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Rosetta following a living comet

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ABSTRACT

The International Rosetta Mission was launched on 2nd March 2004 on its 10 year journey to rendezvous with comet 67P Churyumov-Gerasimenko. Rosetta performed comet orbit insertion on the 6th of August 2014, after which it characterised the nucleus and orbited it at altitudes as low as a few kilometres. In November 2014 Rosetta delivered the lander Philae to perform the first soft landing ever on the surface of a comet. The critical landing operations have been conducted with remarkable accuracy and will constitute one of the most important achievements in the history of spaceflight.

After this critical operation, Rosetta began the escort phase of the comet in its journey in the Solar System heading to the perihelion, reached in August 2015. Throughout this period, the comet environment kept changing with increasing gas and dust emissions. A first phase of bound orbits was followed by a sequence of complex flyby segments which allowed the scientific instruments to perform in depth investigation of the comet environment and nucleus. The unpredictable nature of the comet activity forced the mission control team to implement unplanned changes to the flight plan prepared for this mission phase and to plan the whole mission in a more dynamic way than originally conceived.

This paper describes the details of the landing operations and of the main comet escort phase. It also includes the mission status as achieved after perihelion and the findings about the evolution of the comet and its environment from a mission operations point of view. The lessons learned from this unique and complex operations phase and the plans for the next mission phases, which include a mission extension into 2016, are also described.

1. Introduction

Rosetta is a cornerstone scientific mission of the European Space Agency [1–3], launched on 2nd March 2004 on an Ariane 5G+ rocket. Its main scientific objective was to rendezvous with the nucleus of comet Churyumov-Gerasimenko in 2014, to orbit it for about 1.5 years and to deliver onto the nucleus' surface a landing module named Philae. Seven years of active cruise, in which several planet gravity assist manoeuvres and two asteroid fly-bys were carried out [4–10], were followed by the final part of the cruise, where Rosetta (Fig. 1) had to fly at distances from the Sun that had never been reached before by a solar-powered spacecraft (aphelion was reached on 3rd October 2012 at about 5.3AU distance) [11]. Notwithstanding the large solar array (64 m^2), in order to survive at such Sun distances, the spacecraft had to be almost fully deactivated from June 2011 to January 2014 [12,13] to drastically reduce the power consumption. After re-activation, the final mission phase was flown towards its target, which was reached early August 2014; a full comet mapping and characterisation phase was then carried out, leading to the selection of a landing site for Philae [14].

Section II of this paper describes the operations of the comet orbital phase including the landing event. The evolution of the spacecraft orbit and the planning scheme as a function of the growing comet activity is described in section III. Section IV describes the perihelion phase and the plan for the next mission phases. Lessons learned and conclusions are addressed in sections V and VI respectively.

2. Comet orbital phase

After having characterised the comet to the level of detail necessary for orbiting and landing (global mapping phase), Rosetta began its close observation phase early October 2014 when the orbit radius was changed from ca. 29–19 km and the spacecraft, after an excursion to the night side (120 deg phase angle with the Sun), was moved to the terminator plane (see Fig. 2). On this orbit only the edge of the large solar panels, which are pointing to the Sun, is exposed to the – mostly radial - gas flow originating from

