Fall 10-2015

Properties of Spacecraft Materials Exposed to Ionizing Radiation

Alex Souvall
Utah State University

Gregory Wilson
Utah State University

Katie Gamaunt
Utah State University

Ben Russon
Utah State University

Heather Tippets

JR Dennison
Utah State Univesity

Properties of Spacecraft Materials Exposed to Ionizing Radiation

Alexander Souvall,[1],Gregory Wilson,[1] Katie Gamaunt,[1] Ben Russon,[1] Heather Tippets[2] and JR Dennison[1]
[1] Utah State University - [2]Brigham Young University Idaho

Introduction

Spacecraft experience very harsh conditions, and information on how materials respond to this environment is, by nature, hard to come by. Ground based system can simulate this environment, but the accuracy of the simulations need to be quantified. Comparing data from space flights with ground-based systems allows this to be determined while gathering knowledge of specific materials.

I. Space Environment

The harsh space environment conditions cause numerous effects on materials which are often deleterious. Those include outgassing, charging/discharging, and alterations in electrical, optical, and mechanical properties. To understand and characterize such material degradation, the Space Survivability Test (SST) chamber [3,4] was built by USU's Material Physics Group. It simulates several critical characteristics of the space environment in a controlled setting, allowing quantitative characterization of the effects. These characteristics include: ionizing radiation, electron and photon flux, temperature and neutral gas environment [5].

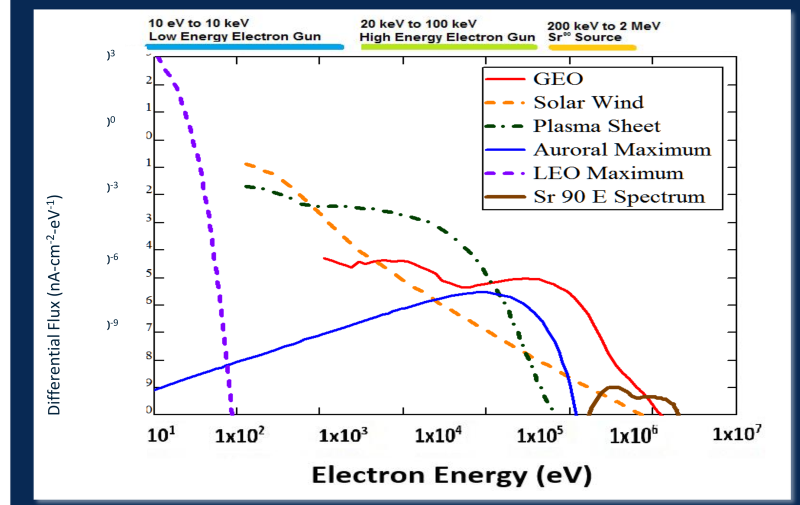


Figure 1 – Typical electron fluxes for various near earth orbits. SR[90] is beta radiation source, as shown in brown, which acts a fair approximation to the space environment for geosynchronous orbit.

Figure 2 – The Space Survivability Test Chamber used to simulate the space environment in a controlled ground-based setting.

Table I. Test matrix: Radiation performance at ~1 MeV Sr[90] beta radiation

Test Type	Radiation Total Dose			Diagnostic Tests	Exposed Parts and Materials
	Exposure Time (days)	Fluence (e/cm^2)	Fluence (kRad)		
COTS Parts	20	~2E12	~23	***In situ:*** CPU operation, USB and Bluetooth interface operation, memory read/write, sensor readings	CPU(s), USB interface(s),SD memory cards, Bluetooth sender/receivers, magnetic sensors
Solar Arrays				***In situ:*** IV curves ***Ex situ:*** UV IV response curves	Stacked solar array assemblies
Optical and Blanket Materials				***Ex situ:*** Microscopy, optical transmission/reflection, bulk/surface conductivity, tensile/hardness	MLI blankets (polyimide, VDA PET), insulated (polyimide, PTFE, Al_2O_3), wiring insulation, FR4 polyimide PCB, Optical (Al_2O_3,SiO_2, Coverglass)
CubeSat Frames	50	~6E12	~56	***In situ:*** Torsional strain, bulk conductivity ***Ex situ:*** Microscopy, bulk conductivity, torsional strain, tensile/hardness	GASPACS: Al, Graphite fiber composite PrintSat: Additive manufacturing (3D printing) Windform XT nano-carbon-impregnated plastic

II. Radiation Testing

Tests are currently underway to demonstrate the capabilities of the SST chamber to study standard ionizing radiation effects [1] for total ionizing doses comparable to several years exposure in space environments. Most tests are *ex situ*, comparing pre- and post- SST radiation exposure to pre- and post-flight effects. Both in-flight ***PrintSat*** and *in situ* SST tests of mechanical properties and conductivity will allow studies of the evolution of these properties with dose. Table I outlines currently planned tests, which include tests of modifications to the following material properties:

Optical: Radiation darkening of standard optical materials (see Figs. 3 and 5)
Electrical: Conductivity and charging properties of spacecraft polymeric and ceramic insulators and composite structural materials.
Mechanical: Stress/Strain curves, hardness, torsional strain, shear stress, and toughness of structural carbon composite materials.

