New Mexico
Research Spotlight Forum

4/17/2019 Advancing Resilience for Space Systems

ADVANCING RESLIENCE FOR SPACE SYSTEMS: Mechanical Engineering Perspective

PRESENTED BY:

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ABOUT YOURSELF: Andrei Zagrai, Professor, Dept. Chair, Mech. Engr, NM Tech

- **Brief biography**: BE, BS, ME – TSURE, Taganrog, Russia, 1996-97. PhD in Mechanical Engineering, University of South Carolina, 2002, Post-Doc Stevens Institute of Technology, NJ
  Assist 2006, Assoc 2011, Full 2017 Professor at New Mexico Tech. Mech. Engr. Department Chair since 2014

- **Research areas and research group interests**:

  Space systems and structures: design and practical realization of condition monitoring solutions for space systems; real-time SHM of satellites, spacecrafts and other space vehicles; spacecraft assembly, pre-launch, launch, in-space, and re-entry diagnosis; mechanical engineering of space systems.

  Sensors and structural health monitoring (SHM): active and passive technologies for structural monitoring; structural analysis and condition assessment; detection and evaluation of incipient structural/material damage; exploiting the damage-induced material nonlinearity as a diagnostic feature; material characterization; structural identification and damage features extraction algorithms.

  Intelligent systems, structures, and mechanisms: analysis and design of the smart/intelligent/adaptronic structures and mechanisms incorporating active materials, smart controls and embedded intelligence; Mechatronics, networks of sensors and actuators for global and local sensing methodologies, artificial intelligence decision support for sensor networks.

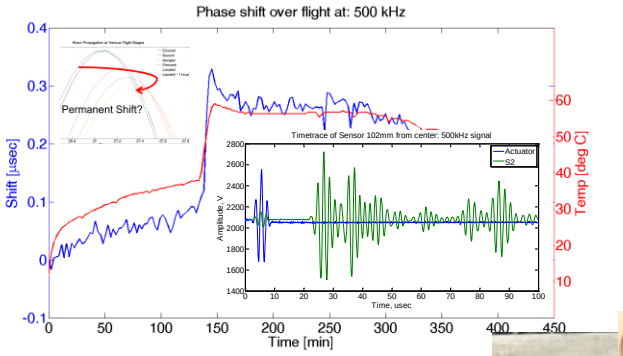
  Structural dynamics: vibration of discrete, continuous, and complex structures; dynamics of structural systems interacting with granular medium (landmines, soil, sand); linear and nonlinear wave propagation in solids, liquids and gases.

- **Research group size and demographics**: currently 1 PhD, 2 MS and 1 UG; 75% male, 25% female.

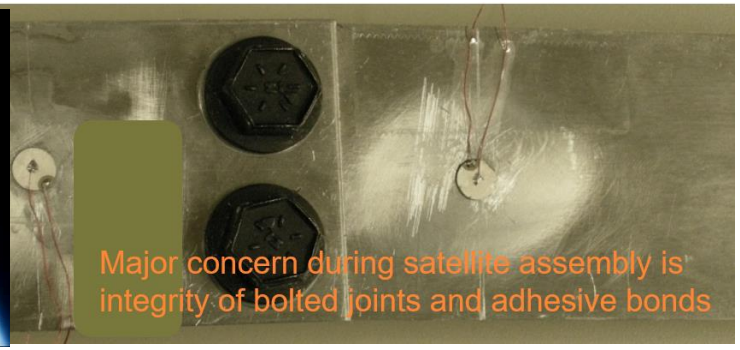
Keywords: Space systems, smart structures, sensors, structural health monitoring (SHM), NDE, flight experiments, structural dynamics, joints.

CURRENT WORK IN ADVANCING RESLIENCE FOR SPACE SYSTEMS

Space structures assessment during flight



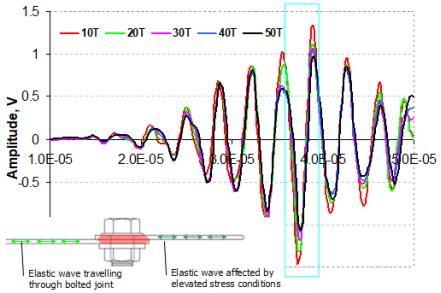
Nonlinear ultrasonic evaluation of bolted joints

