TRAJECTORY PREPARATION FOR THE APPROACH OF SPACECRAFT ROSETTA TO COMET 67P/CHURYUMOV-GERASIMENKO

Ulrich Herfort(1) **and Carlos M. Casas**(2)
(1) *European Space Agency, Robert-Bosch-Str. 5, 64293 Darmstadt, Germany,+49-6151-902132, Ulrich.Herfort@esa.int*
(2)*GMV, Isaac Newton 11, P.T.M. Tres Cantos, E-28760 Madrid, Spain, +34-91-8072100, cmcasas@gmv.com*

Extended Abstract:

The plan to place a spacecraft in orbit around a comet and eventually deploy a lander on its surface presented ESA with a challenge nobody had ever faced: The trajectory of the comet was poorly known and most of its physical properties, in particular its mass, could be determined only once the spacecraft had reached its target. Furthermore, the time to do this was limited, since the lander had to be deployed before the comet became too active. This is in contrast to insertion into planetary orbit, where the trajectory and mass of the target body are well known in advance.

When the preparations for the approach of spacecraft Rosetta to the comet 67P/Churyumov-Gerasimenko started, only two physical parameters of the nucleus were known with good accuracy from observations using ground observatories and the Hubble Space Telescope [1]: the rotation period and the overall brightness. The latter gave an estimate of the size, which was, however, dependent on assumptions on the albedo and therefore much less accurate. Estimates for the mass were based on the size and the density, which could only be guessed, so the maximum and minimum estimates differed by a factor of more than 10. Estimates for the shape and the rotational state were based on light curve measurements [2], [3] and also afflicted with large inaccuracies.

Since an accurate knowledge of those parameters is essential for trajectory design, an approach strategy flexible enough to cope with a large range of possible comet characteristics had to be devised. To validate the chosen strategy, extensive simulations were performed, the results of which led to major changes to the initial plan. There were two types of simulations: Closed-loop and open-loop.

In closed-loop simulations, the procedures to be applied during real operations were followed as closely as possible. In real operations, the states and properties of both the comet and the spacecraft are estimated together after each orbit manoeuvre using radiometric and optical measurements, and the remaining spacecraft trajectory is optimised based on the results of the estimation. In the simulations, both estimated and simulated “real world” orbit files were maintained after each estimation step for both the spacecraft and the comet. For the spacecraft, the “real world” orbit was calculated by propagating the “real world” state from the previous estimation step into the future, taking into account the re-optimised orbit manoeuvres with random errors applied to them. For the comet, the “real world” orbit file and physical properties did not change during the simulation.

In open-loop simulations, the “real world” orbit file of both the spacecraft and the comet is fixed for the entire simulation, and the initial state for each estimation step is obtained by propagating the previous estimation result over the previous manoeuvres. Open-loop simulations are less realistic than closed-loop simulations but require less effort, since the trajectory optimisation can be performed once at the beginning of the case under study and then the estimation process can be simulated independently and repeatedly to assess the achieved accuracy.

The results of the first simulations clearly indicated that the original plan, which foresaw a direct insertion into a bound orbit at the end of the approach phase, was not feasible since the comet mass could not be determined with sufficient accuracy before the insertion manoeuvre. Instead, after several iterations, a new strategy was devised: The initial characterisation of the comet was done from hyperbolic arcs at cometocentric distances between 50 and 120 kilometres. The velocity in these arcs was chosen such that the influence of the initially poorly known comet gravity force on the spacecraft orbit was large enough to provide an accurate determination of the comet mass, but still small enough to allow a reasonably accurate orbit prediction. Orbit manoeuvres were performed regularly to keep the spacecraft close to the comet, in such a way that the comet-spacecraft vector formed two pyramids with the nucleus at the apex.

From these pyramid orbits, the mass, rotational state and shape of the comet could be estimated. Moreover, landmarks on the surface of the nucleus could be identified with sufficient accuracy for a safe insertion into a bound orbit. Following the insertion, the spacecraft entered the Global Mapping and the Close Observation phases, in which the knowledge about the comet properties was further improved by observations from successively closer orbits around the comet.

The validity of the revised strategy was finally fully confirmed when it was put into action during the actual operations, without the need for any modifications.

7. References

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