Rosetta Command and Monitoring Operations for Philae Landing

Francesco Castellini[1], Sabine Kielbassa[2], Carlos Bielsa[3], Federico Zuiani[4]

[1][2][3][4] *ESA/ESOC Flight Dynamics, HSO-GFS, Robert-Bosch-Str. 5, 64293 Darmstadt, Germany, +49(0)6151-900, Francesco.Castellini@esa.int, Sabine.Kielbassa@esa.int, Carlos.Bielsa@esa.int, Federico.Zuiani@esa.int*
[1][2] *Telespazio VEGA Deutschland GmbH, located at ESOC*
[3]*GMV, Isaac Newton 11, P.T.M., 28760 Tres Cantos (Madrid), Spain, +34-91-8072100, cbielsa@gmv.com*
[4]*CGI Deutschland GmbH & Co KG, Rheinstr. 95, 64295 Darmstadt, Germany, federico.zuiani@cgi.com*

Extended Abstract:

On November 12th 2014, the European Space Agency's Philae lander was released by the Rosetta spacecraft and, 7 hours later, achieved the first-ever soft landing on a cometary nucleus. Such an accomplishment required a large effort from the Flight Dynamics (FD) team at ESOC, and this paper describes in detail the FD activities carried out in preparation for the landing and during the critical operations that started about one day before separation. The focus of this paper is on the contribution of spacecraft commanding and monitoring activities to the success of the Philae landing, including the characterisation of comet environment starting several months before separation, the monitoring of spacecraft (SC) health in the days before separation, a variety of analysis and simulation exercises involving the SC and its interaction with the environment, and the flawless execution of the operational timeline from pre-delivery trajectory to lander relay phases.

As part of the exercises of characterisation of comet environment, this paper presents the continuous processing of coma gas modelling started in August 2014, as well as the analysis of optical images and TM from star trackers and sun sensors in the days before separation to assess the likelihood of interference of coma dust particles on the SC sensors.

The monitoring of the SC health included reaction wheel friction torques to ensure the availability of the four reaction wheels for attitude control during the slews before and after separation. Moreover, a precise calibration of the accelerometers bias was instrumental in the accuracy of the lander touch-down, and a long calibration slot with the SC in delta-V manoeuvre attitude was allocated to allow for precise calibration in an environment of thermal stability.

A variety of analyses and simulation exercises were conducted to inform the design of the activity timeline. The comet illumination and landmarks visibility was verified with realistic simulations of the optical images scheduled for the pre-delivery orbit, concluding that there would be sufficient information to reconstruct the spacecraft state within required accuracy. The likely effects of coma drag force on SC and lander trajectories, and of coma drag torque on SC angular momentum were also determined. Finally, test AOCS telecommands were executed in the engineering qualification model and simulation exercises carried out in the weeks before separation involving all ESOC Flight Dynamic Subsystems and the Fight Control Team.

The flawless execution of the operational timeline, covering pre-delivery trajectory, separation and lander relay phases, was the last main contribution of the commanding and TM monitoring subsystems to the success of the Philae landing. A remarkable number of complex activities was accommodated in the course of a few hours around lander separation, including three delta-V manoeuvres, several wheel off-loadings, complex attitude rasters for optical images of the comet nucleus and the descending lander, high gain antenna steerings and a variety of AOCS mode changes. Furthermore, several GO/NOGO decision points were envisaged involving close interaction among the different subsystems, including a GO/NOGO based on delta-V performance soon after the reception of Doppler data for the pre-delivery OCM. The paper will briefly outline the operational timeline from a systems approach perspective.

In addition to presenting the aforementioned activities, the paper provides numerical results from actual operations that confirm their contribution to the success of the landing. Reductions from SC telemetry are presented, including accelerometer bias results that show how even the last update just 4 hours before separation contributed to further improve the pre-delivery OCM accuracy to an error of only 1 mm/s in a 84 cm/s delta-V manoeuvre. The decision of not pre-compensating the SC attitude before lander ejection was also proved correct by attitude TM and the reconstructed lander descent trajectory. Accurate reconstruction of the orbiter and lander trajectories was possible thanks to the optical images collected before, during and after separation, and radio link between orbiter and lander was established soon after ejection.

It was the diverse commanding and monitoring activities described in this paper, together with a robust attitude and trajectory design, accurate landmark optical navigation and flawless performance of the spacecraft platform, that allowed to bring Philae at a touch-down point 118 meters away from the target landing coordinates on the smaller lobe of comet 67P/Churyumov-Gerasimenko, after a purely ballistic descent in an active comet environment.