Orbit determination of Rosetta around comet 67P/Churyumov–Gerasimenko

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ABSTRACT

When Rosetta arrived at comet 67P/Churyumov-Gerasimenko in early August 2014, not much was known about the comet. The orbit of the comet had been determined from years of tracking from ground observatories and a few months of optical tracking by Rosetta during approach. Ground and space-based images had also been used to construct light curves to infer the comet rotation period. But the comet mass, spin axis orientation and shape were still to be determined. The lander Philae was scheduled to land in about three months at a date chosen as a compromise between the time required to acquire sufficient knowledge about the comet and the risk of a rising comet activity worsening the navigation accuracy. During these three months, the comet had to be characterized.

During cruise, Rosetta had been navigated using 2-way Doppler and range tracking in X-band, sometimes augmented by Delta-DOR. For the purpose of relative navigation, during comet approach, inertial directions from Rosetta to the comet as seen by the spacecraft navigation or scientific cameras had additionally been input to the orbit determination system which was then also solving for the comet orbital state. During the proximity phase, because the comet was now well resolved in the camera and because it was necessary also to determine the comet orientation, these inertial directions to comet measurements had to be replaced by observations of recognizable surface features or landmarks. From that point onwards, Rosetta orbit determination has been solving for a state vector which includes the comet and spacecraft orbital states and the comet attitude state.

Upon arrival at the comet, it was necessary to define as soon as possible a body-fixed frame originating in the center of mass. This frame was to be used to communicate between the scientists, the lander team and the Rosetta Mission Operations Center, in particular to specify coordinates of landing sites. Because there was no apparent nutation, the Z axis could be chosen as the spin axis direction. But for that same reason, it was not possible to determine the principal axis of inertia in the XY plane and thus to define the prime meridian based on the inertias as we had hoped. Worse, the absence of nutation meant the position of the center of mass along the Z direction could not be resolved by the comet attitude motion but only weakly determined by the gravitational pull on the spacecraft. This originally led to a correlated uncertainty in the Z coordinates of all landmarks bigger than 100 meters and an increased uncertainty in the estimated comet mass. The initial variability of the landmark Z coordinates between the different solutions was problematic and it was decided to fix the estimated center of mass positions between different orbit determinations until we reached closer orbits when the determination

accuracy would improve significantly. Lacking knowledge on the comet inertias, the prime meridian had to be defined using surface features. Had we used a single landmark to define the prime meridian, it would have been difficult to guarantee the observability of the prime meridian during any orbit determination arc. Instead it was chosen that many landmarks would participate in the definition of the prime meridian in the sense that there should be no average rotation around the Z axis between two sets of landmark coordinates solutions. The coordinates of all landmarks resulting from the orbit determination process would then be used together with the images to build a shape model.

A rough estimate for the comet mass was obtained in early August but it was not until October, one month to landing, when Rosetta was orbiting at 20 kilometers distance and below that reliable estimates for the mass distribution in the form of gravitational spherical harmonics coefficients of degree and order 2 then 3 were derived. The last mass distribution update, including a 7 meters shift in the center of mass position along the Z axis, was performed in early November less than 2 weeks to landing.

In our preparation for the operations in the vicinity of the comet we had been most afraid of the effects of the dust and gas environment around the comet. The comet activity could lead to accelerations and torques on both the spacecraft and the comet. The gas densities and velocities distributions were computed from models fed from the readings of the pressure sensors of the Rosina instrument and then scaled by the orbit determination process or by spacecraft angular momentum measurements. Different methods of estimating the scale factors would lead to significantly different results. While it was not possible to obtain accurate estimates for the drag acceleration, it is to be noted that the actual activity was significantly lower than what we had simulated in our validation campaign. Modelling the drag acceleration did lead to improvements in the orbit determination accuracy and the modelling errors were not causing large navigation errors. Nevertheless it became apparent a few weeks before landing that the comet was subjected to a torque leading to an increase in rotation period of then only about one second per month. This was something we did not prepare for during our validation campaign and this has resulted in a decreased accuracy in long term prediction of the attitude state of the comet.

The characterisation of the comet performed mainly in the three months from arrival to lander delivery has allowed Rosetta to navigate safely and accurately around the comet. The proposed paper will describe the Rosetta orbit determination process including the comet orbit, attitude and gravity field determination, the dynamic and observation models, the filter configuration, the comet frame definition and will discuss the achieved navigation accuracy.