PREDICTION OF THE COMA DRAG FORCE ON ROSETTA

Carlos Bielsa[(1)(2)], **Michael Müller**[(1)] **and Guillem Huguet**[(1)(2)]

[(1)]*ESA/ESOC Flight Dynamics, HSO-GFS,*
Robert-Bosch-Str. 5, 64293 Darmstadt, Germany
+49-6151-90-4253, Carlos.Bielsa@esa.int, Michael.Mueller@esa.int

[(2)]*GMV,*
Isaac Newton 11, P.T.M., 28760 Tres Cantos (Madrid), Spain
+34-91-8072100, cbielsa@gmv.com

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ABSTRACT

Rosetta is a mission of the European Space Agency (ESA) to 67P/Churyumov-Gerasimenko (CG) designed to complete the most detailed study of a comet ever attempted. It was launched on 2 March 2004 and will arrive at CG in mid 2014.

In November 2014, when the comet heliocentric distance is 3 AU, the Philae lander will separate from the orbiter, following a non-propelled trajectory that will deliver the Surface Science Package (SSP) to the landing site of choice on CG's nucleus surface. After this, the Rosetta orbiter will stay closer than a few hundred kilometers from the comet nucleus until the end of 2015. In the comet vicinity the dominating forces are the comet gravity and the drag force due to the presence of cometary atmosphere (coma).

The formation of the coma is due to sublimation of ices on the comet nucleus. The sublimated gases accelerate due to adiabatic expansion and reach a speed of typically 1 km/s relative to the comet nucleus. Even though the gas flow also drags condensed particles from the comet surface, the drag force on Rosetta spacecraft (S/C) is expected to be dominated by the gas.

Rosetta arrives at the comet at a heliocentric distance larger than 3 AU, when the comet activity is low. From Earth based observations of CG, it was estimated that at 3 AU, the drag force is in the order of 10% the gravitational force, whereas at perihelion both forces are in the same order of magnitude. Accordingly, an estimation of the drag force needs to be incorporated for orbit prediction.

Because no accurate model of the coma is available for operations, nor will it be when the S/C is close to the comet, the approach for prediction will be empirical, i.e. past measurements of the drag forces and resulting torques will be used for prediction under changed geometries and levels of comet activity. It is foreseen to also incorporate measurements from remote sensing instruments (e.g. navigation camera) in this process.

In order to exercise this empirical prediction process before arrival at the comet, a physical model of the coma was developed. This model calculates the thermodynamic state around the

comet based on assumed physical parameters on the nucleus surface. For a given trajectory, the physical model is used to simulate measurements of on-board accelerometers, environmental torques on reaction wheels and remote sensing instruments. Based on simulated measurements, it is exercised how past measurements would be scaled to future predictions and the quality of the process can be assessed. The present paper demonstrates this for two mission scenarios: The SSP delivery and a close fly-by at perihelion.

The objective of the SSP delivery phase is to eject the lander from the orbiter such that the SSP reaches a certain target landing site on the nucleus surface following a non-propelled trajectory. During this phase, the Sun is still at a distance of 3 AU, and a low comet activity is expected (mass loss between 2 and 24 kg/s). The orbit has been designed so as to facilitate the prediction of the orbit state: 5 km pericenter, 10 km apocenter and trajectory in the vicinities of the terminator. In addition, prior to the pass during which the lander will separate form the orbiter, the S/C will undergo repeated revolutions under similar conditions. Because both the ejection and touch-down directions are predetermined, the S/C attitude at separation is fixed and needs to be maintained several hours before. There are also constrains on the high gain antenna (HGA) and solar array (S/A) articulation angles.

Our analysis shows that while the acceleration is below the level of sensitivity of the on-board accelerometers, torque measurements provide enough sensitivity to determine the activity of the coma with relative accuracy, although this is only true for certain S/C attitudes, and S/A - HGA articulation angles. Moreover, we calculate the trajectory deviations due to the action of the coma on both the orbiter and the lander for a scenario of maximum activity. The study shows that the orbiter deviation during the 5 hours prior to separation is below a few hundred meters and the effect of the coma on the lander descent trajectory is an order of magnitude lower.

While the comet continues its excursion around the Sun, the orbiter will follow it undergoing a number of close fly-bys, during which it is foreseen that the S/C will get as close as 5 km from the nucleus with relative velocity of 1 m/s. Propellant budget analyses estimate that there will be enough propellant to undertake about 15 close fly-bys before the mission comes to an end.

The most severe conditions will be present at pericenter, when the distance between the Sun and the comet reaches a minimum of 1.24 AU and the highest comet activity is expected (mass loss in the range 130 to 380 Kg/s). The fly-by analysis of the paper will focus on this worst-case scenario. We show that at these levels of comet activity, the use of the accelerometers is feasible. Furthermore, because there will be weeks of separation between two consecutive close fly-bys, coma conditions are expected to change considerably. This suggests the need of including measurements taken by on-board remote sensing instruments into the prediction process. The paper will assess the optimal selection of sensors and scaling methods under different geometries and activity levels.