SpaceOps Conferences
16-20 May 2016, Daejeon, Korea
SpaceOps 2016 Conference

AIAA 2016-2533

Food Production in Space – Operating a Greenhouse in Low Earth Orbit

Daniel Schulze[1], Gary Morfill[2], Benjamin Klein[3], Thorsten Beck[4]
German Aerospace Center (DLR), Oberpfaffenhofen, 82234 Wessling, Germany

and

Claudia Philpot[5]
German Aerospace Center (DLR), 28359 Bremen, Germany

Eu:CROPIS (Euglena and Combined Regenerative Organic-Food Production in Space) is a biological life support mission scheduled for launch in 2017 on-board a Falcon 9 rocket. The spin stabilized satellite will be operated under different levels of acceleration to investigate the growth of tomatoes under simulated Mars and Moon gravity. It comprises two pressurized greenhouses, which are rotated around the spacecraft longitudinal axis, a radiation detector and a secondary payload from NASA AMES research center. Each greenhouse compartment will be operated for 6 months at different rotational speed in order to simulate different gravitational forces. Special care has to be taken in the design and the operations of Eu:CROPIS because biological processes may not be disturbed during spacecraft anomalies, and stable thermal conditions and lighting cycles must be assured.

The 250 kg satellite is built by the DLR Institute for Space Systems and will be operated by the German Space Operations Center (GSOC) – another DLR institution. This allows an exceptionally close cooperation between the operations team and the spacecraft manufacturer. Decisions can be made together on whether a technical solution is to be implemented within the space segment or the ground segment. This approach minimizes the overall mission costs and maximizes the scientific output. Operational benefits arise from the on-board data handling, which permits the re-use of existing mission planning systems and minimizes adjustments to the mission control and data system. Additionally, an experimental but more powerful downlink mode may be used operationally after successful checkout, which could reduce the downlink time and related costs.

This paper gives an overview of the operations concept including LEOP and routine operations, data dissemination and the interfaces to the user segment. It will also describe the technical innovations that have been made in the ground segment to avoid additional effort on the space segment. A new application was developed and added to the Central Checkout System, and is being used for Assembly, Integration and Test (AIT) as well as for the development of flight control procedures.

[1] Flight Director, German Space Operations Center, Germany/ D.Schulze@dlr.de
[2] Ground Segment Manager, German Space Operations Center, Germany/ Gary.Morfill@dlr.de
[3] Systems Engineer, German Space Operations Center, Germany/ Benjamin.Klein@dlr.de
[4] Software Engineer, German Space Operations Center, Germany/ Thorsten.Beck@dlr.de
[5] Systems Engineer, Institute of Space Systems, 28359 Bremen, Germany/ Claudia.Philpot@dlr.de

I. Introduction

THE German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V. - DLR) has developed a satellite platform for scientific payloads in Low Earth Orbit. The platform is called DLR Compact Satellite and is led by the DLR Institute of Space Systems (Bremen, Germany). It was designed in the DLR Concurrent Design Facility in Bremen. Eu:CROPIS is the first mission within the DLR Compact Satellite program and was initiated in 2012 to investigate coupled biological life support systems under accelerations corresponding to gravity levels on the surface of the Moon and Mars. It was proposed by the DLR Institute of Aerospace Medicine in Cologne and the Cell Biology Division of the University of Erlangen. Eu:CROPIS is the name of both, the mission as well as the primary payload on-board the DLR Compact Satellite. A mission duration of 18 months is foreseen.

A. Scientific Objectives

A problem in human space flight is the processing of urine. Water is the only component that is recycled so far. All dissolved substances such as urea and salts are extracted from the urine and then disposed. In the future however, the urine of habitat residents could be used in a closed system to grow fruits and vegetables after proper conversion. Eu:CROPIS shall prove this concept under varying gravity conditions. Two life support systems within the satellite will be combined for producing biomass out of urine. The used biological systems are: a nitrifying trickle filter system being a nitrogen source and the single-celled algae Euglena Gracilis as oxygen producing element. The algae also protect the whole system against high level of ammonia, which can occur during a low nitrification process. Euglena uses gravity and light as hints to reach and stay in regions of the water column optimal for photosynthesis and growth. It has been established as a model organism for studying gravity perception of single cells and was subject to several experiments in space (see [1] and [2]). The trickle filter system is made of lava rock, which is used as a habitat for a variety of microorganisms such as bacteria, fungi and protozoa. The high degree of adaptability of this system with respect to organismic diversity allows the use for the degradation and detoxification of various substances passing through the filter tube (see [3] for details). As higher plant system small tomatoes (Micro-Tina) will be used for biomass production.

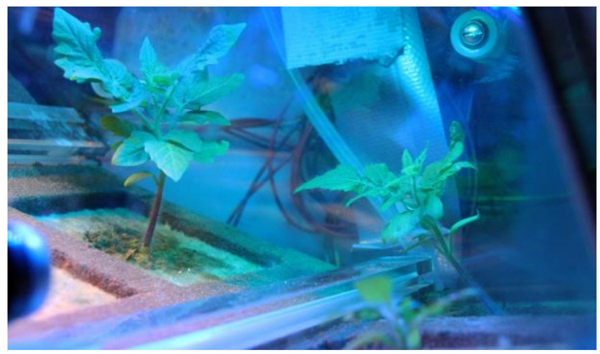

Figure 1: Tomatoes for Moon and Mars habitats. *Insight to the ground science model. Source: DLR.de*

The scientific goal is a seed to seed experiment under gravity levels as on the lunar surface (0.16g) as well as on the surface of Mars (0.38g). During each six months lasting experiment ion concentrations in the water based flow will be measured by ion chromatography and molecular biological analysis will be performed with euglena cells. The Eu:CROPIS long term experiment will serve the purpose of feasibility and technology demonstration in the field of combined biological life support systems and gravitational biological research on a compact satellite system.

B. Secondary Payloads

The DLR Compact Satellite also carries a number of secondary payloads from different research institutions. Payload 2 ("PowerCells in Space") is another biological payload and is provided by NASA AMES. It will test a synthetically altered photosynthetic cyanobacterium for nutrient production, which feeds a non-photosynthetic microbe. Four experiments will be conducted at three different gravity levels.

