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Evaluation of the contribution of solar radiation pressure on the orbital perturbation acting on a satellite in orbit of the asteroid Geographos

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Abstract. *This work consists of evaluating the contribution of solar radiation pressure on the total perturbation acting on a satellite orbiting the asteroid Geographos. The gavitational potential around the asteroid was modelling by the mass concentration method, in order to consider the irregular mass distribution of the asteroid. The results obtained through simulation, using the simulation environment Spacecraft Trajectory Simulator (STRS), shown that at an altitude of approximately 200 km the contribution of the perturbation due to the radiation pressure reaches the same order of magnitude as the perturbation due to the gravitational potential.*

Keywords: Solar Radiation Pressure; Asteroid.

1. Introduction

Since it was first observed by Titus and Bode in 1772, asteroids have been set as one of the main targets in space research. To study asteroids characteristcs such as their dynamics and structure are so importante because their orbits may be suficiently near by the Earth, for example, and mainly to understand the beginning of the solar system. In 2006 the Hayabusa Mission, provided by the japanese space agency, JAXA, have become the first mission to complete a succesful landing on an asteroid surface, the Itokawa, and collect samples of It for later analysis on laboratories. Hayabusa mission was considered remarkable for asteroidsexploration by landing on na irregular body surface since then many others missions have been done with the same subject. To landing or for any other reason to explore asteroids, it is needed to determine how the satellite’s orbit around the asteroid will work, including the guidance, controlling and perturbation parameters. The perturbation disturbing a satellite’s orbit may be provided by any kind of sources, such as the gravitational potential of any body suficiently near by the satellite and by the asteroid itself or by non gravitational sources, like solar radiation pressure. Idependently of the origin of the perturbation, all of them generates an extra force on the orbit, then an extra acceleration, so it’s importante to calculate such perturbation. In this work an evaluation about the impact of the gravitational potential and the solar radiation pressure over the satellite's orbit have been made, considering the mass concentration method (ROCCO, 2019) to determine the iregular gravitational potential of the asteroid. The evaluation consists of determining, as a percentage, the contribution of solar radiation pressure in relation to the total disturbance. An orbital simulation environment, the Spacecraft Trajectory Simulator (STRS), developted by (ROCCO, 2008; ROCCO, 2013) was used to simulate the orbit around the asteroid and determine the contribution of each disturbance applied to the satellite. The use of STRS allowed to compare the results for orbits with different inclinations, in this work the results for equatorial orbit and with inclination of 45° will be shown.

2. Metodology

The mass concentration method is similar to the finite element method, in which the principle of discretizing a solid into small elements is assumed (ROCCO, 2019). The method is developed by dividing the surface of any solid into small triangles, with vertices Vi, and from these triangles form the elements that will discretize the solid. As the coordinates of each vertex are known and, considering a solid of homogeneous density, the center of mass of the solid can be obtained. Thus, it became convenient to discretize the solid into small tetrahedrons, all of which would have a common vertex, the solid's center of mass. Then, as in the finite element method, the masses are allocated to the centroids of the elements, shown in Fig.1.

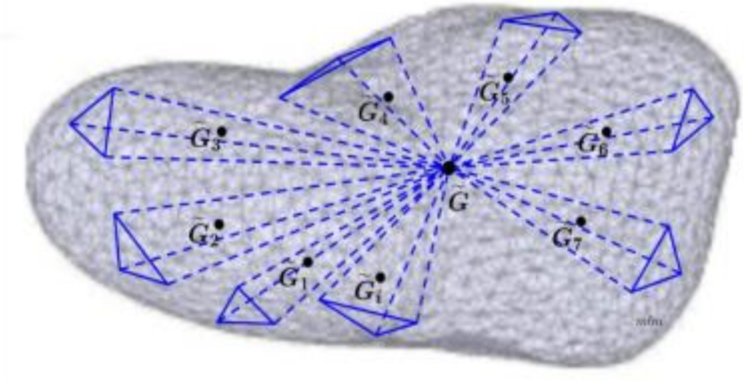

Figure 1. Solid discretized. Font: Mota, 2017.

