# Design of the Martian Satellites Rendezvous Mission via the Combination of Martian Aerocapture and Solar Perturbation Effect

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**Abstract**

We are proposing the Martian aerocapture mission as an innovative space mission of JAXA. During the planning process of it, we also evaluated the possibility of Martian satellites rendezvous missions. In this paper, we address the trajectory schemes which take a spacecraft to Martian satellites with less fuel by the combined use of aerocapture and solar perturbation effect.

## 1 Introduction

Japan Aerospace Exploration Agency (JAXA) has proposed an aero-capture mission at the Mars, which is designed to be launched with Hayabusa No.2 [1],[2] . The purpose of this mission is to establish the aero-capture or -brake techniques at the solar planets, as a way to send a spacecraft to orbit around the planet. In addition, JAXA is exploring the possibilities of observing the Martian satellites as well as the Mars itself. The mission payload in this case, however, is not large enough to have fuels to control the spacecraft trajectory and take it to the Martian satellites.

One of the conceivable ideas to overcome this problem is to control the spacecraft trajectory by the combination of the aero-canpure technique at the Mars and the solar perturbation effect. Of cause the most dominant force at the vicinity of the Mars is its gravity but the solar gravity has a slight effect on the movement of the spacecraft. This force become apparent and cannot be neglected as the distance between the spacecraft and the Mars increases.

This paper discusses how much maneuver, delta-V, can be saved to put the spacecraft to the Martian satellites' orbit when using the aero-capture technique and solar perturbation effect, compared with conventional insertion sequences.

## 2 Mission Sequence

The scheduled mission sequence is as follows.

The spacecraft is launched with Hayabusa No.2 from Tanegashima space center in Japan in summer 2015 and put into the earth synchronized orbit. After several swing-by at the Earth waiting a chance traveling to Mars, the spacecraft leaves the Earth. On arrival at the Mars, the spacecraft has a too large excess speed to stay around the Mars and thus it

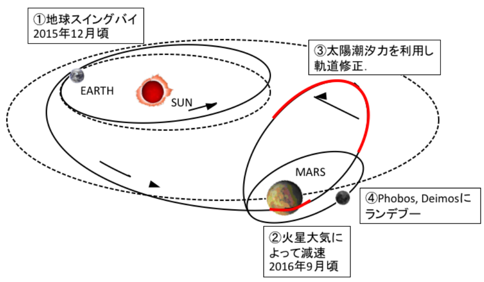


Figure 1: Mission sequence

has to reduce its speed by some measures. In this mission the aero-brake technique is applied.

To make a success of the aero-capture, the choice of the periareon distance between the Mars and spacecraft is important. If the altitude is too low when the spacecraft passes through the atmosphere, it mets with a large drag, lost its lift and crash in the field. On the other hand, if the spacecraft goes too far from the Mars, the aero-brake does not enough work and it fly away to the space. When the spacecraft is adequately slowed down, it stay in the SOI of the Mars and moves under the gravity of the Mars and the Sun.

After captured, the maneuver is necessary to gain the attitude of the next periareon, because if not, the spacecraft loses it speed more and more and stalls to the end. Then it goes to the Martian satellites.

## 3 B-plane Targeting

**B-plane targeting.** The fly-by trajectory is specified by the aim point selected on the B-plane. The direction angle $\theta$ of the aim point, which is a parameter relating to the inclination of the post-fly-by trajectory, is defined by the angle of the B-vector measured from the T-axis in the plane clockwise. The magnitude of the B-vector decides the closest approach distance of the spacecraft. To stay around the Mars after the fly-by, the aim point should be properly chosen.

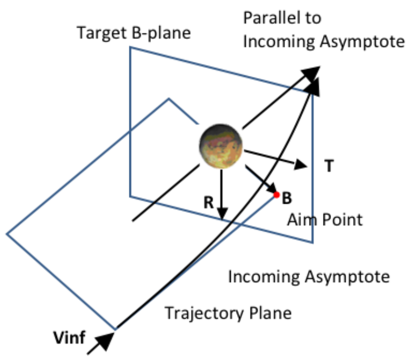


Figure 2: B-plane

**Solar perturbation effect.** Near the boundary of the SOI, the gravity of the Sun cannot be neglected compared with the Mars and the way the perturbation acts on the movement of the spacecraft depends on the positional relationship between the Sun, the Mars and the spacecraft (Figure 3).

As mentioned above, the spacecraft needs maneuvers to gain the second pariareon altitude to avoid getting extra atmospheric drag. Instead of using propulsion, the method utilizing the solar perturbation is introduced : Controllng the post-fly-by trajectory and leading to get adequate polar gravitational force in order to gain the altitude.

