Effects of Atmospheric Drag and Zonal Harmonic on Cosmos1484 Satellite Orbit

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Abstract

The effects of atmosphere drag and zonal harmonics J2 of the gravitational potential of the Cosmos1484 satellite which is near earth orbit has been investigated .Computer simulation at the equation of motion with perturbations using step-by-step integration (Cowell's method) is designed by matlab a 7.10. position , velocity and range of the satellite .

تأثيرات كبح الغلاف الغازي والتوافقيات الكروية على مدار القمر الاصطناعي Cosmos1484

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الخلاصة :

درست التأثيرات التوافقية الكروية الموقعية لجهد الجاذبية الأرضية J2 وقوة كبح الغلاف الغازي على مدار القمر الاصطناعي Cosmos1484 ذو المدار القريب من الارض. تم محاكاة معادلات الحركة مع الاضطرابات المدارية بالحاسوب باستخدام Matlab a 7.10وتكاملها خطوة - خطوة (Cowell's method) ، ومن ثم حساب موقع وسرعة ومدى القمر الاصطناعي.

1. Introduction

There are several sources of perturbations affecting satellite orbital motion from injection point until the end of it's lifetime . In general orbit perturbations can be divided into gravitational and non-gravitational . The gravitational perturbation is due to oblateness of the Earth , the zonal , tesseral, and sectorial spherical harmonics and effect of sun/moon attraction .The non-gravitational perturbations are include atmospheric drag force (the dominant for low earth orbits) , solar radiation pressure(effective for geosynchronous satellites), magnetic forces (due to the interaction of the earth magnetic field with the dipole moment which induced in the satellite) ,etc. The gravitational potential of the nonspherical earth models was initiated by [1],short period and long period perturbations. Details of the gravitational potential theory and atmospheric drag force effect can be found in [2]. Numerical simulation of the equation at orbital motion was performed by [3].The effects of atmosphere drag and zonal harmonics J2 at the gravitational potential of the earth at low earth orbit satellite has been investigated by [4]

In this paper , numerical simulation of the equation of motion at two body problem under the combined effects of atmospheric drag force and J2 spherical harmonics of the oblateness of the gravitational potential has been performed by using Matlab a 7.4 . The atmospheric density is calculated as exponential function of the satellite's altitude from the earth surface and scale height as a function of solar activity indices F10.7 and Ap. The lifetime of low earth orbit satellite is evaluated by calculation of orbit decay.

In section 2 , the orbital dynamic model of the satellite is presented under the perturbation forces. The atmospheric drag force and atmospheric density in section 3 . The J2 spherical harmonic of the oblate Earth is shown in section 4. The simulation results , discussion and conclusion in section 7.

2. Orbital dynamic model

Motion of a body or object in space is an integral part of the preliminary orbit determination process .The Stark problem represents the motion of a test particle ,around a fixed Newtonian force center (i.e., the Kepler problem) subject in addition to a uniform force of constant magnitude and direction[1].The equations of motion of two-body problem can be written in the form[5 ,6]

$$\frac{d^2\vec{r}}{dt^2} = -\frac{u}{r^3}\vec{r} \quad \text{............................(1)}$$

Where $\vec{r}$ is the position vector of the satellite from earth , and μ is the earth gravitational constant (38601.2 km^3/sec^2),

Eq.(1) can be written in cartezian coordinates as follows

$$\ddot{x} = -\frac{u}{r^3}x$$
$$\ddot{y} = -\frac{u}{r^3}y \quad \text{............................(2)}$$
$$\ddot{z} = -\frac{u}{r^3}z$$

