ORBITAL LIFETIME ANALYSIS FOR NANOSATELLITES AT LEO

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RESUMEN

Los nanosatelites en órbitas bajas terrestres (LEO) tienen diversas aplicaciones tales como el monitoreo de las condiciones ambientales, la medición de propiedades de la ionósfera, la optimización de comunicaciones, entre otros. Estas aplicaciones han llevado a incrementar el esfuerzo de estimar el tiempo de vida orbital de un nanosatelite, ya que de este dependerá la duración máxima de cada misión. En este trabajo se estiman tiempos de vida orbital de nanosatelites en LEO teniendo en cuenta la interacción gravitacional, la deformación terrestre, el frenado atmosférico y las condiciones iniciales del satélite. Se encuentran tiempos de vida orbital máximos, medios y mínimos para satelites de 1U, 2U y 3U, en órbita ecuatorial, asumiendo perfiles de densidad acordes a los reportados en la literatura e incertidumbres hipotéticas.

ABSTRACT

Nanosatellites at low earth orbit (LEO) have multiple applications such as monitoring environmental conditions, measuring ionosphere properties, improving communications, among others. These applications have lead to increase the effort of estimating orbital lifetimes for nanosatellites because they define the maximum operational time of a mission. In this report, we estimate orbital lifetimes of nanosatellites at LEO taking into account the gravitational interaction, Earth deformations, atmospheric drag and satellite initial conditions. Highest, mean and lowest lifetimes for nanosatellites of 1U, 2U and 3U in an equatorial orbit are computed by assuming a density profile according to literature and hypothetical uncertainties.

Key Words: CubeSat — Orbital lifetime — Orbital elements — Gravitational potential — Atmospheric density

From the motion equation of a nanosatellite (artificial satellite with a mass between 1 and 10 kg) around Earth, the most relevant interaction is the gravitational one. In order to consider Earth deformations, the gravitational force is obtained via the gravitation potential U which reads

$$U(r,\phi) = -\frac{\mu}{r}\left[\sum_{n=2}^{\infty} J_n \left(\frac{R_T}{r}\right)^n P_n \sin(\phi)\right], \qquad (1)$$

where r is the separation between Earth and the nanosatellite, ϕ is the inclination, R_T is the mean radius of Earth, $P_n(x)$ is the Legendre polynomial, and J_n the so-called J_n coefficient. In this study we take into account the first 14 J_n coefficients to estimate orbital lifetimes.

The atmospheric drag interaction is modeled as

$$\vec{F}_D = -\frac{1}{2}\rho A C_D v\vec{v}, \qquad (2)$$

where ρ, A, C_D and $\vec{v}$ are respectively the atmospheric density, the projected area of the nanosatellite, the drag coefficient and the satellite velocity with respect to the atmosphere.

To estimate lifetimes, it is crucial to use an atmospheric profile as accurate as possible. Unfortunately, the reported profiles above 86 km from Earth surface are obtained via models and not by direct measuring. To overcome this fact, we propose a parametrization, in the range 150-800 km, which satisfactorily fits the atmospheric models: MSIS-90, NASA 1976, and H-P @ 1300 h as Fig. 1 shows.

Note also that Fig. 1 shows two dashed lines, which are our assumptions for the highest and lowest density (one order of magnitude of difference in average). This is done with the aim of simulating uncertainties and to see the effects on the lifetime.

As a first step, we compute orbital lifetimes according to the GARADA project (Qiao et al. 2013) but for equatorial orbits (see Fig. 2). Our results (for a mean density) are in good agreement with those of GARADA and highlight that the orientation has a minor influence on the lifetime. However, if a non negligible density uncertainty is assumed (as we do), lifetimes can differ almost by a factor of 5. This also stresses that the density uncertainty affects the

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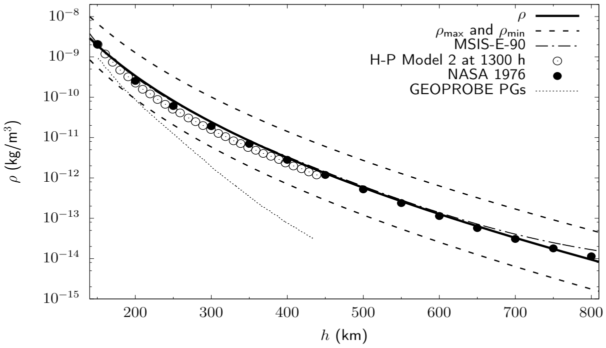

Fig. 1. Comparison among three atmospheric models and our parameterization in the altitude range 150-800 km. The models MSIS-90, H-P@1300 h and NASA 1976 are taken from MSISE90 (1990); Pelz & Newton (1969); NASA (1976) respectively.

