Method of Robust Orbit Insertion and its Application to MMX Mission

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Orbit insertion in the planetary exploration is one of the most critical events in the entire mission sequence. To insert a spacecraft into an orbit around the target body, forceful maneuver to change its trajectory at the exact timing is required. If the orbiter does not conduct the maneuver properly, it flies by the target and escapes into the deep space. This means that the failure of MOI has a strong impact on the outcome of the mission. One strategy here is to design a trajectory with which even in the case of orbit insertion failure, the spacecraft can re-encounter the target planet after a given period, by aiming at synchronous trajectory in advance. We call this method robust orbit insertion. In the framework of two-body problem, possible maximum deflection angle after swing-by can be found analytically as a function of the gravitational parameter, the radius of the body, and V_∞. Besides, the investigation on geometry at swing-by reveals required deflection angle to achieve robust orbit insertion. Figure 1 shows the relationship of velocity vectors at swing-by. When the $V_{\infty out}$ is at the intersection of V_∞ sphere and the sphere of required velocity for synchronous trajectory, condition for robust insertion is met. Therefore, given a V_∞ vector, one can judge if the robust condition can be satisfied at the encounter with the target body.

In this study, we applied the above method to JAXA Martian Moons eXploration (MMX) mission and examined if the method is feasible even when it is adopted in the actual mission sequence. One remarkable peculiarity of this mission is that the orbiter needs to transfer to the trajectory of Phobos, one of the Martian Moons, after it enters Mars orbit. Thus the distribution of necessary ΔV for Mars Orbit Insertion (MOI) shows a complex trend when we map it onto the B-plane; accordingly, it is imperative to check the drawback of total ΔV when we give priority to robust MOI. For the Phobos transfer sequence, we adopted three impulse transfer: ΔV1 to insert into elliptic orbit, ΔV2 to match orbital plane and lift the periapsis altitude, and ΔV3 to lower the apoapsis altitude. Figure 2 shows the contour of necessary total ΔV on the B-plane for the nominal launch case; also depicted are the nominal altitude (black circle), the robust MOI condition (blue circle), and the minimum ΔV condition (blue and green line). It shows there is a slight difference between minimum ΔV condition and robust MOI condition on the circle of the same r_p, which means aiming at robust condition increases total ΔV. To estimate the feasibility of this strategy, we feedbacked the drawback to interplanetary trajectory design; subsequently, it is confirmed that ΔV increases necessary to achieve robust MOI can be smaller than dozens of m/s for two weeks of the launch window. Therefore, if we allow the extra ΔV, the risk of complete MOI failure can be reduced. In the case of maneuver that stops in the middle, further research is necessary. In this case, aiming at synchronous orbit is no longer useful, and necessary cost of Deep Space Maneuver needs to be investigated.

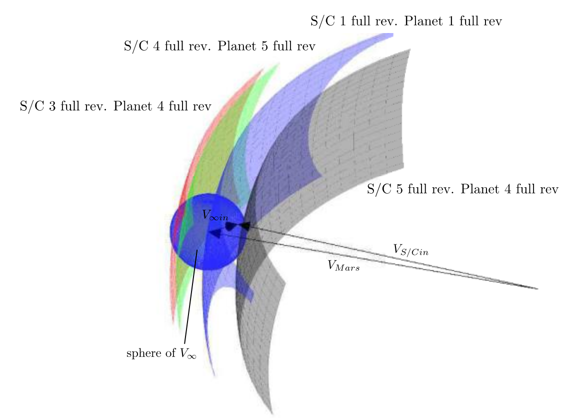

Fig. 1. Geometry of Velocities at Swing-by

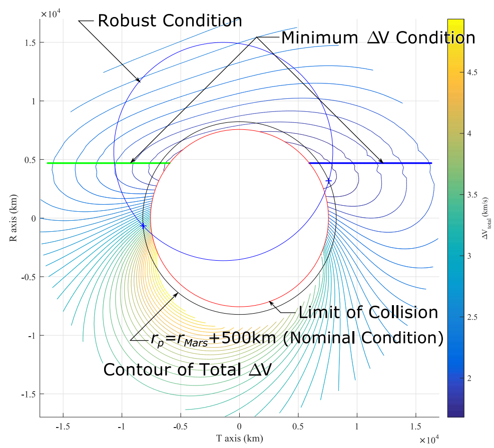

Fig. 2. Conditions on B-plane