When placing a satellite in orbit of a solid with irregular mass distribution, similar to that shown in Fig.1, is applied at the center of mass of the satellite the resulting force generated by the gravitational attractions of the mass concentrations (Gi). Note that this approach is necessary considering that the solid does not represent an example of a central field, such as a sphere. Therefore, the approach used to calculate the gravitational perturbation consists of obtaining the perturbing force acting on the satellite by comparing the vector of the central field force with the vector resulting from the forces generated by the mass concentrations allocated at the centroids of the finite elements that model the irregular solid (ROCCO, 2019).The methodology is performed by determining the mass and position of the center of mass of each tetrahedron Eqs.1-4, and applying the Eqs.5-13, according to Fig.2.

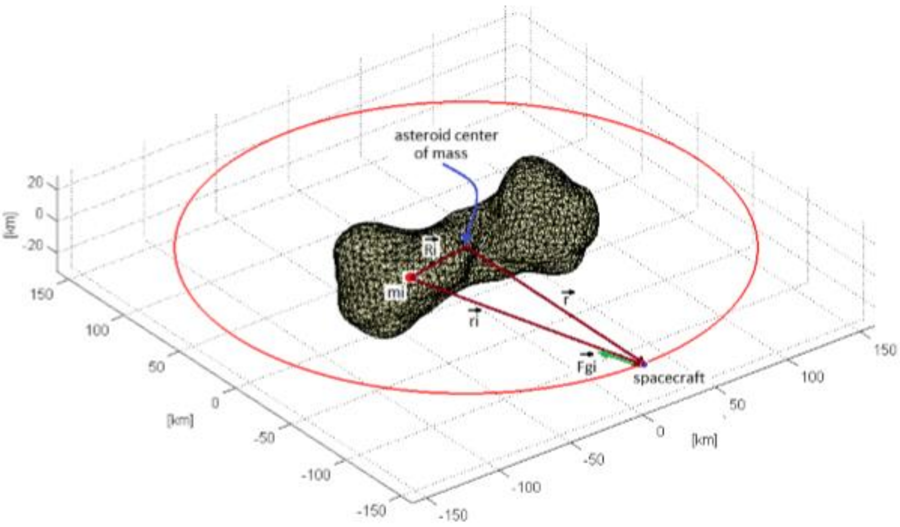

Figure 2. Method development. Font: Rocco, 2019.

$$m = \iiint \rho(x, y, z)dV \tag{1}$$

$$\bar{x} = \frac{\iiint x\rho(x, y, z)dV}{m} \tag{2}$$

$$\bar{y} = \frac{\iiint y\rho(x, y, z)dV}{m} \tag{3}$$

$$\bar{z} = \frac{\iiint z\rho(x, y, z)dV}{m} \tag{4}$$

$$\vec{R}_i = \left[Rix\hat{\imath} + Riy\hat{\jmath} + Riz\hat{k}\right], i = 1,2,3 \; to \; n \tag{5}$$

$$\vec{r} = \left[rx\hat{\imath} + ry\hat{\jmath} + rz\hat{k}\right] \tag{6}$$

$$\vec{r}_i = \left[(rx - Rix)\hat{\imath} + (ry - Riy)\hat{\jmath} + (rz - Riz)\hat{k}\right] \tag{7}$$

$$F_{gix}\hat{\imath} = -\frac{Gmim}{ri}\frac{(rx - Rix)}{ri}\hat{\imath} \tag{8}$$

$$F_{giy}\hat{\jmath} = -\frac{Gmim}{ri}\frac{(ry - Riy)}{ri}\hat{\jmath} \tag{9}$$

