Exploring Small Satellite Resilience: Material Testing Against Solar Energetic Particles

Gabriella Araujo, Alicia Petersen

Department of Mechanical and Aerospace Engineering, University of Florida

INTRODUCTION AND MOTIVATION

- Solar Energetic Protons (SEPs) are high-energy charged particles from the sun. They can strongly interact with the spacecraft, affecting its overall integrity, electronic components, and communication, resulting in single-event upsets and anomalies.
- SEPs can overload sensors such as startrackers and cause solar arrays and spacecraft surface degradation. Resulting anomalies include bit-flip errors in onboard software, navigational errors, interrupted communications, and other issues that can result in spacecraft loss of life (1).
- A better understanding of why a single event upset / anomaly may have occurred, as well as preventative and predictive measures that can be taken, can result in higher success rates and minimal damage with ongoing interactions. This area within the space weather and aerospace engineering community is not as well studied, but having a better understanding of it can be crucial to future mission success.

GOALS

- **Goals: Small Satellite material testing against Solar Energetic Protons (SEPs).** Throughout this research, the goal is to determine factors such as the region of space we might be looking at, the conditions in those regions, the energy ranges and fluxes, and the materials used in small satellites. Using a plasma chamber, we can simulate solar energetic protons against different materials to determine the most resilient materials against space weather events.
- Within this first stage, the focus was to determine better the feasibility of this research within our lab and what components and equipment would be necessary to achieve the desired results.

Figure 1. Space Weather can cause damage to spacecraft (Credit: RHEA Group)

MATERIAL SELECTION FOR MATERIALS TESTING

- When selecting materials for small satellites that can withstand space weather, some possible considerations are that the primary material must withstand intense radiation heating, thermal stability, UV degradation, communication, navigation capabilities to minimize signal interference, and electrostatic discharge protection (2).
- Standard materials: aluminum, magnesium alloys, photopolymer, and z-grade materials such as tantalum and tungsten (3,4).
- Ashby charts can optimize aerospace designs for performance, efficiency, and sustainability when considering a single objective and constraint in material selection.

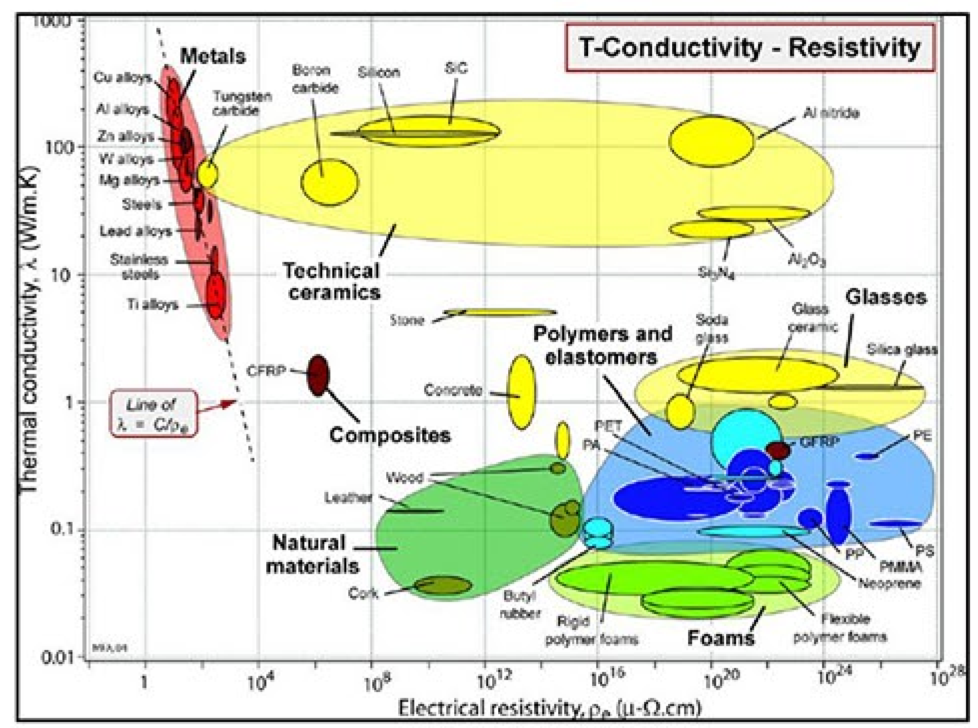

Figure 2. Ashby material selection chart for thermal conductivity against electrical resistivity (Credit: PR∞M Engineering)

SOLAR ENERGETIC PROTON ENERGY RANGES

- The starting goal is to study the conditions that occur in Low Earth Orbit and simulate the SEP events at intensities common in LEO.