3. Atmospheric drag force :

Drag is the resistance offered by atmosphere to the satellite . Drag force acts in a direction opposite to the direction of its motion This drag is greatest during launch and reentry, however, even a satellite in low Earth orbit experiences some drag as it moves through the Earth's thin upper atmosphere. With time, the action of drag on satellite will lead to spiral back into the atmosphere, eventually to disintegrate or burn up. If the space vehicle comes within 120 to 160 km of the Earth's surface, atmospheric drag will bring it down in a few days, with final disintegration occurring at an altitude of about 80 km.The drag force F_D is given by[7,8]

$$F_D = -\frac{1}{2} C_D \rho V^2 S_{Ref} \text{.............}(3)$$

where C_D is the drag coefficient, ρ is the air density, V is the flow velocity of atmospheric particles , and S_{Ref} is the cross sectional area of the body normal to the flow. The drag coefficient depends on the geometric form of the body and is generally determined by experiment ,and the reduction in the period due to atmospheric drag is given by[8]

$$\frac{dP}{dt} = -3\pi a \rho \left(\frac{C_D S_{Ref}}{m}\right) \text{...........}(4)$$

Where a is the semi major axis the satellite and m is the mass of satellite .

4. Atmospheric density model

Some times, the upper atmospheric models , thermosphere and exosphere, called thermospheric drag models .These depends on solar and geomagnetic activities are : J77 ,MSIS [7,9] , DTM78 and DTM94 models [10].In this paper the density of the upper atmosphere is expressed as exponential function of altitude given by[8]

$$\rho = \rho o \exp\left[-\frac{(H-175)}{SH}\right] \text{...........................}(5)$$

Where ρo is the atmospheric density at the initial perigee point , H is the height and SH is the scale height give by and [8]

SH=(900+2.5*(F10.7-70))/(27-0.01*Ap+1.5*(H-200))……….(6)

Where F10.7 is the solar flux index, Ap is the index of solar activity

5.The gravitational perturbation model

The oblateness of the gravitational potential at the earth consists of three part , the zonal harmonics (J2-J6) , tesseral and sectorial .

The zonal spherical harmonics model of the gravitational potential adopted in this paper is given by [11,12 and 13]

$$U = \frac{u}{r}\left[1 - \sum_{n=2}^{\infty}\left(\frac{a_e}{r}\right)^n J_2 P_n \sin\varphi\right] \text{.................}(7)$$

Where zonal harmonic coefficient is given by [6,12] $J_2 = (1.083 \pm 0.3) \times 10^{-6}$

This method is a straightforward step-by-step integration equation of the two body equation of motion with perturbation .The equation of motion may be given[2]

$$\ddot{\vec{r}} + \frac{u}{r^3}\vec{r} = \vec{a}_p \text{.........................}(8)$$

Which is for numerical integration, would be reduced to first-order differential equations

$$\dot{\vec{r}} = \vec{v}$$

$$\dot{\vec{v}} = -\frac{u}{r^3}\vec{r} + \vec{a}_p \quad \text{........................(9)}$$

Where $\vec{a}_p$ is the vector sum of all the perturbing accelerations to be included in the integration. The equations of motion are first reduced into first-order differential equations as shown in the following matrix[14]

$$\frac{dy}{dt} = \begin{bmatrix} y(2) \\ -\frac{u}{r}y(1) + Fdrag + \frac{u}{r}\left(\frac{a_e}{r^2}\right)^2 J2.(3/2 - y(6)/r\hat{}3) \\ y(4) \\ -\frac{u}{r}y(3) + Fdrag + \frac{u}{r}\left(\frac{a_e}{r^2}\right)^2 J2\left(5/2 - y(6)^2/r^3\right) \\ y(6) \\ -\frac{u}{r}y(5) \end{bmatrix} \quad \text{.........(10)}$$

6. The ground station coordinates

The coordinates of ground tracking station proposed in the holly city of Kufa of geographic coordinates (32 27 N ,44.3 E) on oblate geod are given by [5]

$$\begin{aligned} X_{gs} &= -G1\cos\varphi\cos\theta \\ Y_{gs} &= -G1\cos\varphi\sin\theta \quad \text{.............(11)} \\ Z_{gs} &= -G2\sin\varphi \end{aligned}$$

G1,G2 are geodetic of observation station ,where

$$\begin{aligned} G1 &= a_e / \sqrt{1-(2fl - fl^2)\sin^2\varphi} + h \\ G2 &= a_e(1-fl)^2 / \sqrt{1-\left(2fl - fl^2\right)\sin^2\varphi} \text{.............(12)} \end{aligned}$$

The range of the satellite with respect to the ground station is given by

$$Range = \sqrt{\left(y(1) - X_{gs}\right)^2 + \left(y(3) - Y_{gs}\right)^2 + \left(y(5) - Z_{gs}\right)^2} \quad \text{..........(13)}$$

7. Discussion of simulation results and conclusions:

A computer simulation has been developed to the equation at orbital motion of two body problem with perturbations due to atmospheric drag force and the J2 zonal spherical harmonics using Matlab a 7.10 ..