$$F_{giz}\hat{k} = -\frac{Gmim}{ri}\frac{(rz - Riz)}{ri}\hat{k} \tag{10}$$

$$F_{gTx}\hat{\imath} = \sum_{i=1}^{N} F_{gix}\hat{\imath} \quad (11)$$

$$F_{gTy}\hat{\jmath} = \sum_{i=1}^{N} F_{giy}\hat{\jmath} \quad (12)$$

$$F_{gTz}\hat{k} = \sum_{i=1}^{N} F_{giz}\hat{k} \quad (13)$$

$$\vec{F}_p = [\vec{F}_g - \vec{F}_{es}] \quad (14)$$

Unlike potential, the solar radiation pressure is not gravitational in origin. It occurs when photons emitted by the Sun reach the surface of the satellite, causing, mainly, the semi-major axis and the eccentricity of the orbit to change (VILHENA, 1978). As illustrated in Fig.3 (ROCCO 2008), when hitting the satellite, the light or photons can suffer from three effects: absorption; specular reflection; diffuse reflection

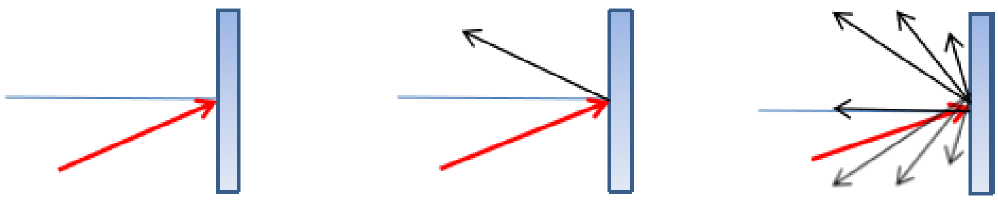

Figure 3. Absorption and reflection. Font: Rocco, 2008.

For each situation there is a disturbing force, which takes into account the radiant energy per unit area I, the radiation incidence angle θ and the respective absorption and reflection coefficients. So the forces are determined by (HARRIS and LYLE, 1969):

$$d\vec{F}_a = \frac{I}{c}[c_a(-\cos\theta\hat{n} + \sin\theta\hat{s})]\cos\theta dA \quad (15)$$

$$d\vec{F}_{re} = \frac{I}{c}[-(1 + c_{re})\cos\theta\hat{n} + (1 - c_{re})\sin\theta\hat{s})]\cos\theta dA \quad (16)$$

$$d\vec{F}_{rd} = \frac{I}{c}\left[-(\cos\theta + \frac{2}{3}c_{rd})\hat{n} + \sin\theta\hat{s})\right]\cos\theta dA \quad (17)$$

The STRS simulation environment was developed by (ROCCO, 2008) and will be briefly presented below.

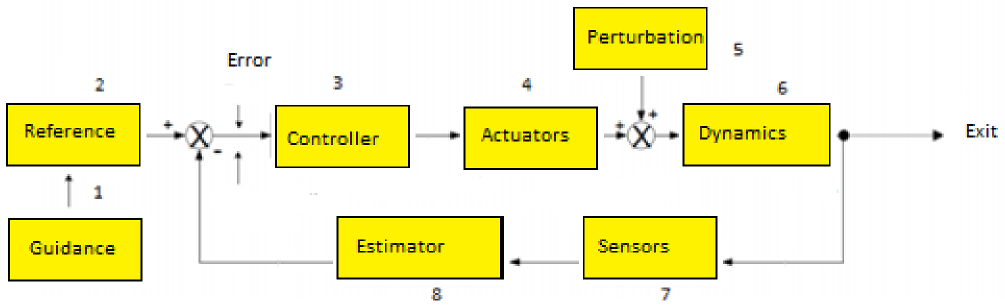

Figure 4. Control system.

The previous figure shows the simplified block diagram of STRS. The simulator operates in closed loop and uses the satellite state propagation (position and velocity) in order to obtain the rates of variation of the orbital elements, in each step of the simulation, considering disturbing accelerations, both environmental and those applied by the vehicle thrusters. These accelerations are obtained through the perturbation models inserted in the STRS. The modeling of each disturbance provides the disturbing force that acts on the vehicle at each step of the simulation, so that it is possible to determine the velocity increments that are inserted in the movement dynamics so that the evolution of the orbital elements over time is obtained as a function of the disturbing forces and the applied thrust (ROCCO, 2019).

