COE CST Eleventh Annual Technical Meeting

Task 323 Structural Health Monitoring (SHM) Framework for Commercial Space Transportation

Portable electro-mechanical impedance SHM hardware unit development and design of spacecraft data acquisition system as a precursor of future flight recorder

Andrei Zagrai (NMT) + team
Dale Amon (Immortal Data, Inc.) + team

Team Members

- New Mexico Institute of Mining and Technology
  - Andrei Zagrai (PI),
  - Funmilola Nwokocha (Ph.D. student)
  - David Hunter (RD)
  - A team of undergraduate junior/senior design (on the left)

Team Members

- Immortal Data, Inc. (Industry partner and matching funds provider)
  - Dale Amon
  - Many other participants as a part of Immortal Data team.

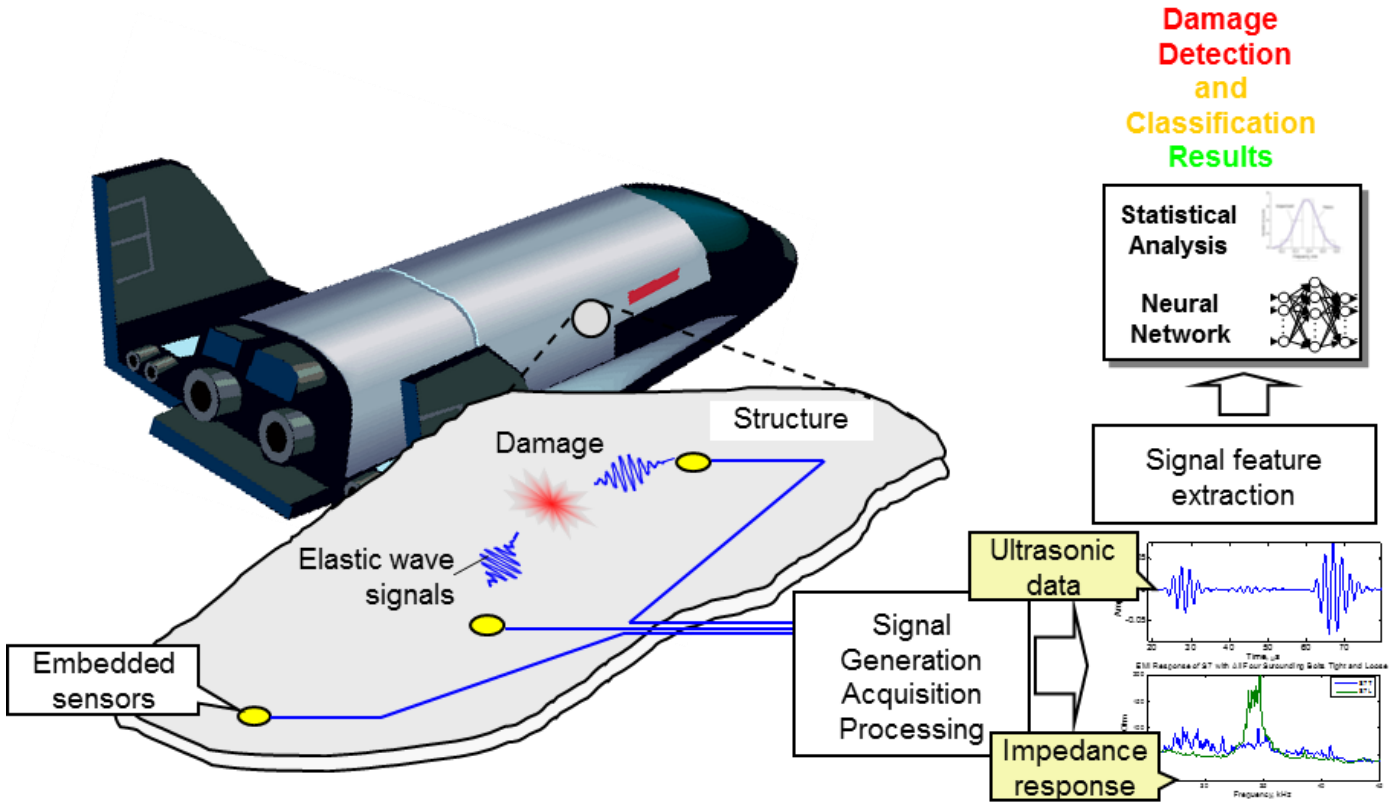
Goal

- This task is aimed at improving safety and affordability of commercial spaceflights.
- In this capacity, it supports AST's mission to ensure protection of the public and property and to carry out safety responsibilities.

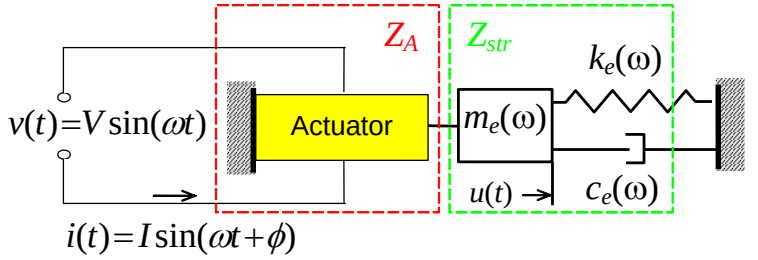
Relevance to Commercial Space Industry

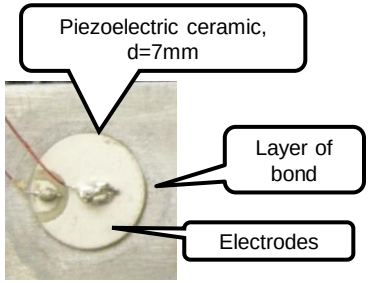
- Structural Health Monitoring (SHM) is viewed as enabler of safety inspections for space structures and systems.
- Distributed flight recorder will improve data survivability and assist with accident reporting.

Structural Health Monitoring



Mechanical coupling between the sensor and the host structure allows for inferring structural impedance/admittance.

