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Combined Effect of Solar Radiation and Solar Tide Perturbations on the Spacecraft Rosetta About the Comet Wirtanen

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I. Introduction

After ESA's highly successful mission of the spacecraft Giotto to Halley's comet a number of international space probes were sent to explore the cometary system. This is because, comets preserve information from the time of formation of our Solar System, 4600 million years ago. Landing on a comet and analyzing its surface is seen as a major scientific milestone to improve our understanding of the origin of the Sun and the planets including Earth. Apart from that, it is a unique technological challenge!

Coping with the present day explorations of comets by spacecraft, the present paper is devoted with twofold. First, is to give summary on Rosetta spacecraft, the first mission ever to orbit and land on a comet which is Wirtanen comet. The second, which is the most important, is to establish general computational algorithm which could be used for the motion of a spacecraft orbiting about asteroid or comet, taking due account of the combined effect of solar radiation and solar tide. The algorithm was applied for the late stage of Rosetta mission about the Wirtanen comet, staring at 10 June 2011, and the variations of the coordinates and velocities are illustrated graphically in the range $f \in [0, 2\pi]$.

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II. Rosetta Mission

Rosetta is a robotic spacecraft of the European Space Agency on a mission to study the comet Wirtanen .It was launched on 2 March 2004 on an Ariane 5 rocket and will reach the comet by mid 2014. Rosetta consists of two main elements: the Rosetta space probe (See Fig.1) and the Philae lander(see Fig.2).

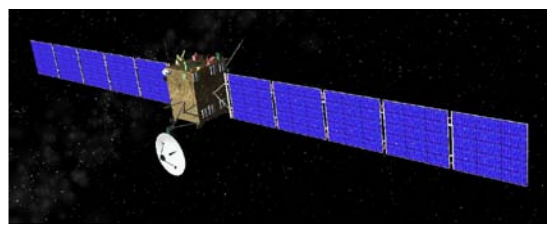

Figure 1 : The Rosetta space probe.

Figure 2 : The Philae lander.

The space probe is intended to orbit and perform long-term exploration of the comet at close quarters. On 10 November 2014 the Philae lander will attempt to land and perform detailed investigations on

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the comet's surface. When it touches down on the comet, the Rosetta lander will use three different techniques (self-adjusting landing gear, harpoons, and ice screws in the landing pads). These ensure that once it has arrived on the surface of the comet, it stays there.Both the probe and the lander carry a large complement of scientific experiments designed to complete the most detailed study of a comet ever attempted.

The probe is named after the Rosetta Stone. The Rosetta Stone was discovered in 1799 by a French soldier in Napoleon's army near the town of Rashid on the River Nile. It proved the key to finally deciphering Egyptian hieroglyphics. The lander is named after the Nile island Philae where an obelisk was found that helped decipher the Rosetta Stone. Hoping in that, the Rosetta mission to be also the key that unlocks the secrets of how life began on Earth.

Rosetta spacecraft specifications are:

Total Launch Mass: 3,000 kg

Propellant: 1,670kg

Philae Comet Lander: 100kg

Main Structure: 2.8 x 2.1 x 2.0 meters

Diameter of solar arrays: 32 meters

Instructions from the ground take up to 50 minutes to reach the spacecraft, so Rosetta must have the 'intelligence' to look after itself. It uses sophisticated on-board computers and software whose tasks include data management, attitude, and orbit control. European Space Operations Centre in Darmstadt, Germany will control the Rosetta spacecraft operations. ESA's 35 m ground station in New Norcia, near Perth, West Australia will relay spacecraft data.

The planned timeline for the mission after its launch:

1- First Earth flyby (March 4, 2005)

2- Mars flyby (February 25, 2007)

3- Second Earth flyby (November 13, 2007)

4- Flyby of asteroid 2867 Šteins (September 5, 2008)

5- Third Earth flyby (November 13, 2009) (see Fig.3)

6- Flyby of asteroid 21 Lutetia (July 10, 2010)

7- Deep-space hibernation (June 2011 - January 2014)

8- Comet approach (January–May 2014)

9- Comet mapping / Characterization (August 2014)

10- Landing on the comet (November 2014)

11- Escorting the comet around the Sun (November 2014 - December 2015)

12- End of mission (December 2015)

Figure 3 : First view of Earth as Rosetta approaches home 13 November 2009.

The illuminated crescent is centered roughly around the South Pole (South at the bottom of the image). The outline of Antarctica is visible under the clouds that form the striking south-polar vortex. Pack ice in front of the coastline with its strong spectacular reflection is the cause for the very bright spots on the image.

