Highlights of Astronomy, Vol. 12
International Astronomical Union, 2002
H. Rickman, ed.

Missions to Phobos and Other Minor Bodies

Vsevolod S. Avduevsky

Center of Wave Mechanics, Russian Academy of Sciences, Russia

Efraim L. Akim, Timur M. Eneev, Mikhail Ya. Marov

Keldysh Institute of Applied Mathematics, Russian Academy of Sciences, Russia

Stanislav D. Kulikov, Roald S. Kremnev

Lavochkin Association, RASA, Russia

Garry A. Popov

Institute of Electrodynamics, Moscow Aviation Institute, Russia

Abstract. A space mission to Mars' moon Phobos with a space vehicle of new generation currently developed by the Russian Aerospace Agency is discussed. The vehicle design incorporates innovative SEP technology focused on small propulsion electric engines which significantly improve the mission energetic capability. The project is optimized around a sample return (PSR) from Phobos and also offers an opportunity for rendezvous/sample return missions from several asteroids, comets, and NEO. Scenario, rationale, and basic profile of PSR mission are presented.

1. Introduction

Planetary exploration is a cornerstone of space science and technology development. After the "Mars 96" loss, an approach to maintain the Russian planetary program at a moderate level of activity was elaborately studied. Various possible scenarios were assessed with the aim of accommodating challenging scientific objectives and squeezing into the existing severe budgetary constraints. The study resulted in the project development of a new generation space vehicle. Its initial phase first started enthusiastically and then met support from the Russian Aerospace Agency.

The basic concept is the use of modern technology, a significant cost reduction of planetary exploration, and the definition of objectives with important science return. This strategy is pursued as a guideline in the development of space vehicle of new generation. The bottom line is the utilization of middle class (Soyuz type) launchers, which serves as the main constraint for the project's profile. Additional energetic capabilities are provided at the expense of the utilization of small propulsion electrojet engines (EPE) based on the SEP technology. This makes some scenarios of Solar System exploration more flexible to achieve important scientific goals. The project is optimized around a sample return mission from Phobos (PSR) and it also offers an opportunity for rendezvous/sample return from several Main belt asteroids, NEO, and comets. Thus the project appears as a milestone in the Russian program of Solar System investigation, being focused on Phobos/Mars exploration, with a potential for ambitious follow–up missions to asteroids and comets. Phase A of the project is completed by now and the PSR mission profile is defined along a general baseline of the new spacecraft development.

2. Scientific objectives

It is highly desirable to investigate in detail the soil composition and properties of asteroid class bodies with the use of both remote sensing and *in situ* techniques, including the most challenging goal of delivering samples of relic matter for laboratory studies. This ultimate goal underlies the overall PSR mission profile and the payload selection. The scientific objectives of the mission are:

- Yield more insight into the problem of the Phobos/Deimos origin and their genetic relation to Mars;
- Explore the physico-chemical properties of Phobos' surface, its inner structure and its relationship with orbital and rotational motions;
- Study Martian near-space environment at the Phobos orbit and the properties of the dust torus;
- Ensure Mars exploration at the inbound phase of the PSR mission and during on-Phobos operations;
- Measure interplanetary plasma en route to Mars.

3. Mission profile

The experience gained from the former Russian "Phobos 88" project is used to provide an important baseline for both the mission concept and spacecraft development. It allows us to solve numerous problems in the project design and implementation. The project is regarded not only as an important component of the international planetary program but also as a modern space technology demonstration. The mission operations include the following phases:

- Launch of spacecraft jointly with injection of rocket on near-circular LEO ($h = 180 - 200$ km; $i = 51.6 - 51.8°$)
- Insertion into an interplanetary Mars–targeted trajectory using chemical propulsion;
- SEP operation during the Earth–Mars trajectory;

https://doi.org/10.1017/S1539299600014507 Published online by Cambridge University Press

- Deceleration and insertion of spacecraft into Mars orbit close to Phobos' orbit followed by maneuvers to approach Phobos using successive ignitions of a chemical propulsion engine;
- Landing on Phobos near the equatorial plane (0 – 30°; ~90°);
- Taking samples from up to ~1.5 m, carrying out *in situ* on-surface measurements;
- Launch of return rocket on an Earth–targeted trajectory and in–flight trajectory corrections;
- Entry of the capsule with samples into Earth's atmosphere, landing and rescue operations.

