RELATIVE ORBIT DYNAMICS IN NEAR-GEOSTATIONARY ORBIT

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Keywords: *Relative motion, orbital perturbations, geostationary orbit, on-orbit servicing.*

ABSTRACT

As the market of satellite communication services is growing continuously, there is an ever-increasing interest in On-Orbit Servicing (OOS) and Space Situational Awareness (SSA) in near-geostationary orbit (GEO). A number of Phase A/B satellite mission studies have been conducted in the last decade, see e.g. [1] and [2], which demonstrates strong demand as well as technological readiness for On-Orbit Servicing in GEO. Potential applications of a geostationary OOS satellite include propellant supply for Client spacecraft life extension, provision of orbit and attitude control in case of Client AOCS malfunction, recovery of a satellite launched into an incorrect orbit, and last but not least, active removal of space debris and de-orbiting of old uncooperative satellites. These considerations call for an in-depth investigation of the dynamics of the relative motion of two spacecraft in near-geostationary orbit.

The relative motion of two close spacecraft in Low Earth Orbit (LEO) was characterized in [3] in terms of a particularly convenient set of relative orbital elements (ROE) with a focus on the secular perturbations due to Earth's oblateness as well as the differential air drag. This relative motion model has been employed since then at German Space Operations Center (GSOC) in various LEO formation-flying experiments, see [4]. The current research aims at extending it to include the effects that might be negligible in LEO but play a significant role at high altitudes. In particular, the perturbations of the relative motion due to solar radiation pressure (SRP) and third-body gravitational pull were studied in terms of magnitude and affected ROE including high-fidelity modeling.

While the influence of the non-spherical gravity field diminishes with increasing altitude, SRP remains fairly constant. Its effects are particularly important for communication satellites equipped with large solar arrays. The key factor driving the differential SRP in its simplest model is the difference in area-to-mass ratio of the two spacecraft. If the Servicer spacecraft should be able to accommodate Client spacecraft within a wide range of area-to-mass ratios, the differential solar radiation pressure becomes an important factor in approach trajectory design and relative orbit prediction. In the present paper, the differential SRP perturbations including shadow modeling are calculated in the inertial frame and linearly transformed to the differential perturbations in ROE. The error in modeled differential SRP perturbations for the selected test scenario lies below 1% in all ROE as compared to the reference generated by numerical propagation of two absolute orbits.

Considering a formation with relatively large radial and/or out-of-plane separation as it can be required for safety purposes in the beginning of a far-range approach, neglecting third-body gravitational perturbations of the Sun and the Moon might have a significant influence on the accuracy of a long-term relative orbit prediction, in particular in relative inclination and eccentricity. However, the research on third-body perturbations in relative orbits has so far been mostly restricted to numerical quantification, and formulations based on the absolute double-averaged model of Prado [5], where the disturbing function was averaged over the satellites revolution period as well as the perturbing body's revolution period. In present research, secular, long- and medium-period lunisolar perturbations of relative orbit were investigated using the single-averaged (over the satellites revolution period only) distribution function of Kozai from [6]. Thus the obtained perturbations depend on the actual position of the perturbing body and therefore give insight to the medium-term behavior of the satellite formation. The error in the modeled lunisolar perturbations for the selected test scenarios lies below 10% as compared to the reference generated by numerical propagation of two absolute orbits.

The ultimate result of this research is a high-fidelity analytical relative motion model, which allows to predict the relative position at epoch $t+\Delta t$ taking into account SRP as well as secular, long- and medium-period third-body perturbations. All calculations are based on the Servicer's absolute orbital elements, obtained e.g. through orbit determination using ground station tracking data. The calculations require information on the previous relative orbit state at epoch t. Perturbations related to the Sun and the Moon depend as well on the geocentric position of the perturbing body. The absolute elements of the Client spacecraft are not required for the relative orbit prediction, and therefore this approach can be used in design of guidance profiles towards uncooperative targets as well as on-board a Servicer spacecraft for approach strategies with high level of autonomy.

1. References

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