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Chapter 12

Rosetta: Twenty-Seven Years of Mission Evolution from First Feasibility Concepts to Final Impact on the Comet*

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Abstract

The Rosetta mission of ESA was focusing on cometary exploration. Like most planetary missions, it required a significant period of time for realization, including many adaptations of the original plan. From the first studies to mission completion, about 27 years passed by with changes related to team composition, mission objectives, target comet and design parameters. A summary of this specific mission evolution will be provided, from the early system design studies to the final surface impact on the comet in September 2016.

I. Introduction

The successful *Giotto* flyby on 14 March 1986 at Comet Halley initiated in Europe significant follow-on activities for cometary exploration. The main scientific objectives related:

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- to provide access to most primitive and pristine materials in our solar system,
- to learn further details about the evolution of our solar system, and
- to understand the contribution of organic materials from comets to the origin of life on Earth.

The Rosetta mission for cometary exploration required, like most planetary missions, a significant period of time including many adaptations of the original plan, until it arrived at its target and completed the mission objectives in September 2016.

The author was already involved from early system definition studies for the so-called Comet Nucleus Sample Return (CNSR) in 1989. Thus, this contribution will emphasize the mission and spacecraft design evolution during this period of 27 years. It will in particular address the technology challenges and the solution approaches of the related changes during this very long mission preparation and operations period.

II. Comet Nucleus Sample Return Mission (CNSR)

A joint ESA/NASA Science team was formed at the end of 1985 to define the scientific objectives for a mission to address in-situ study of comets and the return of samples. In the very early industrial mission and system analyses, starting 1989, the models of the comet were mainly based on the measurements from *Giotto* at Comet Halley. The comet was considered to have the shape of a slightly deformed ball. The mission was planned as a joint mission by ESA and NASA. While NASA contributed the launcher, a Titan-Centaur, and the main spacecraft, derived from the Mariner-Mark-II spacecraft bus, ESA's shares were the Lander and the Return Capsule. The objective was to land the complete spacecraft on the comet, in order to enable drilling and sampling of materials to a depth of 3 m. The acquired comet materials had to be stored in a return capsule to bring the pristine cometary materials to Earth for detailed analyses in laboratories.

A first scientific payload was composed and technology design drivers for rendezvous with the comet, landing on an appropriate surface location, sample acquisition, storage and return of pristine original materials to Earth were analyzed [1]. Crucial technical problems had been identified and analyzed in parallel technology studies, related to drilling in terrain with uncertain surface properties [2], [3], as well as navigation techniques for cometary approach and landing [4]. Due to the significant distances, the related signal propagation delay required challenging autonomous reaction capabilities on those time critical phases [4].

The energy supply at such huge distances towards Sun was based on Radioisotope Thermoelectric Generators (RTGs) to be contributed by NASA.

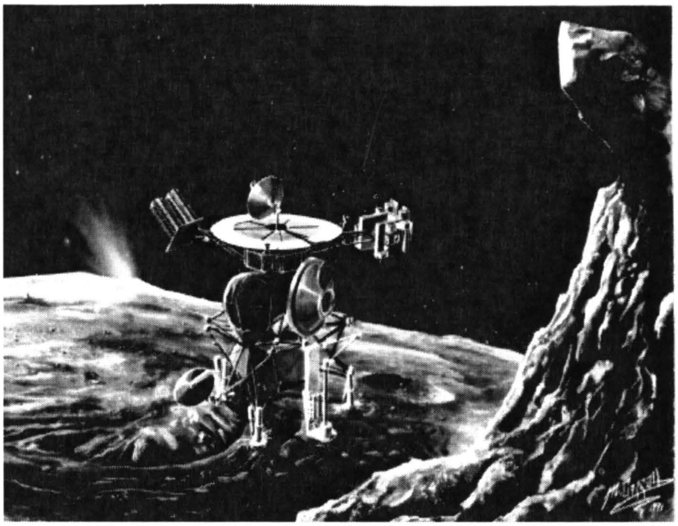

Figure 12–1: CNSR-spacecraft landed on comet. The three Lander legs are fixed to the surface by harpoons and the drill equipment (in front) is deployed for cometary sampling, to bring the materials for storage into the Return Capsule above. Courtesy ESA.

III. RoLand and Champollion

When NASA encountered financial and programmatic difficulties in 1992, analyses for a mission, achievable by ESA on its own, were initiated. This was based on the Ariane-5 launcher. Here a major design driver became the power generation, as RTGs had to be replaced by very large solar arrays to provide sufficient energy at the necessary huge distances towards Sun. Therefore, landing of the complete spacecraft on the comet became impossible. Nevertheless, the scientific community considered both, remote sensing as well as in situ surface science, as essential. In order to deliver the surface science package, a dedicated Lander had to be included. After an Announcement of Opportunity, the two cometary landers, Champollion (by NASA/CNES) including even a sample return, and RoLand (German-led), both at about 45 kg mass, were proposed. The core spacecraft *Rosetta* focused on remote observations.

Due to lack of funding, JPL had to withdraw its contributions in 1996. As consequence both Lander teams merged to construct the *Rosetta* Lander, later called Philae, at a mass of about 100 kg. It carried 10 scientific instruments, an upward thruster pressing it to the surface, fixation by two harpoons, and three ice screws in the landing pads.

IV. Ariane 5 Maiden Flight Failure

After the Ariane-5 maiden flight failure, the next launch would have been *Rosetta* and had to be delayed until the cause for the defects were identified. Due to the related delay, the limited launch window to target comet 46P/Wirtanen was missed. After Ariane-5 returned to service, an intensive search for alternative new comets was initiated, leading to the selection of 67P/Churyumov-Gerasimenko. Nevertheless, this change had significant impact on the redesign of the approach trajectory.