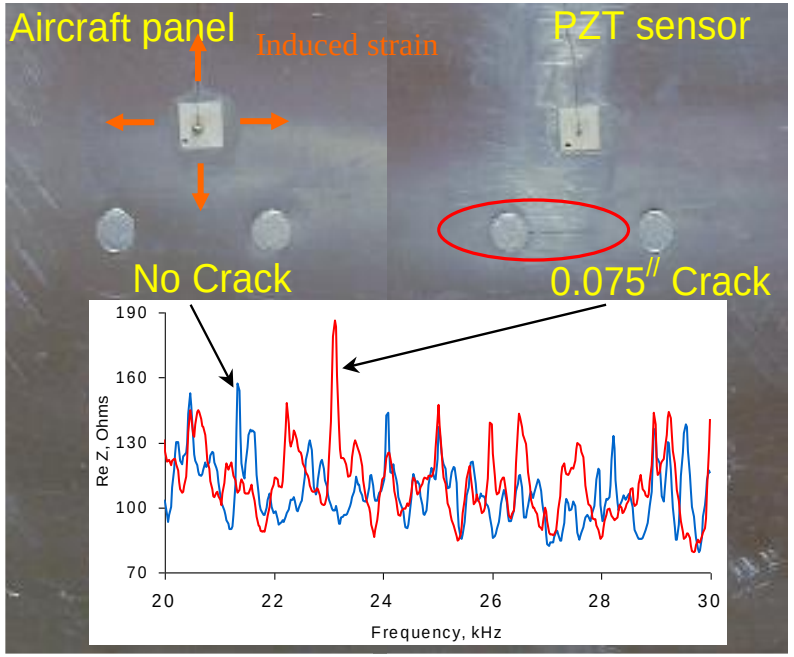




Thin Piezoelectric Sensors 7mm × 0.2mm

Structural impedance

$$z_a(\omega)=\frac{1}{y_a(\omega)}=\frac{1}{i\omega C_a}\left[1-k_{31}^2\left(1-\frac{1}{\varphi\cot\varphi+k_{str}(\omega)/k_a}\right)\right]^{-1}$$



New Mexico Tech Task Description

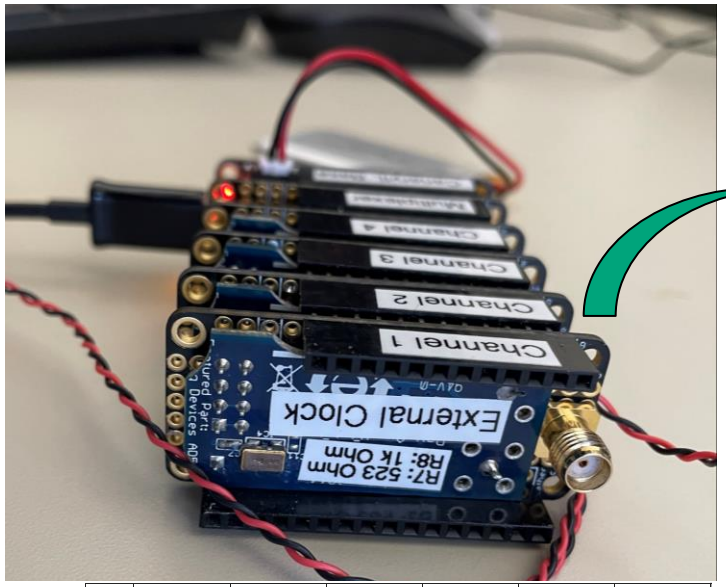
- Task 1: Development of a portable SHM unit for integration with commercial space vehicles.
  - Task 1-1: Multi-channel electro-mechanical impedance SHM unit.
  - Task 1-2: Software integration and impedance calculations chip-embedded on an impedance SHM unit.
  - Task 1-3: Adaptation of electro-mechanical impedance SHM unit for field tests in stratospheric and sub-orbital flight environments.