Figure (1) shows the effect of the atmosphere drag and the earthly harmonic coefficient n the position of the satellite according to time. Whereas recorded the least value for the location (6205 km) while the highest value is (6895 km) . It is up normality can be noticed when we figure (2) shows the relationship between the satellite position with time without effect of perturbations when it begins from (6817 km) up to (6874 km).

The effect of the atmosphere drag and the earthly harmonic coefficient on the velocity of the satellite relative to time is at figure (3) . It shows obviously the minimum value is (7560 km/sec) and the maximum value is (7798 km/sec).This effects is shown clearly in figure (4) which indicates the relationship between the velocity of the satellite relative to time without the effect of atmosphere drag and the earthly harmonic coefficient . The minimum value was (7611 km/sec) and the maximum value was (7654 km/sec).

The figure (5) and (6) shows the effect of atmosphere drag and harmonic coefficient of earth on the range of the satellite with respect to the proposed ground tracking station in the holly city of Kufa. The difference between the two figures value is clear . the effect of perturbations (the atmosphere drag and harmonic coefficient of earth) at the range of the satellite is shown in figure (5). The minimum value is (3664 km) and maximum value is (12690 km) .In figure (6)the minimum and maximum value are (3662 km) and (12680 km) respectively by neglecting the disturbance effects.

From figures (1) , (3) and (5) it can be concluded that , this type of satellites effected obviously by the disturbance resulting from atmospheric drag and the harmonic coefficient of earth. As the around earth number of satellites evolutions increase , the orbit position decrease while the velocity increases , which redoes the satellite life.

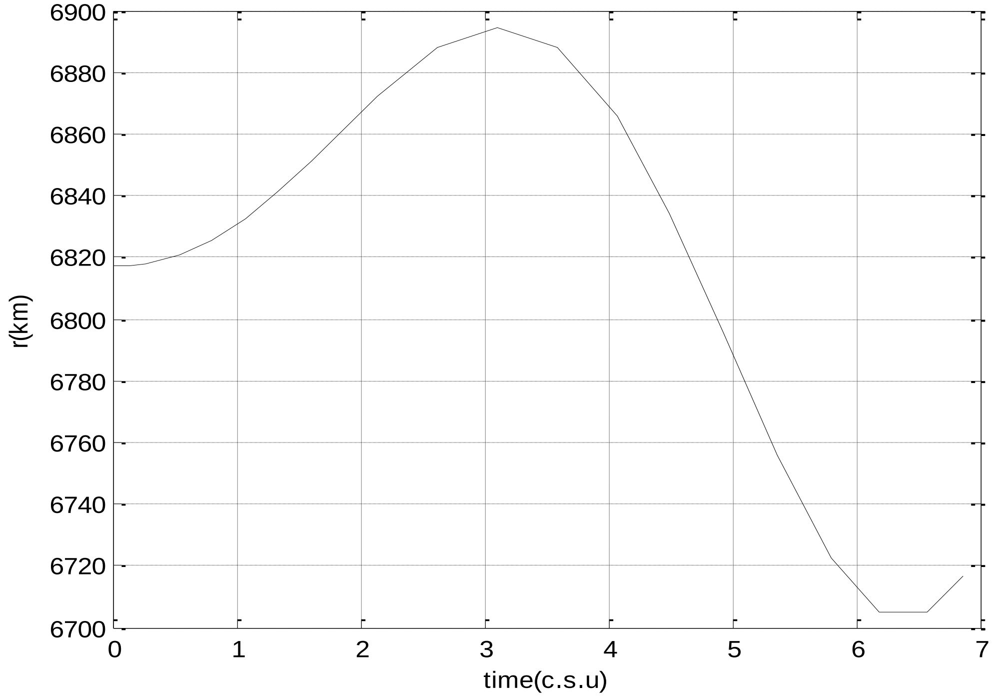

Fig.(1) The relationship between position of satellite and time under effect of atmosphere drag and zonal harmonics J2