Payload 3 (Radiation Measurements in Space – "RAMIS") is an experiment for measuring the radiation field parameters encountered during the mission. RAMIS consists of two modules. One is placed inside the primary payload; the other module is mounted on the outer shell of the satellite. RAMIS is developed by the DLR Institute of Aerospace Medicine.

Payload 4 ("SCORE") is a technology demonstrator for next generation on-board computing in hard- and software, and was developed by the DLR Institute of Space System. It is complemented by a set of three digital cameras that are commanded via SCORE.

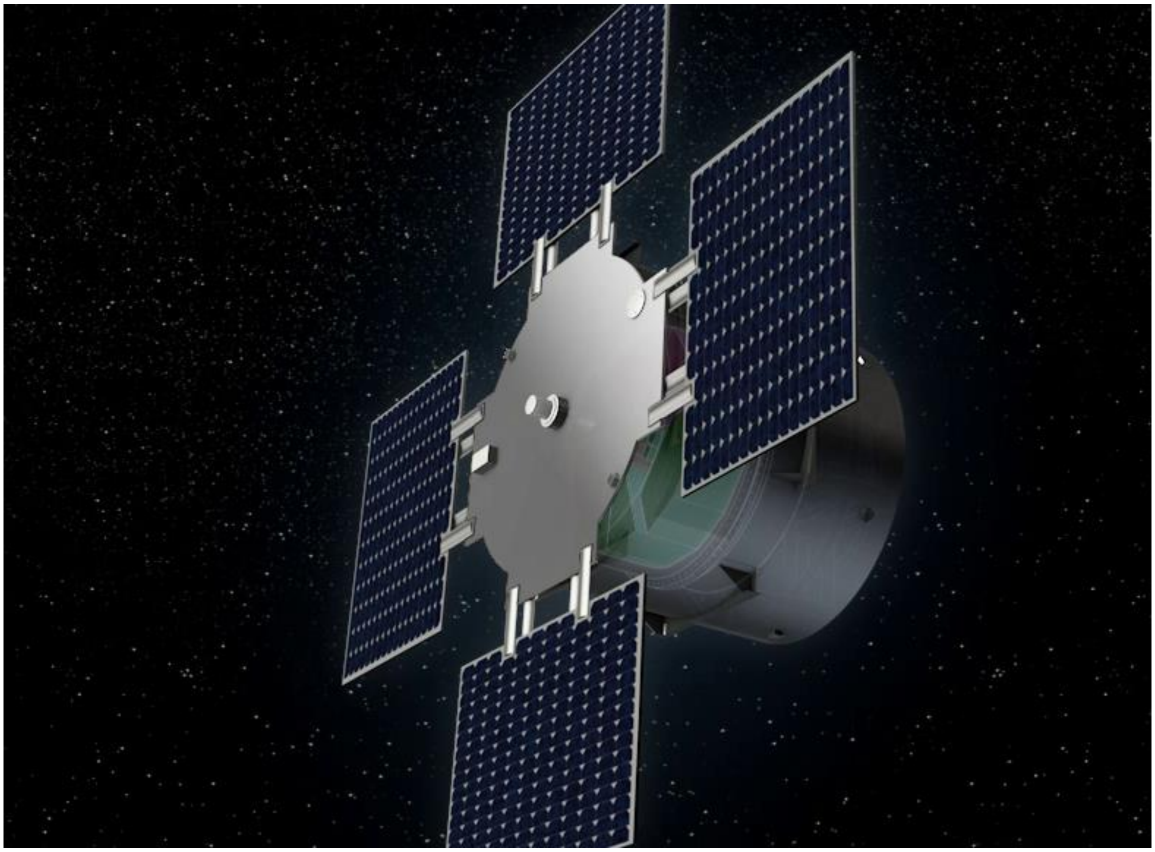

Figure 2: Impression of Eu:CROPIS in orbit. *The deployed configuration has a width of 2.88 m. The satellite is rotating around the principal axis, which is pointed to the sun and is nearly identical to the S/C z-axis, where the solar panels are aligned with. An S-band antenna is seen in the center of the top plate. Source: DLR.de*

C. Space Segment

The spin stabilized Compact Satellite is built by the DLR institute of Space Systems in Bremen. Payload 1 and Payload 2 demand different levels of gravity for their experiments, which is realized at different positions within the cylinder. The satellite contains four gyroscopes, two magnetometers and three magnetic torque rods with a maximum magnetic moment of 30 Am^2 for attitude control (see [4] for details). The single-frequency Phoenix GPS receiver to be used has heritage from the missions PRISMA and PROBA-2 (see [5] and [6]) among others. A Li-Ion battery and four solar panels provide bus power during sunlight and eclipse operations. The solar arrays are aligned with the satellite z-axis (see Figure 2) and will generate 520 Watts on average per orbit. The satellite is spinning around the principal axis, which is pointed to the sun and will be nearly identical with the S/C z-axis. Two S-band antennae ensure stable communication with the ground. One antenna is placed in the center of the top plate; the other one in the center of the bottom plate. The cylinder body has a diameter of 1.0 m and a height of 1.13 m. The spacecraft mass will be approx. 250 kg. Eu:CROPIS will be injected into an orbit of 570 km altitude and 10:30 local time of the descending node.

The on-board software uses the RTEMS operating system and is composed of the command and data-handling (C&DH) software, the attitude and orbit control software and the on-board navigation software. The C&DH software was newly developed at the Institute of Space Systems (see [7]), the other software components have heritage from the DLR TET-1 mission (see [8]). The Eu:CROPIS payload software runs on internal hardware and controls all payload components like cameras, oxygen/ph-sensors, lights etc..