3. Results and Discussion

The study was developed in relation to the asteroid Geographos, which is considered to have an orbit close to Earth, with a perigee around 0.83 AU. It has a diameter of approximately 2.56 km and mass 2.6e13 Kg. It was decided to evaluate the percentage of participation of solar radiation pressure in the disturbance acting on the satellite in relation to different distances between asteroid and satellite, with the objective of reaching the distance at which the radiation pressure equals the generated disturbance by the gravitational potential.

The satellite was considered as a sphere with mass 1000 Kg, so the angle of incidence of the radiation will always be 0° and the area of incidence constant. Except for the semi-major axis, the other five Keplerian elements remained equal, with $e = 0$, $M = 0$, $\omega = 0$, $\Omega = 0$ and $I = 45°$.

Because the interest of the first analysis is to obtain the percentage of radiation disturbance, the disturbance and control subsystems were turned off, that is, both subsystems calculated the disturbance and the control, which is represented by the actuation of the thrusters, but they were not applied to the orbit. Once all concepts were defined, the first simulation considered the distance between the asteroid-satellite system and the Sun with respect to the date of june 6th of 2013, step of 60 s and distance of a = 10 Km, with the result presented in.

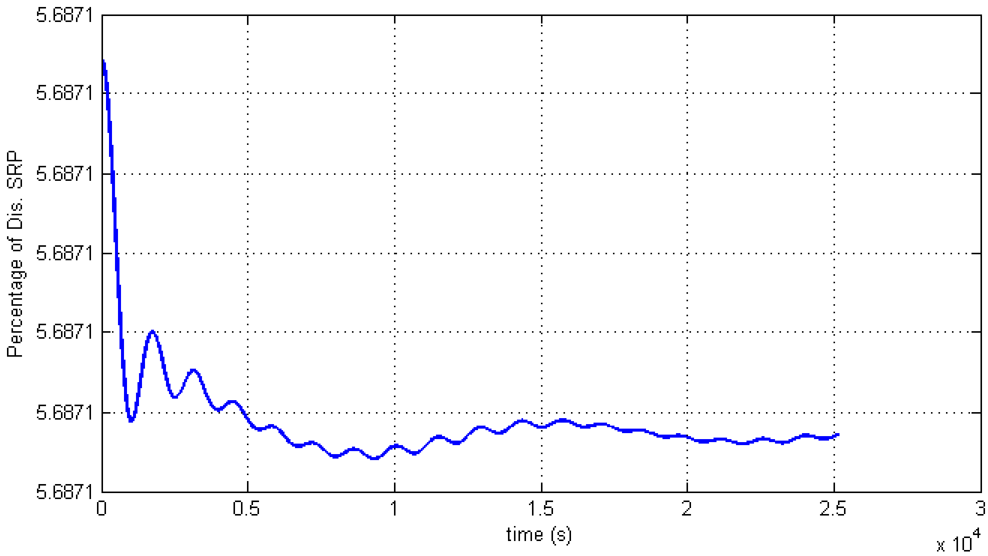

Figure 5. Result obtained.