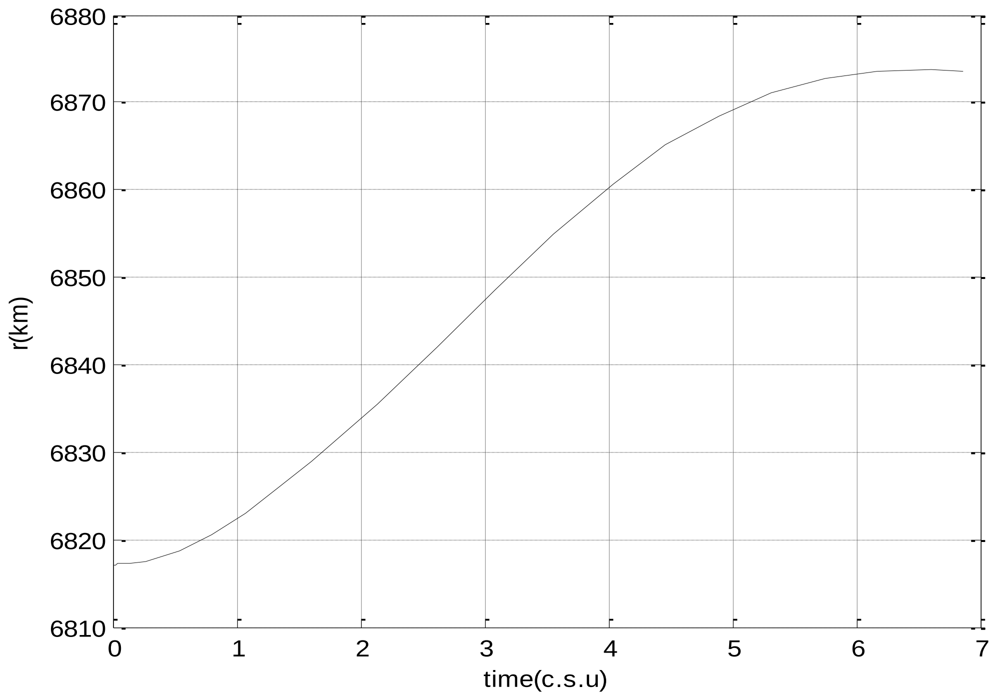

Fig.(2) The relationship between position of satellite and time without effect of atmosphere drag and zonal harmonics J2

