SMART-1 SCIENCE EXPERIMENTS CO-ORDINATION

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ABSTRACT

SMART-1 is the first European Space Agency mission to the Moon [1] [2] [5], due for launch in the first
months of 2003. Its primary goal is to test new technologies for space navigation and science. In its
science experiments, SMART-1 will include new, very compact experiments. This paper aims to demonstrate
some of the science experiment operations foreseen for the mission. We describe the SMART-1 mission, its
orbit and example scenarios for imaging specific targets (such as Tycho and Copernicus craters).

1. THE SMART-1 MISSION

1.1 Overview

SMART-1’s primary objective is to test and validate a new electric propulsion engine for potential use on
larger ESA Cornerstone missions. However, the SMART-1 spacecraft will also carry a number of
scientific instruments and experiments for use en-route to, and in orbit about, the Moon.

1.2 Experiments

The payload comprises several instruments and experiments: the Asteroid-Moon Micro Imager Experiment (AMIE), the Demonstration Compact Imaging X-ray Spectrometer (D-CIXS), the X-ray Solar Monitor (XSM), the SMART-1 Near-Infrared Spectrometer (SIR), the Electric Propulsion Diagnostic Package (EPDP), the Spacecraft Potential, Electron and Dust Experiment (SPED), the Deep Space X/Ka Band TTC Experiment (KaTE), the Radio Science Investigation for SMART-1 (RSIS).

1.3 Objectives

The majority of scientific objectives will be achieved from lunar orbit. The AMIE multispectral high-
resolution camera will mainly aim to image the lunar south pole and map the southern regions of the Moon.
D-CIXS will look for the spatial distribution of major lunar rock types on the sunlit side of the Moon, and the
X-ray emission from the impact of solar wind electrons on the lunar night-side. SIR will gather data to study
the mineralogy of the lunar surface. During this phase, the RSIS experiment will also take place, using AMIE
images and the high accuracy tracking provided by KaTE to measure the lunar libration.

1.4 Mission Phases

The SMART-1 mission has three main phases. Immediately after launch there will be a commissioning phase during which all systems are tested and routine operational sequences are sent to the spacecraft to check that everything is running according to specifications. Commissioning will be followed by a long, fifteen month cruise phase that will take the spacecraft to the Moon. During this phase, all the engine tests will be performed in order to validate the propulsion system. Also during cruise some science data acquisition will be possible during the periods that SMART-1 is not thrusting.
The third phase, lunar operations, starts at Moon arrival. Most of the scientific data will be acquired
during this period.

1.5 Mission Co-ordination

Also in the frame of the mission a co-ordinated utilisation of the experiments is envisaged. The Science
and Technology Operations Co-Ordination (STOC) will be in charge of this task. The STOC will, in light of the capabilities of the experiments, advise experiment teams to study specific features of the Moon simultaneously. The data acquired this way, when cross-checked, will be able to deliver improved scientific return.
The first test analyses performed to date in preparation of STOC activities were related to the AMIE high-
resolution camera. The camera was used to obtain different filter information while completing simulated imaging of the well known craters Tycho and Copernicus. Also, some evaluations were made on other AMIE science objectives, as well as simultaneous AMIE/SIR operation for combined science.

2. LUNAR ORBIT

SMART-1 will be inserted in a Polar Orbit, with pericentre near the lunar south pole. The perilune
distance will vary during the mission (see Fig. 1).

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3. THE AMIE MICRO IMAGER (AMIE)[1][2]

The study performed was based on the SMART-1 imager. AMIE is a compact imaging system. It acquires 1024x1024 pixel images with a field of view of 5.3 degrees by 5.3 degrees. A filter was set in front of the optics, divided into different wavelength zones, as can be seen in Fig. 2.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>No Filter</td>
</tr>
<tr>
<td>915</td>
<td></td>
</tr>
<tr>
<td>960</td>
<td>9</td>
</tr>
<tr>
<td>847</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 2. AMIE filters

The filter layout accommodates the two different camera orientations with respect to the spacecraft movement. This way it is possible to obtain multi-wavelength information using pictures taken of the same area through each of the filters.

