WILD 2 APPROACH MANEUVER STRATEGY FOR STARDUST SPACECRAFT

Kenneth E. Williams
Jet Propulsion Laboratory
California Institute of Technology
Pasadena CA 91109-8099

Abstract

~~As part of NASA's Discovery Program,~~ Stardust will return samples of ~~interstellar particles collected in heliocentric orbit over a period of several years, as well as~~ dust from comet Wild 2 to be collected during an encounter in January 2004. Approach to Wild 2 will be performed with a number of trajectory correction maneuvers following a period of solar conjunction ending in early October 2003. ~~Design of approach maneuvers will be based on orbit determination from both ground-based radiometric observations and optical navigation methods.~~ Accuracy of both the orbit determination and maneuver execution are limited by a number of factors, including the small body ephemeris uncertainty, predictability of small forces arising from 3-axis attitude limit cycling and turns and visibility and resolution of the comet during approach. ~~The approach maneuver plan must account for such possibilities as not seeing Wild 2 until within 10 days of the encounter, as well as planning and execution of maneuvers on a relatively short operational timeline of as little as 6 hours. This plan must also accommodate adjustment of the final target point to maximize sampling quality without compromising safety of the spacecraft during the comet encounter.~~ Placement of ~~approach and follow-on~~ maneuvers, as well as contingency plans ~~for addressing all conceivable operational anomalies~~, will be discussed in light of these considerations.

Extended Abstract

Stardust was selected as part of NASA's Discovery Program. The objective of Stardust is to collect interstellar and comet dust particles, the latter during an encounter with the comet Wild 2 in January 2004. An overview of the Stardust trajectory is shown in Figure 1. The design of the Stardust spacecraft utilizes a three-axis attitude control system (ACS) which includes a star trackers, backup analog sun sensors and an inertial measurement unit (IMU) with gyros and accelerometers allowing for some closed-loop control of propulsive maneuvers. Thrusters are located on the opposite side of the space vehicle from sample collectors to minimize contamination of samples. Since thrusters so positioned do not produce balanced torques, all attitude control maneuvers contribute a translational Δv in addition to intended propulsive maneuvers. These must be accounted for orbit determination purposes and in terms of designing propulsive maneuvers. Power is provided by solar arrays with a battery in reserve, limiting time at which either spacecraft can point far off Sun.

The navigation strategy for approach to comet Wild 2 entails orbit determination (OD) via combination of 2-way ranging and Doppler and optical navigation (OPNAV). B-plane errors of ~15-20 km, 1-sigma, can be achieved, based on analyses performed to date. Such errors permit a close flyby of Wild 2 with a reasonably high probability of maintaining communication with Earth. Time-of-flight errors are somewhat more problematic. With a v-infinity of about 6.1 km/sec, a range error of around 1100 km or 180 sec, 1-sigma, in terms of time of flight, is expected after initial acquisition of the comet by the spacecraft. Improvement is possible in time-of-flight knowledge error from Earth-based observations or, more likely, an aggressive OPNAV campaign, particularly in the last few days prior to encounter. However, late correction of time of flight control error is expensive in terms of delta-v and cannot be accommodated by maneuvers after two days prior to

encounter. This is due to the fact that the spacecraft +x axis with the Whipple shields must be pointed along the v-infinity direction towards the comet to ensure spacecraft safety as it begins to penetrate the coma. Therefore, the time-of-flight problem will be addressed mainly by adjusting timing of the flyby sequence. Time of flight errors on approach need only be managed to remain within acceptable limits, based on dual ground antenna coverage within a period of about 2-3 hours around the nominal encounter time.

The maneuver strategy and targeting philosophy to be used for the Wild 2 approach is are highly robust. Four trajectory correction maneuvers (TCMs) with contingencies are scheduled to achieve the B-plane target within acceptable time-of-flight control limits. Because the OPNAV images are most critical to achieving the desired target near the comet for both dust collection and flyby imaging, the first approach TCM will not be executed until Wild 2 is visible from spacecraft. The plan accommodates an adjustment of targeted range relative to the center of the comet nucleus up to two days prior to encounter. As of this writing, the initial target is 150 km at closest approach. This can be adjusted conveniently to larger ranges while minimizing the probability of large turns off Sun which might otherwise be required to execute TCMs.

This paper will discuss in more detail the strategy for planning and implementing maneuvers by Stardust for approach and rendezvous with comet Wild 2. This discussion will include results from Monte-Carlo maneuver analyses which support this strategy. Delta-v costs are demonstrated to fall well within remaining fuel reserves for nearly all contingencies.

