次期火星探査機のための視覚的軌道設計
Visual Orbit Design for the Next Mars Exploration Mission

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In December, 2011, the working group concerned with the Japanese next Mars exploration mission began to study the use of orbiters to investigate the mechanisms of carbon dioxide and water escape from the Martian atmosphere, and the role played by the solar wind. This will be the successor to the first Japanese mission to Mars involving the NOZOMI spacecraft, and two different orbiters will be deployed around the planet. Orbiter-A will carry out in-situ observations of electric and magnetic fields, particles, plasma and the atmosphere at an altitude of about 100 km above the Martian surface. Orbiter-B will capture images of the escaping atmosphere and monitor solar-wind conditions. The mission life will be a Mars year. This paper describes a visual method for determining the orbits of both spacecraft, and presents examples of possible orbits.

The orbital constraints proposed by the working group are as follows.

Orbital constraints for Orbiter-A

A1. The periapsis altitude is around 150 km.

A2. The apoapsis altitude is between 5000 and 7000 km.

A3. The period during which periapsis occurs on the dayside of the planet is more than two thirds of the mission life.

Orbital constraints for Orbiter-B

B1. The apoapsis altitude is about 4-6 R_M.

B2. The period during which the orbiter is exposed to the solar wind is more than three quarters of the mission life.

B3. The period during which the orbiter can image the local time zone of 12-15 h at the planetary limb is more than three quarters of the mission life.

Orbital constraints for combined observations by both orbiters

C1. The number of times during which Orbiter-B is exposed to the solar wind and can also image Orbiter-A, whose solar zenith angle and altitude are less than 60 deg and about 300-800 km, respectively, is more than one hundred during the mission life.

C2. When C1 is satisfied, the angle between the line-of-sight of the imager onboard Orbiter-B and the velocity vector of Orbiter-A is within 90 ± 20 deg.

The orbital elements are obtained by solving the Lagrange planetary equations for a two-body boundary-value problem, taking only the J2 perturbation into account. Constraint A3 is chosen as an example for explaining the visual method of orbital design. The orbiter's longitude of ascending node and argument of periapsis in a Mars-Sun fixed coordinate system are taken as design variables, and the orbital constraint is used as an evaluation function. A contour map for a period in which periapsis occurs on the dayside is plotted in a coordinate system in which the longitude of ascending node and argument of periapsis are the X and Y axes, respectively. A mission profile is placed on the map, along which the changes in the longitude of ascending node and argument of periapsis during the mission period are plotted. The mission profile can be placed at anywhere on the map, since its shape can be kept almost constant by selecting an initial position determined by the position and direction of the spacecraft during Mars orbit insertion. By looking at the map, it then becomes easy to identify an appropriate initial point for the mission profile that maximizes the period during which periapsis occurs on the dayside.

By the method described above, it is possible to visually determine rough values for the longitude of ascending node and argument of periapsis that are suitable for the mission. This technique is also applicable to the general design of orbits around a planet by choosing a coordinate system appropriate for the given orbital constraints.