The greenhouse contains a filter column, which is filled with small lava rocks, the C.R.O.P. filter (Combined Regenerative Organic-Food Production). The function of the C.R.O.P. filter is the conversion of ammonia from synthetic urine into nitrate by means of different bacteria living on and in the lava rocks. The filter has a volume of approx. 600 mL. Driven by pumps the water circulates through the greenhouse and the filter column. From time to time small amounts of synthetic urine are injected into the system by means of a small pump. The liquid is then transferred into a water storage tank, which contains the Euglena. Ammonia formed by oxidation and bacterial degradation is absorbed by the Euglena and thus a detoxification is achieved. The illumination of the plants is performed by three LED-arrays. Each LED unit contains also two cameras to take images of the plants from the top. The air in the greenhouse is vented through a chamber with a heat exchanger, which is cooled by direct contact to the base plate of the payload compartment. Condensed water is passively driven back into the water tank.

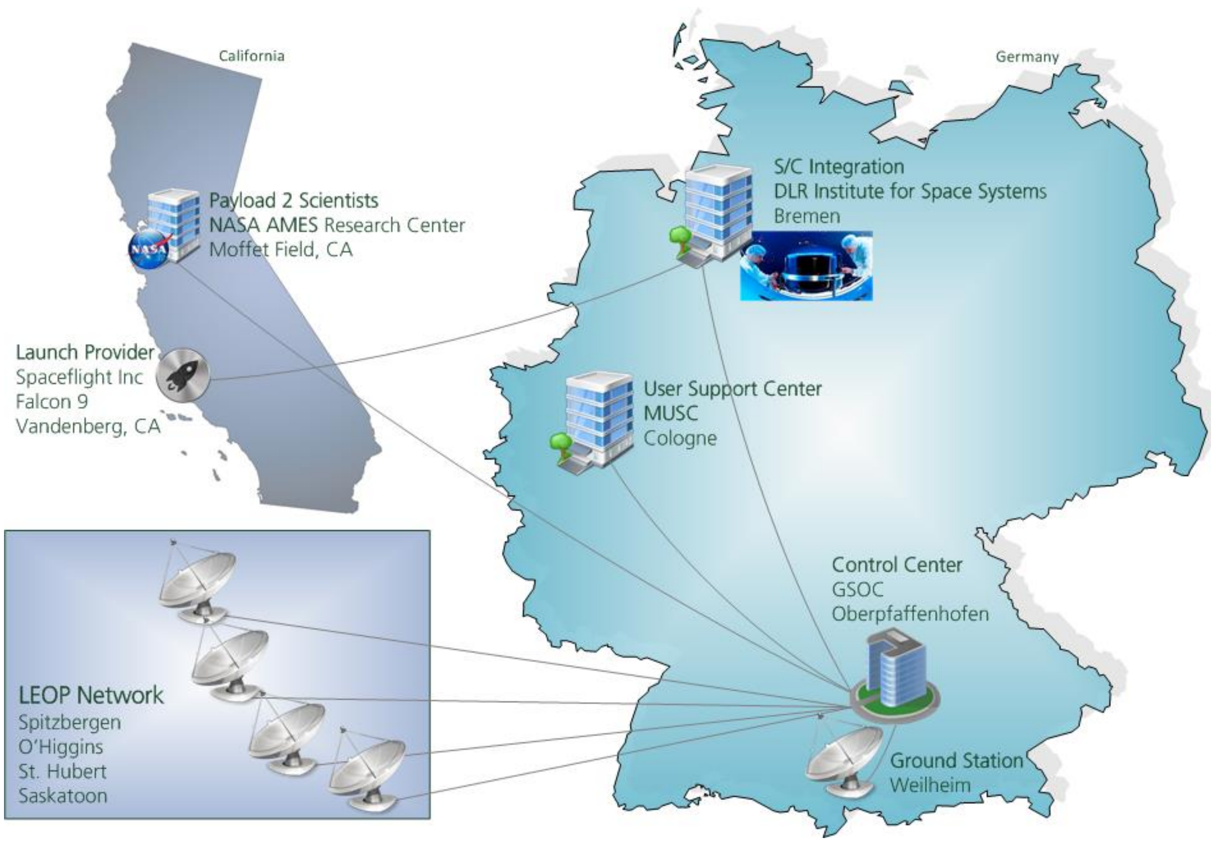

Figure 3: The Eu:CROPIS Ground Segment.

D. Ground Segment

The DLR Compact Satellite will be operated by DLR's German Space Operations Center (GSOC) in Oberpfaffenhofen, close to Munich. The primary ground station is located in Weilheim, 30 kilometers south of Oberpfaffenhofen, and will support four passes per day in the routine phase. Additionally, the KSAT ground station in Spitzbergen can be used for special operations like software uploads or emergency recoveries. The network for the Launch and Early Orbit Phase (LEOP) will be completed by the ground stations O'Higgins (Antarctica), St. Hubert and Saskatoon (both in Canada). Housekeeping and scientific data will be transferred to GSOC where a processing to the level of source packets is made. The Microgravity and User Support Center (MUSC) in Cologne forwards the payload data to the science users of payload 1 and payload 3. Science data of payload 2 will be provided to NASA AMES directly by GSOC along with other products. Data of payload 4 are also pulled directly from the principal investigator in Bremen. An overview of the Eu:CROPIS Ground Segment is shown in Figure 3. The spacecraft will be launched by Spaceflight/SpaceX with a Falcon-9 rocket from Vandenberg Air Force Base in California.

II.Operations Preparation

A. Flight Control Procedures

Mission operations for Eu:CROPIS are based on Flight Control Procedures (FCP) that will be validated on the Flight Model (FM) or partially on the Engineering Model (EM). A basic set of flight control procedures for the satellite bus are defined by the spacecraft manufacturer during the EM and FM integration process. For this purpose, the software ProToS (Procedure Tool Suite; see also [9]) is used, which has been developed at GSOC. ProToS is based on the Eclipse Rich Client Platform and has heritage from the EDRS-A mission control software. It features the following functions:

- Mission database import
- Editor for procedure development
- Procedure repository
- Procedure syntax and consistency validation
- Import/Export of procedures using generic MOIS XML format
- Real-time and time-tagged procedure execution with telemetry evaluation
- Automated generation of execution reports

The execution of procedures requires a connection to the external interface service of the mission control system GECCOS, which is used for assembly, integration and test (AIT) at the manufacturer site. GECCOS [10] is a derivate of the SCOS-2000 system developed by ESA, and will also be used for flight operations at GSOC. After procedure execution and telemetry evaluation ProToS generates a comprehensive execution report - a helpful feature during AIT. ProToS is therefore a valuable extension of the Central Checkout System, but it also helps to reduce the effort on the operations side, as procedures can be easily imported into the procedure database at GSOC via the generic MOIS XML format.

