PREPARATIONS AND STRATEGY FOR NAVIGATION DURING ROSETTA COMET PHASE

Pablo Muñoz[(1)], Frank Budnik[(2)], Bernard Godard[(3)], Trevor Morley[(2)], Vicente Companys[(2)], Ulrich Herfort[(2)], and Carlos Casas[(1)]

[(1)] *GMV, located at ESOC[*]. Email: Pablo.Munoz@esa.int, Carlos.Casas@esa.int*
[(2)] *European Space Agency, located at ESOC[*]. Email: <firstname>.<lastname>@esa.int*
[(3)] *VEGA Space GmbH, located at ESOC[*]. Email: Bernard.Godard@esa.int*
[*] *Robert-Bosch-Strasse 5, 64293 Darmstadt, Germany. +49 6151 900*

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ABSTRACT

Rosetta is an interplanetary cornerstone mission in ESA's long-term space science program. Its main objective is the exploration and study of the comet 67P/Churyumov-Gerasimenko during its approach to the Sun. The spacecraft carries 11 scientific instruments and a lander module, Philae, with 10 additional instruments, for the most detailed study of a comet ever attempted. Launched in March 2004 with an Ariane-5/G1, it used four planetary swing-bys (Earth and Mars) in order to obtain the required velocity to reach the comet. During its long journey, Rosetta had close encounters (fly-bys) with two asteroids: 2867 Steins and 21 Lutetia. The spacecraft entered hibernation mode on 8th June 2011, switching off almost all its systems, except the main computer and several heaters. During 31 months it will fly silently on its way to meet the comet, until 20th January 2014, when the spacecraft is set to reactivate again. Four months later, the Rosetta mission comet phase formally starts. This paper describes the planned navigation strategy and preparations that have been performed by the ESOC Flight Dynamics team to support the navigation operations during the comet phase.

Rosetta navigation around the comet is quite challenging due to uncertain *a priori* knowledge on comet kinematics and dynamical properties. Information on the comet's trajectory, mass, size and shape, moment of inertia, orientation and angular rates, gravitational field, accelerations, torques, coma, etc. must be acquired during the navigation process itself, so that the navigation accuracy is progressively improved. Accurate navigation is a requisite to safely fly closer to the comet, to point scientific instruments to regions of interest on the comet's surface and to provide an accurate descent trajectory for the lander delivery.

Radiometric tracking from ground stations on Earth (range, Doppler, ΔDOR) provides very accurate information on spacecraft's trajectory with respect to solar system barycentre. However, these observations alone are insufficient to obtain an accurate estimate of spacecraft's trajectory relative to the comet, due to large *a priori* uncertainty in the comet's trajectory. Therefore, some method of measuring the relative state is required to improve the relative navigation accuracy. Rosetta is equipped with 4 optical cameras which will be used for this purpose by taking images of the comet to deduce the directions from spacecraft to comet's centre (strategy already successfully used for the Steins and Lutetia fly-bys) or to recognizable features (landmarks) on

the comet's surface. This technique of optical navigation with landmarks has never been used before in ESA spacecraft operations.

Rosetta Mission Comet Phase is split into several sub phases, whose main objectives are:

- Comet Approach Phase: reduce relative velocity and bend trajectory towards the comet.
- Initial Comet Characterization Phase: identify landmarks on the comet's surface, determine comet's shape and rotation state and obtain initial estimate of gravity field.
- Global Mapping Phase: map at least 80% of the comet's surface and improve estimates of navigation parameters to allow for closer trajectories.
- Close Observation Phase: close observation of candidate landing sites.
- Lander Delivery Phase: deliver the lander to the selected landing site.
- Relay Phase: maximize coverage of the lander to provide communications link to Earth.
- Extended Monitoring Phase: follow the comet in its excursion around the Sun to monitor its increasing activity.

For previous Rosetta mission phases, three separate orbit determination programs have been used, each of them covering one specific task:

- OD1: spacecraft orbit determination using radiometric data only.
- OD2: small body orbit determination using astrometric data only.
- OD3: improvement of the spacecraft-body relative state estimation using optical measurements of the direction from spacecraft to body centre.

In preparation of the Rosetta comet phase, a new orbit determination program, OD4, is being developed to perform simultaneous determination of spacecraft orbit relative to the comet, comet orbit relative to the solar system barycentre, comet orientation and angular rates and estimation of other spacecraft and comet dynamic parameters, using radiometric tracking and optical measurements of directions from spacecraft to comet's centre and landmarks on the comet's surface obtained from on-board cameras. Moreover, OD4 program includes all OD1 and OD3 functionalities and will support all upcoming ESA deep space missions. The main new developments for this OD4 program are:

- Comet attitude propagation and estimation: integration of rigid body attitude dynamics and variational equations.
- Comet orbit propagation and estimation: models for gravitational and cometary outgassing accelerations.
- Spacecraft orbit propagation and estimation: acceleration models due to comet's environment (gravitational field, coma drag).
- Optical observations modeling: directions from spacecraft to landmarks.

This paper presents the comet approach and proximity navigation operations strategy, it describes the algorithms and implementation details of the newly developed OD4 program and it shows some results of the navigation analysis that is currently being conducted.