

**PREPARING FOR LANDING ON A COMET – THE ROSETTA LANDER PHILAE.** Jens Biele<sup>1</sup> and Stephan Ulamec<sup>1</sup>, <sup>1</sup>German Aerospace Center (DLR), RB-MUSC, Linder Höhe, 51147 Cologne, Germany, jens.biele@dlr.de, stephan.ulamec@dlr.de).

**Introduction:** Rosetta is a Cornerstone Mission of the ESA Horizon 2000 programme. It is going to rendezvous with comet 67P/Churyumov-Gerasimenko (CG) after a 10 year cruise and will study both its nucleus and coma with an orbiting spacecraft and a landed platform. The latter, named Philae, has been designed to land softly on the comet nucleus and is equipped with 10 scientific instruments to perform in-situ studies of the cometary material [1,2].

Presently, the Rosetta spacecraft is beyond Jupiter orbit and in a spin-stabilized hibernation until Jan 20, 2014. The paper describes the preparations for landing, foreseen in November 2014 at a heliocentric distance of 3 AU, and gives an outlook of near- and on-comet operations. Emphasis is placed on the predicted and to be determined outgassing drag forces, material properties and relief of the comet nucleus surface for landing site selection and for calculation of the descent.

**The last leg of the mission:** After a post-hibernation commissioning early 2014 the Rosetta spacecraft will begin the comet approach phase including orbit insertion. During 2014 remote observations (allowing the selection and characterization of a landing site) will be performed, preparing for the landing. The parameters for the actual separation, descent and landing strategy can only be finalized once the comet nucleus has been characterized from orbit. In particular the shape, state of rotation, gravity field and the gas and dust environment are relevant key parameters. Figure 1 shows a drawing of the Rosetta Lander (Philae). Its mass is ~ 100 kg, its cross-section ~ 1m<sup>2</sup>.

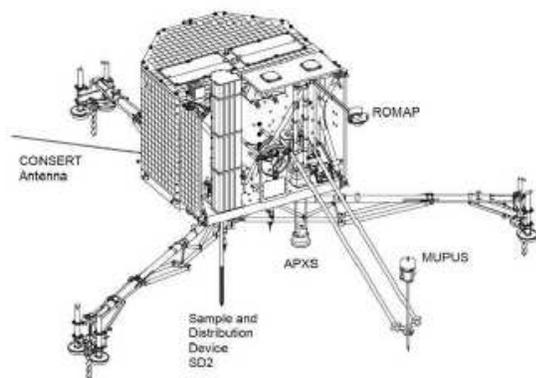


Figure 1

**Mandatory characterization of the comet:** A set of “operational observations” by the orbiter’s scientific instruments and sensors (navigation cameras, reaction wheels, radiometric data) has been defined to enable landing site selection and safe landing. The mandatory observations are:

- Determination of the comet’s global shape (including the polar night parts) and its mass (GM), defining the bulk density
- Rotational dynamics (period, spin axis direction, excited rotation if any)
- Composition maps (color ratios, direct determination of water, CO, CO<sub>2</sub>, organics by spectroscopy)
- Surface temperature maps for selection of engineering thermal models
- Coma gas production rate, dependence on angular distance to subsolar point, coma density, composition (mean molar mass), gas velocity vector; remotely and in situ.
- High-resolution local digital terrain models (DTMs) of the potential landing area, determination of slopes and surface roughness

**Outgassing:** Typically (comet Hale-Bopp being an exception), the gas production rate  $Q$  (global integral) of comets is only observable near perihelion with ground based telescopes. However, for comet missions like Rosetta, it is necessary to estimate the gas production at the large heliocentric distances (3..4 AU) where rendezvous takes place.

rh (AU)		min		max	
		molecules/s	kg/s	molecules/s	kg/s
Perihelion	Q(H <sub>2</sub> O)	4.00E+27	1.20E+02	1.00E+28	2.99E+02
	1.3 Q(CO)	4.00E+25	1.86E+00	5.00E+26	2.32E+01
	Q(CO <sub>2</sub> )	1.00E+26	7.31E+00	8.00E+26	5.84E+01
	<b>SUM</b>	<b>4.14E+27</b>	<b>1.29E+02</b>	<b>1.13E+28</b>	<b>3.81E+02</b>
2	Q(H <sub>2</sub> O)	4.00E+26	1.20E+01	2.00E+27	5.98E+01
	Q(CO)	2.00E+25	9.30E-01	2.00E+26	9.30E+00
	Q(CO <sub>2</sub> )	4.00E+25	2.92E+00	3.00E+26	2.19E+01
	<b>SUM</b>	<b>4.60E+26</b>	<b>1.58E+01</b>	<b>2.50E+27</b>	<b>9.10E+01</b>
3	Q(H <sub>2</sub> O)	1.00E+25	2.99E-01	3.00E+26	8.97E+00
	Q(CO)	7.00E+24	3.25E-01	9.00E+25	4.18E+00
	Q(CO <sub>2</sub> )	2.00E+25	1.46E+00	1.50E+26	1.10E+01
	<b>SUM</b>	<b>3.70E+25</b>	<b>2.09E+00</b>	<b>5.40E+26</b>	<b>2.41E+01</b>
3.5	Q(H <sub>2</sub> O)	1.00E+24	2.99E-02	2.00E+26	5.98E+00
	Q(CO)	6.00E+24	2.79E-01	7.00E+25	3.25E+00
	Q(CO <sub>2</sub> )	1.40E+25	1.02E+00	1.10E+26	8.04E+00
	<b>SUM</b>	<b>2.10E+25</b>	<b>1.33E+00</b>	<b>3.80E+26</b>	<b>1.73E+01</b>