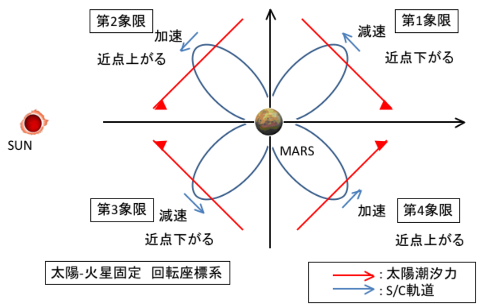


Figure 3: Solar perturbation

## 4 Numerical Simulation

To examine the effect of the position of the aim points on the B-plane on the post-fly-by movement of the spacecraft, a computational simulation is conducted.

The spacecraft is assumed to approach the Mars with a given excessive velocity and calculation is started where it is on the boundary of the SOI of the Mars. The magnitude and the direction of the incoming excessive velocity is given and the position of entering the SOI is variable. The calculation is done every 30 degrees of the angle $\theta$ and seeks the appropriate magnitude of B-vector.

**Aim points leading aero-capture.** Figure 4 and Figure 5 show the aim point which leads the aero-capture after fly-by of the Mars. They are distributed on the line where the the magnitude is about 5700km from the center of the Mars. The hight of periareon of each aim points is about 50km from the surface of the Mars. If the magnitude is over this value, the spacecraft fails to be captured and fly away and if less, it will clash.

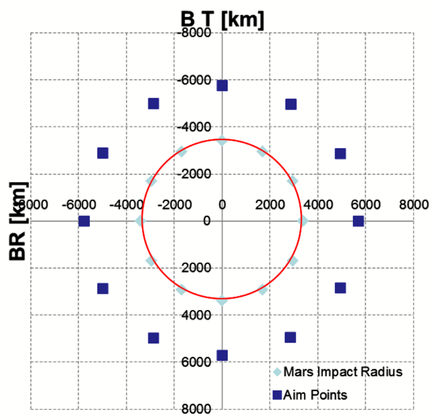


Figure 4: Aim point leading aero-capture

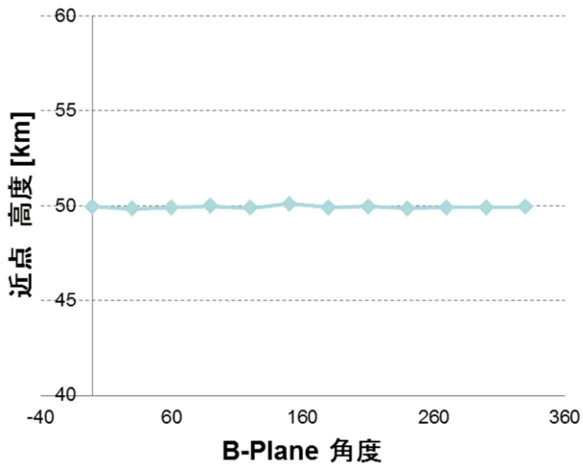


Figure 5: the angle of the aim points and the altitude of periareon

Figures 8 - 9 are the example trajectories of $\theta$=0 and $\theta$=180. In both case, the spacecraft is flied by to the area where the Sun perturbation works to increase the trajectory altitude at the second periareon and it get to the Mars satellite.