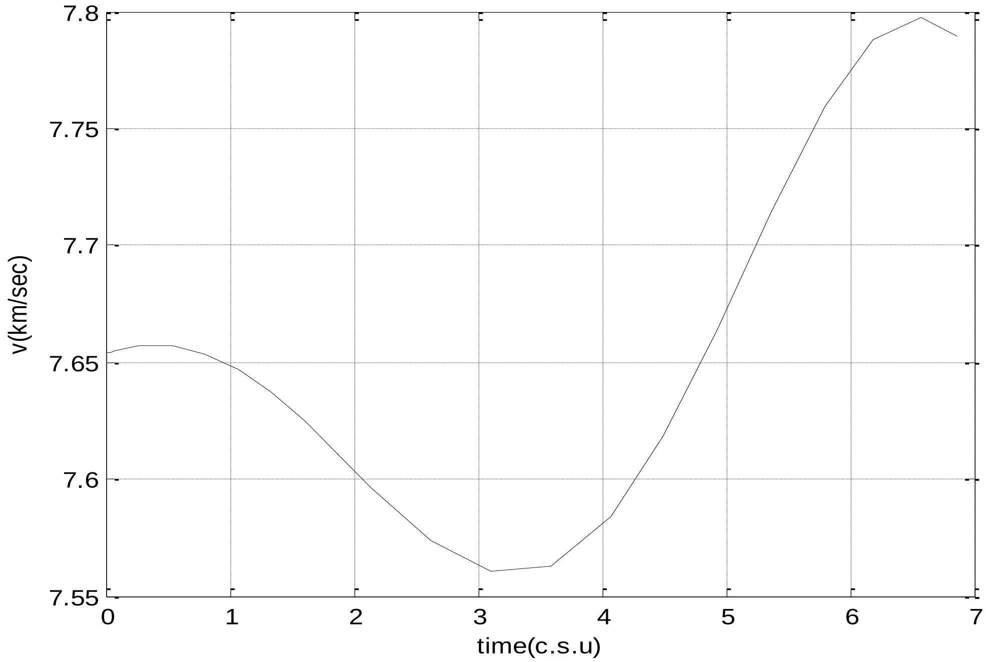

Fig.(3) The variation of velocity of satellite and time under effect of atmosphere drag and zonal harmonics J2

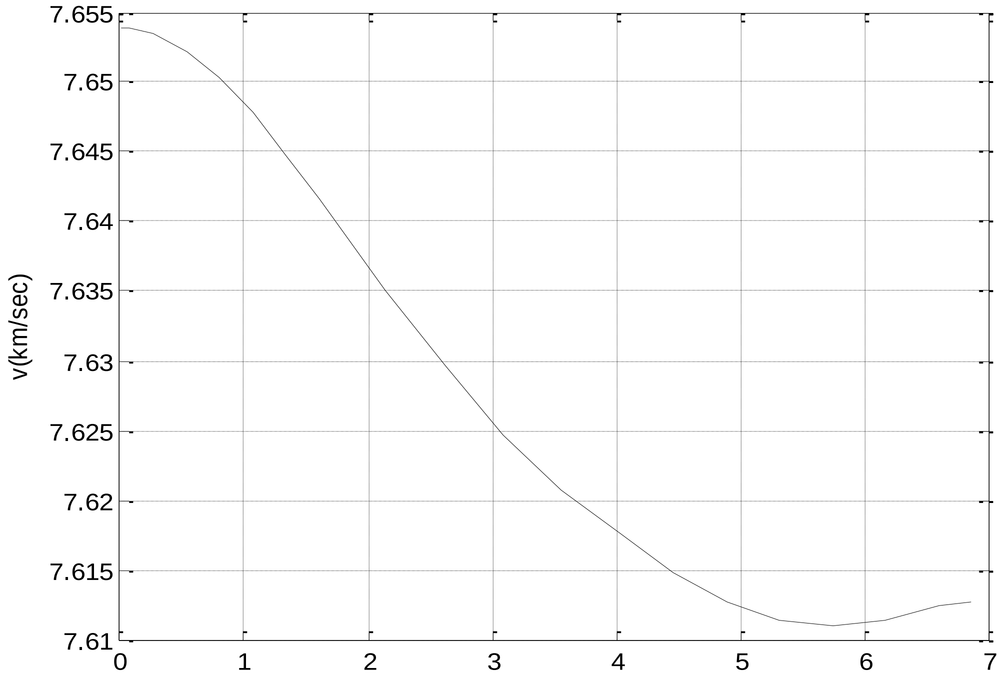

Fig.(4) The variation of velocity of satellite and time without effect of atmosphere drag and zonal harmonics J2