The main characteristics are summarized in Table 1.

Table 1. Mission Profile

Launch Date (provisional)	12.20.2004
E-M transfer time	850 days
SPE operational time	450 days
Date of arrival at Mars	04.19.2007
Maneuvering into Phobos' orbit before landing	120–150 days
Launch Date back to Earth	07.08.2007
Phobos/Mars escape velocity	1.8 km/s
M-E transfer time	285 days
Earth entry velocity	11.56 km/s
Number of corrections	4-5
Arrival at Earth	04.06.2008
Total time of the mission	1290 days

Energetic capabilities of the spacecraft operating in SEP mode are based on a modern solar array technology. The mass/energy ratio q achieved is approximately 20–30 kg/KWt, which is a factor of about 5 less than compared to the routine solar arrays and also to NEP. This innovation resulted in a rather good efficiency q = 40 kg/KWt of the overall SEP system equipped with the electric propulsion engines (EPE) of SPD–100 type. The spacecraft is equipped with 9 of these engines having a specific thrust P_{sp} = 2100 s ensuring a total thrust P = 38 g for the energetic parameters selected as follows: power available at the Earth orbit N = 8.0–9.0 KWt, and effective EPE power in the jet N_c = 4.0–4.5 KWt. This gives rise to an Earth–Mars transfer time from 450 to 850 days for the three launch dates provisionally selected between 11.20.2004 and 07.05.2005. The above parameters require solar arrays as large as 54 m^2, with an efficiency ≈180 W/m^2. Ejected matter of SPD–100 engines is xenon, its mass storage being assessed with the relevant energetic/ballistic parameters involved. SEP utilization allowed us to accommodate the PSR mission energetic constraints and ensures up to ~200 kg of M_{sc} mass increase. The overall mass balance is shown in Table 2.

Table 2. Mass balance

Mass of spacecraft inserted into Earth–Mars trajectory	2140 kg
Mass of spacecraft at the Phobos orbit	1537 kg
Mass of spacecraft at the Phobos approach	1153 kg
Xenon consumption	425 kg
Mass of Phobos lander	975 kg
Mass of return rocket	350 kg
Mass of capsule	12 kg
Mass of samples	170 g

4. Other possible missions

SEP utilization is advantageous for distances between 0.3 and 3.0 AU from the Sun and this supports the idea to expand the basic PSR mission profile to explore other small Solar System bodies. Several groups of the Main belt asteroids, comets, and NEO were analysed in terms of the energy consumption and flight time required. Asteroids of the inner part of the Main belt ($a = 2.2 - 2.5$ AU; $e < 0.15$; $i < 15°$), belonging to classes U (4 Vesta), C (19 Fortuna, 10 Hygiea), S (6 Hebe, 20 Massalia), and M (21 Lutetia), as well as NEO asteroid 433 Eros were selected as the most accessible bodies having a high scientific interest. Also, for a few cometary missions, the energy consumption involved appeared to be even less than for asteroid missions, a consequence of the comet's perihelion being used to come relatively close to the Sun, therefore allowing more energy available for SEP operation. Special attention was given to asteroid Fortuna with an ultimate goal of sample return from this body. For such a mission, the mass of the lander was estimated to be 450–525 kg and that of the return vehicle 230 kg.

5. Conclusion

The challenging concept of modern technology utilization and significant cost reduction served as the baseline for a feasibility study of a new RSA space project for planetary exploration with important scientific objectives (Phase A). Significant cost reduction was accomplished first of all by using middle class launchers such as SOUZ–FREGAT, which places important constraints on the mission profile. Energetic capabilities are expanded through the use of small propulsion electric engines based on the SEP technology utilization. The spacecraft parameters and scientific rationale are principally optimized for a Phobos sample return mission (PSR), with time available for Mars exploration during Phobos approach and operation on its surface. Detailed analysis of the basic rationale of the PSR mission was performed based on the provisional launch date in December 2004. The emergent ballistic characteristics and mass balance ensure a feasibility of the mission implementation within 3.5 years. Rendezvous and/or sample return missions for several classes of the Main belt asteroids, comets and NEOs with the same class of space vehicle were also investigated and proved feasible.