Magnetic Attitude Control of a Spinning Spacecraft Flight Results and Lessons Learned from DLR's Compact Satellite Eu:CROPIS

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Abstract: The German Aerospace Center (DLR) launched on 3rd December 2018 the Euglena Combined Regenerative Organic food Production In Space (Eu:CROPIS) mission. Eu:CROPIS is a mission of DLR's compact satellite class with the objective to test several biological experiments at different levels of artificial gravity. The Eu:CROPIS mission carries experiments and payloads from University of Erlangen, NASA AMES and two DLR Institutes.

A dedicated magnetic attitude control system (ACS), which utilizes a spin stabilized concept, is part of the satellite to achieve this objective. The ACS is designed to handle the technical challenges imposed by the biological payload e.g. the inclusion of water tanks onto the satellite system. Especially during launch and early operational phase (LEOP) the ACS showed its effectiveness to even counteract unexpected anomalies. After that the ACS continued with nominal operation and performed the initial acquisition as expected.

1. INTRODUCTION

Eu:CROPIS is the latest mission within German Aerospace Center's (DLR) compact satellite program. Its major scientific goals are to test and characterize a sustainable life support system within harsh space environment at different levels of gravity. Beside the scientific goals DLR wants to establish key engineering capabilities in house to fully develop and lead a compact satellite program.

There are four payloads accommodated on board

- Eu:CROPIS - Euglena Combined Regenerative Organic food Production In Space [1] - Friedrich-Alexander-University of Erlangen-Nürnberg and DLR Cologne
- PowerCell – NASA Ames Research Center [2]
- RAMIS – RAdiation Measurment In Space – DLR Cologne
- SCORE – SCalable On-boaRd computing – an Experiment - DLR Bremen

The Eu:CROPIS satellite consists of a cylindrical central body with four deployable solar panels. The central body has a diameter of about 1 m and each solar panel can be deployed by roughly 1 m as well. The final satellite system has a mass of 226.62 kg [3] in orbit and a nominal power consumption of about 200 W [4]. Inside the satellite two greenhouse compartments are installed which operate at two different levels of gravity (Moon 0.16 g, Mars 0.38 g).

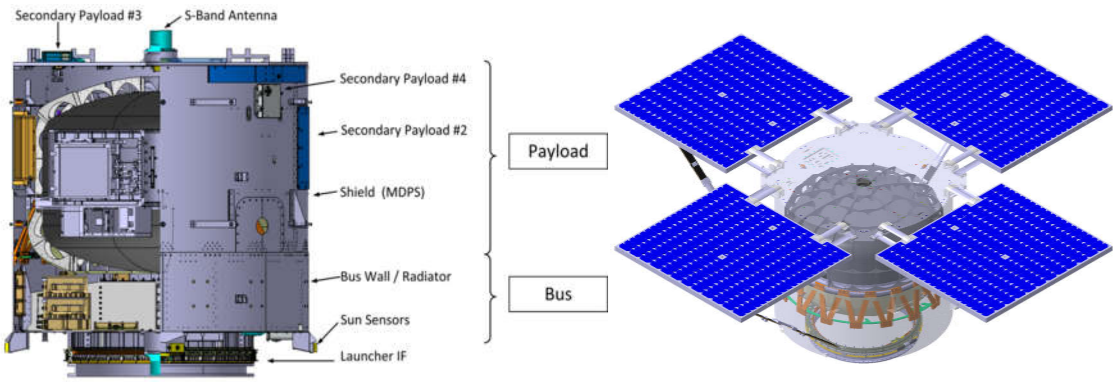

Figure 1 Eu:CROPIS satellite

The satellite is designed as a purely spin stabilized system to provide these different levels of gravity. The spin stabilization generates a centrifugal force which mimics the gravity at a predefined reference radius of 0.35 m. The greenhouses are installed in such a way that the cylindrical wall serves as the "bottom" for the biology.

2. ATTITUDE CONTROL SYSTEM

The spin stabilization is achieved purely by a magnetic attitude control system. There are three orthogonally arranged magnetic torquers on board. Each of them can provide an absolute magnetic dipole moment of $30 Am^2$. Beside the magnetic torquers two magnetometers, ten sun sensors, four angular rate gyroscopes and two GPS receivers are used as redundant sensors. An overview of all AOCS hardware components can be seen in Figure 2.

While the sensor and actuator selection follows a rather classical approach the challenging aspects during development are clearly the interface between the biological payload and the ACS. During the mission plants will grow and consume water which changes the Center of Mass (CoM) as well as the Moment of Inertia (MoI). In addition there are about eight liter [1] of liquids on board which could induce sloshing phenomena. Especially several pumps which transport liquids will induce a disturbance torque as well as a disturbing magnetic field.