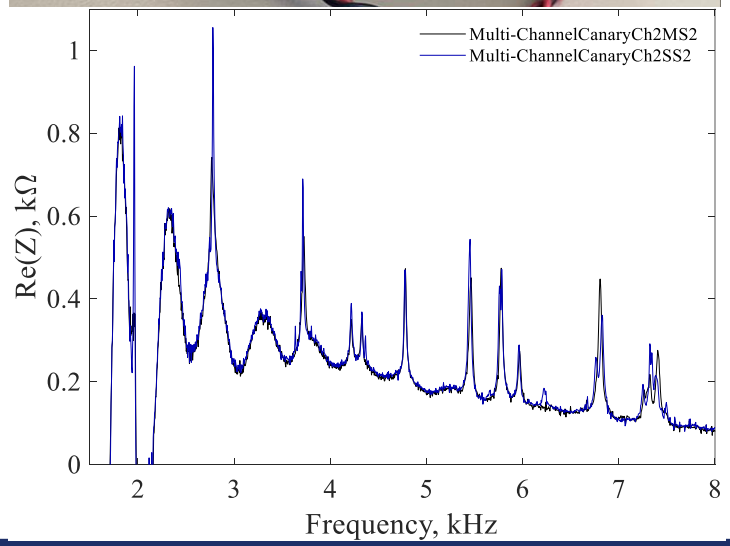
Immortal Data Task Description

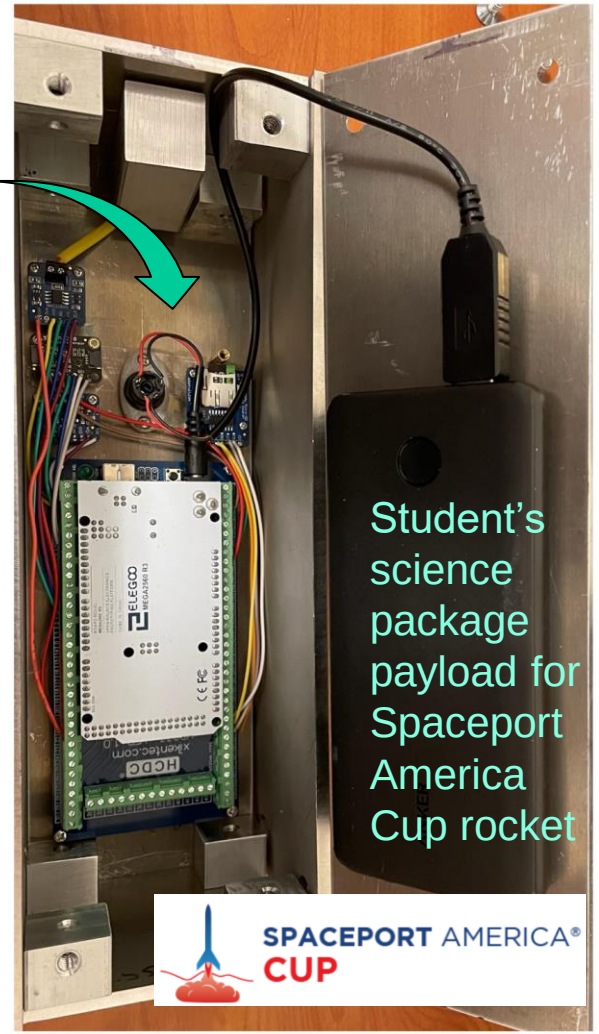
- Task 2: Design of spacecraft data acquisition system as a precursor of future flight recorder.
  - Task 2-1: Establish preliminary specifications for spaceship's data acquisition system design with focus on SHM.
  - Task 2-2: Develop and demonstrate sensor integration and structural health monitoring capabilities of proposed spaceship's data acquisition system.

Multi-Channel Electromechanical Impedance SHM

- First 4-channel EMI SHM was developed
- It allows for SHM in multiple locations
- For the first time, synchronized simultaneous multi-channel EMI SHM was implemented
- Scheduled to compete in Spaceport America Cup.