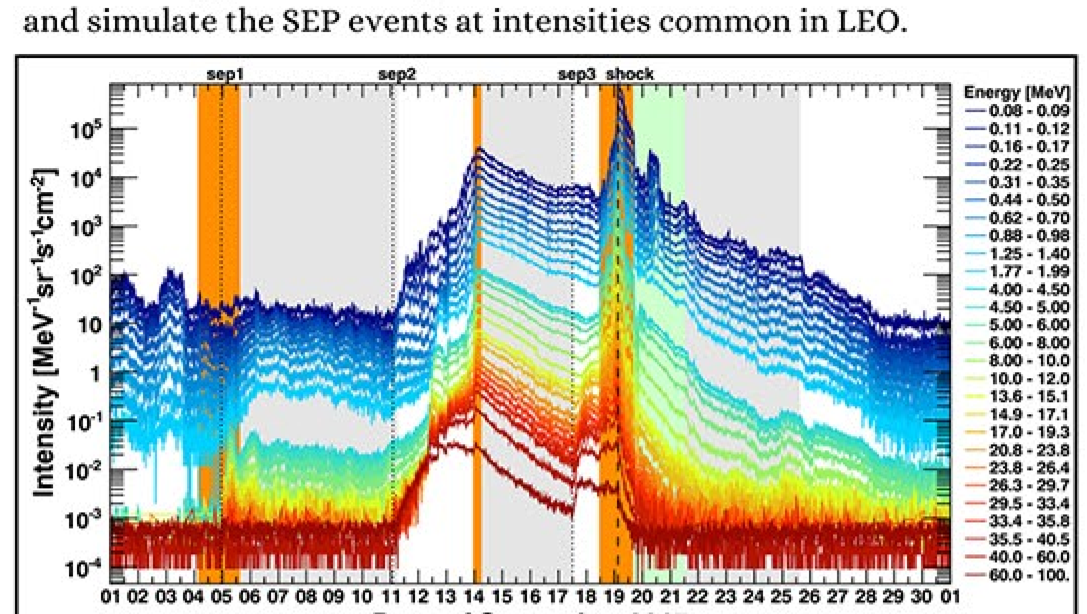

Figure 3. Temporal profiles of proton intensities measured by the Solar Electron and Proton Telescope, Low Energy Telescope, and High Energy Telescope instruments onboard the Solar Terrestrial Relations Observatory-Ahead (5).

FUTURE WORK

- Decision matrices will be used to continue making decisions about the feasibility of the study within our lab and other matters, such as the final material selection for testing.

Particle Source			Option 1		
Objective	Weighting Factor	Parameter	Mag.	Score	Value
Particle Energy Variability	0.25	%	...	...	...
Particle Energy Range	0.25	eV	...	...	...
Cost	0.25	$	...	...	...
Particle Intensity/Flux	0.15	[number of particles] m−2·s−1	...	...	...
Availability of Components	0.10	Resource-rich	...	...	...
Overall value					...

Figure 4. Decision matrix to determine the best particle source through weighing factor comparisons.

- Utilizing the NOAA Scale for Radiation Storms, the following steps will include determining which scales we can simulate and which material properties we want to analyze.

Category		Satellite Operation Effects	Physical Measures	Average Frequency
Scale	Description	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level of >= 10 MeV	1 cycle = 11 years
S 5	Extreme	Satellites may be rendered useless, memory impacts can cause loss of control, serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible.	10^5	1> per cycle
S 4	Severe	May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded.	10^4	3 per cycle
S 3	Strong	Single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely.	10^3	10 per cycle
S 2	Moderate	Infrequent single-event upsets possible.	10^2	25 per cycle
S 1	Minor	None	10	50 per cycle

Figure 5. Adapted from NOAA Solar Radiation Storms Space Weather Scale

REFERENCES

(1) Baker, D. N. and Bodeau, M., "Effects of Space Radiation on Contemporary Space-Based Systems I: Sin-gle Event Upsets, Spacecraft Charging, Degradation of Electronics, and Attenuation on Fiber Cabling,"
Space Weather Effects and Applications, 2021, pp. 3–11.

(2) JR Dennison, Kent Hartley, Lisa Montierth Phillipps, Justin Dekany, James S. Dyer, and Robert H. Johnson, "Small Satellite Space Environments Effects Test Facility," Proceedings of the 28th Annual AIAA/USU Conference on Small Satellites, (Logan, UT, August 2-7, 2014).

(3) Thomsen, Laurence.et. al. NASA's State of the Art Small Spacecraft Technology, 2021. Section 6.4 Radiation Effects and Mitigation Strategies (https://www.nasa.gov/smallsat-institute/sst-soa/structures-materials-and-mechanisms#6.4)

(4) Emanuele A. Slejko, Anna Gregorio, Vanni Lughi,
Material selection for a CubeSat structural bus complying with debris mitigation,
Advances in Space Research Volume 67, Issue 5, 2021, Pages 1468-1476,
ISSN 0273-1177, https://doi.org/10.1016/j.asr.2020.11.037.
(https://www.sciencedirect.com/science/article/pii/S0273117720308383)

(5) Bruno, A., Christian, E. R., de Nolfo, G. A., Richardson, I. G., & Ryan, J. M. (2019). Spectral analysis of the September 2017 solar energetic particle events. Space Weather, 17, 419–437. https://doi.org/10.1029/2018SW002085