III. Computational Developments

In studying the motion of a spacecraft orbiting about comet or asteroid, the combined effect of solar radiation and solar tide should be taken into account. The situation of such problem can allow us to consider the central body as a sphere, and neglect gravitational perturbations. Upon these assumptions the following analysis is devoted.

a) The Equations of motion

The equations of motion of the spacecraft in the non –uniformly rotating pulsating system, when we take the true anomaly f, as the new independent variable rather than the time t are given as (Scheeres 2012)

$$x'' - 2y' = \frac{1}{1 + e\cos f}\left[\frac{-x}{r^3} + \beta + 3x\right], \qquad (1.1)$$

$$y'' + 2x' = \frac{1}{1 + e\cos f}\left[\frac{-y}{r^3}\right], \qquad (1.2)$$

$$z'' + z = \frac{1}{1 + e\cos f}\left[\frac{-z}{r^3}\right], \qquad (1.3)$$

Where the prime indicate differentiation with respect to the true anomaly f, e the eccentricity of spacecraft, and β is constant and describes the relative acceleration of the solar radiation pressure on the spacecraft. These equations have a close affinity with the elliptic restricted three –body problem (Sharaf and Abouelmagd 2012).It is significant to note that Equations (1) only contains two parameters, the eccentricity of the orbit e and the normalized effect of the solar radiation pressure β and that the equations are periodic in the true anomaly f.

For numerical applications, Equations (1) are better written as a first order system as follows

$$x' = u, \quad (2.1)$$

$$y' = v, \quad (2.2)$$

$$z' = w, \quad (2.3)$$

$$u' = 2v + \frac{1}{1+e\cos f}\left[\frac{-x}{r^3} + \beta + 3x\right], \quad (2.4)$$

$$v' = -2u + \frac{1}{1+e\cos f}\left[\frac{-y}{r^3}\right], \quad (2.5)$$

$$w' = -z + \frac{1}{1+e\cos f}\left[\frac{-z}{r^3}\right]. \quad (2.6)$$

b) Orbit determination of spacecraft Rosetta about the comet Wirtanen

i. *The Constants*

The constants $\beta, e,$ the gravitational parameter μ and the orbital parameter p are (Scheeres 2012)

$$\beta = 28.5 \;\; ; \; e = 0.658 \;\; ; \; \mu = 3\times10^{-7}\,\mathrm{km}^3/\mathrm{s}^2 \;\; ; \; p = 1.752\ \mathrm{AU}$$

ii. *The orbital elements of Wirtanen comet*

The orbital elements of Wirtanen comet have been determined by Muraok (cited in Noton 1998) from 83 observations between 1985 and 1997 as follows

$a = 3.0991080$ AU

$e = 0.6567522$

Time at perihelion $= 2450521.7$ Juliandays

$\omega = 356.342^\circ$

$\Omega = 82.205^\circ$

$inc = 11.722^\circ$

period $= 5.456$ years

iii. *The initial position and velocity*

The initial position and velocity of the spacecraft Rosetta relative to Wirtanen comet at zero time: $t_0 =$ 00.0hrs, 10 June 2011 are (Noton 1998)

position :	-0.100	0.200	0.020	million km
velocity :	0.210	-0.560	-0.050	km/s

iv. *The starting value of the true anomaly*

The starting value of the true anomaly f_0 for the numerical solution of the differential equations of motion could be obtained as follows

The zero time $t_0 = 2455722.5$ Julian days .

The semi-major axis

$$a = p/(1-e^2) = 462220155.6\ \mathrm{km}$$

The mean motion

$$n = \sqrt{\mu/a^3} = 4.762127849\times10^{-12}\ \mathrm{rad/day}.$$

The mean anomaly $M = nt_0 = 0.00001169$ rad.

The eccentric anomaly E from Kepler equation

$$M = E - e\sin E \Rightarrow E = 0.0000341813\ \mathrm{rad}.$$

The true anomaly

$$f_0 = 2\tan^{-1}\left(\sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}\right) = 0.00431211^\circ.$$

Consequently, we shall consider $f_0 = 0^\circ$

v. *The variations of the position and velocity in the range* $\mathbf{f} \in [0, 2\pi]$

Solving the differential equations of motion using the above conditions we get for the variations of the position and velocity of the spacecraft Rosetta in the range $f \in [0, 2\pi]$ the following results which are displayed graphically as follows

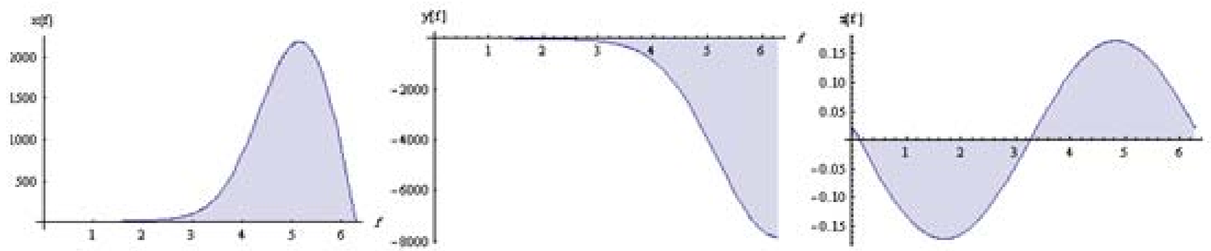

Figure 4 : The variations of position of the spacecraft Rosetta in the range $f \in [0, 2\pi]$.

