Simulating Hypervelocity Impact Plasmas and their Effects on Spacecraft

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Abstract

Spacecraft are routinely bombarded with interplanetary dust particles, called meteoroids, and defunct objects of human origin, called space debris. Collectively we refer to these particles as hypervelocity impactors. Meteoroids have impact speeds up to 72 km/s and space debris have impact speeds <11 km/s in low Earth orbit. Most hypervelocity impactors possess enough energy to ionize and vaporize themselves as well as a significant portion of the spacecraft material upon impact, forming a plasma that rapidly expands into the surrounding vacuum. The associated electrical effects and potential for damage to satellite electronics through these processes remains largely unknown. This area of spacecraft engineering requires a deeper understanding of the underlying physics of the impact generated plasma plume.

We present computational multi-physics simulations of particle impacts on spacecraft. These simulations incorporate elasticity and plasticity of the solid target, phase change and plasma formation, strongly coupled plasma physics due to the high density and low temperature of the plasma, a fully kinetic description of the plasma, and free space electromagnetic radiation. In the early stages of impact, we use a computational continuum dynamics method. For the collisionless plasma expansion, we use an electromagnetic particle-in-cell.

By simulating a series of hypervelocity impacts, we determine basic properties (e.g. temperature, expansion speed, charge state) of the plasma plume for impact speeds of 10-72 km/s. We find for impact speeds of 30-72 km/s, the temperature asymptotes to 2.5 eV; this observation agrees with recent ground-based experiments. We also find that the plasma plume is weakly ionized for impact speeds less than 14 km/s and fully ionized for impact speeds greater than 20 km/s. We show that for angled impacts, plasma and gas expand in a specular manner from the crater, unlike dust and debris. Finally, we simulate a proposed mechanism for the plasma to produce RF radiation. We find that in an idealized case, the plasma produces transverse electromagnetic waves at the plasma frequency. Understanding key parameters of impact plasma plumes, as well as any RF emission mechanisms, will aid in designing more robust and reliable spacecraft that are well protected in the space environment.