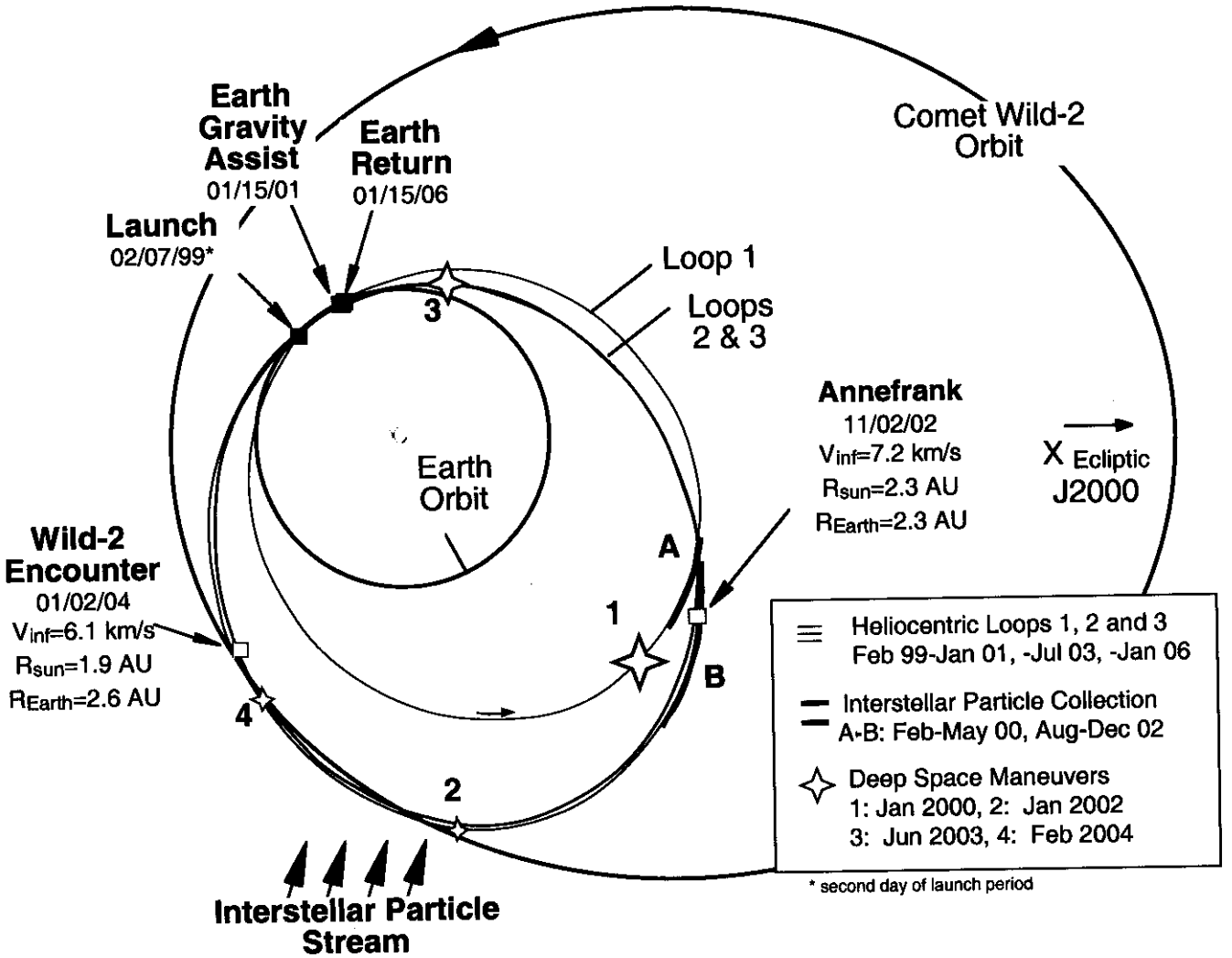

Figure 1. Stardust Mission Trajectory.

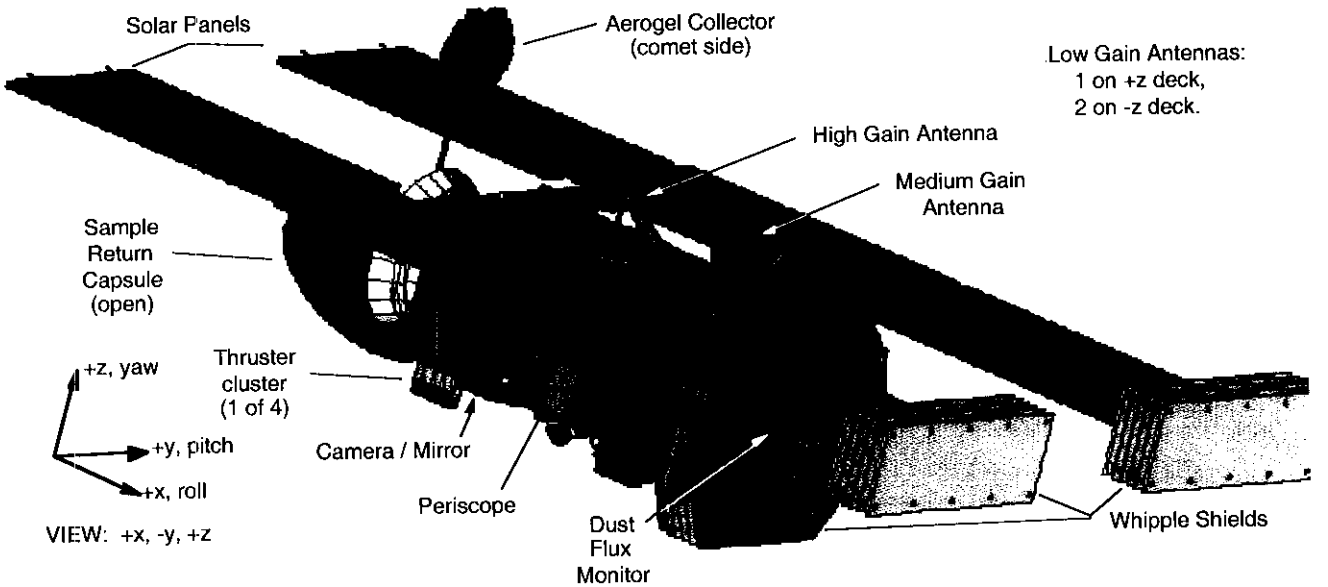

Figure 2. Stardust Spacecraft (+z Axis Normally Pointing Toward Sun or Earth)