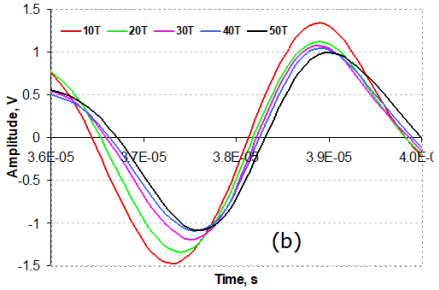


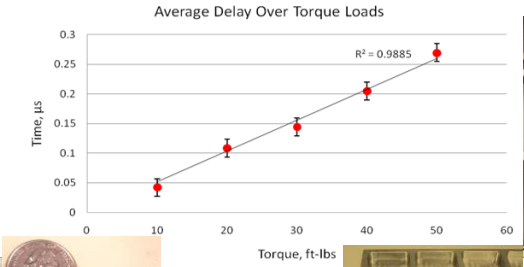
Sound speed — Stress

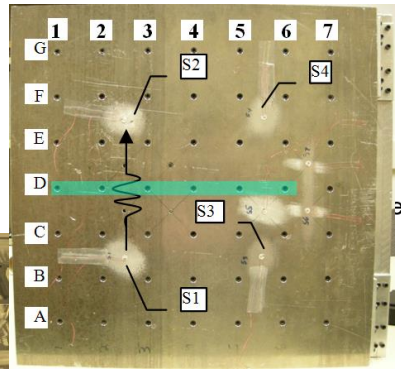
$$\rho c_{l\perp}^2 = \left(K + \frac{4\mu}{3}\right) + \frac{\sigma}{3K}\left(4K - \frac{8\mu}{3} + \frac{2(K-2\mu/3)^2}{\mu} + \frac{K-2\mu/3}{\mu}\cdot A + \frac{2(K+5\mu/3)}{\mu}\cdot B - 2C\right)$$

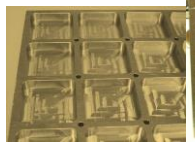
Linear parameters (bulk and shear moduli) — Non-linear parameters

