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Impact-Induced Mission Effects and Risk Assessments (3)

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RISK ASSESSMENT OF HYPERVELOCITY IMPACT-INDUCED ELECTRICAL ANOMALIES ON SPACECRAFT

Abstract

The present research aims to investigate the deleterious hypervelocity impact-induced electrical effects on spacecraft and to assess the associated risks, thereby emphasizing the significance of comprehensive risk assessment in the domain of space missions and spacecraft design.

Hypervelocity impacts, characterized by high-velocity micrometeoroids (major categories: sporadic and showers) and space debris with projectile velocities exceeding the speed of sound collide with surface of spacecraft, whereas impacts caused by relatively larger particles (> 1 mg) can result in noteworthy mechanical damages. Upon impacts where the relative velocity of space debris and meteoroids (< 1 μg) can reach up to 15 - 72.8 km/s, the particle and a small portion of the target surface vaporize, ionize, and generate a radially expanding plasma which can generate a range of electromagnetic and ionizing radiation effects that interact with a spacecraft's electrical systems, potentially causing a variety of electrical anomalies including Single Event Upsets (SEE), Latch-ups, Transient Voltage Events (TVE), Deep Dielectric Charging (DDC), Electrostatic Discharge (ESD), Surface Charging and etc.

The investigation involves reviewing a range of theoretical frameworks, including impact dynamics, plasma effects and classifying insights from statistical analyses of observed spacecraft anomalies, including instances from papers and studies conducted by several institutions. After classifying the anomalies, we analyze the density of each type and merge results from the latest and historically significant test datasets and research studies on this phenomenon to present a conclusion that combines experimental investigations such as ground-based impact simulations and in-flight experiments.

Potential risks associated with hypervelocity impacts on spacecraft include operational perturbations, component failures, and mission loss. Alterations to the spacecraft's trajectory from impacts may cause further complications, while damage to critical components can lead to overall malfunction. In the worst-case scenario, mission loss may and have resulted from irreparable damage based on historical instances, resulting in significant investment and data loss. In light of the challenges posed by hypervelocity impacts, the paper endeavors to provide an insight into the essential preventative measures and design considerations, such as the implementation of effective anomaly detection and mitigation systems, specialized materials with enhanced electrical conductivity, effective grounding and bonding techniques, advanced simulation tools and testing procedures, improved electrical design practices and guidelines to promote the safety, longevity, and success of spacecraft missions which in turn can enable the outcomes of the research providing an impetus for the improvement of the space industry.