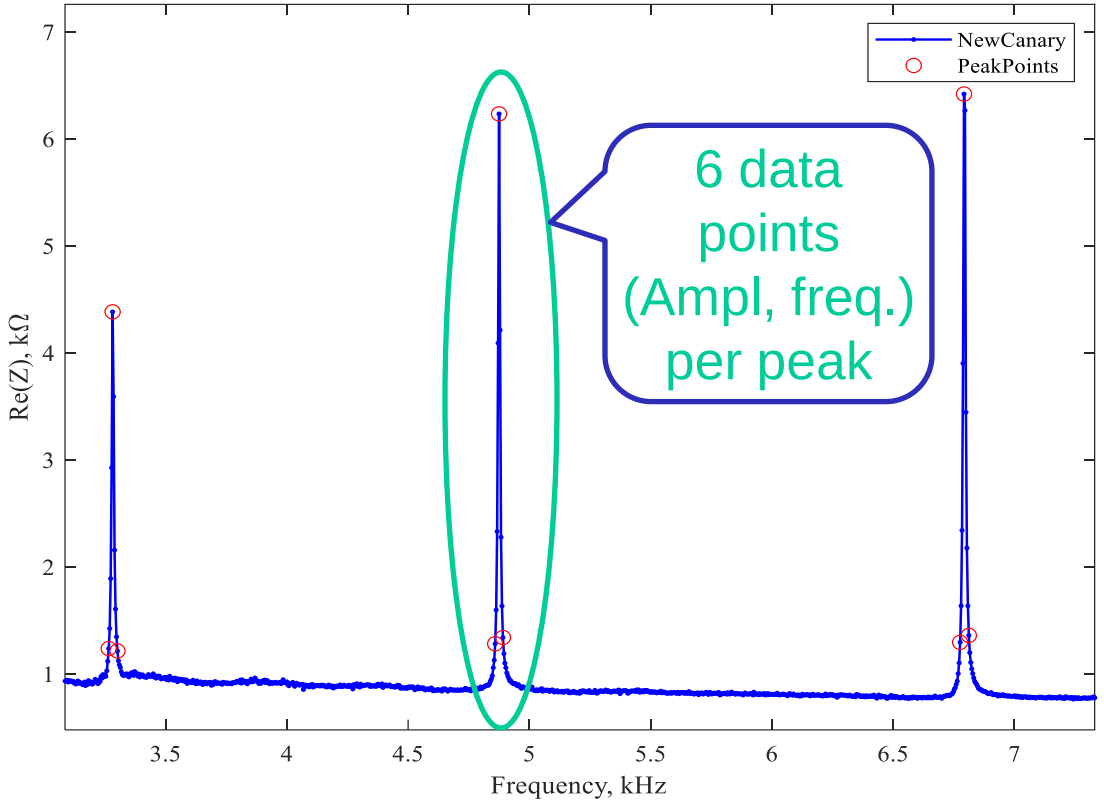






Software Integration & Chip-embedded Processing

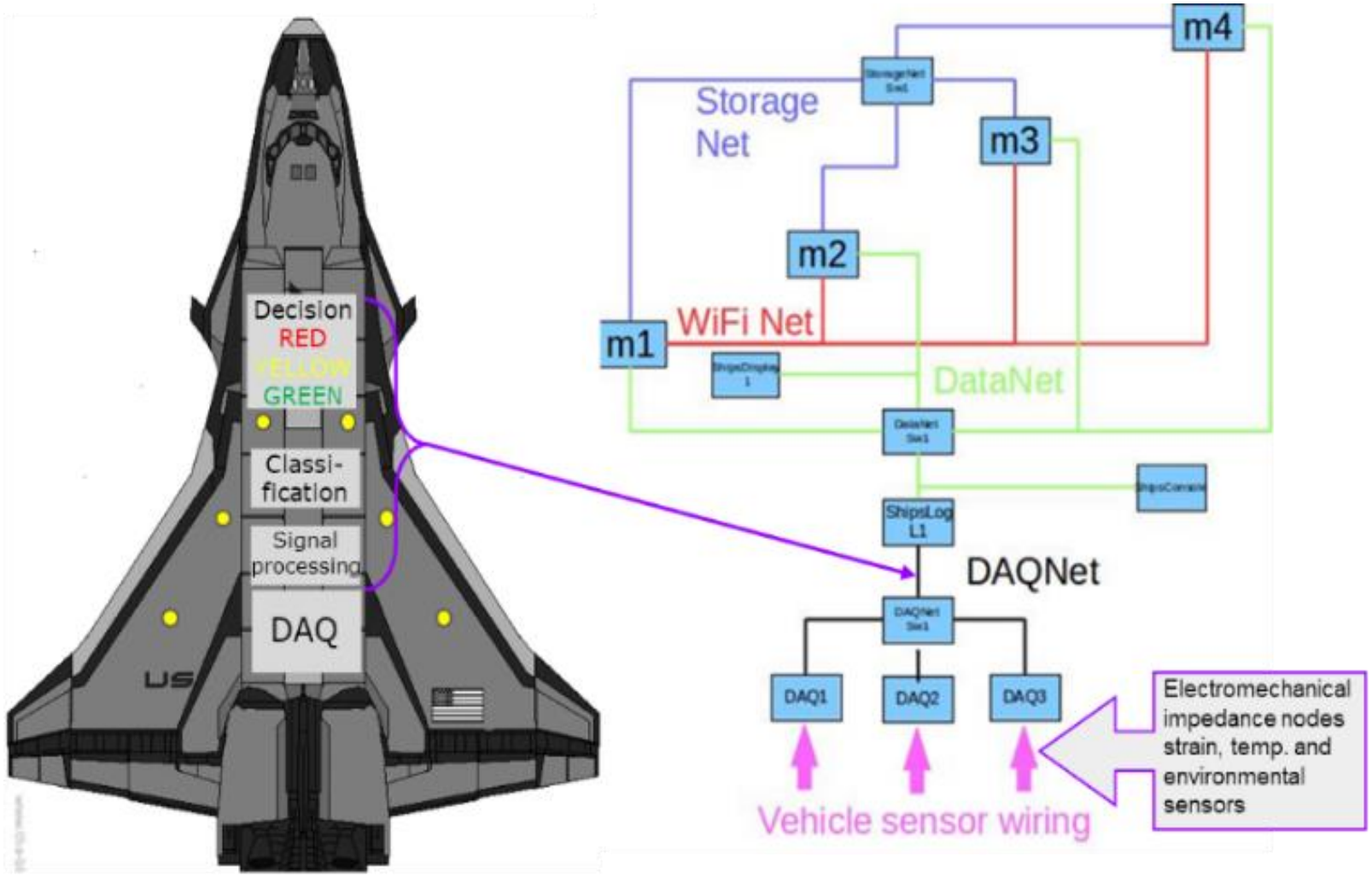
- On-board impedance correction
- On-board correlation coefficient calculation for immediate SHM results.
- 6 data points per peak data reduction scheme for near real time data transmission to distributed blackbox system.



Correlation coefficient determines linear dependency of two impedance signatures

$$\rho(A,B) = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{A_i-\mu_A}{\sigma_A}\right)\left(\frac{B_i-\mu_B}{\sigma_B}\right)$$