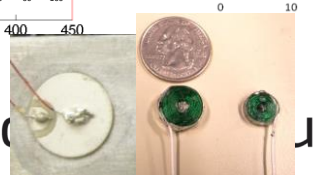




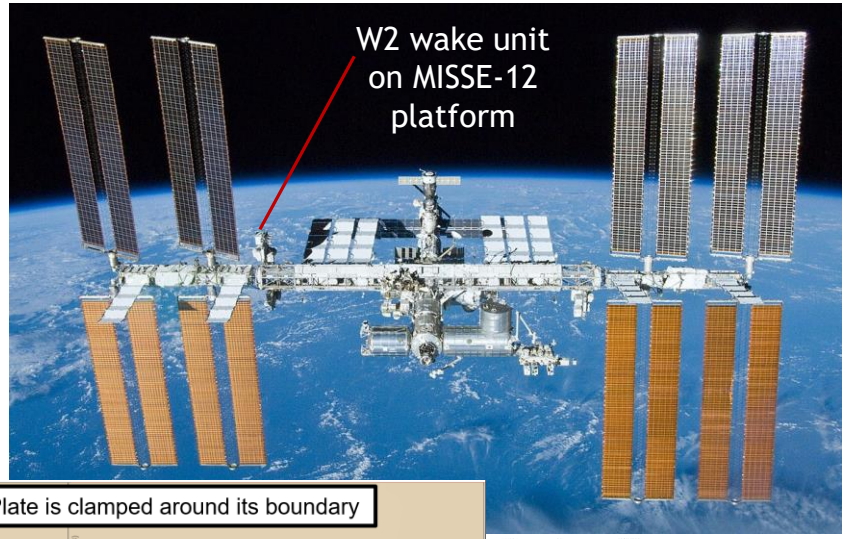


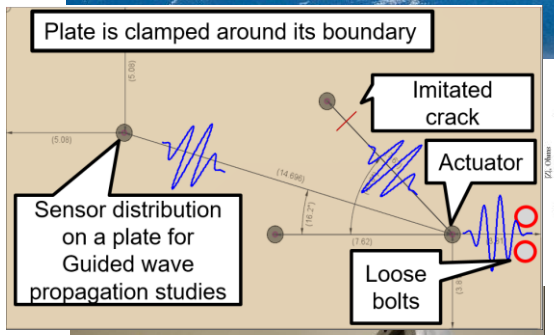


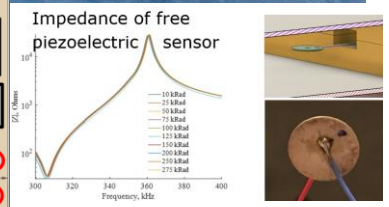


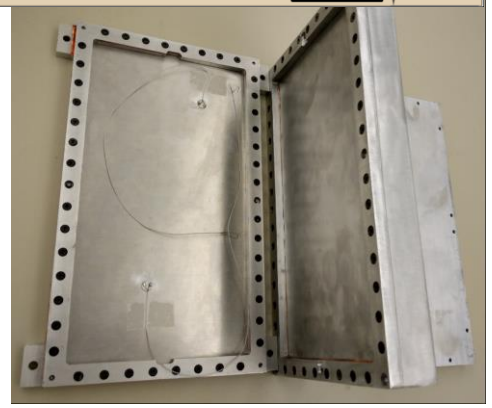


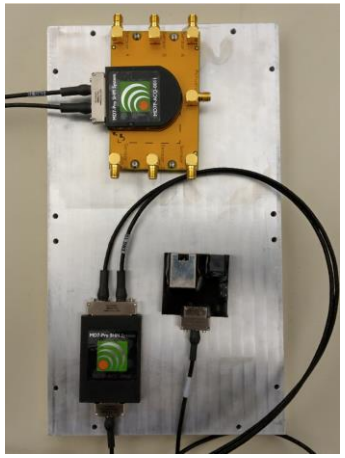
ISS SHM Experiment











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FUNDING SOURCES 2018-2019

"Autonomous Structural Composites for Next Generation Unmanned Aircraft Systems", NASA EPSCoR grant August 2017 – August 2020. Co-PI. Strain-based structural dynamics and impedance assessment

"In Orbit Structural Health Monitoring of Space Vehicles", NASA EPSCoR grant for developing and testing SHM experiments on International Space Station (ISS). Technical Principal Investigator, August 2017 – August 2020.

"Structural Health Monitoring (SHM) Framework for Commercial Space Transportation," FAA Office of Commercial Space Transportation, Center of Excellence for Commercial Space Transportation, 2015-2018, PI. SHM aspects for commercial space transportation, flight testing

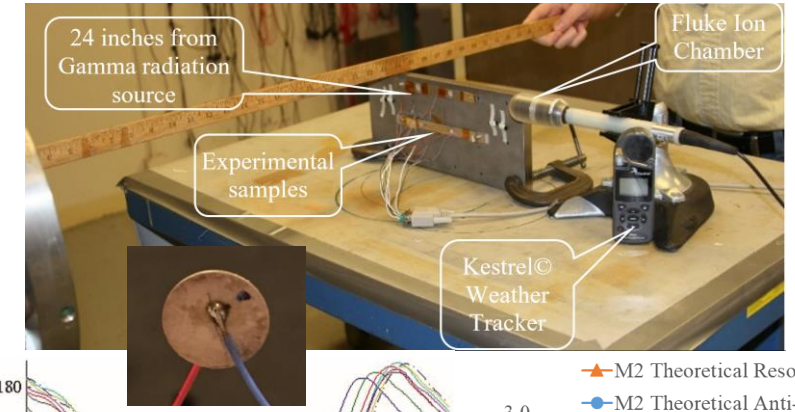
"Intelligent Energetic Systems Engineering (INTENSE) Research Experiences for Undergraduates", NSF, 2018-2021, Senior Personnel. Education

NM Collaborators: NMSU MAE Igor Sevostiyanov – projects, proposals, collaborative research

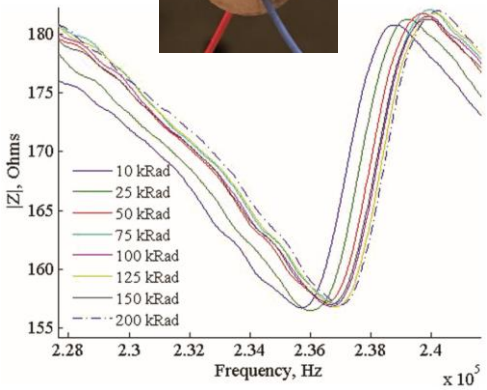
Past: Sandia SURP: "Control of the Structural Boundary Conditions using Piezoelectric Elements and Shunt Circuits."

