Orbital Trajectories in Deimos Vicinity Considering Perturbations of Gravitational Origin

L D Gonçalves¹, E M Rocco¹ and R V de Moraes¹, ²

¹ National Institute of Space Research, INPE, São José dos Campos, Brazil
² Federal University of São Paulo, UNIFESP, São José dos Campos, Brazil

E-mail: lianadgon@gmail.com, evandro.rocco@inpe.br, rodolpho.vilhena@gmail.com

Abstract. The present work studies the possibility of maintaining an artificial satellite near to the Deimos surface, even when considering the intense Mars gravitational attraction. For this, a strategy is used in which the spacecraft orbits Mars, but with the same orbital period of Deimos and similar orbital elements. Using this strategy, the deviations in the keplerian elements that characterize the artificial satellite orbit, the magnitude of the main disturbing forces capable of altering the movement of the spacecraft and the variation of the distance between the spacecraft and Deimos are presented.

1. Introduction
Although smaller and more distant from Mars when compared to Phobos, Deimos was the first of the two moons of Mars discovered. Due to the proximity between Mars and Deimos, as well as the significant difference between their masses, the planet exerts a strong influence on the trajectory of an artificial satellite in the Deimos vicinity.

Thus, the present work aims to present a strategy to maintain an artificial satellite near to Deimos for a long period of time, even when the intense gravitational attraction of the Deimos is considered. For this study the Spacecraft Trajectory Simulator – STRS, [1] was used.

A study of the magnitude of the major disturbing forces capable of altering the orbital motion of an artificial satellite in the Deimos vicinity is made, as well as an analysis of the orbital elements behavior of the artificial satellite when disturbed by such forces.

For the attraction due to the Mars gravitational potential, the model presented by [2], which allows us to expand the spherical harmonics up to degree and order 80 is used. The non-uniform mass distribution of Deimos, its irregular shape, and consequently the non-central gravitational field, is modeled using the polyhedral method for the mass distribution, elaborate from data provided by NASA (National Aeronautics and Space Administration) [3].

2. Mars Gravitational Potential
The gravitational potential U of Mars is modeled in spherical harmonics from Equation (1), [4].

\[ U = \frac{GM}{r} \left\{ 1 + \sum_{l=2}^{\infty} (\frac{\alpha_l}{r}) l \sum_{m=0}^{l} \left[ \bar{C}_{lm} \cos m\lambda + \bar{S}_{lm} \sin m\lambda \right] \bar{P}_{lm}(\sin\phi) \right\} \] (1)
where $G$ is the gravitational constant, $M$ is the mass of the planet, $a_e$ is the equatorial radius, $\tilde{P}_{lm}$ are the Legendre polynomials standardized for degree $l$ and order $m$, $r$ is the radial coordinate fixed in the body, $\phi$ is the latitude and $\lambda$ is the longitude, and $\tilde{C}_{lm}$ and $\tilde{S}_{lm}$ are standardized coefficients for the expansion of spherical harmonics.

Different works using models that use the expansion of Equation (1), for high degree and order values for the expansion of the spherical harmonics for the Moon and for Mars, can be found in [5], [6], [7] and [8].

From the results obtained by the Mars Global Surveyor, the model GMM-2B was developed by [2]. This model is a representation of the spherical harmonics due to the planetary gravity based on the gravitational potential of the celestial body, given by Eq. (1). The model GMM-2B, used in this work, allows us to adopt as maximum precision of the model, the value 80 for degree and order of the spherical harmonics expansion.

3. **Deimos Gravitational Potential**

For the non-central gravitational potential generated by Deimos a polyhedral model developed by NASA (National Aeronautics and Space Administration [3]) was used, which represents the non-uniform mass distribution of the moon.

Based on the polyhedral model and on the methodology used by [9] and [10], was possible to define the mass concentrations corresponding to the mass of each polyhedron, being possible to calculate the gravitational potential generated by each concentration along the trajectory of the satellite disturbed by Deimos.

4. **Strategy to Maintain the Spacecraft in the Deimos Vicinity**

Due to the significant difference of mass between Deimos and Mars, and the fact that Deimos perform an orbit near to Mars, the planet's gravitational field exerts significant influence on the orbit of an artificial satellite around Deimos, making it impossible to maintain a satellite in a stable orbit for a long period of time. The physical and orbital parameters of Mars and Deimos are presented in Tables 1 and 2.

| Table 1. Mars Parameters |
|--------------------------|
| Mass                     | $0.64171 \times 10^{24}$ kg |
| Equatorial radius        | 3396.2 km                  |
| Hill radius              | 22.9 km                    |

| Table 2. Deimos Parameters |
|----------------------------|
| Mass                       | $1.8 \times 10^{15}$ kg   |
| Equatorial radius          | $6.2 \pm 0.18$ km          |
| Semi major axis            | 23463.2 km                |
| Eccentricity               | 0.00033                   |
| Inclination (with respect to the Mars equator) | 0.93° |
| Orbital period             | 1.263 day                 |

The influence sphere radius (Hill radius) presented in Table 1 was calculated from [11]. Due to the fact that Deimos orbits close to Mars, and considering its small mass, the value of the Hill radius to the moon is approximately 22.9 km. Thus, there is a significant influence of the Mars gravitational potential on an artificial satellite in the Deimos vicinity.

