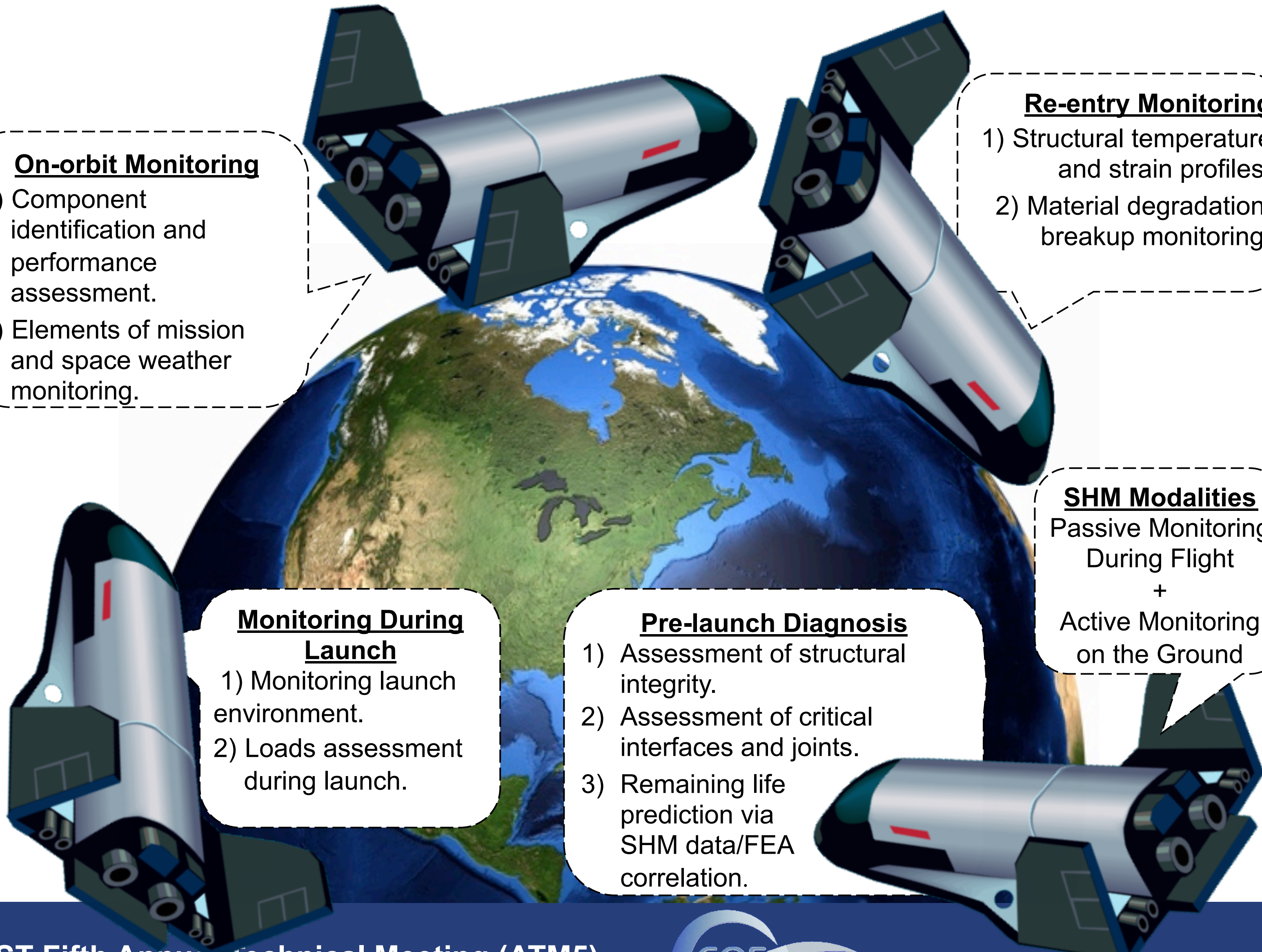




Conclusions and Future Work

- Exposure to cold causes impedance signature to move to higher frequencies, which is consistent with previous investigation in atmosphere. Anomaly at 65ºC has been observed and is currently under investigation
- Correlation between surface temperature and acoustic emission activity during thermal fatigue of Al 6061-T6 has been observed, which opens an opportunity for system disintegration monitoring during reentry.
- Task 323 Structural Health Monitoring Framework

SHM Framework



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.

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.

Task 323 SHM Framework

- Previous work demonstrated utility of SHM and its operation in suborbital flight environment.
- Task 323 focuses on SHM architecture and guidelines for integrating SHM with spaceflight recorder (aka “black box”).
- Year 1: Investigate current approaches on sensor information integration in space vehicle. Identify criticality levels of information collected and its use in decision-making.
- Year 1: Prepare hardware for evaluation of space effects on structural condition and sensor system.

Publications/Presentations

- Zagrai, A.N., Demidovich, N., Cooper, B., Schlavin, J., White, C., Kessler S., MacGillivray, J., Chesebrough, S., Magnusion, L., Puckett, L., Tena, K., Gutierrez, J., Trujillo, B., Gonzales, T., (2015) "Structural Health Monitoring during Suborbital Space Flight," paper at 66th International Astronautical Congress, 14 October 2015, Jerusalem, Israel.
- Anderson, M., Zagrai, A., Doyle, D., Hengeveld, D., and R. Wilson,M.R. (2015) "Consideration of thermal effects in electro-mechanical impedance measurement for space structures", paper International Workshop on Structural Health Monitoring (IWSHM) at Stanford University, 3 September 2015, CA, USA
- Zagrai, A.N., Demidovich, N., Cooper, B., Schlavin, J., White, C., Kessler S., MacGillivray, J., Chesebrough, S., Magnusion, L., Puckett, L., Tena, K., Gutierrez, J., Trujillo, B., Gonzales, T., (2015) "Structural Condition Assessment during Suborbital Space Flight," presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), 23 June 2015, Chantilly, VA, USA.
- Zagrai, A, Cooper, B., Schlavin, J., Clemens, R., White, C., Kessler, S., (2014) "Assessing structural condition during suborbital space flight," Technical presentation at ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, September 9, 2014, Newport, RI, presentation: SMASIS2014-7726.

Acknowledgements

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- AFRL: Derek Doyle, Derek Hengeveld, and Michael R. Wilson
- NMT: Graduate Student Association, Ian Lopez-Pulliam, William Valiant.