

Resonance Effects on Lifetime of Low Earth Orbit Satellites

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ABSTRACT

The subject of satellite lifetime estimation is particularly prominent now in the context of an increasing population of Earth orbiting debris. One of the set of rules commonly adopted (by France in particular) is to deorbit Low Earth Orbit satellites at the end of their operational lifetime so that they don't remain in orbit more than 25 years (if no direct re-entry can be envisaged). Of course, this implies having a good enough accuracy on the prediction of the trajectory for all that period of time.

Orbit lifetime computation for LEO satellites has been extensively studied in the literature. The main factor that makes lifetime prediction difficult is known to be related to atmospheric drag. Recent studies conducted by CNES showed that lifetime uncertainty can be satisfactorily handled by a statistical approach: lifetime deviation from the average value (say 25 years) is of the order of 10 years. Moreover, the initial value of RAAN has (most often) little impact on the results, even if the orbit is (initially) Sun-synchronous. The same remark holds for the initial date.

But there are exceptions, and this paper exhibits particular situations (resonance cases) for which orbit lifetime strongly depends on initial conditions (RAAN, argument of perigee or date).

The first example given here concerns solar radiation pressure, which is not usually considered as having a strong impact on LEOs.

When averaging the Gauss equations over one orbit, assuming that no eclipse occurs and that the acceleration vector is constant, one obtains the mean time derivative of eccentricity as follows:

$$\frac{de}{dt} = \frac{3}{2} \frac{\sqrt{1-e^2}}{n a} Y$$

where Y is the component of the acceleration perpendicular to the perigee vector and in the orbital plane, a stands for the orbit's semi major axis and n is its mean motion.

[Note that the expressions for all the other orbital elements are also given in the paper.]

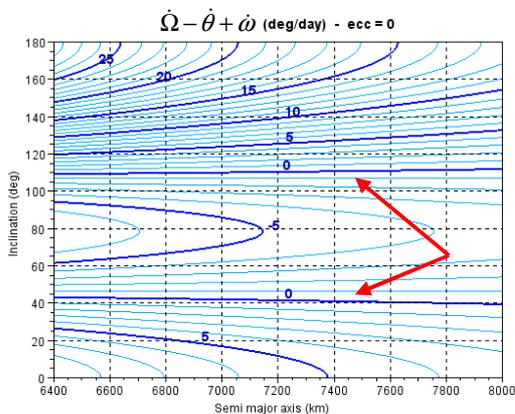
Assuming that the direction of the Sun-Earth vector lies (on average) in the equatorial plane, the acceleration component can be written:

$$Y = -\frac{K}{2} [\sin(\Omega - \theta + \omega) (\cos(i) + 1) + \sin(\Omega - \theta - \omega) (\cos(i) - 1)]$$

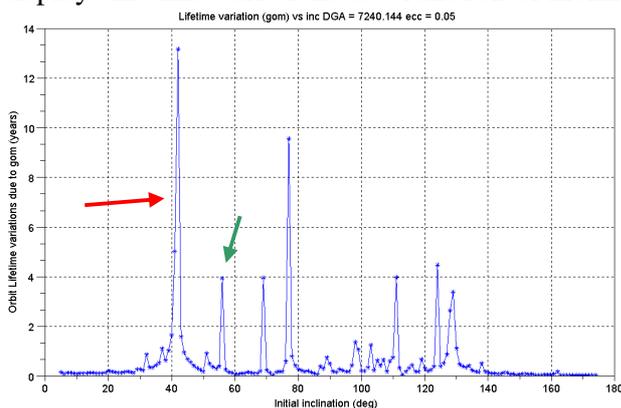
where θ is the right ascension of the Sun, K is a constant, and i , Ω and ω are respectively the orbit's inclination, RAAN and argument of perigee.

One can see that if $|\Omega - \theta \pm \omega|$ is nearly constant, $\frac{de}{dt}$ varies nearly secularly, impacting the perigee altitude, hence drag, and consequently lifetime.

And cases such that $\dot{\Omega} - \dot{\theta} \pm \dot{\omega} = 0$ really exist in the LEO domain as shown in the following figure which represents $\dot{\Omega} - \dot{\theta} + \dot{\omega}$ as a function of semi major-axis and inclination (only the effects coming from J2 are considered here; eccentricity is 0 but the dependence on eccentricity is weak).



The consequence on orbit lifetime is not negligible at all, as shown in the figure below that displays lifetime variations as a function of inclination when only RAAN varies.



For an inclination close to 40 degrees, lifetime can vary by more than 10 years. It can be even worse if inclination is finely tuned to the "resonant" value.

By comparison, in usual cases (Sun-synchronous orbits), lifetime may be changed by only 1 or 2 years depending on the initial local time of the ascending node.

Similar resonance conditions exist that can affect how third body perturbation or drag change the orbit. In the previous plot, some of the peaks originate in third body perturbation (because of terms like $\dot{\Omega} \pm 2\dot{\omega}$ that appear in the doubly averaged equations) or even drag as the mean value of $\frac{de}{dt}$ over one orbit depends on local time of ascending node and argument of perigee, and therefore on the way both quantities are related to each other.

As a summary, this paper shows and explains resonance conditions that affects the lifetime of satellites in Low Earth Orbits. For specific cases (i.e. particular initial conditions) the resonance effects are stronger than the ones coming from the uncertainty on atmospheric drag.

These effects should be taken into account when trying to predict how long the satellite will stay in orbit. But as the exact initial conditions (at the time of the disposal maneuver) may not be known, the best we might be able to do is to find the impact on the lifetime distribution with a statistical analysis.

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