De-Orbiting Timing for Spacecraft in Geostationary Transfer Orbits to Exploit Luni-Solar Perturbations

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End-of-life disposal measures are required for retired spacecraft and spent launch vehicle upper stages in geostationary transfer orbits (GTOs) to control the growth of debris population in this orbital region. Generally, there are two end-of-life disposal strategies for Earth-orbiting satellites: atmospheric re-entry and transfer to a graveyard orbit. Usually, it is not an option to move retired spacecraft or spent upper stages from a low-perigee GTO to a graveyard orbit, since it is fuel-consuming to raise the low perigee to above the LEO region (>2000km) and, needless to say, also to move the apogee away from the GEO region. It is much easier to lower the perigee deeper into the dense atmosphere. Therefore, the atmospheric re-entry is the preferred end-of-life disposal strategy for the GTOs with a low perigee near the dense atmosphere.

There has been a simple guideline widely used in the existing end-of-life disposal measures for atmospheric re-entry from GTOs, that is, a lower perigee height can speed up the orbital decay through the denser atmosphere, or, in other words, a lower perigee can increase the probability of atmospheric re-entry within a given time limit. This fact has been shown by statistical studies [1]. Since the dynamics is highly sensitive, for example, the low perigee may be raised to a large extent later by the solar apsidal resonance, this simple guideline is only justified in a statistical sense but not in a deterministic one. However, the compliance of orbital lifetime with space debris regulations is actually a statistical problem itself [2]. Therefore, this simple guideline is well enough for the design of end-of-life disposal measures for atmospheric re-entry.

The straightest method to lower the perigee is to perform a retrograde delta-V maneuver at apogee, as performed by the SPIRALE GTO satellites [3]. In this paper, we focus on this de-orbiting method for an early atmospheric re-entry. Notice that luni-solar perturbations induce eccentricity oscillation. Therefore, the de-orbiting timing is an important issue, since de-orbiting maneuvers with the same delta-V but performed at different time points will act on the GTO with different eccentricities and then will have different de-orbiting effects. Through analyses and numerical simulations, we have found that, for GTOs, the minimum point of eccentricity oscillation is the optimal timing for the retrograde de-orbiting maneuver at apogee. When the de-orbiting maneuver is performed at this timing, the luni-solar perturbations can be exploited to the most extent to amplify the de-orbitation. The resulting optimal disposal orbit has the smallest semi-major axis, largest eccentricity, and lowest perigee among all the disposal orbits with different de-orbiting timings. Consequently, the optimal disposal orbit has the largest decaying rates for the semi-major axis and eccentricity, encounters solar apsidal resonance earliest, and has the largest probability of atmospheric re-entry within a given time limit among all the disposal orbits.

References

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