The development of payload procedures is supported by the MUSC. Some of these procedures, however, cannot be validated on the FM as they require a running biological experiment. The validation process in this case is made in two steps. First, it is assured that all commands reach the payload correctly in the satellite EM. In a separate step the corresponding commands of the procedure are released on a payload reference model in order to validate the outcome of these commands within the payload. The payload EM only supports a limited number of biological functions.

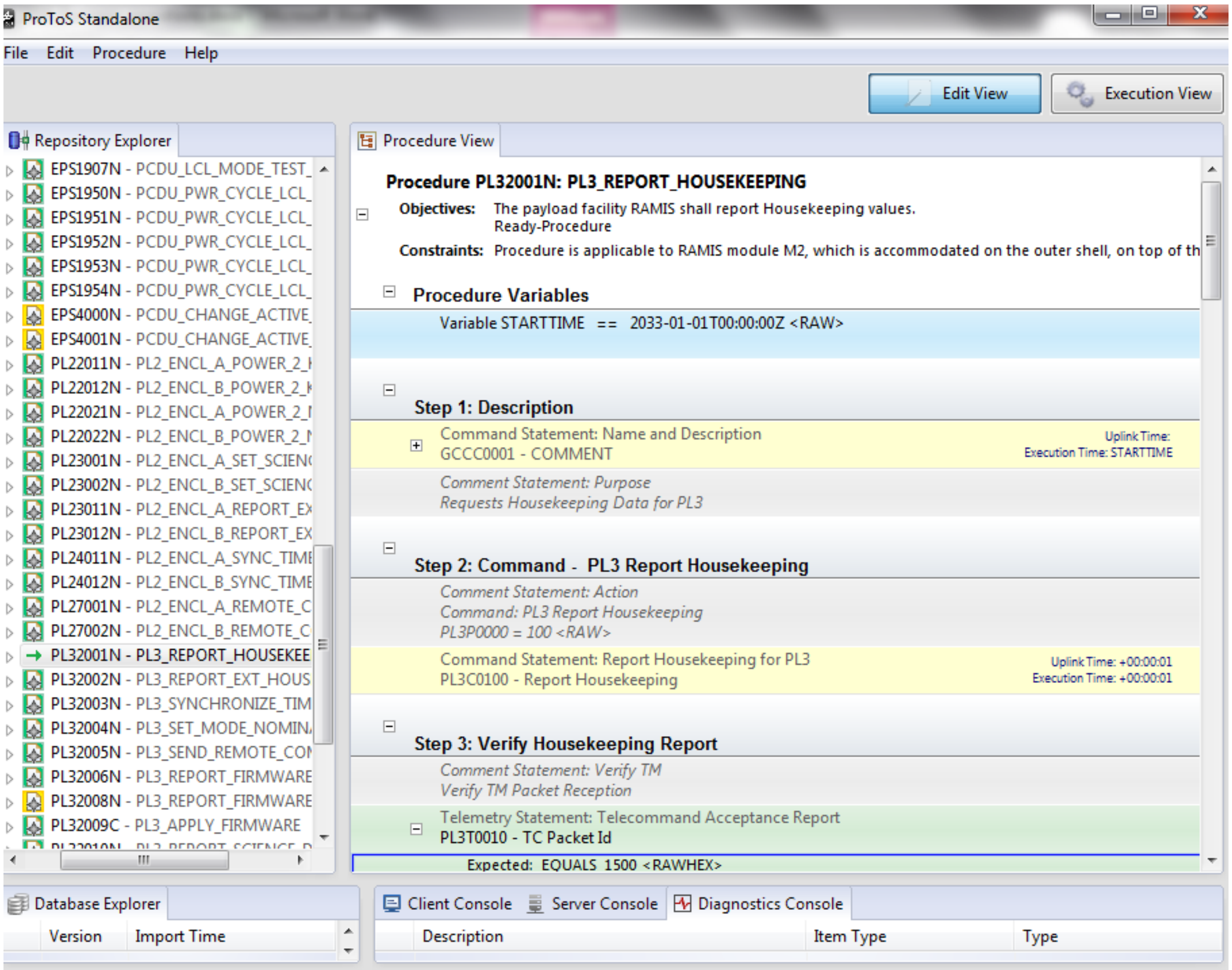

Figure 4: ProToS in Edit View as used for the development of flight control procedures. *By switching to the execution view it is also possible to run the procedure if ProToS has been connected to the Mission Control System.*

B. Operations Concept

The Eu:CROPIS payload has a number of autonomous functions like thermal control loops. Cyclic activities as lighting cycles and the taking of pictures and measurements are also initiated autonomously and do not require commands from ground on a daily basis. All other payload activities e.g. the start of an experiment or configuration changes are commanded on request from the principal investigator (PI). The request is made online through a web form, where the procedures and uplink modalities are specified. For all necessary functions flight control procedures are available at the control center. If the procedure requires parameter input from the PI or is to be executed time-tagged, the missing values are transmitted to GSOC through a defined format and interface, checked for consistency and merged with the procedure. This is an automatic process that takes a couple of minutes, but does not require manual interaction. Most procedures do not have configurable parameters though (so-called ready-procedures), and are already available in the Mission Control System. The spacecraft operator sends the procedure after approval has been given from the Flight Director in the web form. The PI is then able to remotely follow the execution process from the real-time telemetry shown in a tool provided by GSOC. The process of recommendation handling and the TM/TC interfaces between external users and GSOC are shown in Figure 5.

The ground systems in place for command generation, telemetry processing and visualization rely mostly on tools that have been used before in other mission. This approach minimizes the development costs and training effort for the operations team.

