Rosetta Navigation during the End of Mission Phase

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ESA's Rosetta mission ended on 30th September 2016, after 26 months operating around the comet 67P/Churyumov-Gerasimenko to characterize it, deploy the Philae lander on its surface, and monitor its evolution during the perihelion passage. The date for the end of mission was selected to be immediately before entering superior solar conjunction and at a point in the heliocentric orbit where the increasing distance to both Sun and Earth was already imposing major constraints on the scientific operations, due to limited on-board solar power and downlink data rate. The last two months of Rosetta operations, named End of Mission Phase (EoM), were dedicated to fulfil the last high level objective of the mission: to orbit the comet as close as possible and to terminate the mission with a final descent and slow impact on the comet's surface.

From early August to late September 2016, during the EoM-Flyovers phase, the spacecraft flew 15 eccentric orbits with progressively decreasing pericentre radius. Before the EoM phase, the closest that Rosetta had orbited the comet was at 10 km radius in October 2014, and 7 km in May 2016, which ultimately led to a spacecraft safe mode triggered by the high number of dust particles in the star trackers' field of view. In the last months of the mission, the decreasing activity of the comet, as it was moving further away from the Sun, allowed to safely navigate the spacecraft at unprecedentedly low altitudes. Flying so close to the comet is extremely challenging for navigation due to the strong orbital perturbations from the gravity field of such an irregular body. The flyover orbits were defined on a plane tilted 20 deg with respect to the day/night terminator plane, with the pericentre in the day side of the comet at +20 deg latitude. The orbital period was about 3 days, adjusted to keep the pericentres at the same time of day, so that a fixed pattern for spacecraft and scientific operations could be applied. Two manoeuvres per orbital revolution were executed 12 hours before and after pericentre to control all orbital elements. The combination of 3-day orbital period and 12.055 hours of comet's rotation period implies that consecutive flyovers would, nominally, be separated by 10 deg in longitude, thus achieving a decent surface coverage. The sequence of flown pericentre radii reached its minimum in flyover#9 at 3.9 km (~1.5 comet radius), and for the subsequent flyovers it was fixed to 4.1 km. The limiting factor for the minimum distance was the trajectory prediction errors, driven by the prediction accuracy on the resulting orbital period after each pericentre passage, where the comet's gravity field was inducing high orbital period variations, of up to 19 hours. During each planning cycle, this effect had to be accurately predicted for the next flyover in order to pre-compensate it with the two commanded manoeuvres. The flyovers phase was very fruitful for the scientific instrument teams as it allowed for extended periods of observations at altitudes never flown before. Moreover, it was during this phase that the lander search campaign finally succeeded to image Philae at rest on its landing site.

After flyover#15, on 23rd September, the spacecraft was transferred to the initial point of the final descent, at 20 km altitude. On 29th September, 14 hours before impact, the collision manoeuvre was executed to cancel the orbital velocity and drive the spacecraft towards a slow impact (90 cm/s) at the target point on the comet's smaller lobe, in the Ma'at region, next to active pits of high scientific interest. The navigation images and radiometric data acquired immediately after the manoeuvre were quickly processed to determine more precisely the impact trajectory and, based on it, generate accurate spacecraft pointing and scientific commands for the last 80 minutes of the descent. As planned, Rosetta automatically switched off at impact, event that occurred 26 seconds earlier and 33 metres away from the target, well inside the a priori considered uncertainties.

This paper describes the trajectory design for the Rosetta EoM phase, it discusses the encountered navigation challenges and how they were tackled, and it reports the achieved navigation results.