Immortal Data Inc. Distributed Flight Recorder



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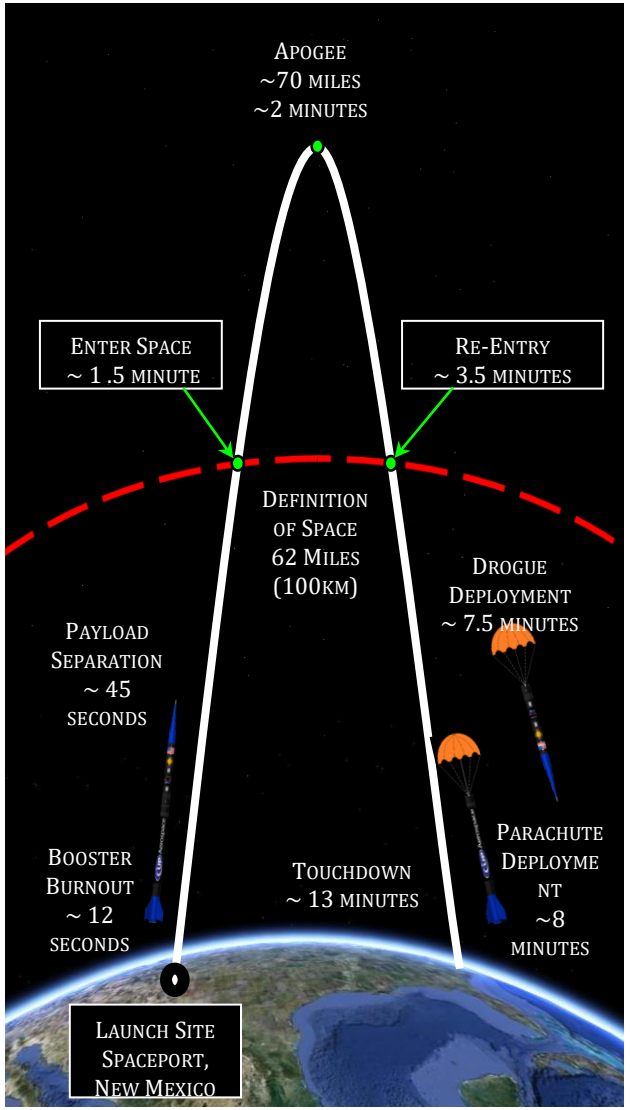
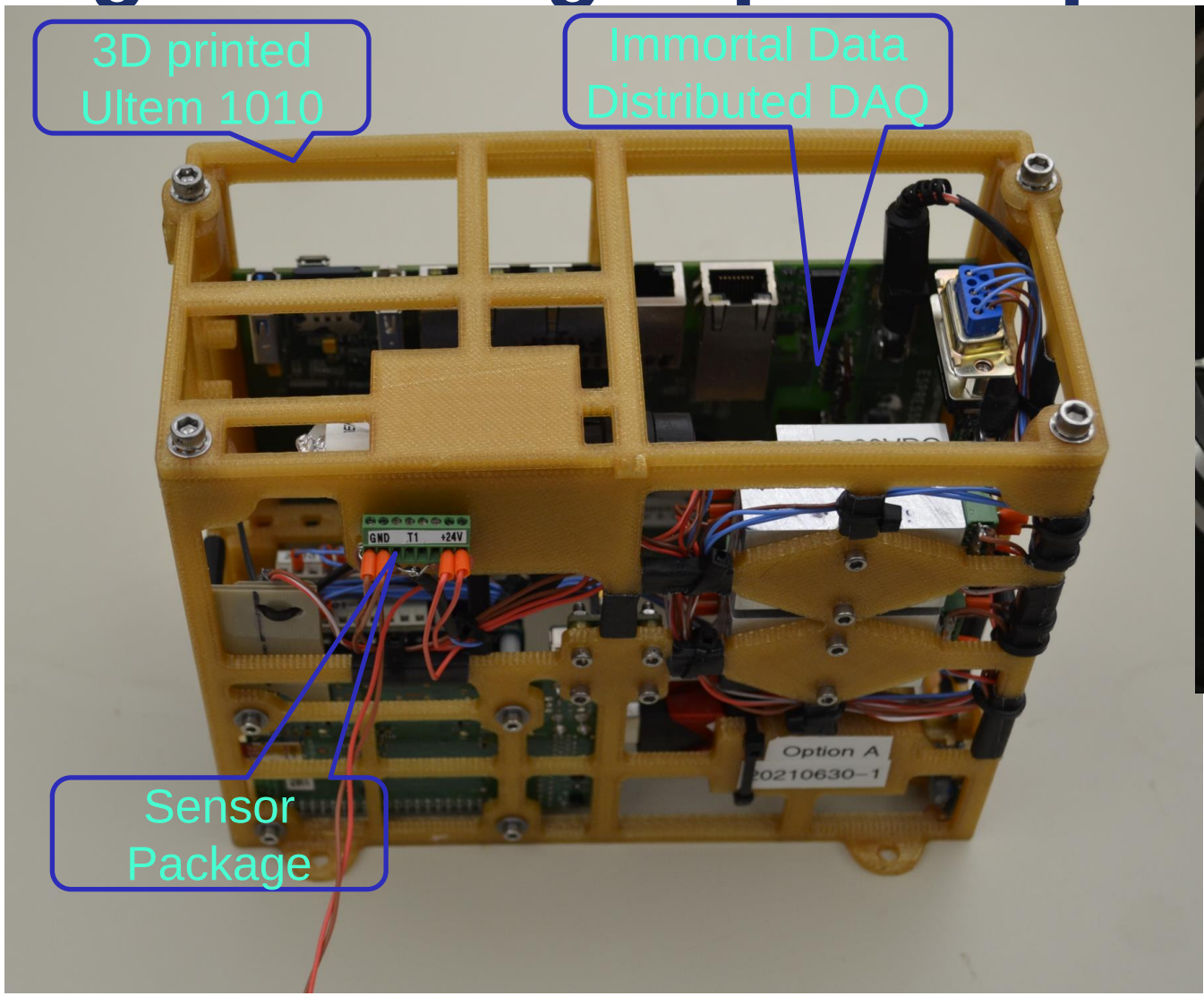
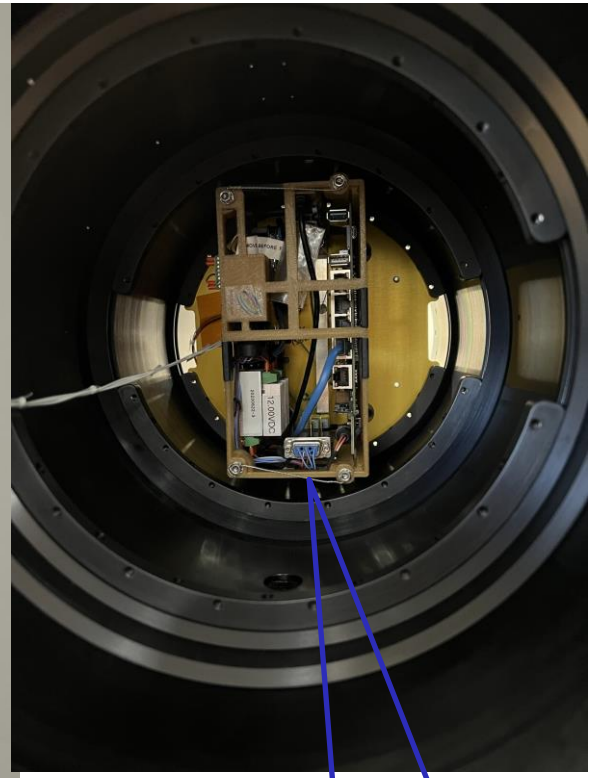
Suborbital Flight Testing: UpAerospace SL-15