4. OBTAINING MULTI FILTER INFORMATION FOR COPERNICUS AND TYCHO CRATERS

4.1 Orbit Selection

Using a software tool called Project Test Bed (PTB) [3], a program that simulates the SMART-1 mission with the trajectory parameters given by the European Space Operations Centre (ESOC), it is possible to select a site of interest in the Moon orbit as well as obtain spacecraft parameters, such as the height and spacecraft velocity in relation to the Moon.

For this scenario, two consecutive orbits were selected that pass by two well-known fresh impact craters, Copernicus and Tycho (Fig. 3). The perilune is at 55 degrees south and 165 degrees east, and the height is 317 km.

4.2 Orbit and scenario parameters

In order to plan how to cover a crater it is necessary to know what is the projection of the AMIE field of view on the Moon.

This is calculated in Eq. 1, using simple trigonometry:

\[
\tan(5.3/2) = \frac{m/2}{d} \Rightarrow m = 2 \times d \times \tan(2.65)
\]

Where \( m \) is the footprint size in one dimension and \( d \) is the distance from SMART-1 to the Moon.

Knowing the orbit height, \( d \), from PTB, as it is shown in Fig. 3:

Fig. 3. Plot of the orbit time versus the height of the spacecraft. The colours refer also to Fig. 5

it is possible, using Eq. 1, to calculate the field of view size projection on the Moon for the all scenario time. The result is shown in Fig. 4:

Fig. 4. AMIE field of view projection size. Near perilune it is possible to have 30 Km FOV and hence 30 m/pixel resolution
4.3 Operations Examples

Fresh impact craters such as Copernicus and Tycho are primary targets for colour imaging.

4.3.1 Copernicus Crater

Copernicus crater is situated at 20 degrees west, 9.6 degrees north and has 94 km diameter.
In this simulated orbit, when SMART-1 passes by Copernicus it is 4946 km above the lunar surface. At this height the field of view of one of the filters of the AMIE camera projected on the Moon is a rectangle of 228 km by 114 km.
Therefore, three pictures are necessary to obtain multi-filter information on this crater, as illustrated in Fig. 6, only with relevant colour filters from Fig. 2. The area covered on the sequence can be seen in Fig 5.

![Fig. 6. Copernicus picturing sequence. Time between pictures: 8 minutes (see 4.3.3)](image)

Some context imaging is also added, including some of the ejecta. The resolution would be about 440 m/pixel.

4.3.2 Tycho Crater

Tycho has 102 Km diameter and is situated 43.4 degrees south and 11.1 degrees west.
As SMART-1 travels south, as can be seen in Fig. 4, the spacecraft gets closer to the Moon. In the simulation, at Tycho latitude SMART-1 is 1399 km above the Moon. This obviously provides an improved resolution for AMIE. One filter projection in this case is a rectangle of 64 km by 32 km, with a resolution of 126 m/pixel. A sequence of four pictures is needed to cover Tycho in this case, as can be seen in Fig. 7.
The area covered on the sequence can be seen in Fig 5.
4.3.3 Time step between pictures

To calculate the time step between pictures a simple calculation was needed. The Spacecraft velocity is simulated with PTB (Fig 8).

\[ V_{FP} = \frac{R_M}{R_M + R_{SC}} V_{SC} \]  

where \( V_{FP} \) is the foot print velocity, \( R_M \) is the radius of the Moon, \( R_{SC} \) is the distance from SMART-1 to the Moon and \( V_{SC} \) is the velocity of the spacecraft.

Having the velocity of the spacecraft (Fig. 9)

\[ \text{Foot-Print Velocity} \]

It is possible using Eq. 2, obtain the foot print velocity for the entire simulation (Fig. 10).

\[ \text{Foot-Print Velocity} \]

Fig. 10. SMART-1 foot print velocity

Knowing the size of one filter of the AMIE camera projected on the Moon, and the velocity of the projection it is easy to calculate the time step.