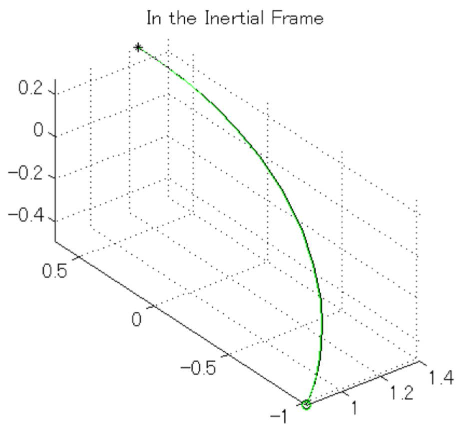


Figure 6: Capture trajectory in the inertial frame.$\theta$=0

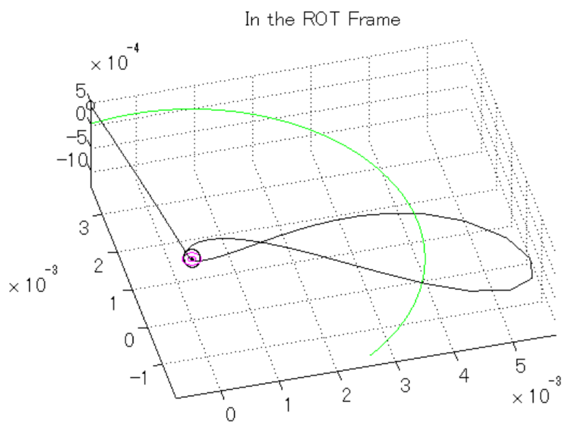


Figure 7: Capture trajectory in the Sun-Mars fixed rotating frame.$\theta$=0

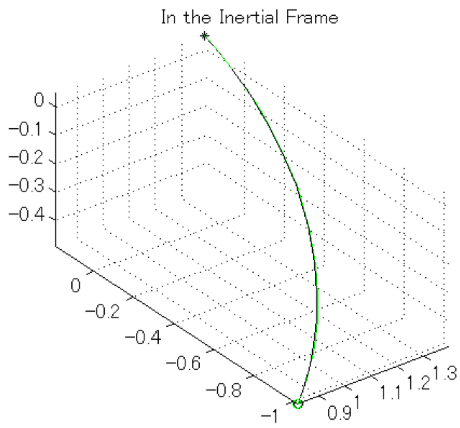


Figure 8: Capture trajectory in the inertial frame.$\theta$=180

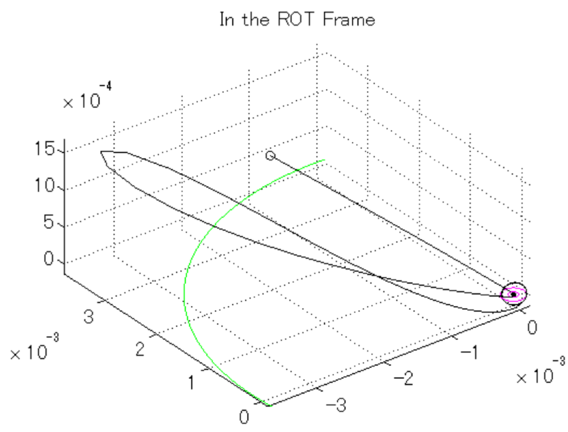


Figure 9: Capture trajectory in the Sun-Mars fixed rotating frame.$\theta$=180

**Maneuvers to put S/C into .Mars satellite orbit** It is required to do two maneuvers to send the spacecraft to the Martian satellites orbit ; (1) dV to insert to the orbit whose radius is the same as the radius of Martian satellites and (2) dV to change its orbital plane after dV1 is done.

Figure 10 shows the necessary dV1, dV2 and the total with respect to the angle $\theta$. The dV1 is not significantly affected by the angle of the aim points and are constant with about 500[m/s]. On the other hand the dV2 varies according to the $\theta$ and have a large magnitude compared to dV1. The minimum values, dV=1.0 km/s, is marked on $\theta$=210 degrees and second is $\theta$=30 degrees, where dV=1.5 km/s. They are symmetry with respect tothe center of the Mars. From this calculation, maneuver to change orbital plane accounts for a large part of the total delta-V in this mission.

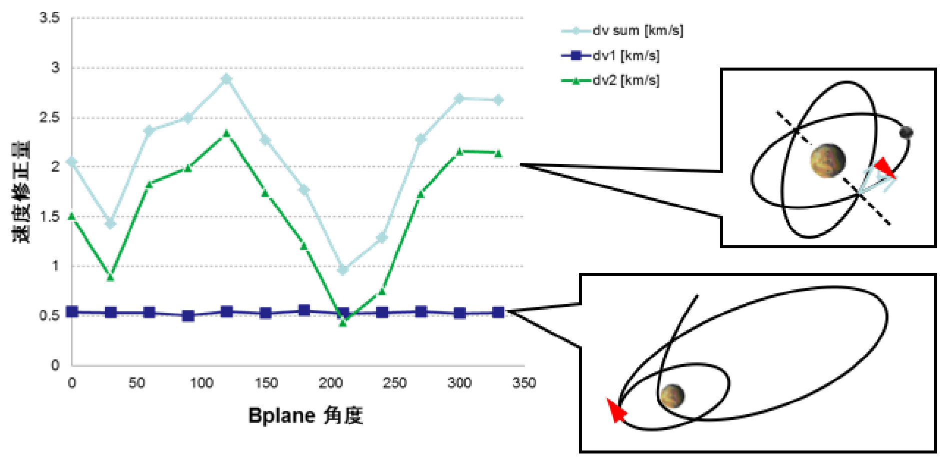


Figure 10: dV to put S/C into Mars satellite orbit

## 5 Conclusion

The calculation suggests the required dV to put the spacecraft to the Martian satellite orbit is 1.0 km/s in the minimum and this value is quite smaller than the value of the direct insertion, which requires 3.4 km/s. Over 70% of dV can be saved.
This result shows the method of trajectory control combining the aero-capture technique and the use of the Solar perturbation is meaningful in the view of necessary maneuvers.

However, this trajectory control method may not be used in this aero-capture mission, because the spacecraft expected is assumed to have the size of 200kg and its maneuver capacity of is less than 100 m/s.

## References


[1] N. Ogawa, et. al, *"Interplanetary Trajectory Design for Mars Aerocapture Demonstrator,"* Astrodynamics Symposium 2011.

[2] S.Narita, et. al, *"Feasibility Study of Dynamic Vibration Absorber Function with Sub Payload Exploration System on HAYABUSA-2,"* Astrodynamics Symposium 2011.