WILD2 APPROACH MANEUVER STRATEGY USED FOR STARDUST SPACECRAFT

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Abstract

Stardust, NASA's first dedicated sample return mission to a comet, successfully flew through the comet dust around Wild2 on January 2, 2004. The spacecraft flew within 236 km of the comet, meeting the mission requirement of 250±50 km on flyby distance. Stardust collected dust particles and took several images of the comet while flying close to Wild2. The spacecraft will return to earth with the comet samples on January 15, 2006. To accomplish the above objective, a large Deep Space Maneuver (DSM3) was implemented during June 17 and 18, 2003 and a series of Trajectory Correction Maneuvers (TCMs) were also implemented during the 30 days prior to encounter. Both maneuver design and executions were influenced by number of factors, including the small body ephemeris uncertainty, predictability of small forces arising from 3-axis attitude limit cycling and spacecraft slews. Maneuver design processes, including contingency plans, and maneuver performance characteristics, are discussed in this paper.

Extended Abstract

The Stardust spacecraft was launched on February 7, 1999 with a primary objective of collecting comet dust particles during the close encounter with comet Wild2 and returning them to earth. The secondary objective is to take a series of images of the Wild2 Comet. Additionally, Stardust will bring back interstellar dust collected at times during the mission. The spacecraft flew-past the Wild2 comet on January 2, 2004 and the objectives laid on Stardust for the comet flyby were successfully accomplished by that time. Telemetry data indicate that the spacecraft flew through jets of particles that bombarded the spacecraft and that on at least 5-10 occasions the first layer of spacecraft shielding was breached. The spacecraft survived all these hits and it is currently on its way back to earth with samples.

The Stardust spacecraft began a three-orbit mission trajectory after launch (Figure 1). A series of maneuvers (DSM and TCMs) were implemented to flyby the spacecraft near Wild2 within required range (200 –300 km) at the closest on January 2, 2004.

The configuration of the Stardust spacecraft, shown in Figure 2, utilizes a three-axis attitude control system (ACS), which includes 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 the spacecraft +z direction. These must be accounted for in the orbit determination process and accounted for when implementing propulsive

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maneuvers. Power is provided by solar arrays with a battery in reserve, limiting the time at which the spacecraft can point far off Sun. DSM3 maneuver was split into two maneuvers and implemented on two days due to power constraints.

Since Stardust launch, the navigation team has encountered difficulty in estimating and predicting a consistent estimate of the translational ΔV's resulting from the unbalanced thruster firings due to ACS activities. Each maneuver is a turn-burn-turn or slew-burn-slew. The Z-axis of the spacecraft is pointed towards sun most of the time for power purposes. The thruster are mounted along -Z-axis and therefore, the spacecraft is slewed to maneuver orientation before a burn and slewed back after the burn. These slews or turns account for a large part of the maneuver execution error.

The navigation strategy for the comet Wild2 approach was to use radiometric (Doppler and range data) and OPNAV images for orbit determination. OPNAV images were also used along with ground observations to periodically generate a new Wild2 ephemeris. This new Wild2 ephemeris was again updated during orbit determination if more recent OPNAV images were used.

Each maneuver, since DSM3, targeted the spacecraft to Wild2. The target flyby distance was 150 km at the time of DSM3 and it was changed to 250 km by TCM12 (December 31, 2003) based on scientific consideration. The flyby B-plane error had to be within 16 km (1σ) to meet the mission requirement (250 ± 50 km) on flyby distance. There was no stringent requirement on time-of-flight. It was planned to implement only critical plane maneuvers beginning at two days prior to encounter (E-2d) to correct the B-plane deviations and not the time-of-flight. The time-of-flight was addressed by adjusting timing of the flyby sequence after TCM11. Time-of-flight errors on approach needed only be managed to remain within acceptable limits.

The maneuver strategy and targeting philosophy used for the Wild2 approach was highly robust. Four trajectory correction maneuvers (TCMs) with contingencies were scheduled during the final 30 days prior to the encounter, to achieve the B-plane target within acceptable uncertainties. Because the OPNAV images were most critical to achieve the desired target near the comet for both dust collection and flyby imaging, TCM10 was not scheduled to be executed until Wild2 was visible from the spacecraft. This plan accommodated an adjustment of targeted range relative to the center of the comet nucleus up to two days prior to the encounter.