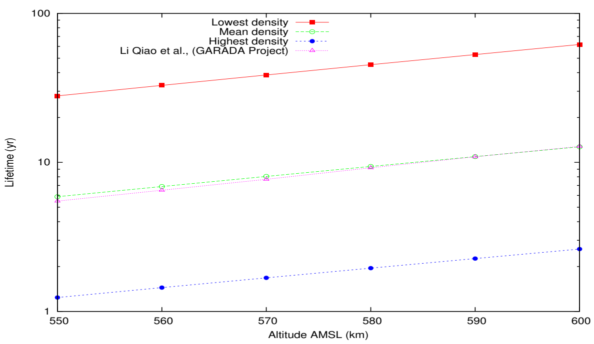

Fig. 2. Lifetimes reported by Qiao et al. (2013) for the GARADA project and the comparison with or calculations according to our assumptions in Fig. 1.

lifetime estimation much more than the orbit orientation.

To provide lifetime estimations for nanostellites, we have assumed hypothetical CubeSats (miniaturized satellite made up of multiples of 10×10×10 cm cubic units) of 1U, 2U and 3U of 1, 2 and 3 kg respectively. For the drag interaction we have fixed $A = 0.01$ m^2 and $C_D = 2.2$ for all cases; the initial altitude is between 200 km and 800 km and all the remaining orbital elements are assumed as zero. Lifetime estimations, according to the previous conditions, are shown in Fig. 3. As becomes clear from these figures, the lifetimes for the GARADA project are very similar to those for CubeSats of 1U because the area-to-mass ratio is similar in both cases. 0.013 m^2/kg for GARADA).

As expected, the lifetime increases with initial altitude and mass. The dependence with the altitude is not exponential, however, for high altitude (~ 600 to 800 km) we infer that the exponential behavior can be a good approximation. From Fig. 3 and the

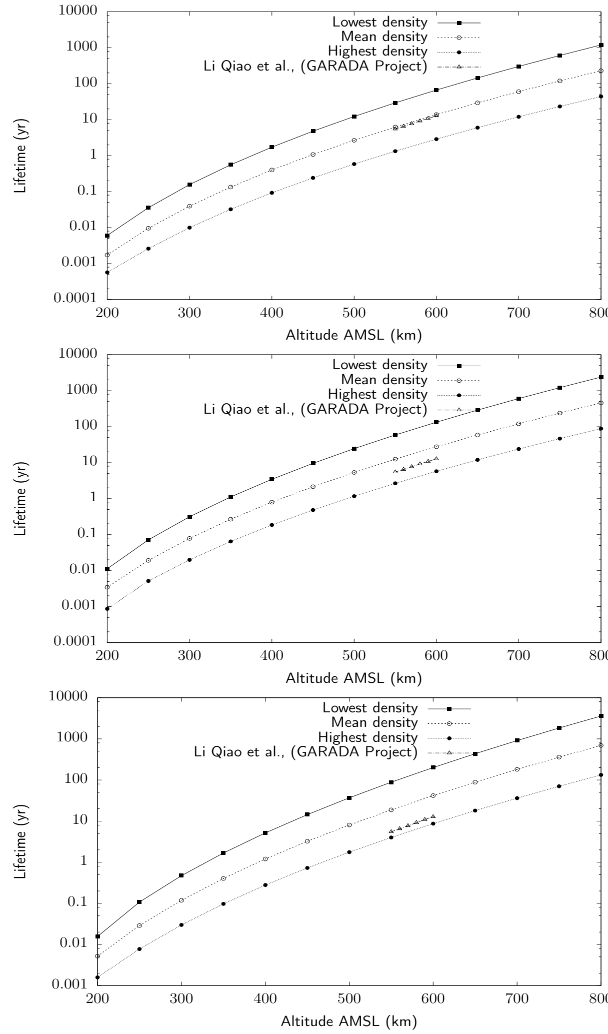

Fig. 3. Lifetimes for CubeSats of 1U (**top**), 2U (**middle**) and 3U (**bottom**). In all cases we plot the results for the GARADA project as a reference point (similar to Fig. 2).

drag interaction, we see that the effect on the lifetime by increasing the mass by a factor of 3 is equivalent to reducing the density by a factor of 3.

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