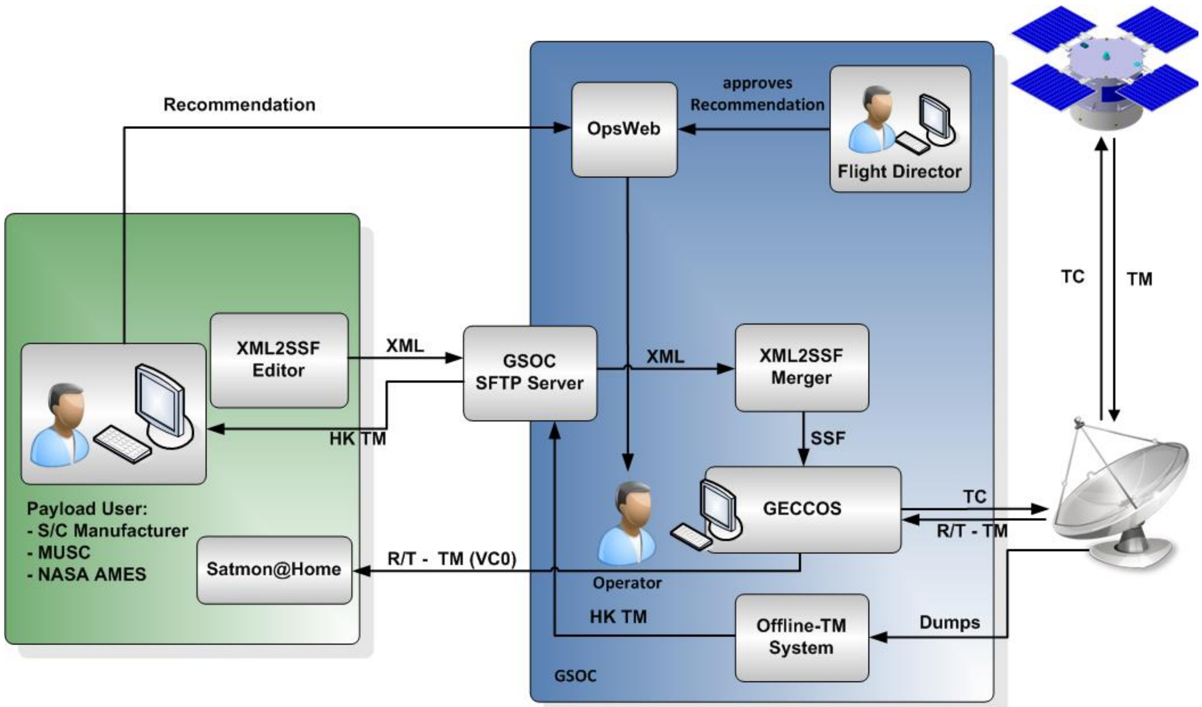

Figure 5: Operations Concept. *On request from the PI flight control procedures are sent to the satellite. Parameter values for procedures are transmitted via XML files, which are processed automatically.*

The close cooperation between the space segment and ground segment teams has contributed to a cost reduction of the mission operation and preparation. The experience and heritage within the ground segment could be considered in an early stage of the C&DH software design. The efficiency of data storage and retrieval for example will profit from the mission planning tools at GSOC in use for the Firebird mission (see [11]). Therefore, Service 11 and Service 15 of the ECSS Packet Utilisation Standard (PUS) were implemented in the C&DH software. A special case in this matter is the downlink of image files taken inside the greenhouse, and whose sizes exceed the maximum size of a single telemetry source packet. It was decided to transfer greenhouse images via PUS Service 13, the dedicated service for the transmission of large data. For this purpose minor enhancements had to be made in turn on the ground segment side to guarantee the maximum scientific return.

III. LEOP

During the Launch and Early Orbit Phase (LEOP) the satellite will be controlled and monitored at GSOC. The launch into a sun-synchronous orbit of around 570 km height is scheduled for the first quarter of 2017 as a secondary payload aboard a Falcon-9 rocket. The LEOP ground station network guarantees a high number of contacts to the satellite, and allows for a quick response to on-board events and the transmission of critical procedures. It will consist of the following antennae:

- Weilheim (WHM) of DLR
- Svalbard (SGS) of KSAT
- St. Hubert (SHB) of CSA
- Saskatoon (SKT) of CSA
- O'Higgins (OHG) of DLR

