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Feasibility of asteroid exploration using CubeSats — ASPECT case study

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Introduction

Operation of a small CubeSat in the deep-space microgravity environment brings additional challenging factors as the increased radiation environment, significant contribution of non-gravitational forces on satellite orbit, or the limited communication opportunities. These factors need to be taken into account in the form of modifications to classic CubeSat architecture. Additionally to increased radiation resistance, the semi-autonomous operation, navigation, and the active orbit correction are required. Such modified CubeSat platform can potentially deliver high performance / mass and cost ratio. The Asteroid Spectral Imaging Mission (ASPECT) is a three unit (3U) CubeSat mission build on these principles. ASPECT is equipped with a visible – near-infrared hyperspectral imager and will deliver both technological knowledge as well as scientific data about the origin and evolution of the small Solar System bodies.

Asteroid CubeSat mission analysis

The deep space environment bring several additional challenges compared to CubeSat operations at low earth orbit (LEO). Following major factors were identified to be addressed for successful CubeSat deep space operations:

- F1 Low-gravity environment
- F2 Reduced set of objects for navigation reference
- F3 Presence of significant perturbation forces as solar /radiation wind pressure, planetary perturbations, own heat radiation force relative to the gravity of the orbiting object
- F4 Increased radiation background (operation outside Earth magnetosphere)
- F5 Limited direct communication opportunities

In order to successfully cope with the abovementioned factors characteristic for deep-space environment following modifications to the classic CubeSat configuration have to be implemented:

- M1 Active propulsion system
- M2 Multi-reference advanced navigation
- M3 Reliable, semi-autonomous mission operation, navigation, and trajectory correction
- M4 Enhanced radiation shielding/tolerance
- M5 Foldable dish antenna or communication utilizing relay spacecraft

ASPECT concept

ASPECT is a 3U CubeSat technological demonstration mission developed for the ESA-NASA AIDA (Asteroid Impact & Deflection Assessment) project. In 2016 it underwent preliminary design study and was down selected as the only CubeSat payload for European AIDA component AIM-D[2] (Asteroid Impact Mission – Deflection Demonstration).

The payload, avionics, and cold gas propulsion units occupy each 1U space. The CubeSat platform provides required subsystems for operating the payload and communication. The operation infrastructure is centered on the S-band radio link, which provides the satellite attitude control location data from the mothercraft, as well as access directly to all the other subsystems of the satellite, negating the need for a traditional failure-prone hub, e.g. an Onboard Computer, to access the subsystems. The system architecture, space-qualified subsystem modules, structural components and the platform software are currently used in the Reaktor Space Lab's Hello World in-orbit demonstration satellite. The ASPECT platform avionics, including the S-band radio equipment, batteries, attitude and orbit control, and the electrical power system, are integrated in a 1U module to minimize external connections and to simplify the system. Also included in the platform section are solar panel connections and all required harnessing. The CubeSat platform will be a radiation-hardened and single-event effect (SEE) resistant to guarantee reliable operation for at least 3 month mission period. The satellite system block diagram is depicted in Fig. 1. All subsystems are monitored and switchable during operations from the electrical power system.

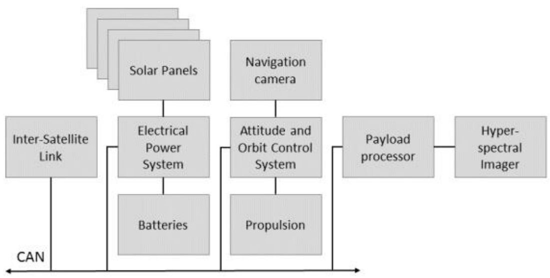

Figure 1. ASPECT high-level systemblock diagram.

Spectral imager payload

The payload is a miniaturized spectral imager extending from the visible up to the shortwave infrared wavelengths. In contrast to more traditional spatial-scanning imaging spectrometers, the Asteroid Spectral Imager utilizes tunable Fabry-Perot Interferometers (FPI) to select the imaged wavelengths. When multiple snapshots are combined, a spectral datacube is formed, where the wavelength bands are separated in the time domain. The instrument is based on the space-qualified designs of the Aalto-1 Spectral Imager and Picasso VISION.

The instrument envelope is 97 mm x 97 mm x 100 mm (roughly 1U), which is split into three measurement channels, one in the visible (VIS), and two in the infrared (NIR and SWIR). The VIS and NIR channels are imaging spectrometers, while the SWIR channel only measures a single point. The target wavelength range is 500 - 900 nm for the VIS channel, 900 - 1600 nm for the NIR channel and 1600 - 2500 nm for the SWIR channel. The spectral separation is done by a tunable Fabry-Perot Interferometer (FPI). All three channels have dedicated FPIs optimized for the desired wavelength range. The imaged wavelengths are freely selectable within these ranges, and the targeted spectral resolution is ca. 10 - 50 nm. All three channels can be operated simultaneously and are independent of each other. Even if a single image sensor or FPI is lost, the mission can still carry on with limited capabilities. The main instrument parameters are listed in Table 1.

Table 1. The main Asteroid Spectral Imager parameters.

Parameter	VIS channel	NIR channel	SWIR channel	notes
Field of View [deg]	6° x 6°	5.3° x 5.3°	5° circular	
Spectral range [nm]	500 – 900	900 – 1600	1600 - 2500	
Image size [pixels]	614 x 614	256 x 256	1 pixel	
No. spectral bands	Ca. 14	Ca. 24	Ca. 30	Tunable in flight
Spectral resolution [nm]	< 20 nm	< 50 nm	< 25 nm	