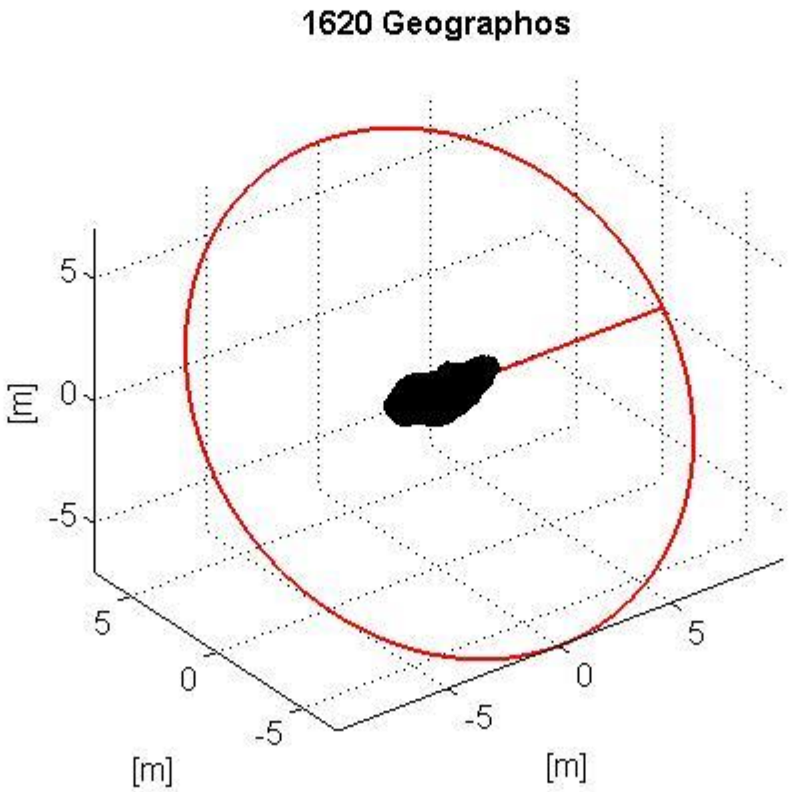

Figure 6. Orbit obtained.

As expected, due to the proximity of the distance between asteroid and satellite, the influence was below 6%. Thus, other simulations were performed with values of a equal to (20, 60, 70, 80, 109, 138, 149 and 200) Km, with the results being in.

Table 1. Results.

Distance (Km)	Percentage
20	16.9
60	41.1
70	43.1
80	44.5
109	46.9
138	48.0
149	48.3
200	49.0

Only in the distance of 200 Km that the objective was reached, being coherent because it is an asteroid with a small dimension, with low potential. The second objective of the analysis was to compare the results of equatorial and transverse orbits with those of 45°, as well.

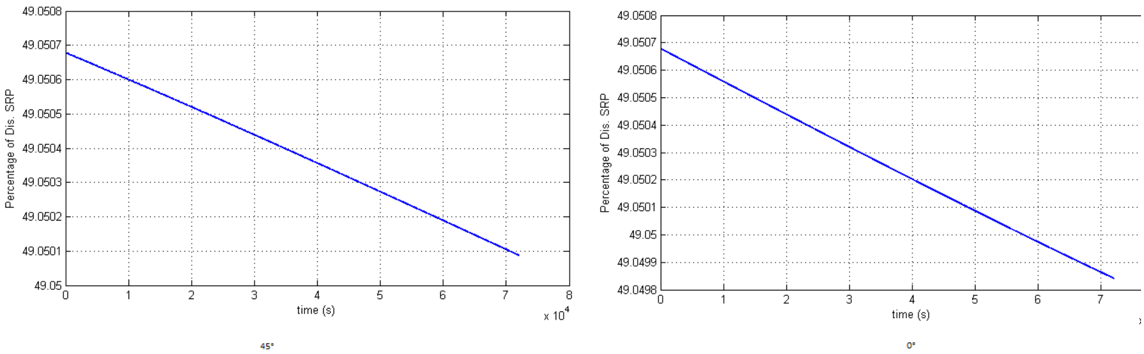

Figure 7. Comparisson between 45° left and 0° right.

The result ramained almolst the same.

4. Conclusion

As expected, the results obtained during a very small distance from the asteroid and the satellite, like 10 and 20 Km shown a low disturbance caused by the solar radiation pressure in comparisson with the potential provided by the asteroid, due to the size of both asteroid and satellite. In the other hand, as the distance grows, so the disturbance does, because the asteroid almolst turns itself into a point of mass.

Such analysis is important to be done, since depending on the distance from the asteroid, the disturbance due to the solar radiation pressure presents a magnitude in the same order of the magnitude of the gravitational potential perturbation. Therefore, it may not be possible to disregard the effects of the disturbance caused by the radiation pressure in the mission analysis of a space vehicle that aims to approach an asteroid whose orbit is similar to the orbit of the asteroid Geographos.

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