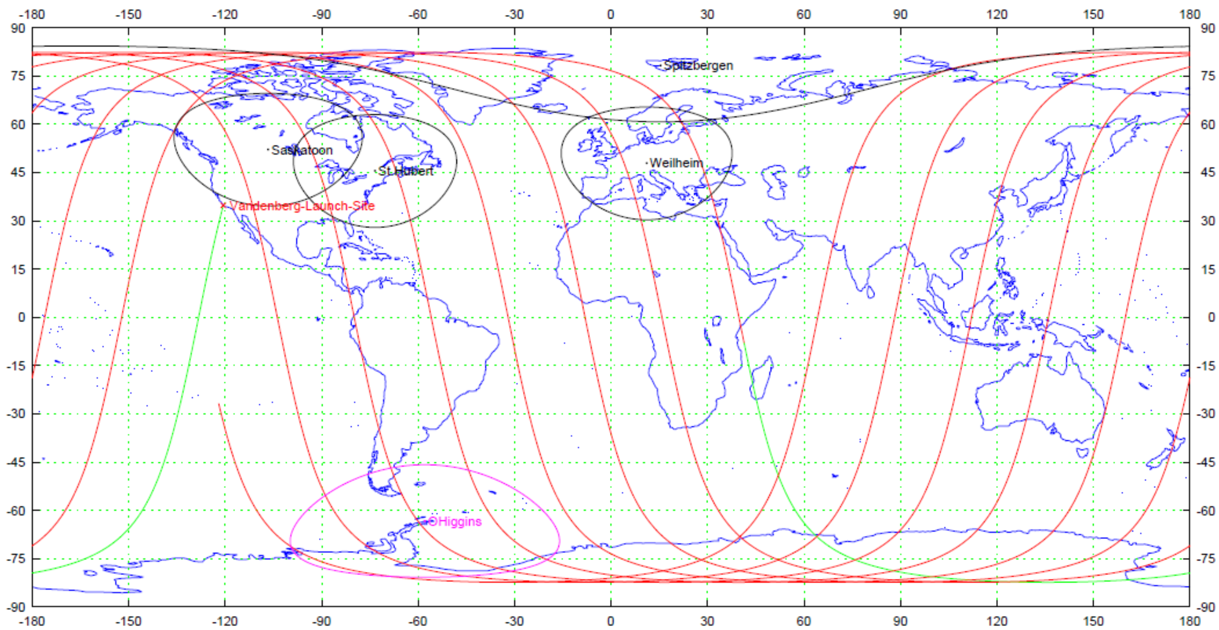

Figure 6: Ground Track of Eu:CROPIS. *Shown are the first seven orbits and the LEOP ground station network consisting of Weilheim (Germany), Svalbard (Norway), St. Hubert (Canada), Saskatoon (Canada) and O'Higgins (Antarctica).*

Until separation from the launcher (~60 minutes after lift-off) the satellite is not powered. After separation from the launcher the satellite will autonomously perform the initialization sequence. It will power the nominal side of hardware, i.e. the on-board computer (OBC) will start the on-board software and activate the AOCS system. The S-band transmitter will be switched on 30 minutes after separation because of a requirement from the launcher. The first step in the attitude control and acquisition sequence is to decrease the tip-off rates from the launcher. Following, the satellite z-axis is pointed perpendicular to the sun direction in order to allow for an illumination of the undeployed solar panels, which are still fixed around the curved area of the cylinder. A rotation around the z-axis is established at 1 rotation per minute (rpm), which is why this configuration is also referred to as "BBQ-attitude". The four panels are illuminated one after another and a stable thermal condition is generated.

Up to this point the sequence is executed autonomously and will be completed within six hours. After the battery is fully loaded in the BBQ-attitude, the angle between sun-vector and rotational axis will be decreased to 60° and the rotation rate will be raised to 5 rpm. This prepares for the deployment of the four solar panels, which will be done symmetrically with the two opposite panels deployed at a time. Eventually, sun-pointing and the transition to nominal mode will be commanded after the successful deployment. The payloads will be switched on when a gravity level of 0.01g (payload 1 reference) has been established.

The Sequence of Events (SOE) will be prepared by GSOC based on input from the satellite manufacturer. It includes all ground actions and acquisition times over ground stations and the flight procedures to be loaded during each passage. Flight Dynamics will deliver updated two-line elements after GPS data have been dumped and an orbit determination is possible.

The duration of the LEOP adds up to two days. The main tasks for the operations team are:

- First acquisition and checkout of satellite status
- Check status of satellite system start-up and on-board processor self-test (OBC-selfie)
- Configuration of the satellite (mostly AOCS related)
- Solar panel deployment
- Extended telemetry check (every pass)
- Comprehensive system data dump (every pass)
- Performing of self-test of redundant on-board computer
- Enabling of battery surveillance
- Enabling of additional system FDIR (Failure Detection, Isolation & Recovery)

- GPS time synchronization
- Loading of background sequence (time tag commands for transmitter switches and data replays)
- Acquisition of required orbital parameters, Orbit determination and prediction
- Preparation and initiation of attitude manoeuvers

IV. Routine Operations

For nominal operations on-board capabilities are employed to facilitate operations and to take care of back-ground tasks. These are time distribution, data collection and downlink, parameter monitoring, thermal and attitude control as well as fault detection, isolation and recovery (FDIR). Monitoring and control of the satellite including replay of recorded data will be conducted via the S-band up- and down-link channels. The contacts between the control center and the satellite will primarily be used for the uplink of procedures to update the mission timeline, and for dumping of housekeeping and science data. Four ground station contacts per day will be scheduled in the routine phase to dump a total volume of 120MB ±15% comprising of:

- 80 MB for Payload 1
- 10 MB for Payload 2
- 10 MB for Payload 3
- 10 MB for Payload 4
- 10 MB for S/C Bus

