

SMART-1 from Conception to Moon Impact

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This paper provides an overview of the SMART-1 project from cradle to grave: from its conception in 1997, launch on 27 September 2003, moon arrival on 11 November 2004, until its impact on the moon surface on 3 September 2006. It is necessarily kept to a sufficiently high level to contain its length, but it is intended to give enough information to provide the basis for those readers who intend to deepen their knowledge in more focused papers in this journal or in the references provided. At the time of writing, the project has been completed for more than one year and I can see, with some historical perspective, all the events that lead to this globally very successful mission. Obviously, the emphasis given to certain topics now is rather different from what it was when the issue was just discovered, but I believe that the reader is more interested in learning the objective facts and how they actually affected the mission performance.

I. Introduction

SMART-1 is the first of the Small Missions for Advanced Research and Technology of the ESA Horizon 2000 Science Plan. The mission study begun in 1997: several configurations [1], electric propulsion options [2], and planetary targets were considered. The mission was finally approved by the Science Programme Committee of ESA in November 1999, on the basis of a lunar mission [3]. The moon was initially chosen as the mission's planetary target, mainly because it is the most easily reachable planetary body. A secondary reason was the lunar scientific investigation that could be performed by means of the instrument technologies that were selected to be onboard.

During the development and optimization of the required flight trajectories, it became clear that the development necessary in this area was of great value for future missions, such as the planned mission to Mercury, BepiColombo [4]. SMART-1 was designed to demonstrate the use of solar electric primary propulsion (SEPP) on a small mission that is representative of a future deep-space science mission. Therefore, the emphasis was placed on the system aspects and on the peculiar flight dynamics and control techniques needed for implementing the mission profile and to operate the spacecraft, rather than on the choice of a particular engine, which is more mission-specific.

The requirement for science output [5] of SMART-1 was considered to be complementary to the technology demonstration objective. To demonstrate practical use of SEPP, the spacecraft should travel beyond an Earth orbit and reach some relevant solar system object. The moon was chosen as a target for its scientific importance and relative ease of access from a commercial geostationary transfer orbit (GTO). It was indeed recognized since the beginning that the only opportunity for a very low launch cost was to be accommodated as an auxiliary payload on a commercial Ariane 5 launch and to be deployed into a standard GTO. The energy requirement needed to reach the lunar orbit from a GTO is rather limited if imparted impulsively. However, the primary electric propulsion provides a very low thrust; hence, the trajectory design is substantially different from that traveled by spacecraft propelled by chemical propulsion. The gentle (maximum 70 mN) and continuous-thrust provided by the SEPP produces a transfer orbit from GTO to

the lunar capture, which was optimized to be performed in a propellant-efficient way.

The problems related to these types of trajectories have been reviewed in [6], and details of the SMART-1 trajectory can be found in [7]. This trajectory, which also made use of specially designed gravity assists and traveled through weak-stability regions is also a mission objective in itself, as it will allow more demanding missions to be accomplished [4]. SMART-1, with its cost at completion of about 110 million Euro, was also the first very-low-budget small mission for science at ESA, and in this sense, it explored and tested new ways of implementing cost-effective procurement and efficient management. The budget constraints of SMART-1 also required a cost-effective approach to spacecraft development and verification, not only considering assembly, integration, and test costs, but also during the design and analysis stages of the development program.

II. Mission Design

A. Technology Objectives

The main design drive of the SMART-1 mission has been to test the primary electric propulsion. The mission was due to qualify the system and its use as primary propulsion. The system aspects such as electrical power supply as well as thrust direction control and mechanical and thermal accommodation were main design drivers. In addition, the characterization of the electromagnetic, plasma, and dust environment created by the functioning of the electric propulsion was addressed by two instruments (described later): Electric Propulsion Diagnostic Package (EPDP) and Spacecraft Potential, Electron and Dust Experiment (SPEDE).

Other technologically advanced items were addressed by the SMART-1 payload. A new deep-space X/Ka-band transponder, essential to missions such as BepiColombo and Solar Orbiter, also allowed a radio-science investigation to monitor the dynamic performances of the electric propulsion system, and an attempt was to be made to measure the rotational state of the moon. It also aimed at assessing capabilities of an advanced X/Ka link for precise Doppler and ranging measurements in preparing future high-precision geodesy and relativity experiments.

Furthermore, the possibility of employing laser communication for future deep-space links was to be investigated: the onboard camera [Asteroid-Moon Imaging Experiment (AMIE)] acquired and imaged the laser beam transmitted by the ESA optical ground station in Tenerife (Spain).

In addition, two of the science instruments were also selected due to their technological advances. The D-CIXS x-ray spectrometer was based on novel features such as the microstructure collimator and the swept-charge detector. The SMART-1 near-IR (SIR) spectrometer was also of high technological relevance for planetary research, for its compactness, derived from a quasi-monolithic commercial quartz grating spectrometer.

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