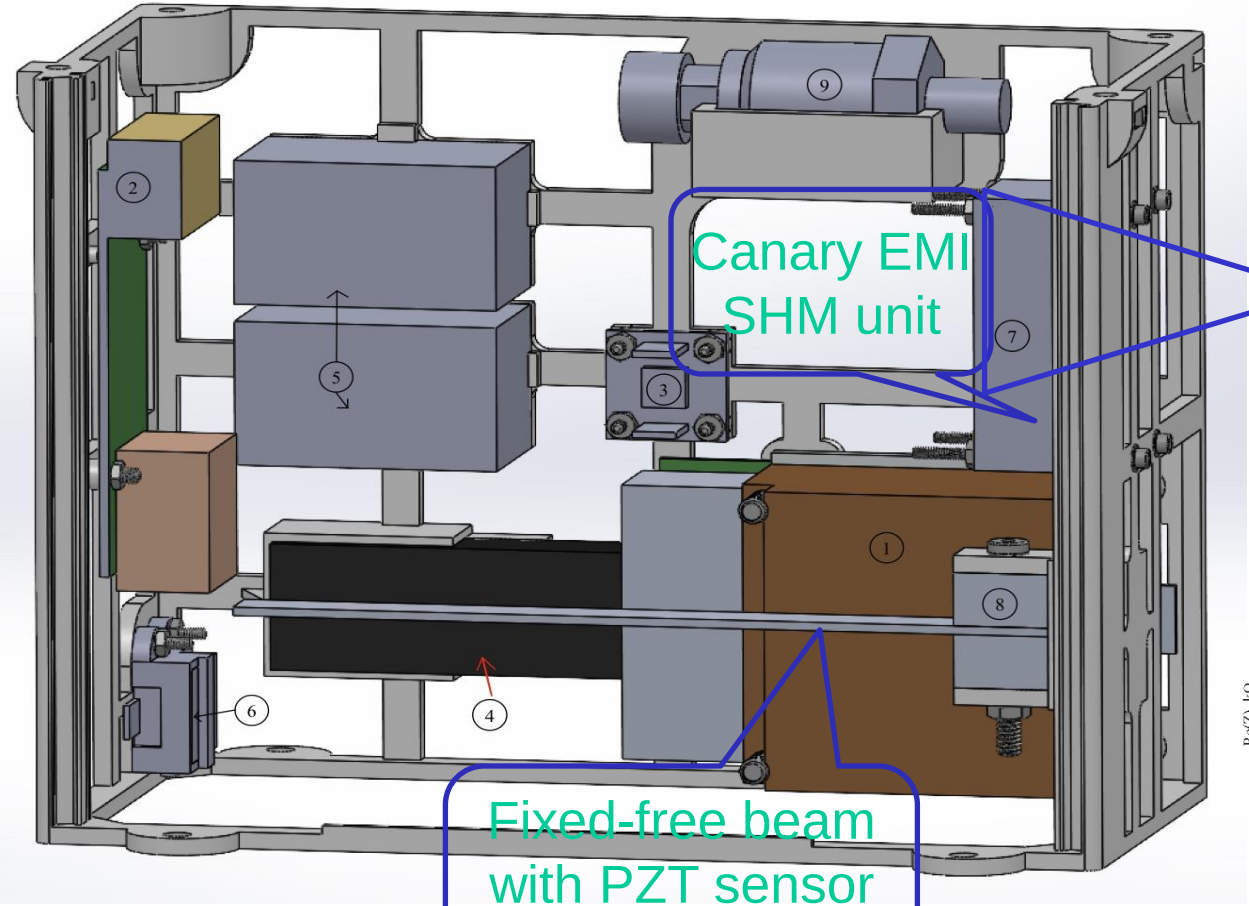


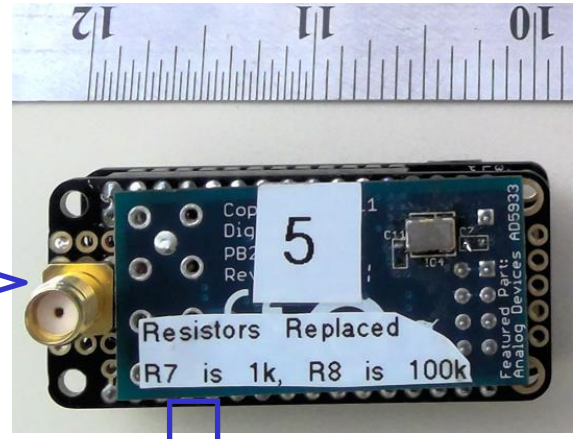


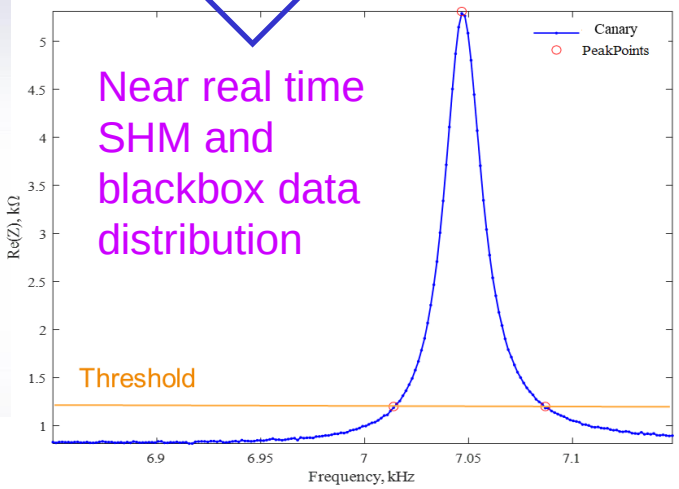


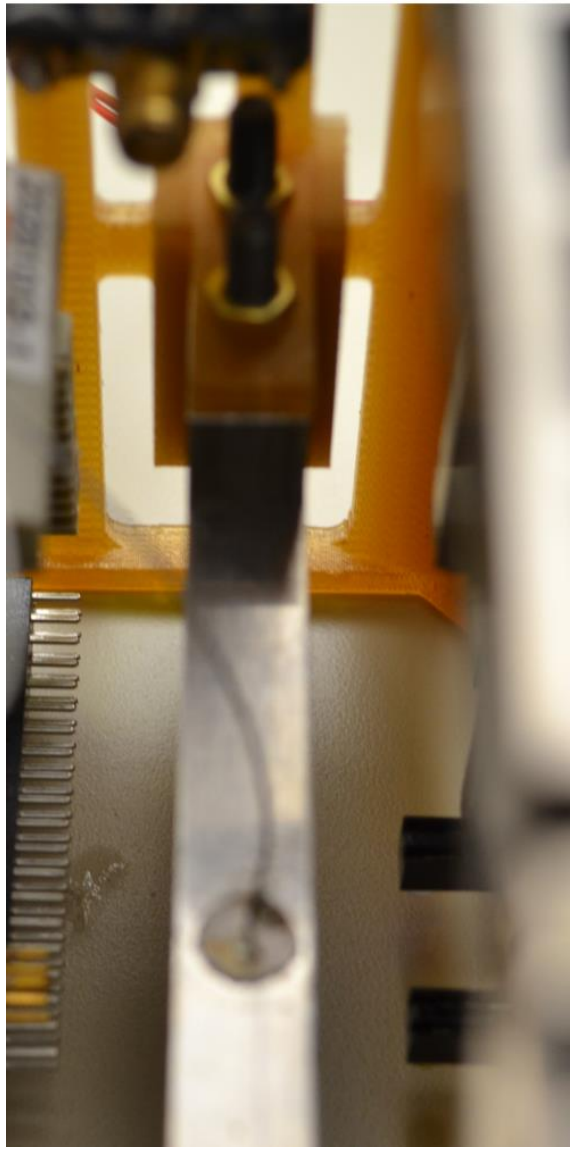
Payload inside Up Aerospace SL-15 launch vehicle

