THE TRAJECTORY CONTROL STRATEGIES FOR AKATSUKI RE-INSERTION INTO THE VENUS ORBIT

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ABSTRACT

The Japanese Venus explorer "Akatsuki (PLANET-C)", which now rotates about the Sun, will approach to Venus again in 2015. For the Venus orbit re-insertion, several trajectory strategies were devised. In this paper, we introduce the difficulties we faced in redesigning the trajectory of Akatsuki after the failure of the first Venus orbit insertion in 2010 and report the newly devised trajectory control strategies which will make it possible that Akatsuki becomes a Venus orbiter.

Akatsuki approached Venus at the altitude of 550 km on Dec. 7, 2010. However, it couldn't perform enough deceleration because of a defect of its propulsion system and made a flyby of Venus. Now, Akatsuki rotates about the Sun with its perihelion inside of the Venus orbit and its aphelion outside of the one. The characteristic of Venus is that its axial tilt is 177.4 degrees. This means that the Earth rotates counter-clockwise when seen from the North (direct) and that Venus does clockwise (retrograde). As observation requirements of the Venus circular orbit, two things should be considered: one is that the orbital plane is close to the Venus equator and the other is that the rotation direction is the same as the Super Rotation of Venus atmosphere. Under these constraints, whereas Akatsuki is expected to rotate retrograde, the result was that its periapsis decreases rapidly and intersects Venus when inserted in the retrograde direction, for Akatsuki passes through the area where the solar perturbation acts in the direction of reducing the velocity. Therefore, we aimed for the altitude maintenance by changing the approach angle to Venus by taking advantages of multiple swing-bys, which resulted in no cases succeeded to keep the periapsis altitude.

In order to overcome these difficulties, a trajectory strategy, named Gravity Brake Method (GBM), was devised. The key idea in this method is the use of the solar perturbation. It prevented from the maintenance of periapsis altitude in the former section but we make the most of it in this method. When probes rotate retrograde, the solar perturbation acts as acceleration in the first and third quadrant (upper right and lower left area) in the Sun-Venus fixed rotation frame (where the Sun always positions at left of Venus) and it does as deceleration in the second and fourth quadrant (upper left and lower right area) in its frame. Initially, we insert the spacecraft to the direct orbit in the deceleration area (the second quadrant), but we choose the apoapsis altitude of 1 million km and make it fly up to just inside of the Hill radius of Venus. By this, we make the most of the solar perturbation of deceleration and make the spacecraft rotate inversely from direct to retrograde during this period. Moreover, when it flies back to near Venus again, the trajectory moves from the first to the fourth quadrant where the perturbation acts as

from deceleration to acceleration. This makes it possible to keep the periapsis altitude in the Venus circular orbit, which was impossible in the former section. The spacecraft performs a couple of maneuvers later on to be an elliptic orbit with a few thousand km times hundreds of thousands km.

The second option of the trajectory strategy is the method named Hohmann Transfer Method (HTM), which Akatsuki orbit contacts the Venus one internally. For this, Akatsuki performs a deceleration maneuver of approximately 80 m/s before the Venus encounter in 2015 and change the approach angle largely in order that the circular orbit begins in the acceleration area (first quadrant) to prevent from decreasing the periapsis. By the fuel consumption of 80 m/s before the orbit insertion, however, the final apoapsis altitude will be a hundred thousand km higher than the one of the GBM.

In this paper, we report the details of the result of trajectory design of Akatsuki which will conduct the Venus orbit insertion for the second time.