Paper ID: 38626
student

ASTRODYNAMICS SYMPOSIUM (C1)
Orbital Dynamics (2) (9)

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LONG-TERM BOUNDED RELATIVE ORBITS UNDER HIGHER ORDER ZONAL HARMONIC PERTURBATIONS

Abstract

In recent years the studies on distributing the functionality of large spacecraft into the smaller ones keep constantly emerging. The problem of searching invariant relative orbits that ensure long-term bounded relative motion is of great significance for various distributed space missions, wherein the spacecraft remain within bounded distances while no or only few station-keeping maneuvers are required. From the numerical and analytical aspects, much research has been dedicated to this problem since it was proposed by Schaub and Alfriend (2001).

Xu et al. (2012) presented a purely numerical method to search the J_2-perturbed bounded relative orbits using the Poincaré surface of section and differential correction algorithm. Furthermore, Baresi and Scheeres (2016) studied naturally bounded relative orbits for quasi-periodic invariant tori via stroboscopic maps and extended their approach to find the bounded orbits around celestial bodies including zonal harmonics up to J_5. Aimed at the closed-form solutions, Lara and Gurfil (2012) found an integrable approximation for the relative motion problem to predict long-term bounded perturbed orbits with arbitrary inclinations. However, the prevalent numerical methods require heavy numerical computations and the analytical ones lack the concise physical meanings or sufficient accuracy in the dynamical model.

Different from the previous numerical and analytical approaches and as the extension of the work (Xu et al. 2012), this paper presents the condition for existence of bounded relative orbits in an invariant torus under the effect of J_n ($n{\geq}3$) zonal perturbations. The Routhian reduction method is utilized to compute the KAM torus holding the constant nodal period (T_Ω) and drift of the right ascension of ascending node (RAAN) per nodal period ($\Delta\Omega$), which is then adopted to obtain the necessary and sufficient the conditions for the existence of relative orbits. To this end, we intend to provide a closed-form solution of the flow from the pair of variables (E, H_z, Δr) (where E is the energy of the orbit, H_z is the polar component of momentum, and Δr is the measure of distance between the periodic orbit and its central manifolds in Poincaré section) to the T_Ω and $\Delta\Omega$. Furthermore, straightforward physical insight is attained by the derivation of the explicit relation from the (E, H_z, Δr) pair to the relative orbital elements and relative Cartesian coordinates, which is beneficial to the construction of the bounded configurations. Numerical simulations substantiate the validity of the proposed methods with efficiency and accuracy allowing for long-term bounded relative motion.