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BALLOONS, CHUTES, TETHERS, AND MORE: TWENTY YEARS OF INNOVATION AND ON-ORBIT LESSONS LEARNED FOR NANOSATELLITE DISPOSAL

Abstract

Since the year 2000, The Aerospace Corporation has built and flown 35 nanosatellites that met or exceeded debris-mitigation guidelines, using a broad spectrum of disposal options with low impact on the satellites' size, weight, and power (SWaP). As community and political pressures grow to impose increasingly strict rules on spacecraft flight and disposal, owner/operators of nanosatellites run the risk of being regulated out of the space business unless a menu of affordable, reliable, and low-SWaP solutions becomes available to ensure their compliance with the goals of debris mitigation. But on-orbit demonstrations of active and passive disposal at the nanosatellite scale have been sparse, and seldom has a single operator developed or flown multiple disposal technologies to compare experiences. This paper and presentation provide an overview of Aerospace's lessons learned, observed performance, and recommendations for multiple disposal approaches and technologies used on its nanosatellites over the last 20 years. AeroCube-4, which launched to low Earth orbit (LEO) in 2012, flew a drag chute developed in house that reliably deployed after 5 years of on-orbit operations and reduced the satellite's remaining on-orbit lifetime from 13 to 3 years. The behavior of the chute during and after deployment was captured in high resolution by AeroCube-4's cameras, providing insight into the robustness of the chute's design. Later, two vehicles of the AeroCube-5 series launched with commercially acquired drag tethers. These tethers were also released several years after launch, and AeroCube-5's cameras monitored their deployment, which included diverse unanticipated behaviors such as twisting, flexing, and oscillating and did not deliver the expected gravity-gradient stabilization or electromagnetic drag effects. Several Aerospace CubeSats have flown propulsion systems, including solid rocket motors, electric propulsion units, and warm gas thrusters, all of which demonstrated varying levels of reliability and efficacy for orbit-altitude changes. Lastly, nearly every Aerospace satellite has had disposal requirements built into the design itself, with functional elements such as deployable solar panels designed to enhance their contribution to end-of-life disposal. Altogether, a picture has formed illustrating the tradeoffs between lifetime reduction, complexity, reliability, and palatability in the nanosatellite form factor. This overview offers the growing population of nanosatellite owner/operators an aid for selecting among a diverse array of disposal options and insight for the international community of regulators on how the space environment can be preserved for future generations while still ensuring the survival and flourishing of its more diminutive inhabitants.