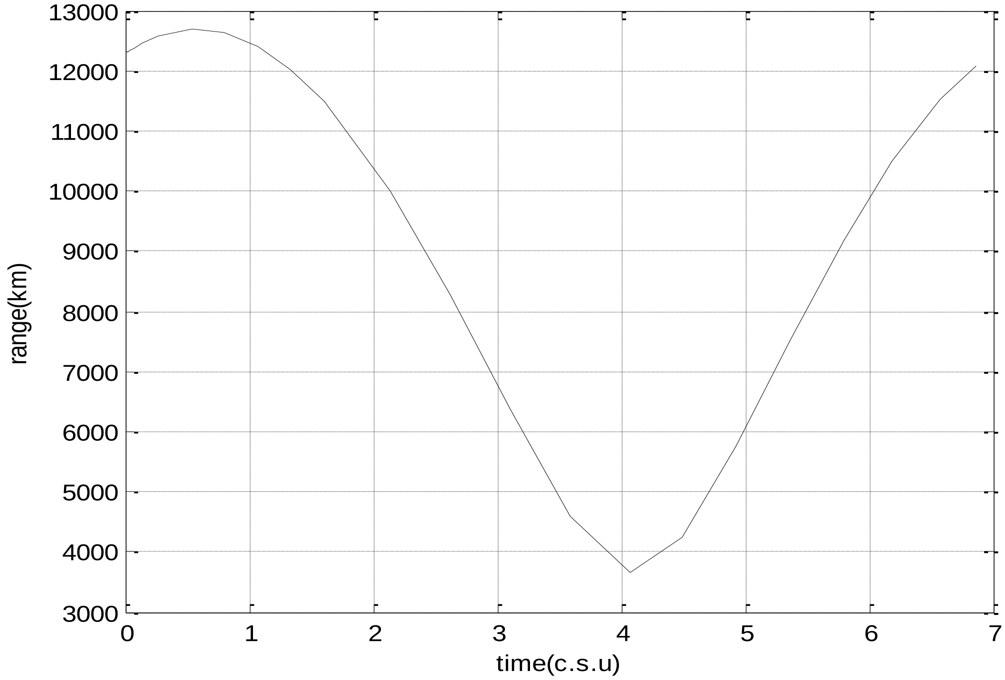

Fig.(5) The effect of atmosphere drag and zonal harmonics J2 at range of satellite with time

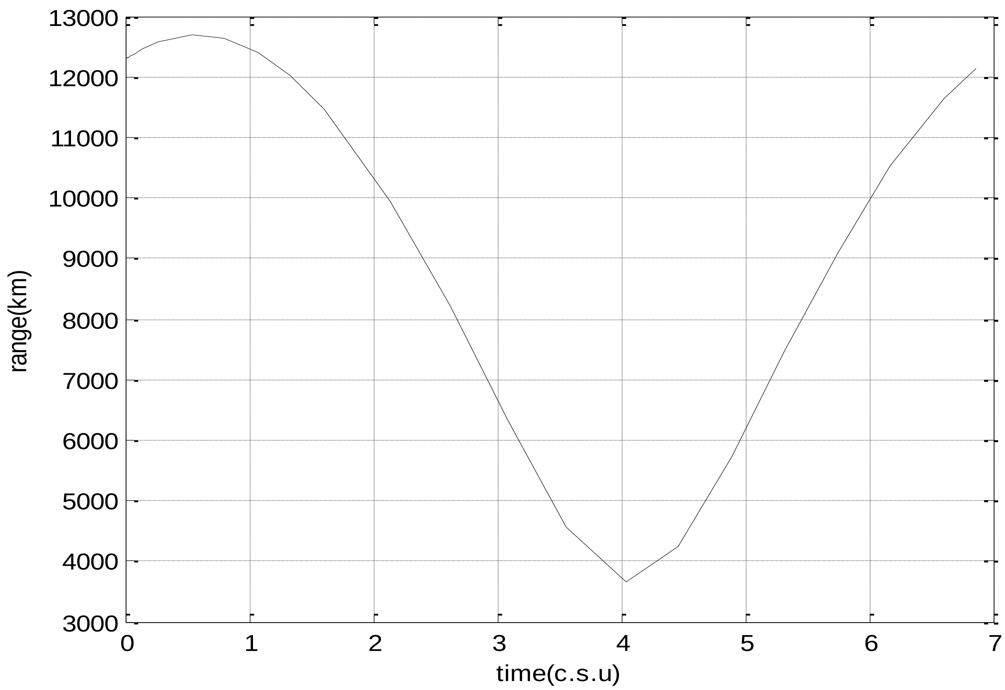

Fig.(6) The range of satellite and time without effect of atmosphere drag and zonal harmonics J2

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