SMART-1 MISSION OVERVIEW FROM LAUNCH, LUNAR ORBIT TO IMPACT

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Introduction: The SMART-1 spacecraft has been launched on 27 Sept. 2003, as an Ariane-5 auxiliary passenger and injected in GTO Geostationary Tranfer Orbit. Thanks to the successful electric propulsion navigation, the SMART-1 spacecraft reached lunar capture on 17 November 2004, and has spiraled down to reach on 15 March 2005 a lunar orbit 400-3000 km for a nominal science period of six months, with 1 year science extension. We shall give the overview of SMART-1 travel from launch, lunar capture, lunar science orbit to impact on 3 September 2006.

SMART-1 spacecraft.

SMART-1 is a 3-axes stabilized spacecraft consisting of a 1-cubic-meter central box and two solar array wings. The complete spacecraft weighed 370 kg at launch. The central structure is designed around a xenon fuel tank with a capacity of 49 liters, containing 82.5kg Xenon at launch. A central equipment deck contains most spacecraft units, with the exception of high heat dissipaters. The solar arrays are sized to deliver 1850 W at the beginning of life. Split into two wings of three panels each, the solar arrays span 14 meters tip to tip. The solar arrays are positioned on opposite sides of the spacecraft and are able to rotate. In the orbit-raising phase this allows the thrust vector and solar arrays to be optimally pointed at the same time. Batteries provide power through eclipse phases of the mission, and they are sized to support a maximum eclipse length of 2.1 hours (no thrusting). Primary propulsion is performed by the PPS-1350-G Hall Effect Thruster. The electric propulsion system is equipped with a software-controlled mechanism to change azimuth and elevation of the thrust vector. Attitude control is performed by reaction wheels, with hydrazine thrusters being used in lower spacecraft modes and to do reaction wheel offloading. Attitude information is obtained through a combination of Sun sensors, gyros and startrackers. The data-handling subsystem contains cold redundancy, with autonomous FDIR software handling any single failures. The onboard software is designed with a high level of autonomy, such that ground command sequence uplinks are executed nominally once every four days. Normal operation can continue in an absence of ground contact for ten days, and the spacecraft can survive in Safe mode for a period of two months or more.

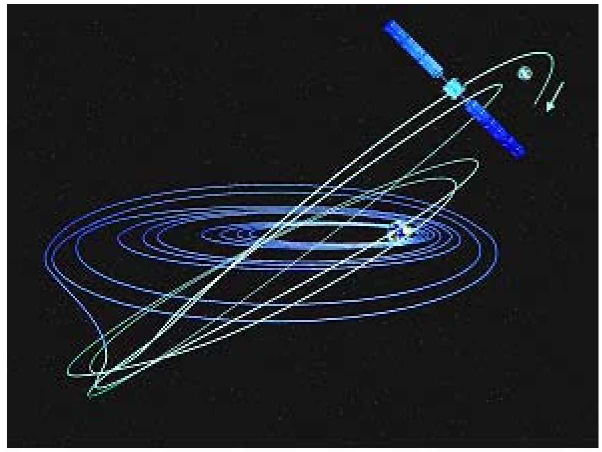

Figure 1: Simplified view of the transfer trajectory.

SMART-1 travel from Earth to Moon

In summary the mission phases and trajectory details are (Figure 1 illustrates the trajectory from the Earth to the Moon):

• Launch and Early Orbit Phase. Launch on 2003/09/27, initial orbit 7,029 * 42263 km.
• Van Allen Belt Escape. Continuous thrust strategy to quickly raise the perigee radius. Escape phase completed by 2003/12/22, orbit 20000 * 63427 km.
• Earth Escape Cruise. Thrust around perigee only to raise the apogee radius.
• Moon resonances and Capture. Trajectory assists by means of Moon resonances. Moon capture on 2004/11/11 at 310,000 km from the Earth and 90,000 km from the Moon.
• Lunar descent. Thrust used to lower the orbit, operational orbit 2,200 * 4,600 km.
• Lunar Science. Until the end of lifetime around 2006/07, interrupted only by a one-month reboost phase in September 2005 to optimise the lunar orbit.

On the 2004/11/15, SMART-1 made history with several notable firsts, including being the first electric propulsion mission to escape Earth orbit, the first to use electric propulsion to enter into orbit around another celestial body, and Europe's first lunar mission.

