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Author: Mr. Yuechen Ma
Beihang University, China

Dr. Yanchao He
DFH Satellite Co., Ltd., China
Dr. Ming Xu
Beihang University, China

CLOSED-FORM SOLUTION OF LONG-TERM INVARIANT RELATIVE ORBIT IN THE ZONAL GRAVITATIONAL FIELD

Abstract

The problem of searching invariant relative orbits that ensure long-term bounded relative motion has been receiving more and more attention for various formation-flying missions, wherein the spacecraft remain within bounded distances while only few station-keeping maneuvers are required. Numerous researches have been dedicated to this problem since it was first proposed by Schaub and Alfriend (CMDA, 2001). However, the prevalent typically numerical methods require heavy numerical computations using the Poincaré mapping and Newton iteration algorithm and the analytical ones lack the concise physical meanings or sufficient accuracy in terms of the dynamical models and analytical approximations.

Differently from the previous numerical or analytical approaches and as the extension of Xu et al (CMDA, 2012), this paper aims to obtain the necessary and sufficient conditions for the existence of bounded relative orbits in an invariant torus under the effect of Jn (n>2) zonal perturbations. The Routhian reduction method is utilized to compute the KAM torus holding the constant nodal period (T_d) and drift of the right ascension of ascending node per nodal period ($\Delta\Omega$). We intend to provide a closed-form solution of the flow from variables (E, Hz, Δr) (where E is the energy, Hz is the polar component of momentum, and Δr is the measure of distance between the periodic orbit and its central manifolds, i.e., quasi-periodic orbits in Poincaré section) to the T_d and Δr. By introducing the cylindrical coordinates, Hamilton-Jacobi theory is applied to derive the canonical solutions and thus periodic and quasi-periodic orbits are treated separately to calculate elliptic integrals with Carlson's method. The canonical solutions are utilized to match the T_d and $\Delta\Omega$ of the chief and deputy non-instantaneously, demonstrating the fact that initial values of the chief and deputy can be assigned to achieve bounded motion. Furthermore, straightforward physical insight is attained by the derivation of the explicit relation from the (E, Hz, Δr) to the relative orbital elements and relative Cartesian coordinates, which is beneficial to the construction of the bounded configurations.

Simulations substantiate the validity of the proposed methods with efficiency and accuracy allowing for long-term bounded relative motion. A typical bounded relative orbits with large magnitude over 1 year in the chief's local-vertical, local-horizontal coordinate frame are generated, which is comparable with some fully numerical methods.