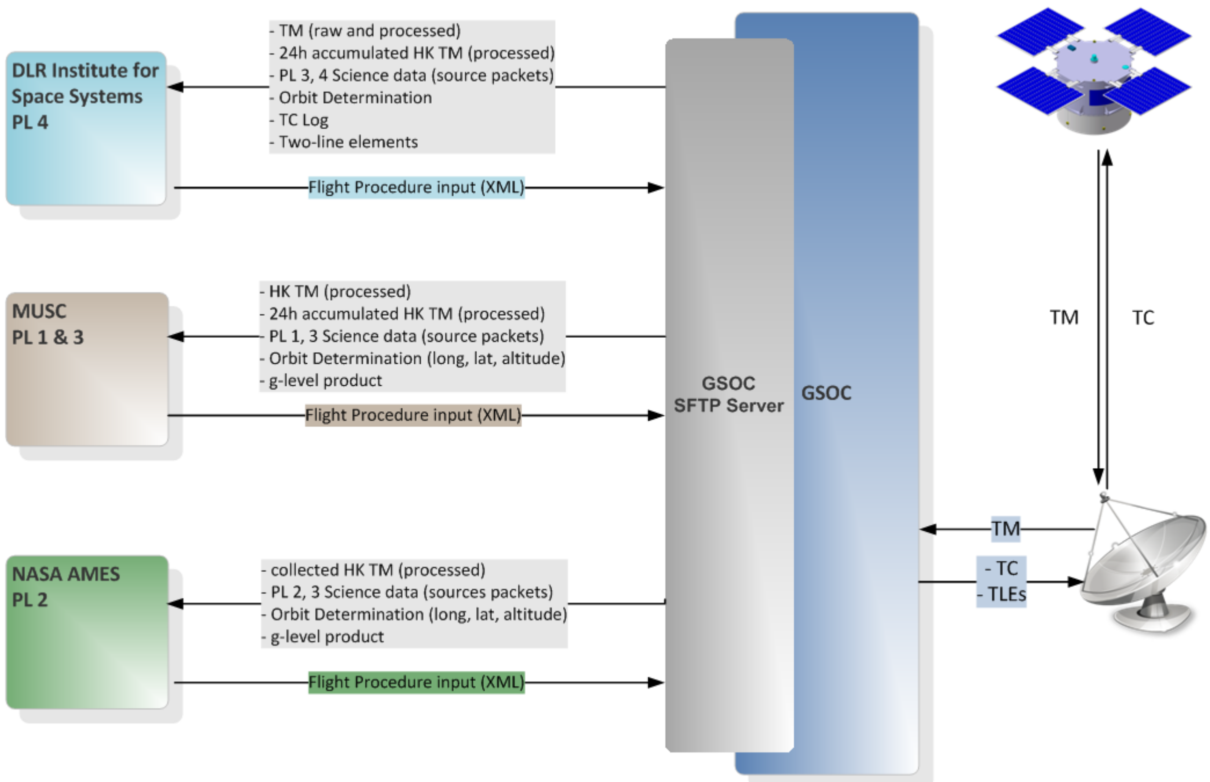

Figure 7: Exchange of data products in the routine phase. *Science data and platform housekeeping telemetry are available on the GSOC SFTP Server not later than 45 minutes after the contact. Additional products like the orbit determination are also provided.*

The transmitter uses a Binary Phase Shift Keying Modulation (BPSK) with a switchable net data rate of 400 kbps or 800 kbps. For both, low and high data rate Reed Solomon (255,223) as block code is used. The transmitter even allows to increase the high data rate by a factor of two and thus to improve the overall performance. This mode is considered experimental on the other hand, as the link budget margins decrease concurrently. It might be chosen however as the new baseline for nominal operations after successful check-out. The housekeeping telemetry and science data will be available not later than 45 minutes after each contact on the GSOC SFTP Server. An overview of the data exchange is given in Figure 7.

Scheduling of the ground stations is done by means of a multi-mission tool taking into account other LEO missions operated at GSOC. The overall goal is to support all missions sequentially over the day, which requires the minimal number of spacecraft operators and avoids workload peaks (see [12] for details). The orbit of Eu:CROPIS is advantageous in this context as its local time of the descending node is not in conflict with other mission to be supported by GSOC.

Figure 8 gives an overview of the experiment schedule. The algae are in a so-called hibernation phase during transport of the satellite to the launch site. Each experiment cycle starts therefore with a two-weeks growing phase of the Euglena at 0.01g. The following threshold experiment monitors the behavior of the algae under spin-up conditions and will take another two weeks. The actual growth of the tomatoes will take place in the next six months under simulated Moon gravity (0.16g), which requires a rotational speed of 120 deg/s around the z-axis. The conduction of the second experiment is similar to the first cycle, but simulates the gravity level on the surface of Mars (0.38g), and uses the second module of the Eu:CROPIS payload. The rotation rate will be increased to 187 deg/s. After both experiment cycles are finished, a restart of the Euglena growth shall be tested in module 1 for two weeks. The total operation phase of Eu:CROPIS will be 16 month, but might be extended by six month.

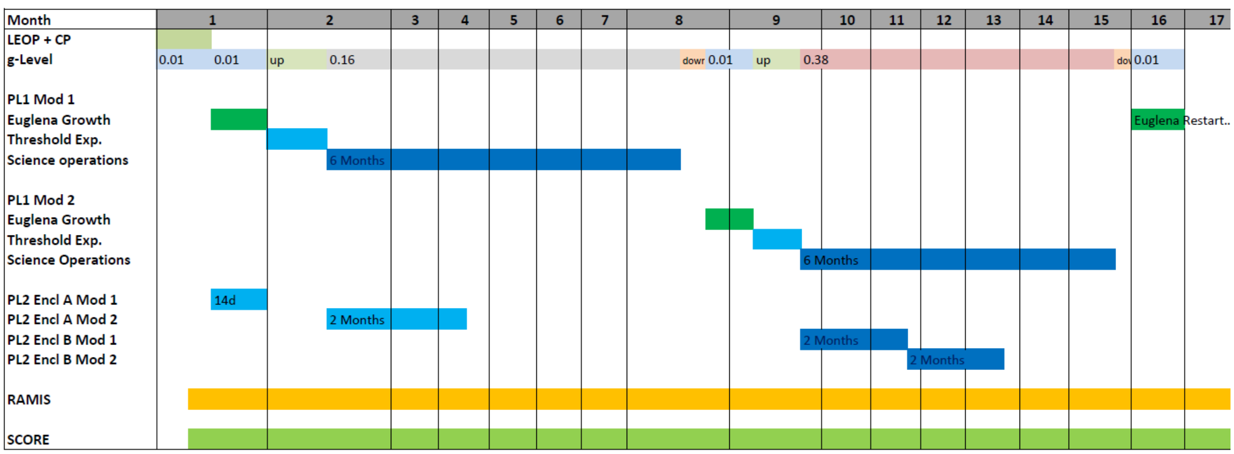

Figure 8: Mission Timeline. *Indicated is also a possible restart of Payload-1 Module-1 using seeds from the tomatoes grown in the first experiment.*

Four experiments are planned for Payload 2 under three different acceleration levels. Payload 3 and 4 are running continuously. As described in chapter II payload commands on a daily basis are not required, but are sent on request by the PI. The transmitter switches and replays of recorded data are commanded on a weekly basis through the mission planning system using a defined command sub-schedule ID. Likewise, each payload has a dedicated sub-schedule ID which makes it the easier to remove or deactivate associated commands in the mission timeline (MTL) on-board.

The C&DH software supports an event report service (PUS Service 5) that allows for a quick diagnose of on-board accidents. On-board events are triggered anytime the monitored parameter is not within its limit for a specific timespan. Additionally, the monitoring may have one or more conditions and may be active only in definite spacecraft modes. FDIR functions are implemented in the hardware (e.g. OBC watchdog and heartbeat monitoring), the C&DH software (e.g. mode transitions in power contingencies) and the AOCS software (e.g. switch of ACS mode in case of pointing errors). The handling of on-board failures is as follows:

- (Payload) parameters are monitored on-board by hardware and software.
- Detected failures are logged in the system log .
- Depending on the severity of the failure automatic actions are taken such as power-cycling of units.