The implemented maneuver sequence to achieve a Wild2 flyby within mission requirements is shown in Figure 3. This maneuver sequence started at E-199d with DSM3 and ended with TCM12 at E-2d. Although, TCM13 (E-18Hr) was planned, there was no need to implement this maneuver. TCM14 at E-6hr was a contingency maneuver and it was not implemented.

This paper will discuss in more detail of the maneuver strategy used and implemented for Stardust to flyby at 250 km about comet Wild2. The discussion will include results of maneuver analyses and performance of the implemented maneuver strategy.

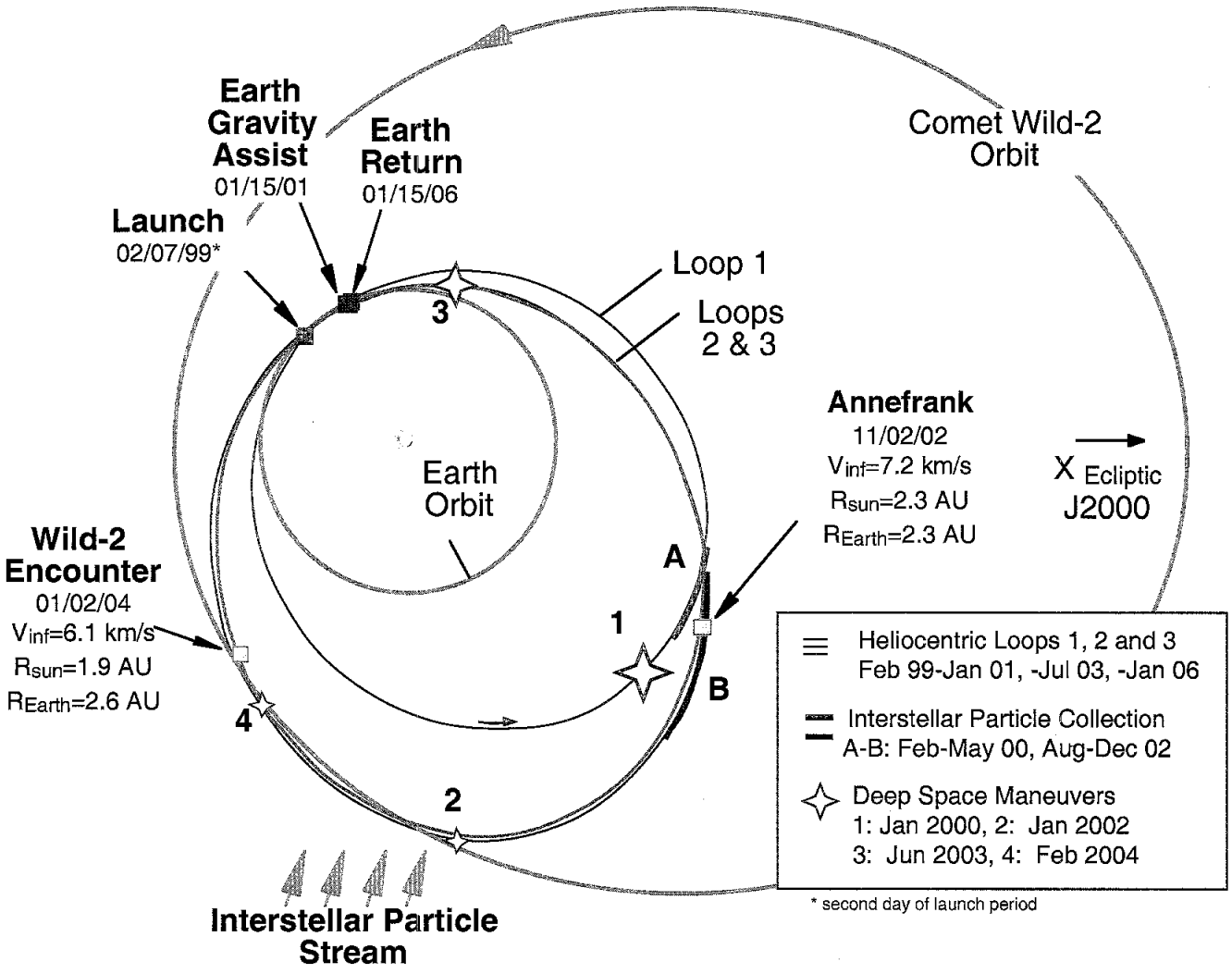

Figure 1. Stardust Mission Trajectory

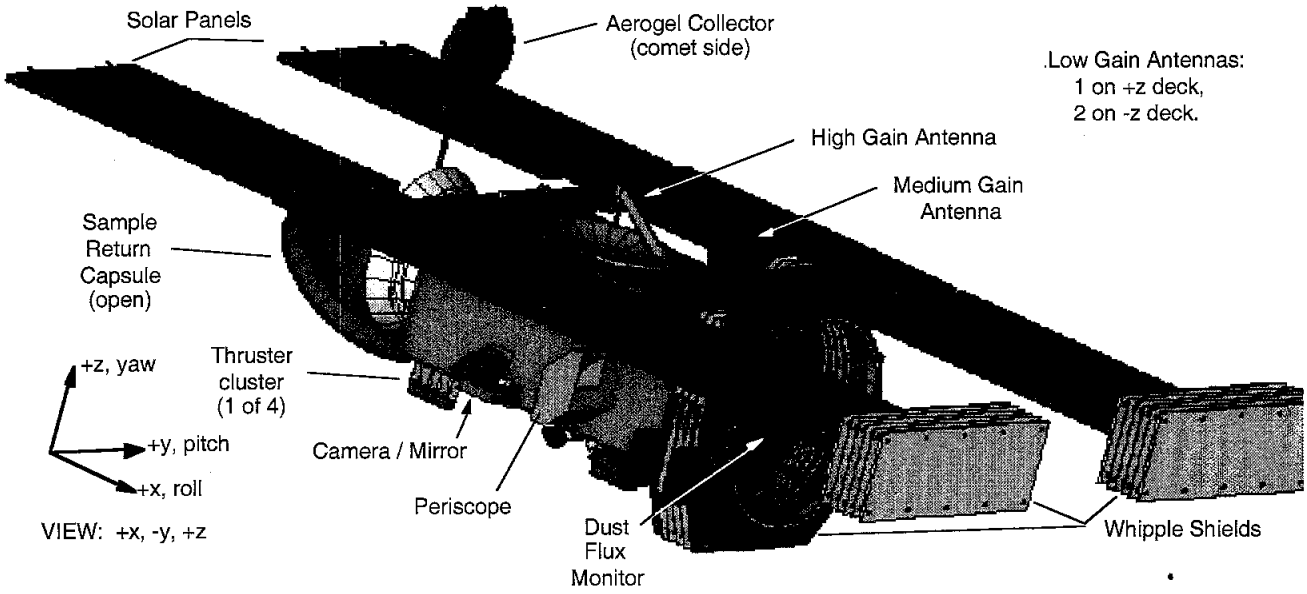

Figure 2. Stardust Spacecraft (+z Axis Normally Pointing Toward Sun or Earth)

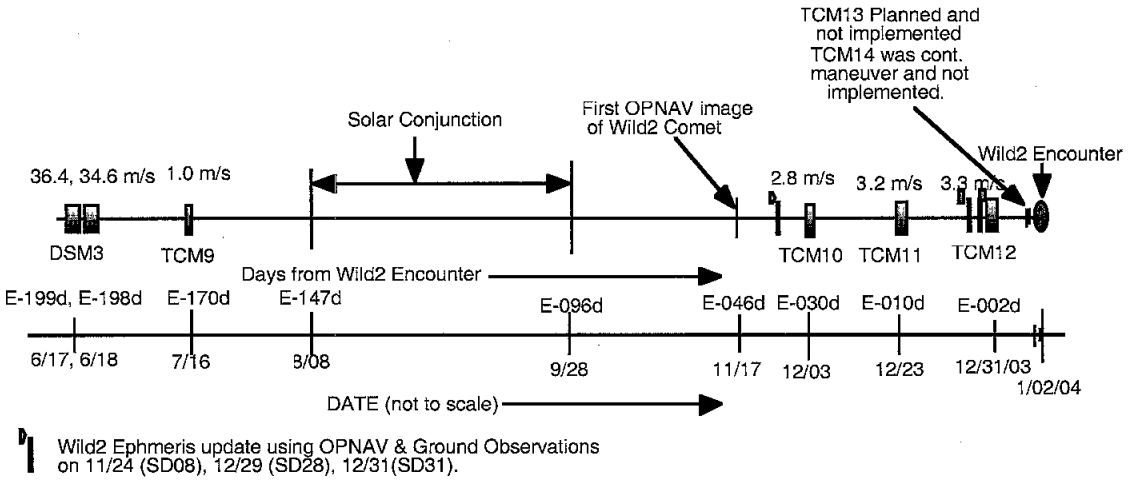

Figure 3: Implemented Maneuver Sequence for Wild2 Encounter