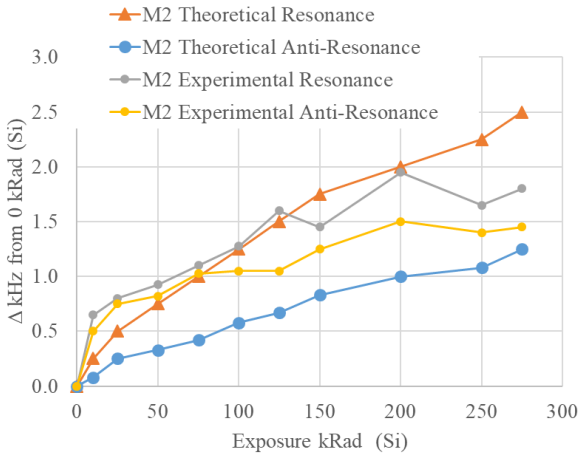
RESEARCH NEEDS

Radiation effects on piezoelectric sensors



Optical surfaces are typically tuned using piezoelectrics





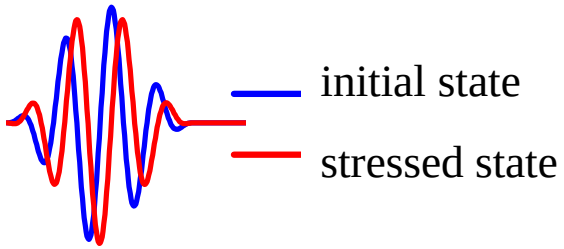
Research will benefits from exposure to different radiation sources and tuning to SNL applications

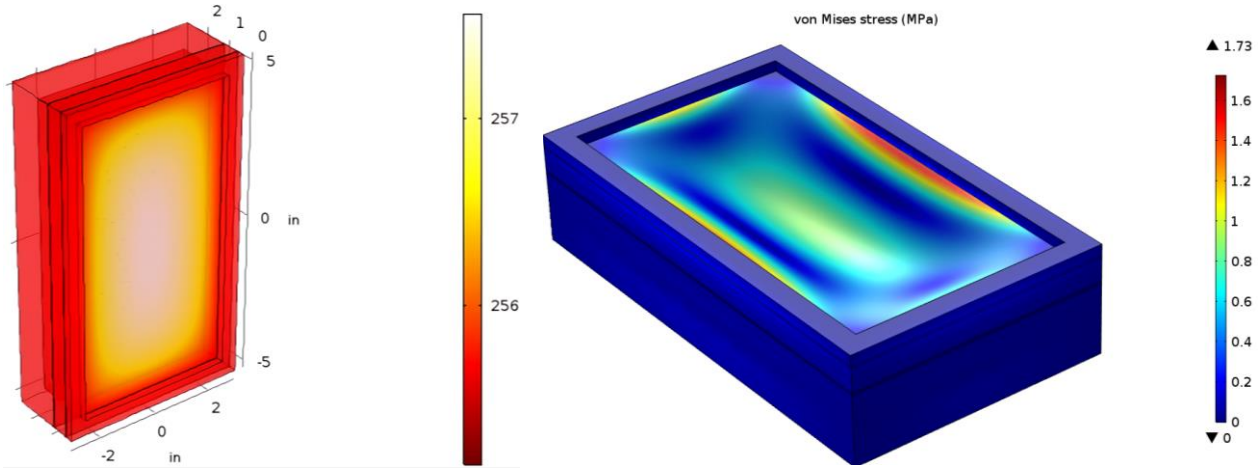
Anderson, M., Zagrai, A., Daniel, J.D., Westpfahl, D.J., Henneke, D., (2018) "Investigating Effect of Space Radiation Environment on Piezoelectric Sensors: Cobalt-60 Irradiation Experiment," ASME Journal of Nondestructive Evaluation, Diagnostics and Prognostics of Engineering Systems, Feb. 2018, Vol. 1, pp. 011007-011007-11.

Mechanical Effects on Optical and Electromagnetic systems (metamaterials, optical surfaces, electronic systems, etc.)

- On-orbit environment changes mechanical state of structure which alters optical and electromagnetic properties
- By monitoring mechanical state, it should be possible to tell how optical and electromagnetic properties have changed
- Suggest adjustment and possibly deliver corrected action.

Example: thermal gradient changes state of stress in structural material, which can be assessed using embedded ultrasonic SHM in real time.





Embedded SHM system may also passively listen to any external (e.g. laser)/internal influences to spacecraft structure