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FROZEN ORBITS AROUND THE EUROPA SATELLITE

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Abstract: The dynamics of orbits around a planetary satellite, taking into account the gravitational attraction of a third-body and the non-uniform distribution of mass (J_2, J_3, and C_{22}) of the planetary satellite is studied. The conditions to get frozen orbits are presented. Low-altitude, near-polar orbits are very desirable for scientific missions to study the satellites, such as the Jupiter's moon Europa. However, previous research has shown that a spacecraft in a low-altitude, near-polar orbit around Europa will have an impact in a relatively short time. Here, using a double-averaged analytical model, we found orbits with constant orbital element in average. Using an approach with the simple-averaged problem, frozen orbits valid for long periods of time are found. A comparison between the averaged models, simple and double, is presented.

keywords: Planetary satellites artificial satellite frozen orbits.

1. INTRODUCTION

Low-altitude, near-polar orbits are very desirable for scientific missions to study the satellites, such as the Jupiter's moon Europa. However, previous research ([1]; [2]; [3]) has shown that a spacecraft in a low-altitude, near-polar orbit around Europa will have an impact in a relatively short time. In this work we consider the effects caused by the non-sphericity (J_2, J_3, and C_{22}) of Europa and the perturbation of the third-body in elliptical orbit (Jupiter is considered) on the orbital motion of a artificial satellite. We present an analytical theory with numerical simulations using a double-averaged analytical model. A special study is made for the case of frozen orbits ([3]; [4]; [5]), that are orbits that try to keep the argument of the periapsis and the eccentricity of the orbit constants, to make the satellite to pass by a given latitude with the same altitude, benefiting the users when they study the data obtained. We fix a parameter to get frozen orbits when new terms are added to the disturbing potential.

As previous researches register that low-altitude, near-polar orbit around of Europa are unstable with short lifetimes, we done a study with respect the terms of short-period taking into account the problem without average in the motion equations, for we observe the effects caused in the orbit of the satellite artificial around Europa.

A comparison between the averaged models, simple and double, is presented as it was suggested in the work of [2]. We observed that the results using the simple-averaged problem resulted in stable frozen orbits with long lifetimes while, taking into account the double-averaged method we found unstable frozen orbits in general with short lifetimes.

2. THE HAMILTONIAN SYSTEM

The Hamiltonian of the dynamical system associated to the problem of the orbital motion of the satellite around Europa taking into account the gravitational attraction of a third-body (P_2) and the non-uniform distribution of mass (J_2, J_3, and C_{22}) of the planetary satellite can be written in the form:

$$K = H_0 + H_{20} + H_{30} + H_{22} + P_2 \tag{1}$$

where

$$H_0 = \frac{\mu^2}{2L^2} + n_E H. \tag{2}$$

The term $n_E H$ is added to reduce the degree of freedom, since the mean longitude of Jupiter is time-dependent ([6]). Here, the term $n_E H$ is taken as order zero as suggested by [7].

Now, doing $H_{20} = \epsilon H_1$, $H_{30} = \epsilon_1 H_2$, $H_{22} = \delta H_3$, $P_2 = \gamma H_4$ we get,

$$K = H_0 + \epsilon H_1 + \epsilon_1 H_2 + \delta H_3 + \gamma H_4 \tag{3}$$

We arrange the Hamiltonian K as:

$$K = H_0^0 + H_1^1 \tag{4}$$

where

$$H_0^0 = \frac{\mu^2}{2L^2} + n_E H \tag{5}$$

$$H_1^1 = \epsilon H_1 + \epsilon_1 H_2 + \delta H_3 + \gamma H_4 \tag{6}$$

The short-period terms are eliminated using the double-averaged method ([8]; [9]) in Eq. (6). The long-period terms are calculated and replaced in the Lagrange planetary equations. The equations of motion are integrated (developing analytical equations) using the software Maple and finally the results are analyzed. With a simplified model for the disturbing potential it is possible to perform an analyses of the orbital motion of the satellite. The part (P_2) of the disturbing function is written up to the same order of the Hamiltonian (H_{20}, H_{30}, H_{22}).

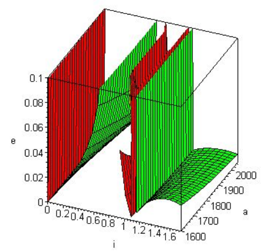

Figure 1 – Initial conditions: Green color $g = 270°$ and $h = 90°$, red color $g = 90°$ and $h = 270°$. Perturbations: $J_2, J_3 > 0, C_{22}$ and P_2

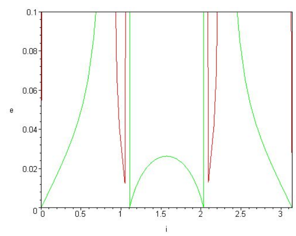

Figure 2 – Initial conditions: $a = 1660.8$ km, green color $g = 270°$ and $h = 90°$, red color $g = 90°$ and $h = 270°$. Perturbations: J_2, J_3, C_{22} and P_2

3. CONCLUSIONS

In this paper, the dynamics of orbits around a planetary satellite, taking into account the gravitational attraction of a third-body (Jupiter) in elliptic orbit and the non-uniform distribution of mass of the planetary satellite (Europa) was studied. Diverse analyses were done, using the long period disturbing potential, obtained through of the averaged models: simple and double, using the unaveraged system and replaced in the Lagrange planetary equations.

We showed that the perturbation of the third-body combined with the J_2, J_3, C_{22} terms of the nonsphericity of the central body it contributes for we found a family of frozen orbits with smaller values of the eccentricity as show in Figure 1 and 2. The unaveraged problem is important, since the orbits in general are of short duration, because it considers the terms of short period and through this potential it is possible to identify a set of initial conditions that are strong candidates for we found low-altitude, near-circular, near-polar frozen orbits. With these initial conditions it is possible to do analyses in the simple and double averaged problem.

Considering the long period disturbing potential using the double-averaged method we found frozen orbits in general with short lifetime (50 days), however, through the analyses and simulations we found orbits with long lifetime around 190 days, but still unstable, where the eccentricity grows exponentially. Considering the simple-averaged method, where the elements of the disturbing body are constant, therefore the orbit of the planet around the planetary satellite is a fixed elliptic orbit, where we found orbits with long lifetime and in this case, stable, being necessary to do small corrections for the artificial satellite to remain in orbit for a lifetime indefinitely. The simple-averaged method showed to be a good resource to identify possible frozen orbits, when compared to the double-averaged problem, because we found orbits with long lifetime. The elements proceeding from the orbit of the third-body had helped to control the orbit of the satellite, becoming stable.

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