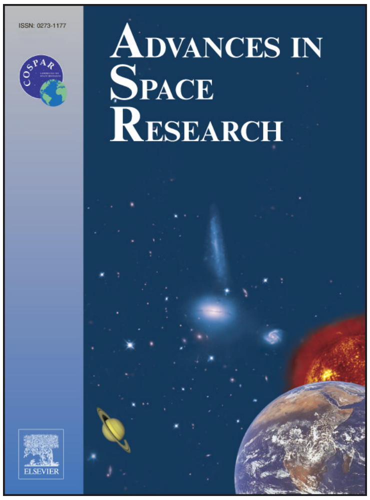

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Atmospheric Interaction with Nanosatellites from Observed Orbital Decay

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Abstract

Nanosatellites have gained considerable presence in low Earth orbits wherein the atmospheric interaction with exposed surfaces plays a fundamental role in the evolution of motion. These aspects become relevant with the increasing applicability of nanosatellites to a broader range of missions objectives. This investigation sets out to determine distinctive drag coefficient development and attributes of atmospheric gas-surface interactions in nanosatellites in the common form of standard 3U CubeSats from observed orbital decay. As orbital decay can be measured with relative accuracy, and its mechanism broken down into its constituent sources, the value of drag-related coefficients can be inferred by fitting modelled orbit predictions to observed data wherein the coefficient of interest is the adjusted parameter. The analysis uses the data of ten historical missions with documented passive attitude stabilisation strategies to reduce uncertainties. Findings indicate that it is possible to estimate fitted drag coefficients in CubeSats with physical representativeness. Assessment of atomic oxygen surface coverage derived from the fitted drag coefficients is broadly consistent with theoretical trends. The proposed methodology opens the possibility to assess atmospheric interaction characteristics by using the unprecedented opportunity arising from the numerous observed orbital decay of nanosatellites.

Keywords: nanosatellite, drag coefficient, orbit decay, atomic oxygen surface coverage

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1. Introduction

Typical operative altitudes for nanosatellites lie within one thousand kilometres in orbits wherein the dominant non-conservative disturbing force is derived from atmosphere-spacecraft interaction. This interaction causes monotonic reduction of orbital eccentricity and semi-major axis, and can produce attitude perturbation torques. These effects are in the main undesirable during the operational life of nanosatellites due to characteristic low mass and volume efficiencies that hinder the establishment of flexible system margins. In the framework of drag force theory, the drag coefficient (C_D) captures the intricacies of atmosphere-surface interactions such as energy and momentum interchange mechanisms. Amongst the drag force constituents, C_D is normally the least tightly defined quantity, which is also subject to significant variation according to atmospheric characteristics. Existing in-situ measurements in Very Low Earth Orbits (VLEO) ($\backsim 150 - 300\,\mathrm{km}$ [15]) have shown that atomic oxygen may populate exposed surfaces greatly controlling interactions' quality and therefore C_D. Acknowledging the key importance of atmospheric drag to the mission and application diversification of nanosatellite platforms, the investigation presented herein sets out to estimate atomic oxygen surface coverage in nanosatellites from observed orbital decay. The proposed method involves a deductive process in which the macroscopic atmospheric interaction characterising the natural evolution of an orbit time span, is captured in fitted values of C_D, hereafter referred to as C_{DF}. Finally, the atomic oxygen surface coverage is estimated from C_{DF} and the theoretical weighted contributions of extreme C_D, i.e. those of a clean and fully contaminated surface.

Atmospheric interaction with exposed surfaces can be explained in terms of the kinetic theory of gases. Gas-surface interaction phenomena or GSIs, in particular those related to the interchange of momentum and energy with a surface, are relevant for this investigation. Under the prevailing atmospheric conditions at LEO altitudes, molecules travel large distances compared to a characteristic length before intermolecular collisions can occur [26]. In addition, particles may manifest bulk ordered and random translational motion. With respect to a reference surface immersed in an atmosphere showing prevalently ordered motion, the stream would move with a distinctive relative speed v_r. To account for the fraction of particles in random translational motion, a Maxwellian velocity distribution (thermal velocity) is typically assumed. The bulk and thermal speed contributions of the particles are related in the dimensionless molecular speed ratio s defined by Eq. (1), wherein k_B is the Boltzmann constant, T_∞ the freestream temperature, and $\overline{m}_m$ the mean molecular mass.

$$s = v_r \sqrt{\frac{\overline{m}_m}{2k_B T_\infty}} \tag{1}$$

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