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NUMERICAL SIMULATION OF DAMAGE BEHAVIOR OF DEORBIT SAIL SURFACE UNDER THE SYNERGISTIC EFFECT OF ATOMIC OXYGEN AND THERMAL CYCLING

Abstract

Deorbit sails are used for the low earth orbit (LEO) spacecraft to reduce the growing orbital debris problems by rapidly removing satellites from orbit after the end of their operational missions. In LEO, harsh environment includes atomic oxygen, ultraviolet radiation, thermal cycling, micrometeoroid and debris bombardment, which may severely damage the film material for deorbit sail. Among which atomic oxygen (AO) is the most threatening effect for hydrocarbon polymer film in LEO. The sail itself consists of $6\mu m$ Mylar membrane. The $200nm$ aluminized coating have been used on the deorbit sail to protect underlying polymers. However, most protective films have pinholes and defects caused by the deposition process or substrate imperfections. The process of assembling, packaging and decompressing for the sail will induce cracks, scratches, and vents on the film material inevitably. At such defect sites, AO will cause the undercutting of the film material, resulting in the fragmentation of the sail surface. Besides, thermal expansion coefficients of the coatings differ markedly from the polymer substrates, which results in cracks due to the thermal cycling after long exposure. The effects of AO undercutting and space thermal cycling typically cause synergistic interactions between each other. In this paper, the defects on the drag sails are experimentally measured using a scanning electron microscope (SEM) and then modeled systematically. The synergistic effect of AO and thermal cycling is studied by the combination of the Monte Carlo model and the Finite Element Method (FEM). The results demonstrate that under the synergistic effect of atomic oxygen and thermal cycling, sail surface erosion will be further exacerbated. Since the defects caused by the packaging and decompressing on the sail surface is relatively dense, AO and thermal cycling combined erosion predictions at neighborhood cracks are studied for various incidence angles of AO. The protective film between cracks hinders the escape of AO, and accelerates the erosion. The computational predictions of AO undercutting at defect sites are validated by the ground laboratory testing. The experimentally observed undercut profiles were compared to predictions from models. This Joint multi-physics model provide a theoretical basis for the reliability assessment of deorbit sail.

Keyword
Deorbit sail, Synergistic effect, Atomic Oxygen undercutting, Thermal Cycling , Computational modeling.