EPSC Abstracts
Vol. 6, EPSC-DPS2011-238-1, 2011
EPSC-DPS Joint Meeting 2011

Mars Express flies by Phobos 4 Times per Martian Year

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1. Introduction

Since its arrival in December 2003, Mars Express (MEX) has spent over 4 Martian years at the Red Planet. Its elliptical, quasi-polar orbit with a maximum altitude of 11 000 km crosses every 5.5 months the circular, equatorial orbit of Phobos at 6000 km altitude. Although hardly foreseen in the original science objectives, this has been turned into a unique science opportunity. This paper explains the flight adjustments needed by the Phobos flybys and shows how their unexpected benefits complement the main science results of the embarked instruments.

2. Objectives and Flight Operations

2.1 MEX Orbit and Phobos Flybys

The crossing of the Phobos and MEX orbits derives from the evolution of an orbit designed to scan all Mars latitudes at the lowest orbital point for surface coverage. Spacecraft design and costs constrained the embarked fuel and imposed to stay on an eccentric orbit which includes Phobos flybys. Today, the small amount of remaining fuel constrains the flyby opportunities. 'Safety-first' principles guide the design of the actively optimised encounters, which differ depending on the science objectives, the proximity (50 to 1000 km) and the illumination of the moon from full day to full night. When one of the Mars Express revolutions would intersect with the Phobos orbit, the dephasing of the two bodies is increased to 1000 seconds if necessary (by a small manoeuvre) well ahead of time. This guarantees a miss-distance of 100 km should a spacecraft 'safe mode' induce a drift (bringing it too close to Phobos). When the geometry makes a collision impossible, close flybys are realised if fuel permits, down to a safe distance of 50 km from the centre of the moon.

2.2 Distances, Pointing, Instruments

As with all Mars Express planning, the instrument requirements can to some extent be combined but often conflict with each other, and with the spacecraft's flexible but modest capabilities. Radio-Science prefers very close approaches and requires that the high-gain antenna point to Earth and be visible from a DSN 70-m ground station which must be booked for the time of closest approach. The high-resolution camera needs moderately close flybys such that Phobos tracking by spacecraft rotation avoids picture smearing, with the further constraint of adequate surface illumination, whereas the radar requires to work in the range 170-400 km. Science Planning at ESAC computes all geometrical parameters relevant for each instrument; only this detailed 'contextual geometry' allow the teams to assess the science quality of a flyby for their instrument, to adapt their measurement strategy, and help in prioritizing observations.

2.3 Spacecraft Constraints

In eclipse season, the power limitations may conflict with energy-demanding pointing towards Phobos when the batteries must be recharged. Before a Conjunction Season, large amounts of data may have to be kept on-board for weeks, or brought back to Earth in a degraded communication context. The flight engineers check all constraints and propose alternatives to overcome limitations without violating safety rules. Phobos flybys led to double the spacecraft rotational speed for unique observations, a method re-used in other contexts like lander contacts.

2.4 Commanding Phobos Observations

Flight Dynamics interacts with the high-resolution camera team to tailor the pointings and construct the attitude commands; in turn, the camera team update the instrument internal observation parameters as late as possible based on the latest orbit measurement and short-term propagation. Mission Planning at ESOC and Science Planning at ESAC handle late high-accuracy operations requests, in combination with the more standard, longer lead-time Mars observations. The prime mission continues in all other orbits, and often in the same ones as the Phobos specials.

3. Results

3.1 Scientific Results

Unique results have been achieved by Mars Express at Phobos, namely: improved ephemerides, the most precise determination of the mass, estimation of the porosity, sharpest images ever acquired, crucial information on the surface properties, and new processes such as backscattering of solar wind protons from the surface.

3.2 The Closest Phobos Flyby Ever

A complex Phobos flyby was performed for gravity field measurement by radio-science in March 2010, which remains the closest ever done and was the highlight of a campaign of 12 flybys within a season. Mars and Earth were close, ideal conditions for Radio Science. The fly-by was initiated by precise orbital manoeuvres to achieve the desired distance and to avoid an occultation by Phobos itself, which could have broken radiometric tracking at the closest and most interesting point. Before and after the flyby, long calibration sessions were performed, where the spacecraft was tracked continuously. Modulation was switched off and NASA's 70-m DSN station in Spain was used to obtain the best possible signal-to-noise ratio. Two more radio science fly-bys of Phobos remain necessary to further improve gravity field estimates and provide answers on the internal mass distribution (one even closer and one further away).

3.3 Detecting Phobos with the Spaceship

Using the spacecraft as a sensor via its technical telemetry can be fruitful for space environment investigations. The passage of Phobos between the Sun and MEX would cause an eclipse which would be observed by a drop in the solar array output; its passage between the Earth and the spacecraft would cause an occultation, observed by degradation in the radio link. Based on predictions of such events, the telemetry was analysed. Although promising signatures have been found in both data types, these have been inconclusive as the impact of Phobos on the measurements is hard to distinguish from other variations. The uncertainty in the Phobos orbit [1], which these events could help to reduce, prevents isolating the impact on the telemetry by time alone. In the future, more accurate orbit predictions may still become achievable using such measurements.

3.4 Popularising Planetary Exploration

The astounding high-resolution 3-D pictures and the suspense of the 'first' for the ever-closer approaches also help improve the visibility of the Agency, its planetary programme and its operations centre. Communicating Phobos flyby news and information to various audiences/channels takes advantage of the fact that flying by a moon is one of the simplest (yet most compelling) topics for general audiences, a point recognised by the Apollo programme 40 years ago. A blog dedicated to Mars Express is activated upon significant flybys: since December 2009, Phobos-flyby articles have attracted almost 100 000 page views in the ESA website plus 150 000 page views in the MEX blog. Phobos pictures have been 'Astronomical Picture of the Day' three times from March 2010 to January 2011 and one was the third-most viewed ESA image in 2010. The interest in the 'little moon' and its origins by the general public and among amateur astronomers continues to grow.

3.5 Phobos Campaigns Help the Mission

Phobos campaigns boost personnel motivation, maintenance of orbital strategy expertise and tightening of the operational procedures critical to the spacecraft and science. Between fully routine and fully exceptional, these high-profile activities present an intermediate scenario, where low operational cost and special tailoring must be combined – a pattern also seen in other areas of the mission like the contacts with the NASA landers on the Mars surface.

4. Summary and Conclusions

All Phobos science possible thanks to the Mars Express mission in the background also finds its limits in the constraints of that prime mission. Phobos optimization requires preserving long-term maintenance of the Mars Express reference orbit for surface coverage of the planet, fuel economy concerns and safety constraints for Europe's only spacecraft at Mars. The science bundle retained for each approach derives from the orbit geometry and drives the spacecraft attitude. With Mars Express, Phobos is one the solar system bodies most visited in 'flyby only', paving the way for future in-situ exploration like the Russian Phobos-Grunt mission planned to be launched in November 2011.

References

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