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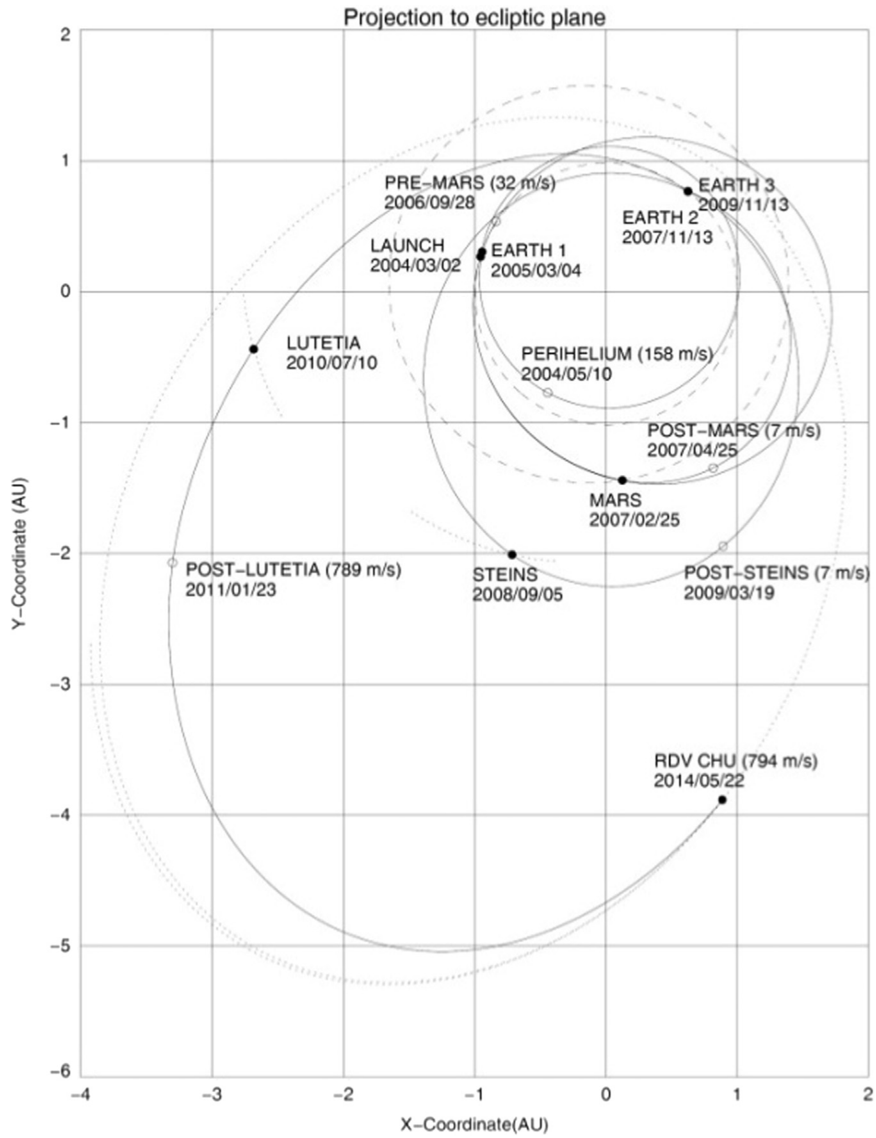

Fig. 1. Rosetta interplanetary trajectory.

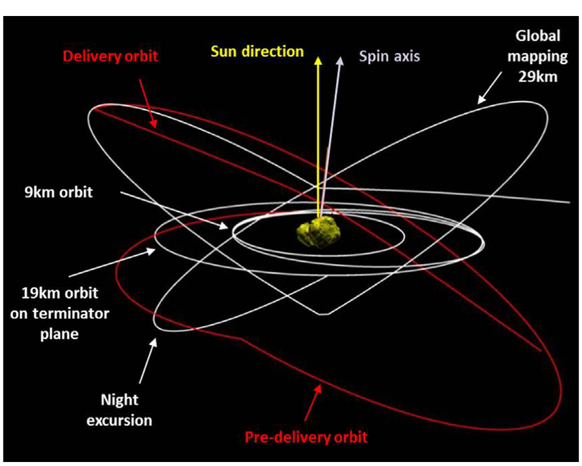

Fig. 2. Global mapping and close observation orbits.

the comet; this reduced to the minimum the aerodynamic accelerations, which could not be predicted accurately enough yet by the comet engineering model being developed in parallel.

A further reduction of the orbit radius to ca. 9 km was then conducted once the operations team had reached an adequate level of confidence in their engineering models of the comet environment. This was possible only after having performed an excursion at lower altitudes when the pericenter of a $9 \times 19\ km^2$ orbit was flown. During this pericenter pass the error on the predicted vs. actual spacecraft position reached a value of ca. 1.7 km at a distance of ca. 10 km thus resulting in an attitude pointing error of ca. 10 deg (see Fig. 3), i.e. translated in pointing error relative to the comet this well beyond the field of view (FoV) of the vast majority of the remote sensing instruments (e.g. navigation and science cameras) and in particular preventing optical navigation.

With the data collected during this pericenter pass the model of the gravity field was updated with second order harmonics (see Fig. 4) and sufficiently accurate navigation on a 9 km circular orbit became possible.

After an initial screening of the whole comet surface, the comet models developed with data collected throughout this phase allowed the selection of the 5 candidate landing sites (see Fig. 5).

The overall process involved several parties, from the mission operations and flight dynamics experts to the Rosetta Principal Investigators, the Philae engineering and operations experts and