Philae landing on comet Churyumov-Gerasimenko: understanding of its descent trajectory, attitude, rebound and final landing site.

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The 12th November 2014, at 16:03 UTC, Philae became the first spacecraft to "softly" land on a comet.
It was released by Rosetta around 8:35 UTC and gently descent to the comet. After 7 hours descent, it touched down the ground 112 m away from its targeted landing point and 51s later than scheduled. Its impact velocity was around 1m/s. This was already great news as the landing dispersion ellipse was 1 km long and the touchdown window, 40 minutes large.
To prevent any rebound, Philae was equipped with two harpoons and a thruster supposed to push the spacecraft to the ground. Unfortunately the anchoring system failed and Philae experienced a two hours long bouncing trajectory, including two touchdowns. Philae finished its ballistic flight more than 1 km from its targeted landing site.
During its descent, called Separation Descent Landing (SDL), Philae was stabilized around its Z axis (axis orthogonal to the landing gear) by a flywheel. At the first touchdown, the flywheel was switch off but continued to rotate 42 min before complete shutdown. As the lander was flying, the deceleration of the flywheel transferred its momentum to Philae providing stabilization during the rebound.
During 57 hours, 10 of 12 scientific instruments on board Philae realized in situ analysis during the First Science Sequence (FSS).The FSS was designed to work only with the two Philae batteries. When batteries run out of energy, Philae was supposed to recharge them with the help of its 6 solar arrays and resume its science activities for the so called Long Term Science (LTS). Unfortunately, as it was poorly illuminated, it failed to recharge its batteries and entered into a hibernation mode waiting for more sunny days. Indeed the lander is equipped by electronics able to withstand very low temperatures and wake-up automatically when illumination conditions improve.

The landing operations were accomplished thanks to the joint work of the ESA, DLR, CNES and scientific teams. The Science Operation and Navigation Center (SONC) located in CNES Toulouse was in charge of

- Supporting the Landing Site Selection Process (LSSP): the objective of LSSP was to find a nominal site and a backup that comply with the Rosetta constraints on the delivery orbit, with the Philae constraints on descent trajectory and landing conditions and mission constraints for further operations (illumination, orbiter lander visibilities).

- Determining after landing the precise location and attitude of Philae as well as the communication opportunities and lander illumination.
- Planning science operations of the Philae instruments and distributes de data among the instruments teams.

The Flight Dynamics team of SONC (SONC-FD), one of the SONC team, was realizing the 2 first activities and this communication focus on the understanding of the landing, trajectory and attitude, as well as final landing site and attitude.
The carried analyses are split into three parts: the reconstruction of the SDL trajectory and attitude up to the first touchdown, the trajectory and attitude during the rebounds and finally the search for the final landing site and estimation of the final attitude.
These analyses are not only interesting from an intellectual point of view but are necessary for the understanding of the scientific data collected during SDL and FSS but also to forecast if Philae is still able to wake up from its hibernation phase and achieve the Long Term Science (LTS). One also needs to compute the best opportunity to enter in contact with it and to prepare the operations of LTS.

Due to the weight and power constraints, Philae was not equipped with specific sensor to determine its trajectory and attitude. The reconstruction of these data is then very tricky and maybe achieved only in a collaborative effort using all available data: scientific measurement and housekeeping data. As example of scientific data, one can mention the pictures taken by the various imagers on board Rosetta (OSIRIS, NAVCAM) and Philae (ROLIS, CIVAP). The CONSERT radar sounder on board Rosetta and Philae provided some ranging between Philae and Rosetta during SDL and FSS. The ROMAP magnetometer (on board Philae) provided assessment of the attitude variation also during SDL and FSS. The list is not exhaustive. The list of usable housekeeping data is shorter: the RF link information between Rosetta and Philae and the current and output voltage produced by the solar arrays of Philae.

The role of the SONC-FD was to centralize the various data, to cross-check them, to analyze them in order to produce trajectories and attitude and to distribute them to the lander community. A second task, based on the final landing site and lander attitude estimation, SONC-FD try to prepare an eventual LTS. This means determining when the lander will have sufficient illumination to wake-up and to compute possible RF link between lander and orbiter.

This communication will present all efforts realized by SONC-FD to reconstruct the lander trajectory and attitude during SDL and rebound as well as the localization of the lander on the comet, place and attitude. For each phase, SDL, rebound, FSS, we will present all input data and assumptions used for the analysis. We then will provide the obtained results. The last part of the presentation, we will be devoted to the forecast of the illumination condition at landing site and the visibility opportunities between Rosetta/Philae.