Another challenging aspect for the ACS is the solar panel deployment. During deployment the satellite changes its MoI rapidly, which has to be taken into account. Therefore the solar panel deployment is not executed autonomously, but requires some supervised interaction by the operations team on ground.

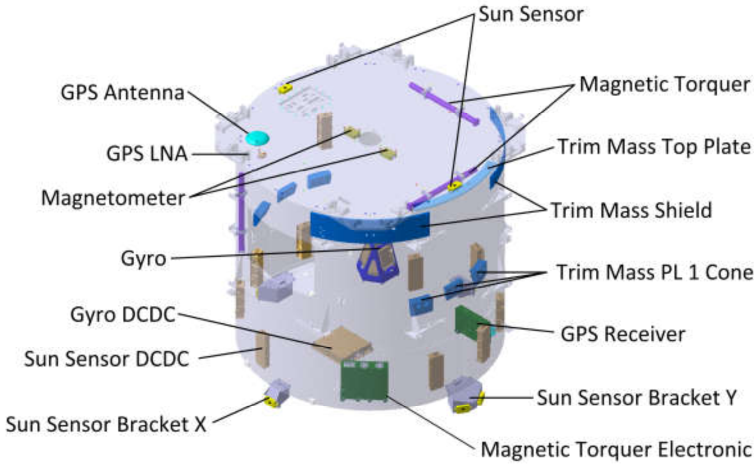

Figure 2 AOCS hardware accommodation within Eu:CROPIS

All of these aspects are addressed during design and development. They lead to a magnetic attitude control system design which enforces many requirements onto the satellite system design.

3. LAUNCH AND EARLY OPERATIONAL PHASE

Eu:CROPIS was launched at 03-Dec-2018 18:34 UTC with the SSO-A (Sun Synchronous Orbit-A) rideshare mission on a SpaceX Falcon 9 rocket. The German Space Operations Center (GSOC) of DLR was used as supervising ground control. During LEOP the ACS was monitored by six people in total, working in two shifts for a period of one week.

Eu:CROPIS was separated from the launching rocket shortly before 19:08 UTC. At this time the on board computer was being booted and the satellite started its operation. The first valid ACS measurements became available one minute later. From there on the ACS operated completely autonomously until a save attitude had been reached.

The first anomaly occurred during separation. The initial angular rate which was induced by separating the spacecraft from the launch system was significantly larger than expected. The first recorded angular rate on board of Eu:CROPIS was $\omega_{b,i}^{b} = [0.745 \quad -9.970 \quad 0.401]$ deg/s. This angular rate exceeded the designed initial angular rate (approx. 2 deg/s). Unfortunately this large angular rate was not recognized until a couple of days later. The reason therefor was that the offline housekeeping data processed inside the monitoring and control system is tagged by the on board GPS time. Due to the fact that the GPS receiver requires some time to provide a time fix, the initial separation phase had a time stamp around 6th December 1980, which is the starting period of the GPS epoch. At first contact, when the real time housekeeping could be directly seen by the operators, the angular rate was already decreased so far that no further action was required.

A classical Bdot controller was used for detumbling. It decreased the spin rate only, see [4] for further details. After the Bdot controller was automatically initiated it took approximately three hours to lower the angular rate magnitude below a threshold of 0.5 deg/s. Reaching this threshold the ACS switched to its spin-up mode.

The spin-up mode regulates the angular rate around the z-axis to a target value. The z-axis is designed to be the major moment of inertia axis. The target angular rate was set to 1 rpm providing a sufficient angular impulse against external disturbances. Eu:CROPIS managed to reach 1 rpm after approximately 2 hours. Eu:CROPIS was then being operated as a spin stabilized spacecraft and its spin-and-point mode was activated.

In spin-and-point mode the spin axis was aligned orthogonally to the satellite Sun vector. This maneuver took approx. 1.5 hours. Afterwards the initial autonomous acquisition phase was completed successfully from ACS point of view.

4. TRANSITION TO NOMINAL OPERATIONS

The moments of inertia were then recalibrated, and the satellite was aligned with its spin axis at a 60 deg angle to the Sun in preparation for solar panel deployment. The solar panel deployment took place at 05-Dec-2018 08:59 UTC. During the process the angular rate experienced an expected drop from 1 rpm down to 0.8 rpm. After deployment the spin rate was restored to 1 rpm, and the satellite's spin axis oriented towards the sun. Deployment, spin up and final orientation took approx. 4.5 hours.

The last step was to spin up the satellite to 5 rpm, which took about 16 h. By reaching 5 rpm the ACS was commanded into its spin-in mode, which is its nominal operational mode.

5. SUMMARY

The present paper gave an overview of the magnetic attitude control system of the Eu:CROPIS satellite. It elaborates on some challenges met during the design process and describes the launch and early operational phase form an attitude control system point of view.

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