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IONOSPHERIC PLASMA DRAG ON SMALL SATELLITES IN LOW-EARTH ORBIT

Abstract

Effective space domain awareness (SDA) and space traffic management (STM) are critical to ensure a sustainable space environment and prevent collisions between active satellites and non-responsive objects such as space debris. In low-Earth orbit (LEO), the residual background atmospheric drag is a major factor that affects an object's trajectory. For LEO above 500 km of altitude, the ionosphere, composed of charged particles, causes the build-up of negative charge on the satellite's surface, ϕ_B, and the formation of plasma sheath and wake structures around an object, increasing its effective collecting area. As a result, small objects can experience a drag force generated by charged particles. In case of large negative charging (i.e., $|\phi_B| > 10$ V), the ionospheric charged drag can become more significant than atmospheric neutral drag. Until recently, the interaction between orbiting objects and the ionosphere has only been examined from a charging perspective. However, a better understanding of the ionosphere charged aerodynamics has become crucial in recent years due to the increasing interest in SDA and STM, along with the rapid growth of small-size satellites and debris in LEO.

There are very few recent research on charged aerodynamics available in the literature. However, the existing studies are limited to objects with simple shapes, such as cylinders or spheres. This work simulates the ionospheric charged aerodynamics of small satellites in LEO with ProPIC, a 3D fully kinetic particle-in-cell (PIC) code previously used to simulate satellite surface charging and space electric propulsion. This work extends ProPIC's capabilities to study 3D charged aerodynamics of satellites with complex shapes, a first time in literature to the best of authors' knowledge.

The study shows that the collective area increases with $|\phi_B|$, and the charged drag strongly correlates to ϕ_B. When the characteristic size of the satellite (L_s) decreases, this correlation increases, causing the charged drag to become larger than the neutral drag for small satellites ($L_s < 10$ cm) with large negative charging ($|\phi_B| > 10$ V). This finding is significant because small satellites become more complex each year and often contain negatively biased elements like solar panels. The charged aerodynamics can also be non negligible for bigger satellites ($L_s \sim O(1\text{ m})$) in polar orbit, where the very large negative charging ($|\phi_B| > 100$–1000 V) caused by precipitating electrons can lead to a considerable amount of charged drag.