2.9 SMART-1

Introduction

SMART-1, the first of the Small Missions for Advanced Research in Technology series in ESA's Scientific Programme, was launched from Kourou, French Guiana by Ariane-5 on 27 September 2003. 42 min after lift off, SMART-1 (Figs. 2.9.1 & 2.9.2) was released into a geostationary transfer orbit of 654 x 35 885 km, inclined at 7°.

The SMART missions were introduced into ESA's science programme to prepare the technology for future Cornerstone missions. SMART-1 is designed mainly to demonstrate innovative and key technologies for future deep-space science missions, with the potential to reduce the size and cost of propulsion systems while increasing manoeuvring flexibility and the mass available for scientific instrumentation. The first technology to be demonstrated on SMART-1 is Solar Electric Primary Propulsion (SEPP), a highly efficient and lightweight propulsion system that is ideal for long-duration deep-space missions. The propulsion system of SMART-1 consists of a single ion engine fuelled by 82 kg of Xe and powered by solar energy. This plasma thruster design is based on the 'Hall effect' and can accelerate ions to speeds up to 16 km/s. It delivers 70 mN of thrust with a specific impulse 5-10 times better than traditional chemical thrusters. The low thrust levels are compensated for by very long thrust intervals – months to years, instead of the minutes for typical chemical engines.

A wide range of other new technologies are being demonstrated in addition to SEPP: a Li-Ion modular battery package, new-generation high-data-rate deep-space communications in the X- and Ka-bands (KaTE), and techniques enabling spacecraft to determine their positions autonomously in space as a step towards fully autonomous navigation. The principal characteristics of the spacecraft are summarised in Table 2.9.1.

Scientific objectives

In synergy with the technology objectives, the science objectives for the lunar investigations include studies of the origin of the Earth-Moon system, accretional processes that led to the formation of planets, the chemical composition and evolution of the Moon, geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high-resolution

Figure 2.9.1. SMART-1 in lunar orbit.

For further information, see http://sci.esa.int/smart-1/

Table 2.9.1. The SMART-1 payload experiments.

Expt. Code	*Investigation Type*	*Main Investigator*	*Team Co-Is*	*Description of Experiment*
AMIE	Principal Investigator	J.L. Josset (CH)	F, NL, I, ESA	5.3° FOV miniaturised CCD-camera, with 4 fixed filters and micro-Data Processing Unit for Moon multi-band imaging. 1.8 kg, 9 W
Laser-link	Guest Technology Investigator	Z. Sodnik (ESA)		Demonstration of a deep-space laser link with ESA Optical Ground Station; sub-aperturing techniques for mitigating atmospheric distortion. Uses AMIE
OBAN	Guest Technology Investigator	F. Ankersen (ESA)		Validation of On-Board Autonomous Navigation algorithm by planetary bodies tracking. Uses star trackers and AMIE images
SPEDE	Principal Investigator	W. Schmidt (FIN)	FIN, S, ESA, USA	Langmuir probes measure spacecraft potential and plasma environment. Support to Electric Propulsion monitoring. 0.7 kg,1.2 W
RSIS	Guest Science Investigator	L. Iess (I)	USA, D, UK, F, ESA, S	Radio-science experiment monitors the Electric Propulsion. Uses KATE and AMIE
SIR	Technology Investigator	U. Keller (D)	D, UK, CH, I, IRL	Miniaturised near-IR (0.9-2.4 µm) grating spectrometer for lunar surface mineralogy studies. 1.7 kg, 2.5 W
D-CIXS/ XSM	Technology Investigator	M. Grande (UK) J. Huovelin (FIN)	FIN, S, E, I, F, ESA, USA	Compact X-ray spectrometer for mapping lunar chemical and variations of X-ray objects. 3.3 kg, 13 W
EPDP	Technology Investigator	G. Noci (I)	I, ESA, FIN, A	Multi-sensor package for monitoring the Electric Propulsion; plasma environment characterisation. 2.3 kg, 18 W
KATE	Technology Investigator	R. Birkl (D)	ESA, UK	X/Ka-band Telemetry, Tracking & Control package, demonstrates telecommunication and tracking 5.2 kg, 18 W

Table 2.9.2. Principal characteristics of the SMART-1 spacecraft.