**Copernicus:**

Size of the filter: 228 km x 114 km

Foot print velocity: 226 m/s

\[ \text{TimeStep} = \frac{114000}{226} = 504 \text{s} = 8.4 \text{min} \]  

**Tycho:**

Size of the filter: 64 km x 32 km

Foot print velocity: 861 m/s

\[ \text{TimeStep} = \frac{32000}{861} = 37 \text{s} \]  

5. FURTHER STUDIES

Some more studies were performed, but need improvement, and work is continuing to this end.

5.1 Global Coverage

For global coverage, it was possible to deduce that using the “No Filter” area of the AMIE camera at high northern latitudes, a picture has about 450 km side. This is more than 10 degrees in Moon latitude coordinates. Therefore global coverage is easily feasible. However for southern latitudes whenever the spacecraft is below 500 km there are some gaps in the coverage along the spacecraft movement due to download time constraints from AMIE to the
spacecraft mass memory [4]. Exact latitudes at which gaps occur vary as the orbit and perilune fluctuate. Considering the coverage obtained by multiple passages, it is possible to see in Fig. 5 that there is a gap between two passages at Tycho latitude. This was corroborated by a new software tool, Mapping and Planning Payload Science (MAPPS), as can be seen in Fig. 11.

**Fig. 11. MAPPS simulation of the same two passages of SMART-1. Shown in Fig. 5.**

In yellow we have the projection of the field of view of one of the colour filters. In green is the SMART-1 trail. In the simulation the spacecraft rotates near the equator, therefore the field of view passes from the left of the trail to the right. The distortion of the field of view is due to the Moon orthographic projection. It is clear that for northern latitudes as SMART-1 is far from the Moon there is overlapping of contiguous fields of view. For southern latitudes between 0 and 70 degrees there is a gap up to 30%. Further studies should be developed in order to create strategies to overcome this problem.

### 5.2 Crater Counting

Statistical studies of the Moon, based on crater counting are possible if pictures of 50 km by 50 km are collected with 50 m resolution or 100 km by 100 km, with 100 m resolution. In this simulation those criteria are achieved when SMART-1 is 50 degrees or more south.

### 5.3 Combining with SMART-1 Near Infrared spectrometer (SIR)

Copernicus and Tycho are also interesting targets for infrared spectrometry. It is then envisaged that while AMIE is imaging, SIR can be collecting spectra. This way, also context imaging is obtained for SIR. This is possible because, nevertheless SIR is always sending data through the CAN bus, not allowing its use by AMIE. The camera has a memory that holds 4 images, what is the maximum needed to picture these targets. Once the measurements are made and SIR stops collecting data, AMIE is able to send the pictures to the mass memory.

### 5.4 South Pole

Very high-resolution images are foreseen for the South Pole. It is possible to get to resolutions of about 50 m/pixel. Longer exposure images are also foreseen to see the bottom of craters, illuminated by rim straylight, and possible ice deposits, as well as high resolution images for illumination and landing site studies.

Further, detailed studies will cover the South Pole-Aitken basin.

### 6. CONCLUSION

When, after a long journey, SMART-1 arrives at the Moon, there is the need to have a science data gathering campaign, well studied and planned in order to maximize the output of the mission. The studies presented in this paper were done in this framework. If we maximize the amount of operations procedures at the Moon, we can be ready for any scenario that we may encounter. Therefore this is just a first step. Much work is still envisaged, with a great amount of discussion between experiment teams, the Science and Technology Working Team (STWT) and the project scientist team. This is needed to ensure the success of the mission.
7. REFERENCES

1. Foing et al. 32nd LPSC, ESA's SMART-1 Mission to the Moon, abstract LPI 32, 1787, 2001

8. ACKNOWLEDGMENTS

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Credits:

Lunar Stripe image (courtesy of USGS)
Lunar crater images (courtesy of NASA)