- Anomaly investigation is made on ground based on the system log and telemetry. Further actions can be taken.
- FDIRs might be adapted during the mission based on experience and contingencies.

In a contingency case FDIR may switch the satellite into the safe-mode and command payload 1 and 2 into the so-called Keep-Alive Mode with reduced power consumption. Here, the active thermal control is still enabled. The illumination for the Euglena and the plants is also active but reduced to a minimum. The goal is to keep the temperature of payload 1 and 2 between 7 and 27°C to ensure a survival of the plants and microorganisms. Payload 1 and 2 are only switched off in case of a severe power shortage. Thermal control and illumination in the payload are switched off consequently presenting a danger to the survival of the organisms and plants. Therefore, an automatic recovery into the Keep-Alive Mode is implemented in the FDIR in case the battery charge level increases again. The concept of anomaly handling and detection has once more profited from the good teamwork between the manufacturer and the operations team.

V. Conclusion

Eu:CROPIS is an exciting demonstrator mission with regard to a closed ecological system for human spaceflight and planetary colonialization. A cost efficient operations concept was established based on the re-use of existing tools and processes at GSOC. This was made possible by an early consideration of operational aspects in the spacecraft design. On the other hand the ground application ProToS had been advanced with innovative features to allow for an efficient usage during spacecraft AIT and the development of flight control procedures. The operations concept furthermore comprises a user-friendly telecommand and telemetry interface for payload users to the control center.

The Compact Satellite is equipped with a high level of autonomy, which allows for safe attitude acquisition, and stable power and thermal conditions during the LEOP. Additionally FDIR functions are in place to be prepared for spacecraft anomalies. Focus has lied on a minimum impact on running biological experiments to guarantee the maximum scientific output. The close cooperation between spacecraft manufacturer and the operations team is one of the key factors for an efficient and successful interplay between space and ground segment.

Appendix

Acronym List

AIT	Assembly, Integration and Test
EM	Engineering Model
BPSK	Binary Phase Shift Keying Modulation
FCP	Flight Control Procedure
FDIR	Fault Detection, Isolation and Recovery
FM	Flight Model
g	Gravitational Constant
GECCOS	GSOC Enhanced Command & Control Operating System
GSOC	German Space Operations Center
LEOP	Launch and Early Orbit Phase
MCS	Mission Control System
MIB	Mission Information Base
MOIS	Mission Operations Information System
MPS	Mission Planning System
MTL	Mission Timeline
MUSC	Microgravity and User Support Center
OBC	On-board Computer
PI	Principal Investigator
RAMIS	Radiation Measurement In Space
S/C	Spacecraft
SSF	Saved Stack Files

References

[1] Strauch, S. M., Schuster, M., Lebert, M., Richter, P., Schmittnägel, M., Häder, D.-P.; "A closed ecological system in a space experiment", *SP-663 Proceedings, Journal of Gravitational Physiology*, 2008

[2] Nasir, A., Strauch, S. M., Becker, I., Sperling, A., Schuster, M., Richter, P. R., Weißkopf, M., Ntefidou, M., Daiker, V., An, Y. A., Li, X. Y., Liu, Y. D., Lebert, M.; "The influence of microgravity on Euglena gracilis as studied on Shenzhou 8", *Plant Biology*, 2013

[3] Bornemann, G., Waßer, K., Tonat, T., Moeller, R., Bohmeier, M., Hauslage, J.; "Natural microbial populations in a water-based biowaste management system for space life support", *Life Sciences in Space Research*, 7, Elsevier, 2015, p. 39-52

[4] Heidecker, A., Kato, T., Maibaum, O., Hölzel, M.; "Attitude Control of the Eu:CROPIS Mission", *65th International Astronautical Congress*, Toronto, Canada, 2014

[5] Ardaens, J. S., D'Amico, S., Montenbruck, O.; "Flight results from the PRISMA GPS-based navigation", *5th ESA ,Workshop on Satellite Navigation Technologies*, Noordwijk, The Netherlands, 2010

[6] Montenbruck, O., Issler, J. L., Markgraf, M., Mercier, F., Santandrea, S., Garcia, A., Naudet, J., Serre, S.; "GPS-Based Precise orbit determination and real-time navigation of the PROBA-2 spacecraft", *5th ESA Workshop on Satellite Navigation Technologies*, Noordwijk, The Netherlands, 2010

[7] Dannemann, F., Greif, F.; "Software Platform of the DLR Compact Satellite Series", *4S Symposium*, Mallorca, Spain, 2014

[8] Maibaum, O., Heidecker, A.; "Software Evolution from TET-1 to Eu:CROPIS", *10th IAA International Symposium on Small Satellites for Earth Observation*, Berlin, Germany, 2015

[9] Beck, T., Schlag, L., Hamacher, J. P.; "ProToS: Next Generation Procedure Tool Suite for Creation, Execution and Automation of Flight Control Procedures", *SpaceOps 2016, 14th International Conference on Space Operations*, Daejeon, South Korea, 2016

[10] Stangl, C., Braun, A., Geyer, M. P.; "GECCOS - the new Monitoring and Control System at DLR-GSOC for Space Operations, based on SCOS-2000", *SpaceOps 2014, 13th International Conference on Space Operations*, Pasadena, USA, 2014

[11] Wörle, M. T., Spörl, A., Hartung, J., Lenzen, C., and Mrowka, F., "The Mission Planning System for the Firebird Spacecraft Constellation", *SpaceOps 2016, 14th International Conference on Space Operations*, Daejeon, South Korea, 2016.

[12] Morfill, G., Maurer, E. Zimmermann, S., Nibler, R.; "Multi-Mission Synergies in Routine Operations of Low Earth Orbiting Satellites", *SpaceOps 2016, 14th International Conference on Space Operations*, Daejeon, South Korea, 2016