III. Direct Comparison Between Ground-based and In-flight Tests

Numerous ground-based radiation exposure tests have been performed. However, very few direct comparisons have been made to in-flight (or even post-flight) missions. SST chamber will make direct comparisons between the data from the space flight missions in Section 4, and tests performed in the chamber. Table I outlines currently planned tests which have in-flight data to make these comparisons. These measurements will serve as validation of the capabilities and allow us to develop experience and protocols for future tests, while also providing useful information for specific projects.

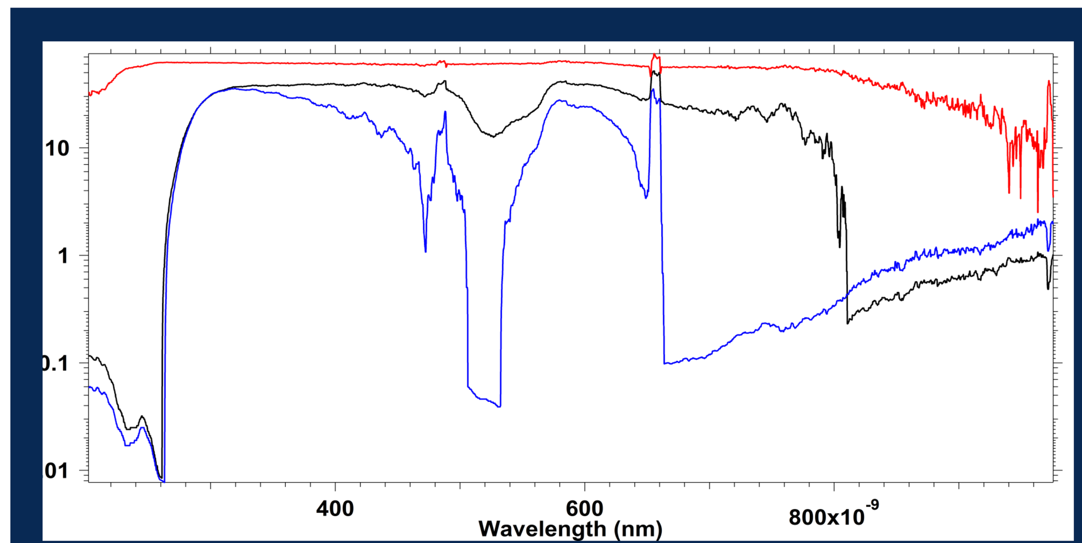
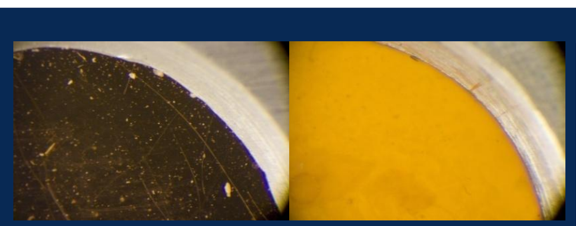


Figure 3 – Transmission spectra of Fused Silica (red), Sapphire (blue) and Borosilicate (black) taken before radiation exposure.



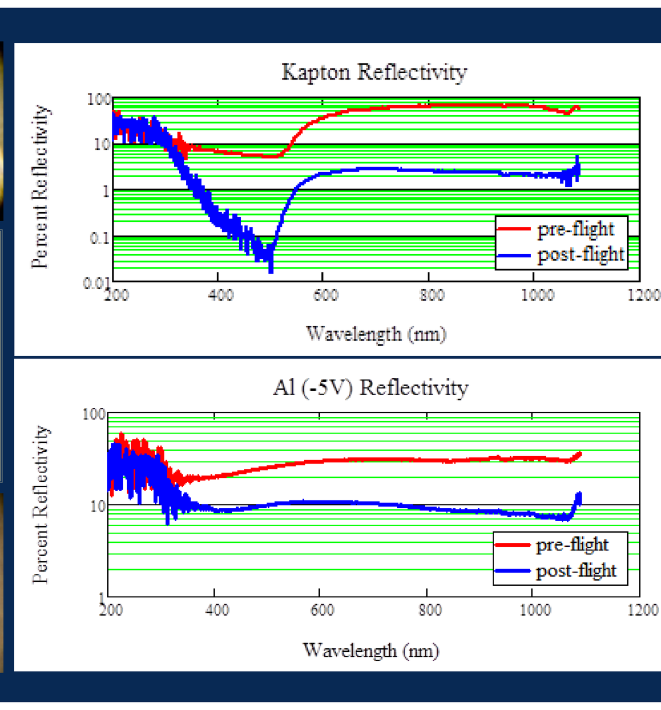


Figure 4 (Right) - Specular reflectance of pre- and post flight samples
Figure 5a (Above) – Optical microscopy of Kapton before (left) and after (right)
Figure 5b (Below) – Optical microscopy of Al before (left) and after (right) .