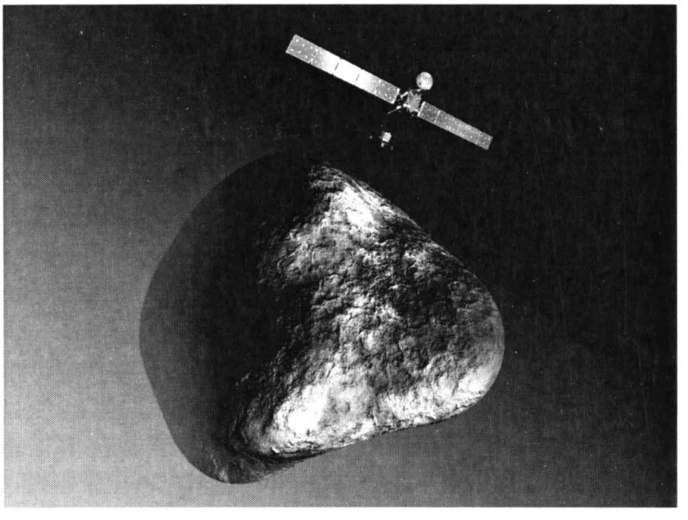

Figure 12–2: Expected cometary shape during spacecraft and mission design. Courtesy ESA.

V. The Rosetta Mission

Rosetta was realized by 50 contractors from 14 European countries and the United States. Major subcontractors were Astrium Ltd., that built the spacecraft platform; Astrium France, that supplied the spacecraft avionics; and Alenia Spazio, Turin, Italy, for assembly, integration, and verification. Finally, launch occurred on 2 March 2004. After an interplanetary transfer, including several flybys at Earth, Venus, and Mars, *Rosetta* finally arrived in 2014 at the comet and was inserted in an orbit around the comet.

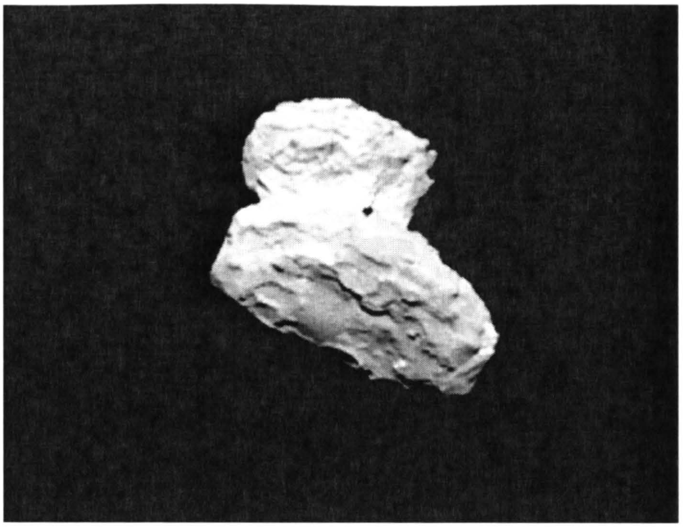

Figure 12–3: The surprising shape of the comet P67 Churyumov-Gerasimenko. Courtesy ESA.

After a period of near-range observations, on 12 November 2014, the lander Philae was delivered to the surface of comet P67 Churyumov-Gerasimenko. ESOC flight dynamics provided impressive precision at orbit insertion and comet approach targeting.

Fortunately, all devices to guarantee surface attachment (cold gas thruster, harpoons, ice screws) failed, therefore, three landings occurred, with final settling near a very interesting cliff, a site where nobody would have dared to land.

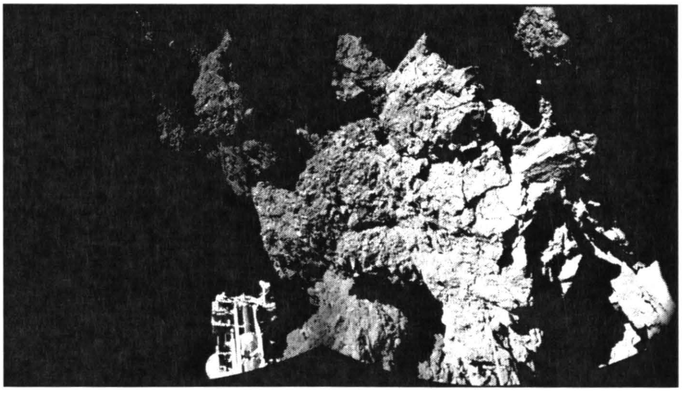

Figure 12–4: Final settling of Philae in a cometary crevasse. One lander leg (visible at the right) is in contact with the comet material. Courtesy ESA.

All Philae instruments acquired data and transferred them to Earth, before Philae was hibernated. In August 2015, the perihelion passage offered near-range observation of the most active phase of the comet. Finally, at the end of September 2016, the *Rosetta* spacecraft ended the mission with a controlled impact on the cometary surface, despite never being constructed for that purpose.

VI. Conclusions

There was an evolution of the Rosetta mission from a cometary nucleus sample return mission to a remote observation spacecraft, accompanied by the cometary lander Philae, due to encountered changes in partnership. Delays in mission definition progress and launcher defects required reselection of the target comet, as the interplanetary trajectory based on several planetary fly-bys was extremely sensitive to timing. After delivery to the comet, all three Philae surface fixation tools unfortunately failed and finally settled Philae in a scientifically much more interesting area. During the 27 years of *Rosetta,* many evolutions and unforeseeable budgetary and technology surprises occurred, and the mission struggled for survival. Nevertheless, at the end, more interesting results than ever expected were returned.

Acknowledgments

The challenges of Rosetta enabled friendships to many people in companies and agencies over this very long period.

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