At the point defined as capture, the spacecraft passed through a position 310,000 km from the Earth and 90,000 km from the Moon in free drift. To achieve this, the thruster had been started 288 times, accumulating 3652 hours firing time, since launch vehicle injection into GTO. Shortly after capture, a 4.5 day continuous thrust braking maneuver was executed, to increase orbital stability, and to begin the lunar decent phase. The criticality of the braking maneuver and lunar descent phase is illustrated by the fact that if the electric propulsion system had not been functional the spacecraft would have escaped Moon orbit around 2004/12/18.

By end of February 2005 the spacecraft reached its operational orbit of 2,200 x 4,600 km (perilune x apolune distance). Note the difference with the baseline 2,000 x 10,000 km orbit. To achieve this, the thruster performed and additional 236 thrust arcs, adding another 953 hours to the cumulative thrust time

Since March 2005 three instruments have been operating from a 400-3000 km lunar science orbit: the AMIE miniature high resolution multicolour camera AMIE for lunar geomorphology (resolution down to 40 m per pixel), SIR infrared spectrometer (0.9-2.5 microns down to 400 m FOV) for mineralogy, and D-CIXS X-ray spectrometer for elemental composition (Foing et al. 2001, 2006).

Since January 2005 SMART-1 has been in its operational orbit performing scientific operations that were interrupted only by a one-month reboost phase in September 2005 to re-optimize the orbit. Without orbit control, natural degradation of the orbit causes the spacecraft to impact the Moon on the far side by mid-august 2006. With orbit control, the impact date and location could be influenced such an Earth observation campaign could be organized to observe it. This paper describe also ESA preparation for operations close to Moon impact. The orbit evolved towards the end of the mission, the different spacecraft sub-systems were affected by the changing orbit and close proximity of the Moon, and special operations were needed at low altitude and around the time of impact.

Because of gravitational perturbations by the Earth and the Sun, the SMART-1 orbit had to irremediably intersect the lunar surface, having exhausted its main Xe fuel. If we would have left the spacecraft on a natural course, it would have impacted the far side of the Moon on 17 August 2006. We have extended the mission at low altitude allowing an impact on the near side, in a dark part near the terminator, under good observation conditions for Earth telescopes.

The hydrazine subsystem is one of the Attitude and Orbit Control Systems (AOCS) actuators. It provides impulse to perform detumble operations and momentum management of the SMART-1 spacecraft during all phases of the mission from launcher separation throughout the mission. It was not intended for ΔV manoeuvres.

Using the hydrazine attitude thrusters to provide an extra impulse of some 12 m/s on 23 June -3 July, the spacecraft impact has been changed from 17 August on the far side to 3 September on the near side. Note that the differences between these orbits is only of 1 km in perilune and the maneuver had to target this 1 km accuracy one month in advance (some 140 orbits or about 3 million km). The last small maneuver at the end of July has narrowed down the impact time on 3 September to two possible times 5h42 UTC, or 0h36 UTC on the previous orbit due to topography uncertainties.

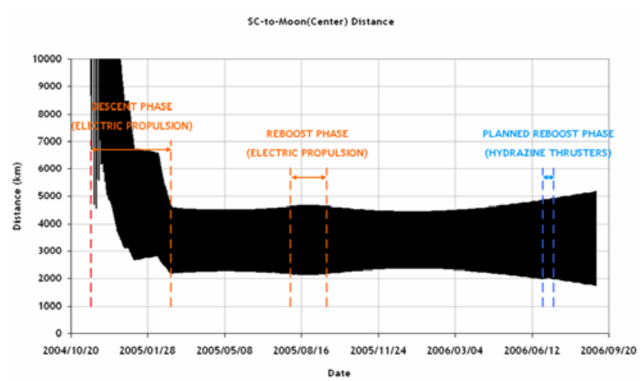

Figure 2: Spacecraft-to-Moon-centre distance from capture to impact. The descent phase and the first reboost phase that extended the mission lifetime were done using the electric propulsion system. After all propellant for the electric propulsion has been used up , the hydrazine subsystem was used for orbit raising in an unconventional way

References: [1] Foing, B. et al (2001) Earth Moon Planets, 85, 523 . [2] Racca, G.D. et al. (2002) Earth Moon Planets, 85, 379. [3] Racca, G.D. et al. (2002) P&SS, 50, 1323. [4] Foing, B. et al, ASR 37 (2006) 6-13

Links: http://sci.esa.int/smart-1/, http://sci.esa.int/ilewg/