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Author: Dr. Aaron J. Rosengren
Aristotle University of Thessaloniki, Greece

Dr. Jérôme Daquin
Royal Melbourne Institute of Technology (RMIT) University, Australia

THE DYNAMICS OF PASSIVE DEBRIS MITIGATION AND REMEDIATION

Abstract

Only recently has the precarious state of the Earth's navigation satellite constellations, perched on the threshold of chaos, been fully appreciated and understood. The circumterrestrial phase space where these satellites exist is permeated by a devious network of lunisolar secular resonances (i.e., those caused by the Moon and the Sun on long timescales) that mercilessly distort their orbits, slowly pumping the eccentricities to Earth-reentry values. This fortuitous dynamical situation, however, can be judiciously exploited for space debris remediation in the new paradigm of self removal of satellites through resonances and chaos, from their otherwise long lifetime orbits. Indeed, even in the geosynchronous region, where it has traditionally been thought that space objects would remain indefinitely due to the absence of atmospheric drag, there exist many natural disposal trajectories brought on by resonant interactions. These considerations emphasize the importance of investigating the analytical character of the mechanisms that drive these complicated behaviors and of developing realistic dynamical models for numerical cartographic studies of the phase space. Moreover, such dynamical assessments are of considerable practical interest for the identification of long-term stability regimes, such that satellites (and their aging components) placed in these graveyards will not interfere with the constellations.

In this paper, we will present our investigations on the detection of regular structures and chaotic zones in the circumterrestrial space from low-altitude orbits up to the geosynchronous regime and beyond, for the purposes of passive debris mitigation and remediation. The overlap of the predominant lunisolar secular resonances furnish a number of interesting disposal hatches at moderate and low eccentricity orbits. We will examine the phase-space topology induced by these resonant harmonics, and outline how the identification of the hyperbolic and elliptic fixed points of the resonances can lead to explicit criteria for defining optimal disposal strategies. Furthermore, we will explore whether increasing the satellite's area-to-mass ratio using a solar sail would promote the deorbiting process, through coupled gravitational and radiation pressure perturbations or by steering the satellite into a short-lived resonance.

The solution to the debris proliferation problem throughout all regions can only be found by coupling a deep understanding of the dynamical environments occupied by artificial satellites and space debris with technical, political, and legal solutions. This paper will link theoretical aspects of resonances and chaos with practical applications, and will provide fundamental insight into the basic features of the long-term dynamics of Earth satellite orbits.