Suborbital SHM Experiment

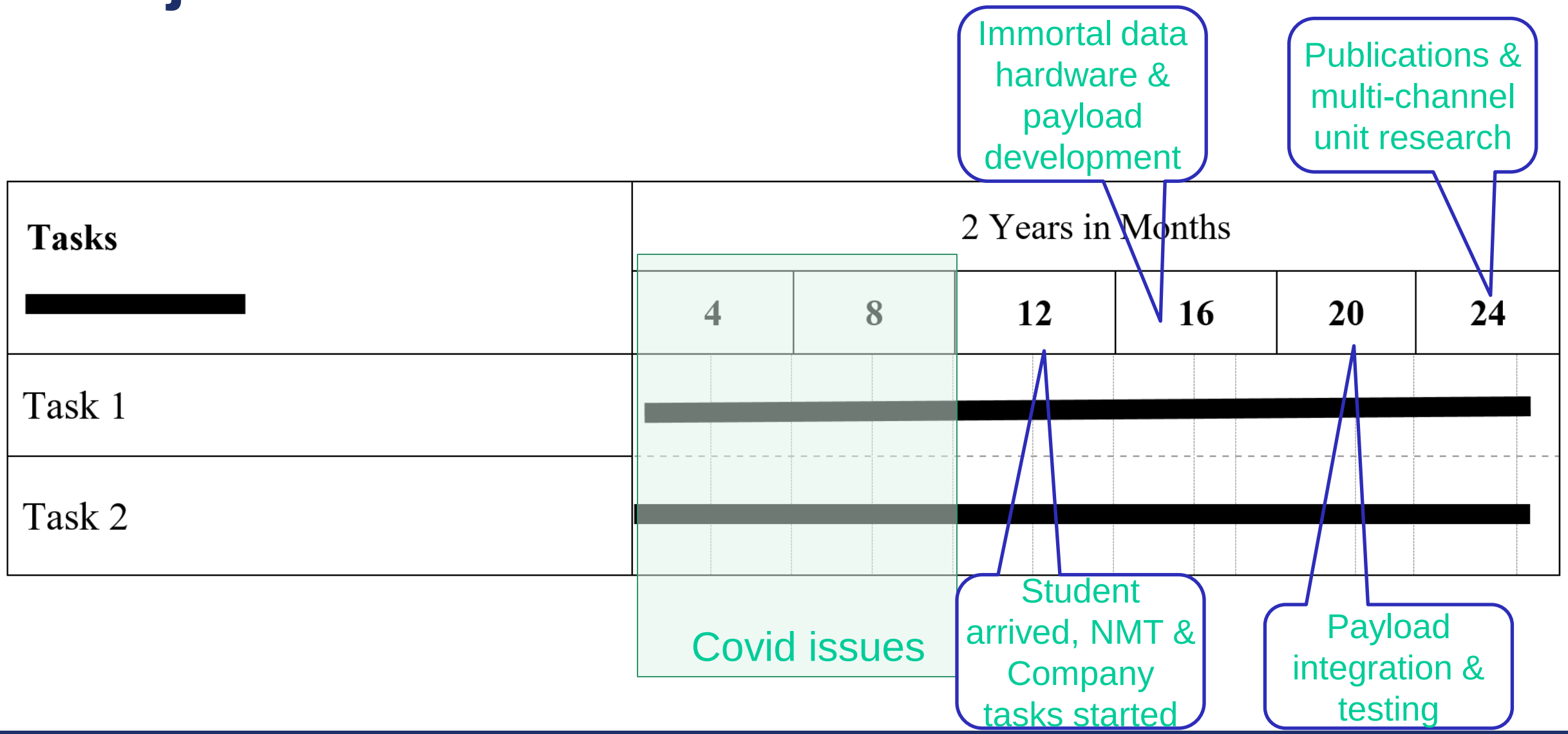








Project Schedule



Results

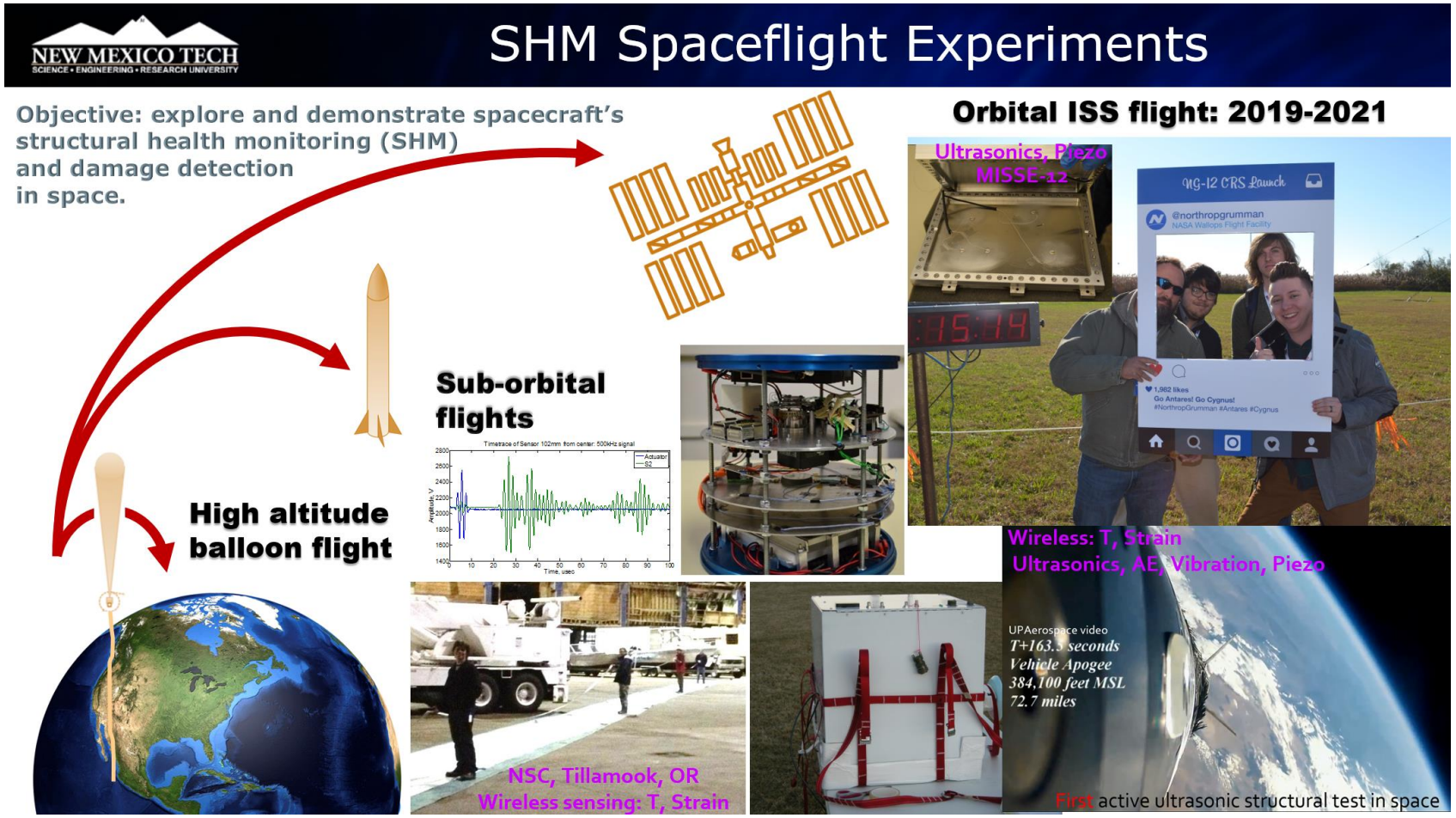
- Research and engineering tasks of this project were completed.
- Close collaboration between the university (New Mexico Tech) and small business company (Immortal Data, Inc.) was established and maintained.
- Practical demonstration of integration of a space vehicle's SHM system with distributed flight recorder is scheduled during the suborbital flight.
- Undergraduate student team and a PhD student gained experience working on a practical problem with industry.

Publications and Presentations

1. Nwokocha, F., Zagrai, A., Hunter, D., (2022) “Multichannel Electromechanical Impedance Structural Diagnostics in Plate Specimens,” to appear in Proceedings of the ASME 2022 International Mechanical Engineering Congress and Exposition, paper IMECE2022- 95937, October 30 – November 3, 2022, Columbus, OH.
2. Nwokocha, F., Zagrai, A., Amon, D., Hunter, D., and Demidovich, N., (2022) “Suborbital Test of the Electro-Mechanical Impedance Structural Health Monitoring System,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), 27 - 30 June 2022, Madison, WI.
3. Nwokocha, F., Hunter, D., Zagrai, A., Amon, D., Cvetic-Thomas, D., Weathers, D., Tattershall, A., Robergs, D., and Jackson, E., (2022) “Electro-mechanical Impedance Structural Health Monitoring as an Integral Component of a Flight Recorder for Space Vehicles,” Proceedings of SPIE Smart Structures + Nondestructive Evaluation, 6 - 9 March 2022, Long Beach, CA.