Thus, the strategy to maintain the artificial satellite close to Deimos adopted in this work, is to maintain the satellite in orbit of Mars, but with the same orbital period of Deimos and initial conditions similar to Deimos orbit around Mars. A study using this approach, for a satellite in the vicinity of Phobos, can be found in [12] and [13]. For this approach was used a reference system similar to that adopted in...
rendezvous and docking maneuvers. The coordinate axes H-bar, R-bar and V-bar shown in Figures 2 to 4 represent, respectively, the coordinates in the opposite direction of the angular momentum, in the direction of the center of the central body and in the direction of the velocity vector [14].

In Figure 1 the red orbit is the orbit of the artificial satellite around Mars and the green orbit is the orbit of Deimos. We can clearly see that the satellite orbits Mars, so it is possible to maintain it close to Deimos. This study was accomplished for a simulation time of 5 days, 30 days and 100 days.

From Figures 2 to 4 we can see that the satellite remains very close to Deimos, but over time it is moving away. This is because Deimos and the satellite are disturbed by Mars, but the satellite is also disturbed by Deimos. Due to this disturbance of Deimos, the satellite ceases to have the similar keplerian elements to the moon. Therefore, the disturbance due Mars, added to the disturbance due Deimos, causes the distance between the satellite and Deimos to increase over the time.

In Figures 5 to 7 the keplerian elements that characterize the orbit of the artificial satellite are presented, only for the case of simulation time of 100 days.

In Figures 5 to 7 the keplerian elements that characterize the orbit of the artificial satellite are presented, only for the case of simulation time of 100 days.
Figures 5 and 7 show that the deviation in the semi-major axis and the inclination were more pronounced at the beginning of the simulation, when the satellite was closer to Deimos. Due to the effect of the disturbances, as the satellite moves away from Deimos, the deviation in the eccentricity increases. It is worth noting that the deviations presented are to the satellite orbit around Mars, following the proposed approach.

Figures 8 to 15 show the perturbation velocity increment due to Deimos, Mars, the total perturbation and the distance between the spacecraft and Deimos for the simulation time of 5 and 30 days, and Figures 16 to 20 show the increment of velocity Disturbing due to Deimos, Mars, Sun, the total disturbance on the spacecraft and the distance between the satellite and Deimos for the simulation time of 100 days.
Figure 12. Disturbance due Deimos (30 days).

Figure 13. Disturbance due Mars (30 days).

Figure 14. Total disturbance (30 days).

Figure 15. Distance satellite-Deimos (30 days).

Figure 16. Disturbance due to Deimos (100 days).

Figure 17. Disturbance due to Mars (100 days).

Figure 18. Disturbance due to Sun (100 days).

Figure 19. Total disturbance (100 days).
It can be noticed difference in magnitude of the perturbation due to the gravitational potential of the studied bodies. Even with significantly higher mass, in the case of the initial conditions studied, Mars exerts less influence than Deimos. However, such a difference is not enough to maintain the spacecraft orbiting Deimos indefinitely, and the sum of the disturbances causes the orbital elements to evolve over time and the spacecraft distances itself from the moon, as seen in Figures 15 and 20. The inconstancy in the gravitational potential of Mars (Figures 9, 13 and 17) is also notable. This is because is considered high degree and order values in the expansion of the spherical harmonics of the planet.

When Figures 16 and 20 (and the respective figures for the case of 5 and 30 days) are compared, is possible to observe that there are peaks of greater perturbation due to the gravitational potential of Deimos. This is due to the fact that there are moments of closer approximation between the spacecraft and Deimos, as seen, for example, in Figures 16 and 20.

5. Conclusions
The perturbations studied have close magnitudes, which makes difficult to maintain a spacecraft orbiting Deimos. However, with the adopted approach is possible to realize trajectories near to Deimos surface, even when considered the Mars gravitational attraction. Was verified the variation in the orbital elements, mainly in the semi-major axis and eccentricity due essentially to the Deimos non-central gravitational potential and the Mars gravitational attraction. The approach of the spacecraft to Deimos, as well as to maintain the spacecraft in this region could be of great importance for observation, conducting experiments or even landing.

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