Stabilisation: 3-axis, zero momentum
Attitude control: autonomous star tracker, Sun sensor, rate sensor gyro, reaction wheels, reaction control hydrazine system, thruster engine gimbals
Mass: 350 kg at launch
Size: 1 m cube, 14 m from tip-to-tip of solar arrays
Propellants: 82 kg of xenon and 4 kg of hydrazine
Power: two solar wings of three panels each; total area 10 m^2, generating 1950 W @ 1 AU. Supported by 5 Li-ion batteries totalling 600 Wh storage
Telemetry data rate: S-band 62 Kbit s^{-1}, X-band: 2 Kbit s^{-1} (from lunar orbit), Ka-band 120 Kbit s^{-1}
Onboard memory: redundant 4 Gbit solid-state mass memory
Primary propulsion: Stationary Plasma Thruster PPS-1350, nominal 70 mN thrust at 1350 W inlet power and Specific Impulse of 16 000 Ns kg^{-1}

Figure 2.9.2. SMART-1 attached to its Ariane launch vehicle.

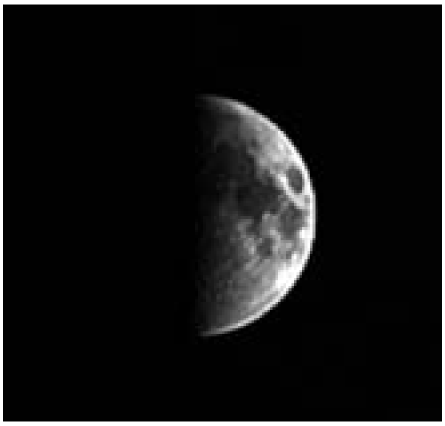
mapping. SMART-1 carries seven instruments (Table 2.9.2) with which 10 experiments will be performed during the mission. Part of the payload monitors the electric propulsion and spacecraft environment, and tests novel spacecraft and instrument technologies:

— the diagnostic instruments include SPEDE, the spacecraft potential plasma and charged particles detector, to characterise the spacecraft and its environment, together with EPDP, a suite of sensors monitoring secondary thrust-ions, charging and deposition effects;
— KaTE supports radio science (RSIS) to monitor the acceleration provided by the electric propulsion and is used as a test bed for turbo-code techniques to improve the return of scientific data;
— RSIS, a set of radio-science and technology investigations, aimed at characterising the X/Ka-band deep-space communication channels and demonstrating a method for measuring the libration of the Moon from orbit by using high-resolution images from AMIE, and accurate orbit determination by tracking in Ka-band in preparation for BepiColombo.

The remote-sensing instruments for imaging and spectrometry are all highly miniaturised:

— D-CIXS, a compact X-ray spectrometer based on novel Swept Charge Device (SCD) detectors and micro-collimator optics, to perform lunar geochemistry, by fluorescence mapping of the major rock-forming elements (Mg, Si, Al, O, Fe), and to monitor bright X-ray sources during cruise;
— XSM, an X-ray solar monitor, to observe variations in the Sun from activity and flares, and to serve in the calibration of the D-CIXS determination of absolute lunar elemental abundances;
— SIR, a miniaturised quasi-monolithic point-spectrometer, is the first-ever near-IR

Figure 2.9.3. The Moon imaged by AMIE on 29 January 2004.



lunar spectrometer to survey the distribution of the main minerals in the lunar crust;
- AMIE, a miniature camera based on 3-D integrated electronics, imaging the Moon in four spectral bands defined by thin-film filters, and supporting three guest investigations: Laser-Link, a demonstration of acquisition of a deep-space laser-link from the ESA Optical Ground Station at Tenerife; OBAN, the demonstration of an autonomous navigation tool; and RSIS for the in-orbit measurement of lunar libration.

Status

By the end of January 2004, the spacecraft had completed more than 200 orbits, with all functions normal. It had accumulated more than 1700 h of thrust, using 27.1 kg of Xe, which provided a velocity increase of about 1.22 km/s. It was in a highly elliptic orbit with a perigee of 14 312 km and an apogee of 59 491 km and an orbital period of 24 h 53 min. This orbit was optimised to limit the length of the eclipses in March 2004. After 4 months of regular passages through the near-Earth radiation belts and suffering heavily from energetic particle events, SMART-1 has reached a much quieter environment. With the ion engine off for most of the month, February 2004 was used to commission the payload. A first test image of the Moon was obtained by AMIE on 18 January (Fig. 2.9.3). The efficiency of the electric propulsion system and the higher level of electric power available (resulting from low solar cell degradation and lower power consumption) means that SMART-1 will be able to arrive at the Moon earlier than Spring 2005, as was anticipated at launch, and will not require the lunar swing-bys. Lunar capture will occur either in mid-November or mid-December 2004, with the spacecraft reaching its final orbit about 6 weeks later. After capture, it will fly over the lunar north pole, aiming at a point of closest approach above the south pole, so achieving a wide polar orbit. During the following weeks, the ion engine will gradually reduce the size and duration of the orbit, to improve the view of the lunar surface. In early 2005, the mission will enter its nominal 6-month science phase.