Table 1 – Assumed global gas production rates CG [3]

We therefore made an educated guess on the min-max gas production rate (pre-perihelion) for 67P/Churyumov-Gerasimenko, based on the general principle that observations, if not too indirect, shall have priority versus model calculations. Observational data have been modified and supplemented by models (relative water production rate), though. The result is presented in table 1.

**Landing capabilities:** Philae's tripod landing gear is a sophisticated mechanism with a damping mechanism (up to 1.2 m/s in z axis), rotation (360°) and tilt ( $\pm 3.5^\circ$ ) capability, a cardanic joint, a clutch, and "ice screws" at each foot increasing the lateral friction coefficient. Relative to the landing site's surface normal (the plumb line is not important due to  $\mu$ -gravity), attitude and attack angles of up to 30° can be accommodated. A flywheel (4 – 6 Nms in z) prevents tumbling during the descent and a cold-gas thruster provides up to 1 m/s  $\Delta v$  during descent (commandable) and a similar amount after touchdown for preventing rebound, while two pyro-driven harpoons anchor the lander up to 2.5 m in the comet surface material.

**Surface strength:** The surface strength of comets is still not well constrained but believed to be in the 1 kPa – 100 kPa range [4,5]. Philae has been designed for compressive strengths between 2 kPa and 2 MPa. For a compressive strength less than 2kPa, Philae's baseplate would touch the ground (but then effectively stopping further penetration) and the 360° rotation capability of the landing gear would be compromised. Still, all experiments could be performed. Only for compressive strengths < 100Pa (equivalent to tensile strengths of less than 5 . . . 10Pa) the mission objectives would be compromised. For compressive strengths > 2 MPa (solid ice), the harpoons may not anchor safely.

**Landing site selection:** The mission of Philae is rather unique, since the landing site can only be selected after arriving at the target, comet 67P, and characterizing it. Landing site selection is a complex, iterative process under extreme schedule pressure (few months in 2014). Basically, technically feasible landing areas for the lander and the orbiter are determined from the first available comet models (shape, mass, rotation, gas drag) and refined; illumination (photovoltaic energy for the long-term mission, thermal aspects) and a scientific prioritization (based on composition, etc.) are taken into account. This leads to a selection of up to 5 potential landing sites (ranked) which subsequently are observed in greater detail by the orbiter's instruments to

assure landing safety (in particular, surface roughness and slope distributions).

Mainly due to spacecraft trajectory propagation uncertainties stemming from the uncertain and fluctuating coma drag properties, the landing ellipse of Philae is estimated (conservatively) to have a typical radius of 500 m. Descent times of a few hours from a low trajectory (~ 2 km height) are realistic. At least during part of the descent, an RF link between lander and orbiter will be available, while a number of scientific experiments aboard the lander are performed (including a bistatic radar experiment, which gives the distance between lander and orbiter as a function of time).

**Landing site characterization:** Immediately after touchdown, uplink of descent measurements (incl. downlooking camera images) ensues, complemented by a partially stereo panoramic image around the lander. Telemetry from subsystems (solar generator) and instruments (cameras, magnetometer, accelerometers) will be used to obtain a first characterization of the achieved landing site and soil properties. Lander images will be combined with orbiter images and 3D digital terrain models (DTMs) to determine Philae's coordinates and attitude within 12 hours after landing; orientation can also be assessed with magnetometer measurements and checked with solar generator output housekeeping (HK) of Philae's 6 solar panels.

**FSS and LTS:** Within 1 hour after landing, the first science sequence (FSS) ensues, which will basically execute each experiment once in a period of 2 ½ days, by relying on battery power only. Subsequently, the long-term science phase (LTS) will allow to characterize many physical and chemical properties of the comet's surface and subsurface and their variations with heliocentric distance in detail [1,2]. Nominal end of mission is reached at a heliocentric distance of 2 AU, about 3 months after landing.

#### References:

- [1] Bibring, J.-P., et al. (2007), *Space Science Rev.*, 128, 205-220. [2] Biele, J. and Ulamec, S. (2008), *Space Science Rev.* 138, 275-289. [3] Biele, J., Herfort, U. (2012), *ESA TN RO-ESC-TN-5566* . [4] Biele, J., et al. (2009), *Acta Astronautica*, 65, 1168-1178. [5] Biele, J. et al. (2012) *IAC-12 - A3,4,2,x13152*.