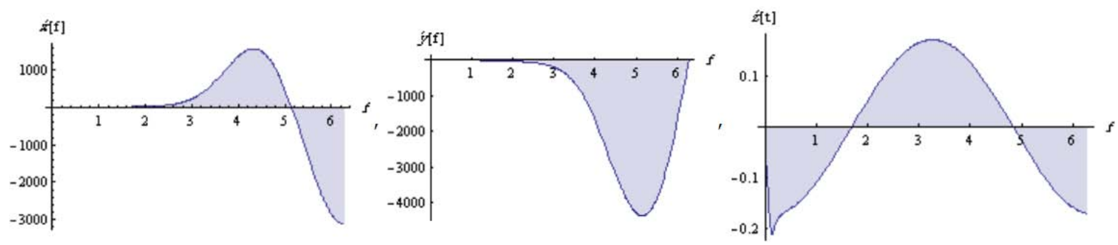

Figure 5 : The variations of velocity of the spacecraft Rosetta in the range $f \in [0, 2\pi]$.

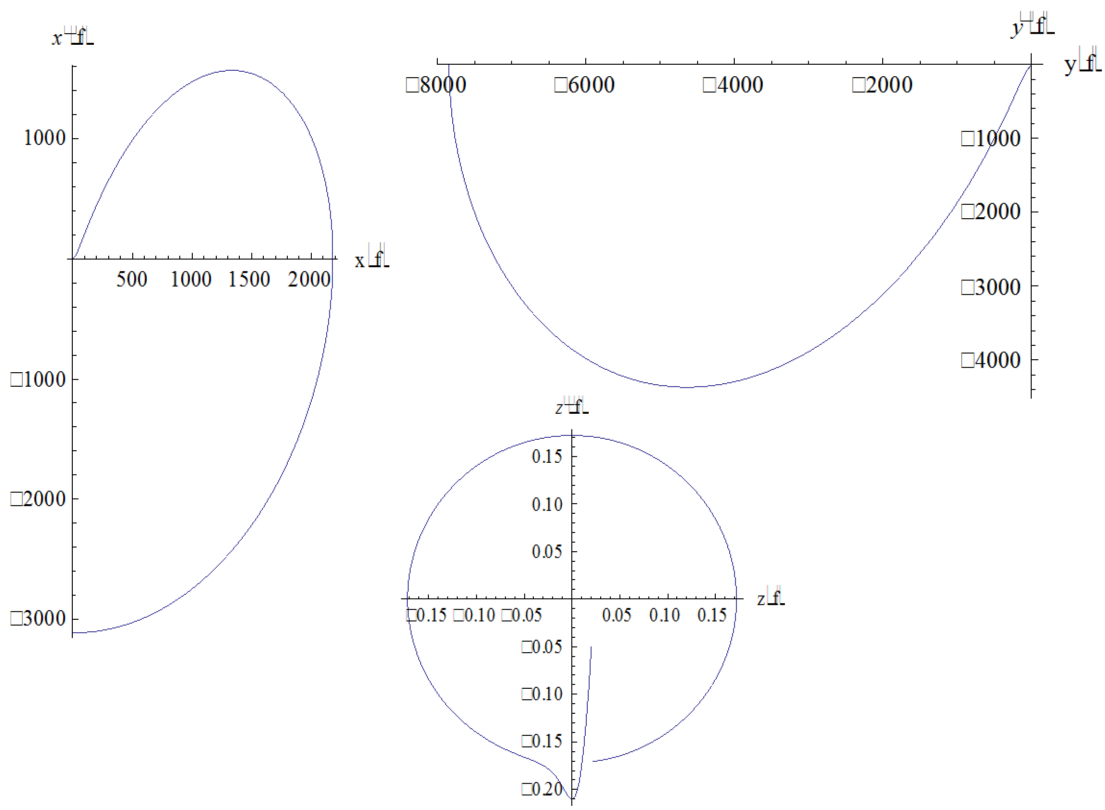

Figure 6 : Parametric plots between position and velocity.

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IV. Conclusion

In the present paper ,a general computational algorithm was establish for the motion of a spacecraft orbiting about asteroid or comet, taking due account of the combined effect of solar radiation and solar tide. The algorithm was applied for the late stage of Rosetta mission, staring at 10 June 2011, and the variations of the coordinates and velocities are illustrated graphically in the range $f \in [0, 2\pi]$.

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