Trajectory Monitoring and Control of the New Horizons Pluto Encounter

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The New Horizons (NH) spacecraft was launched on January 19, 2006 at a record high C3 of 157.75 km^2/s^2 and flew by Jupiter on February 28, 2007 for a gravity assist of gaining additional speed, which assured a 9.5-year flight time to Pluto, at the distance of 32.9 AU from the Sun and 31.9 AU from Earth. The Pluto encounter date is selected to be on July 14, 2015. Having passed the orbits of Saturn, Uranus, and Neptune and completed the long cruise across the solar system, the NH spacecraft is now approaching Pluto at a speed of about 14 km/s.

New Horizons is the first mission to Pluto. Because of the high Pluto arrival velocity, it is not feasible to place the spacecraft in orbit around Pluto. The first Pluto exploration must be conducted using a flyby, which makes the flyby trajectory critical as it directly affects the mission's scientific objectives, which include conducting an initial reconnaissance of the Pluto system and investigating the geology, surface composition, and atmosphere of Pluto and its moon Charon. At the time when the New Horizons mission was formulated, Charon was the only moon of Pluto. Since 2005, four new Pluto moons, Nix, Hydra, Kerberos, and Styx, have been discovered.

Observation and measurement of the Pluto system for the planned science investigations are to be fulfilled during the New Horizons Pluto flyby. Measurement of the surface composition and geology of the bodies will be conducted by the New Horizons onboard optical instrument LORRI, Ralph, and Alice through remote sensing, while measurement of the atmosphere of Pluto and Charon involves not only the onboard instrument REX, but also two Deep Space Network (DSN) stations and the Sun. The atmosphere measurement is achieved by analyzing the media (radio waves and UV light) after passing through the Pluto and Charon atmosphere. Radio waves from two DSN stations will be transmitted simultaneously to the NH spacecraft when Pluto and Charon are passing between Earth and the NH spacecraft, i.e., during the Earth occultation by Pluto and the Earth occultation by Charon. The UV light from the Sun will be analyzed by the onboard instrument Alice when Pluto and Charon are passing between Sun and the NH spacecraft, i.e., during the Sun occultation by Pluto and the Sun occultation by Charon. The New Horizons trajectory is designed to make all the science investigations possible in the single Pluto flyby, providing the required Sun-Earth-spacecraft geometry for the atmosphere measurement and the necessary conditions for the remote sensing.

The New Horizons nominal Pluto encounter trajectory and associated geometry and key event timeline during the flyby will be described in the paper. The nominal encounter trajectory has a fixed Pluto closest approach (C/A) time that is constrained by the atmosphere measurement. If the predicted Pluto arrival time is earlier or later than the selected arrival time, the flight trajectory will need to be adjusted with a trajectory correction maneuver (TCM) to modify the speed of the NH spacecraft relative to Pluto. The trajectory path going through the Pluto system is designed to support the science observations and measurements planned for the Pluto encounter. The Pluto flyby trajectory is specified in terms of the

Pluto B-plane target. The designed trajectory is called the nominal trajectory. The estimated trajectory from navigation orbit determination (OD) including propagation to the future is compared with the nominal trajectory. Their difference indicates how much the current flight path is off the desired flight path and the necessary trajectory correction.

NH spacecraft position and velocity is tracked from the three NASA DSN stations located in Goldstone of USA, Canberra of Australia, and Madrid of Spain through a two-way non-coherent Doppler and ranging technique by the X-band radio waves. From the DSN tracking, the spacecraft orbit with respect to Earth is determined. Spacecraft position with respect to Pluto is based on current knowledge of estimated Pluto orbit which has large uncertainties. Optical images taken by the cameras on the NH spacecraft will tie the spacecraft position directly to the imaging objects of Pluto and its moons. Combined ground radio tracking and onboard optical images improve the accuracy of the spacecraft position with respect to Pluto, as well as the orbits of Pluto and its moons.

As the NH spacecraft approaches Pluto, a series of optical images devoted for orbit determination are planned in accordance with the planned TCMs. Estimates of spacecraft position and Pluto position are updated periodically. Change of the Pluto system barycenter and change of Pluto and Charon obits with respect to the Pluto system barycenter could affect the planned science observations and measurements. The Pluto flyby path is reviewed with respect to the science measurement requirements with each OD solution update. The nominal Pluto encounter trajectory is updated or revised. Besides keeping the science observation on target, the safety of the NH spacecraft is also checked. If the latest images of the Pluto system show a high potential hazard of dust particles to the spacecraft along the planned nominal trajectory, the NH spacecraft can change its course to switch to one of the candidate SHBOT (Safe Haven By Other Trajectory) trajectories. There are three decision making points planned for switching from the nominal trajectory to a SHBOT trajectory, at P-30d (30 days prior to Pluto C/A time), at P-20d, and at P-14d. Such a trajectory switch can be made through a TCM that directs the spacecraft course to the new Pluto B-plane target of the selected SHBOT trajectory. An example of the nominal trajectory and three candidate SHBOT trajectories is shown in Figure 1. Flight trajectory status, Pluto B-plane target update, and trajectory adjustments of the NH spacecraft during the Pluto system flyby will be discussed in the paper.

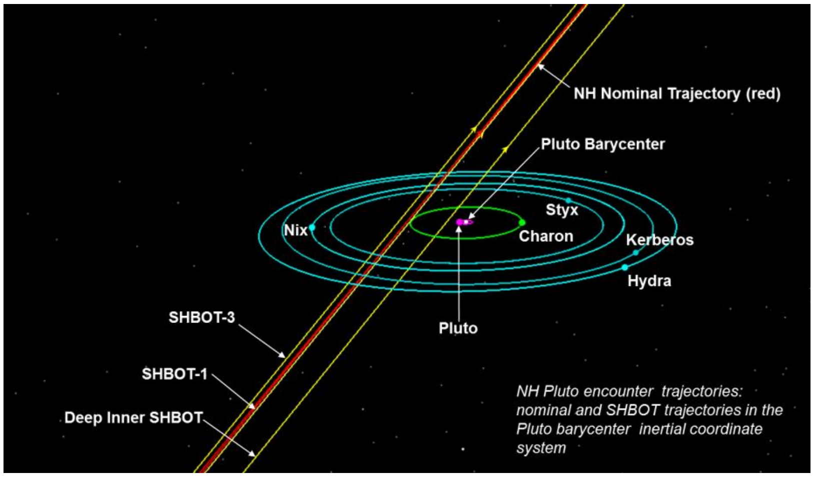

Figure 1. New Horizons Nominal and SHBOT Trajectories