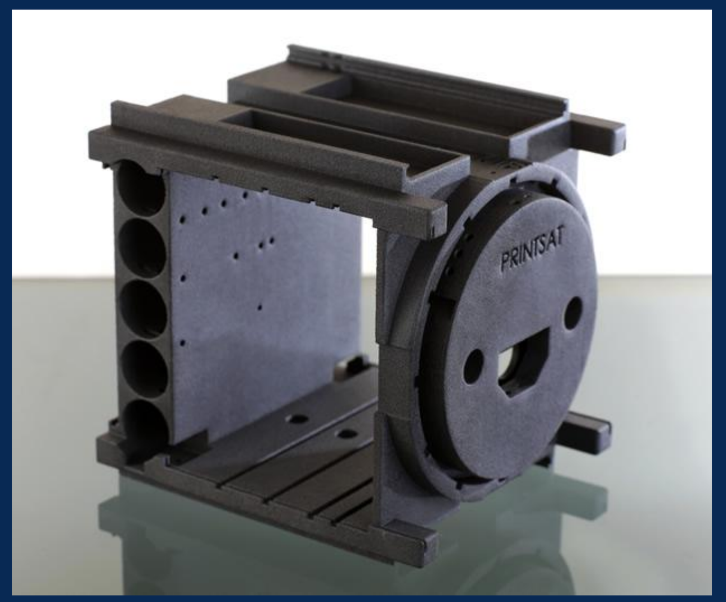


Figure 6 – PrintSat built using Windform and additive manufacturing techniques to be flown Oct 29. In flight tests will be compared to ground tests performed at USU.

Figure 7 – MISSE, materials mounted to the ISS for long duration in flight radiation tests. Samples were characterized before and after flight.

IV. Space Flight Missions

The USU ***SUSpECS*** experiment on MISSE-6 exposed many spacecraft materials to 18 months of the International Space Station environment, and were returned in pristine condition for comparative testing [6]. The SST was initially developed to test the verisimilitude of ground-based testing, through comparison of samples that have undergone simulated space exposure to those flown on MISSE.

PrintSat, a 1U CubeSat mission designed by Montana State University and CRP, Inc. will be launched on October 29, 2015 into a high-radiation polar orbit for several years. A primary objective of the mission is test the evolution with total ionizing dose of mechanical properties of the additive manufacturing (3D printing) Windform XT nano-carbon-impregnated plastic used to fabricate the CubeSat frame. The tests include in-flight monitoring of conductivity and torsional stress.

A second prototype 1-U CubeSat frame, the USU Get-Away-Special ***GASPACS,*** [2] uses graphite fiber composite structural elements will undergo pre- and post-SST exposure tests.

UtahState University

REFERENCES
[1] ASTM F1892, "Standard Guide for Ionizing Radiation (Total Dose) Effects Testing of Semiconductor Devices," ASTM International, West Conshohocken, PA, 2012
[2] USU Space Dynamics Laboratory Enabling Technologies Program Grant, "Deploy an Inflatable Boom and UV Rigidize the Boom From a 1-U CubeSat Platform in LEO, 2015.
[3] 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).
[4] JR Dennison, Crystal Frazier, Erik Stromberg, Ben Russon, Heather Tippets, Lisa Phillipps, Alex Souvall, and James S. Dyer, "Small Satellite Verification and Assessment Test Facility with Space Environments Effects Ground-testing Capabilities," Paper Number SSC15-P-2, *29th Annual AIAA/USU Conference on Small Satellites*, (Logan, UT, August 8-13, 2015).
[5] Katie Gamaunt, Heather Tippets, Alex Souvall, Ben Russon and JR Dennison, "The Space Survivability Test Chamber," *American Physical Society Four Corner Section Meeting,* Arizona State University, Tempe, AZ, October 16-17, 2015.
[6] JR Dennison, Amberly Evans, Danielle Fullmer, and Joshua L. Hodges, "Charge Enhanced Contamination and Environmental Degradation of MISSE-6 SUSpECS Materials," *IEEE Trans. on Plasma Sci.*, **40**(2), 254-261 (2012).

Scan code to access accompanying paper and references, as well as other USU MPG articles.