RADIOMETRIC ORBIT DETERMINATION ACTIVITIES IN SUPPORT OF NAVIGATINGDEEP SPACE 1 TO COMET BORRELLY

By

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Extended Abstract

Mission Background

On September 22nd of 2001, The DS1 spacecraft had a very close encounter with the Comet Borrelly. The results of this encounter were a wealth of scientific data, including the first high quality visible images ever taken of a cometary nucleus.

The events leading up this encounter ranged from the routine to the surprising. This paper will try to address the impact that some of these events had on a critical aspect of spacecraft operations: Orbit Determination (OD).

Due to the exceedingly sparse supply of attitude control gas (hydrazine) onboard DS1 (less than 2kg at encounter. Rayman [3]), another means of attitude control was necessary to insure mission success. This means amounted to making use of the ion engine gimbals as a means of controlling spacecraft pitch and yaw (Collins, [2]). This dramatically reduced (but did not eliminate) the drain on hydrazine, with the requirement that the ion engine be left running at nearly a 100% duty cycle.

This requirement for 100% operation of the ion engine also required a dynamic low-thrust mission profile that was to last several months: nearly up to but not including the encounter with Borrelly itself. This profile was constrained to constant select attitudes. Quite often, these non-slewing, static attitudes forced the creation of a sub-optimal mission profile. The initial design and re-targeting of this mission profile is outside of the scope of this paper, and is planned to be the subject of a future paper.

This was necessarily complicated due to the method of attitude estimation that was in place since June of 2000 (Collins, [2]). Bootstrapping the ACS from zero knowledge was inherently difficult, and made more so by the nature of the DS1 gyro, whose unconstrained drift and bias characteristics produced an attitude decay as great as 3 degrees per hour. (Vanelli, [6]).

Effects on Navigation

Due to the nature of DS1's somewhat degenerate condition, its operations requirements were necessarily constraining. This paper will attempt to assess the impact of chronic attitude loss during the low-thrust mission burns which where the de facto way of life or the spacecraft and its flight team. Navigating DS1 while its ion engine is operating is already a difficult task (McElrath, 4), made more so by unconstrained, undocumented attitude slews during nearly- continuous ion thrusting.

Attitude Losses, Causes and Durations During 2001. (Table)

03/13/01@1600	03/16/01@2000	Planned Reboot following FSW upload
07/15/01@2000	07/24/01@1800	Solar interference with Star Observations
08/16/01@1200	08/24/01@1100	Solar interference with Star Observations
09/13/01@1700	09/14/01@0100	Unknown

The first period of attitude loss covered by this paper occurred as a planned reboot following FSW upload activities for the final SW image needed for success off the flyby. (The contents of this upload and its operational use are covered in Collins [2], and Bhaskaran, [1].) As a result of not modeling drift during this time and using a short arc solution for OD (with correspondingly sparse data tracking data), pointing prediction errors of up to 50 mrads (100,000 km out of plane) built up over the following two weeks.

The second and third attitude outages (and corresponding unmodeled low-thrust vector drift) occurred within one and two months of the encounter with Borrelly. The nearness of these two events to the encounter itself created quite a burden on the mission burn profile, requiring quick assessment of the effects and quick re-design of the mission profile. A solid OD was necessary to provide an accurate assessment.

Without this solid, concise OD, additional re-targeting (with the possible risk of exceeding control authority of the engine) would need to be performed at a later date, at greater operational costs to the limited manpower off the flight team, and possibly at the risk of further reducing the amount of hydrazine available for 11th hour RCS TCMs.

The fourth outage in question occurred within a week of the encounter. Its mention here is for the sake of completeness but its impact is not critical to the scope of this paper. The impact of this attitude outage on the encounter with Comet Borrelly is covered fully in Bhaskaran [1].

Conclusion.

The first attempt to acquire an image of the Comet Borrelly occurred on August 25th. This was one day after the completion of the attitude recovery efforts in mid-August. The successful optical identification of Comet Borrelly showed to it to be within one pixel (520km) of where it was predicted (Bhaskaran [1]). This refreshingly small residual can be attributed to the careful modeling of all spacecraft accelerations during periods of spacecraft activity into which little visibility existed, if any. As pointed out by (McElrath [5]), navigating a low-thrust spacecraft is already complicated, and can be made more so by short data arcs, short tracking passes and infrequent passes. Future low-thrust missions should take care to minimize other sources of non-gravitational acceleration, or take care to document them well enough for NAV operations to be not be compromised by a lack of visibility into spacecraft activities.

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Condensed Abstract

In summer of 2001, en route to its encounter with Comet Borrelly, the DS1 spacecraft had critical difficulties maintaining on board knowledge of inertial attitude. Correcting these losses of attitude had a continual impact on the near constant low-thrust mission profile. Successfully modeling this attitude impact to maintain the OD allowed for timely redevelopment of mission burn profiles, and insured success of the DS1 mission as it began the important approach phase of it's encounter with Comet Borrelly.

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