4. Cvetic-Thomas, D., Tattershall, A., Jackson, E., Robergs, D., Nwokocha, F., and Zagrai, A (2021) “Mechanical Design and Development of a Suborbital Payload for Real-Time Data Acquisition and Structural Health Monitoring,” Proceedings of the ASME 2021 International Mechanical Engineering Congress and Exposition, paper IMECE2021-71881, November 1-5, 2021, Virtual, Online.
5. Amon, D., Zagrai, A., Nwokocha, F., Hunter, D., and Demidovich, N., (2021) “Structural Health Monitoring as a Part of Spaceship’s Data Acquisition System,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 21 - 24, 2021, Virtual, Online.
6. Zagrai, A., (2021) “Structural Health Monitoring of Spacecrafts: from Assembly to Deployment and Operation,” presentation at the virtual International Conference on Condition Monitoring, Jharkhand, India, 21–22, January 2021.

Awards, & Recognitions

- Invited as panelist to NASA Flight Opportunity event to share flight experience and talk to suborbital flight community.



Conclusions and Future Work

- The team comprising of undergraduate and PhD students, a faculty and engineers at the emerging small business company designed, developed and tested hardware, measurement technologies, algorithms, software and data analysis approaches successfully completing project tasks.
- A collaborative work of a company and educational institution is a highlight of this project. Students gained industry experience.
- Future: demonstration results of a joint work during suborbital flight and further dissemination in commercial space industry.